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Generation Maintenance Application Center: Combined Cycle Combustion Turbine Inlet Cooling System Model Maintenance Report

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Generation Maintenance Application Center: Combined Cycle Combustion Turbine Inlet Cooling System Model Maintenance Report

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PRODUCT DESCRIPTION

This report addresses maintenance of inlet cooling systems of gas turbines at combustion turbine combined cycle (CTCC) power plants, and it also has a broader purpose: to present a model for approaching a CTCC plant maintenance program in such a way as to leverage the Electric Power Research Institute (EPRI) Preventive Maintenance Basis Database (PMBD). The PMBD, a widely used resource at nuclear and fossil plants, is also applicable to CTCC plants, but systems and components that are unique to those plants warrant strategic consideration. This report focuses on one specific system (the inlet cooling system) as a detailed example.

Background

Combustion turbine combined cycle facilities utilize various systems and components that are unique to these types of power generation plants, and that are not typically found in a nuclear or fossil power plant. Accordingly, the use of the EPRI Preventive Maintenance Basis Database by owners of CTCC plants is somewhat limited to only those components that are common to both types of power plants and have previously been added to the PMBD. With the growth in the number of CTCC facilities, the EPRI Generation Maintenance Application Center (EPRI GenMAC) has committed to providing maintenance guidance for many of these unique or unaddressed components and systems, and to facilitate the addition of these to the PMBD.

Objectives

The primary objective of this project is to provide a system-level tool that can assist CTCC facility owners in implementing a maintenance program that will ultimately improve system reliability and plant availability. Specifically, the objectives are the following:

- To establish maintenance tasks that leverage the EPRI PMBD resource
- To adjust task descriptions and intervals to accurately reflect actual combined cycle operation and design
- To provide a template from which CTCC facilities can build a maintenance program with a strong technical basis

Approach

EPRI worked with a collaborative group of owners, operators, original equipment manufacturers (OEMs), and vendors to develop tactical guidance addressing common failure mechanisms of CTCC components and systems and to subsequently provide guidance for appropriate preventive maintenance, repair and replacement, and troubleshooting of major components installed at a CTCC facility. The guidance in this technical report was developed in conjunction with the expert elicitation process and with technical input received from maintenance personnel during site visits.

Results

This technical report provides comprehensive insight for managers of CTCC facilities to effectively address ongoing maintenance issues. The report presents an overview of inlet cooling system design parameters, familiarizes the user with the components that make up this system at a CTCC facility, and provides information on system and component functions. However, the main focus of the report is on providing site personnel with insight into various failure mechanisms, along with detailed guidance for performing preventive maintenance on a typical inlet cooling water system. The report also documents the decision making process that underlies the implementation of a maintenance basis.

Applications, Value, and Use

The primary benefit of this report is to provide a model maintenance program that can be used to streamline the implementation of a cost-effective program at any CTCC facility by reducing the implementation effort needed to analyze various system differences among sites. This guideline can be used by CTCC facility owners during in-house development of maintenance crews, when providing training for contract maintenance travelers to overcome the loss of knowledge due to turnover, and to provide a consistent, risk-informed maintenance program for major components of the CTCC system analyzed in this report.

Keywords

Combined cycle
Combustion turbine
Evaporative cooling
Inlet cooling
Preventive maintenance
Troubleshooting

CONTENTS

***1* INTRODUCTION 1-1**

1.1 Background 1-1

1.2 Objectives 1-1

1.3 Contents of the Report 1-2

1.4 Industry Definitions and Nomenclature 1-3

1.5 Definitions Associated with Maintenance Activities 1-4

1.5.1 Preventive Maintenance 1-4

1.5.1.1 Periodic Maintenance 1-4

1.5.1.2 Condition-Based Maintenance 1-5

1.5.2 Corrective Maintenance 1-5

1.5.3 Initial Basis for PM Tasks and Frequencies 1-5

1.6 Acronyms 1-5

1.7 Listing of Key Points 1-8

***2* SYSTEM/COMPONENT DESCRIPTION 2-1**

2.1 Typical Inlet Cooling System Installations 2-1

2.1.1 Simplified System Schematics 2-1

2.1.2 Boundary Statements 2-2

2.2 System Descriptions 2-3

2.2.1 Inlet Chiller System Description 2-3

2.2.2.1 General Description 2-3

2.2.1.2 Unique System Design Features 2-10

2.2.2 Evaporative Cooling System Description 2-10

2.2.2.1 General Description 2-10

2.2.2.2 Unique System Design Features 2-14

2.3 System Components 2-15

3 INLET COOLING SYSTEM FAILURE MECHANISMS 3-1

3.1 Problems Associated with Inlet Cooling Systems 3-1

3.1.1 Problems Associated with Inlet Chiller Systems 3-1

3.1.2 Problems Associated with Evaporative Cooling Systems 3-3

3.2 Detailed Failure Mechanism Data 3-5

4 SYSTEM TROUBLESHOOTING, VULNERABILITY, AND RISK ANALYSIS 4-1

4.1 System Troubleshooting 4-1

4.2 Troubleshooting the Inlet Cooling Water System 4-4

4.2.1 Background 4-4

4.2.2 System Troubleshooting Guidance 4-4

4.3 System Vulnerabilities and Risks 4-11

4.3.1 Objectives of the Model Maintenance Program 4-11

4.3.2 Overview of the Model Maintenance Program for the Inlet Cooling System 4-11

4.3.3 Observations from Vulnerability Analysis 4-15

4.3.3.1 Aligning to Hours/Starts-Based Inspections 4-15

4.3.3.2 Program Comparison Using the PMBD 4-16

4.4 Component Vulnerabilities and Risks 4-17

4.4.1 Cooling Tower Cell – Mechanical Draft – Cross Flow Analysis 4-18

4.4.2 Heat Exchanger – Air Cooled Analysis 4-23

4.4.3 Chiller and Centrifugal Compressor Analysis 4-25

4.4.4 Instrumentation and Control Analysis 4-27

4.4.5 Motor <15 Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed Analysis 4-28

4.4.6 Motor <15 Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed Analysis 4-34

4.4.7 Circulating Water and Auxiliary Circulating Water Pump – Horizontal – Single Stage – Single Suction Analysis 4-39

4.4.8 Evaporative Cooler Feed Pump – Vertical – Close Coupled 4-43

4.4.9 Air Operated Valve – Diaphragm Analysis 4-45

4.4.10 Air Operated Valve – Piston Analysis 4-49

4.4.11 Motor Operated Valve – AC Limitorque Analysis 4-52

4.4.12 Solenoid Operated Valve Analysis 4-56

4.4.13 Conductivity Analyzer Analysis 4-57

4.4.14 Glycol Analyzer Analysis 4-58
4.4.15 Glycol Slip Stream Filter Analysis 4-58
4.4.16 Sump Analysis 4-58

***5* EXAMPLES OF JOB PLANS 5-1**
5.1 Content and Format for Job Plans 5-1
5.1.1 General Guidance and Considerations 5-1
5.1.1.1 Fundamental Work Package Attributes for Ensuring Quality 5-1
5.1.1.2 Inclusion of Maintenance Experience 5-2
5.1.1.3 Establishing the Appropriate Level of Detail 5-3
5.1.2 Recommended Job Plan Content 5-3
5.1.2.1 Task Overview 5-3
5.1.2.2 Pre-Job Considerations 5-4
5.1.2.3 Contingency Considerations 5-5
5.1.2.4 Detailed Work Instructions 5-6
5.1.2.5 Post-Maintenance Testing 5-6
5.1.2.6 Feedback Mechanism 5-7
5.1.2.7 References 5-7
5.2 Job Plans for Inlet Cooling System Components 5-8
Job Plan #1 Cooling Tower Cell – Mechanical Draft – Cross Flow (Hot Water Basin Cleaning) 5-8
Job Plan #2 Cooling Tower Cell – Mechanical Draft – Cross Flow (Inspections) 5-11
Job Plan #3 Cooling Tower Cell – Mechanical Draft – Cross Flow (Instrumentation Functional Testing) 5-22
Job Plan #4 Cooling Tower Cell – Mechanical Draft – Cross Flow (Oil Sampling, Filtering, and Analysis) 5-24
Job Plan #5 Cooling Tower Cell – Mechanical Draft – Cross Flow (Thermal Performance Monitoring) 5-26
Job Plan #6 Vibration Monitoring 5-28
Job Plan #7 Heat Exchanger – Air Cooled (Replacement) 5-35
Job Plan #8 Heat Exchanger – Air Cooled (Major Inspection) 5-38
Job Plan #9 Chiller and Centrifugal Compressor (Internal Inspection – Compressor) 5-43
Job Plan #10 Chiller and Centrifugal Compressor (Overhaul) 5-47
Job Plan #11 Chiller and Centrifugal Compressor (Annual Inspection and Test) 5-50
Job Plan #12 Chiller and Centrifugal Compressor (Glycol Analysis) 5-57

Job Plan #13 Chiller and Centrifugal Compressor (Quarterly Inspection and Test) 5-59
Job Plan #14 Calibration – Non-Redundant, Critical 5-64
Job Plan #15 Calibration – Redundant, Critical 5-70
Job Plan #16 Calibration – Non-Critical 5-76
Job Plan #17 Motor – Medium Voltage <15Kv (Air Filter Replacement).....5-82
Job Plan #18 Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed (Oil Analysis).....5-85
Job Plan #19 Motor – Medium Voltage <15Kv (Refurbishment).....5-88
Job Plan #20 Motor – Medium Voltage <15Kv (Tests – Off Line).....5-96
Job Plan #21 Motor – Medium Voltage <15Kv (Tests – On Line).....5-102
Job Plan #22 Motor – Medium Voltage <15Kv (Thermography).....5-107
Job Plan #23 Pump – Horizontal – Single Stage – Single Suction (Refurbishment).....5-110
Job Plan #24 Evaporative Cooler Feed Pump – Vertical – Close Coupled (Packing or Seal Replacement).....5-116
Job Plan #25 Evaporative Cooler Feed Pump – Vertical – Close Coupled (Refurbishment).....5-119
Job Plan #26 AOV – Diaphragm (Calibration of Actuator).....5-124
Job Plan #27 AOV – Diaphragm (Calibration, Inspection, and Test).....5-127
Job Plan #28 AOV – Diaphragm (Diagnostic Testing).....5-132
Job Plan #29 AOV – Diaphragm (Packing Inspection/Adjustment) 5-136
Job Plan #30 AOV – Piston (Calibration of Actuator) 5-138
Job Plan #31 AOV – Piston (Calibration, Inspection, and Test) 5-141
Job Plan #32 AOV – Piston (Diagnostic Testing) 5-146
Job Plan #33 AOV – Piston (Packing Inspection/Adjustment).....5-150
Job Plan #34 MOV – AC Limitorque (Diagnostic Test).....5-152
Job Plan #35 MOV – AC Limitorque (Functional Tests) 5-155
Job Plan #36 MOV – AC Limitorque (Inspection and Lubrication).....5-159
Job Plan #37 Solenoid Operated Valve (Functional Test – Leak Tests) 5-163
Job Plan #38 Solenoid Operated Valve (Valve Body Bonnet – Elastomer Replacement) 5-165

***6* PERSONNEL SAFETY ISSUES 6-1**
6.1 General 6-1
6.2 Safety Guidance for Maintenance Personnel 6-1
6.2.1 Personal Protective Equipment (PPE) 6-1

6.2.1.1 General 6-1
6.2.1.2 Hard Hats 6-1
6.2.1.3 Hearing Protection 6-1
6.2.1.4 Eye and Face Protection 6-2
6.2.1.5 Respiratory Protection 6-2
6.2.1.6 Foot Protection 6-2
6.2.2 Safety Harnesses and Safety Nets 6-2
6.2.3 Fire Protection and Prevention 6-2
6.2.4 Housekeeping and Foreign Material Exclusion 6-3
6.2.5 Material Handling 6-4
6.2.6 Rigging 6-4
6.2.7 Hand Tools and Power Tools 6-5
6.2.8 Welding and Cutting and Other “Hot” Work 6-6
6.2.9 Gas Welding and Cutting Safety 6-6
6.2.10 Arc Welding and Cutting 6-7
6.2.11 Electrical Safety 6-7
6.2.12 Lockout and Tagging of Circuits 6-8
6.2.13 Scaffolding 6-8
6.2.14 Floor and Wall Openings 6-9
6.2.15 Cranes, Hoist, Elevators, and Conveyors 6-9
6.2.16 Ladders 6-11
6.2.17 Compressed-Gas Cylinders 6-11
6.2.18 Permit-Required Confined Spaces 6-12
6.3 Worker Safety and Health Guidelines for CTCC Facility Owners 6-13
6.3.1 General Safety Requirements for CTCC Facility Owners 6-13
6.3.2 Occupational Safety and Health 6-14
6.3.3 Injury and Illness Prevention Programs 6-14
6.3.3.1 Construction Injury and Illness Prevention Programs 6-14
6.3.3.2 Operations and Maintenance Injury and Illness Prevention Programs 6-15
6.3.4 Safety Training Programs 6-17

7 REFERENCES 7-1
7.1 EPRI Technical Reports 7-1
7.2 Technical Publications and Articles 7-2
7.3 Utility Procedures, Manuals, and Design Documents 7-2

_A_ LISTING OF KEY POINTS A-1
A.1 Key Human Performance Points A-1
A.2 Key O&M Cost Points A-2
A.3 Key Technical Points A-3
A.4 Key Supervisory Observation Points A-4

_B_ EFFECTIVE USE OF THE EPRI PMBD VULNERABILITY TOOL B-1
B.1 Overview of the Vulnerability Tool B-1
B.2 Using Vulnerability to Manage Degradation B-1
B.2.1 Evaluating PM Recommendations for Effectiveness B-3
B.2.2 Evaluating Failures for Causes and Corrective Actions B-5
B.2.3 Addressing Failures in Green and Yellow B-6
B.3 Interval Sensitivity B-7
B.4 Task Deferral Using the PM Basis B-9

LIST OF FIGURES

Figure 1-1 Scope and Content of This EPRI Report 1-2
Figure 1-2 Types or Categories of Maintenance 1-4
Figure 2-1 Simplified Schematic of an Inlet Chiller System at a CTCC Plant 2-1
Figure 2-2 Simplified Schematic of an Evaporative Cooling System at a CTCC Plant 2-2
Figure 2-3 Plan View of Four Modular Refrigeration Buildings at a CTCC Plant 2-4
Figure 2-4 Typical Modular Cooling Tower at a CTCC Plant 2-4
Figure 2-5 Typical Cooling Tower Hot Water Distribution Manifolds at a CTCC Plant 2-5
Figure 2-6 Typical Cooling Tower Cold Water Sumps at a CTCC Plant 2-5
Figure 2-7 Typical Cooling Tower Fan at a CTCC Plant 2-6
Figure 2-8 Typical Cooling Tower Fan Drive Motor and Pulley at a CTCC Plant 2-6
Figure 2-9 Typical Primary Glycol Circulating Pumps at a CTCC Plant 2-7
Figure 2-10 Typical Circulating Water Pump Configuration at a CTCC Plant 2-8
Figure 2-11 Typical Secondary Glycol Pump Configuration at a CTCC Plant 2-8
Figure 2-12 Typical Electric-Motor-Driven Refrigeration Compressor at a CTCC Plant 2-10
Figure 2-13 Evaporative Coolers at a CTCC Plant 2-11
Figure 2-14 Evaporative Cooler Sump Configuration at a CTCC Plant 2-11
Figure 2-15 Typical Evaporative Cooler Circulating Water Pumps at a CTCC Plant 2-12
Figure 2-16 Typical Evaporative Cooler Banks at a CTCC Plant 2-12
Figure 2-17 Typical Evaporative Cooler Media 2-13
Figure 2-18 Typical Evaporative Cooler Mist Eliminator 2-13
Figure 2-19 Typical Evaporative Cooler System Distribution Head and Flow Measurement Station 2-14
Figure 3-1 Significance of Program Effectiveness Color Coding 3-5
Figure 4-1 Generic Process: System Troubleshooting (Preliminary Evaluation) (EPRI 1003093) 4-2
Figure 4-2 Generic Process: System Troubleshooting (Detailed System Troubleshooting) (EPRI 1003093) 4-3
Figure 5-1 Typical Elements of a Maintenance Job Plan 5-3
Figure B-1 Relationship Between Equipment Reliability and Maintenance Costs B-2
Figure B-2 Reduction of Overall Effectiveness B-4
Figure B-3 Impacts of Changing Refurbishment Intervals B-9
Figure B-4 PM Deferrals, Grace Period, and Late Dates B-10

LIST OF TABLES

Table 2-1 Inlet Cooling Systems Equipment Type and PMBD Cross-Reference 2-15

Table 3-1 Failure Locations, Mechanisms, and Influences for Cooling Tower Cell (Mechanical Draft – Cross Flow) 3-6

Table 3-2 Failure Locations, Mechanisms, and Influences for Air Cooled Type Heat Exchangers 3-18

Table 3-3 Failure Locations, Mechanisms, and Influences for Chiller and Centrifugal Compressors 3-21

Table 3-4 Failure Locations, Mechanisms, and Influences for Pressure Transmitters 3-25

Table 3-5 Failure Locations, Mechanisms, and Influences for Pressure Switches 3-26

Table 3-6 Failure Locations, Mechanisms, and Influences for Temperature Switches 3-29

Table 3-7 Failure Locations, Mechanisms, and Influences for Motors – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed 3-29

Table 3-8 Failure Locations, Mechanisms, and Influences for Motors (<15kv) – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed 3-39

Table 3-9 Failure Locations, Mechanisms, and Influences for Pumps – Horizontal – Single Stage – Single Suction 3-48

Table 3-10 Failure Locations, Mechanisms, and Influences for Pumps – Vertical – Close Coupled 3-53

Table 3-11 Failure Locations, Mechanisms, and Influences for AOVs – Diaphragm 3-57

Table 3-12 Failure Locations, Mechanisms, and Influences for AOVs – Piston 3-62

Table 3-13 Failure Locations, Mechanisms, and Influences for MOVs – AC Limitorque 3-67

Table 3-14 Failure Locations, Mechanisms, and Influences for Solenoid Operated Valves 3-71

Table 4-1 Troubleshooting Inlet Chiller Cooling Water System Components 4-5

Table 4-2 Troubleshooting Evaporative Cooling Water System Components 4-10

Table 4-3 Overview of the Model Maintenance Program for the Inlet Cooling System 4-11

Table 4-4 Determining the Program Effectiveness Output 4-17

Table 4-5 EPRI PMBD Baseline PM for Cooling Tower Cell – Mechanical Draft – Cross Flow 4-19

Table 4-6 Failure Modes Affected by Model Maintenance Program 4-20

Table 4-7 EPRI PMBD Baseline PM for Heat Exchanger – Air Cooled 4-23

Table 4-8 Failure Modes Affected by Model Maintenance Program for Heat Exchanger – Air Cooled 4-24

Table 4-9 EPRI PMBD Baseline PM for the Chiller and Centrifugal Compressor 4-26

Table 4-10 Failure Modes Affected by Model Maintenance Program for the Chiller and Centrifugal Compressor 4-27
Table 4-11 Model Maintenance Program for Calibration of Instrumentation and Controls 4-27
Table 4-12 EPRI PMBD Baseline PM for Motor <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed 4-29
Table 4-13 Failure Modes Affected by Model Maintenance Program for Motor <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed 4-30
Table 4-14 EPRI PMBD Baseline PM for Motor <15 Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed 4-34
Table 4-15 Failure Modes Affected by Model Maintenance Program 4-36
Table 4-16 EPRI PMBD Baseline PM for Circulating Water and Auxiliary Circulating Water Pump – Horizontal – Single Stage – Single Suction 4-40
Table 4-17 Failure Modes Affected by Model Maintenance Program for Circulating Water and Auxiliary Circulating Water Pumps 4-41
Table 4-18 EPRI PMBD Baseline PM for Evaporative Cooler Feed Pump – Vertical – Close Coupled 4-43
Table 4-19 Failure Modes Affected by Model Maintenance Program for Evaporative Cooler Feed Pump – Vertical – Close Coupled 4-44
Table 4-20 EPRI PMBD Baseline PM for Air Operated Valve – Diaphragm 4-46
Table 4-21 Failure Modes Affected by Model Maintenance Program for Air Operated Valve – Diaphragm 4-48
Table 4-22 EPRI PMBD Baseline PM for Air Operated Valve – Piston 4-49
Table 4-23 Failure Modes Affected by Model Maintenance Program for Air Operated Valve – Piston 4-51
Table 4-24 EPRI PMBD Baseline PM for Motor Operated Valve – AC Limitorque 4-52
Table 4-25 Failure Modes Affected by Model Maintenance Program for Motor Operated Valves Without Diagnostic Test 4-54
Table 4-26 Failure Modes Affected by Model Maintenance Program for Motor Operated Valves with Diagnostic Test 4-55
Table 4-27 EPRI PMBD Baseline PM for Solenoid Operated Valve 4-56
Table 4-28 Failure Modes Affected by Model Maintenance Program for Solenoid Operated Valves 4-57
Table 4-29 EPRI PMBD Baseline PM for Conductivity Analyzer 4-57
Table 4-30 EPRI PMBD Baseline PM for Glycol Analyzer 4-58
Table 4-31 Model Maintenance Program for the Glycol Slip Stream Filter Analysis 4-58
Table 4-32 EPRI PMBD Baseline PM for the Sump 4-58
Table B-1 Interval Sensitivity B-7
Table B-2 Impacts of Removing or Extending the Interval of a Particular Task B-8
Table B-3 Impacts of Changing Refurbishment Intervals B-8

1
INTRODUCTION

This guideline provides system- and component-level information regarding the maintenance of major systems typically installed at a combined cycle facility. It combines recommendations offered by major equipment manufacturers with lessons learned from owner/operators of combined cycle facilities.

1.1 Background

Combustion turbine combined cycle (CTCC) facilities utilize various systems and components that are unique to these types of power generation plants, and that are not typically found in a nuclear or fossil power plant. Accordingly, although owners of CTCC facilities do currently use of the EPRI Preventive Maintenance Basis Database (PMBD), their use of that resource is somewhat limited, to only those components that are common to both types of power plants and have been previously added to the PMBD. With the growth in the number of CTCC facilities, the EPRI Generation Maintenance Application Center (EPRI GenMAC) has made a commitment to provide maintenance guidance for many of these unique or unaddressed components and systems, and to facilitate the addition of these to the PMBD.

1.2 Objectives

The primary objective of this project is to provide a system-level tool that can assist CTCC facility owners in implementing a maintenance program that will ultimately improve system reliability and plant availability. Specifically, the objectives are the following:

- To establish maintenance tasks that leverage the EPRI PMBD resource
- To adjust task descriptions and intervals to accurately reflect actual combined cycle operation and design
- To provide a template from which other CTCC facilities can build a maintenance program with a strong technical basis

This report provides information that will help CTCC owners properly operate and care for the equipment installed in the inlet cooling systems of their plants. The guidance from the project will promote the safe, efficient, and cost-effective operation and maintenance of major types of equipment that are unique to CTCC facilities. Furthermore, this report pilots the concept of the *model maintenance program,* which provides a broad yet comprehensive maintenance basis for major components in the inlet cooling system. This will benefit the public by enabling combustion turbines to produce low-carbon electricity at minimal cost with high reliability.

1.3 Contents of the Report

Figure 1-1 illustrates the general structure and content of this technical report. The figure identifies key sections in the report that provide guidance to owners to effectively address CTCC component maintenance issues.

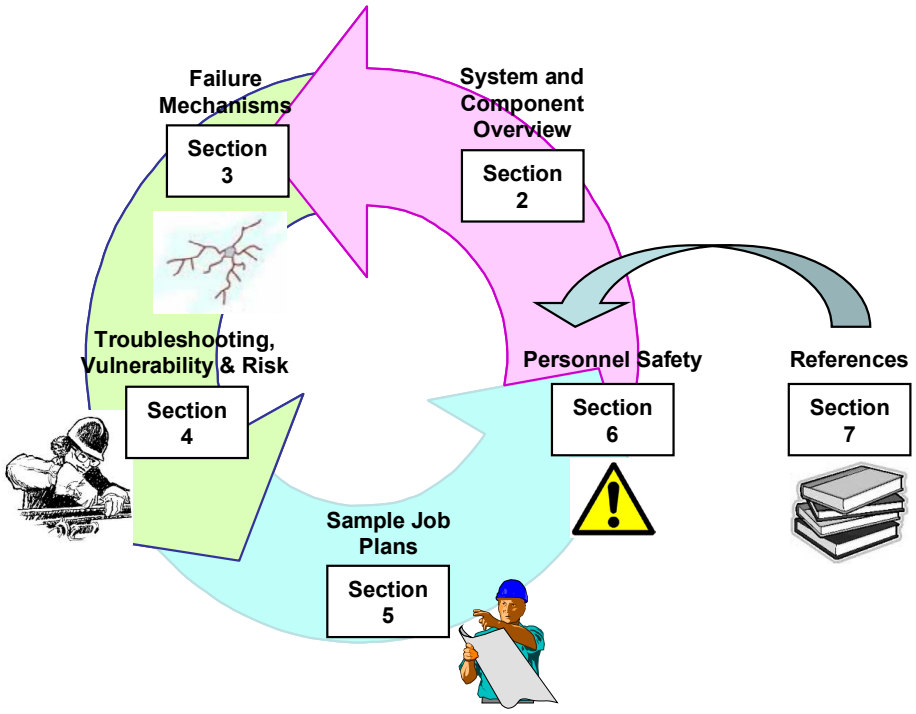


Figure 1-1
Scope and Content of This EPRI Report

This section provides an introduction to the report, and Section 2 provides an overview of system design parameters and familiarizes the user with inlet cooling system components and their functions. Sections 3 and 4 provide insight into various failure mechanisms and present detailed guidance for system troubleshooting, vulnerability, and risk analyses for variation from the standard PM guidance provided in the PMBD. Examples of various job plans are provided in Section 5. Personnel safety guidelines are provided in Section 6, and Section 7 provides the user with a complete listing of references that were used during the development of this report.

Appendix A of the report is a complete listing of the key points. Guidance on the use of the PMBD vulnerability tool is provided in Appendix B.

1.4 Industry Definitions and Nomenclature

Condition-Based Maintenance (CBM) – A process that requires technologies and people skills, and combines and uses all available direct diagnostic and performance data, process parameter trends, operator logs, and visual inspections to make and communicate timely recommendations regarding corrective actions or maintenance requirements of major/critical equipment.

Corrective Maintenance (CM) – A maintenance action performed to correct a deficiency of a plant component that has failed or is significantly deficient such that failure is imminent (within the current operating cycle or preventive maintenance interval of the component) and the component no longer conforms to (or cannot perform) its design function.

Facilities – Structures, systems, and components not associated with power generation. Structures may include training facilities, warehouses, maintenance shops, and administrative offices. Systems may include fire protection, plumbing, lighting, sewer, and drainage.

Frequency-Based or Periodic Maintenance (FBM) – Activities that include time-based actions that preclude, mitigate, or detect degradation of a structure, system, or component to restore it to original "like new" condition or extend its useful life by mitigating degradation to an acceptable level.

Preventive Maintenance (PM) – Activities performed to prevent unsatisfactory equipment conditions or performance from occurring.

Work Instructions – Instructions for performance of the work to be accomplished, the level of detail of which is dependent on the assigned planning level. When applicable, approved procedures may be referenced and may suffice as work instructions.

Work Order – A document used to control work and/or testing activities.

1.5 Definitions Associated with Maintenance Activities

The following sections provide an overview of the various types of maintenance activities that can be performed on system components. The four types or categories of maintenance are shown in Figure 1-2.

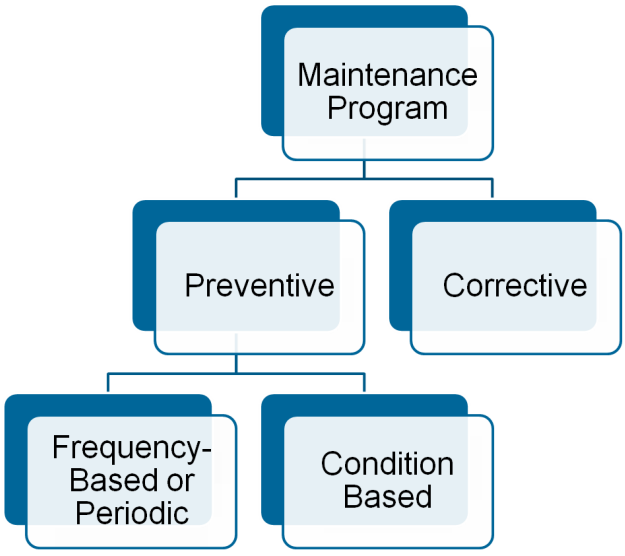


Figure 1-2
Types or Categories of Maintenance

1.5.1 Preventive Maintenance

Preventive maintenance (PM) tasks are performed to prevent unsatisfactory equipment conditions or performance. The distinction between predictive maintenance and periodic maintenance is presented below.

1.5.1.1 Periodic Maintenance

Periodic maintenance includes time-based actions that preclude, mitigate, or detect degradation of a structure, system, or component to either restore it to original "like new" condition or extend its useful life by mitigating degradation to an acceptable level. Periodic maintenance may be performed to prevent breakdown and can involve servicing such as lubrication, filter changes, cleaning, testing, adjustments, calibrations, and inspections. Periodic maintenance can also be initiated because of the results of predictive maintenance, vendor recommendations, or experience. Examples of periodic maintenance are the following:

- Scheduled valve re-packing because of anticipated leakage based on previous experience
- Major or minor overhauls based on experience factors or vendor recommendations
- Instrument calibrations used to meet plant specifications that are not part of a routine surveillance

1.5.1.2 Condition-Based Maintenance

Condition-based maintenance (CBM) is a methodology for performing preventive-maintenance activities based on the actual condition of the equipment rather than on the basis of fixed intervals or hours of operation. Examples of condition monitoring are the following:

- Vibration analysis for all rotating equipment
- Thermography for temperature surveys of electrical equipment, bearings, and couplings, and for leak detection and overheating
- Oil analysis (tribology) to determine the equipment condition and also the lubricant condition
- Electrical testing for motors and generators

Condition-based maintenance would constitute the work triggered by condition monitoring as listed in the examples above.

1.5.2 Corrective Maintenance

Corrective maintenance involves tasks generated as a result of equipment failure. Corrective tasks are generated when equipment is purposely operated to failure, or to correct a deficiency of a plant component that has failed or is significantly deficient such that failure is imminent (within the current operating cycle or preventive maintenance interval of the component) and the component no longer conforms to its design function.

1.5.3 Initial Basis for PM Tasks and Frequencies

The maintenance information presented in Sections 4 and 5 of this report provides insight into the PM tasks and frequencies initially developed in the EPRI PMBD. However, the user of this report should recognize that the PM tasks and frequencies recommended for the model maintenance program were developed with input from CTCC facility personnel with extensive maintenance, engineering, and operations experience. Accordingly, the guidance contained in this report takes into consideration actual plant operating history along with wear data, as well as gas turbine manufacturers' initial recommendations for scheduled PM activities.

1.6 Acronyms

AC – Alternating Current

ANSI – American National Standards Institute

AOV – Air Operated Valve

AR – As-Required

ASME – American Society of Mechanical Engineers

ASTM – American Society for Testing and Materials

BEP – Best Efficiency Point

CFR – Code of Federal Regulations

CHS – Critical, High-Duty Cycle, Severe Service Condition

CM – Corrective Maintenance

CTCC – Combustion Turbine Combined Cycle

DA – Dielectric Absorption

DC – Direct Current

DCS – Distributed Control System

DP – Delta Pressure

DT – Delta Temperature

E/P – Electro-Pneumatic Current to Pressure

EHC – Electro-Hydraulic Controls

EPRI – Electric Power Research Institute

FME – Foreign Material Exclusion

FRP – Fiberglass Reinforced Plastic

GenMAC – Generation Maintenance Application Center

GRP – Glass Reinforced Plastic

GT – Gas Turbine

HGP – Hot Gas Path

HP – High Pressure

HRSG – Heat Recovery Steam Generator

I&C – Instrumentation and Control

I/P – Current (I) to Pressure

ID – Inside Diameter

IEEE – Institute of Electrical and Electronics Engineers

IIPP – Injury and Illness Prevention Plan

IP – Intermediate Pressure

IR – Insulation Resistance

ISA – International Society of Automation

IST – In-Service Testing

Kv – Kilovolts

LOTO – Lock-Out/Tag-Out

LP – Low Pressure

MCC – Motor Control Center

MI – Major Inspection

MIC – Microbiologically Induced Corrosion

MMP – Model Maintenance Program

MO – Motor Operator

MOV – Motor Operated Valve

MSDS – Material Safety Data Sheet

MW – Megawatt

NDE – Non-Destructive Examination

NFPA – National Fire Protection Association

NHM – Non-Critical, High-Duty Cycle, Mild Service Condition

NIST – National Institute of Standards and Technology

NPSHA – Net Positive Suction Head Available

O&M – Operations and Maintenance

OEM – Original Equipment Manufacturer

OSHA – Occupational Safety and Health Administration

P&ID – Piping and Instrumentation Drawing

PH – Precipitation Hardening

PI – Polarization Index

PLC – Programmable Logic Controller

PM – Preventive Maintenance

PMBD – Preventive Maintenance Basis Database

PMT – Post-Maintenance Testing

PPE – Personal Protective Equipment

psi – Pounds per Square Inch

PVC – Polyvinyl Chloride

RPM – Revolutions per Minute

RTD – Resistance Temperature Device

SOV – Solenoid Operated Valve

UV – Ultraviolet

1.7 Listing of Key Points

Throughout this report, key information is summarized in Key Points. Key Points are bold-lettered boxes that succinctly restate information covered in detail in the surrounding text, making the key point easier to locate.

The primary intent of a Key Point is to emphasize information that will allow individuals to act for the benefit of their plant. EPRI personnel who reviewed this report assisted in the selection of the information included in these Key Points.

The Key Points are organized into four categories: Human Performance, O&M Cost, Technical, and Supervisory Observation. Each category has an identifying icon to draw attention to it for the benefit of readers who are quickly reviewing the report. The Key Points are shown in the following way:



Key Human Performance Point

Denotes information that requires personnel action or consideration in order to prevent personal injury, prevent equipment damage, and/or improve the efficiency and effectiveness of the task.



Key O&M Cost Point

Emphasizes information that will result in overall reduced costs and/or an increase in revenue through additional or restored energy production.



Key Technical Point

Targets information that will lead to improved equipment reliability.



Key Supervisory Observation Point

Identifies tasks or series of tasks that can or should be observed by maintenance first line supervisors to improve the performance of the maintenance staff and improve the reliability of the component.

Appendix A of this report contains a listing of all Key Points in each category. The listing restates each Key Point and provides a reference to its location in the body of the report. By reviewing this listing, users of this report can determine if they have taken advantage of key information that the writers of the report believe would benefit their plants.

2
SYSTEM/COMPONENT DESCRIPTION

The purpose of this section is to provide owner maintenance and engineering personnel with an overview of inlet cooling systems typically installed at a gas turbine combined cycle plant.

2.1 Typical Inlet Cooling System Installations

2.1.1 Simplified System Schematics

Figures 2-1 and 2-2 illustrate simplified schematics of two types of inlet cooling systems that can be found at a CTCC facility. One design is an inlet chiller system, and the other design is an evaporative cooling system. These schematics also depict boundary points, although actual boundary points and configuration may differ depending on site-specific designs.

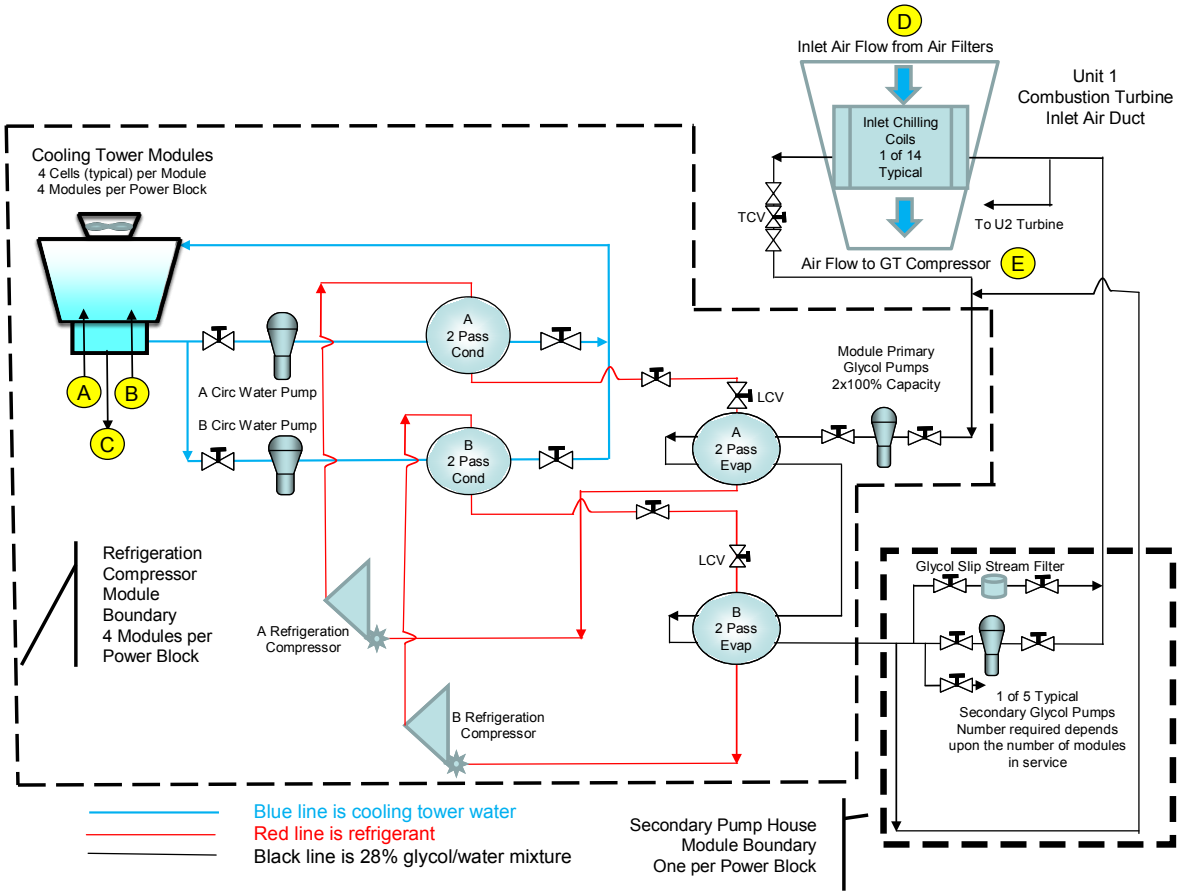


Figure 2-1
Simplified Schematic of an Inlet Chiller System at a CTCC Plant

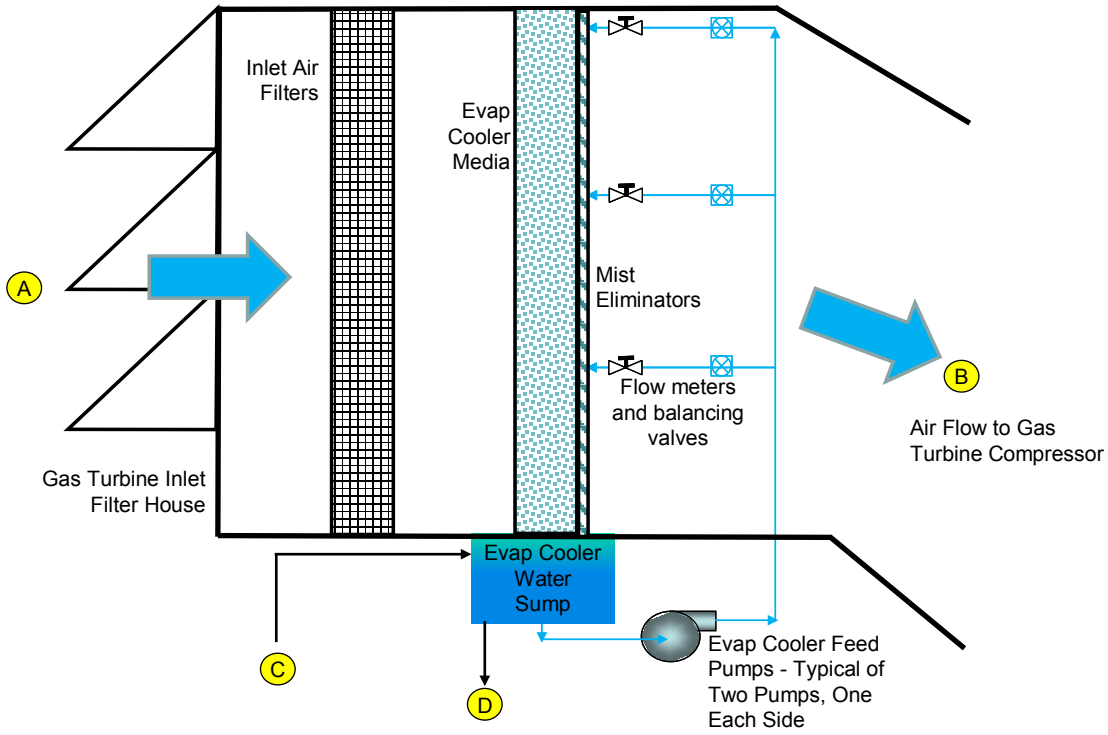


Figure 2-2
Simplified Schematic of an Evaporative Cooling System at a CTCC Plant

2.1.2 Boundary Statements

As shown in Figures 2-1 and 2-2, the boundaries associated with inlet cooling systems installed at a combustion turbine combined cycle facility are noted as follows. The inlet chiller system is primarily a closed loop system, with the refrigerant, glycol, and cooling water continuously circulating through the system. For an inlet chiller system (Figure 2-1), typical system boundaries are:

- A – The outlet of the cooling water makeup line to the cold water basin
- B – The outlet of the chemical feed system to the cooling tower
- C – The inlet connection from the cold water basin to the cooling tower blowdown line
- D – The gas turbine warm air inlet to the cooling coils
- E – The gas turbine cold air discharge from the cooling coils

The evaporative cooling system is primarily a closed loop system with only a makeup and blowdown line as the external connections to the system. For an evaporative cooling system (Figure 2-2), typical system boundaries are:

- A – The gas turbine warm air inlet to the evaporative cooler media
- B – The gas turbine cold air discharge from the mist eliminators
- C – The outlet of the cooling water makeup line to the sump
- D – The connection between the water sump and the blowdown line

2.2 System Descriptions

As noted for the purposes of this technical report, two system descriptions are provided so as to discuss two different inlet cooling system designs – the inlet chiller design and the evaporative cooler design.

2.2.1 Inlet Chiller System Description

2.2.2.1 General Description

Gas turbine electrical output is inversely proportional to ambient temperature, while electrical demand generally increases with high ambient temperatures. Cooler air, being denser, gives the turbine a higher mass flow rate and pressure ratio, resulting in an increase in power output and efficiency. Consequently, while demand is increased, gas turbine capacity is diminished. Through the utilization of various inlet air chilling technologies, gas turbine inlet air temperatures can be reduced, and in the case of refrigeration-based systems, can typically be optimized at a constant temperature of approximately 45ºF.

The inlet chiller system consists of four (4) modular refrigeration compressor buildings, that each contain two (2) packaged refrigeration compressors, complete with one (1) condenser and one (1) evaporator per compressor. Each of the compressor buildings includes its own power distribution panels and motor control centers. Figure 2-3 shows the modular nature of the chiller configuration, with four (4) cooling tower modules located on top of the primary compressor buildings (to the left of the combustion turbine/HRSGs), as well as the secondary pump module shown in the lower left corner of the figure.

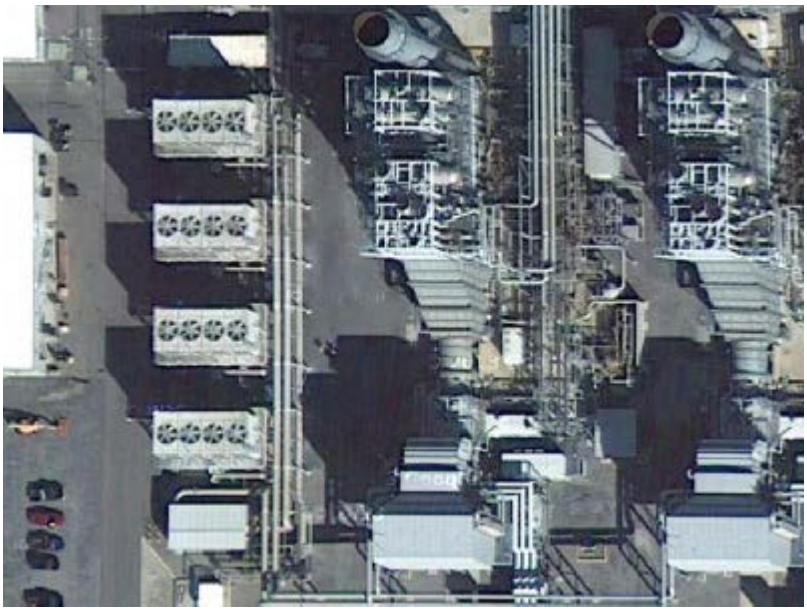


Figure 2-3
Plan View of Four Modular Refrigeration Buildings at a CTCC Plant

Located on top of the compressor buildings are the modular cooling towers, which are illustrated in Figure 2-4.



Figure 2-4
Typical Modular Cooling Tower at a CTCC Plant

Each cooling tower consists of four (4) modular cooling tower cells, which are built off site and set in place. Each cell is complete with hot water distribution manifolds, cold water sumps, cooling tower fan, and drive motor. These cooling tower components are illustrated in Figures 2-5 through 2-8.



Figure 2-5
Typical Cooling Tower Hot Water Distribution Manifolds at a CTCC Plant



Figure 2-6
Typical Cooling Tower Cold Water Sumps at a CTCC Plant



Figure 2-7
Typical Cooling Tower Fan at a CTCC Plant



Figure 2-8
Typical Cooling Tower Fan Drive Motor and Pulley at a CTCC Plant

Once set in place, all the cold water sumps are tied together. Due to the outdoor location, each cold water sump is provided with a thermostatically controlled sump heater to prevent freezing.

The intake structure of each gas turbine is provided with multiple air-to-liquid cooling coils downstream of the inlet air filters. These coils contain a mixture of glycol and water (28% glycol to water is the design specification ratio), which is circulated through the system. The glycol/water mixture is cooled through a two-stage refrigeration cycle, utilizing industrial grade refrigeration packages. Each package consists of two (2) electric-motor-driven refrigeration

compressors. Each compressor, utilizing a standard refrigerant (R134a), compresses the gas, which discharges into a two-pass condenser and then a two-pass evaporator and is then returned to the compressor. In the condenser, the compressed refrigerant vapor is condensed to a liquid, and the heat of compression is removed by the circulating water. The liquid refrigerant then passes through an expansion valve, or pressure reducing valve, as it enters the evaporator, where it vaporizes, absorbing the heat from the glycol/water mixture, before the refrigerant returns back to the compressor. On the tube side of the condensers is cooling water from a four-cell modular evaporative cooling tower supplied with the package. On the tube side of the two-pass evaporators is the glycol/water mixture.

One (1) compressor is associated with one (1) condenser and one (1) evaporator, and from the glycol side, they operate in series, meaning that as the glycol leaves the first evaporator, it enters the second evaporator. There are two (2) 100% redundant glycol circulating pumps associated with each module that provides adequate pressure to pump the glycol through both evaporators.

Figure 2-9 illustrates a typical configuration for the primary glycol circulating pumps.



Figure 2-9
Typical Primary Glycol Circulating Pumps at a CTCC Plant

With respect to the circulating water from the cooling tower, the system operates in parallel, meaning that there are two (2) separate 100% capacity circulating water pumps from the cooling towers, each of which is dedicated to a specific condenser. Figure 2-10 illustrates a typical configuration for the circulating water pumps.



Figure 2-10
Typical Circulating Water Pump Configuration at a CTCC Plant

Once the glycol/water mixture leaves the second condenser, it goes to the secondary pump house module, which contains a total of five (5) secondary pumps. These secondary pumps provide adequate head pressure to circulate the chilled glycol/water mixture through the coil banks in the gas turbine inlet air duct and then return it to the refrigeration modules. The total number of secondary pumps required to be in service at any given time is equal to the number of refrigeration modules in service minus one (for example, if there are three (3) refrigeration modules in service, then there would have to be two (2) secondary glycol pumps in service). Figure 2-11 illustrates a typical configuration for a secondary pump.



Figure 2-11
Typical Secondary Glycol Pump Configuration at a CTCC Plant

Located at the suction line to the secondary pumps is a bypass line that connects back to the return line from the gas turbine inlets, which is referred to as the glycol bridge. This glycol bridge ensures adequate supply pressure to the primary glycol pumps located in the refrigeration modules. Also enclosed in the secondary pump house is a slip-stream filter, which takes a tap from the discharge line, runs it through a 50-μ filter bag, and discharges it back to the pump suction line. This ensures that any small particulates in the glycol mixture are removed.

The cooling coils located within the gas turbine inlet air duct are made of copper tubing with aluminum fins. There are a total of fourteen (14) tube banks located within each inlet duct. Each bank is supplied with a manually operated inlet and an outlet valve so that the flow through each tube bank can be balanced during initial commissioning. There are also condensate drain pans located beneath each coil bank to catch and drain any moisture that might condense from the ambient air. There is one (1) temperature control valve located on the outlet of the cooling coils, for each of the combustion turbines, which monitors and controls the bulk inlet air temperature to the compressor section of the combustion turbine.

To supply both gas turbine inlets for a given power block with adequate cooling, based upon the host facility's site conditions, there are a total of four (4) refrigeration modules and one (1) secondary pump house module. Contained in these modules are the following major components:

- Eight (8) electric-motor-driven refrigeration vapor compressors (Figure 2-12)
- Sixteen (16) evaporative cooling towers, four (4) per chiller module
- Eight (8) primary glycol/water pumps, two (2) per chiller module
- Five (5) secondary chilled water pumps
- Eight (8) circulating water pumps, two (2) per cooling tower
- Two (2) sets of gas turbine inlet air cooling coils, one (1) per combustion turbine, with each containing fourteen (14) individual segments or tube banks
- Two (2) temperature control valves, one (1) per combustion turbine
- Associated valves, instrumentation, and controls, including fire detection and refrigerant leak detection in each chiller module enclosure



Figure 2-12
Typical Electric-Motor-Driven Refrigeration Compressor at a CTCC Plant

2.2.1.2 Unique System Design Features

The inlet chiller system at the host site utilizes centrifugal oil-less compressors and shell-and-tube heat exchangers (condensers and evaporators). Other designers of inlet chiller systems may utilize screw-type compressors (which may require a separator vessel to ensure lube oil is not carried over with the refrigerant), while other variations include air-cooled condensers, no secondary glycol pump requirements, or different means of providing adequate supply pressure to the primary glycol pumps (e.g., head tanks versus bridging lines). Users of this report should be aware the unique inlet chiller system design encountered at the host site may not represent one of the more commonly used systems installed at other CTCC facilities.

The inlet cooling system at the host site was designed to operate with a 28% glycol water mixture, but the site is currently operating with a ratio that is approximately 15%. Other systems may require different ratios, and in some cases up to 40% glycol, which would be based upon local ambient conditions.

2.2.2 Evaporative Cooling System Description

2.2.2.1 General Description

Gas turbine electrical output is inversely proportional to ambient temperature, while electrical demand generally increases with high ambient temperatures. Consequently, while demand is increased, gas turbine capacity is diminished. Through the utilization of various inlet air chilling technologies, gas turbine inlet air temperatures can be reduced. Evaporative coolers can lower the air temperature into the gas turbine compressor; however, the amount of cooling is limited by the atmospheric wet bulb temperature. A typical configuration of evaporative coolers at a CTCC facility is shown in Figure 2-13.



Figure 2-13
Evaporative Coolers at a CTCC Plant

Evaporative cooling techniques will decrease the bulk temperature of the inlet air flowing to the combustion turbine, thus increasing air density and mass flow. This will increase the combustion turbine output and efficiency.

Evaporative cooling is predominantly a closed loop system that consists of a sump or reservoir located beneath the gas turbine inlet filter house, which is illustrated in Figure 2-14.



Figure 2-14
Evaporative Cooler Sump Configuration at a CTCC Plant

This sump provides suction capacity for two (2) 50% capacity evaporative cooler circulating pumps, as shown in Figure 2-15.

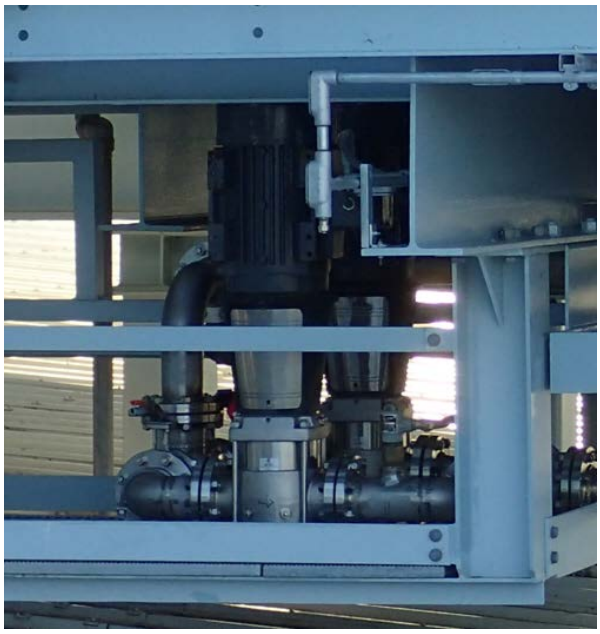


Figure 2-15
Typical Evaporative Cooler Circulating Water Pumps at a CTCC Plant

Each of these pumps circulates water to the one of three different levels of evaporative cooler media banks, which are shown in Figure 2-16.



Figure 2-16
Typical Evaporative Cooler Banks at a CTCC Plant

Evaporative cooler media is a cellulosic material looking very similar to a cardboard, but much stronger. This media is in the flow path of, and perpendicular to, the air-flow to the gas turbine compressor, located behind the inlet air filters. As the air passes over the wetted evaporative air cooler media, it is cooled by the evaporation process of the water, and the air increases in mass as it increases in moisture. Figure 2-17 illustrates the typical evaporative cooler media.

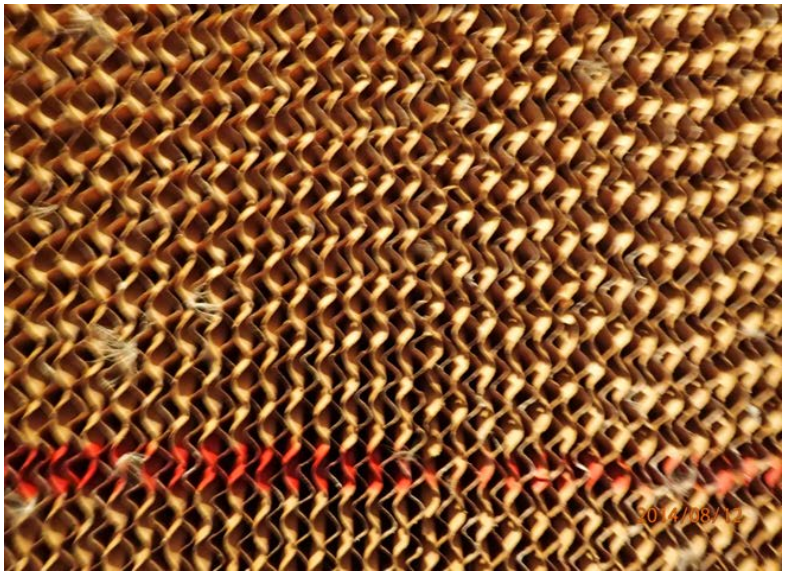


Figure 2-17
Typical Evaporative Cooler Media

To ensure that no free water is entrained in the air stream, downstream of the evaporative cooler media, the air passes through a mist eliminator, which captures and drains away any free water that may be entrained in the air stream. The cleaned, cool air then enters the combustion turbine. A mist eliminator is shown in Figure 2-18.



Figure 2-18
Typical Evaporative Cooler Mist Eliminator

Excess water that drains from the evaporative cooler media is captured and drains back to the sump. As this water is cycled through again, any solids and impurities in the water will remain, and will cycle up, or increase, as the water evaporates. Consequently, the system will continually monitor the conductivity of the water in the system, and will blow down some of the water to the plant drain system as necessary. There is a float-type level switch that monitors sump level, and if the level drops below a set point, will open a makeup valve to refill the sump. Figure 2-19 illustrates a typical configuration of the distribution headers and flow measurement station.

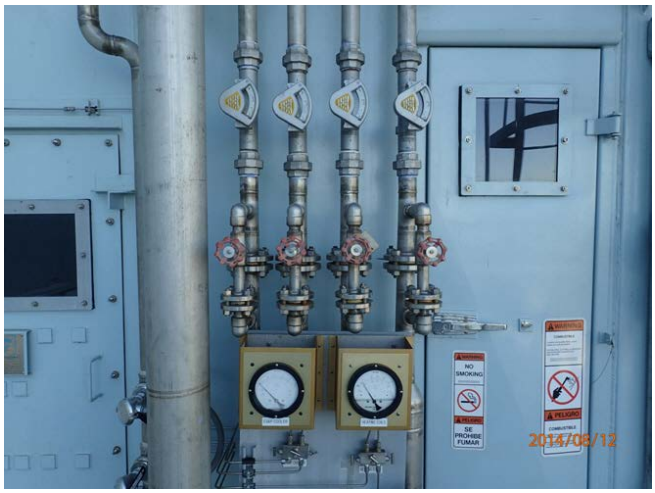


Figure 2-19
Typical Evaporative Cooler System Distribution Head and Flow Measurement Station

The evaporative coolers must be drained and laid up prior to the winter and recommissioned prior to the summer peak season. Decommissioning involves flushing, draining, and cleaning the system. Recommissioning requires refilling the sumps with clean water and calibrating system instrumentation.

2.2.2.2 Unique System Design Features

The system that was installed at the host facility consisted of a single sump installed on each of the three levels with a dedicated pump, high and low level switches, flow control, and blowdown system associated with each of the three modules. This is in effect three 33% capacity systems, but if any of the systems were unavailable, then the entire evaporative cooler system would not be unavailable due to laminar flow concerns with the gas turbine. In addition, the blowdown is not controlled by conductivity, as in some of the other systems, but is in continual blowdown, which was set to a minimal value. Finally, the evaporative cooler installed at the host facility was in front of the inlet air filters, instead of behind the filters.

2.3 System Components

The purpose of this section is to document the Preventive Maintenance Basis Database (PMBD) templates that were used to provide baseline PM guidance for components typically installed in an inlet cooling system at a CTCC facility.

EPRI has developed the PMBD to help its members create a maintenance strategy that is based on failure modes and their frequencies. This database is able to analyze the impact of changing the maintenance strategy by changing the interval at which a maintenance task is performed or even eliminating the task itself. In addition to providing the failure rate changes that are associated with the task frequency changes, this database provides other information such as an As-Found Condition Checklist, Most Probable Degradation Checklist, and other information to allow the maintenance professional to develop a comprehensive strategy.

Table 2-1 is a listing of the major equipment types installed in an inlet cooling system for a combustion turbine combined cycle plant. The table is sorted alphabetically by PMBD component type and then by PMBD component template name. The components listed in the left-hand column represent typical plant equipment that matches the PMBD component type and template. Components not addressed in the PMBD are listed alphabetically at the end of the table. The order in which the components are listed in this table is maintained throughout the report in the Section 4 analyses and in the Section 5 job plans.

The table provides a cross-reference to the sections in the EPRI PMBD that correspond to each of the major equipment types. In the PMBD, detailed PM tasks and frequencies are provided, and for the purposes of this report became the basis from which the model maintenance program was developed.

Table 2-1
Inlet Cooling Systems Equipment Type and PMBD Cross-Reference

Equipment Type	PMBD Component Type	PMBD Component Template	PMBD Template Rev. No.	Failure Mechanism Table
Cooling Tower Cell Including Fan	Cooling Tower	Mechanical Draft – Cross Flow	0	3-1
Inlet Chilling Coils	Heat Exchanger	Air Cooled	0	3-2
Chiller and Centrifugal Compressor Including Solenoid Operated Variable Orifice Valve, Condenser, and Evaporator Tube Bundles	HVAC	Chiller and Centrifugal Compressor	0	3-3
Pressure Transmitters	I&C	Pressure Sensor and Transmitter	0	3-4
Pressure Switches	I&C	Pressure Switch	1	3-5
Temperature Switches	I&C	Temperature Switch	0	3-6

Table 2-1 (continued)
Inlet Cooling Systems Equipment Type and PMBD Cross-Reference

Equipment Type	PMBD Component Type	PMBD Component Template	PMBD Template Rev. No.	Failure Mechanism Table
Horizontal Motor for Chiller Compressor	Motor	Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed	0	3-7
Vertical Motors for the Chilled Water Pumps, Chilled Water Booster Pumps, and Cooling Water Pumps	Motor	Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed	0	3-8
Auxiliary Circulating Water Pump and Glycol Primary and Secondary Circulating Pumps	Pump	Horizontal – Single Stage – Single Suction	0	3-9
Evaporative Cooling Water Pump	Pump	Vertical – Closed Coupled	0	3-10
Air Operated Valve	Valve	Air Operated – AOV – Diaphragm	0	3-11
Air Operated Valve	Valve	Air Operated – AOV – Piston	0	3-12
Motor Operated Valve	Valve	Motor Operated – MOV	0	3-13
Solenoid Operated Valve	Valve	Solenoid Operated – SOV	0	3-14
Conductivity Analyzer	NA	NA	OEM	Not Included
Glycol Analyzer	NA	NA	OEM	Not Included
Glycol Slip-Stream Filter	NA	NA	OEM	Not Included
Sump	NA	NA	OEM	Not Included

3
INLET COOLING SYSTEM FAILURE MECHANISMS

3.1 Problems Associated with Inlet Cooling Systems

This section briefly discusses major maintenance issues associated with both types of the inlet cooling systems – the inlet chiller design and the evaporative cooling design.

3.1.1 Problems Associated with Inlet Chiller Systems

Inlet chiller systems are designed to provide a constant inlet air temperature to the combustion turbine through the use of an industrial compression based refrigeration system, to chill the airflow stream to the turbine/compressor. As noted previously, the system consists of multiple compressors, cooling towers, and associated fans/pumps, as well as primary and secondary glycol pumps, and heat transfer coils located in the inlet ducts of the combustion turbines.

With the complexity of the system in general, there are multiple failure points that may impact an inlet chiller system; however, there are also inherent built-in redundancies within the system as well. In the host site that was visited, each of the four compressor packages had an independent PLC-type controller, with limited interface with the plant distributed control system (DCS).

The cooling tower modules, which are prepackaged cross flow cooling tower cells, are typically ganged together in series to achieve the appropriate amount of cooling capacity. These cooling modules can present multiple maintenance issues, which must be accounted for.



Key Technical Point

As with many cross flow towers, one of the most repetitive issues is associated with the distribution boxes, sometimes referred to as splitter valves in cross flow cooling towers, which control the amount of water to each side of the cooling tower cell.

These distribution boxes are often maintenance intensive; however, controlling flow to each side of the tower is critical to optimizing the cooling capacity within the tower cell.

Once the water flow is balanced, water is then distributed to the fill media, through a series of manifolds and spray nozzles.



Key Technical Point

Inlet chiller manifolds and spray nozzles can also present problems with plugging and breaking and must be inspected routinely as well, to ensure proper flow distribution.

If water flow isn't evenly distributed, not only side to side but within each side, the cooling tower capacity may be limited, and this may ultimately limit the capacity of the condensers and consequently the refrigeration cycle.

Cooling tower fans can also present issues with vibration and will need to be monitored. Many towers are provided with vibration switches, but switches are historically unreliable, and generally only provide an indication once something has already happened.



Key O&M Cost Point

Given the cost of pulling a fan and/or motor, when the cost of crane rental is factored in, it is often financially advantageous to replace vibration switches with sensors that can be read remotely by portable data collectors that can assist with vibration analysis.

Given that the motors are located in a warm, moist environment, they must be properly designed for the atmosphere. In certain facilities, it has been noted that motors were not properly suited for this application, and this was not realized until after there had been several rebuilds.

The system is somewhat independent of the ambient temperatures, although the cooling tower's ability to cool the condenser is impacted by high ambient conditions, which may in turn limit the overall effectiveness of the chiller package.



Key Technical Point

As with any refrigeration compressor, it is imperative that the system avoid what is referred to as Low Delta T Syndrome, which will cause the compressor to surge and ultimately lead to compressor failure.

Low Delta T occurs when the temperature rise across the refrigeration system is too low and the compressor is lightly loaded, at which point there can be significant axial movement within the compressor shaft, causing both radial and axial rubs on shaft seals on both the suction and discharge sides. Low Delta T is a system problem best controlled by operating procedures and system design. A good maintenance program can minimize the effects, but cannot prevent the inherent damage to compressors and heat exchangers operated in a Low Delta T condition.

The refrigerant, after it is compressed, discharges into a condenser, where the heat of compression is given up to the circulating water from the cooling tower, and then the refrigerant discharges to the evaporator, where the water/glycol mixture evaporates the refrigerant and returns it to the compressor. At the host site, both of these vessels were shell-and-tube type heat exchangers, with a butterfly, motor actuated level control valve located between the two heat exchangers that controlled the level in the condenser, to avoid flooding the evaporator.



Key Human Performance Point

As with any shell-and-tube type heat exchanger, there always exists the possibility of fouling or tube leaks, and it is incumbent upon a prudent operator to periodically clean and inspect the tube bundles. This includes performing a representative eddy current evaluation of the tubes, to look for tube wall thinning and cracking.

The level control valve, sometimes referred to as a variable orifice valve, which is between the condenser and evaporator in some installations, has been problematic. Proper calibration and testing of the valve and actuator assembly will resolve most of the potential problems associated with the variable orifice or level control valves. Repairs to the level control valve can pose issues as well, due to the fact that there are not always proper isolation valves, which makes removal of the level control valve difficult.

There are also a number of pumps associated with an inlet chiller system. At the host site, there were a total of twenty-one (21) vertical inline centrifugal pumps (although other manufacturers may utilize different configurations). The pumps at the host site all used C-frame motor mounts, which eliminates many of the issues with alignment and reduces some of the problems with mechanical seal leakage. Possible problems associated with any pumping system include leakage around mechanical seals or packing glands, as well as typical problems with any rotating equipment, such as vibration, misalignment, and so on.



Key O&M Cost Point

Failure to maintain proper glycol/water ratios within the system can possibly lead to the corrosion of system piping, as glycol will act as a passivating agent on the carbon steel piping systems. Not only can this cause pipe wall thinning, but the products of corrosion can also create further problems with valves, fouling of condensers, plugging of sensing lines, and other similar issues.

At the host site, a slip strip-stream filter was installed around the secondary glycol pumps to continually filter the glycol/water to remove any particulate matter that may accumulate in the glycol.

Finally, the air to glycol/water heat exchanger located in the combustion turbine inlet duct (in some units downstream of the filters, while in others upstream of the filters), can possibly develop leaks. Some systems are equipped with liquid/glycol detectors in the inlet air ducts, before the air compressors, to detect possible leakage of the glycol into the inlet air stream. In most installations, these coil-type heat exchangers are finned tubes, but it is imperative to understand the materials of construction of both the tubes and the fins. At one site it was discovered that the tubes were manufactured of copper, while the fins were made of aluminum, which sets up a galvanic cell, which is further exacerbated by the atmospheric conditions present at the tube banks. This will eventually lead to galvanic attack at the fin-tube interface that could lead to the development of leaks. It would be advisable to pressure test these tube banks with air prior to the summer run season.

3.1.2 Problems Associated with Evaporative Cooling Systems

Evaporative cooling systems, in comparison to inlet chiller systems, are simpler and have much less equipment to maintain. Typically, as can be seen from the simplified schematic in Section 2, there are only a few small pumps, sumps, associated instrumentation, and the cooler media.

The pumps utilized in most evaporative cooler applications are close coupled, which in general eliminates concerns associated with seal leakage and alignment issues. The pumps could still experience possible problems with bearings, as well as typical electric motor faults, but the size of the pumps and motors associated with these pumps, coupled with the location, often precludes routine data collection.



Key O&M Cost Point

One of the biggest potential issues with an evaporative cooling system is water quality, and while it is an operational issue, it can and will present maintenance issues such as media fouling and in rare cases possibly even pluggage of instrumentation.

In addition, if the water is allowed to stagnate for an extended period of time in the evaporative cooler sump, then it is possible for bacterial growth to occur in the system.

The evaporative cooler media should be inspected on a routine basis, especially if the media is located in front of the filters, for plugging and fouling from airborne contaminants such as feathers, leaves, and dirt.



Key Supervisory Observation Point

In general, cleaning of evaporative cooling media should be done by hand, or potentially through the use of a pressure washer utilizing the low-pressure setting, to avoid damaging the media.

Since this media is predominantly manufactured from a fibrous material, it is also prone to damage from installation and maintenance activities, which can bend over, or otherwise close up the air passages within the media bundles. If this is limited in nature, then it is perhaps acceptable; however, if the damage is excessive, then the media bundle will have to be replaced.

During the annual commissioning of the system, it is imperative that the flow to all evaporative cooler media sections be balanced, and that the entire media section be wetted. If this is not the case, it is possible that there may be uneven cooling of the air flow to the combustion turbine compressor, which in some circumstances can cause problems with the compressor.



Key Technical Point

During the annual commissioning of an evaporative cooling system, it is also imperative to inspect the integrity of the sealing system.

There have been limited occurrences of cases in which water bypassed the media and mist eliminators and was ingested into the compressor directly. Given that the water purity requirements for evaporative coolers generally allow for potable or well water, there are typically high levels of solids present in the water. As this water was ingested, and eventually evaporated as it travelled through the compressor, the solids remained and fouled the compressor, causing diminished compressor output and consequently degraded turbine output.

3.2 Detailed Failure Mechanism Data

The failure mechanism tables in this section provide detailed information regarding the location and types of various failure mechanisms associated with major components typically installed in two different types of inlet cooling water systems at a CTCC facility. These tables are provided as an indication of the baseline program's effectiveness at the failure mode level as found in the EPRI Preventive Maintenance Basis Database (PMBD).

Section 4 of this report contains an analysis for each system component that illustrates the EPRI baseline PMBD tasks and frequencies versus the new tasks and frequencies recommended as the model maintenance program. One of the tables in each analysis illustrates the failure modes affected by the model maintenance program and the change in risk. Failure modes that are **not** affected are still included in the corresponding component failure tables provided in this section of the report, and can be referenced as needed to meet plant-specific needs.

Figure 3-1 illustrates the significance of the color-coded program effectiveness scores that are shown in the tables, and indicates the degree to which a degradation mode is covered by one or more PM tasks. Task Effectiveness asks, if the degradation mechanism is present, what is the likelihood the mechanism is found or leads to further investigation. The three levels are defined as High – 97%, Medium – 80%, and Low – 50%. So a highly effective task would have 97% chance or greater of detecting the degraded mechanism.

Program Effectiveness	Degradation Mode Coverage
Green	Mode is covered by two or more tasks of High effectiveness
Yellow	Mode is covered by one task of High effectiveness
Orange	Mode is covered by one or more tasks of Medium effectiveness; but no tasks of High effectiveness
Red	Mode is covered by one or more tasks of Low effectiveness; but no tasks of High or Medium effectiveness

Figure 3-1
Significance of Program Effectiveness Color Coding

Table 3-1
Failure Locations, Mechanisms, and Influences for Cooling Tower Cell (Mechanical Draft – Cross Flow)

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Casing	Leakage of air	Failed air seal at pipe penetration	Green
	Leakage of water	Failed caulk	Green
Cold water basins	Sludge buildup	Silt, mud, debris	Red
Cold water basins and walls	Cracking, spalling	Settlement, undermining due to leakage, design issues	Orange
	Expansion joint deterioration	Design issues, improper materials or installation	Red
	Expansion joint deterioration	Normal use	Red
Coupling - disc pack or diaphragm, if present	Fatigue	Misalignment, or other improper installation - shaft fit, gap setting, or key sizing	Red
	Fatigue	Vibration, starts and stops	Red
	Loose fasteners	Vibration	Red
	Wear	Corrosion, environment	Red
	Wear	Normal wear	Yellow
Coupling - pin and bushing, if present	Damaged coupling half	Human error - improper installation - shaft fit, gap setting, mismatched halves, or key sizing	Red
	Damaged coupling half	Misalignment	Red
	Loose hub fasteners	Human error, under-torqued, cross threaded	Red
	Loose pins	Human error, under-torqued, cross threaded	Red
	Wear of elastomeric element	Chemical attack	Red
	Wear of elastomeric element	Human error - improper installation - shaft fit, gap setting, or key sizing	Red
	Wear of elastomeric element	Misalignment	Red

Table 3-1 (continued)
Failure Locations, Mechanisms, and Influences for Cooling Tower Cell (Mechanical Draft – Cross Flow)

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Coupling - pin and bushing, if present (continued)	Wear of elastomeric element	Normal wear	Yellow
	Wear of pins	Normal wear	Yellow
Drift eliminators - blade type (all types)	Existence of air gaps	Vibration from air turbulence	Green
Drift eliminators - blade type (PVC type)	Existence of air gaps	Aging of supports, moisture	Green
Drift eliminators - blade type (wood type)	Existence of air gaps	Aging, moisture	Green
Drift eliminators - cellular type	Existence of air gaps at partitions and structure	Aging of seals	Green
	Existence of air gaps at partitions and structure	Vibration from air turbulence	Green
	Overloaded and failed	Silt and algae build up	Green
Drive shaft - graphite composite	Cracked	Alignment, mechanical impact, improper handling	Red
	Degraded	UV exposure	Yellow
	Distortion (twisted)	Motor starts, especially when fan is reverse rotating	Red
Fan assembly	Air seal discs - missing or damaged	Personnel error, vibration	Orange
	Blade fatigue failure (may also affect other structural components)	Operation near stalled condition, e.g., from over-pitched blades, significantly unequal pitch	Green
	Blade fiber bloom	UV exposure, air abrasion	Yellow
	Blade inadequate airflow, loss of performance	Improper blade pitch or excessive tip clearance	Red
	Blade leading edge erosion	Excessive drift	Orange
	Blade leading edge erosion	Normal wear	Orange
	Blade plugged drain holes	Contamination, dirt, debris	Red

Table 3-1 (continued)
Failure Locations, Mechanisms, and Influences for Cooling Tower Cell (Mechanical Draft – Cross Flow)

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Fan assembly (continued)	Blade structural failure	Vibration from effects of aerodynamic interaction with surrounding structures or supports	Green
	Blade tracking deviation	Improper blade installation	Orange
	Hub corrosion	Water chemistry, failed coating	Red
	Imbalance	Debris, ice, etc. lodged in blade tips	Orange
	Loose hardware - hub and blades	Inadequate maintenance, vibration	Red
Fill	Cracked and broken	Icing	Red
	Cracked and broken	Normal use, vibration	Yellow
	Dislodged splash bars	Icing, vibration, damaged grids, missing bench ties, excessively hot water	Red
	Failed (sagging) splash bars	Improper grid spacing	Red
	Failed concrete grid supports	Corrosion, poor design	Green
	Failed wood grid supports	Mechanical abrasion due to water impingement	Green
Gearbox anti-rotation device, if present	Corroded, failed	Environment	Red
	Worn ratchet, stuck	Normal use	Yellow
Gearbox base or mounting	Loss of structural rigidity	Cracked welds, loose bolts, missing shims, corrosion	Red
	Soft foot, deformation due to structural resonance	Imperfections in base, Improper installation, Vibration	Red
Gearbox bearings - rolling element (radial and thrust)	Wear	Degraded lubricant - contamination, e.g., water ingress	Orange
	Wear	Improper installation, e.g., bearing preload	Red

Table 3-1 (continued)
Failure Locations, Mechanisms, and Influences for Cooling Tower Cell (Mechanical Draft – Cross Flow)

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Gearbox bearings - rolling element (radial and thrust) (continued)	Wear	Incorrect, mixed, or insufficient lubricant	Red
	Wear	Maintenance induced errors - improper fit, handling, or installation	Red
	Wear	Manufacturing defects	Red
	Wear	Misalignment of bearing housing or driver, preloads due to internal or external forces such as fan balancing, or thermal growth	Red
	Wear	Normal wear	Orange
	Wear	Vibration	Orange
Gearbox bolting	Failed	Manufacturing defect, e.g., wrong material	Red
	Loose or failed	Personnel error, e.g., improper torque, wrong material	Red
	Loose or failed	Vibration	Red
Gearbox fan - external	Dirty or corroded	Environment, bad drift eliminators	Red
	Loose	Personnel error	Red
Gearbox gaskets	Leaks	Aging (regardless of time in service)	Yellow
	Leaks	Corrosion of O-ring grooves	Yellow
	Leaks	Improper material	Orange
	Leaks	Personnel error, e.g., damaged mating surfaces, improper torque	Orange
Gearbox gears	Asymmetric wear	Axial thrust produced by improper assembly	Red
	Broken teeth (fatigue)	Cavitation, i.e., inadequate lubrication	Yellow
	Wear	Contaminated lubricant	Orange

Table 3-1 (continued)
Failure Locations, Mechanisms, and Influences for Cooling Tower Cell (Mechanical Draft – Cross Flow)

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Gearbox gears (continued)	Wear	Debris	Red
	Wear	Degraded lubricant	Yellow
	Wear	Excessive mechanical loading; misalignment of bearing housing, shaft, driver, or driven component; preloads due to internal or external forces; thermal growth	Orange
	Wear	Inadequate lubrication	Red
	Wear	Manufacturing defects	Red
	Wear	Normal use	Yellow
Gearbox instrumentation (oil temperature, oil level)	Improper setup	Personnel error	Red
	Inaccurate or failed	Drift, contamination, corrosion, water ingress	Red
Gearbox oil	Degraded	Normal use, contamination	Red
Gearbox oil breather	Plugged	Contamination, dirt	Red
Gearbox oil line (external), if present	Crushed	Personnel error	Red
	Loose fittings	Vibration, improper installation	Red
Gearbox oil line (suction only), if present	Air in-leakage	Vibration, personnel error (damage)	Red
Gearbox pressure relief valve, if present	Clogged	Debris, oil sludge	Red
	Premature opening	Age, vibration	Red
Gearbox shaft oil seals	Leakage	Installation error	Orange
	Wear, leakage	Normal use, high temperature	Orange
Gearbox sump oil heater, if present	Incorrect set point	Personnel error	Red
	Open circuit	Age	Red

Table 3-1 (continued)
Failure Locations, Mechanisms, and Influences for Cooling Tower Cell (Mechanical Draft – Cross Flow)

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Hot water basin	Cracking and spalling of splash box cover, concrete only	Chemical additives in water treatment, rebar corrosion	Green
	Flow restriction	Debris, biological growth	Green
	Nozzle damage	Mechanical cleaning, personnel error	Green
	Nozzle plugging	Debris, biological growth	Green
	Rot induced sagging or failure of splash box cover, wood only	Improper chemical treatment of water, biological	Green
	Sagging or failure of splash box cover, FRP only	UV exposure	Green
	Separation from curbs and seals	Deck support sagging and failure	Green
Hot water distribution downtakes	Leakage between wood pieces	Aging, water damage, flow turbulence	Green
Hot water distribution valve	Gasket failure	Aging	Green
	Stem and bushing thread wear	Normal use	Green
	Stem to disk separation	Flow turbulence	Green
	Wrap failure at stub to header connection - leakage	Normal use, inadequate valve support, vibration	Green
Hot water header - FRP only	Failure of wood pipe supports	Thrust at startup	Green
	Fiber bloom	UV exposure	Green
	Leakage at bell and spigot joints	Installation error, thrust at startup	Green
	Leakage at bell and spigot joints	O-ring aging	Green
	Mechanical damage	Personnel error	Green
Louver ice retainers (sacrificial)	Damaged	Icing and erosion	Red
Louver support arms - concrete type	Cracking and spalling	Freeze thaw cycles, rebar corrosion	Red
Louvers - all types	Broken	Icing, wind	Red

Table 3-1 (continued)
Failure Locations, Mechanisms, and Influences for Cooling Tower Cell (Mechanical Draft – Cross Flow)

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Louvers - concrete type	Cracking and spalling	Freeze thaw cycles, chemical additives in water treatment, tendon corrosion	Red
Louvers - FRP type	Leakage causing ice accumulation and subsequent ice damage	Degraded caulk	Orange
Louvers - plywood type	Leakage causing ice accumulation and subsequent ice damage	Wood rot	Orange
Motor anti-rotation device, if present	Corroded, failed	Environment	Red
	Worn ratchet, stuck	Normal use	Orange
Motor base	Loss of structural rigidity	Cracked welds, loose bolts, missing shims, corrosion	Red
	Soft foot, deformation	Imperfections in base, Improper installation, Vibration	Red
Motor bearing grease seals	Wear	Environment, debris	Red
	Wear	Excessive grease	Red
	Wear	Imbalance or misalignment, improper installation, incorrect lubricant	Red
	Wear	Material defect	Red
	Wear	Normal wear, duty cycle	Red
	Wear	Temperature excursions	Red
Motor bearing lubrication delivery and drain tubes	Loose	Vibration or personnel error	Red
Motor bearings - rolling element	Damaged	Excessive grease	Red
	Wear	Degraded or dirty grease	Orange
	Wear	Excessive mechanical loading	Red
	Wear	Incorrect or mixed grease, Insufficient grease	Red

Table 3-1 (continued)
Failure Locations, Mechanisms, and Influences for Cooling Tower Cell (Mechanical Draft – Cross Flow)

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Motor bearings - rolling element (continued)	Wear	Maintenance induced errors such as improper fit, handling, or installation	Red
	Wear	Misalignment during initial assembly or wear of other components	Red
	Wear	Normal wear	Green
Motor endbells or bearing housings	Damaged or misaligned mating surfaces	Personnel error	Red
	Wear - bearing fit area	Degraded bearing lubrication, personnel error - damage to fit area	Orange
Motor fan - external	Dirty or corroded	Environment, bad drift eliminators	Red
	Loose	Personnel error	Red
	Loose or blocked cover	Dirt, debris	Red
Motor frame	Cracked	Impact damage, Improper handling	Red
	Cracked	Structural resonance	Red
	Deformation	Impact damage, Improper handling	Red
Motor gaskets	Improper installation	Personnel error	Red
	Material defect (cracks or porosity)	Age	Red
Motor leads and electrical connections	Insulation degradation	Age	Red
	Insulation degradation	Contamination	Red
	Insulation degradation	Improper installation, Improper testing, damaged	Red
	Insulation degradation	Manufacturing defect	Red
	Insulation degradation	Temperature	Red
	Insulation degradation	Vibration and starting movement	Red
Motor lubrication - grease	Degraded, loss of lubricating qualities	Moisture, dirt	Red

Table 3-1 (continued)
Failure Locations, Mechanisms, and Influences for Cooling Tower Cell (Mechanical Draft – Cross Flow)

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Motor lubrication - grease - open bearing	Degraded, loss of lubricating qualities	Age	Red
Motor lubrication - grease - shielded bearing	Degraded, loss of lubricating qualities	Age	Orange
Motor rotor bars and shorting rings (cast type)	Corrosion	Environment	Red
	Cracked	Age, cycle fatigue	Orange
	Cracked	Manufacturing or design deficiency	Red
	Mechanical interference between rotor and stator	Wear of other components	Red
Motor rotor fans and hardware	Cracked welds	Fatigue	Red
	Loose hardware	Personnel error	Red
Motor shaft	Shaft integrity and cracking	Cycle fatigue, latent manufacturing defects	Red
	Wear - journal and coupling areas	Contamination of lubricant	Yellow
	Wear - journal and coupling areas	Corrosion	Yellow
	Wear - journal and coupling areas	Misalignment	Yellow
Motor space heaters	Broken, loose or grounded connections	Personnel error	Red
	Broken, loose or grounded connections	Vibration	Red
	Open element	Age	Red
Motor stator laminations	Breakdown of insulation	Contamination	Red
	Breakdown of insulation	Heat	Red
	Breakdown of insulation	Manufacturing defects	Red
	Breakdown of insulation	Vibration	Red
	Physical damage	Personnel error	Red

Table 3-1 (continued)
Failure Locations, Mechanisms, and Influences for Cooling Tower Cell (Mechanical Draft – Cross Flow)

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Motor stator winding - blocking, bracing, and wedges	Fretting of insulation materials	Movement during running and starts	Red
	Loose blocking and bracing	Electrical and surge transients	Red
	Loose blocking and bracing	Manufacturing defect	Red
	Loose blocking and bracing	Vibration	Red
Motor stator windings	Insulation degradation	Age	Red
	Insulation degradation	Contamination	Red
	Insulation degradation	Electrical and surge transients	Red
	Insulation degradation	Heat above rated	Red
	Insulation degradation	Manufacturing defect	Red
	Insulation degradation	Vibration	Red
Shroud	Cracking	UV exposure, vibration	Yellow
	Loose fasteners and anchors	Vibration	Orange
	Mechanical damage from irregular tip clearance or contact with blades	Personnel error (mispositioned)	Green
Stairs and walkways - concrete type	Corrosion of galvanized hand rail and connections	Environment	Green
	Cracking and spalling	Freeze-thaw cycles, rebar corrosion	Green
Stairs and walkways - FRP type	Cracked molded stair unit	Poor manufacturing, UV, normal wear and tear	Green
	Cracked molded stair unit	UV, normal wear and tear	Green
	Damaged	High winds	Green
	Damaged, deteriorated	Ice, algae, rain	Green
	Fiber bloom	UV	Green
Stairs and walkways - hardware	Corrosion	Moisture, galvanic attack	Green
	Loose	Vibration, dimensional changes of structure (especially after dry-out)	Green

Table 3-1 (continued)
Failure Locations, Mechanisms, and Influences for Cooling Tower Cell (Mechanical Draft – Cross Flow)

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Stairs and walkways - wood type	Damaged	High winds	Green
	Damaged, deteriorated	Ice, algae, rain	Green
	Rot - various kinds	Aging	Green
Structural hardware (e.g., fasteners, shear connectors, diagonal straps)	Corrosion	Moisture and water chemistry, galvanic attack	Yellow
	Erosion	Exotic materials such as silicon bronze without proper protection	Yellow
	Loose	Vibration, dimensional changes of structure (especially after dry-out)	Yellow
Structural members - concrete (beams only), if present	Beam displacement on seat	Improper design or construction permitting excessive movement	Orange
Structural members - concrete (deck members, beams, columns, joints), if present	Spalling, cracking	Freeze thaw cycles, chemical additives in water treatment, rebar corrosion	Orange
	Spalling, cracking	Rebar corrosion due to design and construction issues, e.g., insufficient concrete coverage, poor quality concrete	Orange
Structural members - FRP (deck members, beams, columns, joints), if present	Fraying, layer separation	Improper chemical treatment of water, vibration	Yellow
	Fraying, layer separation	UV exposure, especially at high levels	Yellow
	Mechanical damage	Episodic weather-related events, e.g., from falling ice, high winds, seismic events	Yellow

Table 3-1 (continued)
Failure Locations, Mechanisms, and Influences for Cooling Tower Cell (Mechanical Draft – Cross Flow)

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Structural members - wood (deck members, beams, columns, joints), if present	Erosion	Mechanical abrasion due to water impingement	Green
	Mechanical damage	Episodic weather related events, e.g., from falling ice, high winds, seismic events	Yellow
	Rot - various kinds	Improper chemical treatment of water, biological	Yellow
	Splitting	Thermal cycling, wind, UV exposure, vibration	Yellow
Tower anchorage	Anchor bolt corrosion	Water chemical quality (groundwater or from leakage)	Red
	Mechanical damage	Installation error, personnel error	Red
Vibration sensors and instrumentation	Improper setup or mounting	Personnel error	Red
	Inaccurate or failed	Drift, contamination, corrosion, electrical surge	Red
Vibration trip switch	Improper setup or mounting	Personnel error	Red
	Water in-leakage	Seal failure	Orange
Wind vanes, if present (to direct air motion radially)	Dislodged	Normal use, vibration, high wind (GRP type fails more frequently than panel type)	Orange

Table 3-2
Failure Locations, Mechanisms, and Influences for Air Cooled Type Heat Exchangers

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Support Plates, Frames, Drain Pan	Corrosion	Condensation	Yellow
Tube Exterior and Fins	Corrosion	Environment, salt-laden air, boric acid	Yellow
	Mechanical damage	Personnel error	Red
	Fouling	Unfiltered air	Yellow
	Reduced heat transfer	Detached fins caused by corrosion of tension wound fins	Red
Tube Joint	Defective joint	Improper installation	Yellow
	Defective joint	Water hammer	Yellow
	Defective joint	Improper plugging	Yellow
Tube Plugs	Loose or missing	Improper installation	Orange
Tube Sheets	Corrosion	Material selection for fresh water environments	Yellow
	Corrosion	Improper cathodic protection	Yellow
	Corrosion	Improper material in brackish and salt water environments	Orange
	Cracking of ligaments	Improper plugging or rolling of tubes	Red
Tubes - Copper Alloy	Erosion (internal, e.g., general wall loss)	Sediment with high flow velocity	Red
	Erosion (internal)	Foreign material lodged in tube	Red
	Erosion (internal-localized, most prevalent at inlet end)	Suspended solids with high flow velocity	Red
	Erosion at end of sleeve or coating	Flow-induced eddies	Red
	Pitting corrosion	Siltation and sedimentation due to low flow rate, improper lay up	Red

Table 3-2 (continued)
Failure Locations, Mechanisms, and Influences for Air Cooled Type Heat Exchangers

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Tubes - Copper Alloy (Brass Only)	Transgranular stress corrosion cracking	Improper chemistry or putrefaction of organic material	Red
Tubes - Stainless Steel	MIC	Fluid quality (worse with rough ID tube surface, discontinuities and welds, low flow rate with water temperature range 60 deg to 90 deg F)	Red
	Manganese pitting corrosion	Oxidizing biocides and manganese in raw water	Red
	Erosion (internal localized)	Foreign material lodged in tube	Yellow
Tubes (All)	Defect	Manufacturing or fabrication defect	Red
	Microfouling	Fluid quality, water chemistry control, low flow velocity, water temperature range of 60 deg to 90 deg F	Red
	Macrofouling	Debris causing a thermal performance issue, e.g., clam shells, fish, rocks, other foreign material and marine debris, sand, silt, zebra mussels	Orange
	Wear at baffle plate	Vibration	Red
Waterbox Channel, Partition Plate, and Nozzles	Graphitization of cast iron components, if present	Water quality (accelerated by brackish or salt water)	Green
	Cracking or degradation of coating	Improper material	Red
	Erosion	Bolting failure	Red
	Gasket leakage	Process fluid, chemistry	Yellow
	Corrosion	Water chemistry	Orange
	Cracking or degradation of coating, if present and can lead to corrosion	End of life, age	Yellow
	Corrosion	Improperly designed or operated cathodic protection	Green

Table 3-2 (continued)
Failure Locations, Mechanisms, and Influences for Air Cooled Type Heat Exchangers

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Waterbox Channel, Partition Plate, and Nozzles (continued)	Gasket leakage	Improper installation or frequent disassembly	Yellow
	Gasket leakage	Improper material or design (e.g., when changing type of gasket)	Yellow
	Gasket leakage	Age	Green
	Corrosion (when no coating is present)	Raw water, sedimentation due to low flow rate	Green
	Erosion	High flow rate	Green
	Cracking or degradation of coating	Installation error	Red

Table 3-3
Failure Locations, Mechanisms, and Influences for Chiller and Centrifugal Compressors

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Bearings	Wear	Vibration, misalignment of coupling	Yellow
	Wear	Run time	Green
	Wear	2 phase process fluid (shock loading)	Yellow
	Wear	Lubrication failure	Green
Capacity Control (Pre-Rotation Vanes)	Binding	Control failure	Green
	Binding	Bound/broken linkage	Green
	Binding	Vibration	Green
	Binding	Aging	Green
Chiller Instrumentation and Control Devices: Capacity, Oil Pressure, Oil Level, Refrigerant High and Low Pressure, Freeze Protection	Drift	Aging	Yellow
	Drift	Heat	Yellow
	Drift	Vibration	Yellow
	Misadjustment	Personnel error	Yellow
	Component failure	Aging, duty cycle	Green
	Component failure	Heat	Green
	Component failure	Vibration	Green
	Plastic tubing failure	Aging (refrigerant attack)	Orange
	Plastic tubing failure	Vibration	Orange
	Elastomer failure	Aging	Green
	Elastomer failure	Heat	Green
	General tubing failure	Vibration	Orange
Compressor System Failure	Inadequate system differential pressure	Low load	Green
Compressor, Gaskets	Leakage	Improper torquing	Red
	Leakage	Assembly error	Red
	Leakage	Duty cycle (thermal cycling)	Yellow

Table 3-3 (continued)
Failure Locations, Mechanisms, and Influences for Chiller and Centrifugal Compressors

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Compressor, Impeller	Wear, cracked	Aging	Yellow
	Wear, cracked	2-phase process fluid	Orange
	Erosion	Aging	Yellow
	Erosion	2-phase process fluid	Orange
Compressor, Lubrication Failure	Low oil level	Personnel error	Green
	Low oil level	Leakage	Green
	Incorrect oil	Personnel error	Red
	Oil degradation	Aging, duty cycle	Yellow
	High or low oil pressure	Aging of pump, duty cycle	Green
	High or low oil pressure	Clogged / crushed lines	Green
	High or low oil pressure	Weak relief spring, duty cycle	Green
Compressor, Shaft Seal	Cracked	Run time, i.e., Heat/friction	Green
	Wear	Run time, i.e., Heat/friction	Green
	Leakage	Misalignment	Green
Coupling	Wear	Misalignment	Yellow
	Wear	Lubrication failure	Yellow
	Wear	Run time	Yellow
Electronic/Electrical Devices: Transmitters, Temperature Control Valves, Programmable Logic Controls, Level/Flow Switches, RTDs, I/P Transducers	Drift	Contamination	Red
	Drift	Vibration	Red
	Drift	Temperature	Red
	Drift	Personnel error, installation method and location	Red
	Loose connections	Vibration	Red
	Loose connections	Temperature	Red
	Loose connections	Personnel error, installation method and location	Red

Table 3-3 (continued)
Failure Locations, Mechanisms, and Influences for Chiller and Centrifugal Compressors

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Fasteners/Hardware	Loose / missing	Vibration	Orange
	Loose / missing	Improper torquing	Orange
Gear Box	Wear	Vibration, misalignment of coupling	Yellow
	Wear	Run time	Green
	Wear	Lubrication failure	Green
	Wear	2 phase process fluid (shock loading)	Yellow
Heat Exchangers: Condenser	Water side fouling	Water quality, biofouling	Green
	Water side fouling	Debris	Green
	Tube sheet and head erosion	Water quality	Yellow
	Tube sheet and head erosion	Flow velocity	Yellow
	Improper water side flow rate	Degraded control valve	Green
	Improper water side flow rate	Improper valve line-up	Green
	Improper water side flow rate	Plugged suction strainer	Green
	Glycol fouling	Fluid leak	Orange
Heat Exchangers: Evaporator	Water side freezing	Control failure	Orange
	Water side fouling	Poor water chemistry	Green
Oil Return System: Eductor, Sump Level Switch, SOV	Plugged	Foreign material	Orange
	Failed component	Aging (cycles)	Orange
	Stuck	Contamination	Orange
	Coil failure	Heat (normally energized are most susceptible)	Orange
	Elastomer and gasket failure	Aging (cycles)	Orange
	Elastomer and gasket failure	Heat	Orange
Pressure Relief Valve (Safety Valve)	Spring failure	Fatigue	Orange
	Fails to reseat	Debris	Orange
	Fails to reseat	Installation error	Orange
	Set point drift	Vibration	Red

Table 3-3 (continued)
Failure Locations, Mechanisms, and Influences for Chiller and Centrifugal Compressors

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Purge Unit	Excessive purge	Environment, heat, dirt, contamination	Yellow
	Excessive purge	Malfunction of controls, heater, condenser, SOVs, refrigerant system	Yellow
	Ineffective purge, allows noncondensables to remain in condenser	Malfunction of controls, heater, condenser, SOVs, refrigerant system	Yellow
	Ineffective purge, allows noncondensables to remain in condenser	Environment, heat, dirt, contamination	Yellow
Refrigerant Metering Device	Plugged	Dryer mechanism failure	Orange
	Plugged	Corrosion, wear products	Orange
	Plugged	Foreign material from maintenance actions	Orange
	Failed float valve	Float ball failure	Orange
	Failed float valve	Missing lever pins	Orange
	Failed float valve	Stuck	Orange
Refrigerant Operated Control Valve	Stuck	Water quality	Green
	Leaking bellows or capillary	Vibration	Green
	Leaking bellows or capillary	Aging, duty cycle	Green
	Water side leak	Failed gasket	Green
	Failed spring	Debris	Yellow
	Failed spring	Fatigue, normal wear	Green
Rupture Disk	Misoperation	Improper installation, personnel error	Yellow
	Misoperation	Design of discharge piping	Yellow
Solenoid Valves	Stuck	Contamination	Green
	Coil failure	Heat, duty cycle (normally energized are most susceptible)	Green
	Elastomer and gasket failure	Heat, duty cycle	Green

Table 3-4
Failure Locations, Mechanisms, and Influences for Pressure Transmitters

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Internal wiring and connections	Broken, loose, or grounded	Personnel error	Red
	Broken, loose, or grounded	Vibration	Red
Sensing lines and associated components, e.g., condensate pot, sealed reference legs, bellows, manifold, root valves and isolation valves	Plugged line	Sediment, debris	Red
	Liquid binding in a non-liquid line	Condensation	Red
	Air binding in a liquid sensing line	Non-condensable gases	Red
	Broken or cracked line, or loose fitting	Personnel error (climbing or stepping on the line)	Orange
	Broken or cracked line, or loose fitting	Vibration	Yellow
	Leaking valves	Worn packing	Yellow
	Fitting leak	Maintenance (connect/reconnect)	Yellow
	Fitting and/or tubing leak	External contamination, corrosion and pitting, probably a result of improper maintenance or environment	Orange
	Damaged bellows	Manufacturing defect	Red
	Leaking bellows or reference filled leg	Normal wear /fatigue	Orange
Sensor, capacitance cell	Leakage	Manufacturing defect	Red
Sensor, e.g., capacitance cell, Bourdon tube, piezo electric, strain gauge	Component failure	Age	Yellow
	Drift	Overpressure event	Red
	Component failure	Vibration	Red
Transmitter electronics	Misadjustment	Personnel error	Red
	Drift	Age, temperature	Yellow
	Component failure	Age, temperature	Yellow
	Component failure	Vibration	Red

Table 3-5
Failure Locations, Mechanisms, and Influences for Pressure Switches

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Diaphragm pressure boundary	Material (stainless steel) degradation due to erosion/corrosion	Age, high temperature, fluid quality	Red
	Torn stainless steel diaphragm	Age, high duty cycle, vibration	Red
Elastomers (diaphragms, gaskets, and O-rings)	Material degradation	Age, moisture, fluid quality	Red
	Material degradation	High temperature	Red
	Material degradation	Misapplication, material selection, moisture, fluid quality, high temperature	Red
Electrical switch	Contacts fused due to arcing	Age, high duty cycles	Red
	Corroded contacts due to moisture intrusion	Age, moisture	Red
	Cracked and/or corroded	Vibration	Red
	Loose electrical connections	Personnel error	Red
	Loose electrical connections	Vibration	Red
	Loose switch and/or mounting plate fasteners	Vibration	Red
	Short between adjacent electrical terminations	Personnel error (Inappropriate modification of lug insulation barrel)	Red
Inline process snubber	Erratic switch actuation due to inadequate snubber performance	Process pressure fluctuations	Red
Mechanical linkage	Locking screw missing	Personnel error (lack of knowledge of screw function)	Red
	Locking screw stripped	Maintenance (loosen/re-tighten)	Red
	Set point drift	Alignment change/binding due to temperature extremes	Red
	Stuck or bound	Alignment change/binding due to age, High temperature, vibration	Red

Table 3-5 (continued)
Failure Locations, Mechanisms, and Influences for Pressure Switches

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Mechanical linkage (Bourdon tube)	Linkage arm ring failure	Vibration	Red
	Sheared pivot pin	Pressure pulsations or oscillations	Red
Mechanical linkage (DPIS meter movement)	Stuck or bound	Back-plate/meter needle alignment/binding due to age, high temperature, vibration	Red
Mercury switch	Early actuation due to vibration	Vibration	Red
Micro switch	Button sticking	Age, contamination, moisture	Red
	Contact resistance high	Infrequently exercised/energized contacts, contamination, high temperature, moisture	Red
	Failure to maintain alignment	Maintenance (complex activity), vibration	Red
	Incorrect set point	Improper (i.e., too little) torquing	Red
Sensing device	Set point drift	Change in adjustment setting due to vibration	Red
	Set point drift	Fluid quality, e.g., process media sediment	Red
	Set point drift	Leakage due to vibration	Red
	Set point drift	Material degradation due to age, normal use, contamination, moisture	Red
	Set point drift	Material degradation due to high temperature	Red
	Set point drift	Material degradation due to overpressure event (hammer)	Red
Sensing device (bellows)	Puncture	Personnel error (inappropriate tool used to test-actuate switch)	Red
Sensing device (Bourdon tube)	Leaking device	Material degradation due to cyclic failure	Red
Sensing device (diaphragm)	Leaking device	Material degradation due to manufacturing defect	Red
	Leaking device	Material degradation due to vibration	Red
	Physical deformation of diaphragm causes (possibly significant) set point shift	New pressure switch first time exposure to system operating pressure	Red

Table 3-5 (continued)
Failure Locations, Mechanisms, and Influences for Pressure Switches

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Sensing device (dp bellows)	High-pressure bellows internal crack	Material degradation due to cyclic failure	Red
	Torque tube failure	Material degradation due to Contamination from corrosion due to quality of the fluid, moisture	Red
Sensing device (dp diaphragm) and/or linkage	Stuck or bound	High continuously applied differential pressure, high temperatures	Red
Sensing line and tube fittings	Blocked, plugged	Fluid quality - sediment and/or contamination in oil system	Red
	Blocked, plugged	Raw water or borated water deposition.	Red
	Broken or cracked line, or loose fitting	Personnel error (climbing or stepping on the line)	Red
	Broken or cracked line, or loose fitting	Vibration	Red
	Entrained air in sensing lines	Dissolved or entrained air in process fluid	Red
	Fitting and/or tubing leak	External contamination, corrosion and pitting, probably a result of improper maintenance or environment	Red
	Fitting leak	Maintenance (connect/reconnect)	Red
	Inline check valve improper installation	Personnel error (installed backwards)	Red
	Leaking manifold valve seats	Galled stem threads	Red
	Leaking stainless steel flexible hose	Vibration	Red
	Leaking valves	Worn packing	Red
Weather proof cover	Environmental boundary failure	Corrosion, moisture, high temperature	Red

Table 3-6
Failure Locations, Mechanisms, and Influences for Temperature Switches

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Electrical Switch	Cracked and/or corroded	Vibration	Yellow
	Button sticking	Age	Green
	Loose connections	Personnel error	Red
	Loose connections	Vibration	Red
Mechanical Linkage	Set point drift	Alignment change/binding due to temperature extremes	Red
Sensing Device (Other Types)	Set point drift	Material degradation due to age, normal wear	Yellow
	Set point drift	Change in adjustment setting due to vibration	Red
	Set point drift	Leakage due to corrosion	Yellow
	Set point drift	Leakage due to vibration	Yellow
Sensing Device (Temperature Bulb and Capillary)	Loss of capillary fill	Personnel error (climbing or stepping on the line)	Orange
	Loss of capillary fill	Vibration	Yellow

Table 3-7
Failure Locations, Mechanisms, and Influences for Motors – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Baffles	Loose hardware	Manufacturing defect	Red
	Loose hardware	Vibration	Red
	Loose hardware	Personnel error	Red
Bearing and Winding Temperature and Vibration Probes	Broken, loose, or grounded connections	Personnel error	Red
	Instrument drift	Normal use	Red
	Broken, loose, or grounded connections	Vibration	Red
Bearing Insulation (External)	Broken, cracked, or detached	Improper handling or installation	Yellow
	Insulation shorting	Contamination (e.g., paint, lubricant, dirt, salt corrosion) or external grounds	Red

Table 3-7 (continued)
Failure Locations, Mechanisms, and Influences for Motors – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Bearing Insulation (Internal)	Broken, cracked, or detached	Improper handling or installation	Red
	Insulation shorting	Contamination from conductive particles (e.g., wear, rust, etc.) in the lubricant	Red
Bearing Metering Orifice	Blocked	Contamination (e.g., sludge, lubricant system cleanliness), debris	Red
	Blocked	Installation error (e.g., covered by gasket)	Red
Bearing Seals (All Types)	Wear	Improper installation	Orange
	Leakage	Incorrect lubricant	Orange
Bearing Seals (Contact Type)	Wear	Normal wear, duty cycle.	Orange
	Wear	High temperature environment	Orange
	Wear	Material defect	Orange
	Leakage (e.g., deformed)	Excessive lubricant	Orange
Bearing Seals (Non-Contact Type)	Wear	Imbalance or misalignment	Orange
	Wear	Environment, debris	Orange
Bearings - Sleeve	Wear	Degraded lubricant due to normal usage, motor speed, contamination, temperature	Green
	Wear	Incorrect or mixed lubricant	Yellow
	Wear	Insufficient lubricant	Yellow
	Wear	Excessive lubricant level (slinger ring non-force-fed lubricating systems)	Yellow
	Wear	Misalignment during initial assembly or wear of other components	Orange
	Wear	Circulating electric currents	Green
	Wear	Babbitt imperfection (e.g., cold spot, hydrogen porosity, loss of bond, etc.)	Yellow
	Wear	Excessive mechanical loading	Yellow
	Wear	Soft foot	Yellow

Table 3-7 (continued)
Failure Locations, Mechanisms, and Influences for Motors – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Bearings - Sleeve (continued)	Wear	Maintenance induced errors such as incorrect bearing, improper internal clearance, fit, handling, or installation	Yellow
	Wear	Failure of anti-rotation pin (horizontal motors only)	Yellow
	Wear	Failure of Babbitt (e.g., fatigue, abrasion, erosion, bond failure, etc.)	Green
	Wear	Fretting due to vibration from improper fit (pinch) from the bearing housing to the bearing shell	Yellow
	Wear	Rough journal or runner	Yellow
	Wear	Normal wear	Green
Breather Caps and Sight Glass Vents	Blocked	Personnel error (e.g., improper installation)	Yellow
	Blocked	Contamination (e.g., paint, dirt)	Yellow
Filters - Air Coolers	Clogged or dirty	Environment	Yellow
Frame, Enclosure, and Mounting	Loose or damaged	Vibration	Red
	Deformation - changes in bearing line bore centers	Voids in base	Yellow
	Deformation - changes in bearing line bore centers	Damage-personnel error	Yellow
	Cracked, broken internal welds	Structural resonance	Red
	Cracked, broken internal welds	Damage-personnel error	Red
	Soft foot	Improper installation, e.g., not cleaning mating surfaces, improper shimming	Yellow
	Soft foot	Imperfections in motor base or motor mounting feet	Yellow
	Clogged air screens	Environment	Yellow
	Clogged air screens	lubricant from leaks	Yellow
	Loose or damaged	Personnel error	Red

Table 3-7 (continued)
Failure Locations, Mechanisms, and Influences for Motors – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Gaskets - General	Loss of integrity	Age, material defect (cracks)	Yellow
	Loss of integrity	Installation error	Yellow
Internal Cooling Coil - Bearing Cooling Water	Leakage	Improper installation	Orange
	Corrosion	Cooling water chemistry	Red
	Erosion	Flow rate	Yellow
	Coil separation - joint failure	Personnel error	Orange
	Coil separation - joint failure	Vibration	Orange
	Coil separation - joint failure	Manufacturing defect	Orange
	Packing or gasket failures	Improper material	Orange
	Packing or gasket failures	Personnel error	Orange
	Damaged fins, impeded heat transfer	Personnel error	Red
	Fouling	Debris	Red
	Fouling	Algae, zebra mussels, etc.	Orange
Lubrication - Oil	Degraded, loss of lubricating qualities	Temperature above 140 F, Moisture, Dirt	Yellow
	Degraded, loss of lubricating qualities	Normal wear	Yellow
	Insufficient or excessive level	Leakage, personnel error	Yellow
Machine Fits	Damaged, misaligned	Personnel error, Manufacturing defect	Yellow
Motor Lead Electrical Connections - Crimped Lugs	High resistance	Contamination	Yellow
	Loose	Improper installation - incorrect lug size or crimping technique	Yellow
	High resistance	Oxidation	Yellow
	Insulation degradation	Age, temperature, radiation	Red
	Insulation degradation	Improper installation of the insulation	Red

Table 3-7 (continued)
Failure Locations, Mechanisms, and Influences for Motors – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Motor Leads	Abrasion	Improper routing through motor frame into main junction box	Red
	Insulation degradation	Contamination, e.g., lubricant, dirt, moisture	Red
	Insulation degradation	Age	Yellow
	Insulation degradation	Manufacturing defect	Red
	Insulation degradation	Damage from terminating and determination	Red
	Insulation degradation	High temperature	Red
	Insulation degradation	Improper testing	Red
	Insulation degradation	Vibration from starting movement	Red
	Insulation degradation	Improper positioning in main junction box	Red
Oil Slinger Rings	Wear	Duty cycle	Orange
	Out of round	Manufacturing defect, handling, removal and installation	Orange
	Wear (ID scalloping)	Lubricant level too high	Orange
Oil Slinger Rings - Two-Piece Design	Separation	Improper assembly, normal use, improper design	Orange
Piping and Connections	Leakage	Personnel error, vibration	Yellow
Rotor Bars and Shorting Rings	Loose	Normal use	Orange
	Loose	Manufacturing or design deficiency	Orange
	Loose	Cyclic fatigue from driven equipment (pulsating load or line voltage), cyclic fatigue due to number of starts during life of motor	Orange
	Loose	Thermal fatigue from number of consecutive starts within a limited time period	Orange
	Cracked, brazed joint failure	Manufacturing or design deficiency	Orange

Table 3-7 (continued)
Failure Locations, Mechanisms, and Influences for Motors – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Rotor Bars and Shorting Rings (continued)	Cracked, brazed joint failure	Cyclic fatigue from driven equipment (pulsating load or line voltage), cyclic fatigue due to number of starts during life of the motor	Yellow
	Cracked, brazed joint failure	Thermal fatigue from excessive number of consecutive starts within a limited time period	Orange
	Material defect (cracks or porosity), improper design	Manufacturing or design deficiency	Orange
	Deformation	Lamination stack shifts, rotor bar creep	Red
	Deformation	Heat due to excessive number of consecutive starts within a limited time period	Red
	Corrosion	Environment, e.g., salt water spray	Red
	Cracked, brazed joint failure	Excessive number of consecutive starts within a limited time period	Orange
Rotor Cage - Lamination Support, i.e., Spider	Loose (cage is loose on spider)	Improper clamping pressure, design, loss of torque on clamping through bolts	Yellow
	Loose (cage is loose on spider)	Excessive number of consecutive starts	Yellow
	Loose (cage is loose on spider)	Weld failure of spider or lamination stack locking key	Yellow
	Loose (cage is loose on spider)	Manufacturing defect, e.g., improper fit	Yellow
	Loose (cage is loose on spider)	Total number of starts over the life of the motor	Yellow
Rotor Cage - Solid Lamination Design (Non-Spider Design)	Loose (cage is loose on shaft)	Excessive number of consecutive starts	Yellow
	Loose (cage is loose on shaft)	Improper clamping pressure, design, loss of torque on clamping through bolts	Yellow
	Loose (cage is loose on shaft)	Manufacturing defect, e.g., improper fit	Yellow

Table 3-7 (continued)
Failure Locations, Mechanisms, and Influences for Motors – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Rotor Cage - Solid Lamination Design (Non-Spider Design) (continued)	Loose (cage is loose on shaft)	Total number of starts over the life of the motor	Yellow
	Loose (cage is loose on shaft)	Weld failure of lamination locking mechanism	Yellow
Rotor Fans and Hardware	Loose hardware	Personnel error	Red
	Cracked welds	Duty cycle - fatigue	Red
Rotor Fans with Interference Fit Design	Loose on shaft	Manufacturing defect, improper interference fit, improper installation	Red
Rotor Laminations	Insulation breakdown	Contamination	Red
	Insulation breakdown	Thermal aging	Red
	Insulation fretting	Vibration from loose laminations	Red
	Damaged or defective	Manufacturing or installation error	Red
	Stress fatigue cracks	Magnetic cycling and transients	Red
	Stress fatigue cracks	High rotor speed (3600 rpm)	Red
	Loose parts - vent ducts, clamping plate fingers	Settling	Red
	Loose parts - vent ducts, clamping plate fingers, balance weights	Vibration	Orange
	Dirty	Contamination	Orange
Rotor Retaining Rings (Predominantly on 2-Pole Motors)	Loose	Vibration and movement from thermal expansion of shorting ring	Yellow
	Loose	Improper fit, improper design, wrong material	Yellow
Rotor Spider - Integral Design Where Spider Arms Are Welded to Shaft	Loose (cracked weld)	Manufacturing defect, inadequate weld	Orange

Table 3-7 (continued)
Failure Locations, Mechanisms, and Influences for Motors – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Rotor Spider - Spider to Shaft Interference Fit Design	Loose (broken weld from spider arms to shaft interference sleeve)	Manufacturing defect, inadequate weld	Orange
	Loose (spider is loose on shaft)	Manufacturing defect, inadequate interference fit, loss of position locking mechanism, e.g., loss of tack weld	Orange
Shaft	Wear (coupling fit area)	Manufacturing defect of coupling	Yellow
	Wear (coupling fit area)	Manufacturing defect of shaft	Yellow
	Wear (coupling fit area)	Improper coupling fit to shaft	Yellow
	Shaft cracking	Latent manufacturing defects, wrong material	Yellow
	Shaft cracking	Cyclic torsional loading, wrong material	Yellow
	Wear (journal)	Normal use	Orange
	Wear (journal)	Damaging contamination of lubricant (hard particles, excessive water, contaminants from lubricant fills, sand)	Orange
	Wear (journal)	Corrosion, mainly from water in the lubricant	Orange
	Wear (journal)	Shaft currents, electrolysis (worse on machines without insulated bearings)	Orange
	Wear (journal)	Misalignment	Orange
	Sagging	Standby without rotation in horizontal motors	Yellow
	Bowing	Thermal bowing due to circulating currents or uneven magnetic forces	Yellow
	Wear (coupling fit area)	Wrong coupling	Yellow
Space Heater Wiring	Degraded insulation	Age, material type	Yellow

Table 3-7 (continued)
Failure Locations, Mechanisms, and Influences for Motors – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Space Heaters	Broken, loose, or grounded connections	Personnel error	Green
	Broken, loose, or grounded connections	Vibration	Green
	Open element	Age	Green
	Open element	Failure of control circuit component	Orange
Stator Laminations	Insulation breakdown	Contamination	Red
	Insulation fretting	Vibration from loose laminations	Red
	Improper fit of back iron (OD of laminations)	Manufacturing defect	Red
	Damaged	Personnel or manufacturing error	Red
	Loose parts - vent ducts, clamping plate fingers, through bolts	Vibration, thermal cycling	Red
	Insulation breakdown	Thermal aging	Red
Stator Windings, Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Insulation degradation	Internal partial discharge	Red
	Failure of surge ring support brackets	Improper design	Red
	Insulation degradation	Winding design deficiency	Red
	Insulation degradation	Heat above normal running temperature (the greater the delta T above normal the faster the degradation)	Yellow
	Insulation degradation	Vibration	Yellow
	Insulation degradation	Normal use	Yellow
	Insulation degradation	Contamination, e.g., lubricant, dirt, salt spray, moisture, etc.	Yellow
	Insulation degradation	Electrical and surge transients	Red
	Insulation degradation	Normal exposure to radiation	Yellow
	Insulation degradation	Manufacturing defect or installation deficiencies	Red

Table 3-7 (continued)
Failure Locations, Mechanisms, and Influences for Motors – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Stator Windings, Includes Blocking, Bracing, Tying, Surge Rings, Wedges (continued)	Insulation degradation	Movement during starting, (depends on the total number of starts)	Red
	Loose blocking, bracing, and tying eventually leading to winding failure	Vibration	Orange
	Loose blocking, bracing, and tying eventually leading to winding failure	Normal use	Orange
	Loose blocking, bracing, and tying eventually leading to winding failure	Manufacturing defect - design or materials	Red
	Loose blocking, bracing, and tying eventually leading to winding failure	Movement during starting (depends on total number of starts)	Orange
	Broken surge ring	Manufacturing defect	Red
	Failure of surge ring support brackets	Maximum radial flexing during starts, thermal elongation of stator coils can cause failure of supports if improperly designed	Red
	Fretting of insulation materials	Relative movement of adjacent insulating materials with improper blocking and bracing	Red
	Loose wedges	Improper fit of wedges to stator core slot	Red
	Loose wedges	Loss of resin bond	Red
	Insulation degradation	External corona discharge	Red
	Loose wedges	Poor selection of wedge material	Red
Surge Capacitors	Insulation degradation	Normal use	Yellow
	Insulation degradation	Voltage transients and surges	Red
	Bushing tracking	Contamination	Yellow
	Bushing damage	Personnel error	Red

Table 3-7 (continued)
Failure Locations, Mechanisms, and Influences for Motors – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Surge Capacitors (continued)	Leakage	Normal use	Yellow
	Leakage	Personnel error	Red
	Leakage	Heat above rated	Yellow
Winding Electrical Connections - Brazed	High resistance	Improper brazing accelerated by starting movement (end turn)	Red
	High resistance	Improper brazing accelerated by thermal cycling	Red

Table 3-8
Failure Locations, Mechanisms, and Influences for Motors (<15kv) – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Baffles	Loose hardware	Manufacturing defect	Red
	Loose hardware	Vibration	Red
	Loose hardware	Personnel error	Red
Bearing and Winding Temperature and Vibration Probes	Broken, loose or grounded connections	Personnel error	Red
	Instrument drift	Normal use	Red
	Broken, loose or grounded connections	Vibration	Red
Bearing Insulation (External)	Broken, cracked, or detached	Improper handling or installation	Yellow
	Insulation shorting	Contamination (e.g., paint, lubricant, dirt, salt corrosion) or external grounds	Red
Bearing Insulation (Internal)	Broken, cracked, or detached	Improper handling or installation	Red
	Insulation shorting	Contamination from conductive particles (e.g., wear, rust, etc.) in the lubricant	Red
Bearing Metering Orifice	Blocked	Contamination (e.g., sludge, lubricant system cleanliness), debris	Red
	Blocked	Installation error (e.g., covered by gasket)	Red

Table 3-8 (continued)
Failure Locations, Mechanisms, and Influences for Motors (<15kv) – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Bearing Seals (All Types)	Wear	Improper installation	Orange
	Leakage	Incorrect lubricant	Orange
Bearing Seals (Non-Contact Type)	Wear	Normal wear, duty cycle.	Orange
	Wear	High temperature environment	Orange
	Wear	Material defect	Orange
	Leakage (e.g., deformed)	Excessive lubrication	Orange
	Wear	Imbalance or misalignment	Orange
	Wear	Environment, debris	Orange
Bearings - Rolling Element	Wear	Degraded lubricant due to normal usage, motor speed, contamination, temperature	Green
	Wear	Degraded grease due to normal usage, motor speed, contamination, temperature	Green
	Wear	Incorrect or mixed lubricant	Yellow
	Wear	Insufficient lubricant	Yellow
	Wear	Excessive lubricant	Yellow
	Wear	Misalignment during initial assembly or wear of other components	Orange
	Wear	Circulating electric currents	Green
	Wear	Excessive mechanical loading	Yellow
	Wear	Soft foot	Yellow
	Wear	Maintenance induced errors such as incorrect bearing, improper internal clearance, fit, handling, or installation	Yellow
	Wear	Normal wear	Green
Breather Caps and Sight Glass Vents	Blocked	Personnel error (e.g., improper installation)	Yellow
	Blocked	Contamination (e.g., paint, dirt)	Yellow
Filters - Air Coolers	Clogged or dirty	Environment	Yellow

Table 3-8 (continued)
Failure Locations, Mechanisms, and Influences for Motors (<15kv) – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Frame, Enclosure, and Mounting	Loose or damaged	Vibration	Red
	Deformation - changes in bearing line bore centers	Voids in base	Yellow
	Deformation - changes in bearing line bore centers	Damage - personnel error	Yellow
	Cracked, broken internal welds	Structural resonance	Red
	Cracked, broken internal welds	Damage - personnel error	Red
	Soft foot	Improper installation, e.g., not cleaning mating surfaces, improper shimming	Yellow
	Soft foot	Imperfections in motor base or motor mounting feet	Yellow
	Clogged air screens	Environment	Yellow
	Clogged air screens	Lubricant from leaks	Yellow
	Loose or damaged	Personnel error	Red
Gaskets - General	Loss of integrity	Age, material defect (cracks)	Yellow
	Loss of integrity	Installation error	Yellow
Internal Cooling Coil - Bearing Cooling Water	Leakage	Improper installation	Orange
	Corrosion	Cooling water chemistry	Red
	Erosion	Flow rate	Red
	Coil separation - joint failure	Personnel error	Orange
	Coil separation - joint failure	Vibration	Orange
	Coil separation - joint failure	Manufacturing defect	Orange
	Packing or gasket failures	Improper material	Orange
	Packing or gasket failures	Personnel error	Orange

Table 3-8 (continued)
Failure Locations, Mechanisms, and Influences for Motors (<15kv) – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Internal Cooling Coil - Bearing Cooling Water (continued)	Damaged fins, impeded heat transfer	Personnel error	Red
	Fouling	Debris	Red
	Fouling	Algae, zebra mussels, etc.	Orange
Lubrication - Grease	Degraded, loss of lubricating qualities	Age	Orange
	Degraded, loss of lubricating qualities	Temperature above 140 F, moisture, dirt	Orange
	Insufficient or excessive amount	Personnel error	Red
Lubrication - Oil	Degraded, loss of lubricating qualities	Temperature above 140 F, moisture, dirt	Orange
	Degraded, loss of lubricating qualities	Normal wear	Orange
	Insufficient or excessive level	Leakage, personnel error	Yellow
Machine Fits	Damaged, misaligned	Personnel error, manufacturing defect	Yellow
Motor Lead Electrical Connections - Crimped Lugs	High resistance	Contamination	Yellow
	Loose	Improper installation - incorrect lug size or crimping technique	Yellow
	High resistance	Oxidation	Yellow
	Insulation degradation	Age, temperature, radiation	Red
	Insulation degradation	Improper installation of the insulation	Red
Motor Leads	Abrasion	Improper routing through motor frame into main junction box	Red
	Insulation degradation	Contamination, e.g., lubricant, dirt, moisture	Red
	Insulation degradation	Age	Yellow
	Insulation degradation	Manufacturing defect	Red
	Insulation degradation	Damage from terminating and determination	Red
	Insulation degradation	High temperature	Red

Table 3-8 (continued)
Failure Locations, Mechanisms, and Influences for Motors (<15kv) – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Motor Leads (continued)	Insulation degradation	Improper testing	Red
	Insulation degradation	Vibration from starting movement	Red
	Insulation degradation	Improper positioning in main junction box	Red
Piping and Connections	Leakage	Personnel error, vibration	Yellow
Rotor Bars and Shorting Rings	Loose	Normal use	Orange
	Loose	Manufacturing or design deficiency	Orange
	Loose	Cyclic fatigue from driven equipment (pulsating load or line voltage), cyclic fatigue due to number of starts during life of motor	Orange
	Loose	Thermal fatigue from number of consecutive starts within a limited time period	Orange
	Cracked, brazed joint failure	Manufacturing or design deficiency	Orange
	Cracked, brazed joint failure	Cyclic fatigue from driven equipment (pulsating load or line voltage), cyclic fatigue due to number of starts during life of the motor	Yellow
	Cracked, brazed joint failure	Thermal fatigue from excessive number of consecutive starts within a limited time period	Orange
	Material defect (cracks or porosity), improper design	Manufacturing or design deficiency	Orange
	Deformation	Lamination stack shifts, rotor bar creep	Red
	Deformation	Heat due to excessive number of consecutive starts within a limited time period	Red
	Corrosion	Environment, e.g., salt water spray	Red
	Cracked, brazed joint failure	Excessive number of consecutive starts within a limited time period	Orange

Table 3-8 (continued)
Failure Locations, Mechanisms, and Influences for Motors (<15kv) – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Rotor Cage - Lamination Support, i.e., Spider	Loose (cage is loose on spider)	Improper clamping pressure, design, loss of torque on clamping through bolts	Yellow
	Loose (cage is loose on spider)	Excessive number of consecutive starts	Yellow
	Loose (cage is loose on spider)	Weld failure of spider or lamination stack locking key	Yellow
	Loose (cage is loose on spider)	Manufacturing defect, e.g., improper fit	Yellow
	Loose (cage is loose on spider)	Total number of starts over the life of the motor	Yellow
Rotor Cage - Solid Lamination Design (Non-Spider Design)	Loose (cage is loose on shaft)	Excessive number of consecutive starts	Yellow
	Loose (cage is loose on shaft)	Improper clamping pressure, design, loss of torque on clamping through bolts	Yellow
	Loose (cage is loose on shaft)	Manufacturing defect, e.g., improper fit	Yellow
	Loose (cage is loose on shaft)	Total number of starts over the life of the motor	Yellow
	Loose (cage is loose on shaft)	Weld failure of lamination locking mechanism	Yellow
Rotor Fans and Hardware	Loose hardware	Personnel error	Red
	Cracked welds	Duty cycle - fatigue	Red
Rotor Fans with Interference Fit Design	Loose on shaft	Manufacturing defect, improper interference fit, improper installation	Red
Rotor Laminations	Insulation breakdown	Contamination	Red
	Insulation breakdown	Thermal aging	Red
	Insulation fretting	Vibration from loose laminations	Red
	Damaged or defective	Manufacturing or installation error	Red
	Stress fatigue cracks	Magnetic cycling and transients	Red
	Stress fatigue cracks	High rotor speed (3600 rpm)	Red

Table 3-8 (continued)
Failure Locations, Mechanisms, and Influences for Motors (<15kv) – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Rotor Laminations (continued)	Loose parts - vent ducts, clamping plate fingers	Settling - predominantly on vertical motors	Red
	Loose parts - vent ducts, clamping plate fingers, balance weights	Vibration	Orange
	Dirty	Contamination	Orange
Rotor Retaining Rings (Predominantly on 2-Pole Motors)	Loose	Vibration and movement from thermal expansion of shorting ring	Yellow
	Loose	Improper fit, improper design, wrong material	Yellow
Rotor Spider - Spider to Shaft Interference Fit Design	Loose (cracked weld)	Manufacturing defect, inadequate weld	Orange
	Loose (broken weld from spider arms to shaft interference sleeve)	Manufacturing defect, inadequate weld	Orange
	Loose (spider is loose on shaft)	Manufacturing defect, inadequate interference fit, loss of position locking mechanism, e.g., loss of tack weld	Orange
Shaft	Wear (coupling fit area)	Manufacturing defect of coupling	Yellow
	Wear (coupling fit area)	Manufacturing defect of shaft	Yellow
	Wear (coupling fit area)	Improper coupling fit to shaft	Yellow
	Shaft cracking	Latent manufacturing defects, wrong material	Yellow
	Shaft cracking	Cyclic torsional loading, wrong material	Yellow
	Wear (Journal)	Normal use	Orange
	Wear (Journal)	Damaging contamination of lubricant (hard particles, excessive water, contaminants from lubricant fills, sand)	Orange
	Wear (Journal)	Corrosion, mainly from water in the lubricant	Orange

Table 3-8 (continued)
Failure Locations, Mechanisms, and Influences for Motors (<15kv) – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Shaft (continued)	Wear (Journal)	Shaft currents, electrolysis (worse on machines without insulated bearings)	Orange
	Wear (Journal)	Misalignment	Orange
	Sagging	Standby without rotation in horizontal motors	Yellow
	Bowing	Thermal bowing due to circulating currents or uneven magnetic forces	Yellow
	Wear (coupling fit area)	Wrong coupling	Yellow
Space Heater Wiring	Degraded insulation	Age, material type	Yellow
Space Heaters	Broken, loose or grounded connections	Personnel error	Green
	Broken, loose or grounded connections	Vibration	Green
	Open element	Age	Green
	Open element	Failure of control circuit component	Orange
Stator Laminations	Insulation breakdown	Contamination	Red
	Insulation fretting	Vibration from loose laminations	Red
	Improper fit of back iron (OD of laminations)	Manufacturing defect	Red
	Damaged	Personnel or manufacturing error	Red
	Loose parts - vent ducts, clamping plate fingers, through bolts	Vibration, thermal cycling	Red
	Insulation breakdown	Thermal aging	Red
Stator Windings, Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Insulation degradation	Internal partial discharge	Red
	Failure of surge ring support brackets	Improper design	Red
	Insulation degradation	Winding design deficiency	Red
	Insulation degradation	Heat above normal running temperature (the greater the delta T above normal the faster the degradation)	Yellow
	Insulation degradation	Vibration	Yellow

Table 3-8 (continued)
Failure Locations, Mechanisms, and Influences for Motors (<15kv) – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Stator Windings, Includes Blocking, Bracing, Tying, Surge Rings, Wedges (continued)	Insulation degradation	Normal use	Yellow
	Insulation degradation	Contamination, e.g., lubricant, dirt, salt spray, moisture, etc.	Yellow
	Insulation degradation	Electrical and surge transients	Red
	Insulation degradation	Normal exposure to radiation	Yellow
	Insulation degradation	Manufacturing defect or installation deficiencies	Red
	Insulation degradation	Movement during starting, (depends on the total number of starts)	Red
	Loose blocking, bracing, and tying eventually leading to winding failure	Vibration	Orange
	Loose blocking, bracing, and tying eventually leading to winding failure	Normal use	Orange
	Loose blocking, bracing, and tying eventually leading to winding failure	Manufacturing defect - design or materials	Red
	Loose blocking, bracing, and tying eventually leading to winding failure	Movement during starting (depends on total number of starts)	Orange
	Broken surge ring	Manufacturing defect	Red
	Failure of surge ring support brackets	Maximum radial flexing during starts, thermal elongation of stator coils can cause failure of supports if improperly designed	Red
	Fretting of insulation materials	Relative movement of adjacent insulating materials with improper blocking and bracing	Red
	Loose wedges	Improper fit of wedges to stator core slot	Red

Table 3-8 (continued)
Failure Locations, Mechanisms, and Influences for Motors (<15kv) – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Stator Windings, Includes Blocking, Bracing, Tying, Surge Rings, Wedges (continued)	Loose wedges	Loss of resin bond	Red
	Insulation degradation	External corona discharge	Red
	Loose wedges	Poor selection of wedge material	Red
Surge Capacitors	Insulation degradation	Normal use	Yellow
	Insulation degradation	Voltage transients and surges	Red
	Bushing tracking	Contamination	Yellow
	Bushing damage	Personnel error	Red
	Leakage	Normal use	Yellow
	Leakage	Personnel error	Red
	Leakage	Heat above rated	Yellow
Winding Electrical Connections - Brazed	High resistance	Improper brazing accelerated by starting movement (end turn)	Red
	High resistance	Improper brazing accelerated by thermal cycling	Red

Table 3-9
Failure Locations, Mechanisms, and Influences for Pumps – Horizontal – Single Stage – Single Suction

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Automatic Oilers	Improper oil flow	Misadjusted, improper installation	Orange
Bearing Oil Slinger Ring	Wear	Normal wear	Orange
Bearing Seals - Labyrinth and/or Lip	Wear	Normal wear	Yellow
	Wear	Improper installation or material defect	Yellow
	Wear	Imbalance or misalignment of shaft	Yellow
Bearing Temperature RTDs, If Present	Open circuit	Age	Orange

Table 3-9 (continued)
Failure Locations, Mechanisms, and Influences for Pumps – Horizontal – Single Stage – Single Suction

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Bearings - Antifriction (Radial and Thrust)	Wear - fatigue	Degraded lubricant - contamination, e.g., water ingress	Yellow
	Wear - fatigue	Normal wear	Yellow
	Wear - fatigue	Incorrect or mixed lubricant	Green
	Wear - fatigue	Insufficient lubricant because of incorrect level or frequent starting (delay in oil reaching second bearing in duplex bearings)	Yellow
	Wear - fatigue	Misalignment of pump bearing housing or pump driver, or thermal growth	Yellow
	Wear - fatigue	Excessive hydraulic loading, e.g., from off-BEP operation	Yellow
	Wear - fatigue	Improper installation - oil ring or slinger ring, or pump bearing preload, or incorrect fits	Red
Breather Caps and Sight Glass Vents	Clogged	Debris or personnel error	Yellow
	Clogged	Contamination	Red
Connections and Piping	Leaks	Installation error, improper sealant	Red
	Leaks	Vibration	Red
Discharge and Suction Flanges	Erosion	Design of system piping	Red
	Erosion	Process fluid quality	Red
	Erosion	Flashing to steam	Yellow
	Erosion	Casting defects	Yellow
	Deformation	Pipe stress, misalignment of suction and discharge flanges	Yellow
Gaskets and O-Rings	Leaks caused by erosion	Improper fit, material or surface condition	Green
	Leaks caused by degraded material properties	High temperature	Green

Table 3-9 (continued)
Failure Locations, Mechanisms, and Influences for Pumps – Horizontal – Single Stage – Single Suction

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Gaskets and O-Rings (continued)	Leaks caused by degraded material properties	Improper installation, contamination, or incorrect material	Yellow
	Leaks caused by deformation	Improper installation , e.g., compression or torquing, warped flange	Green
Impeller	Wear	Cavitation from low NPSHA or off-BEP operation	Green
	Wear	Recirculation	Green
	Physical damage	Fatigue from corrosion, or stress corrosion cracking	Yellow
	Physical damage	Pressure pulsations	Green
	Physical damage	Manufacturing defect	Yellow
	Physical damage	Debris	Red
	Loose	Improper installation, material, or fit tolerances	Red
	Loose	Pressure pulsations or vibration	Red
	Improper OD	Manufacturing or personnel error	Red
	Wear	Normal wear	Red
	Wear	Improper axial positioning	Orange
	Wear	Cavitation from system configuration	Yellow
	Wear	Process fluid quality	Yellow
Internal Bearing Cooler, If Present	Leaks - erosion	Fluid quality	Yellow
	Leaks - mechanical joint failures	Vibration	Yellow
	Leaks - mechanical joint failures	Manufacturing defect or personnel error	Yellow
	Leaks - packing / gasket failures	Personnel error	Yellow
	Fouling, plugging	Debris	Yellow
	Fouling	Chemistry	Yellow
	Leaks - corrosion	Poor water chemistry, raw water	Yellow

Table 3-9 (continued)
Failure Locations, Mechanisms, and Influences for Pumps – Horizontal – Single Stage – Single Suction

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Lube Oil	Housing leaks	Temperature, normal wear	Yellow
	Housing leaks	Vibration	Red
	Housing leaks	Improper assembly	Red
	Degraded	Contamination, biological growth, debris, sludge, or water	Yellow
	Degraded	Normal wear	Red
	Degraded	Temperature	Red
Pump Base Plate and Foundation	Failed anchor, grout, or base plate	Degraded grout (e.g., collapsed voids, vibration)	Red
	Failed anchor, grout, or base plate	Improper installation	Yellow
	Failed anchor, grout, or base plate	Pipe stress	Green
Pump Casing	Leaks	Improper torquing or pipe stress	Orange
	Discharge nozzle erosion	Normal wear	Yellow
	Discharge nozzle erosion	System design	Orange
	Corrosion / erosion or damage to internals	Off-BEP operation	Orange
	Corrosion / erosion or damage to internals	Improper installation or incorrect material	Orange
	Corrosion / erosion or damage to internals	Normal wear	Orange
Seal - Mechanical	Leaks	Vibration	Orange
	Leaks	Improper installation, or seal selection	Yellow
	Leaks	Plugged drain or improper venting	Yellow
	Leaks	Off-BEP operation	Yellow
	Leaks	Contamination of seal water or process fluid quality	Yellow

Table 3-9 (continued)
Failure Locations, Mechanisms, and Influences for Pumps – Horizontal – Single Stage – Single Suction

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Seal - Mechanical (continued)	Leaks	Excessive axial shaft movement	Yellow
	Leaks	Extended shutdown (in dry condition or with no seal water flow)	Red
	Leaks	Normal wear	Red
Seal - Packing	Excessive leakage	Fluid quality	Orange
	Excessive leakage	Improper installation, packing selection or over-torquing	Yellow
	Excessive leakage	Normal wear	Yellow
	Excessive leakage	Extended shutdown in dry condition (no flow through the packing)	Yellow
Shaft	Cracked or damaged	Stress corrosion cracking	Red
	Cracked or damaged	Manufacturing defect or material	Red
	Cracked or damaged	High cycle fatigue	Yellow
	Bent	Misalignment - rubbing at bearing, seal, impeller wear rings	Yellow
	Bent	Improper layup or warm-up	Orange
	Bent	Thermal shock or water hammer	Orange
	Bent	Improper storage or installation	Yellow
	Bent	Debris	Yellow
	Cracked or damaged	Debris	Yellow
Stuffing Box	Leaks	Improper installation	Yellow
Wear Ring, If Closed Impeller	Wear or galling	Process fluid quality	Orange
	Wear or galling	Improper installation, fits, clearances, alignment, or materials	Green
	Wear or galling	Excessive mechanical or hydraulic loading	Red

Table 3-10
Failure Locations, Mechanisms, and Influences for Pumps – Vertical – Close Coupled

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Bearings - Antifriction	Wear	Degraded lubricant from age, contamination or water ingress, temperature	Orange
	Wear	Incorrect lubricant	Red
	Wear	Insufficient lubricant	Orange
	Wear	Excessive mechanical or hydraulic loading	Red
	Wear	Maintenance induced errors from improper fit, handling, installation, or wrong bearing	Red
	Wear	Age, normal wear	Orange
Casing and Cover	Corrosion/erosion	Fluid quality and chemistry	Red
	Corrosion/erosion	Improper material	Red
	Erosion	High flow velocities	Red
	Erosion	Improper impeller fit, loose	Red
	Cavitation or recirculation	Improper NPSHA, low intake water level, or off-BEP operation	Red
	Cavitation or recirculation	System configuration	Red
	Deformation	Thermal shock	Red
Gaskets, O-Rings	Leakage	Improper fit	Orange
	Leakage	Contaminated surface	Orange
	Leakage	Age	Orange
	Leakage	Poor surface condition, warped	Orange
	Leakage	Improper torque	Orange
	Leakage	Wrong material	Orange
Impeller	Wear	High Delta T transient	Red
	Wear	System configuration or improper operation (low NPSHA, e.g., low intake water level or off-BEP operation)	Red
	Wear	Normal wear, process fluid quality	Yellow
	Wear	Debris	Red

Table 3-10 (continued)
Failure Locations, Mechanisms, and Influences for Pumps – Vertical – Close Coupled

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Impeller (continued)	Wear	Wrong material	Orange
	Wear	Improper vertical setting	Red
	Wear	Vortexing or recirculation from off-BEP operation, low intake water level or incorrect sump design	Red
	Physical damage	Fatigue from corrosion, manufacturing defect, pressure pulsations, or stress corrosion cracking	Orange
	Physical damage	Debris	Red
	Loose or failed impeller key or locking collar	Vibration or pressure pulsations	Red
	Loose or failed impeller key or locking collar	Installation error	Red
	Loose or failed impeller key or locking collar	Improper material	Red
	Loose or failed impeller key or locking collar	Excessive fit tolerances	Red
Mechanical Seal	Leakage	Inadequate flush / cooling water	Yellow
	Leakage	Off-BEP operation	Yellow
	Leakage	Excessive axial shaft movement	Yellow
	Leakage	Vibration	Yellow
	Leakage	Worn throttle bushing	Yellow
	Leakage	Normal wear	Green
	Leakage	Fluid quality / contamination	Yellow
	Leakage	Improper installation (misalignment of shaft or stuffing box, over-tightening, shaft sleeve run-out)	Yellow
Motor Support Stand	Corrosion of motor mounting flange	Environment	Yellow
	Corrosion of motor mounting flange	Improper maintenance or installation (Loose motor mounting bolts, damaged flange)	Orange
	Cracked welds	Excessive vibration	Orange
	Cracked welds	Manufacturing defect	Red

Table 3-10 (continued)
Failure Locations, Mechanisms, and Influences for Pumps – Vertical – Close Coupled

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Motor Support Stand (continued)	Cracked welds	Installation and removal stresses	Red
	Deformation	Installation and removal stresses	Red
	Loose fasteners	Excessive vibration	Red
Packing	Excessive leakage	Worn throttle bushing	Yellow
	Excessive leakage	Normal wear	Green
	Excessive leakage	Fluid quality, contamination	Yellow
	Excessive leakage	Plugged packing gland drain	Yellow
	Excessive leakage	Improper packing selection	Yellow
	Excessive leakage	Improper installation (over-tightening, shaft sleeve run-out)	Yellow
Pump Base and Mounting	Failed grout	Excessive vibration	Orange
	Failed grout	Age	Orange
	Failed grout	Environment	Orange
	Failed grout	Improper installation	Orange
	Failed grout	Excessive mechanical loading, e.g., foundation settling, pipe strain	Orange
	Loose bolts	Excessive vibration	Red
	Failed anchor or base plate	Improper installation (wrong bolts, incorrect torque)	Red
	Failed anchor or base plate	Manufacturing defect / improper bolt tolerances	Red
	Failed anchor or base plate	Excessive vibration	Red
	Failed anchor or base plate	Pipe strain	Red
	Failed anchor or base plate	Corrosion - bolts, environment	Red
Shaft	Cracked	Shaft whip, running at > 10% off-BEP	Red
	Cracked	Stress corrosion cracking	Red
	Cracked	Manufacturing defect	Red
	Cracked	Thermal fatigue	Red
	Cracked	Torsional or bending fatigue	Red

Table 3-10 (continued)
Failure Locations, Mechanisms, and Influences for Pumps – Vertical – Close Coupled

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Shaft (continued)	Cracked	Mechanical shock	Red
	Loss of shaft diameter	Misalignment	Red
	Loss of shaft diameter	Corrosion	Yellow
	Loss of shaft diameter	Wear from bearings	Yellow
	Bent	Misalignment from rubbing at bearing, seal, impeller, or wear rings	Red
	Bent	Thermal shock	Red
	Bent	Improper installation or storage	Red
	Bent	Mechanical shock, e.g., debris impact, hydraulic water hammers	Red
	Loss of shaft diameter	Wear from packing	Yellow
Wear Rings	Wear or galling	Quality of process fluid	Yellow
	Wear	Excessive mechanical or hydraulic loading	Red
	Wear	Material selection	Red
	Wear	Improper installation (e.g., improper fits, clearances, and tolerances, improper lift setting, misalignment)	Red
	Galling	Excessive mechanical or hydraulic loading	Red
	Galling	Material selection	Red
	Galling	Improper installation (e.g., improper fits, clearances, and tolerances, improper lift setting, misalignment)	Red
	Wear	Normal wear	Yellow

Table 3-11
Failure Locations, Mechanisms, and Influences for AOVs – Diaphragm

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Accumulators, If Present	Leaks	Fittings	Red
	Leaks - through-wall	Condensation or rust from air contamination and temperature	Yellow
Actuator	Broken spring	Fatigue	Red
	Bushing wear	Misalignment, e.g., valve wear	Red
	Bushing wear	Improper installation	Red
	Bushing wear	Improper lubrication	Red
	Bushing wear	Actuator orientation other than vertical	Orange
	Elastomer failure: diaphragm (leakage)	Improper installation	Red
		Alignment of actuator shaft	Red
		Surfaces not mated properly	Red
		Rough sealing surfaces / burrs / FME from plant or manufacturing errors	Red
		Improper torquing top hat/cover/casing fasteners	Red
		Over-pressurization (regulator failure)	Red
		Over-pressurization - personnel error	Red
	Elastomer failure: diaphragm (loss of elasticity)	Age	Orange
		Heat from ambient and process conditions	Yellow
		Heat from packing leak	Red
		Contamination by a lubricant	Red
		Chemical/air contamination	Red
	Elastomer failure: gaskets (yoke and actuator housing)	Surfaces not mated properly	Red

Table 3-11 (continued)
Failure Locations, Mechanisms, and Influences for AOVs – Diaphragm

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Actuator (continued)	Elastomer failure: O-rings and gaskets (bushings, top hat/cover)	Age	Red
		Heat from ambient and process conditions	Orange
		Heat from packing leak	Red
		Lack of lubrication	Red
		Improper lubricant	Red
		Compression set	Red
		Chemical/Air contamination	Red
		Improper installation	Red
		Rough sealing surfaces / burrs / FME from plant or manufacturing errors	Red
	Improper installation of the diaphragm (leak)	Diaphragm plate alignment, surface finish, torquing	Red
	Loose actuator shaft or stem	Diaphragm plate torquing	Red
	Loose actuator shaft or stem	Failure to use Locktite or Belleville washers, if applicable	Red
	Mechanical failure - handwheel manual operator	Overstressed	Red
	Mispositioned - handwheel manual operator	Personnel error	Red
	Restricted vent path (filter, muffler, screens, speed control device)	Paint / FME	Red
		Condensation in certain orientations	Red
	Spring relaxation	Heat from ambient and process conditions	Orange
	Spring relaxation	Material type	Red
	Spring relaxation	Application	Red
	Spring relaxation	Initial preload	Red
Check Valves - Air Line	Clogged	Contamination	Red
	Clogged	Aging of elastomers	Red
	Clogged	Spring degradation	Red

Table 3-11 (continued)
Failure Locations, Mechanisms, and Influences for AOVs – Diaphragm

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Coupling: Direct	Binding between anti-rotation plate and coupling block	Manufacturing defect	Red
		Misalignment of coupling block	Red
	Incorrect setup	Personnel error	Red
	Loose	Improper fastener torquing	Red
	Loose	Damaged threads	Red
	Loose	Fatigue - repeated use of same set screws	Red
Coupling: Fixed Moment Arm	Broken/bent linkages	Misadjustment	Red
	Bushing/bearing wear	Improper fastener torquing	Red
	Bushing/bearing wear	Normal wear - number of cycles	Yellow
	Incorrect setup	Personnel error	Red
	Loose linkages	Improper fastener torquing	Red
	Worn key	Misadjustment	Red
Coupling: Rack and Pinion	Gear wear	End stop adjustment	Red
Coupling: Scotch Yoke	Bushing/bearing wear	Normal wear - number of cycles	Red
	Bushing/bearing wear	Lack of lubrication	Orange
	Incorrect setup	Personnel error	Red
	Roller pin failure	Duty cycle and wear of other components	Green
	Roller pin failure	End stop adjustment	Red
	Worn yoke	Duty cycle	Orange
External Air Filter	Clogged	Contaminated air	Red
	Leaks	Degraded elastomers	Yellow
Limit Switches	Contact misalignment	Vibration	Red
	Corroded contacts	Water and humidity	Red
	Corroded wiring, terminals, or connections	Environment	Red
	Elastomer failure	Age	Red

Table 3-11 (continued)
Failure Locations, Mechanisms, and Influences for AOVs – Diaphragm

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Limit Switches (continued)	Elastomer failure	Heat from ambient and process conditions	Orange
	Elastomer failure	Heat from packing leak	Red
	Elastomer failure	Lack of lubrication	Red
	Elastomer failure	Improper lubricant	Red
	Elastomer failure	Compression set	Red
	Elastomer failure	Chemical contamination	Red
	Elastomer failure	Improper installation	Red
	Elastomer failure	Rough sealing surfaces / burrs / FME from plant or manufacturing errors	Red
	Loose connections or terminals	Vibration	Red
	Misadjusted	Personnel error	Red
	Misadjusted	Loose fasteners	Red
	Wear, e.g., cams, lever arms, bushings	Vibration	Orange
		Material properties and design	Red
		Improper installation	Red
Packing	Excessive friction	Improper torque of the gland	Red
	Excessive friction	Improper packing configuration	Red
	Leakage	Normal wear	Yellow
	Leakage	Gouged stem	Red
	Leakage	Scored stuffing box	Red
	Leakage	Improper torque of the gland	Red
	Leakage	Improper packing configuration	Red
Pneumatic Tubing	Crushed or damaged	Personnel error	Yellow
	Improper installation	Personnel error	Red
	Leaking fittings and tubing	Vibration	Orange

Table 3-11 (continued)
Failure Locations, Mechanisms, and Influences for AOVs – Diaphragm

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Seat (Moving Part)	Broken spring in pilot valves	Fatigue	Red
	Chipped	Debris	Red
	Chipped	Improper installation	Red
	Cracked	Design	Red
	Cracked	Manufacturing defect	Red
	Cracked	Debris	Red
	Crud build-up	Fluid quality	Red
	Wear/erosion	Inadequate seat load	Red
Speed Control Valves	Inappropriate response	Contamination	Red
	Inappropriate response	Aging of elastomers	Red
	Inappropriate response	Spring degradation	Red
	Inappropriate response	Misadjustment	Red
	Inappropriate response	Improper lubrication, including excessive	Red
Valve Body Bearing/Bushing, If Present	Wear	System dynamics / Flow induced vibration	Red
Valve Body Seat	Chipped	Debris	Red
	Chipped	Improper installation	Red
	Cracked	Design	Red
	Cracked	Manufacturing defect	Red
	Cracked	Debris	Red
	Crud build-up	Fluid quality	Red
	Wear/erosion, including soft or hard seating materials	Inadequate seat load	Red
Valve Guides	Worn	Orientation (horizontal only)	Red
	Worn	High duty cycle under DP in any orientation	Red
Valve Stem	Bent	Over thrust	Red
	Rough surface leading to excessive friction	Packing components	Red
	Wear	Normal wear from packing	Red

Table 3-12
Failure Locations, Mechanisms, and Influences for AOVs – Piston

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Actuator	Broken spring	Fatigue	Red
	Bushing / cylinder wear	Misalignment, e.g., valve wear	Red
	Bushing / cylinder wear	Improper installation	Red
	Bushing / cylinder wear	Improper lubrication	Red
	Bushing / cylinder wear	Actuator orientation other than vertical	Orange
	Elastomer failure - leakage (piston, bushings)	Actuator orientation other than vertical	Orange
	Elastomer failure - leakage (piston, bushings, top hat/cylinder seals)	Age	Red
		Heat from ambient and process conditions	Orange
		Heat from packing leak	Red
		Lack of lubrication	Red
		Improper lubricant	Red
		Compression set	Red
		Chemical/air contamination	Red
		Improper installation	Red
		Alignment of piston shaft	Red
		Rough sealing surfaces / burrs / FME from plant or manufacturing errors	Red
	Mispositioned - handwheel manual operator	Overstressed	Red
		Personnel error	Red
	Restricted vent path (filter, muffler, screens, speed control device)	Paint / FME	Red
		Condensation in certain orientations	Red
	Spring relaxation	Heat from ambient and process conditions	Orange
	Spring relaxation	Material type	Red
	Spring relaxation	Application	Red
	Spring relaxation	Initial preload	Red

Table 3-12 (continued)
Failure Locations, Mechanisms, and Influences for AOVs – Piston

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Air Pump	Bound spool piece	Contamination	Red
	Elastomer failure	Age	Red
	Elastomer failure	Heat from ambient and process conditions	Yellow
	Elastomer failure	Heat from packing leak	Red
	Elastomer failure	Lack of lubrication	Red
	Elastomer failure	Improper lubricant	Red
	Elastomer failure	Compression set	Red
	Elastomer failure	Chemical/air contamination	Red
	Elastomer failure	Improper installation	Red
	Elastomer failure	Rough sealing surfaces / burrs / FME from plant or manufacturing errors	Red
	Elastomer failure	Over-pressurization (regulator failure)	Red
Air Pump	Elastomer failure	Over-pressurization - personnel error	Red
Check Valves - Air Line	Stuck	Contamination	Red
	Stuck	Aging of elastomers	Red
	Stuck	Spring degradation	Red
Check Valves - Piston/Actuator	Stuck	Contamination	Red
	Stuck	Aging of elastomers	Red
	Stuck	Spring degradation	Red
Coupling: Direct	Binding between anti-rotation plate and coupling block	Manufacturing defect	Red
		Misalignment of coupling block	Red
	Incorrect setup	Personnel error	Red
	Loose	Improper fastener torquing	Red
	Loose	Damaged threads	Red
	Loose	Fatigue - repeated use of same set screws	Red
Coupling: Fixed Moment Arm	Broken/bent linkages	Misadjustment	Red
	Bushing/bearing wear	Improper fastener torquing	Red
	Bushing/bearing wear	Age - number of cycles	Yellow

Table 3-12 (continued)
Failure Locations, Mechanisms, and Influences for AOVs – Piston

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Coupling: Fixed Moment Arm (continued)	Incorrect setup	Personnel error	Red
	Loose linkages	Improper fastener torquing	Red
	Worn key	Misadjustment	Red
Coupling: Scotch Yoke	Gear wear	End stop adjustment	Red
	Bushing/bearing wear	Age - number of cycles	Red
	Bushing/bearing wear	Lack of lubrication	Orange
	Incorrect setup	Personnel error	Red
	Roller pin failure	Duty cycle and wear of other components	Green
	Roller pin failure	End stop adjustment	Red
	Worn yoke	Duty cycle	Orange
External Air Filter	Clogged	Contaminated air	Red
	Leaks	Degraded elastomers	Green
Limit Switches	Contact misalignment	Vibration	Red
	Corroded contacts	Water and humidity	Red
	Corroded wiring, terminals, or connections	Environment	Red
	Elastomer failure	Age	Red
	Elastomer failure	Heat from ambient and process conditions	Orange
	Elastomer failure	Heat from packing leak	Red
	Elastomer failure	Lack of lubrication	Red
	Elastomer failure	Improper lubricant	Red
	Elastomer failure	Compression set	Red
	Elastomer failure	Chemical contamination	Red
	Elastomer failure	Improper installation	Red
	Elastomer failure	Rough sealing surfaces / burrs / FME from plant or manufacturing errors	Red
	Loose connections or terminals	Vibration	Red

Table 3-12 (continued)
Failure Locations, Mechanisms, and Influences for AOVs – Piston

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Limit Switches (continued)	Misadjusted	Personnel error	Red
	Misadjusted	Loose fasteners	Red
	Wear, e.g., cams, lever arms, bushings	Vibration	Red
	Wear, e.g., cams, lever arms, bushings	Material properties and design	Red
	Wear, e.g., cams, lever arms, bushings	Improper installation	Red
Packing	Excessive friction	Improper torque of the gland	Red
	Excessive friction	Improper packing configuration	Red
	Leakage	Age	Yellow
	Leakage	Gouged stem	Red
	Leakage	Scored stuffing box	Red
	Leakage	Improper torque of the gland	Red
	Leakage	Improper packing configuration	Red
Pneumatic Tubing	Crushed or damaged	Personnel error	Yellow
	Improper installation	Personnel error	Red
	Leaking fittings and tubing	Vibration	Orange
Seat (Moving Part)	Broken spring in pilot valves	Fatigue	Red
	Chipped	Debris	Red
	Chipped	Improper installation	Red
	Cracked	Design	Red
	Cracked	Manufacturing defect	Red
	Cracked	Debris	Red
	Crud build-up	Fluid quality	Red
	Wear/erosion	Inadequate seat load	Red

Table 3-12 (continued)
Failure Locations, Mechanisms, and Influences for AOVs – Piston

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Speed Control Valves	Inappropriate response	Contamination	Red
	Inappropriate response	Aging of elastomers	Red
	Inappropriate response	Spring degradation	Red
	Inappropriate response	Misadjustment	Red
	Inappropriate response	Improper lubrication, including excessive	Red
Valve Body Bearing/Bushing, If Present	Wear	System dynamics / flow-induced vibration	Red
Valve Body Seat	Chipped	Debris	Red
	Chipped	Improper installation	Red
	Cracked	Design	Red
	Cracked	Manufacturing defect	Red
	Cracked	Debris	Red
	Crud build-up	Fluid quality	Red
	Wear/erosion, including soft or hard seating materials	Inadequate seat load	Red
Valve Guides	Worn	Orientation (horizontal only)	Red
	Worn	High duty cycle under DP in any orientation	Red
Valve Stem	Bent	Over thrust	Red
	Rough surface leading to excessive friction	Packing components	Red
	Wear	Normal wear from packing	Red

Table 3-13
Failure Locations, Mechanisms, and Influences for MOVs – AC Limitorque

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Drive Train	Damage to de-clutch mechanism	Personnel error - excessive force	Red
	Damage to soft clutch mechanism, if present	Normal wear of elastomers, duty cycle	Red
	Drive sleeve / gear case O-ring seal failure	Normal wear, duty cycle	Red
		Personnel error - installation	Red
	Key and key way failures	Inappropriate key material, overload, improper assembly	Red
	Misalignment of worm to worm gear	Personnel error	Red
	Stem nut locknut failure	Personnel error - improper staking	Red
	Thrust bearing - incorrect preloading	Personnel error	Red
	Thrust bearing wear	Inadequate lubrication or overload, duty cycle	Red
	Worm bearing - worn or seized	Inadequate lubrication or overload, duty cycle	Red
	Worn or damaged gears (worm, drive, motor pinion)	Excessive force, inadequate lubrication (lack of or contaminated or wrong lubricant)	Red
Fasteners	Broken, missing	Corroded	Red
	Loose	Personnel or procedural error	Red
Gasket and O-Rings	Degraded	Aging	Red
	Damaged or degraded	Personnel error	Red
Hand Wheel	Loose or mispositioned	Personnel error - overstressed, e.g., inappropriate use of a force multiplier	Red
Heater, If Present	Failed	Age	Red
Lubricant - Gearbox	Contaminated - loss of lubricity, results in reduced efficiency and output torque	Moisture and rust	Red
	Hardened - loss of lubricity, results in reduced efficiency and output torque	Aging, temperature (depends on lubricant, time code assumes long life grease, older types degrade faster)	Orange

Table 3-13 (continued)
Failure Locations, Mechanisms, and Influences for MOVs – AC Limitorque

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Lubricant - Limit Switch Compartment	Contaminated, binding	Moisture and rust	Red
	Hardened, binding	Aging, temperature (depends on lubricant, time code assumes long life grease, older types degrade faster)	Orange
Lubricant - Valve Stem	Contaminated - loss of lubricity, results in reduced thrust output (becomes significant sooner for low margin valves)	Moisture and rust	Red
	Hardened - loss of lubricity, results in reduced thrust output (becomes significant sooner for low margin valves)	Aging, temperature (some lubricant types are temperature sensitive)	Orange
	Inadequate application of lubricant	Design (short stroke) or personnel error	Red
	Loss of lubricant	Steam leak	Red
Lubricant - Valve Stem, Gearbox, Limit Switch Compartment	Incorrect or inadequate lubricant	Personnel error	Red
Motor	Bearings - worn	Manufacturing defect	Red
	Rotor - magnesium bar corrosion	Design defect, duty cycle, moisture and high ambient temperature or locked rotor (stall) event(s)	Red
	Stator winding - degraded insulation	Age, temperature	Red
		Locked rotor (stall) event(s)	Red
		Moisture, exposure to environment, personnel error	Red
Packing	Binding	Gouged stem	Red
		Incorrect torque, incorrect packing configuration	Red
	Leakage	Gouged stem	Red
		Incorrect torque, incorrect packing configuration	Red
		Normal wear, duty cycle	Yellow

Table 3-13 (continued)
Failure Locations, Mechanisms, and Influences for MOVs – AC Limitorque

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Seat	Chipped, cracked, corroded, or torn	Debris, excessive seating force, i.e., actuator misadjustment, design or manufacturing defect	Red
	Crud buildup	Foreign material, fluid quality, biological growth	Red
	Distorted	Excessive seating force, i.e., actuator misadjustment	Red
	Eroded or steam cut	Inadequate seating force, i.e., actuator misadjustment, improper throttling	Red
	Leak by	Normal wear	Red
Spring Pack	Hydraulic lock	Design defect	Red
Switch - Limit	Damaged	Personnel error, water hammer	Red
	High contact resistance	Contamination and corrosion from gasket or O-ring failure	Yellow
	Loss of contact	Normal wear, improper spring tension	Yellow
	Misadjusted, misaligned	Personnel error	Red
Switch - Torque	High contact resistance	Contamination and corrosion from gasket or O-ring failure	Red
	Loss of contact	Normal wear, improper spring tension	Orange
	Misadjusted, misaligned, unbalanced	Personnel error	Red
	Roll pin failure	Declutching under load, improper installation or setup - personnel error	Red
		Hammering from non-locking gear set - may occur from diagnostic testing or operation	Red
Valve Guides	Loose retaining pins (if present and design specific)	Flow-induced vibration	Red
	Worn guides	Duty cycle, chronic operation under DP in any orientation; also horizontal orientation with no DP	Red

Table 3-13 (continued)
Failure Locations, Mechanisms, and Influences for MOVs – AC Limitorque

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Valve stem	Bent	Improper set-up or testing (over-thrust or over-torque)	Red
	Cracked due to stem embrittlement (17-4PH and >550 degF)	Improper material for high temperature operation	Yellow
	Stem-disk separation	Overload, manufacturing defect, thermal binding, fatigue, pressure locking	Red
Valve Stem - Stem Nut	Stem or stem nut thread damage, i.e., low output thrust	Corrosion (salt), overload, improper lubrication, contamination	Red
		Misalignment or debris	Red
Wiring	Cracked terminal blocks, loose wires or lugs, poor crimps, pinched wires, cracked or damaged insulation	Personnel error	Red
	Degraded insulation	Aging, temperature	Red

Table 3-14
Failure Locations, Mechanisms, and Influences for Solenoid Operated Valves

Failure Location	Degradation Mechanism	Degradation Influence	Program Effectiveness
Coil	Insulation breakdown	Heat	Orange
	Insulation breakdown	Moisture ingress	Red
Diaphragms	Cracking	Heat	Orange
	Cracking	Radiation	Orange
	Sticking	Heat	Orange
	Sticking	Radiation	Orange
O-rings	Aging	Radiation	Orange
	Aging	Age, heat	Orange
	Sliding wear	Number of cycles	Orange
	Sliding wear	Heat	Orange
	Sliding wear	Radiation	Orange
Plunger	Clogged ports	Quality of process medium	Red
	Sticking	Presence of lubricant	Red
Springs	Change of spring constant	Number of cycles	Orange
		Heat	Orange
		Constant compression	Orange
Switches	Misadjusted	Personal error	Red
Valve seat	Crud buildup on plunger / seat	Quality of process medium	Red
	Damaged seat	Flow conditions of process medium	Red
	Damaged seat	Debris	Red
Wiring, Insulation, or Connectors (Component: Actuator)	Improper crimping	Personal error	Red
	Pinched insulation	Personal error	Red

4
SYSTEM TROUBLESHOOTING, VULNERABILITY, AND RISK ANALYSIS

This section and Section 5 (Examples of Job Plans) were built by working with site personnel, industry experts, and the EPRI Preventive Maintenance Basis Database (PMBD) to craft a useful troubleshooting guide and optimized maintenance program. Using site experience and methodology described in Appendix B, a program is provided that fits into current CTCC maintenance programs by fitting time-based inspections into annual steam turbine minor inspections (often concurrent with a hot-gas path inspection) and steam turbine major inspection intervals and online maintenance activities. Risks increased as a result of reducing tasks or increasing the time between tasks being performed are addressed through condition-monitoring tasks such as system owner walkdowns, performance monitoring, diagnostics, and the use of predictive maintenance technologies like thermography and vibration analysis.

4.1 System Troubleshooting

Figure 4-1 illustrates the generic process for performing preliminary troubleshooting of a given power generation system, such as an inlet cooling system. The figure emphasizes the need to define the problem, determine and validate system operating conditions, and subsequently determine whether the symptoms adversely affect system/component performance or reliability.

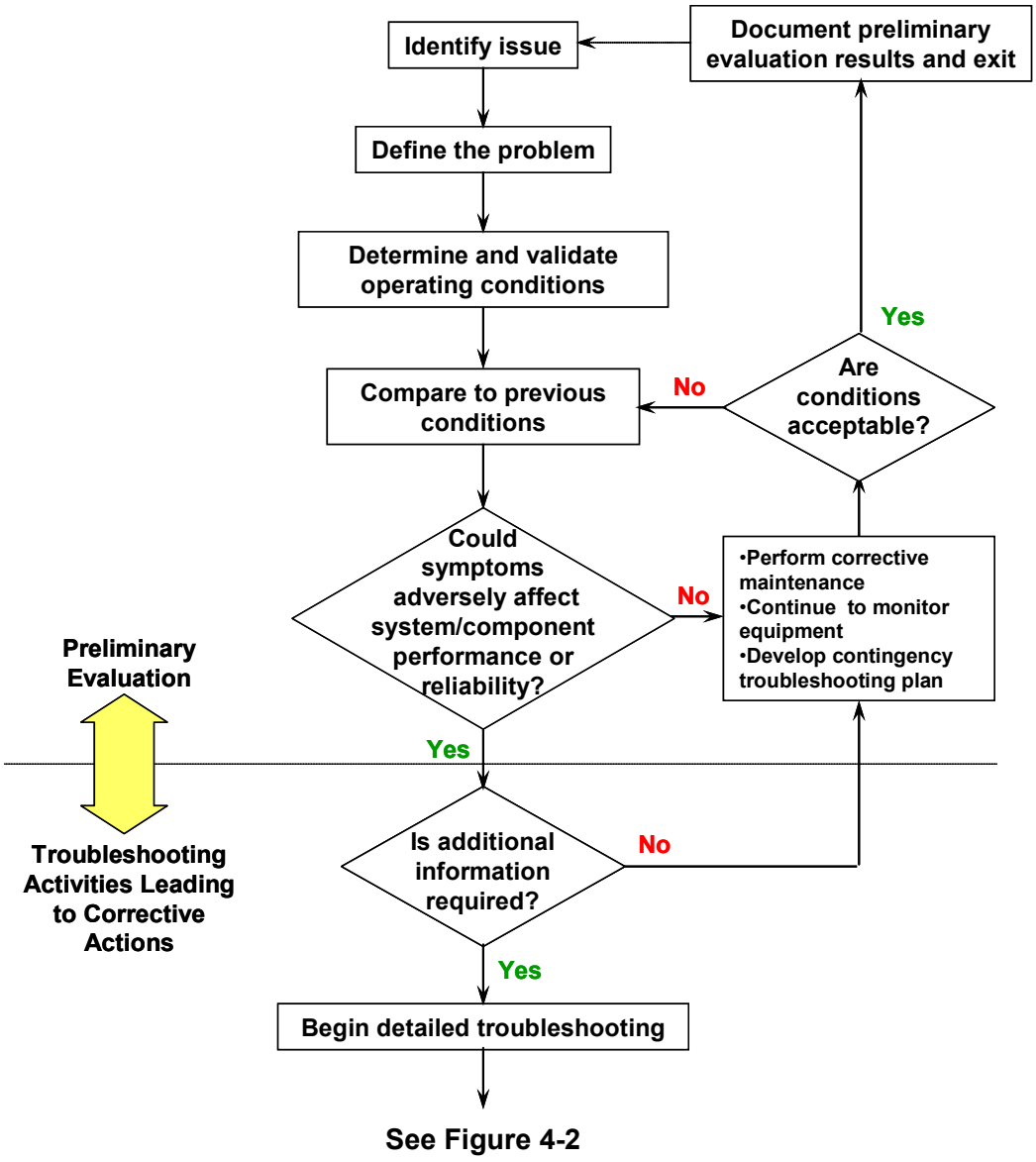


Figure 4-1
Generic Process: System Troubleshooting (Preliminary Evaluation) (EPRI 1003093)

Figure 4-2 illustrates the detailed system troubleshooting process that may be undertaken to investigate the symptoms and performance problems being experienced. The figure emphasizes the need to identify failure modes, develop a troubleshooting plan (especially if the system is evaluated while on-line), identify the cause(s) of the problem, and restore system performance. Additional guidance regarding system and component troubleshooting is provided in EPRI Report 1003093, *System and Equipment Troubleshooting Guideline*.

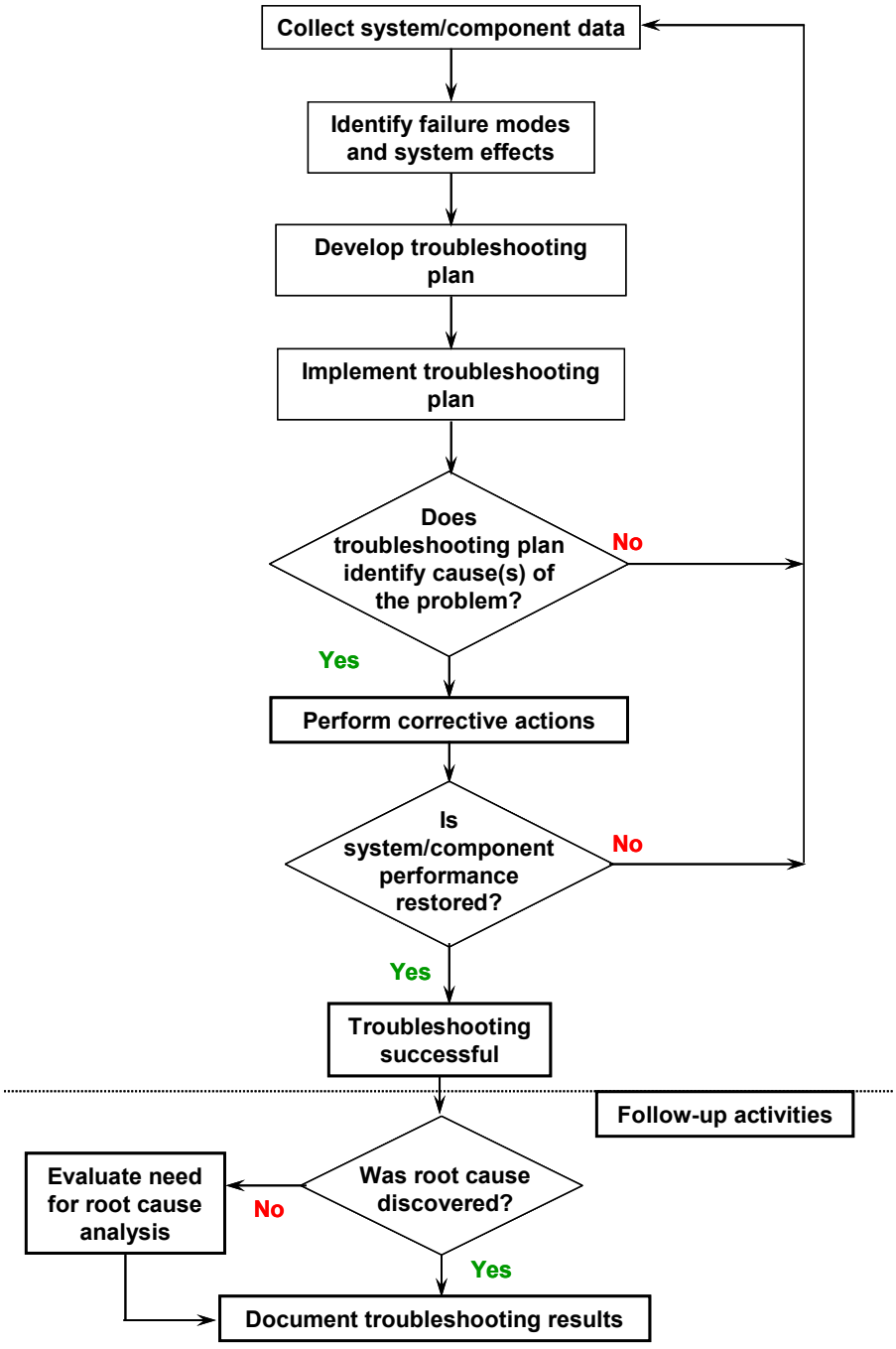


Figure 4-2
Generic Process: System Troubleshooting (Detailed System Troubleshooting) (EPRI 1003093)

4.2 Troubleshooting the Inlet Cooling Water System

4.2.1 Background

The following information was developed with the assistance of plant personnel from the sites visited during the development of this technical report. The intent of this troubleshooting section is to provide insight into how system component failure or malfunction can affect system performance, and what corrective actions and proactive countermeasures can be taken to restore the system to operation. These actions should complement the preventive maintenance tasks recommended in each component's model maintenance program that are presented in Section 4.4 of this report.

4.2.2 System Troubleshooting Guidance

Tables 4-1 and 4-2 illustrate typical troubleshooting techniques for components typically installed in the two types of inlet cooling systems described in this report. These two system designs are the inlet chiller system and the evaporative cooling system.

Table 4-1
Troubleshooting Inlet Chiller Cooling Water System Components

System Component	Sub-Component	Triggers	Symptoms	Secondary Symptoms	Corrective Action Required	Proactive Countermeasures
Refrigeration Compressor Skid	Variable Orifice Valve	High Glycol Temperature	High Condenser Level		Variable orifice valve not opening properly	During the preseason commissioning activities, the variable orifice valve should be tested and calibrated
	Compressor		Low Discharge Pressure		Check motor power supply and terminal connections	There should be a PM in place (along with the calibration of breakers, etc.), to check electrical integrity of the system
	Compressor		Loss of Refrigerant		Check seals for leakage	The preseason inspection of the system should include an evaluation of the shaft seals
	Evaporator		High Differential Pressure		At first opportunity, clean evaporator	PM should be in place for periodic cleaning of the refrigeration systems
	Condenser		High Differential Pressure		At first opportunity, clean condenser	PM should be in place for periodic cleaning of the refrigeration systems
	Condenser		Loss of Refrigerant		Check condenser for tube leak	Periodic testing of tubes should include eddy current of tube bank
	Evaporator		Loss of Refrigerant		Check evaporator for tube leak	Periodic testing of tubes should include eddy current of tube bank
Block Valves		Glycol Flow	Downstream Flow		Open valve, flush and try to reseat	There should be a PM to inspect the mechanical integrity of the system
			Inadequate Cooling of Gas Turbine Inlet Air		If valves are lined up properly, a valve may not be operating properly and may have to be replaced	There should be a PM to inspect the mechanical integrity of the system

Table 4-1 (continued)
Troubleshooting Inlet Chiller Cooling Water System Components

System Component	Sub-Component	Triggers	Symptoms	Secondary Symptoms	Corrective Action Required	Proactive Countermeasures
Temperature Control Valve		Inadequate Cooling of Turbine Inlet Air (Low Delta T)	Valve Not Tracking Demand		Calibrate temperature control valve, or clean air supply filter to operator	Part of the PM should include calibration of the valve as well as cleaning the air filter on the instrument air supply line
Secondary Glycol Pumps			Low Header Pressure		Check motor power supply and terminal connections	There should be a PM in place (along with the calibration of breakers, etc.), to check electrical integrity of the system
Primary Glycol Pumps			Low Header Pressure		Check motor power supply and terminal connections	There should be a PM in place (along with the calibration of breakers, etc.), to check electrical integrity of the system
Chiller Coils (Note 1)			Low Header Pressure		Check the system for coil leaks or damage	During the preseason commissioning of the system, the coils should be inspected and pressurized with water and tested for leaks
Cooling Tower	Cooling Tower Pumps		Inadequate Cooling Water Flow		Check cooling tower pump strainers for pluggage	
Cooling Tower	Cooling Tower Fans		Inadequate Cooling of the Cooling Water		Check motor power supply and terminal connections	
Evaporator			Low Header Pressure	Compressor Trips	Inspect the evaporator/ condenser for tube leaks	Periodic testing of tubes should include eddy current of tube bank

Table 4-1 (continued)
Troubleshooting Inlet Chiller Cooling Water System Components

System Component	Sub-Component	Triggers	Symptoms	Secondary Symptoms	Corrective Action Required	Proactive Countermeasures
Cooling Tower	Fan/Motor	Noise/ Vibration	Vibration	Noise	Inspect fan assemblies for mechanical integrity, and possible fan blade damage	All fan assemblies should be inspected as part of periodic PM
	Fan/Motor		Vibration	Noise	Check for adequate lubrication in motor and fan assembly	Periodic PM of the system should include verification of the motor and fan lubrication
Cooling Tower	Cooling Tower Fill	Cooling Tower Not Cooling Adequately	Improper Water Distribution	Poor Condenser Performance	Clean or replace the fill	Inspection should be done on a routine basis to inspect the tower components including fill, drift eliminators, water distribution headers, and nozzles, to check for fill/drift eliminators that have become plugged due to foreign materials, scale buildup, or collapse of the film pack structure, and to check the distribution system, including for nozzles that are broken or showing signs of corrosion
	Distribution Nozzles/ Headers (Note 2)		Water Channeling Through Fill Sections	Poor Condenser Performance	Inspect water distribution headers and nozzles for plugged or broken nozzles	Inspection should be done on a routine basis to inspect the tower components including fill, drift eliminators, water distribution headers, and nozzles, to check for fill/drift eliminators that have become plugged due to foreign materials, scale buildup, or collapse of the film pack structure, and to check the distribution system, including for nozzles that are broken or showing signs of corrosion

Table 4-1 (continued)
Troubleshooting Inlet Chiller Cooling Water System Components

System Component	Sub-Component	Triggers	Symptoms	Secondary Symptoms	Corrective Action Required	Proactive Countermeasures
	Condenser		Compressor Surging	Compressor Trips	Verify that the balance chamber in the cooling tower is working properly	During the annual commissioning of the system, the balancing chamber should be cleaned and inspected
	Fan/Motor		Improper Water distribution	Poor Condenser Performance	Check motor power supply and terminal connections	There should be a PM in place (along with the calibration of breakers, etc.), to check electrical integrity of the system
Cooling Tower	Cooling Tower Drift Eliminators	Water Carry Over From Fan (Note 3)	Water Entrainment in Cooling Tower Plume		Inspect drift eliminators for missing or damaged sections	Inspection should be done on a routine basis to inspect the tower components including fill, drift eliminators, water distribution headers, and nozzles, to check for fill/drift eliminators that have become plugged due to foreign materials, scale buildup, or collapse of the film pack structure, and to check the distribution system, including for nozzles that are broken or showing signs of corrosion

Table 4-1 (continued)
Troubleshooting Inlet Chiller Cooling Water System Components

System Component	Sub-Component	Triggers	Symptoms	Secondary Symptoms	Corrective Action Required	Proactive Countermeasures
Circulating Water Pump	Motor	Low Circulating Water Header Pressure	Inadequate Cooling in the Condenser	Low Delta T	Check motor power supply and terminal connections	There should be a PM in place (along with the calibration of breakers, etc.), to check electrical integrity of the system
	Strainer		Inadequate Cooling in the Condenser	High Differential Pressure, Low Delta T	Verify that the pump suction screens are clean, and not preventing adequate pump suction	The suction screens should be cleaned before each summer run season, and the differential pressure should be monitored
Condensers	Tube Bundles		Inadequate Cooling in the Condenser	Low Delta T	Verify that the pump suction screens are clean, and not preventing adequate pump suction; shut system down and inspect tube sheet and tubes to see if there is micro or macro fouling of tube bundles	Differential pressure across the system should be monitored on a daily basis

Notes/Comments:
1. The System Owner may want to consider installing moisture detectors downstream of the coils, if they do not already exist.
2. The cross flow towers utilized in most chiller applications use distribution headers with spray manifolds and not the traditional hot water basins found in typical cross flow cooling towers.
3. Drift eliminators will be located between the cooling tower fill and the fans; if there are sections missing, it may allow water to be entrained in the air stream.

Table 4-2
Troubleshooting Evaporative Cooling Water System Components

System Component	Sub-Component	Triggers	Symptoms	Secondary Symptoms	Corrective Action Required	Proactive Countermeasures
Evaporative Cooler	Evaporative Cooler Feed Pump	Inadequate Cooling of Turbine Air	MWs Do Not Increase	Low Water Flow	Check motor power supply and terminal connections	There should be a PM in place (along with the calibration of breakers, etc.), to check electrical integrity of the system
	Evaporative Cooler Feed Sump		MWs Do Not Increase	Low Water Flow	Check water level and level control in sump	There should be a PM in place to calibrate the sump level controls, including the float switches, the make-up control valve, and the blowdown valve and conductivity analyzer
	Water Distribution		Compressor Vibration		Verify that the water flow is balanced across each of the evaporative cooler media sections and that the troughs are not plugged and overflowing	Every cooler needs to be balanced every year prior to run season so that the flow across each of the sections of cooler media is equalized (Note 1)
	Drift Eliminators	Loss of CT MW	Combustion Turbine MW Decreasing with Evaporative Cooler Placed into Service		Shut off evaporative cooler and perform an on-line water wash	The system needs to be inspected to ensure the connections are tight and all seals are in place (Note 2)

Notes:
1. Some combustion turbine compressors are sensitive enough to variations in temperature distribution in the inlet air flow caused by non-homogenous temperature distribution that there have been issues with compressor vibrations.
2. There have been issues in the past with water bypassing the coolers and fouling the compressors.

4.3 System Vulnerabilities and Risks

The purpose of this section is to discuss vulnerabilities and risks associated with modifying PM task scopes and frequencies of system components provided in the EPRI PMBD.

4.3.1 Objectives of the Model Maintenance Program

As noted earlier in this report, the objective of the model maintenance program is to provide a system-level tool that can assist CTCC facility owners in implementing a maintenance program that will ultimately improve system reliability and plant availability. Specifically, the objectives are to:

- Establish maintenance tasks that leverage the EPRI PM Basis Database (PMBD) resource
- Adjust task descriptions and intervals to accurately reflect actual combined cycle operation and design
- Provide a template from which other CTCC facilities can build a maintenance program with a strong technical basis

4.3.2 Overview of the Model Maintenance Program for the Inlet Cooling System

Table 4-3 provides an overview of the major tasks the analysis team developed for the entire system.

Table 4-3
Overview of the Model Maintenance Program for the Inlet Cooling System

Task Category	Steam Turbine Minor Inspection (Notes 1 and 3)	Steam Turbine Major Inspection (Notes 2 and 3)	Other Frequency
Cooling Tower – Mechanical Draft – Cross Flow			
Hot Water Basin Cleaning			**3M Job Plan #1**
Inspections			**4Y Job Plan #2**
Instrumentation Functional Testing			**1Y Job Plan #3**
Oil Sampling, Filtering, and Analysis			**3M Job Plan #4**
Operator Rounds			**1S**
System Owner Walkdown			**3M**
Thermal Performance Monitoring			**1Y Job Plan #5**
Vibration Monitoring			**1M Job Plan #6**

Table 4-3 (continued)
Overview of the Model Maintenance Program for the Inlet Cooling System

Task Category	Steam Turbine Minor Inspection (Notes 1 and 3)	Steam Turbine Major Inspection (Notes 2 and 3)	Other Frequency
Heat Exchanger – Air Cooled			
Replacement			**AR Job Plan #7**
Annual Monitoring and Walkdown			**1Y**
Major Inspection		**Job Plan #8**	
Operator Rounds			**1S**
Chiller and Centrifugal Compressor			
Internal Inspection – Compressor			**AR Job Plan #9**
Overhaul			**AR Job Plan #10**
Annual Inspection and Test			**1Y Job Plan #11**
Glycol Analysis			**6M Job Plan #12**
Operator Rounds			**1S**
Quarterly Inspection and Test			**3M Job Plan #13**
Vibration Analysis			**3M Job Plan #6**
Instrumentation			
Instrument Calibration – Non-Redundant, Critical			**1Y Job Plan #14**
Instrument Calibration – Redundant, Critical	**Job Plan #15**		
Instrument Calibration – Non-Critical			**AR Job Plan #16**
Motor – Medium Voltage < 15 Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed			
Air Filter Replacement			**AR Job Plan #17**
Oil Analysis			**6M Job Plan #18**
Operator Rounds			**1S**

Table 4-3 (continued)
Overview of the Model Maintenance Program for the Inlet Cooling System

Task Category	Steam Turbine Minor Inspection (Notes 1 and 3)	Steam Turbine Major Inspection (Notes 2 and 3)	Other Frequency
Motor – Medium Voltage < 15 Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed (continued)			
Refurbishment			**AR** **Job Plan #19**
System Owner Walkdown			**3M**
Tests – Off Line	**Job Plan #20**		
Tests – On Line			**2Y** **Job Plan #21**
Thermography			**1Y** **Job Plan #22**
Vibration Monitoring			**3M** **Job Plan #6**
Motor – Medium Voltage < 15 Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed			
Air Filter Replacement			**AR** **Job Plan #17**
Operator Rounds			**1S**
Refurbishment			**AR** **Job Plan #19**
System Owner Walkdown			**3M**
Tests – Off-line	**Job Plan #20**		
Tests – On-line			**2Y** **Job Plan #21**
Thermography			**1Y** **Job Plan #22**
Vibration Monitoring			**3M** **Job Plan #6**
Pump – Horizontal – Single Stage – Single Suction			
Operator Rounds			**1S**
Performance Trending			**2Y**
Refurbishment			**AR** **Job Plan #23**
System Owner Walkdown			**6M**
Vibration Analysis			**3M** **Job Plan #6**

Table 4-3 (continued)
Overview of the Model Maintenance Program for the Inlet Cooling System

Task Category	Steam Turbine Minor Inspection (Notes 1 and 3)	Steam Turbine Major Inspection (Notes 2 and 3)	Other Frequency
Evaporative Cooler Feed Pump – Vertical – Closed Coupled			
Operator Rounds			**1S**
Packing or Seal Replacement			**AR Job Plan #24**
Performance Trending			**3Y**
Refurbishment			**AR Job Plan #25**
System Owner Walkdown			**3Y**
Valve – Air Operated – AOV – Diaphragm			
Calibration of Actuator		**Job Plan #26**	
Calibration, Inspection, and Test	**Job Plan #27**		
Diagnostic Testing			**AR Job Plan #28**
Operator Rounds			**1S**
Packing Inspection / Adjustment			**2Y Job Plan #29**
Valve – Air Operated – AOV – Piston			
Calibration of Actuator		**Job Plan #30**	
Calibration, Inspection, and Test	**Job Plan #31**		
Diagnostic Testing			**AR Job Plan #32**
Operator Rounds			**1S**
Packing Inspection / Adjustment			**2Y Job Plan #33**
Valve – Motor Operated – MOV – AC Limitorque			
Diagnostic Test		**Job Plan #34**	
Functional Tests	**Job Plan #35**		
Inspection and Lubrication	**Job Plan #36**		

Table 4-3 (continued)
Overview of the Model Maintenance Program for the Inlet Cooling System

Task Category	Steam Turbine Minor Inspection (Notes 1 and 3)	Steam Turbine Major Inspection (Notes 2 and 3)	Other Frequency
Valve – Solenoid Operated – SOV			
Functional Test – Leak Tests			**2Y Job Plan #37**
Valve Body Bonnet – Elastomer Replacement		**Job Plan #38**	
Conductivity Analyzer			
Calibration			**1Y**
Glycol Slip Stream Filter			
Operator Rounds			**1S**
Replace and Inspect Filter			**6M**
Sump			
Cleaning			**1Y**

Notes:
1. The steam turbine minor inspection is often conducted concurrently with the hot gas path inspection.
2. The steam turbine major inspection is commonly conducted concurrently with the gas turbine major inspection.
3. Except for extreme climate circumstances, both the inlet chiller and evaporative cooler system designs are typically shut down for several months at a time during the winter months. Accordingly, these systems are generally maintained during the off season, and maintenance activities may not have to coincide with a major or minor steam turbine inspection as suggested in this table. For the purposes of this report, the minor and major steam turbine inspection frequencies are three and six years, respectively. The job plans in Section 5 of this report clarify the recommended timing for each associated listing of preventive maintenance activities.

By adjusting the intervals of most of the tasks to Hot Gas Path (HGP) and Major Inspection (MI), the program for this system is simplified and adapted from the calendar-based baseline in the PMBD without incurring excessive vulnerability to the failure modes of the critical equipment.

4.3.3 Observations from Vulnerability Analysis

4.3.3.1 Aligning to Hours/Starts-Based Inspections

One challenge in using current PMBD data is that the data is collected and communicated in a calendar-year based format. Wear out time codes are in years—for example, an Unconditional Wear out of two years is "UW2," and if it were six months, it would be "UW0.5." The challenge is that combined cycle facilities handle major maintenance not in calendar-years, but rather with a combination of run hours and major equipment starts as a base. In some cases, maintenance is scheduled using operational factors such as how quick a particular start was or whether power augmentation was in use during a run.

The methodology used by the team was that, in a common run-hours based scenario, the Hot Gas Path inspection would be estimated as three calendar years and a Major Inspection would be six calendar years. The equivalency could vary from site to site, but given that the hours and starts-

based rationale automatically factors in duty cycle, and most operators manage their outages mainly around the HGP and major inspections, a maintenance plan that is aligned with these is usable.

4.3.3.2 Program Comparison Using the PMBD

The EPRI PM Basis Database includes a vulnerability tool that allows for analysis of the entire program against the baseline by reporting the change in the level of degradation surveillance the planned tasks give for identified failure modes.

The program provides a number of outputs. The two key outputs that were used for building these programs were the *Reliability Benefit Compared to Baseline* and *Program Effectiveness*.

Reliability Benefit Compared to Baseline

Reliability Benefit Compared to Baseline can be expressed in a percentage. The calculation utilizes three factors (Annual Failure Rate with No PM Program, Annual Failure Rate with Baseline PM Program, and Annual Failure Rate with Custom PM Program). The factors are determined as follows:

- *Annual Failure Rate with No PM Program* is determined by the program using the time code and stressor sensitivity for each degradation mode to estimate the number of failures over the life of the component. These factors are summed up and annualized. This yields the *Annual Failure Rate with No PM Program*
- *Annual Failure Rate with Baseline PM Program* is determined by using individual failure rates for each degradation mode and reducing that rate based on the cumulative effectiveness of the tasks using the baseline selections and intervals. Those factors are summed up and annualized. This yields the *Annual Failure Rate with Baseline PM Program.*
- *Annual Failure Rate with Custom PM Program* is determined by using the calculation method for *Annual Failure Rate with Baseline PM Program*, but using the task and interval mix for the Custom Program.

After these factors are calculated, the *Reliability Benefit Compared to Baseline* is calculated as follows:

$$\textit{Reliability Benefit Compared to Baseline} = 1 - \left(\frac{\textit{Annual Failure Rate with Custom PM Program} - \textit{Annual Failure Rate with Baseline PM Program}}{\textit{Annual Failure Rate with No PM Program} - \textit{Annual Failure Rate with Baseline PM Program}}\right)$$

In this case, a custom program with the same failure rate as baseline would yield 1.00 or 100% reliability benefit, where a custom program with no protection at all would yield the same annual failure rate as with no PM program, resulting in 0.00 or 0% *Reliability Benefit Compared to Baseline*.

Program Effectiveness

The second output is *Program Effectiveness*, and it is a bit more qualitative than *Reliability Benefit Compared to Baseline*. Table 4-4 shows how this output is determined.

Table 4-4
Determining the Program Effectiveness Output

Program Effectiveness	Degradation Mode Coverage
Green	Mode is covered by two or more tasks of High effectiveness
Yellow	Mode is covered by one task of High effectiveness
Orange	Mode is covered by one or more tasks of Medium effectiveness but no tasks of High effectiveness
Red	Mode is covered by one or more tasks of Low effectiveness but no tasks of High or Medium effectiveness

Task effectiveness asks, if the degradation mechanism is present, what is the likelihood the mechanism is found or leads to further investigation. The three levels are defined as High – 97%, Medium – 80%, and Low – 50%. Therefore, a highly effective task would have 97% chance or greater of detecting the degraded mechanism.

The important lesson learned for users is that PMBD output is used for initial guidance, and each user should examine the output against site experience to justify their task mix. In the tables below that describe certain failure modes affected by the model maintenance program, new risks are introduced in some cases. In other instances the risk of a given failure mode is improved as a result of implementing the model maintenance program.

In each of the following sections, an analysis has been performed for each system component that illustrates the EPRI Baseline PMBD tasks and frequencies versus those new tasks and frequencies recommended as the model maintenance program. This comparison is illustrated in the first table in each section. The second table illustrates the failure modes affected by the model maintenance program and the change in risk. The failure modes that are **not** affected are still included in the corresponding component failure tables provided in Chapter 3 of this report, and can be referenced as needed to meet plant-specific needs.

4.4 Component Vulnerabilities and Risks

The purpose of this section is to provide the technical basis for modifying the preventive maintenance tasks and frequencies for inlet cooling water system components and to compare the baseline guidance from the EPRI PMBD with the recommended activities of the model maintenance program. In each case, the EPRI PMBD tasks and frequencies are based on a CRITICAL component categorization, a HIGH duty cycle, and SEVERE service conditions (i.e., CHS).

As shown in the following component analysis tables, system owners are encouraged to include as-required (AR) tasks recommended in the EPRI PMBD in their model maintenance programs. These condition-based activities should be performed when warranted by as-found conditions of each system component. Consequently, the frequency with which these tasks are performed will vary among CTCC facilities.

4.4.1 Cooling Tower Cell – Mechanical Draft – Cross Flow Analysis

For Cooling Tower Cell – Mechanical Draft – Cross Flow, the EPRI PMBD defines CHS conditions as follows:

- Critical: Functionally important, e.g., risk significant, required for power production or other regulatory requirements.
- High Duty Cycle: Continuous operation.
- Severe Service Condition: Poor water quality (e.g., brackish, treated waste water, debris laden (silt, sand, leaves), low temperatures (icing), high UV exposure, excessive environmental conditions (such as dust, salt, corrosive spray), high wind. Additionally, towers whose structural members are composed of the following materials and have reached or exceed the operating ages noted below should be considered to operate in a severe service condition when considering which PM task intervals should be used.
  - Wood ≥ 10 years
  - FRP (fiber reinforced plastic) ≥ 10 years
  - Concrete ≥ 20 years

The EPRI Baseline Cooling Tower Cell – Mechanical Draft – Cross Flow program for CHS conditions from the EPRI PMBD is as shown below in Table 4-5. The recommended Model Maintenance Program tasks for this component are also illustrated in the table.

Table 4-5
EPRI PMBD Baseline PM for Cooling Tower Cell – Mechanical Draft – Cross Flow

EPRI Baseline PMBD Task Name	EPRI Baseline PMBD (CHS) Frequency	Model Maintenance Task Name	Model Maintenance Program Frequency
Drift Eliminator Cleaning and Inspection	AR	*Drift Eliminator Cleaning and Inspection*	AR
Motor Lubrication and Inspection	AR	*Motor Lubrication and Inspection*	AR
Motor Testing	AR	*Motor Testing*	AR
Oil Change	AR	*Oil Change*	AR
Trip Switch Replacement	AR	*Trip Switch Replacement*	AR
Hot Water Basin Cleaning	3M	*Hot Water Basin Cleaning*	3M
Access Features Inspection	2Y	*Inspections*	4Y
Cold Water Basin Inspection and Cleaning	2Y		
Fan, Shroud, and Gearbox Inspection	2Y		
Fill Inspection	2Y		
Hot Water Basin Inspection	2Y		
Plenum Inspection	2Y		
Structural Inspection	2Y		
Instrumentation Functional Testing	1Y	*Instrumentation Functional Testing*	1Y
Oil Sampling, Filtering, and Analysis	1M	*Oil Sampling, Filtering, and Analysis*	3M
Operator Rounds	1S	*Operator Rounds*	1S
System Owner Walkdown	1M	*System Owner Walkdown*	3M
Thermal Performance Monitoring	1M	*Thermal Performance Monitoring*	1Y
Vibration Monitoring	1M	*Vibration Monitoring*	1M

The vulnerability analysis showed a 94% reliability benefit for the MMP as compared to the EPRI Baseline.

The EPRI program derives most of its reliability benefit from the System Owner Walkdown and Fan, Shroud, and Gearbox Inspection tasks. A vulnerability analysis shows that the System Owner Walkdown task alone yields 49% of the reliability benefit for the entire program, and eliminating it from the baseline program increases the failure rate by 6%. A vulnerability analysis shows that the Fan, Shroud, and Gearbox Inspection task alone yields 43% of the reliability benefit for the entire program, and eliminating it from the baseline program increases the failure rate by 71%. Combining all of the Inspection tasks into a single task yields 71% of the reliability benefit for the entire program, and eliminating these tasks from the baseline program increases the failure rate by 116%.

The Inspection-type tasks have been combined into a single task, *Inspections*, with a frequency of 4 years. The failure rate and reliability benefit only changed a minor amount when compared to a 2-year frequency. *Thermal Performance Testing* is recommended annually. The time duration between tasks should be decreased if there are known conditions that justify more frequent performance monitoring. The *Oil Sampling* task was changed to a 3-month frequency. The vulnerability analysis showed no effect on reliability and failure rate as a result of this change.

The following table illustrates the failure modes affected for this component.

Table 4-6
Failure Modes Affected by Model Maintenance Program

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Orange	Red	Cold Water Basins	Sludge buildup	Silt, mud, debris	UW2_3
New	Orange	Red	Motor Lubrication - Grease - Open Bearing	Degraded, loss of lubricating qualities	Age	UW3_5
New	Orange	Red	Gearbox Bearings - Tolling Element (Radial and Thrust)	Wear	Misalignment of bearing housing or driver, preloads due to internal or external forces such as fan balancing, or thermal growth	W1_2
New	Green	Orange	Motor Lubrication - Grease - Shielded Bearing	Degraded, loss of lubricating qualities	Age	UW4_6
New	Orange	Red	Coupling - Disc Pack or Diaphragm, If Present	Wear	Corrosion, environment	W1_3

Table 4-6 (continued)
Failure Modes Affected by Model Maintenance Program

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Green	Red	Motor Lubrication - Grease	Degraded, loss of lubricating qualities	Moisture, dirt	W2
New	Yellow	Orange	Gearbox Shaft Oil Seals	Wear, leakage	Normal use, high temperature	UW5_8
New	Yellow	Orange	Fan Assembly	Blade leading edge erosion	Normal wear	UW5_10
New	Yellow	Orange	Gearbox Bearings - Rolling Element (Radial and Thrust)	Wear	Normal wear	UW5_10
New	Green	Yellow	Structural Members - Wood (Deck Members, Beams, Columns, Joints), If Present	Rot - various kinds	Improper chemical treatment of water, biological	UW5_10
New	Orange	Red	Gearbox Sump Oil Heater, If Present	Open circuit	Age	UW6_10
New	Yellow	Orange	Gearbox Bearings - Rolling Element (Radial and Thrust)	Wear	Degraded lubricant - contamination, e.g., water ingress	W2_4
New	Green	Orange	Motor Bearings - Rolling Element	Wear	Degraded or dirty grease	W2_4
New	Yellow	Orange	Gearbox Bearings - Rolling Element (Radial and Thrust)	Wear	Vibration	W3_4

Table 4-6 (continued)
Failure Modes Affected by Model Maintenance Program

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Yellow	Red	Fill	Dislodged splash bars	Icing, vibration, damaged grids, missing bench ties, excessively hot water	R
New	Yellow	Orange	Gearbox Gears	Wear	Excessive mechanical loading; misalignment of bearing housing, shaft, driver, or driven component; preloads due to internal or external forces; thermal growth	W3_5
New	Orange	Red	Motor Fan - External	Dirty or corroded	Environment, bad drift eliminators	W3_5
New	Orange	Red	Coupling - Disc Pack or Diaphragm, If Present	Fatigue	Misalignment, or other improper installation - shaft fit, gap setting, or key sizing	W0.5_2
New	Yellow	Orange	Fan Assembly	Blade leading edge erosion	Excessive drift	W3
New	Yellow	Red	Fill	Cracked and broken	Icing	R
New	Yellow	Red	Fill	Failed (sagging) splash bars	Improper grid spacing	R
New	Yellow	Orange	Gearbox Gears	Wear	Contaminated lubricant	W2_6

The justification for the deviation from baseline can be summarized as follows:

- The recommended 2-year interval for the *Inspections* task was extended to 4 years. The 4-year interval is in range of all degradation mechanisms that are not random. The new degradation mechanisms have at least one medium effectiveness task remaining to detect that mechanism.
- If there is a history of failures or the utility begins to experience failures, the utility should consider increasing the frequency with which the inspections are performed.

4.4.2 Heat Exchanger – Air Cooled Analysis

For Heat Exchanger – Air Cooled, the EPRI PMBD defines CHS conditions as follows:

- Critical: Functionally important, e.g., risk significant, required for power production or other regulatory requirements.
- High Duty Cycle: Continuous or alternated operation.
- Severe Service Condition: Frequent temperature and pressure cycling, or operation outside of OEM specifications, or high flow rates, or water chemistry problems, or tube vibration, or two-phase flow, or poor quality of the process and cooling mediums. This does not imply operation beyond design code limits. Heat exchangers with poor lay-up conditions are not within the scope of these recommendations.

The EPRI Baseline Heat Exchanger – Air Cooled program for CHS conditions from the EPRI PMBD is as shown below in Table 4-7. The resultant Model Maintenance Program tasks for this component are also illustrated in the table.

Table 4-7
EPRI PMBD Baseline PM for Heat Exchanger – Air Cooled

EPRI Baseline PMBD Task Name	EPRI Baseline PMBD (CHS) Frequency	Model Maintenance Task Name	Model Maintenance Program Frequency
Replacement	AR	*Replacement*	AR
Performance Monitoring	3M	*Annual Monitoring and Walkdown*	1Y
System Owner Walkdown	3M		
Air Side Inspection	4Y	*Major Inspection*	6Y
Cleaning	4Y		
NDE Inspection	4Y		
Tube Side Internal Inspection	4Y		
Operator Rounds	1S	*Operator Rounds*	1S

The vulnerability analysis showed a 94% reliability benefit for the MMP as compared to the EPRI Baseline.

The EPRI program derives most of its reliability benefit from the baseline tasks included in the Major Inspection task. A vulnerability analysis shows this task yields 85% of the reliability benefit for the entire program, and eliminating it from the baseline program increases the failure rate by 286%.

The team opted to combine the System Owner Walkdown and Performance Monitoring tasks into the single task, *Annual Monitoring and Walkdown*. These tasks can all be performed by site personnel if there is not a System Owner at the site. The following table illustrates the failure modes affected for this component.

Table 4-8
Failure Modes Affected by Model Maintenance Program for Heat Exchanger – Air Cooled

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Green	Yellow	Tube Joint	Defective joint	Water hammer	R
New	Yellow	Orange	Tubes (All)	Macrofouling	Debris causing a thermal performance issue, e.g., clam shells, fish, rocks, other foreign material and marine debris, sand, silt, zebra mussels	R
New	Yellow	Red	Tubes (All)	Microfouling	Fluid quality, water chemistry control, low flow velocity, water temperature range of 60 deg to 90 deg F	R
New	Green	Yellow	Waterbox Channel, Partition Plate, and Nozzles	Gasket leakage	Process fluid, chemistry	R
New	Yellow	Orange	Tube Sheets	Corrosion	Improper material in brackish and salt water environments	W5_10
New	Orange	Red	Tubes - Copper Alloy	Erosion (internal, e.g., general wall loss)	Sediment with high flow velocity	W5_10
New	Orange	Red	Tubes - Copper Alloy	Erosion (internal - localized, most prevalent at inlet end)	Suspended solids with high flow velocity	W5_10
New	Green	Orange	Waterbox Channel, Partition Plate, and Nozzles	Corrosion	Water chemistry	W5_10
New	Orange	Red	Tube Exterior and Fins	Mechanical damage	Personnel error	R
New	Yellow	Red	Tube Exterior and Fins	Reduced heat transfer	Detached fins caused by corrosion of tension wound fins	R
New	Green	Yellow	Tube Joint	Defective joint	Improper installation	R

Table 4-8 (continued)
Failure Modes Affected by Model Maintenance Program for Heat Exchanger – Air Cooled

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Green	Yellow	Tube Joint	Defective joint	Improper plugging	R
New	Green	Yellow	Waterbox Channel, Partition Plate, and Nozzles	Gasket leakage	Improper installation or frequent disassembly	R
New	Green	Yellow	Waterbox Channel, Partition Plate, and Nozzles	Gasket leakage	Improper material or design (e.g., when changing type of gasket)	R

The justification for the deviation from baseline can be summarized as follows:

- Eight of the new degradation mechanisms occur randomly.
- The remaining four new degradation mechanisms have a time code W5_10. These will be detected during the *Major Inspection*.
- Some installations have the cooling coils located upstream of the inlet filters. In these installations users should consider increasing the frequency of the *Annual Monitoring and Inspection* to detect external fouling.

4.4.3 Chiller and Centrifugal Compressor Analysis

For Chiller and Centrifugal Compressor, the EPRI PMBD defines CHS conditions as follows:

- Critical: Functionally important, e.g., risk significant, required for power production or other regulatory requirements.
- High Duty Cycle: Continuous operation.
- Severe Service Condition: High or excessive humidity, excessive temperatures (high / low) or temperature variations, excessive environmental conditions (e.g., salt, corrosive, high radiation, spray, steam), high vibration.

The EPRI Baseline Chiller and Centrifugal Compressor program for CHS conditions from the EPRI PMBD is as shown below in Table 4-9. The resultant Model Maintenance Program tasks for this component are also illustrated in the table.

Table 4-9
EPRI PMBD Baseline PM for the Chiller and Centrifugal Compressor

EPRI Baseline PMBD Task Name	EPRI Baseline PMBD (CHS) Frequency	Model Maintenance Task Name	Model Maintenance Program Frequency
Internal Inspection - Compressor	10Y	*Internal Inspection - Compressor*	AR
Overhaul	AR	*Overhaul*	AR
Calibration	2Y	*Annual Inspection and Test*	1Y
Internal Inspection - Heat Exchangers	2Y		
Oil Analysis	1Y		
Refrigerant Analysis	1Y		
System Testing - Functional Tests	AR		
Glycol Analysis	6M	*Glycol Analysis*	6M
Operator Rounds	1S	*Operator Rounds*	1S
External Inspection	3M	*Quarterly Inspection and Test*	3M
System Testing - Performance Tests	2Y		
Vibration Analysis	1Y	*Vibration Analysis*	3M

The vulnerability analysis showed a 102% reliability benefit for the MMP as compared to the EPRI Baseline.

The EPRI program derives most of its reliability benefit from the baseline tasks included in the Annual Inspection and Test task. A vulnerability analysis shows this task yields 102% of the reliability benefit for the entire program, and eliminating it from the baseline program increases the failure rate by 138%.

The team reviewed the failure history, and found that the failure rate is very high. The recommended MMP was designed to restore reliability. Task frequencies are based on the current practice at the host utility. When reliability reaches acceptable levels, the MMP should be reviewed and task frequencies adjusted to minimize cost and maintain reliability.

The following table illustrates the failure modes affected for this component.

Table 4-10
Failure Modes Affected by Model Maintenance Program for the Chiller and Centrifugal Compressor

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
Improved	Orange	Yellow	Chiller Instrumentation and Control Devices: Capacity, Oil Pressure, Oil Level, Refrigerant High and Low Pressure, Freeze Protection	Drift	Heat	UW2
Improved	Orange	Yellow	Chiller Instrumentation and Control Devices: Capacity, Oil Pressure, Oil Level, Refrigerant High and Low Pressure, Freeze Protection	Drift	Vibration	W1_2
Improved	Orange	Yellow	Chiller Instrumentation and Control Devices: Capacity, Oil Pressure, Oil Level, Refrigerant High and Low Pressure, Freeze Protection	Drift	Aging	UW3_6

The justification for the deviation from baseline can be summarized as follows:

- There are no new degradation mechanisms.
- The MMP results in three improved degradation mechanisms.

4.4.4 Instrumentation and Control Analysis

The Model Maintenance Program calibration tasks are illustrated in Table 4-11.

Table 4-11
Model Maintenance Program for Calibration of Instrumentation and Controls

Task	Hot Gas Path (HGP)	Major Inspection (MI)	Other
Calibration – Non-Redundant, Critical			1Y
Calibration – Redundant, Critical	X		
Calibration – Non-Critical			AR

Given that the inlet cooling system is highly automated and requires coordination with several plant systems during the plant transition between start-up, shutdown, and when transitioning through different loads, there was not much justification to extending maintenance intervals for critical instruments beyond one year, given the risks associated with malfunction and the information feedback that comes from calibration.

As for redundant and/or non-critical items, most of the wearout time codes in the database indicate an 18-month failure-free period. These data may be influenced by a bias from the source (i.e., nuclear), where instruments are often inspected and calibrated during refueling outages, and those historically take place on an 18-month interval. Given that, the HGP interval does not incur excessive risks.

4.4.5 Motor <15 Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed Analysis

For Motor < 15 Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed, the EPRI PMBD defines CHS conditions as follows:

- Critical: Functionally important, e.g., risk significant, required for power production or other regulatory requirements.
- High Duty Cycle: Continuous or alternated. Additional comments in the PMBD Task Basis and table entries can be found for 2-pole (3600 rpm) motors because of their susceptibility to higher vibrations, increased centrifugal forces, and decreased bearing and lubrication life. Their duty cycle should be treated as High Duty Cycle.
- Severe Service Condition: High or excessive humidity, excessive temperatures (high or low) or temperature variations, excessive environmental conditions (e.g., salt, corrosive, high radiation, spray, steam), high external vibration.

The EPRI Baseline Motors, Medium Voltage < 15 Kv program for CHS conditions from the EPRI PMBD is as shown below in Table 4-12. The resultant Model Maintenance Program tasks for this component are also illustrated in the table.

Table 4-12
EPRI PMBD Baseline PM for Motor <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed

EPRI Baseline PMBD Task Name	EPRI Baseline PMBD (CHS) Frequency	Model Maintenance Task Name	Model Maintenance Program Frequency
Calibration	2Y		
Oil Lubrication	AR	*Oil Lubrication*	AR
Partial Refurbishment	AR	*Partial Refurbishment*	AR
Air Filter Replacement	1M	*Air Filter Replacement*	AR
Refurbishment	10Y	*Refurbishment*	AR
Thermography	6M	*Thermography*	1Y
Oil Analysis	6M	*Oil Analysis*	6M
Operator Rounds	1S	*Operator Rounds*	1S
System Owner Walkdown	3M	*System Owner Walkdown*	3M
Electrical Tests - Off-line	2Y	*Tests - Off-line*	Steam Turbine Minor Inspection
Mechanical Tests - Off-line	2Y		
Electrical Tests - On-line	3Y	*Tests - On-line*	2Y
Mechanical Tests - On-line	1Y		
Vibration Monitoring	3M	*Vibration Monitoring*	3M

The vulnerability analysis showed a 91% reliability benefit for the MMP as compared to the EPRI Baseline.

The EPRI program derives most of its reliability benefit from the Refurbishment task. A vulnerability analysis shows this task yields 53% of the reliability benefit for the entire program, and eliminating it from the baseline program increases the failure rate by 69%. This is, however, an expensive and time-consuming task.

An analysis was conducted using the PMBD to identify a set of tasks that could identify the onset of degradation in the motor, allowing the *Refurbishment* to be scheduled. This would change the *Refurbishment* to a condition-based activity. The EPRI program derives 90% of its reliability from the Model Maintenance Program tasks selected in Table 4-12. If these tasks are performed, the *Refurbishment* can be scheduled as a condition-based activity.



Key Technical Point

Thermography is recommended for electrical motors and associated connections, although as the PMBD indicates, the value of this task is minimized by other tasks, such as *System Owner Walkdown* and *Electrical Testing*. *Thermography* does, however, have the capability of detecting affected failure modes much sooner in the degradation process.

The *Tests - Online* task is inclusive of the Electrical Tests - On-line and Mechanical Tests - On-line tasks from the PMBD. The *Tests - Offline* task is inclusive of the Electrical Tests - Off-line and Mechanical Tests - Off-line tasks from the PMBD. Also included in the vulnerability analysis was some additional guidance from site resources.

The analysis assumes that the instrumentation calibration is performed in accordance with instrumentation and control analysis section of this report. It also assumes that any stator temperature measurement devices, RTDs, or thermocouples have built-in redundancy and they are replaced and/or repaired during an overhaul.



Key Human Performance Point

This analysis was performed for oil-lubricated horizontal motors. If grease-lubricated horizontal motors are installed at a facility, appropriate tasks should be undertaken to properly maintain the grease in accordance with current industry practice that is consistent with the EPRI PMBD.

The following table illustrates the failure modes affected for this component.

Table 4-13
Failure Modes Affected by Model Maintenance Program for Motor <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Green	Yellow	Filters - Air Coolers	Clogged or dirty	Environment	UW0.5_2
New	Green	Yellow	Frame, Enclosure, and Mounting	Clogged air screens	Environment	UW3_5
New	Orange	Red	Internal Cooling Coil - Bearing Cooling Water	Corrosion	Cooling water chemistry	UW5_10
New	Orange	Red	Rotor Fans and Hardware	Cracked welds	Duty cycle - fatigue	UW5_15
New	Orange	Red	Bearing Insulation (Internal)	Insulation shorting	Contamination from conductive particles (e.g., wear, rust, etc.) in the lubricant	W5_10

Table 4-13 (continued)
Failure Modes Affected by Model Maintenance Program for Motor <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Orange	Red	Rotor Bars and Shorting Rings	Corrosion	Environment, e.g., salt water spray	W5_10
New	Green	Yellow	Stator Windings, includes Blocking, Bracing, Tying, Surge Rings, Wedges	Insulation degradation	Vibration	W10
New	Yellow	Orange	Stator Windings, Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Loose blocking, bracing, and tying eventually leading to winding failure	Vibration	W10
New	Green	Yellow	Motor Leads	Insulation degradation	Age	UW40
New	Yellow	Orange	Oil Slinger Rings - Two Piece Design	Separation	Improper assembly, normal use, improper design	UW15_25
New	Yellow	Red	Rotor Laminations	Insulation breakdown	Thermal aging	UW40
New	Green	Yellow	Space Heater Wiring	Degraded insulation	Age, material type	UW20_40
New	Yellow	Red	Stator Laminations	Insulation breakdown	Thermal aging	UW40
New	Yellow	Orange	Stator Windings, Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Loose blocking, bracing, and tying eventually leading to winding failure	Movement during starting (depends on total number of starts)	UW20_40
New	Green	Yellow	Shaft	Wear (coupling fit area)	Improper coupling fit to shaft	UW20_30

Table 4-13 (continued)
Failure Modes Affected by Model Maintenance Program for Motor <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Yellow	Orange	Shaft	Wear (journal)	Normal use	UW20_30
New	Yellow	Orange	Rotor Laminations	Dirty	Contamination	W10_20
New	Green	Yellow	Surge Capacitors	Insulation degradation	Normal use	UW20_40
New	Green	Yellow	Surge Capacitors	Leakage	Normal use	UW20_40
New	Yellow	Red	Rotor Laminations	Insulation breakdown	Contamination	W20
New	Yellow	Orange	Rotor Laminations	Loose parts - vent ducts, clamping plate fingers, balance weights	Vibration	W10_30
New	Yellow	Red	Stator Laminations	Insulation breakdown	Contamination	W20
New	Green	Yellow	Stator Windings, Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Insulation degradation	Normal use	UW40
New	Yellow	Orange	Stator Windings, Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Loose blocking, bracing, and tying eventually leading to winding failure	Normal use	UW40
New	Yellow	Red	Rotor Laminations	Insulation fretting	Vibration from loose laminations	W40
New	Yellow	Red	Stator Laminations	Insulation fretting	Vibration from loose laminations	W40
New	Green	Yellow	Frame, Enclosure, and Mounting	Clogged air screens	Lubricant from leaks	R

Table 4-13 (continued)
Failure Modes Affected by Model Maintenance Program for Motor <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Green	Yellow	Shaft	Wear (coupling fit area)	Manufacturing defect of coupling	W10
New	Green	Yellow	Shaft	Wear (coupling fit area)	Manufacturing defect of shaft	W10
New	Yellow	Orange	Shaft	Wear (journal)	Corrosion, mainly from water in the lubricant	W10_20
New	Yellow	Orange	Shaft	Wear (journal)	Shaft currents, electrolysis (worse on machines without insulated bearings)	W10_15
New	Green	Yellow	Stator Windings, Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Insulation degradation	Normal exposure to radiation	W40

The justification for the deviation from baseline can be summarized as follows:

- Filter inspection will be included in the *Operator Rounds*. Filter replacement will be done on an as-needed basis, based on the inspection results.
- Cracked welds will result in a change in vibration. The *Vibration Monitoring* will detect this degradation mechanism.
- The *Operator Rounds* will detect gasket failures. Gaskets can be replaced or repaired on an as-needed basis.
- All of the rotor, stator, insulation, and electrical components will be monitored or detected by the motor testing. Motor *Refurbishment* can be scheduled based on these test results.
- All of the shaft degradation mechanisms can be detected with *Vibration Monitoring*. Motor refurbishment can be scheduled based on these test results.

4.4.6 Motor <15 Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed Analysis

For Motor < 15 Kv – Vertical – Sold Shaft – Rolling Element – Oil/Grease Lubed, the EPRI PMBD defines CHS conditions as follows:

- Critical: Functionally important, e.g., risk significant, required for power production or other regulatory requirements.
- High Duty Cycle: Continuous or alternated. Additional comments in the PMBD Task Basis and table entries can be found for 2-pole (3600 rpm) motors because of their susceptibility to higher vibrations, increased centrifugal forces, and decreased bearing and lubrication life. Their duty cycle should be treated as High Duty Cycle.
- Severe Service Condition: High or excessive humidity, excessive temperatures (high or low) or temperature variations, excessive environmental conditions (e.g., salt, corrosive, high radiation, spray, steam), high external vibration.

The EPRI Baseline Motors, Medium Voltage < 15 Kv program for CHS conditions from the EPRI PMBD is as shown below in Table 4-14. The resultant Model Maintenance Program tasks for this component are also illustrated in the table.

Table 4-14
EPRI PMBD Baseline PM for Motor <15 Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed

EPRI Baseline PMBD Task Name	EPRI Baseline PMBD (CHS) Frequency	Model Maintenance Task Name	Model Maintenance Program Frequency
Calibration	2Y		
Oil Analysis	6M		
Oil Lubrication	AR	*Oil Lubrication*	AR
Partial Refurbishment	AR	*Partial Refurbishment*	AR
Air Filter Replacement	1M	*Air Filter Replacement*	AR
Grease Lubrication	AR	*Grease Lubrication*	AR
Refurbishment	10Y	*Refurbishment*	AR
Operator Rounds	1S	*Operator Rounds*	1S
System Owner Walkdown	3M	*System Owner Walkdown*	3M
Electrical Tests - Off-line	2Y	*Tests - Off-line*	Steam Turbine Minor Inspection
Mechanical Tests - Off-line	2Y		
Electrical Tests - On-line	3Y	*Tests - On-line*	2Y
Mechanical Tests - On-line	1Y	*Tests - On-line*	2Y
Thermography	6M	*Thermography*	1Y
Vibration Monitoring	3M	*Vibration Monitoring*	3M

The vulnerability analysis showed a 90% reliability benefit for the MMP as compared to the EPRI Baseline without oil-related tasks included.

The EPRI program derives most of its reliability benefit from the Refurbishment task. A vulnerability analysis shows this task yields 49% of the reliability benefit for the entire program, and eliminating it from the baseline program increases the failure rate by 63%. This is, however, an expensive and time-consuming task.

An analysis was conducted using the PMBD to identify a set of tasks that could identify the onset of degradation in the motor, allowing the *Refurbishment* to be scheduled. This would change the *Refurbishment* to a condition-based activity. The EPRI program derives 90% of its reliability from the Model Maintenance Program tasks selected in Table 4-14. If these tasks are performed, the *Refurbishment* can be scheduled as a condition-based activity.



Key Technical Point

Thermography is recommended for electrical motors and associated connections, although as the PMBD indicates, the value of this task is minimized by other tasks such as *System Owner Walkdown* and *Electrical Testing*. *Thermography* does, however, have the capability of detecting affected failure modes much sooner in the degradation process.

The *Tests - Online* task is inclusive of the Electrical Tests - On-line and Mechanical Tests - On-line tasks from the PMBD. The *Tests - Offline* task is inclusive of the Electrical Tests - Off-line and Mechanical Tests - Off-line tasks from the PMBD. Also included in the vulnerability analysis was some additional guidance from site resources.

The analysis assumes that the instrumentation calibration is performed in accordance with the instrumentation and control analysis section of this report. It also assumes that any stator temperature measurement devices, RTDs, or thermocouples have built-in redundancy and they are replaced and/or repaired during an overhaul.

The analysis was performed for a grease-lubricated bearing. The following table illustrates the failure modes affected for this component.

Table 4-15
Failure Modes Affected by Model Maintenance Program

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Green	Yellow	Filters - Air Coolers	Clogged or dirty	Environment	UW0.5_2
New	Green	Yellow	Frame, Enclosure, and Mounting	Clogged air screens	Environment	UW3_5
New	Orange	Red	Internal Cooling Coil - Bearing Cooling Water	Corrosion	Cooling water chemistry	UW5_10
New	Orange	Red	Rotor Fans and Hardware	Cracked welds	Duty cycle - fatigue	UW5_15
New	Orange	Red	Bearing Insulation (Internal)	Insulation shorting	Contamination from conductive particles (e.g., wear, rust, etc.) in the lubricant	W5_10
New	Orange	Red	Internal Cooling Coil - Bearing Cooling Water	Erosion	Flow rate	W5_10
New	Orange	Red	Rotor Bars and Shorting Rings	Corrosion	Environment, e.g., salt water spray	W5_10
New	Green	Yellow	Stator Windings, Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Insulation degradation	Vibration	W10
New	Yellow	Orange	Stator Windings, Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Loose blocking, bracing, and tying eventually leading to winding failure	Vibration	W10
New	Green	Yellow	Motor Leads	Insulation degradation	Age	UW40
New	Yellow	Red	Rotor Laminations	Insulation breakdown	Thermal aging	UW40

Table 4-15 (continued)
Failure Modes Affected by Model Maintenance Program

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Green	Yellow	Space Heater Wiring	Degraded insulation	Age, material type	UW20_40
New	Yellow	Red	Stator Laminations	Insulation breakdown	Thermal aging	UW40
New	Yellow	Orange	Stator Windings, Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Loose blocking, bracing, and tying eventually leading to winding failure	Movement during starting (depends on total number of starts)	UW20_40
New	Green	Yellow	Shaft	Wear (coupling fit area)	Improper coupling fit to shaft	UW20_30
New	Yellow	Orange	Shaft	Wear (journal)	Normal use	UW20_30
New	Yellow	Orange	Rotor Laminations	Dirty	Contamination	W10_20
New	Green	Yellow	Surge Capacitors	Insulation degradation	Normal use	UW20_40
New	Green	Yellow	Surge Capacitors	Leakage	Normal use	UW20_40
New	Yellow	Red	Rotor Laminations	Insulation breakdown	Contamination	W20
New	Yellow	Orange	Rotor Laminations	Loose parts - vent ducts, clamping plate fingers, balance weights	Vibration	W10_30
New	Yellow	Red	Stator Laminations	Insulation breakdown	Contamination	W20
New	Green	Yellow	Stator Windings, Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Insulation degradation	Normal use	UW40

Table 4-15 (continued)
Failure Modes Affected by Model Maintenance Program

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Yellow	Orange	Stator Windings, Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Loose blocking, bracing, and tying eventually leading to winding failure	Normal use	UW40
New	Yellow	Red	Rotor Laminations	Insulation fretting	Vibration from loose laminations	W40
New	Yellow	Red	Stator Laminations	Insulation fretting	Vibration from loose laminations	W40
New	Green	Yellow	Frame, Enclosure, and Mounting	Clogged air screens	lubricant from leaks	R
New	Green	Yellow	Shaft	Wear (coupling fit area)	Manufacturing defect of coupling	W10
New	Green	Yellow	Shaft	Wear (coupling fit area)	Manufacturing defect of shaft	W10
New	Yellow	Orange	Shaft	Wear (journal)	Corrosion, mainly from water in the lubricant	W10_20
New	Yellow	Orange	Shaft	Wear (journal)	Shaft currents, electrolysis (worse on machines without insulated bearings)	W10_15
New	Green	Yellow	Stator Windings, Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Insulation degradation	Normal exposure to radiation	W40

The justification for the deviation from baseline can be summarized as follows:

- Filter inspection will be included in the *Operator Rounds*. Filter replacement will be done on an as-needed basis, based on the inspection results.
- Cracked welds will result in a change in vibration. The *Vibration Monitoring* will detect this degradation mechanism.
- The *Operator Rounds* will detect gasket failures. Gaskets can be replaced or repaired on an as needed basis.
- All of the rotor, stator, insulation, and electrical components will be monitored or detected by the motor testing. Motor *Refurbishment* can be scheduled based on these test results.
- All of the shaft degradation mechanisms can be detected with *Vibration Monitoring*. Motor refurbishment can be scheduled based on these test results.

4.4.7 Circulating Water and Auxiliary Circulating Water Pump – Horizontal – Single Stage – Single Suction Analysis

For Pump – Horizontal – Single Stage – Single Suction, the EPRI PMBD defines CHS conditions as follows:

- Critical: Functionally important, e.g., risk significant, required for power production or other regulatory requirements.
- High Duty Cycle: Continuous operation, which includes alternating between operating pumps.
- Severe Service Condition: Frequently operates off-BEP, i.e., ±>10% of the BEP (best efficiency point, otherwise known as the design point), OR experiences extended operation (for 1 or more hours) at minimum flow conditions, OR sees frequent starts and stops that exceed ~ 10 per month, OR experiences 1 or more of the following: pump speed greater than 3600 rpm (3600 rpm is not considered a severe service condition); low NPSHA (net positive suction head available); process fluids containing chemicals, silt, debris; or exhibiting multi-phase flow, high temperatures, or high vibration; or corrosive environmental conditions, e.g., salt spray.

The EPRI Baseline Horizontal, Single Stage, Single Suction Pump program for CHS conditions from the EPRI PMBD is as shown below in Table 4-16. This template is the closest in the PMBD to the pumps that are actually installed at the host utility. Although the pumps at that CTCC facility are horizontal by design, they are oriented in a vertical position. The resulting Model Maintenance Program tasks for this component are also illustrated in the table.

Table 4-16
EPRI PMBD Baseline PM for Circulating Water and Auxiliary Circulating Water Pump – Horizontal – Single Stage – Single Suction

EPRI Baseline PMBD Task Name	EPRI Baseline PMBD (CHS) Frequency	Model Maintenance Task Name	Model Maintenance Program Frequency
Functional Testing	NA		
Oil Analysis	3M		
Acoustic Monitoring	AR	*Acoustic Monitoring*	AR
Packing or Seal Replacement	AR	*Packing or Seal Replacement*	AR
Refurbishment	AR	*Refurbishment*	AR
Operator Rounds	1S	*Operator Rounds*	1S
Performance Trending	2Y	*Performance Trending*	2Y
System Owner Walkdown	3M	*System Owner Walkdown*	6M
Vibration Analysis	1M	*Vibration Analysis*	3M

The vulnerability analysis showed a 95% reliability benefit for the MMP as compared to the EPRI Baseline.

The EPRI program derives most of its reliability benefit from the Performance Trending Task. A vulnerability analysis shows this task yields 83% of the reliability benefit for the entire program, and eliminating it from the baseline program increases the failure rate by 403%.

The following table illustrates the failure modes affected for this component.

Table 4-17
Failure Modes Affected by Model Maintenance Program for Circulating Water and Auxiliary Circulating Water Pumps

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Green	Yellow	Impeller	Loose	Pressure pulsations or vibration	R
New	Orange	Red	Shaft	Bent	Debris	R
New	Orange	Red	Shaft	Bent	Thermal shock or water hammer	R
New	Green	Yellow	Impeller	Improper OD	Manufacturing or personnel error	R
New	Green	Yellow	Impeller	Loose	Improper installation, material, or fit tolerances	R
New	Orange	Red	Shaft	Bent	Improper layup or warm-up	R
New	Orange	Red	Shaft	Bent	Improper storage or installation	R
New	Orange	Red	Shaft	Bent	Misalignment - rubbing at bearing, seal, impeller wear rings	R
New	Green	Yellow	Wear Ring, If Closed Impeller	Wear or galling	Excessive mechanical or hydraulic loading	R
New	Green	Yellow	Wear Ring, If Closed Impeller	Wear or galling	Improper installation, fits, clearances, alignment, or materials	R
New	Green	Yellow	Lube Oil	Housing leaks	Temperature, normal wear	UW5_10
New	Yellow	Red	Breather Caps and Sight Glass Vents	Clogged	Contamination	R
New	Yellow	Red	Breather Caps and Sight Glass Vents	Clogged	Debris or personnel error	R
New	Orange	Red	Gaskets and O-Rings	Leaks caused by degraded material properties	High temperature	R
New	Orange	Red	Gaskets and O-Rings	Leaks caused by degraded material properties	Improper installation, contamination, or incorrect material	R

Table 4-17 (continued)
Failure Modes Affected by Model Maintenance Program for Circulating Water and Auxiliary Circulating Water Pumps

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Green	Yellow	Internal Bearing Cooler, If Present	Leaks - mechanical joint failures	Vibration	W5_10
New	Green	Yellow	Lube Oil	Housing leaks	Vibration	W5_10
New	Green	Yellow	Connections and Piping	Leaks	Vibration	W10_15
New	Green	Yellow	Automatic Oilers	Improper oil flow	Misadjusted, improper installation	R
New	Yellow	Red	Connections and Piping	Leaks	Installation error, improper sealant	R
New	Orange	Red	Gaskets and O-Rings	Leaks caused by deformation	Improper installation, e.g., compression or torquing, warped flange	R
New	Orange	Red	Gaskets and O-Rings	Leaks caused by erosion	Improper fit, material, or surface condition	R
New	Yellow	Red	Internal Bearing Cooler, If present	Leaks - mechanical joint failures	Manufacturing defect or personnel error	R
New	Yellow	Red	Internal Bearing Cooler, If present	Leaks - packing / gasket failures	Personnel error	R
New	Yellow	Red	Lube Oil	Housing leaks	Improper assembly	R
New	Orange	Red	Stuffing Box	Leaks	Improper installation	R

The justification for the deviation from baseline can be summarized as follows:

- All of the new red degradation mechanisms are random and will be detected by the recommended tasks.
- All of the failure modes that have vibration as a degradation influence will be detected by the *Vibration Analysis* or *Operator Rounds*.
- Housing leaks will be detected by *Operator Rounds*.
- Oil Analysis was not a selected task because the pumps at the host utility had very small oil sumps. If a larger reservoir is present, other users should consider adding oil analysis to their MMP.

4.4.8 Evaporative Cooler Feed Pump – Vertical – Close Coupled

For Pump – Vertical – Close Coupled, the EPRI PMBD defines CHS conditions as follows:

- Critical: Functionally important, e.g., risk significant, required for power production or other regulatory requirements.
- High Duty Cycle: Continuous operation, which includes alternating between operating pumps.
- Severe Service Condition: Frequently operates off-BEP, i.e. ±>10% of the BEP (best efficiency point, otherwise known as the design point), OR experiences extended operation for 1 or more hours at minimum flow conditions, OR sees frequent starts and stops that exceed ~10 per month, OR experiences 1 or more of the following: pump speed >=1800 rpm; low NPSHA (net positive suction head available); debris; or exhibiting multi-phase flow, high temperatures, or high vibration

The EPRI Baseline Pump – Vertical – Close Coupled program for CHS conditions from the EPRI PMBD is as shown below in Table 4-18. The recommended Model Maintenance Program tasks for this component are also illustrated in the table.

Table 4-18
EPRI PMBD Baseline PM for Evaporative Cooler Feed Pump – Vertical – Close Coupled

EPRI Baseline PMBD Task Name	EPRI Baseline PMBD (CHS) Frequency	Model Maintenance Task Name	Model Maintenance Program Frequency
Packing or Seal Replacement	AR	*Packing or Seal Replacement*	AR
Refurbishment	AR	*Refurbishment*	AR
Operator Rounds	1S	*Operator Rounds*	1S
Performance Trending	2Y	*Performance Trending*	3Y
System Owner Walkdown	3M	*System Owner Walkdown*	3Y

The vulnerability analysis showed a 100% reliability benefit for the MMP as compared to the EPRI Baseline.

The EPRI program derives most of its reliability benefit from the baseline tasks included in the Performance Trending task. A vulnerability analysis shows this task yields 81% of the reliability benefit for the entire program, and eliminating it from the baseline program increases the failure rate by 154%.

The *System Owner Walkdown* and *Operator Rounds* tasks are also very effective. The reliability benefits for these tasks are 47% and 45%, respectively. Decreasing the frequency of the *Performance Trending* and *System Owner Walkdown* to 6 years caused the reliability benefit to drop to 95%; therefore the 3-year frequency is recommended.

The following table illustrates the failure modes affected for this component.

Table 4-19
Failure Modes Affected by Model Maintenance Program for Evaporative Cooler Feed Pump – Vertical – Close Coupled

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Green	Yellow	Mechanical Seal	Leakage	Fluid quality / contamination	R
New	Green	Yellow	Mechanical Seal	Leakage	Off-BEP operation	R
New	Green	Yellow	Mechanical Seal	Leakage	Vibration	R
New	Green	Yellow	Packing	Excessive leakage	Fluid quality, contamination	R
New	Green	Yellow	Mechanical Seal	Leakage	Excessive axial shaft movement	R
New	Green	Yellow	Mechanical Seal	Leakage	Improper installation (misalignment of shaft or stuffing box, over-tightening, shaft sleeve run-out)	R
New	Green	Yellow	Mechanical Seal	Leakage	Inadequate flush / cooling water	R
New	Green	Yellow	Mechanical Seal	Leakage	Worn throttle bushing	W1_2
New	Yellow	Orange	Motor Support Stand	Corrosion of motor mounting flange	Improper maintenance or installation (loose motor mounting bolts, damaged flange)	R
New	Orange	Red	Motor Support Stand	Cracked welds	Installation and removal stresses	R
New	Orange	Red	Motor Support Stand	Cracked welds	Manufacturing defect	R10

Table 4-19 (continued)
Failure Modes Affected by Model Maintenance Program for Evaporative Cooler Feed Pump – Vertical – Close Coupled

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Green	Yellow	Packing	Excessive leakage	Improper installation (over-tightening, shaft sleeve run-out)	R
New	Green	Yellow	Packing	Excessive leakage	Improper packing selection	R
New	Green	Yellow	Packing	Excessive leakage	Plugged packing gland drain	R
New	Green	Yellow	Packing	Excessive leakage	Worn throttle bushing	W1_2

The justification for the deviation from baseline can be summarized as follows:

- Thirteen of the new degradation mechanisms occur randomly.
- The remaining two new degradation mechanisms have a time code W1_2. These will be detected during the *Operator Rounds* task.

4.4.9 Air Operated Valve – Diaphragm Analysis

For AOV – Diaphragm, the EPRI PMBD defines CHS conditions as follows:

- Critical: Functionally important, e.g., risk significant, required for power production or other regulatory requirements.
- High Duty Cycle: Operates frequently, e.g., used for control of process flow.
- Severe Service Condition: Exposed to environments (internal and external to the component), or to process fluids, that adversely affect reliability; internally or externally subjected to high temperature, temperature swings, rain, spray, freezing, chemicals, dust, or high radiation; passes corrosive fluids.

The EPRI Baseline AOV – Diaphragm program for CHS conditions from the EPRI PMBD is as shown below in Table 4-20. The resultant Model Maintenance Program tasks for this component are also illustrated in the table.

Table 4-20
EPRI PMBD Baseline PM for Air Operated Valve – Diaphragm

EPRI Baseline PMBD Task Name	EPRI Baseline PMBD (CHS) Frequency	Model Maintenance Task Name	Model Maintenance Program Frequency
Actuator Assembly Overhaul	5Y		
Packing Replacement	5Y		
Rebuild / Replace Accessories	5Y		
Refer to Valve - Solenoid Operated - SOV	AR	*Refer to Valve - Solenoid Operated - SOV*	AR
Seat Leakage Test	AR	*Seat Leakage Test*	AR
Diagnostic Testing	AR	*Diagnostic Testing*	AR
Calibration of Actuator	5Y	*Calibration of Actuator*	6Y
Calibration of Accessories	2Y	*Calibration, Inspection, and Test*	*3Y*
Functional Valve Stroke Test	AR		
Stroke Time Test	AR		
Operator Rounds	1S	*Operator Rounds*	1S
Packing Inspection / Adjustment	2Y	*Packing Inspection / Adjustment*	2Y

The vulnerability analysis showed a 96% reliability benefit for the MMP as compared to the EPRI Baseline.

The EPRI program derives most of its reliability benefit from the Calibration of Actuator and Calibration, Inspection, and Test tasks. A vulnerability analysis shows that these tasks combined yield 82% of the reliability benefit for the entire program, and eliminating them from the baseline program increases the failure rate by 24%.

The addition of *Diagnostic Testing* to the MMP results in better than baseline failure rate and reliability benefit. The reliability is 14% better than baseline.

Diagnostic Testing checks the operability of all the accessories, the actuator, and the valve as a single integrated unit. As a minimum it provides a verification of the calibration data and the calibration process. This verification includes being within overall tolerances for the complete valve as a system.

For example, if valve timing or travel data indicate a problem, *Diagnostic Testing* can usually indicate if the source is inappropriate friction, possibly from a packing problem or from internal damage, or if it is a result of worn springs.

Travel and seat load information on the seating area can raise the likelihood of internal leakage, which can often be confirmed by acoustic or thermographic techniques. There are limits to these capabilities. For example, although leakage may be confirmed, the extent of the leakage can only be assessed by an inspection of the seat, i.e., an overhaul. The techniques may not always be applicable. For example, a cold water valve in a noisy environment may not be assessable by thermography or acoustics. A control valve that needs to shut off in an emergency may not be able to be tested for leakage in realistic shut-off conditions.

Nevertheless, *Diagnostic Testing* can be used to decide if the source of a problem is the operator or the valve, and whether the problem can be corrected without tearing down the whole valve.

Diagnostic test results allow trending of useful valve parameters. These parameters may include travel, total friction, air pressures, spring rate, seat load, etc., and may be used to adjust PM intervals.

Because the diagnostic test data can be trended, it is possible to use the data, with some qualification, to defer overhauls and replacements when the condition of the equipment appears to be good and stable over time, or to decide if an overhaul is appropriate. However, there is one major exception to this claim. *Diagnostic Testing* does not provide information on the condition of the diaphragm if there is no leakage. The condition of other soft goods can be inferred from diagnostic information because they typically deteriorate gradually and give signs of progressive leakage. For example, O-ring piston seals degrade this way. Similarly, soft goods in accessories typically show degradation over time through increasing calibration drift.

The following table illustrates the failure modes affected for this component.

Table 4-21
Failure Modes Affected by Model Maintenance Program for Air Operated Valve – Diaphragm

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Green	Orange	Coupling: Scotch Yoke	Worn yoke	Duty cycle	UW10
New	Green	Yellow	External Air Filter	Leaks	Degraded elastomers	UW5_10
New	Green	Yellow	Actuator	Elastomer failure: diaphragm (loss of elasticity)	Heat from ambient and process conditions	W5
New	Yellow	Orange	Actuator	Elastomer failure: O-rings and gaskets (bushings, top hat/cover)	Heat from ambient and process conditions	W5
New	Yellow	Orange	Limit Switches	Elastomer failure	Heat from ambient and process conditions	W5
New	Green	Yellow	Coupling: Fixed Moment Arm	Bushing/bearing wear	Normal wear - number of cycles	UW20_30
New	Yellow	Orange	Actuator	Spring relaxation	Heat from ambient and process conditions	W10
New	Yellow	Orange	Actuator	Bushing wear	Actuator orientation other than vertical	W5_10
New	Green	Orange	Coupling: Scotch Yoke	Bushing/bearing wear	Lack of lubrication	W5
New	Orange	Red	Limit Switches	Wear, e.g., cams, lever arms, bushings	Material properties and design	W1.5
Improved	Red	Orange	Actuator	Elastomer failure: diaphragm (loss of elasticity)	Age	UW5

The justification for the deviation from baseline can be summarized as follows:

- There is one failure location that moved to Red, or no protection. The limit switches will be inspected and tested as part of the *Calibration, Inspection, and Test* task.
- The valves evaluated did not have a scotch yoke and are oriented vertically.
- The remaining Orange MMP Tasks have protection from other tasks.
- There is one improved failure location as a result of the MMP.
- Adding *Diagnostic Testing* results in better than baseline reliability.

4.4.10 Air Operated Valve – Piston Analysis

For AOV – Piston, the EPRI PMBD defines CHS conditions as follows:

- Critical: Functionally important, e.g., risk significant, required for power production or other regulatory requirements.
- High Duty Cycle: Operates frequently, e.g., used for control of process flow.
- Severe Service Condition: Exposed to environments (internal and external to the component), or to process fluids, that adversely affect reliability; internally or externally subjected to high temperature, temperature swings, rain, spray, freezing, chemicals, dust, or high radiation; passes corrosive fluids.

The EPRI Baseline AOV – Piston program for CHS conditions from the EPRI PMBD is as shown below in Table 4-22. The resultant Model Maintenance Program tasks for this component are also illustrated in the table.

Table 4-22
EPRI PMBD Baseline PM for Air Operated Valve – Piston

EPRI Baseline PMBD Task Name	EPRI Baseline PMBD (CHS) Frequency	Model Maintenance Task Name	Model Maintenance Program Frequency
Packing Replacement	5Y		
Rebuild / Replace Accessories	5Y		
Actuator Assembly Overhaul	5Y		
Refer to Valve - Solenoid Operated - SOV	AR	*Refer to Valve - Solenoid Operated - SOV*	AR
Seat Leakage Test	AR	*Seat Leakage Test*	AR
Diagnostic Testing	AR	*Diagnostic Testing*	AR
Calibration of Actuator	5Y	*Calibration of Actuator*	6Y
Calibration of Accessories	2Y	*Calibration, Inspection, and Test*	3Y
Functional Valve Stroke Test	AR		
Stroke Time Test	AR		
Operator Rounds	1S	*Operator Rounds*	1S
Packing Inspection / Adjustment	2Y	*Packing Inspection / Adjustment*	2Y

The vulnerability analysis showed a 91% reliability benefit for the MMP as compared to the EPRI Baseline.

The EPRI program derives most of its reliability benefit from the Calibration of Actuator and Calibration, Inspection, and Test tasks. A vulnerability analysis shows that these tasks combined yield 81% of the reliability benefit for the entire program, and eliminating them from the baseline program increases the failure rate by 24%.

The addition of Diagnostic Testing results in better than baseline failure rate and reliability benefit. The reliability is 10% better than baseline.

Diagnostic Testing checks the operability of all the accessories, the actuator, and the valve as a single integrated unit. As a minimum it provides a verification of the calibration data and the calibration process. This verification includes being within overall tolerances for the complete valve as a system. The *Diagnostic Testing* task requires an AOV test set that most users may not have access to. It would result in an improved program if users would pursue diagnostic testing for critical valves.

For example, if valve timing or travel data indicate a problem, the diagnostic testing can usually indicate if the source is inappropriate friction, possibly from a packing problem or from internal damage, or if it is a result of worn springs.

Travel and seat load information on the seating area can raise the likelihood of internal leakage, which can often be confirmed by acoustic or thermographic techniques. There are limits to these capabilities. For example, although leakage may be confirmed, the extent of the leakage can only be assessed by an inspection of the seat, i.e., an overhaul. The techniques may not always be applicable. For example, a cold water valve in a noisy environment may not be assessable by thermography or acoustics. A control valve that needs to shut off in an emergency may not be able to be tested for leakage in realistic shut-off conditions.

Nevertheless, *Diagnostic Testing* can be used to decide if the source of a problem is the operator or the valve, and whether the problem can be corrected without tearing down the whole valve.

Diagnostic test results allow trending of useful valve parameters. These parameters may include travel, total friction, air pressures, spring rate, seat load, etc., and may be used to adjust PM intervals.

Because the diagnostic test data can be trended, it is possible to use the data, with some qualification, to defer overhauls and replacements when the condition of the equipment appears to be good and stable over time, or to decide if an overhaul is appropriate. However, there is one major exception to this claim. *Diagnostic Testing* does not provide information on the condition of the diaphragm if there is no leakage. The condition of other soft goods can be inferred from diagnostic information because they typically deteriorate gradually and give signs of progressive leakage. For example, O-ring piston seals degrade this way. Similarly, soft goods in accessories typically show degradation over time through increasing calibration drift. The following table illustrates the failure modes affected for this component.

Table 4-23
Failure Modes Affected by Model Maintenance Program for Air Operated Valve – Piston

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Green	Orange	Coupling: Scotch Yoke	Worn yoke	Duty cycle	UW10
New	Green	Yellow	Packing	Leakage	Age	UW10
New	Green	Orange	Actuator	Elastomer failure - leakage (piston, bushings, top hat/cylinder seals)	Heat from ambient and process conditions	W5
New	Green	Yellow	Air Pump	Elastomer failure	Heat from ambient and process conditions	W5
New	Yellow	Orange	Limit Switches	Elastomer failure	Heat from ambient and process conditions	W5
New	Green	Yellow	Coupling: Fixed Moment Arm	Bushing/bearing wear	Age - number of cycles	UW20_30
New	Yellow	Orange	Actuator	Bushing/cylinder wear	Actuator orientation other than vertical	W5_10
New	Yellow	Orange	Actuator	Elastomer failure - leakage (piston, bushings)	Actuator orientation other than vertical	W5_10
New	Green	Orange	Coupling: Scotch Yoke	Bushing/bearing wear	Lack of lubrication	W>5

The justification for the deviation from baseline can be summarized as follows:

- There are no failure locations that moved to Red, or no protection.
- The valves evaluated did not have a scotch yoke and are oriented vertically.
- The remaining Orange MMP Tasks have protection from other tasks.
- Adding *Diagnostic Testing* results in better than baseline reliability.

4.4.11 Motor Operated Valve – AC Limitorque Analysis

For MOV – AC Limitorque, the EPRI PMBD defines CHS conditions as follows:

- Critical: Functionally important, e.g., risk significant, required for power production or other regulatory requirements.
- High Duty Cycle: Valves subject to a significant pressure drop wear much faster than the actuators themselves. Wear rates for both actuators and valves with low pressure drops are similar. Consequently, where there is no significant pressure drop, the appropriate duty cycle column on the template may be chosen for the actuator-valve as a combined unit. When there is any significant pressure drop across the valve, the task intervals on the template should be chosen separately for the actuator and the valve according to the duty cycle limits in the following:
  - Cycle rate with no significant DP (across the valve) based on IEEE 382 for 2000 cycles over 40 years: >50 cycles/year
  - Cycle rate with significant DP (across the valve): >4 cycles/year
  - Duty Cycle Notes:
    1. Significant DP is defined as >10% of the rated pressure class, e.g., >15 psi for 150 psi class.
    2. A cycle is defined as: Open to Close to Open, or: Close to Open to Close.
- Severe Service Condition: Experiencing one or more of the following: excessive process fluid temperatures (>400F) or ambient temperatures (>120F or <32F), a history of degradation caused by excessive environmental conditions (e.g., salt, corrosive fluids or ambient vapors, sand or dust), high vibration (e.g., a history of vibration-induced degradation).

The EPRI Baseline MOV – AC Limitorque program for CHS conditions from the EPRI PMBD is as shown below in Table 4-24. The recommended Model Maintenance Program tasks for this component are also illustrated in the table.

Table 4-24
EPRI PMBD Baseline PM for Motor Operated Valve – AC Limitorque

EPRI Baseline PMBD Task Name	EPRI Baseline PMBD (CHS) Frequency	Model Maintenance Task Name	Model Maintenance Program Frequency
Actuator - Internal Visual Inspection	3Y		
Actuator - Overhaul	AR	*Actuator - Overhaul*	AR
Functional Test - Leak Rate	AR	*Functional Test - Leak Rate*	AR
Functional Test - Position Verification	AR	*Functional Test - Position Verification*	AR

Table 4-24 (continued)
EPRI PMBD Baseline PM for Motor Operated Valve – AC Limitorque

EPRI Baseline PMBD Task Name	EPRI Baseline PMBD (CHS) Frequency	Model Maintenance Task Name	Model Maintenance Program Frequency
Packing Adjustment/ Replacement	AR	*Packing Adjustment/ Replacement*	AR
Valve Rebuild	AR	*Valve Rebuild*	AR
Diagnostic Test	AR	*Diagnostic Test*	6Y
Functional Test - Stroke Time	AR	*Functional Tests*	3Y
Functional Test - Stroke Verification	NA		
Functional Test - Valve Obturator (i.e., Actuator) Movement	AR		
Actuator - External Visual Inspection	2Y	*Inspection and Lubrication*	3Y
Valve Stem Lubrication	2Y		

The vulnerability analysis showed an 89% reliability benefit for the MMP as compared to the EPRI Baseline.

The EPRI program derives most of its reliability benefit from the Actuator - Internal Visual Inspection task. A vulnerability analysis shows that task alone yields 86% of the reliability benefit for the entire program, and eliminating it from the baseline program increases the failure rate by 67%.

However, the team determined that in a combined cycle environment, an intrusive inspection with a fixed time frame on a heavily used, largely automated system did not provide the type of feedback that less intrusive diagnostics could.

Adding the *Diagnostic Test* results in an MMP reliability benefit of 100%. The *Diagnostic Test* task addresses the valve-actuator assembly as a combined unit. The electrical thrust diagnostics provide the most reliable qualitative indication of a change in conditions within either the valve or the actuator. Most of the sources of degradation and failure can be picked up by the diagnostic tests, with the electrical tests providing somewhat better and certainly more efficient coverage than the direct thrust diagnostics. This is because the electrical tests can be performed at the motor control center and do not require personnel to be physically present at the valve. Consequently, the electrical tests can be performed much more frequently than the direct force tests.

In fact, the effectiveness of the electrical diagnostic tests is also the key to avoiding the need for tasks focused specifically on the valve, other than packing adjustments. Cracked or bent valve stems, stem to stem nut thread damage, and worn valve guides are the situations in which the effectiveness of electrical diagnostics enable a detailed internal valve inspection to be avoided altogether. Direct thrust diagnostics also play a role in defending against these problems, but that

task is performed at the valve, and therefore on a much longer interval than the electrical diagnostics. It should be noted that the *Diagnostic Test* can be conducted with a motor operated valve actuator test set. Tables 4-25 and 4-26 illustrate the failure modes affected for the MOV without and with Diagnostic Test, respectively.

Table 4-25
Failure Modes Affected by Model Maintenance Program for Motor Operated Valves Without Diagnostic Test

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Yellow	Orange	Lubricant - Valve Stem	Hardened - loss of lubricity, results in reduced thrust output (becomes significant sooner for low margin valves)	Aging, temperature (some lubricant types are temperature sensitive)	UW5_10
New	Yellow	Orange	Switch - Torque	Loss of contact	Normal wear, improper spring tension	UW10
New	Yellow	Red	Switch - Torque	High contact resistance	Contamination and corrosion from gasket or O-ring failure	W10
New	Yellow	Orange	Lubricant - Limit Switch Compartment	Hardened, binding	Aging, temperature (depends on lubricant, time code assumes long life grease, older types degrade faster)	UW20_40
New	Orange	Red	Motor	Stator winding - degraded insulation	Age, temperature	UW40
New	Green	Yellow	Packing	Leakage	Normal wear, duty cycle	UW20_40
New	Yellow	Red	Wiring	Degraded insulation	Aging, temperature	UW40
Improved	Red	Yellow	Valve Stem	Cracked due to stem embrittlement (17-4 PH and >550 deg F)	Improper material for high temperature operation	W8_40

The justification for the deviation from baseline can be summarized as follows:

- All new red failure modes are very long term wear out type modes. They would be detected by the *Diagnostic Test* task, if performed.
- The remaining new failure modes have at least one medium effectiveness task that will detect them.
- There is one improved failure mode.

Table 4-26
Failure Modes Affected by Model Maintenance Program for Motor Operated Valves with Diagnostic Test

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Yellow	Orange	Lubricant - Valve Stem	Hardened - loss of lubricity, results in reduced thrust output (becomes significant sooner for low margin valves)	Aging, temperature (some lubricant types are temperature sensitive)	UW5_10
New	Yellow	Orange	Switch - Torque	Loss of contact	Normal wear, improper spring tension	UW10
New	Yellow	Orange	Switch - Torque	High contact resistance	Contamination and corrosion from gasket or O-ring failure	W10
New	Yellow	Orange	Lubricant - Limit Switch Compartment	Hardened, binding	Aging, temperature (depends on lubricant, time code assumes long life grease, older types degrade faster)	UW20_40
New	Orange	Red	Motor	Stator winding - degraded insulation	Age, temperature	UW40
New	Green	Yellow	Packing	Leakage	Normal wear, duty cycle	UW20_40
New	Yellow	Red	Wiring	Degraded insulation	Aging, temperature	UW40
Improved	Red	Yellow	Valve Stem	Cracked due to stem embrittlement (17-4 PH and >550 deg F)	Improper material for high temperature operation	W8_40
Improved	Red	Orange	Drive Train	Worm bearing - worn or seized	Inadequate lubrication or overload, duty cycle	W40

The justification for the deviation from baseline can be summarized as follows:

- All new red failure modes are very long term wear out type modes.
- The remaining new failure modes have at least one medium effectiveness task that will detect them.
- There are two improved failure modes.

4.4.12 Solenoid Operated Valve Analysis

For Solenoid Operated Valve, the EPRI PMBD defines CHS conditions as follows:

- Critical: Functionally important, e.g., risk significant, required for power production or other regulatory requirements.
- High Duty Cycle: Normally energized OR >1000 cycles per year.
- Severe Service Condition: High or excessive humidity, excessive temperatures (high / low) or temperature variations, excessive environmental conditions (e.g., salt, corrosive, high radiation, spray, steam), high vibration, or the presence of high flow rates or particulates in the process medium.

The EPRI Baseline Solenoid Operated Valve program for CHS conditions from the EPRI PMBD is as shown below in Table 4-27. The recommended Model Maintenance Program tasks for this component are also illustrated in the table.

Table 4-27
EPRI PMBD Baseline PM for Solenoid Operated Valve

EPRI Baseline PMBD Task Name	EPRI Baseline PMBD (CHS) Frequency	Model Maintenance Task Name	Model Maintenance Program Frequency
Functional Test - Operability	AR	*Functional Test - Operability*	AR
Functional Test - Timed Stroke Test	AR	*Functional Test - Timed Stroke Test*	AR
Functional Test - Leak Tests	AR	*Functional Test - Leak Tests*	2Y
Valve Body Bonnet - Elastomer Replacement	5Y	*Valve Body Bonnet - Elastomer Replacement*	6Y

The vulnerability analysis showed a 102% reliability benefit for the MMP as compared to the EPRI Baseline.

The EPRI program derives its reliability benefit from the Valve Body Bonnet - Elastomer Replacement tasks. A vulnerability analysis shows this task yields 100% of the reliability benefit for the entire program, and eliminating it from the baseline program increases the failure rate by 147%.

The *Functional Test – Leak Tests* will ensure that the valve remains capable of isolating flow. Performing this task will also enable decreasing the frequency of the *Valve Body Bonnet - Elastomer Replacement* task and maintaining a reliability benefit near the baseline program.

The following table illustrates the failure modes affected for this component.

Table 4-28
Failure Modes Affected by Model Maintenance Program for Solenoid Operated Valves

Risk Effect	Baseline Program	Model Maintenance Program	Failure Location	Degradation Mechanism	Degradation Influence	Time Code
New	Yellow	Orange	Diaphragms	Cracking	Heat	W5
New	Yellow	Orange	Diaphragms	Sticking	Heat	W5
New	Yellow	Orange	O-rings	Aging	Age, heat	W5_10
New	Yellow	Orange	O-rings	Sliding wear	Heat	W5_10
New	Yellow	Orange	O-rings	Sliding wear	Number of cycles	W5_10
New	Yellow	Orange	Diaphragms	Cracking	Radiation	W5
New	Yellow	Orange	Diaphragms	Sticking	Radiation	W5
New	Yellow	Orange	O-rings	Aging	Radiation	W5_10
New	Yellow	Orange	O-rings	Sliding wear	Radiation	W5_10

The justification for the deviation from baseline can be summarized as follows:

- No failure modes lost all highly effective tasks. All maintained at least one.
- All of the new degradation mechanisms have a time code W5_10. The frequency of the *Valve Body Bonnet - Elastomer Replacement* task is within this range and will correct all these degradation mechanisms.

4.4.13 Conductivity Analyzer Analysis

There is currently no EPRI Baseline Conductivity Analyzer component in the EPRI PMBD. The recommended Model Maintenance Program task for this component is illustrated in Table 4-29.

Table 4-29
EPRI PMBD Baseline PM for Conductivity Analyzer

EPRI Baseline PMBD Task Name	EPRI Baseline PMBD (CHS) Frequency	Model Maintenance Task Name	Model Maintenance Program Frequency
None	None	*Calibration*	1Y

Conductivity analyzers, integral to the evaporative cooler system, will be maintained similarly to other critical, non-redundant I&C components, and are typically calibrated each spring before the system is restarted.

4.4.14 Glycol Analyzer Analysis

There is currently no EPRI Baseline Glycol Analyzer component in the EPRI PMBD. The recommended Model Maintenance Program task for this component is illustrated in Table 4-30.

Table 4-30
EPRI PMBD Baseline PM for Glycol Analyzer

EPRI Baseline PMBD Task Name	EPRI Baseline PMBD (CHS) Frequency	Model Maintenance Task Name	Model Maintenance Program Frequency
None	None	*Calibration*	AR

Glycol analyzers, integral to chiller systems, will be maintained similarly to other critical, redundant I&C components, and calibrated accordingly.

4.4.15 Glycol Slip Stream Filter Analysis

There is currently no EPRI Baseline Glycol Filter component in the EPRI PMBD. The recommended Model Maintenance Program tasks for this component are illustrated in Table 4-31.

Table 4-31
Model Maintenance Program for the Glycol Slip Stream Filter Analysis

EPRI Baseline PMBD Task Name	EPRI Baseline PMBD (CHS) Frequency	Model Maintenance Task	Model Maintenance Program Frequency
NA	NA	*Operator Rounds*	1S
		Replace and Inspect Filter	6M

The *Operator Rounds* task will monitor filter differential pressure.

The filter replacement will ensure the filter remains operational.

4.4.16 Sump Analysis

There is currently no EPRI Baseline Sump component in the EPRI PMBD. The recommended Model Maintenance Program task for this component is illustrated in Table 4-32.

Table 4-32
EPRI PMBD Baseline PM for the Sump

EPRI Baseline PMBD Task Name	EPRI Baseline PMBD (CHS) Frequency	Model Maintenance Task Name	Model Maintenance Program Frequency
None	None	*Cleaning*	1Y

The sump should be cleaned of debris and biological growth on an annual basis.

5
EXAMPLES OF JOB PLANS

The purpose of this section is to provide CTCC facility maintenance personnel with sample job plans for the model maintenance program tasks provided in this report. General guidance regarding the content of typical job plans (also referred to as maintenance instructions or work packages) is provided below. The guidance recognizes that unlike a fossil power plant, a CTCC facility will typically not have a separate organization for maintenance planning, and may not have designated individuals whose primary function is planning maintenance activities (i.e., work planners). The general guidance presented below represents best practices without regard to availability of resources and should be customized as needed to best meet the needs of each owner's organizational structure.

5.1 Content and Format for Job Plans

5.1.1 General Guidance and Considerations

5.1.1.1 Fundamental Work Package Attributes for Ensuring Quality

Work may be planned to anticipate error-likely situations and to incorporate controls that effectively prevent, catch, or mitigate error during the performance of a specific task by specific individuals.

Industry experience also suggests the following regarding work planning:

> Identifying the opportunities for error and eliminating them is one of the key responsibilities of those developing procedures and planning work packages. The planning stage of work management is an opportunity to identify critical steps of an activity. The structure of the task can be planned in light of single-error vulnerabilities to reduce possible consequences should people err. Additional controls or barriers can be built into the procedure to prevent or catch errors. Feedback from previous occasions and industry operating experience relevant to the task can be factored into the work plan.



Key Human Performance Point

One key attribute associated with the consistent development of high-quality job plans is the *critical task analysis*.

A critical task analysis basically consists of the following four steps:

1. Develop a task list
2. Identify and prioritize critical tasks
3. Identify critical steps of each particular task, considering the following:
   - Pinpoint error-likely situations at each critical step
   - Characterize the consequences if errors occur at the critical step
   - Identify missing defenses, or weaknesses in existing defenses
4. Identify and incorporate needed controls or safeguards

Other key (or critical) attributes associated with a good-quality work package may include the following:

- Content is consistent with the knowledge, skills, and experience of the work force as well as with management expectations.
- Work packages are developed with site instructions/procedures, which may include in some cases the aid of a writer's guide.
- Work packages are reviewed to check them for technical accuracy and consistency with the writer's guide, if applicable.
- Work packages are validated by qualified users. (Can the procedure/work instruction be implemented/used as written?)
- Work packages are current and are revised appropriately.
- Work packages include relevant operating experience and lessons learned, as appropriate.
- A feedback process is used as a means to continuously improve the quality of the work packages.

5.1.1.2 Inclusion of Maintenance Experience

The work planner should consider use of applicable maintenance experience and equipment performance history when planning work instructions. Most owners recognize industry maintenance experience as a source that provides valuable insight on improving work planning processes based on the learning experiences and/or knowledge from other utilities.

Maintenance experience that the planner determines may provide safety, quality, time, or cost benefits to maintenance instructions and/or activities should be added to the owner's information management system. A copy of the maintenance experience may also be provided to maintenance team/discipline leader(s) for future reference.



Key Human Performance Point

When planning a job plan or maintenance work package, the planner should search for relevant maintenance experience, and if such information is identified that is relative to the work being performed, then it should be placed in the work package.

5.1.1.3 Establishing the Appropriate Level of Detail

The level of detail contained in a work package and work instructions results after careful consideration of numerous factors, and will vary from job to job. When the work planner proactively considers inputs and appropriately varies the resulting work package category level, scope, content, and level of detail, the planner takes a "graded approach" to the work planning process.

5.1.2 Recommended Job Plan Content

The format, structure, and content of job plans vary from plant to plant, and will also vary depending upon the work level categorization. Figure 5-1 illustrates the typical components of a maintenance job plan (work package). Note that the primary difference between job plans is the level of detail of work/special instructions. In some cases, the level of detail is much less, either because a higher reliance is placed on the skill of the craft or because some work instruction details are already described in an existing instruction or procedure that is simply cross-referenced in the work package.

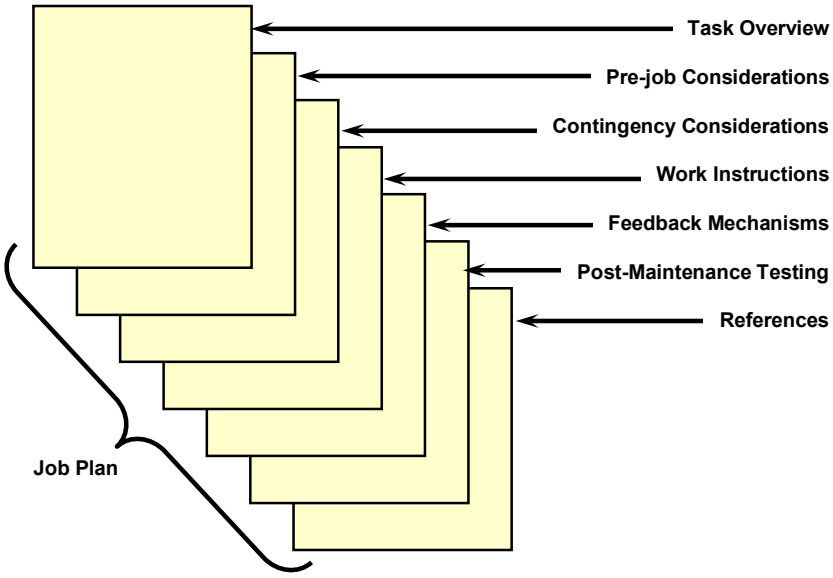


Figure 5-1
Typical Elements of a Maintenance Job Plan

5.1.2.1 Task Overview

The work planner should ensure that the cover sheet includes the following:

- Unique Work Order or Task Number
- Equipment Description – The noun name (or tag number) of the component on which the work is being performed, manufacturer/model information, etc.
- Problem Description – Initial problem description as defined by the initiator
- Scope of Work – The work scope as defined by the work planner after validation of the initial problem description

5.1.2.2 Pre-Job Considerations



Key Human Performance Point

The work planner should typically prepare a pre-job brief traveler for any maintenance activities posing risk to unit operation/generation.

The pre-job brief traveler may be a specific activity incorporated within the work instructions, or it may be a separate item included in the work package. It should be initiated by maintenance planners during the planning process and expanded upon as the work order progresses to the implementation phase.

In developing the pre-job traveler, the planner should consider the following:

- Critical job steps
- Job safety analysis
- Potential adverse outcomes
- Contingency or compensatory actions
- Error-likely situations and defenses
- Relevant maintenance experience
- Review/discussion of the following maintenance procedures:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

The traveler should be reviewed during the post-job critique to improve work package and pre-job briefing quality, and archived as appropriate to support future work package development.

5.1.2.3 Contingency Considerations



Key Human Performance Point

The work planner should review bill-of-materials, drawings, component maintenance philosophy, and maintenance history to identify parts and consumables that are likely to be needed for the job.

As noted in the preceding section, the planner should also identify/flag contingency parts and communicate to the supply chain organization(s) whether the part will be needed on site to support the work. It is typically necessary for the planner to ensure that the correct parts/replacement items are installed in the plant for the work being prescribed and planned. Care should also be taken to ensure that replacement parts are consistent with plant design documentation.



Key Technical Point

Only replacement parts that are physically identical to the original should be installed unless an alternate replacement item has been determined to be a suitable equivalent.

The planner should also reserve or initiate procurement of the needed parts or services, and identify the date that staging is required. Typically, staging represents material that is picked and segregated into kits by work management personnel for each job, and placed in a separate and secure location in the warehouse. Staging facilitates a more level workload in the warehouse as well as assisting the craft labor with expeditious issuance of the needed parts.

In some cases it may be beneficial to walk down staged material for certain work activities well in advance of the work, to further ensure efficient delivery of material when warehouse facilities are remote from the plant.

The work planner should notify appropriate organizations when engineering evaluations or reviews are required to support issue and use of required parts/services, as necessary. If the planner has reason to believe the needed parts will not be available by the preparation milestone, then they should identify the restraint.

The work planner should also be made aware of potential obsolescence issues that could adversely impact the procurement and availability of necessary parts. *Obsolescence* is a term commonly used in the fossil industry to refer to one of the following conditions:

1. The condition of being out of date due to development of better or more economical products, methods, processes, machinery, or facilities, resulting in a loss of value or competitive advantage. Items may be available in the market but are no longer needed in a specific application.
2. The condition of no longer being available in the market due to lack of manufacturer support. Items are needed in a specific application but are no longer available or supported by the original manufacturer and are difficult to procure otherwise.

Although work planners are typically not responsible for resolving part obsolescence issues and procuring alternative items, they should be aware that obsolescence can result from either of the following scenarios:

- Part Obsolescence – The supplier/manufacturer no longer makes the part.
- Obsolete Equipment – Items in plant service are no longer manufactured or supported by the original manufacturer or are otherwise difficult to procure.

In summary, accurate and timely planning of work should allow the procurement process to optimize the cost of materials and inventory. The work planner should have an appreciation for the criticality of the parts, and planning of work should take into consideration lead times for obtaining parts where stock is not maintained in inventory.

In some cases the work package may identify and contain guidance regarding the proper application and use of special tools and equipment. Typically, the planner should identify these items and include guidance when there is reason to believe the craft labor may benefit from additional instructions or when the improper use of the special tools/equipment could have an adverse effect on the maintenance work activities or the equipment being serviced.

5.1.2.4 Detailed Work Instructions

Typical content of work instructions as well as level of detail is provided in the example job plans later in this section.

5.1.2.5 Post-Maintenance Testing

This section of the work package provides post-maintenance tests as well as activities that should be perform post-maintenance to return the work location to pre-work conditions or better. Post-maintenance testing is performed to verify that all components and systems are capable of performing their intended functions following maintenance activities. It will also verify that original deficiencies have been corrected and that no new deficiencies were introduced during the maintenance activity. The tests performed should be commensurate with the maintenance work performed and the importance of the equipment to facility safety and reliability. Post-maintenance testing may be specified in the current work order package, in a procedure, or in a subsequent work order package.

Post-maintenance testing may be performed with the equipment operating under normal operating conditions or under specific test conditions. Post-maintenance testing provides an initial break-in or run-in period for adjustments, calibrations, and/or monitoring of equipment performance characteristics (vibration, temperature, flow, etc.). Post-maintenance testing should include documentation of results for future reference and trending.

5.1.2.6 Feedback Mechanism



Key Human Performance Point

The job plan should contain a means for the craft labor to provide feedback to the maintenance organization regarding the quality and clarity of the work package.

This feedback is typically only one of many elements of the plant's maintenance feedback process. Means of providing feedback to the persons planning maintenance work regarding the quality of the work package can be accomplished during several stages of work.

5.1.2.7 References

A listing of source documents and references used to compile and assemble the work package should be considered for inclusion. This list may include the following:

- Existing maintenance work instructions and/or procedures
- Replacement part information (vendor manual, assembly drawing, bill of material, critical spares database, etc.)
- Component identification (master equipment list, P&ID, electrical drawings, etc.)
- Technical equipment specifications
- Maintenance experience and equipment performance history

5.2 Job Plans for Inlet Cooling System Components

Job Plan #1 Cooling Tower Cell – Mechanical Draft – Cross Flow (Hot Water Basin Cleaning)

Task Overview

Task Timing and Objective

Due to the fact that these systems are typically shut down and laid up during the off-peak season, Hot Water Basin Cleaning would not need to be performed during this time. Consequently, the task frequency would need to be adjusted accordingly. During peak seasons, the task timing is quarterly. Hot Water Basin Cleaning has the objective of ensuring that the basin is clean, free of debris, and functioning properly. For CHM conditions the task, by itself, mainly addresses problems with the hot water basin, shroud, and stairs and walkways.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

In addition to cleaning the hot water basin and ensuring it is free of debris, the hot water basin should be inspected for the following anomalies:

- Cracking and spalling of splash box cover, concrete only
- Flow restriction
- Nozzle damage
- Nozzle plugging

- Rot-induced sagging or failure of splash box cover, wood only
- Sagging or failure of splash box cover, FRP only
- Separation from curbs and seals

Task Justification and Degradation Progression

Refer to the Task Objective, which now contains the information about the dominant component failure mechanisms. Summary timing information on the dominant degradation processes, while no longer provided here, is contained in the component degradation table.

Example Worksheets

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Cross Flow Hot Water Basin Cleaning (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Hot Water Basin	Cracking or spalling of splash box cover, concrete only
	Hot Water Basin	Flow restriction
	Hot Water Basin	Nozzle damage
	Hot Water Basin	Nozzle plugging
	Hot Water Basin	Rot-induced sagging or failure of splash box cover, wood only
	Hot Water Basin	Sagging or failure of splash box cover, FRP only
	Hot Water Basin	Separation from curbs and seals
	Shroud	Damaged
	Shroud	Loose fasteners or anchors
	Stairs and Walkways - Concrete Type	Corroded galvanized hand rail or connections
	Stairs and Walkways - Concrete Type	Spalled or cracked
	Stairs and Walkways - FRP Type	Cracked molded stair unit
	Stairs and Walkways - FRP Type	Damaged or deteriorated
	Stairs and Walkways - FRP Type	Fiber bloom
	Stairs and Walkways - Hardware	Corroded
	Stairs and Walkways - Hardware	Loose
	Stairs and Walkways - Wood Type	Damaged or deteriorated
	Stairs and Walkways - Wood Type	Rotted

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #2 Cooling Tower Cell – Mechanical Draft – Cross Flow (Inspections)

Task Overview

Task Timing and Objective

The task timing for these inspections is every four years, and the task consists of the following inspections:

- Access Features Inspection
- Cold Water Basin Inspection and Cleaning
- Fan, Shroud, and Gearbox Inspection
- Fill Inspection
- Hot Water Basin Inspection
- Plenum Inspection
- Structural Inspection

Access Features Inspection has the objective of ensuring that those features that provide access to each cell's internals and the tower's exterior are safe for personnel to use. For CHM conditions the task, by itself, mainly addresses problems with stairs and walkways.

Cold Water Basin Inspection and Cleaning has the objective of ensuring that the basin is structurally sound and the water returned to the condenser is clean and free of debris. For CHM conditions the task, by itself, mainly addresses problems with the cold water basin, drift eliminators, and fill, and provides a limited inspection of structural members and tower anchorage.

Fan, Shroud, and Gearbox Inspection has the objective of ensuring that the driven components in each tower cell are capable of performing their functions, and the fan shroud is structurally sound and has the proper clearance to the fan blades. For CHM conditions the task, by itself, mainly addresses problems with fan assembly; the shroud; the gearbox, drive shaft and couplings; and vibration sensors and instrumentation, and provides a limited inspection of the stairs and walkways.

Fill Inspection has the objective of ensuring that each tower cell will be able to provide its expected cooling capacity. For CHM conditions the task, by itself, mainly addresses problems with the fill and drift eliminators, and provides a limited inspection of structural members.

Hot Water Basin Inspection has the objective of ensuring that the basin and distribution header are structurally sound and functioning properly. For CHM conditions the task, by itself, mainly addresses problems with the hot water basin and distribution components, shroud, and stairs and walkways.

Plenum Inspection has the objective of ensuring that the tower and each of its cells are structurally sound and that all mechanical internals are in good operating condition. For CHM conditions the task, by itself, mainly addresses problems with the structural members, casing, fan assembly, gearbox, vibration sensors and instrumentation, and stairs and walkways.

Structural Inspection has the objective of ensuring that the tower is structurally sound and is safe to operate and maintain. For CHM conditions the task, by itself, mainly addresses problems with the structural members, casing, drift eliminators, fill, hot water distribution components, and stairs and walkways.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Many of the inspections noted below overlap from one task to the other, and need not be performed concurrently for the same cooling tower cell.

- The Access Features Inspection should include inspection of the stairs and walkways.
- The Cold Water Basin Inspection and Cleaning should include inspection of the basin, drift eliminators, fill, and tower anchorage.
- The Fan, Shroud, and Gearbox Inspection should include inspection of the fan assembly, gearbox, shroud, stairs and walkways, and vibration sensors and instrumentation.
- The Fill Inspection should include inspection of drift eliminators, fill, hot water distribution piping, and structural members.
- The Hot Water Basin Inspection should include inspection of the hot water basin, hot water distribution down-takes and valve, hot water header, shroud, and stairs and walkways.
- The Plenum Inspection should include inspection of the casing, drift eliminators, fan assembly, gearbox, stairs and walkways, structural hardware, and structural members.
- The Structural Inspection should include inspection of the casing, drift eliminators, fill, hot water distribution system, stairs and walkways, structural hardware, and structural members.

Task Justification and Degradation Progression

Refer to the Task Objectives, which now contain the information about the dominant component failure mechanisms. Summary timing information on the dominant degradation processes, while no longer provided here, is contained in the component degradation table.

Example Worksheets

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Cross Flow Access Features Inspection (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Stairs and Walkways - Concrete Type	Corroded galvanized hand rail or connections
	Stairs and Walkways - Concrete Type	Spalled or cracked
	Stairs and Walkways - FRP Type	Cracked molded stair unit
	Stairs and Walkways - FRP Type	Damaged or deteriorated
	Stairs and Walkways - FRP Type	Fiber bloom
	Stairs and Walkways - Hardware	Corroded
	Stairs and Walkways - Hardware	Loose
	Stairs and Walkways - Wood Type	Damaged or deteriorated
	Stairs and Walkways - Wood Type	Rotted

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Counter Flow Cold Water Basin Inspection and Cleaning (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Cold Water Basins	Sludge buildup
	Cold Water Basins and Walls	Deteriorated or failed expansion joint
	Cold Water Basins and Walls	Spalled or cracked
	Drift Eliminators - Blade Type (All Types)	Excessive air gaps
	Drift Eliminators - Blade Type (PVC Type)	Existence of air gaps
	Drift Eliminators - Blade Type (Wood Type)	Excessive air gaps at partitions and structure
	Fill	Cracked or broken
	Fill	Dislodged splash bars
	Fill	Failed concrete grid supports

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Counter Flow Cold Water Basin Inspection and Cleaning (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Fill	Failed or sagging splash bars
	Fill	Failed wood grip supports
	Tower Anchorage	Corroded anchor bolts
	Tower Anchorage	Damaged

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Cross Flow Fan, Shroud, and Gearbox Inspection (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Fan Assembly	Blade failure
	Fan Assembly	Blade fiber bloom
	Fan Assembly	Blade leading edge erosion
	Fan Assembly	Blades are not tracking properly
	Fan Assembly	Corroded hub
	Fan Assembly	Degraded thermal performance
	Fan Assembly	Failed blade
	Fan Assembly	Loose hardware
	Fan Assembly	Missing or damaged air seal discs
	Fan Assembly	Plugged bladed drain holes
	Gearbox Anti-Rotation Device, if present	Corroded or failed
	Gearbox Anti-Rotation Device, if present	Worn or stuck ratchet
	Gearbox Base or Mounting	Unusual noise or vibration
	Gearbox Gaskets	Leakage
	Gearbox Oil Breather	Plugged
	Gearbox Oil Line (External), if present	Crushed
	Gearbox Oil Line (External), if present	Loose fittings
	Gearbox Shaft Oil Seals	Leakage
	Gearbox Sump Oil Heater, if present	Failed heater
	Shroud	Cracked

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Cross Flow Fan, Shroud, and Gearbox Inspection (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Shroud	Damaged
	Shroud	Loose fasteners or anchors
	Stairs and Walkways - Concrete Type	Corroded galvanized hand rail or connections
	Stairs and Walkways - Concrete Type	Spalled or cracked
	Stairs and Walkways - FRP Type	Cracked molded stair unit
	Stairs and Walkways - FRP Type	Damaged or deteriorated
	Stairs and Walkways - FRP Type	Fiber bloom
	Stairs and Walkways - Hardware	Corroded
	Stairs and Walkways - Hardware	Loose
	Stairs and Walkways - Wood Type	Damaged or deteriorated
	Stairs and Walkways - Wood Type	Rotted
	Vibration Sensors and Instrumentation	Improper setup or mounting

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Cross Flow Fill Inspection (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Drift Eliminators - Blade Type (All Types)	Excessive air gaps
	Drift Eliminators - Blade Type (PVC Type)	Existence of air gaps
	Drift Eliminators - Blade Type (Wood Type)	Existence of air gaps at partitions and structure
	Drift Eliminators - Cellular Type	Existence of air gaps at partitions and structure
	Drift Eliminators - Cellular Type	Overloaded and failed
	Fill	Cracked or broken
	Fill	Dislodged splash bars
	Fill	Failed concrete grid supports
	Fill	Failed or sagging splash bars
	Fill	Failed wood grid supports

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Cross Flow Fill Inspection (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Hot Water Basin	Nozzle damage
	Hot Water Basin	Separation from curbs and seals
	Structural Members - Concrete (Beams Only), if present	Beam displaced from seat
	Structural Members - Concrete (Deck Members, Beams, Columns, Joints), if present	Spalled or cracked
	Structural Members - FRP (Deck Members, Beams, Columns, Joints), if present	Damage
	Structural Members - FRP (Deck Members, Beams, Columns, Joints), if present	Frayed or separated layers
	Structural Members - Wood (Deck Members, Beams, Columns, Joints), if present	Damage
	Structural Members - Wood (Deck Members, Beams, Columns, Joints), if present	Eroded
	Structural Members - Wood (Deck Members, Beams, Columns, Joints), if present	Rotted
	Structural Members - Wood (Deck Members, Beams, Columns, Joints), if present	Split

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Cross Flow Hot Water Basin Inspection (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Hot Water Basin	Cracking or spalling of splash box cover, concrete only
	Hot Water Basin	Flow restriction
	Hot Water Basin	Nozzle damage
	Hot Water Basin	Nozzle plugging
	Hot Water Basin	Rot-induced sagging or failure of splash box cover, wood only
	Hot Water Basin	Sagging or failure of splash box cover, FRP only
	Hot Water Basin	Separation from curbs and seals
	Hot Water Distribution Down-Takes	Leakage between wood pieces

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Cross Flow Hot Water Basin Inspection (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Hot Water Distribution Valve	Gasket failure
	Hot Water Distribution Valve	Stem and bushing thread wear
	Hot Water Distribution Valve	Stem to disk separation
	Hot Water Distribution Valve	Wrap failure at stub to header connection - leakage
	Hot Water Header - FRP Only	Failure of wood pipe supports
	Hot Water Header - FRP Only	Fiber bloom
	Hot Water Header - FRP Only	Leakage at bell and spigot joints
	Hot Water Header - FRP Only	Mechanical damage
	Shroud	Damaged
	Shroud	Loose fasteners or anchors
	Stairs and Walkways - Concrete Type	Corroded galvanized hand rail or connections
	Stairs and Walkways - Concrete Type	Spalled or cracked
	Stairs and Walkways - FRP Type	Cracked molded stair unit
	Stairs and Walkways - FRP Type	Damaged or deteriorated
	Stairs and Walkways - FRP Type	Fiber bloom
	Stairs and Walkways - Hardware	Corroded
	Stairs and Walkways - Hardware	Loose
	Stairs and Walkways - Wood Type	Damaged or deteriorated
	Stairs and Walkways - Wood Type	Rotted

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Cross Flow Plenum Inspection (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Casing	Leakage of air
	Drift Eliminators - Blade Type (All Types)	Excessive air gaps
	Drift Eliminators - Blade Type (PVC Type)	Existence of air gaps

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Cross Flow Plenum Inspection (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Drift Eliminators - Blade Type (Wood Type)	Existence of air gaps at partitions and structure
	Drift Eliminators - Cellular Type	Existence of air gaps at partitions and structure
	Drift Eliminators - Cellular Type	Overloaded and failed
	Fan Assembly	Blade failure
	Fan Assembly	Blade fiber bloom
	Fan Assembly	Failed blade
	Fan Assembly	Missing or damaged air seal discs
	Gearbox Gaskets	Leakage
	Gearbox Shaft Oil Seals	Leakage
	Stairs And Walkways - Concrete Type	Corroded galvanized hand rail or connections
	Stairs And Walkways - Concrete Type	Spalled or cracked
	Stairs And Walkways - FRP Type	Cracked molded stair unit
	Stairs And Walkways - FRP Type	Damaged or deteriorated
	Stairs And Walkways - FRP Type	Fiber bloom
	Stairs And Walkways - Hardware	Corroded
	Stairs And Walkways - Hardware	Loose
	Stairs And Walkways - Wood Type	Damaged or deteriorated
	Stairs and Walkways - Wood Type	Rotted
	Structural Hardware (e.g., Fasteners, Shear Connectors, Diagonal Straps)	Corroded
	Structural Hardware (e.g., Fasteners, Shear Connectors, Diagonal Straps)	Eroded
	Structural Hardware (e.g., Fasteners, Shear Connectors, Diagonal Straps)	Loose
	Structural Members - Concrete (Beams Only), if present	Beam displaced from seat
	Structural Members - Concrete (Deck Members, Beams, Columns, Joints), if present	Spalled or cracked

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Cross Flow Plenum Inspection (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Structural Members - FRP (Deck Members, Beams, Columns, Joints), if present	Damage
	Structural Members - FRP (Deck Members, Beams, Columns, Joints), if present	Frayed or separated layers
	Structural Members - Wood (Deck Members, Beams, Columns, Joints), if present	Damage
	Structural Members - Wood (Deck Members, Beams, Columns, Joints), if present	Eroded
	Structural Members - Wood (Deck Members, Beams, Columns, Joints), if present	Rotted
	Structural Members - Wood (Deck Members, Beams, Columns, Joints), if present	Split

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Cross Flow Structural Inspection (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Casing	Leakage of air
	Drift Eliminators - Blade Type (All Types)	Excessive vibration
	Drift Eliminators - Blade Type (PVC Type)	Existence of air gaps
	Drift Eliminators - Blade Type (Wood Type)	Existence of air gaps at partitions and structure
	Drift Eliminators - Cellular Type	Existence of air gaps at partitions and structure
	Drift Eliminators - Cellular Type	Overloaded and failed
	Fill	Cracked or broken
	Fill	Dislodged splash bars
	Fill	Failed concrete grid supports

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Cross Flow Structural Inspection (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Fill	Failed or sagging splash bars
	Fill	Failed wood grid supports
	Hot Water Basin	Cracking or spalling of splash box cover, concrete only
	Hot Water Basin	Nozzle damage
	Hot Water Basin	Rot-induced sagging or failure of splash box cover, wood only
	Hot Water Basin	Sagging or failure of splash box cover, FRP only
	Hot Water Basin	Separation from curbs and seals
	Stairs and Walkways - Concrete Type	Corroded galvanized hand rail or connections
	Stairs and Walkways - Concrete Type	Spalled or cracked
	Stairs and Walkways - FRP Type	Cracked molded stair unit
	Stairs and Walkways - FRP Type	Damaged or deteriorated
	Stairs and Walkways - FRP Type	Fiber bloom
	Stairs and Walkways - Hardware	Corroded
	Stairs and Walkways - Hardware	Loose
	Stairs and Walkways - Wood Type	Damaged or deteriorated
	Stairs and Walkways - Wood Type	Rotted
	Structural Hardware (e.g., Fasteners, Shear Connectors, Diagonal Straps)	Corroded
	Structural Hardware (e.g., Fasteners, Shear Connectors, Diagonal Straps)	Eroded
	Structural Hardware (e.g., Fasteners, Shear Connectors, Diagonal Straps)	Loose
	Structural Members - Concrete (Beams Only), if present	Beam displaced from seat
	Structural Members - Concrete (Deck Members, Beams, Columns, Joints), if present	Spalled or cracked
	Structural Members - FRP (Deck Members, Beams, Columns, Joints), if present	Damage

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Cross Flow Structural Inspection (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Structural Members - FRP (Deck Members, Beams, Columns, Joints), if present	Frayed or separated layers
	Structural Members - Wood (Deck Members, Beams, Columns, Joints), if present	Damaged
	Structural Members - Wood (Deck Members, Beams, Columns, Joints), if present	Eroded
	Structural Members - Wood (Deck Members, Beams, Columns, Joints), if present	Rotted
	Structural Members - Wood (Deck Members, Beams, Columns, Joints), if present	Split

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #3 Cooling Tower Cell – Mechanical Draft – Cross Flow (Instrumentation Functional Testing)

Task Overview

Task Timing and Objective

The task timing is annually, and Instrumentation Functional Testing has the objective of ensuring the operability of monitoring and protective components. For CHM conditions the task, by itself, mainly addresses problems with gearbox instrumentation, vibration sensors, instrumentation, and trip switch.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

The Instrumentation Functional Testing should verify the functionality of gearbox instrumentation (oil temperature, oil level), vibration sensors and instrumentation, and the vibration trip switch.

Task Justification and Degradation Progression

Refer to the Task Objective, which now contains the information about the dominant component failure mechanisms. Summary timing information on the dominant degradation processes, while no longer provided here, is contained in the component degradation table.

Example Worksheets

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Cross Flow Instrumentation Functional Testing (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Gearbox Instrumentation (Oil Temperature, Oil Level)	Improper display or indicated value
	Gearbox Instrumentation (Oil Temperature, Oil Level)	Inaccurate or failed
	Vibration Sensors and Instrumentation	Improper display or indicated value
	Vibration Sensors and Instrumentation	Improper setup or mounting
	Vibration Trip Switch	Improper setup or mounting
	Vibration Trip Switch	Water in-leakage

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #4 Cooling Tower Cell – Mechanical Draft – Cross Flow (Oil Sampling, Filtering, and Analysis)

Task Overview

Task Timing and Objective

Due to the fact that these systems are typically shut down and laid up during the off-peak season, Oil Sampling, Filtering, and Analysis would not need to be performed during this time. Consequently, the task frequency would need to be adjusted accordingly. During peak seasons, the task timing is quarterly. Oil Sampling, Filtering, and Analysis has the objective of ensuring that the lubricating properties of the gearbox oil remain within expected tolerances, that the oil is cleared of filterable contaminants and wear particles, and that the gearbox's internal wear surfaces (e.g., bearings and gears) are not exhibiting more than nominal degradation. This PM task is an alternative to the Oil Change PM. If this task is performed, the Oil Change task should not be scheduled, but rather should become an on-condition task based on the results of the oil analysis. If Oil Change is the preferred PM, then this task should not be performed.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

This task should include inspection of the gearbox bearings, gears, oil, oil breather, and oil seals.

Task Justification and Degradation Progression

Refer to the Task Objective, which now contains the information about the dominant component failure mechanisms. Summary timing information on the dominant degradation processes, while no longer provided here, is contained in the component degradation table.

Example Worksheets

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Cross Flow Oil Sampling, Filtering, and Analysis (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Gearbox Bearings - Rolling Element (Radial and Thrust)	High ferrous wear particles in oil sample
	Gearbox Gears	High ferrous wear particles in oil sample
	Gearbox Gears	Out of specification oil viscosity
	Gearbox Oil	Out of specification oil viscosity, high moisture content, or high particle count

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #5 Cooling Tower Cell – Mechanical Draft – Cross Flow (Thermal Performance Monitoring)

Task Overview

Task Timing and Objective

The task timing is annually, and Thermal Performance Monitoring has the objective to verify that the tower is operating within normal parameters by trending and evaluating a wide variety of its thermal parameters to identify abnormal conditions. For CHM conditions the task, by itself, mainly addresses problems with the drift eliminators, fan blades, fill, and plugging of the hot water basin nozzles.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Thermal Performance Monitoring should consider inspection of the drift eliminators, the fan assembly, and the hot water basin.

Task Justification and Degradation Progression

Refer to the Task Objective, which now contains the information about the dominant component failure mechanisms. Summary timing information on the dominant degradation processes, while no longer provided here, is contained in the component degradation table.

Example Worksheets

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Cross Flow Thermal Performance Monitoring (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Fan Assembly	Improper blade pitch or excessive tip clearance
	Motor Amperage	Improper motor power consumption at design operating condition

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #6 Vibration Monitoring

Task Overview

This job plan has been developed to apply to the following types of equipment:

- Cooling Tower Cell – Mechanical Draft – Cross Flow
- Chiller and Centrifugal Compressor
- Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed
- Motor – Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed
- Pump – Horizontal – Single Stage – Single Suction

Task Timing and Objective

For the Cooling Tower Cell – Mechanical Draft – Cross Flow, these systems are typically shut down and laid up during the off-peak season. Vibration Monitoring would not need to be performed during this time. Consequently, the task frequency would need to be adjusted accordingly. During peak seasons, the task timing is monthly. Vibration Monitoring has the objective of detecting issues in the rotating and structural components that indicate degraded or unsafe conditions. For CHM conditions the task, by itself, mainly addresses problems with the structural members and shroud, fan assembly, gearbox, motor, drive shaft and couplings, vibration sensors and instrumentation, and to a lesser degree stairs and walkways.

For the Chiller and Centrifugal Compressor, the task timing is quarterly. Vibration Analysis is focused on the detection of wear and misalignment in couplings and bearings, and in other components. The task does not present much opportunity for interval extension.

For Motors, Vibration Monitoring should be performed quarterly. It has the objective of ensuring continued equipment operation by detecting wear in bearings and other rotating components before failure occurs. For CHM conditions the task, by itself, mainly addresses misalignment and wear of rotating components. In a full program for CHM conditions, the failure rate is sensitive to the task interval.

For Pump – Horizontal – Single Stage – Single Suction, Vibration Analysis should be performed quarterly. It addresses sources of vibration in rotating parts as well as flow noise such as cavitation. Reliability is not very sensitive to the task interval.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

For the Cooling Tower – Mechanical Draft – Cross Flow, Vibration Monitoring should include inspections of the coupling, drive shaft, fan assembly, gearbox base or mounting, gearbox bearings, gearbox bolting, gearbox gears, motor anti-rotation device, motor base, motor bearings, motor endbells or bearing housings, motor fan, motor frame, motor lubrication, motor rotor bars and shorting rings, motor rotor fans and hardware, motor shaft, shroud, stairs and walkways, structural hardware, structural members, vibration sensors and instrumentation, and vibration trip switch.

For the Chiller and Centrifugal Compressor, Vibration Analysis should include checking for signs of high vibration of the bearings, the compressor impeller, the coupling, and the gearbox.

For Motors, Vibration Monitoring should include:

- Spectral and trend analysis of the readings, looking for evidence of misalignment and unusual spectrums that may indicate the existence of problems, e.g., bearing wear, loose internals, loose or excessively worn bearing mating surfaces, loose windings, or faulty couplings.

Additionally (if practical):

- Visually inspect for signs of leaking lubricant, if possible
- Listen for any unusual noises that may indicate problems with the bearings, coupling, or other components
- Visually inspect the coupling guard, if present, for signs of loose fasteners and damage

(Note: Man hours assigned to this task include only the time needed to take the readings using portable or handheld tools. Additional time should be allocated to perform a detailed signature analysis and to trend the data collected. This task is generally performed on both the driver and driven components; it may also provide information on the condition of the coupling.)

For Pump – Horizontal – Single Stage – Single Suction, Vibration Analysis should include analysis of the readings looking for evidence of misalignment and unusual spectrums that may indicate the existence of problems. Note that vibration is performed on the driver and driven components. Additionally:

- Visually inspect for signs of leaking lubricant, if present
- Listen for unusual noises that may indicate coupling problems
- Visually inspect for loose fasteners and damage
- Visually inspect the coupling guard, if present, for signs of loose fasteners and damage

Task Justification and Degradation Progression

Cooling Tower Cell – Mechanical Draft – Cross Flow

Vibration Monitoring and analysis of cooling tower fans, whether driven through gear boxes or belt drives, is critical to the detection of mechanical wear and misalignment of the machine train. Most cooling tower fans and drives are equipped with vibration switches that will detect abnormally high vibrations, but will not assist in the early detection of emergent faults. If monitoring intervals are allowed to be extended too long, catastrophic failure of the machine train may occur.

Chiller and Centrifugal Compressor

Vibration Analysis is focused on the detection of wear and misalignment in couplings and bearings. Wear and misalignment in couplings can become important contributors to failure if the task interval is extended too far.

Motor – Medium Voltage <15Kv

Vibration Monitoring is very effective for addressing all the causes of wear in anti-friction bearings. Additionally, vibration monitoring addresses all causes of failures originating in the shaft, all causes of failures originating in the rotor, and worn or loose stator windings. Cracks, weld failures, and deformation in the frame, enclosure and mounting, or soft foot, and other deformation or misalignment causing or caused by failure of machine fits, are also likely to result in detectable vibration. Most of the causes of bearing failure appear randomly over a period of several months to 2 years. The appearance of wear and cracks in the shaft, all degradation mechanisms in the rotor, and a worn or loose stator, although random in occurrence times, are not expected within a few years. The onset of degradation in the frame, such as deformation, cracking, and soft foot, shares similar timing characteristics as for the shaft and armature. Progression to failure could be rapid if the vibration is close to a structural resonance, and could be almost immediate if caused by personnel error.

Pump – Horizontal – Single Stage – Single Suction

Vibration Analysis mainly addresses wear and damage to rotating components such as bearings and the pump shaft, the balancing device, and gear drive and auxiliary oil pumps, as well as wear or damage caused by erosion on impellers and internal parts such as diffusers and inter-stage sealing. These can nearly all develop as long-term wearout mechanisms, with at least 20 years or much longer before expected failure occur. However, a wide variety of random causes of damage to the same components can also occur unless this task is performed very frequently, in sharp contrast to the much more relaxed time frame that would be suggested by the longer-term wearout mechanisms.

Example Worksheets

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Cross Flow Vibration Monitoring (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Coupling - Disc Pack or Diaphragm, if present	Excessive vibration
	Coupling - Pin and Bushing, if present	Excessive vibration
	Drive Shaft - Graphite Composite	Excessive vibration
	Fan Assembly	Excessive vibration
	Gearbox Base or Mounting	Excessive vibration
	Gearbox Bearings - Rolling Element (Radial and Thrust)	Excessive vibration
	Gearbox Bolting	Excessive vibration
	Gearbox Gears	Excessive vibration
	Motor Anti-Rotation Device, if present	Excessive vibration
	Motor Base	Excessive vibration
	Motor Bearings - Rolling Element	Excessive vibration
	Motor Endbells or Bearing Housings	Excessive vibration
	Motor Endbells or Bearing Housings	Unusual bearing noise
	Motor Fan - External	Dirty or corroded
	Motor Fan - External	Loose
	Motor Fan - External	Loose or blocked cover
	Motor Frame	Excessive vibration
	Motor Lubrication - Grease	Excessive vibration
	Motor Lubrication - Grease - Open Bearing	Excessive vibration

As-Found Worksheet – Cooling Tower Cell – Mechanical Draft – Cross Flow Vibration Monitoring (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Motor Lubrication - Grease - Shielded Bearing	Excessive vibration
	Motor Rotor Bars and Shorting Rings (Cast Type)	Excessive vibration
	Motor Rotor Fans and Hardware	Excessive vibration
	Motor Shaft	Excessive vibration
	Shroud	Excessive vibration
	Stairs and Walkways - Hardware	Loose
	Stairs and Walkways - Wood Type	Rotted
	Structural Hardware (e.g., Fasteners, Shear Connectors, Diagonal Straps)	Corroded
	Structural Hardware (e.g., Fasteners, Shear Connectors, Diagonal Straps)	Eroded
	Structural Hardware (e.g., Fasteners, Shear Connectors, Diagonal Straps)	Excessive vibration
	Structural Members - FRP (Deck Members, Beams, Columns, Joints), if present	Excessive vibration
	Structural Members - Wood (Deck Members, Beams, Columns, Joints), if present	Excessive vibration
	Structural Members - Wood (Deck Members, Beams, Columns, Joints), if present	Rotted
	Vibration Sensors and Instrumentation	Improper display or indicated value
	Vibration Sensors and Instrumentation	Improper setup or mounting
	Vibration Trip Switch	Excessive vibration
	Vibration Trip Switch	Failed switch

As-Found Worksheet – Chiller and Centrifugal Compressor Vibration Analysis (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Bearings	High vibration
	Compressor, Impeller	High vibration

As-Found Worksheet – Chiller and Centrifugal Compressor Vibration Analysis (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Coupling	High vibration
	Gearbox	High vibration

Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed Motor – Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed Vibration Analysis (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Bearings - Sleeve	Excessive vibration
	Frame, Enclosure, and Mounting	Excessive vibration
	Frame, Enclosure, and Mounting	Soft foot
	Frame, Enclosure, and Mounting	Task is not likely to discover the condition
	Lubrication - Oil	Excessive vibration
	Machine Fits	Excessive vibration
	Rotor Bars and Shorting Rings	Excessive vibration
	Rotor Bars and Shorting Rings	Task is not likely to discover the condition
	Rotor Cage - Lamination Support, i.e., Spider	Excessive vibration
	Rotor Cage - Solid Lamination Design (Non-Spider Design)	Excessive vibration
	Rotor Fans and Hardware	Task is not likely to discover the condition
	Rotor Fans with Interference Fit Design	Task is not likely to discover the condition
	Rotor Laminations	Excessive vibration
	Rotor Laminations	Task is not likely to discover the condition
	Rotor Retaining Rings (Predominantly on 2-Pole Motors)	Excessive vibration
	Rotor Spider - Integral Design Where Spider Arms Are Welded to Shaft	Excessive vibration
	Rotor Spider - Spider to Shaft Interference Fit Design	Excessive vibration
	Shaft	Excessive vibration
	Stator Laminations	Task is not likely to discover the condition

Pump – Horizontal – Single Stage – Single Suction Vibration Analysis (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Bearings - Antifriction (Radial and Thrust)	Excessive vibration
	Impeller	Excessive vibration
	Pump Base Plate and Foundation	Failed anchor, grout or base plate
	Pump Casing	Excessive vibration
	Shaft	Excessive vibration
	Wear Ring, if Closed Impeller	Excessive vibration

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #7 Heat Exchanger – Air Cooled (Replacement)

Task Overview

Task Timing and Objective

Replacement of the Heat Exchanger – Air Cooled should be performed on an as-required basis. The objective of this task is to restore the equipment to an as-new condition, either through replacement or complete reconditioning.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Inspection of the following subcomponents will provide indication as to whether the heat exchanger can be refurbished or be replaced:

- Support plates, frames, drain pan – for corrosion
- Tube exterior and fins
- Tube joint
- Tube plugs
- Tube sheets
- Tubes – copper alloy, brass, and/or stainless steel
- Tubes – stainless steel
- Waterbox channel, partition plate, and nozzles

Task Justification and Degradation Progression

The objective of this task is to replace the heat exchanger coils in the turbine inlet air duct, due to leaking and/or excessive pluggage. This is to ensure that there is adequate heat transfer occurring between the chilled glycol and inlet ambient air being drawn into the combustion turbine. It is recommended that this task be performed on an as-required basis depending on testing and system performance. If degradation is allowed to progress, it may result in glycol ingestion into the combustion turbine. Total replacement should be based on the conditions found by other tasks and an economic evaluation.

Example Worksheets

As-Found Worksheet – Heat Exchanger – Air Cooled Replacement (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Support Plates, Frames, Drain Pan	Corroded
	Tube Exterior and Fins	Corroded
	Tube Exterior and Fins	Fouled
	Tube Exterior and Fins	Mechanical damage
	Tube Joint	Defective joint
	Tube Plugs	Loose or missing
	Tube Sheets	Corroded
	Tube Sheets	Cracked ligaments
	Tubes - Copper Alloy	Eroded at the end of the sleeve or coating
	Tubes - Copper Alloy	Internally eroded
	Tubes - Copper Alloy	Pitted
	Tubes - Copper Alloy (Brass Only)	End of useful life
	Tubes - Stainless Steel	Corroded
	Tubes - Stainless Steel	End of useful life
	Tubes - Stainless Steel	Eroded
	Tubes (All)	Defective
	Tubes (All)	Excessive wear of the baffle plate
	Tubes (All)	Fouled
	Waterbox Channel, Partition Plate, and Nozzles	Corroded
	Waterbox Channel, Partition Plate, and Nozzles	Cracked or degraded coating
	Waterbox Channel, Partition Plate, and Nozzles	Eroded

As-Found Worksheet – Heat Exchanger – Air Cooled Replacement (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Waterbox Channel, Partition Plate, and Nozzles	Gasket leakage
	Waterbox Channel, Partition Plate, and Nozzles	Graphitization of cast iron components

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #8 Heat Exchanger – Air Cooled (Major Inspection)

Task Overview

Task Timing and Objective

Major Inspection of the Heat Exchanger – Air Cooled should be performed approximately every six (6) years, but doesn't necessarily have to coincide with outage events on other major plant equipment. This task includes an Air Side Inspection, Cleaning, NDE Inspection, and a Tube Side Internal Inspection.

The objective of the Air Side Inspection is to discover any conditions that could affect performance. For CHM conditions the task, by itself, is to find degraded conditions on the exterior of the coil and any external indications of leakage.

The objective of Cleaning is to remove corrosion, fouling, and scaling material from the inner surface of tubes.

The objective of NDE Inspection is specifically to detect tube corrosion and erosion, as well as degradation of the components that make up the main interior support and flow transition elements.

The objective of a Tube Side Internal Inspection is to detect degradation of the channel, partition plate, and tube sheet, and macrofouling of the heat exchanger.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Air Side Inspection may include the following:

- Inspect for evidence of corrosion.
- Inspect for evidence of leakage.
- Inspect for loose, missing, or damaged fasteners.
- Visually inspect for the presence, amount, and type of fouling.
- If necessary, clean the exterior of the tubes and fins.
- Check that air dams are intact around the coil.

Cleaning may include the following:

- Determine the appropriate cleaning method or process that will provide the best results while limiting damage to the tubes. Current cleaning methods that are available:
  - Metal scrapers
  - Plastic scrapers
  - Nylon brushes
  - Hydrolazing
  - Chemical cleaning

The NDE tasks as scheduled in the template are intended for tube inspections. Other items may also be addressed as required and indicated below.

- Eddy current using bobbin or special probes
- Dye penetrant, as required for crack inspection
- Ultrasonic thickness, as required for visual identified erosion or corrosion

Tube Side Internal inspection may include the following:

- Inspect for evidence of erosion or corrosion.
- Measure selected tubes for evidence of wall thinning.
- Inspect gaskets, O-rings, and channel heads for evidence of leakage.
- Inspect for loose, missing, or damaged fasteners.
- If Performance Monitoring or other inspections indicate the need, perform a borescope inspection on a representative sample of tubes.
- Visually inspect for the presence, amount, and type of fouling.
- If the heat exchanger has copper alloy tubes with tube sleeves, a borescope should be used to identify erosion at the end of the sleeves.
- Coating should be inspected for degradation.

- If appropriate, determine the degree of fouling in order to make the necessary adjustment in the cleaning interval.
- Inspect the condition of the cathodic protection, if present.
- Verify that previously plugged tubes are still plugged (i.e., use the tube plug map).

Task Justification and Degradation Progression

This inspection is focused on detecting the extent of internal tube erosion, corrosion, and scaling, as well as the structural integrity of the fasteners and supports. The above failure causes are random in nature with a wide range of possible development times, depending on condition. The occurrence of these events might influence the frequency of Internal Inspection.

Example Worksheets

As-Found Worksheet – Heat Exchanger – Air Cooled Air Side Inspection (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Support Plates, Frames, Drain Pan	Corroded
	Tube Exterior and Fins	Corroded
	Tube Exterior and Fins	Fouled
	Tube Exterior and Fins	Mechanical damage
	Tube Joint	Leakage
	Tube Plugs	Improper operation
	Waterbox Channel, Partition Plate, and Nozzles	Gasket leakage

As-Found Worksheet – Heat Exchanger – Air Cooled Cleaning (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Tube Exterior and Fins	Task is not likely to discover the condition
	Tubes - Copper Alloy	Internally eroded
	Tubes - Copper Alloy	Pitted
	Tubes - Stainless Steel	Corroded
	Tubes - Stainless Steel	Eroded
	Tubes (All)	Fouled

As-Found Worksheet – Heat Exchanger – Air Cooled NDE Inspection (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Tube Exterior and Fins	Corroded
	Tube Exterior and Fins	Mechanical damage
	Tube Sheets	Corroded
	Tube Sheets	Cracked ligaments
	Tubes - Copper Alloy	Internally eroded
	Tubes - Copper Alloy	Pitted
	Tubes - Copper Alloy	Task is not likely to discover the condition
	Tubes - Copper Alloy (Brass Only)	Transgranular stress corrosion cracking
	Tubes - Stainless Steel	Corroded due to manganese pitting
	Tubes - Stainless Steel	Eroded
	Tubes - Stainless Steel	MIC
	Tubes (All)	Defective
	Tubes (All)	Task is not likely to discover the condition
	Waterbox Channel, Partition Plate, and Nozzles	Corroded
	Waterbox Channel, Partition Plate, and Nozzles	Eroded
	Waterbox Channel, Partition Plate, and Nozzles	Graphitization of cast iron components

As-Found Worksheet – Heat Exchanger – Air Cooled Tube Side Internal Inspection (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Tube Plugs	Loose or missing
	Tube Sheets	Corroded
	Tube Sheets	Cracked ligaments
	Tubes - Copper Alloy	Eroded at the end of the sleeve or coating

As-Found Worksheet – Heat Exchanger – Air Cooled Tube Side Internal Inspection (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Tubes - Copper Alloy	Task is not likely to discover the condition
	Tubes (All)	Fouled
	Waterbox Channel, Partition Plate, and Nozzles	Corroded
	Waterbox Channel, Partition Plate, and Nozzles	Cracked or degraded coating
	Waterbox Channel, Partition Plate, and Nozzles	Eroded
	Waterbox Channel, Partition Plate, and Nozzles	Gasket leakage
	Waterbox Channel, Partition Plate, and Nozzles	Graphitization of cast iron components

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #9 Chiller and Centrifugal Compressor (Internal Inspection – Compressor)

Task Overview

Task Timing and Objective

For Internal Inspection – Compressor, the task should be performed on an as-needed basis. The task changes oil filters and refrigerant dryers and addresses leaking gaskets, and wear, corrosion, and erosion in internal components. Several wearout mechanisms, as well as many random failure modes, strongly constrain the interval.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

The Compressor Internal Inspection should include:

- Inspect for loose, damaged, or missing parts, fasteners, and components
- Inspect the float valve for proper operation, and check for evidence of wear, sticking, or a leaking float
- Inspect the metering orifice for cleanliness
- Check the integrity of the pressure rupture disk and for the presence of moisture in the vent line

- Check pressure control tubing for integrity and damage. Note that replacement of plastic pressure control tubing on chillers is not to be performed at every internal inspection, and may only require replacement approximately every three years.
- Perform electrical insulation test on the oil pump motor, if internal to the refrigerant system
- Change air and oil filters and dryers
- Verify that the oil pump is operating correctly, the oil level is correct, and the pump is providing specified pressures
- Inspect the oil lines for damage
- Megger the compressor motor if it is the hermetically sealed type
- Inspect gaskets and seals (including the seal of motor leads on hermetic units)
- Inspect the impeller for wear and damage (does not need to be done at every inspection interval)
- Ensure that the refrigerant level is correct and there is no evidence of leakage
- Verify that the pressure relief device is closed with no evidence of leakage
- Verify that the purge unit is seated and not venting
- If present, verify that the refrigerant operated control valve is operating properly
- Verify that all lubrication levels are correct and there is no evidence of leakage
- Inspect all compressor / motor couplings for wear and proper alignment
- Ensure that the capacity control (pre-rotation) vanes are free and not bound
- Verify that the shaft seal shows no evidence of leakage
- Verify proper operation of the separator oil heater
- Ensure that the cooling water flow rate to the heat exchanger is correct and that the inlet and outlet temperatures and pressures are within specification
- Verify the general condition and performance of the unit, e.g., verify that the superheat and sub-cooling are within specifications, and that the refrigerant control valve is within its expected operating range

Task Justification and Degradation Progression

The Internal Inspection is focused on changing oil filters and refrigerant dryers, addressing relief valve drift, oil return system coil failures, aging of the lubrication pump, leaking gaskets, and corrosion and erosion in general, and checking the electrical insulation of motors. It also provides an opportunity to address worn, eroded, or cracked impellers and binding pre-rotation vanes in centrifugal compressors. Most of the above failure mechanisms are wearouts starting at around 10 to 15 years.

Example Worksheets

As-Found Worksheet – Chiller and Centrifugal Compressor Internal Inspection – Compressor (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Bearings	Excessive wear
	Capacity Control (Pre-Rotation Vanes)	Bound
	Chiller Instrumentation and Control Devices: Capacity, Oil Pressure, Oil Level, Refrigerant High and Low Pressure, Freeze Protection	Damaged tubing
	Compressor, Gaskets	Leakage
	Compressor, Impeller	Eroded
	Compressor, Impeller	Excessive wear
	Compressor, Lubrication Failure	Clogged or crushed lines
	Compressor, Lubrication Failure	Low lubricant level
	Compressor, Lubrication Failure	Weak relief spring
	Compressor, Lubrication Failure	Worn oil pump
	Compressor, Shaft Seal	Leakage
	Coupling	Excessive wear
	Fasteners/ Hardware	Loose or missing
	Gear Box	Excessive wear
	Oil Return System: Eductor, Sump Level Switch, SOV	Failed coil
	Oil Return System: Eductor, Sump Level Switch, SOV	Failed component
	Oil Return System: Eductor, Sump Level Switch, SOV	Failed gasket
	Oil Return System: Eductor, Sump Level Switch, SOV	Plugged
	Oil Return System: Eductor, Sump Level Switch, SOV	Stuck
	Pressure Relief Valve (Safety Valve)	Failed spring
	Pressure Relief Valve (Safety Valve)	Failed to reseat
	Pressure Relief Valve (Safety Valve)	Improper operation
	Pressure Relief Valve (Safety Valve)	Set point drift

As-Found Worksheet – Chiller and Centrifugal Compressor Internal Inspection – Compressor (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Purge Unit	Improper operation
	Purge Unit	Insufficient refrigerant
	Refrigerant Metering Device	Failed float valve
	Refrigerant Metering Device	Stuck float valve
	Refrigerant Operated Control Valve	Improper operation

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #10 Chiller and Centrifugal Compressor (Overhaul)

Task Overview

Task Timing and Objective

The Overhaul task should be performed on an as-needed basis. Overhaul principally addresses failures of gaskets, aging of the oil pump, worn bearings, and worn couplings.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Overhaul of the chiller and compressor should be considered after inspection of the bearings, capacity control (pre-rotation) vanes, gaskets, impeller, lubrication failure, shaft seal, coupling, fasteners/hardware, gearbox, and oil return system (i.e., eductor, sump level switch, SOV).

Task Justification and Degradation Progression

Overhaul is a task performed on an as-required basis. Overhaul principally addresses failures of gaskets, aging of the oil pump, worn bearings, and worn couplings. In addition, it covers damaged rotary screw elements for rotary screw compressors, and worn bearing journals, a failed shaft seal, a cracked or scored shaft, a worn or failed unloader valve, loose mounting bolts, or a cracked frame on the reciprocating compressors.

Example Worksheets

As-Found Worksheet – Chiller and Centrifugal Compressor Overhaul (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Bearings	Excessive wear
	Capacity Control (Pre-Rotation Vanes)	Bound
	Compressor, Gaskets	Leakage
	Compressor, Impeller	Eroded
	Compressor, Impeller	Excessive wear
	Compressor, Lubrication Failure	Clogged or crushed lines
	Compressor, Lubrication Failure	Low lubricant level
	Compressor, Lubrication Failure	Weak relief spring
	Compressor, Lubrication Failure	Worn oil pump
	Compressor, Shaft Seal	Leakage
	Coupling	Excessive wear
	Fasteners/ Hardware	Loose or missing
	Gear Box	Excessive wear
	Oil Return System: Eductor, Sump Level switch, SOV	Failed coil
	Oil Return System: Eductor, Sump Level switch, SOV	Failed component
	Oil Return System: Eductor, Sump Level switch, SOV	Failed gasket
	Oil Return System: Eductor, Sump Level switch, SOV	Plugged
	Oil Return System: Eductor, Sump Level switch, SOV	Stuck

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #11 Chiller and Centrifugal Compressor (Annual Inspection and Test)

Task Overview

Task Timing and Objective

These inspections should be performed annually. The Annual Inspection and Test tasks include Calibration, Internal Inspection – Heat Exchangers, Oil Analysis, Refrigerant Analysis, and System Testing – Functional Tests.

Calibration addresses drift, misadjustment, leaks, loose connections, and component failures of chiller controls. The interval is well determined by a combination of short-term wearout and random failure modes, giving little opportunity to increase the interval.

Internal Inspection – Heat Exchangers addresses fouling of heat exchangers (Evaporator and Condenser), improper water side flow rate, and leaking gaskets. The interval is not determined by the failure mode data and may be too long to have much influence on the targeted failure mechanisms.

Oil Analysis reveals incorrect or degraded oil, and wear particles. The interval protects against a few important, fairly short-term wearout mechanisms, with only modest opportunity for interval extension.

Refrigerant Analysis tests the refrigerant for the presence of moisture, acid, and oil. A significant number of random failure modes, a few of them quite common, suggest a fairly short interval, but it is not strongly constrained.

System Testing – Functional Tests verifies that overall operation is as required, and focuses on purge unit failures. The interval is not strongly supported by the failure mode data but needs to be fairly frequent to address random purge unit failure mechanisms.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Calibration checks should be made of instrumentation and controls associated with chiller instrumentation and control devices (e.g., capacity, oil pressure, oil level, refrigerant high and low pressure, freeze protection), electronic/electrical devices (e.g., transmitters, temperature control valves, programmable logic controls, level/flow switches, RTDs, I/P transducers, heat exchangers (i.e., condenser), the refrigerant operated control valve, and solenoid valves.

The Heat Exchanger Internal Inspection should include:

- Inspect for loose, damaged, or missing parts, fasteners, and components
- Inspect condenser heat exchanger for evidence of fouling, corrosion, tube sheet degradation, and the condition of the sacrificial anode; clean and re-coat the tube sheet as necessary
- If required, eddy current test the heat exchanger looking for tube wall thinning and for tube sheet and baffle damage or wear
- Replace condenser heat exchanger seals and gaskets
- Inspect the float valve for proper operation, and check for evidence of wear, sticking, or a leaking float
- Check the integrity of the pressure rupture disk and for the presence of moisture in the vent line
- Check pressure control tubing for integrity and damage
- Change air and oil filters and dryers
- Ensure that the refrigerant level is correct and there is no evidence of leakage
- Ensure that the cooling water flow rate to the heat exchanger is correct and that the inlet and outlet temperatures and pressures are within specification
- Verify that the pressure relief device is closed with no evidence of leakage
- Verify that the purge unit is seated and not venting
- Verify that all lubrication levels are correct and there is no evidence of leakage
- Verify that the oil pump is operating correctly and providing specified pressures
- Inspect the oil lines for damage
- If applicable, verify that the oil level is correct
- Ensure that the capacity control (pre-rotation) vanes are free and not bound

- Verify that the shaft seal and all gaskets show no evidence of leakage
- Verify that proper operation of the separator oil heater
- Verify the general condition and performance of the unit, e.g., verify that the superheat and sub-cooling are within specifications, and that the refrigerant control valve is within its expected operating range

Oil Analysis should inspect bearings and the gearbox and look for lubrication failure in the compressor.

Refrigerant Analysis should look for evidence of degraded, contaminated, or insufficient refrigerant leading to compressor system failure, gasket failure, impeller wear, failure of the oil return system, inoperability of the purge unit, or improper readings from the refrigerant metering device.

System Testing – Functional Tests should include:

- Verify that the capacity control devices respond as expected
- Verify the flow switch operates correctly
- Verify that key operational parameters are in the normal operating range

Task Justification and Degradation Progression

Calibration

Calibration addresses drift, misadjustment, leaks, loose connections, and component failures of chiller controls such as refrigerant freeze protection and high and low refrigerant pressure, oil level and pressure, and capacity controls. Individual instruments or controls could be pressure switches, relays, electrical or electronic transmitters, temperature control valves, programmable logic controls, level and flow switches, RTDs, I to P transducers, solenoid valves, and pneumatic devices. Many of the above causes of drift in instrumentation and controls are random, and wearouts are on relatively short time scales of 1 or 2 years. There are a considerable number of failure causes and a relatively high proportion of control devices in HVAC systems. It is not surprising that control failures are dominant degradation mechanisms for this equipment.

Internal Inspection – Heat Exchangers

The Heat Exchanger Internal Inspection is focused on fouling of heat exchangers, improper water side flow rate, leaking gaskets, and corrosion and erosion in general. Instances of water side fouling of condenser heat exchangers appear to be randomly occurring degradations that can be dominant failure causes for chiller equipment operating with poor water quality. The time scale on these degradations is uncertain, but they are expected to require attention in just a few years (up to 5 years).

Oil Analysis

Oil Analysis is performed on compressor oil regardless of the type of compressor, and measures degradation of the oil, presence of particulates, moisture content, and acid content. Oil analysis can reveal incorrect or degraded oil and can detect wear particles from worn bearings in most types of compressors. These wearout mechanisms can become dominant degradation mechanisms in one to three years if the oil quality is permitted to deteriorate.

Refrigerant Analysis

Refrigerant Analysis tests the refrigerant for the presence of moisture, acid, and oil. The task contributes to detecting conditions that lead to oil return system failures on centrifugal compressors, whether from a plugged eductor, inadequate system differential pressure, or other component failure. Refrigerant Analysis also addresses gasket failures, excessive or ineffective purging of non-condensable gases, and plugged refrigerant metering devices. All the failure causes for the oil return system contribute to making this a dominant failure mechanism for chiller units with centrifugal compressors, but only the plugged eductor and inadequate system differential pressure have random occurrences that may affect the interval for this task. Leaking gaskets, and the several other causes of failure in the oil return system, are expected on significantly longer timescales than 1 year. The plugged refrigerant metering device, and excessive or ineffective purging, also have random occurrences.

System Testing – Functional Tests

The Functional Test consists of a start and load sequence on large compressors, verifies that capacity control devices respond correctly, verifies that the flow switch operates correctly, and confirms that key parameters are in the normal operating range. It may be conducted as a post-maintenance test to verify operability and readiness to return to service, and as an in-service test on standby equipment, or on swapping over trains.

Example Worksheets

As-Found Worksheet – Chiller and Centrifugal Compressor Calibration (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Chiller Instrumentation and Control Devices: Capacity, Oil Pressure, Oil Level, Refrigerant High and Low Pressure, Freeze Protection	Cannot be calibrated
	Chiller Instrumentation and Control Devices: Capacity, Oil Pressure, Oil Level, Refrigerant High and Low Pressure, Freeze Protection	Out of tolerance
	Electronic/Electrical Devices: Transmitters, Temperature Control Valves, Programmable Logic Controls, Level/Flow Switches, RTDs, I/P Transducers	Cannot be calibrated
	Electronic/Electrical Devices: Transmitters, Temperature Control Valves, Programmable logic controls, Level/Flow switches, RTDs, I/P Transducers	Out of tolerance

As-Found Worksheet – Chiller and Centrifugal Compressor Calibration (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Heat Exchangers: Condenser	Degraded control valve
	Heat Exchangers: Condenser	Failed control valve
	Refrigerant Operated Control Valve	Cannot be calibrated
	Refrigerant Operated Control Valve	Out of tolerance
	Solenoid Valves	Cannot be calibrated
	Solenoid Valves	Out of tolerance

As-Found Worksheet – Chiller and Centrifugal Compressor Internal Inspection – Heat Exchangers (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Fasteners/Hardware	Loose or missing
	Heat Exchangers: Condenser	Degrade control valve
	Heat Exchangers: Condenser	Eroded tube or shell
	Heat Exchangers: Condenser	Failed control valve
	Heat Exchangers: Condenser	Fouled
	Heat Exchangers: Condenser	Plugged suction strainer
	Heat Exchangers: Evaporator	Fouled

As-Found Worksheet – Chiller and Centrifugal Compressor Oil Analysis (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Bearings	Excessive wear
	Compressor, Lubrication Failure	Degraded lubricant
	Compressor, Lubrication Failure	Incorrect lubricant
	Compressor, Lubrication Failure	Low lubricant level
	Gear Box	Excessive wear

As-Found Worksheet – Chiller and Centrifugal Compressor Refrigerant Analysis (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Compressor System Failure	Degraded refrigerant
	Compressor, Gaskets	Degraded refrigerant
	Compressor, Impeller	Degraded refrigerant
	Oil Return System: Eductor, Sump Level Switch, SOV	Degraded refrigerant
	Purge Unit	Degraded refrigerant
	Purge Unit	Insufficient refrigerant
	Refrigerant Metering Device	Contaminated refrigerant
	Refrigerant Metering Device	Degraded refrigerant
	Refrigerant Operated Control Valve	Improper operation

As-Found Worksheet – Chiller and Centrifugal Compressor System Testing – Functional Tests (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Capacity Control (Pre-Rotation Vanes)	Improper operation
	Chiller Instrumentation and Control Devices: Capacity, Oil Pressure, Oil Level, Refrigerant High and Low Pressure, Freeze Protection	Improper operation
	Purge Unit	Excessive purge
	Purge Unit	Improper operation
	Solenoid Valves	Improper operation

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #12 Chiller and Centrifugal Compressor (Glycol Analysis)

Task Overview

Task Timing and Objective

Due to the fact that these systems are typically shut down and laid up during the off-peak season, Glycol Analysis would not need to be performed during this time. Consequently, the task frequency would need to be adjusted accordingly. During peak seasons, the task timing is six months. Glycol Analysis prevents glycol fouling of the condenser heat exchanger by detecting fluid composition changes. The interval is chosen to provide adequate advanced warning of failure; there may be some scope to increase the interval marginally.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Glycol Analysis should be performed to prevent glycol fouling of the condenser heat exchanger. This is done by detecting fluid composition changes in the glycol mixture.

Task Justification and Degradation Progression

This task is only applicable when a glycol cooling fluid is used, and addresses the change in fluid composition that results from fluid leaks. If this goes unchecked, glycol fouling of the condenser heat exchanger is the result. Leakage that is the precursor to this failure mechanism has a random occurrence pattern.

Example Worksheets

As-Found Worksheet – Chiller and Centrifugal Compressor Glycol Analysis (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Heat Exchangers: Condenser	Degraded refrigerant

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #13 Chiller and Centrifugal Compressor (Quarterly Inspection and Test)

Task Overview

Task Timing and Objective

Due to the fact that these systems are typically shut down and laid up during the off-peak season, Quarterly Inspections and Tests would not need to be performed during this time. Consequently, the task frequency would need to be adjusted accordingly. During peak seasons, the task timing is every three months, and consists of External Inspection and System Testing – Performance Tests.

External Inspection mainly addresses the detection of leaks and the verification of operating parameters, including system capacity and control in the form of local area temperatures and pressures. The interval is not strongly determined, but the task addresses a large number of random failure modes.

System Testing – Performance Tests address integrated system performance, especially with respect to controls and instrumentation. There appears to be some opportunity to increase the interval by about a year.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

External Inspection should include:

- Verify the general condition and performance of the unit and that no noticeable vibration is present
- Inspect for loose, missing, or damaged hardware, parts, and components
- Check DP across air filter, if present
- Verify that the superheat and sub-cooling are within specifications
- Verify that the refrigerant control valve is within its expected operating range
- Ensure that the refrigerant level is correct (trend the additions) and there is no evidence of leakage; use leak detector if possible
- Ensure that the cooling water flow rate to the heat exchanger is correct and that the inlet and outlet temperatures and pressures are within specification
- Verify that the pressure relief device is closed with no evidence of leakage
- Verify that the purge unit is seated and not venting
- If present, verify that the refrigerant operated control valve is operating properly
- Inspect all pneumatic devices for evidence of leaks and for loose or damaged air supply tubing
- Verify that all lubrication levels are correct and there is no evidence of leakage
- Inspect all compressor / motor couplings for wear and proper alignment
- Monitor compressor thrust bearing temperatures and check condition of belts and sheaves on larger units
- Verify that the oil pump is operating correctly and proving specified pressures
- Inspect the oil lines for damage
- If applicable, verify that the oil level is correct
- Ensure that the capacity control devices are free and not bound
- Verify that the shaft seal and all gaskets show no evidence of leakage
- Verify proper operation of the separator oil heater
- Additional information on motor inspections can be found under Low Voltage Motors

System Testing – Performance Tests should verify that the cooling capacity is within specification. The testing should measure, track and trend the DT, DP, and flow of the water side of condensers and evaporator heat exchangers:

- Chilled water inlet temperature
- Chilled water outlet temperature
- Chilled water flow
- Cooling water inlet temperature
- Cooling water outlet temperature
- Cooling water flow

The testing should also measure and verify that refrigerant is within normal temperature and pressure ranges, and verify that the chiller power input is within specification (i.e., measure, track, and trend the compressor motor amperage as a function of chiller load).

Task Justification and Degradation Progression

External Inspection

The External Inspection is focused on the detection of leaks of water, oil, air, or refrigerant, on the verification of operating parameters such as system capacity and control in the form of local area temperatures and pressures, and on the detection of problems in the oil return system, coupling, and purge unit. Important parameters are condenser water side pressure and flow rate, temperature control valve position, and refrigerant temperature, which all assist in detecting water side fouling of condenser tubes. External leaks are most likely from failed shaft seals, failed gaskets, pneumatic control device tubing and fittings, and refrigerant actuated control valves. Additional significant items are sticking of the refrigerant actuated control valves, and binding of pre-rotation vanes on centrifugal compressors. Problems with the oil return system, purge unit, and coupling involve both random and fairly short-term wearout mechanisms. Water side fouling of condenser tubes, leaking pneumatic fittings, and leaking gaskets are all considered to be random, so they can occur at any time. Shaft seal leakage appears to have a failure free period of 5 to 10 years. Control malfunctions, often detectable by observation of area temperatures and pressures, are important failure mechanisms that occur randomly and relatively frequently.

System Testing – Performance Tests

These tests address the integrated system performance and are therefore not directly separable from performance testing for air handling equipment, ducting, and dampers. A major focus is the performance of controls and instrumentation. Drift, component failures, and misadjustment of these components form one of the dominant failure causes for HVAC systems. In addition, water side fouling of condenser heat exchangers is also an important failure cause and can be detected by performance testing. Other failure causes such as improper heat exchanger water flow rates caused by other component failures, or a plugged refrigerant metering device or failed refrigerant float valve, are also of potential significance. Condenser heat exchanger fouling, drift of instrumentation and controls, and other control system failures or misadjustment are random

occurrences and wearout effects are seen on a time scale of 1 to 2 years. Their occurrence characteristics suggest they can happen at any time; their relatively short time scales and the large number of possible control malfunctions are responsible for the fact that they are dominant failure mechanisms.

Example Worksheets

As-Found Worksheet – Chiller and Centrifugal Compressor External Inspection (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Capacity Control (Pre-Rotation Vanes)	Improper operation
	Chiller Instrumentation and Control Devices: Capacity, Oil Pressure, Oil Level, Refrigerant High and Low Pressure, Freeze Protection	Improper operation
	Compressor System Failure	Improper operation
	Compressor, Lubrication Failure	Improper lubricant pressure
	Compressor, Lubrication Failure	Low lubricant level
	Compressor, Shaft Seal	Leakage
	Coupling	Unusual noise
	Fasteners/ Hardware	Loose or missing
	Heat Exchangers: Condenser	Improper operation
	Heat Exchangers: Evaporator	Fouled
	Heat Exchangers: Evaporator Improper Operation Oil Return System: Eductor, Sump Level Switch, SOV	Improper operation
	Pressure Relief Valve (Safety Valve)	Failed to reseat
	Pressure Relief Valve (Safety Valve)	Improper operation
	Purge Unit	Excessive purge
	Purge Unit	Improper operation
	Refrigerant Operated Control	Improper operation
	Solenoid Valves	Improper operation

As-Found Worksheet – Chiller and Centrifugal Compressor System Testing – Performance Tests (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Capacity Control (Pre-Rotation Vanes)	Improper operation
	Chiller Instrumentation and Control Devices: Capacity, Oil Pressure, Oil Level, Refrigerant High and Low Pressure, Freeze Protection	Improper operation
	Compressor System Failure	Improper operation
	Compressor, Impeller	Improper operation
	Heat Exchangers: Condenser	Improper operation
	Heat Exchangers: Evaporator	Fouled
	Heat Exchangers: Evaporator	Improper operation
	Purge Unit	Excessive purge
	Purge Unit	Improper operation
	Refrigerant Metering Device	Improper operation
	Refrigerant Operated Control Valve	Improper operation
	Solenoid Valves	Improper operation

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #14 Calibration – Non-Redundant, Critical

Task Overview

Task Timing and Objective

This task is to be performed on an annual basis for the following reasons:

- These instruments protect critical equipment (e.g., condenser).
- Inaccuracy may result in unit trips.
- Prudent industry practice for critical non-redundant instrumentation calibration is every 12 months.
- Calibration is performed at this frequency to prevent the many random degradation mechanisms.

The purpose of this task is:

- To ensure that the critical non-redundant instrumentation is accurate and trustworthy.
- To provide feedback on as-found and as-left calibration history utilizing consistent plant calibration sheets to track and trend system health.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

The following general inspection activities should be considered:

- ISA guidelines should be followed in calibrating these instruments
- Good documentation is needed and should include the following:
  - The make and model of calibrating instrument
  - The calibration date of the calibration instrument
  - The date of the calibration activity
  - The design specification
  - The as-found and as-left measurement
- Only qualified personnel should perform this task

Task content should include the activities listed in the following table:

Instrument	Preventive Maintenance Task	EPRI Time Code
Pressure Sensor and Transmitter	Calibration: • Perform a visual inspection or walkdown, as far as practical, of the instrument's sensing line, looking for evidence of air leaks; damaged, crushed, or broken tubing; loose tubing connections; loose or missing tubing clamps; or corroded tubing and connectors. • Verify and adjust, as needed, the device's zero span. • Verify and adjust, as needed, the device's linearity and hysteresis. • It is strongly suggested that a minimum 5-point calibration response check be performed. A 9-point check should be considered for more critical devices.	18M
Temperature Switch	Calibration: • Perform a visual inspection to check for tightness of the connections, general cleanliness, over-heated components, and cracked terminations and cases. • Verify and adjust, as needed, the device's zero span. • Verify and adjust, as needed, the device's linearity and hysteresis. • It is strongly suggested that a minimum 5-point calibration response check be performed. A 9-point check should be considered for more critical devices.	18M

Instrument	Preventive Maintenance Task	EPRI Time Code
Pressure Switch	Calibration: • Perform a visual inspection or walkdown, as far as practical, of the instrument's sensing line, looking for evidence of air leaks; damaged, crushed, or broken tubing; loose tubing connections; loose or missing tubing clamps; or corroded tubing and connectors. • Verify and adjust, as needed, the device's zero span. • Verify and adjust, as needed, the device's linearity and hysteresis. • It is strongly suggested that a minimum 5-point calibration response check be performed, a 9-point check should be considered for more critical devices.	18M
Pressure Regulator	Set Point Verification should include the following: • Visually inspect for loose, damaged, or missing hardware and parts, or corrosion. • Perform set point verification test at the device's operational set points and compare to historical. • Make adjustments as required.	6Y

Task Justification and Degradation Progression

A vulnerability analysis shows the following impact on reliability under CHM conditions:

Instrument	Calibration PM Reliability Benefit Compared to Baseline
Pressure Sensor and Transmitter	0.45
Temperature Switch	0.80
Pressure Switch	0.84
Pressure Regulator	0.22

It is felt that for critical equipment with no redundancy an annual calibration is prudent, given the number of random degradation mechanisms. Of course, this can be altered based on the experience of an individual site under specific conditions.

Example Worksheets

Calibration Worksheet		
Calibration Point	**As-Found**	**As-Left**

Measurement Worksheet		
Measurement	**As-Found**	**Notes on Remediation**

As-Found Worksheet (check off any unacceptable conditions)			
Unsatisfactory	**Component Type Name**	**Failure Location**	**Reportable Condition**
	Temperature Switch	Sensing device (other types)	Cannot be calibrated
	Temperature Switch	Sensing device (other types)	Out of tolerance
	Temperature Switch	Electrical switch	Cannot be calibrated
	Temperature Switch	Electrical switch	Out of tolerance
	Temperature Switch	Electrical switch	Loose connections
	Temperature Switch	Sensing device (temperature bulb and capillary)	Cannot be calibrated
	Temperature Switch	Sensing device (temperature bulb and capillary)	Out of tolerance
	Temperature Switch	Mechanical linkage	Cannot be calibrated
	Temperature Switch	Mechanical linkage	Out of tolerance
	Pressure Switch	Sensing line and tube fittings	Broken or cracked line, or loose fitting
	Pressure Switch	Sensing line and tube fittings	Fitting and/or tubing leak
	Pressure Switch	Sensing line and tube fittings	Leaking valves
	Pressure Switch	Sensing device	Cannot be calibrated
	Pressure Switch	Sensing device	Out of tolerance
	Pressure Switch	Elastomers, gaskets, and O-rings	Cannot be calibrated
	Pressure Switch	Elastomers, gaskets, and O-rings	Out of tolerance
	Pressure Switch	Electrical switch	Cannot be calibrated
	Pressure Switch	Electrical switch	Out of tolerance
	Pressure Switch	Mechanical linkage	Cannot be calibrated

As-Found Worksheet (check off any unacceptable conditions)			
Unsatisfactory	**Component Type Name**	**Failure Location**	**Reportable Condition**
	Pressure Switch	Mechanical linkage	Out of tolerance
	Pressure Sensor and Transmitter	Transmitter electronics	Cannot be calibrated
	Pressure Sensor and Transmitter	Transmitter electronics	Out of tolerance
	Pressure Sensor and Transmitter	Sensing lines and associated components, e.g., condensate pot, sealed reference legs, bellows, manifold, root valves, and isolation valves	Cracked or broken
	Pressure Sensor and Transmitter	Sensing lines and associated components, e.g., condensate pot, sealed reference legs, bellows, manifold, root valves, and isolation valves	Damaged bellows
	Pressure Sensor and Transmitter	Sensing lines and associated components, e.g., condensate pot, sealed reference legs, bellows, manifold, root valves, and isolation valves	Fitting or tubing leak
	Pressure Sensor and Transmitter	Sensing lines and associated components, e.g., condensate pot, sealed reference legs, bellows, manifold, root valves, and isolation valves	Leaking bellows
	Pressure Sensor and Transmitter	Sensing lines and associated components, e.g., condensate pot, sealed reference legs, bellows, manifold, root valves, and isolation valves	Leaking valves
	Pressure Sensor and Transmitter	Sensor, e.g., capacitance cell, Bourdon tube, piezo electric, strain gauge	Cannot be calibrated
	Pressure Sensor and Transmitter	Sensor, e.g., capacitance cell, Bourdon tube, piezo electric, strain gauge	Out of tolerance
	Pressure Sensor and Transmitter	Internal wiring and connections	Cannot be calibrated
	Pressure Sensor and Transmitter	Internal wiring and connections	Out of tolerance

As-Found Worksheet (check off any unacceptable conditions)			
Unsatisfactory	**Component Type Name**	**Failure Location**	**Reportable Condition**
	Pressure Sensor and Transmitter	Sensor, capacitance cell	Cannot be calibrated
	Pressure Sensor and Transmitter	Sensor, capacitance cell	Out of tolerance
	Pressure Regulator	Regulator	Cannot be calibrated
	Pressure Regulator	Regulator	Out of tolerance
	Pressure Regulator	Elastomer	Failed
	Pressure Regulator	Pneumatic connections	Loose

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #15 Calibration – Redundant, Critical

Task Overview

Task Timing and Objective

This task should be performed approximately every three (3) years and doesn't necessarily have to coincide with outage events associated with other plant equipment, for the following reasons:

- Although these instruments protect critical equipment (e.g., condenser) and inaccuracy may result in unit trips, the presence of on-line redundancy significantly reduces the risk.
- The age-related effects have wearout times from 3 to 5 years and longer.
- While the EPRI baseline specifies a 18-month frequency, redundancy provides reasonable protection until the hot gas path inspection.

Calibration assures that the device is performing within specification, and demonstrates the absolute accuracy of the output.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

The following general inspection activities should be considered:

- ISA guidelines should be followed in calibrating these instruments.
- Good documentation is needed and should include the following:
  - The make and model of calibrating instrument
  - The calibration date of the calibration instrument
  - The date of the calibration activity
  - The design specification
  - The as-found and as-left measurement
- Only qualified personnel should perform this task.

Task content should include the activities listed in the following table:

Instrument	Preventive Maintenance Task	EPRI Time Code
Pressure Sensor and Transmitter	Calibration: • Perform a visual inspection or walkdown, as far as practical, of the instrument's sensing line, looking for evidence of air leaks; damaged, crushed, or broken tubing; loose tubing connections; loose or missing tubing clamps; or corroded tubing and connectors. • Verify and adjust, as needed, the device's zero span. • Verify and adjust, as needed, the device's linearity and hysteresis. • It is strongly suggested that a minimum 5-point calibration response check be performed. A 9-point check should be considered for more critical devices.	18M
Temperature Switch	Calibration: • Perform a visual inspection to check for tightness of the connections, general cleanliness, over-heated components, and cracked terminations and cases. • Verify and adjust, as needed, the device's zero span. • Verify and adjust, as needed, the device's linearity and hysteresis. • It is strongly suggested that a minimum 5-point calibration response check be performed. A 9-point check should be considered for more critical devices.	18M

Instrument	Preventive Maintenance Task	EPRI Time Code
Pressure Switch	Calibration: • Perform a visual inspection or walkdown, as far as practical, of the instrument's sensing line, looking for evidence of air leaks; damaged, crushed, or broken tubing; loose tubing connections; loose or missing tubing clamps; or corroded tubing and connectors. • Verify and adjust, as needed, the device's zero span. • Verify and adjust, as needed, the device's linearity and hysteresis. • It is strongly suggested that a minimum 5-point calibration response check be performed. A 9-point check should be considered for more critical devices.	18M
Pressure Regulator	Set Point Verification should include the following: • Visually inspect for loose, damaged, or missing hardware and parts, or corrosion. • Perform set point verification test at the device's operational set points and compare to historical. • Make adjustments as required.	6Y

Task Justification and Degradation Progression

A vulnerability analysis shows the following impact on reliability under CHM conditions:

Instrument	Calibration PM Reliability Benefit Compared to Baseline
Pressure Sensor and Transmitter	0.45
Temperature Switch	0.80
Pressure Switch	0.84
Pressure Regulator	0.22

Pressure Sensor and Transmitter – The age-related effects have wearout times from 3 to 5 years and longer. Many other random degradation mechanisms, potentially detected by this task, are not addressed very effectively because Calibration is not performed frequently enough.

Temperature Switch – Calibration at 18M to 3Y will provide good protection from the age-related failure mechanisms, but is not very effective against other, random, mechanisms. Note that here, and in the listing of degradation mechanisms, remaining failure free means remaining within specifications.

Pressure Switch – These failure mechanisms are all wearout situations with an expected failure free period of at least 3 years (drift and leaks) or much longer.

Pressure Regulator – These are wearout failure mechanisms with an expected failure free period of 5 years or more, although a particularly high level of vibration could lead to earlier failure.

Example Worksheets

Calibration Worksheet		
Calibration Point	**As-Found**	**As-Left**

Measurement Worksheet		
Measurement	**As-Found**	**Notes on Remediation**

As-Found Worksheet (check off any unacceptable conditions)			
Unsatisfactory	**Component Type Name**	**Failure Location**	**Reportable Condition**
	Temperature Switch	Sensing device (other types)	Cannot be calibrated
	Temperature Switch	Sensing device (other types)	Out of tolerance
	Temperature Switch	Electrical switch	Cannot be calibrated
	Temperature Switch	Electrical switch	Out of tolerance
	Temperature Switch	Electrical switch	Loose connections
	Temperature Switch	Sensing device (temperature bulb and capillary)	Cannot be calibrated
	Temperature Switch	Sensing device (temperature bulb and capillary)	Out of tolerance
	Temperature Switch	Mechanical linkage	Cannot be calibrated
	Temperature Switch	Mechanical linkage	Out of tolerance
	Pressure Switch	Sensing line and tube fittings	Broken or cracked line, or loose fitting
	Pressure Switch	Sensing line and tube fittings	Fitting and/or tubing leak
	Pressure Switch	Sensing line and tube fittings	Leaking valves

As-Found Worksheet (check off any unacceptable conditions)			
Unsatisfactory	**Component Type Name**	**Failure Location**	**Reportable Condition**
	Pressure Switch	Sensing device	Cannot be calibrated
	Pressure Switch	Sensing device	Out of tolerance
	Pressure Switch	Elastomers, gaskets, and O-rings	Cannot be calibrated
	Pressure Switch	Elastomers, gaskets, and O-rings	Out of tolerance
	Pressure Switch	Electrical switch	Cannot be calibrated
	Pressure Switch	Electrical switch	Out of tolerance
	Pressure Switch	Mechanical linkage	Cannot be calibrated
	Pressure Switch	Mechanical linkage	Out of tolerance
	Pressure Sensor and Transmitter	Transmitter electronics	Cannot be calibrated
	Pressure Sensor and Transmitter	Transmitter electronics	Out of tolerance
	Pressure Sensor and Transmitter	Sensing lines and associated components, e.g., condensate pot, sealed reference legs, bellows, manifold, root valves, and isolation valves	Cracked or broken
	Pressure Sensor and Transmitter	Sensing lines and associated components, e.g., condensate pot, sealed reference legs, bellows, manifold, root valves, and isolation valves	Damaged bellows
	Pressure Sensor and Transmitter	Sensing lines and associated components, e.g., condensate pot, sealed reference legs, bellows, manifold, root valves, and isolation valves	Fitting or tubing leak
	Pressure Sensor and Transmitter	Sensing lines and associated components, e.g., condensate pot, sealed reference legs, bellows, manifold, root valves, and isolation valves	Leaking bellows
	Pressure Sensor and Transmitter	Sensing lines and associated components, e.g., condensate pot, sealed reference legs, bellows, manifold, root valves, and isolation valves	Leaking valves

As-Found Worksheet (check off any unacceptable conditions)			
Unsatisfactory	**Component Type Name**	**Failure Location**	**Reportable Condition**
	Pressure Sensor And Transmitter	Sensor, e.g., capacitance cell, Bourdon tube, piezo electric, strain gauge	Cannot be calibrated
	Pressure Sensor And Transmitter	Sensor, e.g., capacitance cell, Bourdon tube, piezo electric, strain gauge	Out of tolerance
	Pressure Sensor and Transmitter	Internal wiring and connections	Cannot be calibrated
	Pressure Sensor and Transmitter	Internal wiring and connections	Out of tolerance
	Pressure Sensor and Transmitter	Sensor, capacitance cell	Cannot be calibrated
	Pressure Sensor and Transmitter	Sensor, capacitance cell	Out of tolerance
	Pressure Regulator	Regulator	Cannot be calibrated
	Pressure Regulator	Regulator	Out of tolerance
	Pressure Regulator	Elastomer	Failed
	Pressure Regulator	Pneumatic connections	Loose

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #16 Calibration – Non-Critical

Task Overview

Task Timing and Objective

This task is to be performed on an as-required basis. Calibration should ensure that the non-critical instrumentation is accurate and trustworthy to minimize impact on unit performance. The task also provides feedback on as-found and as-left calibration history utilizing consistent plant calibration sheets to track and trend system health.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

The following general inspection activities should be considered:

- ISA guidelines should be followed in calibrating these instruments.
- Good documentation is needed and should include the following:
  - The make and model of calibrating instrument
  - The calibration date of the calibration instrument
  - The date of the calibration activity
  - The design specification
  - The as-found and as-left measurement
- Only qualified personnel should perform this task.

Task content should include the following activities:

Instrument	Preventive Maintenance Task	EPRI Time Code
Pressure Sensor and Transmitter	Calibration: • Perform a visual inspection or walkdown, as far as practical, of the instrument's sensing line, looking for evidence of air leaks; damaged, crushed, or broken tubing; loose tubing connections; loose or missing tubing clamps; or corroded tubing and connectors. • Verify and adjust, as needed, the device's zero span. • Verify and adjust, as needed, the device's linearity and hysteresis. • It is strongly suggested that a minimum 5-point calibration response check be performed. A 9-point check should be considered for more critical devices.	
Temperature Switch	Calibration: • Perform a visual inspection to check for tightness of the connections, general cleanliness, over-heated components, and cracked terminations and cases. • Check operational set-point vs. design set point by insertion into a bath or oven.	
Pressure Switch	Calibration: • Perform a visual inspection or walkdown, as far as practical, of the instrument's sensing line, looking for evidence of air leaks; damaged, crushed, or broken tubing; loose tubing connections; loose or missing tubing clamps; or corroded tubing and connectors. • Check operational set-point vs. design set point using a pressure test device.	
Limit Switches	• Visually inspect for loose, damaged, or missing hardware or parts, corrosion, wear, elastomer failure, contact misalignment, and improper adjustment. • Repair and replace any findings. • Perform a valve stroke test to determine the appropriate set points for the limit switches.	

Task Justification and Degradation Progression

A vulnerability analysis shows the following impact on reliability under NHM (Non-critical, High Cycle, Mild Stress) conditions:

Instrument	Calibration PM Reliability Benefit Compared to Baseline
Pressure Sensor and Transmitter	0.36
Temperature Switch	0.01
Pressure Switch	0.45
Pressure Regulator	1.00

Under NHM (Non-critical, High Cycle, Mild Stress) conditions, calibration is recommended on a 6Y or AR basis for each of these instruments.

Pressure Sensor and Transmitter – The age-related effects have wearout times from 3 to 5 years and longer. Many other random degradation mechanisms, potentially detected by this task, are not addressed very effectively because Calibration is not performed frequently enough.

Temperature Switch – These failure mechanisms are all wearout situations with an expected failure free period of at least 5 years (drift) or much longer.

Pressure Switch – These failure mechanisms are all wearout situations with an expected failure free period of at least 3 years (drift and leaks) or much longer.

Pressure Regulator – These are both wearout failure mechanisms with an expected failure free period of 5 years or more, although a particularly high level of vibration could lead to earlier failure.

Example Worksheets

Calibration Worksheet		
Calibration Point	**As-Found**	**As-Left**

Measurement Worksheet		
Measurement	**As-Found**	**Notes on Remediation**

As-Found Worksheet (check off any unacceptable conditions)			
Unsatisfactory	**Component Type Name**	**Failure Location**	**Reportable Condition**
	Temperature Switch	Sensing device (other types)	Cannot be calibrated
	Temperature Switch	Sensing device (other types)	Out of tolerance
	Temperature Switch	Electrical switch	Cannot be calibrated

As-Found Worksheet (check off any unacceptable conditions)			
Unsatisfactory	**Component Type Name**	**Failure Location**	**Reportable Condition**
	Temperature Switch	Electrical switch	Out of tolerance
	Temperature Switch	Electrical switch	Loose connections
	Temperature Switch	Sensing device (temperature bulb and capillary)	Cannot be calibrated
	Temperature Switch	Sensing device (temperature bulb and capillary)	Out of tolerance
	Temperature Switch	Mechanical linkage	Cannot be calibrated
	Temperature Switch	Mechanical linkage	Out of tolerance
	Pressure Switch	Sensing line and tube fittings	Broken or cracked line, or loose fitting
	Pressure Switch	Sensing line and tube fittings	Fitting and/or tubing leak
	Pressure Switch	Sensing line and tube fittings	Leaking valves
	Pressure Switch	Sensing device	Cannot be calibrated
	Pressure Switch	Sensing device	Out of tolerance
	Pressure Switch	Elastomers, gaskets, and O-rings	Cannot be calibrated
	Pressure Switch	Elastomers, gaskets, and O-rings	Out of tolerance
	Pressure Switch	Electrical switch	Cannot be calibrated
	Pressure Switch	Electrical switch	Out of tolerance
	Pressure Switch	Mechanical linkage	Cannot be calibrated
	Pressure Switch	Mechanical linkage	Out of tolerance
	Pressure Sensor and Transmitter	Transmitter electronics	Cannot be calibrated
	Pressure Sensor and Transmitter	Transmitter electronics	Out of tolerance
	Pressure Sensor and Transmitter	Sensing lines and associated components, e.g., condensate pot, sealed reference legs, bellows, manifold, root valves, and isolation valves	Cracked or broken

As-Found Worksheet (check off any unacceptable conditions)			
Unsatisfactory	**Component Type Name**	**Failure Location**	**Reportable Condition**
	Pressure Sensor and Transmitter	Sensing lines and associated components, e.g., condensate pot, sealed reference legs, bellows, manifold, root valves, and isolation valves	Damaged bellows
	Pressure Sensor and Transmitter	Sensing lines and associated components, e.g., condensate pot, sealed reference legs, bellows, manifold, root valves, and isolation valves	Fitting or tubing leak
	Pressure Sensor and Transmitter	Sensing lines and associated components, e.g., condensate pot, sealed reference legs, bellows, manifold, root valves, and isolation valves	Leaking bellows
	Pressure Sensor and Transmitter	Sensing lines and associated components, e.g., condensate pot, sealed reference legs, bellows, manifold, root valves, and isolation valves	Leaking valves
	Pressure Sensor and Transmitter	Sensor, e.g., capacitance cell, Bourdon tube, piezo electric, strain gauge	Cannot be calibrated
	Pressure Sensor and Transmitter	Sensor, e.g., capacitance cell, Bourdon tube, piezo electric, strain gauge	Out of tolerance
	Pressure Sensor and Transmitter	Internal wiring and connections	Cannot be calibrated
	Pressure Sensor and Transmitter	Internal wiring and connections	Out of tolerance
	Pressure Sensor and Transmitter	Sensor, capacitance cell	Cannot be calibrated
	Pressure Sensor and Transmitter	Sensor, capacitance cell	Out of tolerance
	Pressure Regulator	Regulator	Cannot be calibrated
	Pressure Regulator	Regulator	Out of tolerance
	Pressure Regulator	Elastomer	Failed
	Pressure Regulator	Pneumatic connections	Loose

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #17 Motor – Medium Voltage <15Kv (Air Filter Replacement)

Task Overview

This job plan has been developed to apply to the following types of medium voltage motors:

- Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed
- Motor – Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed

Task Timing and Objective

Motor – Medium Voltage <15Kv Air Filter Replacement should be performed on an as-required basis. The condition of the filter should be assessed during operator rounds when the filter can be inspected visually or by reading a pressure differential. If the filter cannot be assessed or inspected visually, then replacement on a quarterly basis under CHS conditions is recommended. The purpose of this task is to prevent the buildup of dirt and debris in the motor's air passages. For CHM conditions the task, by itself, mainly addresses issues with the motor filters. In a full PM program for CHM conditions, the failure rate is not sensitive to the task interval.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Motor – Medium Voltage <15Kv Air Filter Replacement should include the following:

- Ensure that the air filter housing is not damaged or showing evidence of corrosion or rust
- Remove the old air filters and inspect air passages, as much as practical, for debris and dirt buildup
- Replace the air filters with an approved replacement filter

Task Justification and Degradation Progression

The task mainly addresses issues with the clogging of the filter media which, if left unchecked, will lead to high motor winding temperatures, and depending upon the type of lubrication system, potential oil ingress into the electrical windings. As the filter clogs, the differential pressure across the filter will increase, decreasing the amount of cooling air flowing to the motor, and the motor will try to draw air in from other sources such as the bearing seals and may pull oil/grease in with the air, which may lead to contamination of the electrical windings. Dirt and grease deposition on the windings will lead to electrical faults and increase in motor temperatures. Routine changes of the air filters will ensure an adequate supply of clean air to the motor windings.

Example Worksheets

Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed Motor – Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed Air Filter Replacement (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Bearing Seals (All Types)	Task is not likely to discover the condition
	Bearing Seals (Contact Type)	Task is not likely to discover the condition
	Filters - Air Coolers	Clogged or dirty
	Frame, Enclosure, and Mounting	Clogged air screens
	Internal Cooling Coil - Bearing Cooling Water	Task is not likely to discover the condition

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #18 Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed (Oil Analysis)

Task Overview

Task Timing and Objective

Due to the fact that these systems are typically shut down and laid up during the off-peak season, Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed Oil Analysis would not need to be performed during this time. Consequently, the task frequency would need to be adjusted accordingly. During peak seasons, the task timing is every 6 months, and it has the objective of ensuring equipment reliability and operability by maintaining high quality lubrication and detecting the wear of rotating components. For CHM conditions the task, by itself, mainly addresses the discovery of bearing and seal wear for all types of bearings, and bearing cooling water leaks. In a full program for CHM conditions, the failure rate is not sensitive to the task interval.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed (Oil Analysis should include:

- Analyze the oil for wear particles, contaminants, and water, and for lubricity qualities
- Check for signs of oil leakage

Information on additional tests and their expected limits are available in ASTM, EPRI, and OEM documents and related references.

- Take samples as specified by the analysis being performed.
- Draw the sample of oil from both the reservoir and after the filter, if possible. Note that if the sample lowers the oil level, oil must be added to compensate for the sample taken. Do not over-fill the bearing reservoir.
- Each sample should be tested for the following minimal characteristics: water; metal, such as Babbitt; and physical properties, such as lubricity, including additive packages.
- Refer to the motor OEM's documents and the oil supplier's documents for limits and additional tests.
- All results should be trended.

The following is a partial list of tests that may be performed:

- Wear Particle Analysis
- Wear Metals and Organo-Metallic Additives
- Rotating Pressure Vessel Oxidation Test ASTM D2272
- Remaining Useful Life Evaluation Routine ASTM D6971
- Determination of the Sludging and Corrosion Tendencies ASTM D4310
- Antioxidant Levels by Fourier Transform Infrared Analysis
- Foaming Characteristics ASTM D892
- Air Release Characteristics (Gas Bubble Separation) ASTM D3427
- Emulsion Characteristics ASTM D1401

Task Justification and Degradation Progression

Oil Analysis can detect when the oil is getting into a degraded condition from either normal use, wear of other components, in-leakage of water from leaks in lube oil cooling heat exchangers or internal bearing coolers, or worn labyrinth seals.

These are all wearout mechanisms that typically can cause failures after 5 to 10 years of service, but they can also be caused by several random processes at much shorter times.

Example Worksheets

Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed Oil Analysis (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Bearings - Sleeve	Excessive wear
	Internal Cooling Coil - Bearing Cooling Water	Contaminated oil
	Internal Cooling Coil - Bearing Cooling Water	Packing or gasket failures
	Lubrication - Oil	Degraded or loss of lubricating qualities
	Lubrication - Oil	Task is not likely to discover the condition
	Oil Slinger Rings	Task is not likely to discover the condition
	Shaft	Task is not likely to discover the condition

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #19 Motor – Medium Voltage <15Kv (Refurbishment)

Task Overview

This job plan has been developed to apply to the following types of medium voltage motors:

- Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed
- Motor – Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed

Task Timing and Objective

Motor – Medium Voltage <15Kv Refurbishment should be performed on an as-required basis. The task has the objective of the restoring the equipment to an as-new condition, either through replacement or complete reconditioning. For CHM conditions the task, by itself, addresses all degradations. In a full program for CHM conditions, the failure rate is moderately sensitive to the task interval.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Motor – Medium Voltage <15Kv Refurbishment should include:

- Inspect for any damaged, loose, or missing parts
- Clean and inspect the rotor winding and core for damaged or loose windings, end turns, ties, wedging, and rotor iron; missing end turns, ties, and wedging; and detached, loose, or damaged shorting ring; also test winding and insulation resistance
- Retreat rotor to restore proper insulation and mechanical rigidity
- Check the shaft for bowing and run-out
- Verify insulation and electrical connections of rotor slip rings, if present
- Resurface slip rings to proper micron finish
- Inspect and test oil and air coolers
- Inspect shaft bearing journals for wear, pitting, and damage; resurface, as required, to restore journals to proper micron finish
- Balance the rotor
- Clean and inspect the stator winding and core for contamination; damaged or loose windings, end turns, blocking, wedging, ties, and stator iron; detached or loose surge ring; and evidence of corona discharge damage; also test winding and insulation resistance
- Verify proper operation of winding RTDs
- Clean air passages
- Tighten end windings and retreat stator to restore proper insulation and mechanical rigidity
- Inspect and test all supply cables, motor heaters, and alarms
- Inspect and refurbish the anti-rotation device, as required
- Replacement or reconditioning (Babbitt bearings only) of the bearings, bearing seals, gaskets, O-rings, and bearing insulation. After replacement, the bearing insulation should be tested to assure it provides the required degree of isolation from electrical currents that could damage the bearing.
- Ultrasonically test the bearing Babbitt for proper bond and the presence of voids (Babbitt bearings only)
- Inspect and test for leaks in the oil cooling system
- If present, inspect and test for leaks in the stator cooling system
- Verify the operation, alarm action, general condition, and calibration of local bearing temperature indicators
- Check for damaged, loose, or missing parts

- Removal of motor end covers and inspection plates and covers to allow access to motor bearings and windings without floating the rotor (i.e., rotor positioning and alignment are not to be affected by this inspection)
- Check for any damaged, loose, or missing parts
- Inspect bearings for abnormal wear, loss of Babbitt, pitting, and indications of lubrication problems such as discoloration and scorching
- Inspect the internal bearing insulation for integrity, damage, flash over, tracking, and proper insulation levels as recommended by the OEM
- Inspect and test the bearing RTDs for damage and proper temperature indication
- Perform a bearing journal and thrust runner inspection looking for indications of abnormal wear, proper RMS surface finish, proper alignment and positioning, and damage (Babbitt bearings only)
- Inspect bearing seals for wear, alignment, and damage
- Inspect the oil cooler, reservoir, and oil piping for leaking, mechanical integrity, fouling, cleanliness, pitting, corrosion, erosion, and damage
- Remove and inspect the upper end turn air baffles for damage, electrical tracking, and cleanliness. With the air baffles removed, inspect winding end turns for dusting, looseness, electrical tracking, mechanical integrity of the ties and blocking, and any damage to the windings.
- Inspect for indication of loose coil wedges
- Inspect internal coating for integrity and damage
- Inspect internal motor leads for degradation of or damage to the lead wire insulation
- Motor rotor fans should be inspected for damaged, cracked, or missing blades, or loose hardware
- Inspect the pawls and ratchet plates of any anti-rotation devices for damage and abnormal wear. If possible, perform an uncoupled break-away test on vertical motors employing an anti-rotation device.
- Remove covers and inspect all junction and termination boxes and contents for damage, grounded wiring indications of electrical arcing or tracking, and the condition and tightness of connections and insulation systems
- If present at the motor, inspect current transformers and/or surge capacitors for leakage, damage, and the proper tightness of the connections
- Inspect for damaged, loose, missing, or vibrating parts; externally visible oil leaks around bearings and bearing seals; external water leaks around water bearing and stator cooling interfaces; broken or loose grounding cables; damaged conduits and seal flex; damaged wiring and insulators; damaged junction boxes and their gaskets; and blocked / clogged / plugged air filters and inlet air screens
- Install new air filters

- Inspect bearing slinger rings for proper operation and movement (Babbitt bearings only)
- Verify proper oil level; oil should not be discolored
- Inspect for plugged oil sight glass vent
- Verify proper motor strip heater status indication
- Listen for unusual noises

Task Justification and Degradation Progression

The Refurbishment task provides protection from a large number of degradation mechanisms that can cause failures over a period of many years.

Although a significant number of these mechanisms are thought to initiate randomly or to progress erratically, the expert group thought that the combination of condition monitoring tasks described above would lead to full refurbishment being an on-condition task that does not require a regular schedule. Exposure to heat, age, vibration and contamination should be a significant consideration when estimating if and when to refurbish.

The condition of bearings is adequately addressed by vibration and acoustic monitoring and is likely the main trigger for a refurbishment. Frame and mounting degradations are also covered by vibration monitoring and by visual inspection. All the rotor degradations are also covered by vibration monitoring. The full condition of stator laminations and windings might only be revealed during refurbishment, although good indication of most of their degradation mechanisms can be obtained by motor analysis. Degradation of the winding and lamination insulation is not expected to occur for many years, perhaps for 40 years.

Refurbishment addresses essentially all the failure mechanisms, some of which are not effectively addressed by other tasks. However, all of these are random occurrences for which Refurbishment at an interval of 10 years or more will not provide effective protection either. Nevertheless, some utilities may decide on an individual basis that a refurbishment is indeed necessary for very critical motors at 10 to 15 years. This refurbishment can be a condition-based task if predictive maintenance tasks are used effectively.

Example Worksheets

Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed Motor – Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed Refurbishment (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Baffles	Loose Hardware
	Bearing and Winding Temperature and Vibration Probes	Broken, loose or grounded connections
	Bearing and Winding Temperature and Vibration Probes	Out of calibration
	Bearing Insulation (External)	Broken, cracked, or detached
	Bearing Insulation (External)	Degraded insulation

Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed Motor – Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed Refurbishment (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Bearing Insulation (Internal)	Broken, cracked, or detached
	Bearing Insulation (Internal)	Degraded insulation
	Bearing Metering Orifice	Blocked
	Bearing Seals (All Types)	Excessive wear
	Bearing Seals (All Types)	Leakage
	Bearing Seals (Contact Type)	Deformed
	Bearing Seals (Contact Type)	Excessive wear
	Bearing Seals (Non-Contact Type)	Excessive wear
	Bearings - Rolling Element	Excessive wear
	Breather Caps and Sight Glass Vents	Blocked
	Filters - Air Coolers	Clogged or dirty
	Frame, Enclosure, and Mounting	Clogged air screens
	Frame, Enclosure, and Mounting	Cracked or broken internal welds
	Frame, Enclosure, and Mounting	Deformed
	Frame, Enclosure, and Mounting	Loose or damaged
	Frame, Enclosure, and Mounting Soft Foot Gaskets - General	End of useful life
	Internal Cooling Coil - Bearing Cooling Water	Corroded
	Internal Cooling Coil - Bearing Cooling Water	Damaged fins
	Internal Cooling Coil - Bearing Cooling Water	Eroded
	Internal Cooling Coil - Bearing Cooling Water	Fouled
	Internal Cooling Coil - Bearing Cooling Water	Leakage
	Internal Cooling Coil - Bearing Cooling Water	Packing or gasket failures
	Internal Cooling Coil - Bearing Cooling Water	Separated coil
	Lubrication - Grease	Degraded

Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed Motor – Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed Refurbishment (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Lubrication - Grease	Insufficient or excessive amount
	Lubrication - Oil	Degraded
	Lubrication - Oil	Insufficient or excessive level
	Machine Fits	Damaged or misaligned
	Motor Lead Electrical Connections - Crimped Lugs	Degraded insulation
	Motor Lead Electrical Connections - Crimped Lugs	High resistance
	Motor Lead Electrical Connections - Crimped Lugs	Loose
	Motor Leads	Abraded, worn, or damaged
	Motor Leads	Degraded insulation
	Piping and Connections	Leakage
	Rotor Bars and Shorting Rings	Corroded
	Rotor Bars and Shorting Rings	Cracked, brazed joint failure
	Rotor Bars and Shorting Rings	Deformed
	Rotor Bars and Shorting Rings	Loose
	Rotor Bars and Shorting Rings	Material defect - cracked or porous
	Rotor Cage - Lamination Support, i.e., Spider	Loose cage on spider
	Rotor Cage - Solid Lamination Design (Non-Spider Design)	Loose cage on shaft
	Rotor Fans and Hardware	Cracked welds
	Rotor Fans and Hardware	Loose hardware
	Rotor Fans with Interference Fit Design	Loose on shaft
	Rotor Laminations	Damaged or defective
	Rotor Laminations	Dirty
	Rotor Laminations	Insulation breakdown
	Rotor Laminations	Insulation fretting
	Rotor Laminations	Loose parts
	Rotor Laminations	Stress fatigue cracks

Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed Motor – Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed Refurbishment (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Rotor Retaining Rings (Predominantly on 2-Pole Motors)	Loose
	Rotor Spider - Integral Design Where Spider Arms are Welded to Shaft	Loose (cracked weld)
	Rotor Spider - Spider to Shaft Interference Fit Design	Loose (broken weld from spider arms to shaft interference sleeve)
	Rotor Spider - Spider to Shaft Interference Fit Design	Loose (spider is loose on shaft)
	Shaft	Bowed
	Shaft	Excessive journal wear
	Shaft	Excessive wear in coupling fit area
	Shaft	Sagged
	Shaft	Shaft cracking
	Space Heater Wiring	Degraded insulation
	Space Heaters	Broken, loose, or grounded connections
	Space Heaters	Open element
	Stator Laminations	Damaged
	Stator Laminations	Improper fit of back iron (OD of laminations)
	Stator Laminations	Insulation breakdown
	Stator Laminations	Insulation fretting
	Stator Laminations	Loose parts
	Stator Windings - Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Broken surge ring
	Stator Windings - Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Failure of surge ring support brackets
	Stator Windings - Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Fretting of insulation materials
	Stator Windings - Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Insulation degradation
	Stator Windings - Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Loose blocking, bracing, or tying

Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed Motor – Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed Refurbishment (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Stator Windings - Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Loose wedges
	Surge Capacitors	Bushing damage
	Surge Capacitors	Bushing tracking
	Surge Capacitors	Insulation degradation
	Surge Capacitors	Leakage
	Winding Electrical Connections - Brazed	High resistance

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #20 Motor – Medium Voltage <15Kv (Tests – Off Line)

Task Overview

This job plan has been developed to apply to the following types of medium voltage motors:

- Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed
- Motor – Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed

Task Timing and Objective

The Motor – Medium Voltage <15Kv Off-Line electrical and mechanical motor tests should be conducted approximately every three (3) operating seasons, and do not necessarily have to coincide with outage events on other plant equipment.

Electrical Tests – Off-Line has the objective of discovering electrical degradation of the machine's insulation system and electrical connections that cannot be detected while the machine is running or on-line. For CHM conditions the task, by itself, mainly addresses the discovery of degraded insulation, degraded electrical connections, and high resistance shorts and grounds in electrical components. In a full program for CHM conditions, the failure rate is not sensitive to the task interval.

Mechanical Tests – Off-Line for medium voltage motors has the objective of discovering the degradation of mechanical components that may require a minimal level of intrusive inspection and can only be detected while the machine is off-line. For CHM conditions the task, by itself, discovers evidence of bearing seal leakage and wear, blocked or dirty air filters and screens, frame damage, performance and structural issues of the internal bearing oil cooler (if present), and damage to rotor fans and hardware. In a full program for CHM conditions, the failure rate is not sensitive to the task interval.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Motor – Medium Voltage <15Kv Off-Line Electrical Tests can only be conducted meaningfully when all parts of the motor are within 10° F of ambient temperature. The tests should include some or all of the following; these tests should be trended and compared to historical data to derive their maximum benefit:

- Winding resistance
- Insulation resistance
- Polarization indexing
- Motor circuit evaluation
- AC high pot.
- DC step voltage
- Surge testing
- Power factor tip-up testing

Motor – Medium Voltage <15Kv Off-Line Mechanical Tests might include:

- Perform borescope inspection of all accessible motor internals, air passages, and air gap
- Verify proper alignment
- Inspect motor mountings for indications of soft foot
- Hand rotate to determine presence of any shaft run-out, binding, or rubbing noise
- Inspect for damaged, loose, missing or vibrating parts; externally visible oil leaks around bearings and bearing seals; external water leaks around water bearing and stator cooling interfaces; broken or loose grounding cables; damaged conduits and seal flex; damaged wiring and insulators; damaged junction boxes and their gaskets; and blocked / clogged / plugged air filters and inlet air screens.
- Inspect bearing slinger rings for proper operation and movement
- Verify proper oil level; oil should not be discolored
- Inspect for plugged oil sight glass vent
- Listen for unusual noises

Task Justification and Degradation Progression

Electrical Off-Line motor testing uses high-voltage static motor test equipment that is designed to detect weaknesses and faults in motor insulation. It can detect weaknesses or faults in motor winding and ground wall insulation: insulation resistance (IR), polarization index (PI), dielectric absorption (DA), DC step voltage, and surge tests to evaluate all the insulation in motors and coils. The motor circuit can be analyzed with resistance, impedance, capacitance, phase angle, and dissipation factor/quality factor measurements.

Mechanical Off-Line motor testing uses mechanical inspection techniques to detect potential mechanical failures of the motor. It will inspect internal components for mechanical damage.

The degradation mechanisms addressed by this task include a large number of random and wearout conditions covering a wide span of development time scales. This task will enable the detection and trending of the degradation mechanisms over time.

Example Worksheets

Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed Motor – Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed Tests – Off Line – Electrical (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Bearing Insulation (External)	Degraded insulation
	Lubrication - Oil	Insufficient or excessive level
	Motor Lead Electrical Connections - Crimped Lugs	Degraded insulation
	Motor Lead Electrical Connections - Crimped Lugs	Loose
	Motor Leads	Abraded
	Motor Leads	Degraded insulation
	Space Heater Wiring	Degraded insulation
	Space Heaters	Broken, loose, or grounded connections
	Space Heaters	Open element
	Stator Windings - Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Degraded insulation
	Surge Capacitors	Bushing damage
	Surge Capacitors	Bushing tracking
	Surge Capacitors	Degraded insulation
	Surge Capacitors	Task is not likely to discover the condition
	Winding Electrical Connections - Brazed	High resistance

Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed Motor – Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed Tests – Off Line – Mechanical (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Bearing Insulation (External)	Broken, cracked, or detached
	Bearing Seals (All Types)	Excessive wear
	Bearing Seals (All Types)	Leakage
	Bearing Seals (Contact Type)	Deformed
	Bearing Seals (Contact Type)	Excessive wear
	Bearing Seals (Non-Contact Type)	Excessive wear
	Breather Caps and Sight Glass Vents	Blocked
	Filters - Air Coolers	Clogged or dirty
	Frame, Enclosure, and Mounting	Clogged air screens
	Frame, Enclosure, and Mounting	Deformed
	Frame, Enclosure, and Mounting	Loose or damaged
	Frame, Enclosure, and Mounting	Soft foot
	Gaskets - General	End of useful life
	Internal Cooling Coil - Bearing Cooling Water	Coil separation
	Internal Cooling Coil - Bearing Cooling Water	Corroded
	Internal Cooling Coil - Bearing Cooling Water	Fouled
	Internal Cooling Coil - Bearing Cooling Water	Leakage
	Internal Cooling Coil - Bearing Cooling Water	Packing or gasket failures
	Lubrication - Oil	Insufficient or excessive level
	Machine Fits	Damaged or misaligned
	Piping and Connections	Leakage
	Rotor Bars and Shorting Rings	Task is not likely to discover the condition
	Rotor Fans and Hardware	Task is not likely to discover the condition
	Rotor Fans with Interference Fit Design	Task is not likely to discover the condition
	Rotor Laminations	Dirty
	Rotor Laminations	Task is not likely to discover the condition

Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed Motor – Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed Tests – Off Line – Mechanical (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Shaft	Bowed
	Shaft	Sagged
	Shaft	Task is not likely to discover the condition
	Space Heater Wiring	Task is not likely to discover the condition
	Space Heaters	Broken, loose, or grounded connections
	Stator Laminations	Task is not likely to discover the condition
	Stator Windings - Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Broken surge ring
	Stator Windings - Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Failure of surge ring support brackets
	Stator Windings - Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Fretting of insulation materials
	Stator Windings - Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Loose blocking, bracing, or tying
	Stator Windings - Includes Blocking, Bracing, Tying, Surge Rings, Wedges	Loose wedges
	Surge Capacitors	Bushing damage
	Surge Capacitors	Bushing tracking
	Surge Capacitors	Leakage

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #21 Motor – Medium Voltage <15Kv (Tests – On Line)

Task Overview

This job plan has been developed to apply to the following types of medium voltage motors:

- Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed
- Motor – Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed

Task Timing and Objective

The Motor – Medium Voltage <15Kv On-Line electrical and mechanical motor tests should be conducted every two years.

Electrical Tests – On-Line has the objective of discovering electrical degradation of the machine's insulation system that may be detected while the machine is on-line. For CHM conditions the task, by itself, mainly addresses degradation of rotor components, and degraded wound rotor winding connections. In a full program for CHM conditions, the failure rate is not sensitive to the task interval.

Mechanical Tests – On-Line for medium voltage motors has the objective of discovering degraded mechanical components that can be detected while the machine is running or on-line. For CHM conditions the task, by itself, addresses practically all sources of bearing degradation for all types of bearings and many other failures in the oil distribution and bearing systems (such as problems with the oil slinger rings and blocked orifices, as well as leaking internal bearing cooling coils, if present), and discovers blocked or dirty air passages and filters and failed space heaters in standby motors. In a full program for CHM conditions, the failure rate is not sensitive to the task interval.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Motor – Medium Voltage <15Kv On-Line Electrical Tests could include some or all of the following; these tests should be trended and compared to historical data to derive their maximum benefit:

- Motor current and power signature analysis
- Applied voltage and running current testing
- Partial discharge

Motor – Medium Voltage <15Kv On-Line Mechanical Tests might include:

- Verification of name plate motor speed
- Acoustic monitoring
- Bearing temperature monitoring (continuous in most cases) and trending
- Winding temperature monitoring and trending
- Monitor cooling water pressure, temperature, and flow
- Inspect for damaged, loose, missing or vibrating parts; externally visible oil leaks around bearings and bearing seals; external water leaks around water bearing and stator cooling interfaces; broken or loose grounding cables; damaged conduits and seal flex; damaged wiring and insulators; damaged junction boxes and their gaskets; and blocked / clogged / plugged air filters and inlet air screens
- Inspect bearing slinger rings for proper operation and movement
- Verify proper oil level; oil should not be discolored
- Inspect for plugged oil sight glass vent
- Verify proper motor strip heater status indication
- Listen for unusual noises
- Could also include percent load, duty cycle, and number of starts where appropriate and measurable
- It would also be useful to include other periodic monitoring data such as vibration and thermography results into the trends.

Task Justification and Degradation Progression

Electrical On-Line testing uses advanced software algorithms to monitor and assess conditions across a motor/machine system that impact the health and performance of the motor within the system. It evaluates the quality of power fed to a motor, assesses motor performance indicators, and tracks the amount and condition of load placed on the motor.

Mechanical On-Line testing uses acoustic noise detection and audible noise detection to identify the presence degradation mechanisms such as looseness, rubbing, and temperature measurement to detect overheating.

The degradation mechanisms addressed by this task include a large number of random and wearout conditions covering a wide span of development time scales. This task will enable the detection and trending of the degradation mechanisms over time.

Example Worksheets

Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed Motor – Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed Tests – On Line – Electrical (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Motor Lead Electrical Connections - Crimped Lugs	High resistance
	Motor Lead Electrical Connections - Crimped Lugs	Loose
	Rotor Bars and Shorting Rings	Cracked brazed joint
	Rotor Bars and Shorting Rings	Loose
	Rotor Bars and Shorting Rings	Material defect (cracked or porous)
	Rotor Cage - Lamination Support, i.e., Spider	Task is not likely to discover the condition
	Rotor Cage - Solid Lamination Design (Non-Spider Design)	Task is not likely to discover the condition
	Shaft	Task is not likely to discover the condition
	Stator Laminations	Task is not likely to discover the condition
	Winding Electrical Connections - Brazed	High resistance

Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed Motor – Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed Tests – On Line – Mechanical (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Bearing and Winding Temperature and Vibration Probes	Broken, loose or grounded connections
	Bearing Metering Orifice	Blocked
	Bearings - Sleeve	Excessive wear
	Filters - Air Coolers	Clogged or dirty
	Frame, Enclosure, and Mounting	Clogged air screens
	Gaskets - General	End of useful life
	Internal Cooling Coil - Bearing Cooling Water	Coil separation
	Internal Cooling Coil - Bearing Cooling Water	Fouled
	Internal Cooling Coil - Bearing Cooling Water	Leakage
	Internal Cooling Coil - Bearing Cooling Water	Packing or gasket failures
	Internal Cooling Coil - Bearing Cooling Water	Task is not likely to discover the condition
	Lubrication - Oil	Insufficient or excessive level
	Oil Slinger Rings	Excessive wear
	Oil Slinger Rings	Out of round
	Oil Slinger Rings - Two Piece Design	Separated
	Piping and Connections	External leakage
	Space Heaters	Broken, loose or grounded connections
	Space Heaters	Open element

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #22 Motor – Medium Voltage <15Kv (Thermography)

Task Overview

This job plan has been developed to apply to the following types of medium voltage motors:

- Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed
- Motor – Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed

Task Timing and Objective

For motors, the Thermography task should be yearly. Thermography has the objective of detecting abnormal thermal conditions that may be indicative of component degradation and that exhibit themselves as localized heating (i.e., hot spots) or differential temperatures between similar subcomponents or locations (e.g., wiring connections). For CHM conditions the task, by itself, mainly addresses the discovery of bearing wear, poor electrical contact or connections, and clogged air passages or filters. In a full program for CHM conditions, the failure rate is not sensitive to the task interval.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Thermography for Motor – Medium Voltage <15Kv should include:

- Inspection for unusual and unbalanced heating of the connections at the main motor and motor heater leads and their respective power cable interfaces
- Unusual differences in exit air temperatures when compared to historical values
- Inspection for unusual heating in motor bearing and windings that cannot be attributed to normal thermal patterns and temperatures

Task Justification and Degradation Progression

The main application of thermography is to provide indication of the condition of power cable connections, and to complement other indications of bearing wear from causes related to lubrication failure. Since the bearing temperature is directly measured by in situ RTDs or thermocouples, thermography plays a backup role. Thermography can usually only give an indication of increased temperatures in the general surface region of the bearing casing, where this is accessible. Other indications of bearing wear are oil and vibration analysis, and motor current monitoring. Occasionally, thermography may also be useful in detecting blocked air passages. The lubrication-related causes of bearing wear appear randomly over a period of many months to 2 years. Blocked air passages and high resistance electrical connections have a similar time scale.

Example Worksheets

Motor – Medium Voltage <15Kv – Horizontal – Filters – Sleeve Bearing – Oil Lubed Motor – Medium Voltage <15Kv – Vertical – Solid Shaft – Rolling Element – Oil/Grease Lubed Thermography (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Bearings - Sleeve	Task is not likely to discover the condition
	Filters - Air Coolers	Task is not likely to discover the condition
	Frame, Enclosure, and Mounting	Task is not likely to discover the condition
	Lubrication - Oil	Task is not likely to discover the condition
	Motor Lead Electrical Connections - Crimped Lugs	Hot spot
	Shaft	Hot spot
	Shaft	Task is not likely to discover the condition

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #23 Pump – Horizontal – Single Stage – Single Suction (Refurbishment)

Task Overview

Task Timing and Objective

Pump – Horizontal – Single Stage – Single Suction Refurbishment should be performed on an as-required basis. The objective of refurbishment is to restore the pump to as near to as-new condition as possible.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Pump – Horizontal – Single Stage – Single Suction Refurbishment should include the following:

- Prior to removal and disassembly, check and record pump thrust, compare to historical
- Perform radial clearance checks of bearings and impeller wear rings, if closed impeller
- Document as-found / as-left dimensions on machine fits, clearances, and motor and pump lift
- Inspect and document condition of welds, piping, and hardware such as bolts and fasteners
- In general replace all components beyond OEM tolerances and specifications; document the wear and condition
- Inspect for damage, wear, and deterioration of all gaskets, O-rings, and elastomers
- Replace all gaskets, O-rings, and elastomers

- Replace anti-friction bearings; inspect and document wear and condition
- Inspect sleeve and thrust bearings; replace as necessary; document as-found and as-left conditions
- Inspect and note the general condition of the journal and cleanliness of the bearing housing
- Inspect the condition of bearing RTDs and thermocouples
- Inspect the condition of any permanently mounted vibration probes or devices
- Inspect casing for thinning, cracking, and corrosion / erosion
- Inspect shaft for damage, defects, run-out, and radial position
- Inspect impellers and wear rings for wear and damage; balance and size if required
- Inspect interior of pump, nozzle, and fits for wear, erosion, damage, and proper clearances
- Clean and inspect stuffing box and gland for damage, corrosion, and wear
- Replace packing, if present
- Replace / rebuild seals, if present
- Inspect the shaft and shaft sleeve for defects or damage
- Look for loose, missing, or damaged bolts, studs, nuts, and parts
- Verify shaft run-out
- Clean and check for fit and flatness of mating surfaces and joints
- Refer to PM actions for the appropriate coupling component type
- For seals:
  - Perform diagnostics on old seal, such as determine amount of seal face wear for wear rate evaluation, condition of elastomers, presence of any debris, condition of the spring, and the extent of the setscrew indentations into the shaft sleeve
  - Check seal injection piping condition and verify flow
  - Inspect seal flange to horizontal split case joint for proper engagement
  - Replace with new seal
- For packing:
  - Inspect and note condition of removed packing and packing sleeve
  - Verify configuration of packing and lantern rings
  - Replace with new packing using correct configuration, material, and number of rings
  - Replace sleeve if damaged
  - Torque to proper value

- For sleeve bearings:
  - Inspect the condition of and verify against OEM specifications all fits and tolerances
  - Inspect integrity of the bearing housing and clean
  - Inspect the bearing journal for damage or wear
  - Inspect the bearing housing cleanliness and integrity
  - Record as-found / as-left dimensions on all machine fits
  - Verify the proper orientation of old and new bearings, and the bearing to housing fit
  - Inspect the condition and integrity of the bearing Babbitt
  - Inspect all oil passages and slinger and flinger rings
  - Inspect oil seal(s) and verify for proper orientation
  - Verify the presence of housing to casing dowel pins, their fit, and final radial alignment
- For anti-friction bearings:
  - Before starting disassembly, verify proper oil level
  - Verify proper bearing preload where applicable
  - Verify bearing part numbers, both as-found and as-left
  - Perform as-found inspection of bearing condition, looking for indications of abnormal wear, damage, or fatigue. Also inspect new bearing for damage and freedom of movement prior to installation.
  - Ensure that proper bearing orientation and installation procedures are followed
  - Inspect shaft and bearing housing condition and dimensions at the bearing interface; obtain proper dimensions from OEM technical manual
  - Inspect oil passages for clogging and slinger and flinger rings for damage
  - Inspect oil seal and assure proper orientation
  - Verify housing to casing dowel pins, and final radial alignment
- For Kingsbury type bearings:
  - Verify as-found and as-left orientation
  - Record as-found and as-left end play, and that it is within specifications
  - Inspect shoe surface condition and Babbitt integrity
  - Inspect shoe button for damage and wear
  - Verify anti-rotation pin integrity
  - Verify thrust disk to shaft fit
  - Verify proper thrust nut integrity, locking method, and torque

  - Verify thrust disk flatness, perpendicularity, and run-out
  - Verify housing condition, cleanliness, and integrity
  - Verify housing to casing dowel pins, fits, and final radial alignment
- Other:
  - Check DP across the lube oil filter; clean the filter or replace if necessary. Note condition of the filter and associated components
  - Inspect the general cleanliness and condition of all components
  - Inspection for loose, missing, or damaged bolts and parts
  - Inspection for abnormal noises and vibration, oil leaks, piping and flange leaks, damaged or missing insulation, abnormal pipe movement and damaged or misadjusted pipe hangers, and the general condition of expansion bellows
  - Inspect foundation for damage, missing or loose bolts/nuts, and damaged grout
  - Verify the presence of electrical ground straps
  - Verify the presence and condition of the coupling guard
  - Verify the proper operation and oil level of the oiler, if present
  - Verify that the bearing temperatures are within normal operational limits and slinger rings are moving freely
  - Ensure that breather tube and sight glass vents are clear
  - Verify that the equipment is tagged and properly identified
- For packing:
  - Verify proper leak-off rate
  - Verify that the gland bolts are not loose or damaged
- For seals:
  - Note and report any seal leakage
  - Verify that the gland bolts are not loose or damaged
  - Proper seal injection flow
- After reinstallation and prior to coupling, check and record uncoupled pump lift and motor thrust; compare to historical
- Verify proper motor rotation before coupling

Task Justification and Degradation Progression

Refurbishment addresses most parts of the pump and most of the degraded conditions that could be encountered. The most influential items are the longer term wearout mechanisms such as the effects of erosion and damage to the casing penetrations, discharge nozzle, and suction and discharge flanges.

Example Worksheets

Pump – Horizontal – Single Stage – Single Suction Refurbishment (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Automatic Oilers	Improper oil flow
	Bearing Oil Slinger Ring	Excessive wear
	Bearing Seals - Labyrinth and/or Lip	Excessive wear
	Bearing Temperature RTDs, if present	Open RTD circuit
	Bearings - Antifriction (Radial and Thrust)	Excessive wear
	Breather Caps and Sight Glass Vents	Clogged
	Connections and Piping	Leakage
	Discharge and Suction Flanges	Deformed
	Discharge and Suction Flanges	Excessive erosion
	Gaskets and O-Rings	Leakage
	Impeller	Damaged
	Impeller	Excessive wear
	Impeller	Improperly sized
	Impeller	Loose
	Internal Bearing Cooler, if present	External leakage
	Internal Bearing Cooler, if present	Fouled
	Internal Bearing Cooler, if present	Fouled or plugged
	Internal Bearing Cooler, if present	Internal leakage
	Lube Oil	Degraded
	Lube Oil	Housing leaks
	Pump Base Plate and Foundation	Failed anchor, grout, or base plate
	Pump Casing	Corroded or eroded or damaged internals
	Pump Casing	Excessive discharge nozzle erosion
	Pump Casing	Leakage
	Seal - Mechanical	Leakage

Pump – Horizontal – Single Stage – Single Suction Refurbishment (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Seal - Packing	Excessive leakage
	Shaft	Bent
	Shaft	Cracked or damaged
	Stuffing Box	Leakage
	Wear Ring, if closed impeller	Excessive wear or galling

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #24 Evaporative Cooler Feed Pump – Vertical – Close Coupled (Packing or Seal Replacement)

Task Overview

Task Timing and Objective

Packing or Seal Replacement of the Evaporative Cooler Feed Pump – Vertical – Close Coupled should be performed on an as-required basis. This task is focused on replacement of the packing and mechanical seals.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Evaporative Cooler Feed Pump – Vertical – Close Coupled Packing/Seal Replacement is done in place and should include the following:

- Inspect the shaft and shaft sleeve for defects or damage
- Look for loose, missing, or damaged bolts, studs, nuts, and parts
- Verify shaft run-out
- Clean and inspect stuffing box for wear, damage, and presence of corrosion

For seals:

- Check seal injection piping condition and verify flow
- Replace with new correct seal



Key Technical Point

Perform diagnostics on an old seal, so as to determine the amount of seal face wear for wear rate evaluation, condition of elastomers, presence of any debris, condition of the spring, and extent of the setscrew indentations into the shaft sleeve.

For packing:

- Inspect and note condition of removed packing and packing sleeve
- Replace sleeve if worn
- Verify configuration of packing and lantern rings
- Replace with new packing using correct configuration, material, and number of rings
- Tighten to plant procedure
- Verify correct seal leak rate

Task Justification and Degradation Progression

This task is focused on the replacement of mechanical seals and packing and is an on-condition task. The seals and packing wear out in 6 to 10 years, at the earliest, under normal circumstances.

Example Worksheets

Evaporative Cooler Feed Pump – Vertical – Close Coupled Packing or Seal Replacement (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Mechanical Seal	Leakage
	Packing	Excessive leakage

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #25 Evaporative Cooler Feed Pump – Vertical – Close Coupled (Refurbishment)

Task Overview

Task Timing and Objective

Refurbishment of the Evaporative Cooler Feed Pump – Vertical – Close Coupled should be performed on an as-required basis. The objective is to restore the pump to as near to as-new condition as possible.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Evaporative Cooler Feed Pump – Vertical – Close Coupled Refurbishment should include the following:

- Prior to removal and disassembly, check and record uncoupled pump lift and motor thrust; compare to historical
- Document as-found / as-left dimensions on machine fits, clearances, and motor and pumps lifts
- Inspect and document conditions including the presence of corrosion or erosion of welds, column piping, protective coatings, the suction strainer, and hardware such as bolts, fasteners, and gaskets
- In general replace all components beyond OEM tolerances and specifications; document wear and condition

- Inspect for damage, wear, and deterioration of all gaskets, O-rings, and elastomers
- Replace all gaskets, O-rings, and elastomers
- Replace anti-friction bearings; inspect and document wear and condition
- Inspect pump casing and cover assemblies for thinning, cracking, erosion, and erosion / corrosion
- Inspect shaft for damage, defects, and run-out
- Inspect impeller and wear rings for wear, damage, and galling; balance if required
- Inspect stuffing box / gland for damage, corrosion, and wear
- Replace / rebuild seals, if present (see below)
- Replace all packing, if present (see below)
- Clean and check for fit and flatness of all mating surfaces and joints
- Verify fit and tolerances of the motor support stand
- Inspect discharge head and motor support stand for corrosion, cracked welds, and deformation
- Inspect for the general cleanliness and condition of all components
- Inspect for loose, missing, or damaged bolts and parts
- Inspect for abnormal noises and vibration, oil leaks, piping and flange leaks, damaged or missing insulation, abnormal pipe movement and damaged or misadjusted pipe hangers, and the general condition of expansion bellows
- Inspect pump mounting plate for damage, missing or loose bolts / nuts, and damaged grout
- Verify the presence of electrical ground straps
- Verify the presence and condition of the coupling guard
- Verify the proper operation and oil level of the oiler, if present
- Verify that the equipment is tagged and properly identified
- Refer to PM actions for the appropriate coupling component type
- After reinstallation and prior to coupling, check and record uncoupled pump lift and motor thrust; compare to historical data
- Verify proper motor rotation before coupling
- Perform PMT of coupled motor and pump

For seals:

- Note and report any seal leakage
- Check seal injection piping condition and verify flow
- Inspect the shaft and shaft sleeve for defects or damage

- Verify shaft run-out
- Look for loose, missing, or damaged bolts, studs, nuts, and parts
- Replace with new correct seal
- Verify that the gland bolts are not loose or damaged
- Verify proper seal injection flow



Key Technical Point

Perform diagnostics on an old seal, so as to determine the amount of seal face wear for wear rate evaluation, condition of elastomers, presence of any debris, condition of the spring, and extent of the setscrew indentations into the shaft sleeve.

For packing:

- Inspect and note condition of removed packing and packing sleeve
- Verify configuration of packing and lantern rings
- Clean and inspect stuffing box for wear, damage, and presence of corrosion
- Replace with new packing using correct configuration, material, and number of rings
- Verify that the gland bolts are not loose or damaged
- Torque to proper value
- Check for leaks
- Verify proper leak-off rate

Task Justification and Degradation Progression

Refurbishment addresses most parts of the pump and most of the degraded conditions that could be encountered. The most influential items are the longer term wearout mechanisms such as the effects of corrosion/erosion on the pump casing and cover, worn antifriction bearings, a cracked shaft, and failed grout at the pump base.

Example Worksheets

Evaporative Cooler Feed Pump – Vertical – Close Coupled Refurbishment (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Bearings - Antifriction	Excessive wear
	Casing and Cover	Corroded or eroded
	Casing and Cover	Damaged
	Casing and Cover	Deformed
	Casing and Cover	Eroded
	Gaskets, O-Rings	Leakage
	Impeller	Damaged
	Impeller	Excessive wear
	Impeller	Loose or failed impeller key or locking collar
	Mechanical Seal	Leakage
	Motor Support Stand	Corroded motor mount
	Motor Support Stand	Cracked welds
	Motor Support Stand	Deformed
	Motor Support Stand	Loose fasteners
	Packing	Excessive leakage
	Pump Base and Mounting	Failed anchor or base plate
	Pump Base and Mounting	Failed grout
	Pump Base and Mounting	Loose bolting
	Shaft	Bent
	Shaft	Cracked
	Shaft	Loss of shaft diameter
	Wear Rings	Excessive wear
	Wear Rings	Excessive wear or galling

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #26 AOV – Diaphragm (Calibration of Actuator)

Task Overview

Task Timing and Objective

This task should be performed approximately every six (6) years, but does not necessarily have to coincide with outage events tied to other plant equipment. The focus of this task is on the design specifications of the actuator to provide assurance that the valve is capable of performing its design function. The interval is suggested but not strongly determined by the failure mode data, except for the scotch yoke type of coupling where wearout may be expected in about 5 years.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Calibration of the actuator should include:

- Spring preload (uncoupled) / bench set
- Check for air leakage from pneumatic components
- Stroke length
- Inspection of coupling and proper torquing, as required
- Verify correct position of the handwheel, if applicable

The visual inspection should include:

- Structural integrity
- Subcomponent damage
- Loose, broken, missing fasteners, especially in high vibration areas
- Damaged or loose electrical connections
- Observe obvious process fluid leaks
- Actuator shaft condition
- Condition of the valve stem and coupling

It is recommended that an informal external inspection be performed every time when cognizant persons are physically at the valve. Such informal inspections should not replace the scheduled inspection.

Task Justification and Degradation Progression

Calibration of the actuator verifies that the overall valve is functioning within design tolerances. Focus on the design specifications of the actuator provides assurance that the valve is capable of performing its design function. A large number of random failure mechanisms is addressed, including many that occur commonly, some of which are expected to occur sometime in a 5-year time frame. The scotch yoke type of coupling is also susceptible to wear from several influences with an expected time to failure of about 5 years.

Example Worksheets

Measurement Worksheet				
Measurement	**Specification**	**As-Found**	**As-Left**	**Notes**

AOV – Diaphragm – Calibration of Actuator (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Accumulators, if present	Cannot be calibrated
	Accumulators, if present	Out of tolerance
	Actuator	Cannot be calibrated
	Actuator	Degraded diaphragm
	Actuator	Failed handwheel

AOV – Diaphragm – Calibration of Actuator (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Actuator	Mispositioned handwheel
	Actuator	Out of tolerance
	Coupling: Direct	Cannot be calibrated
	Coupling: Direct	Out of tolerance
	Coupling: Fixed Moment Arm	Cannot be calibrated
	Coupling: Fixed Moment Arm	Out of tolerance
	Coupling: Rack and Pinion	Cannot be calibrated
	Coupling: Rack and Pinion	Out of tolerance
	Coupling: Scotch Yoke	Cannot be calibrated
	Coupling: Scotch Yoke	Out of tolerance

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #27 AOV – Diaphragm (Calibration, Inspection, and Test)

Task Overview

Task Timing and Objective

These tasks should be performed approximately every three (3) years, but do not necessarily have to coincide with outage events tied to other plant equipment. Calibration, Inspection, and Test consists of the Calibration of Accessories, a Functional Valve Stroke Test, and a Stroke Time Test.

The intent of Calibration of Accessories is to ensure that each accessory is functioning correctly within design tolerances (e.g., start and stop points, travel, timing).

A Functional Valve Stroke Test is done to verify that the valve operates as a complete unit, and has not already failed.

A Stroke Time Test is performed to verify that the valve operates as a complete unit, including the solenoid valve.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Calibration of Accessories should include:

- Set limit switches
- Pressure regulator set point (see I&C - Pressure Regulator)
- I-P / E-P transducer (see I&C - I to P and E to P Transducer)

- Positioner (see I&C - Positioner)
- Booster tuning (see I&C - Booster)
- Pressure switches (see I&C - Pressure Switch)
- Position transmitter (see I&C - Positioner)
- Speed control valves
- Air leakage check, e.g., a delta P test

The visual inspection should include:

- Structural integrity
- Subcomponent damage
- Loose, broken, or missing fasteners, especially in high vibration areas
- Damaged or loose electrical connections
- Observe obvious process fluid leaks
- Actuator shaft condition
- Condition of the valve stem and coupling

It is recommended that an informal external inspection be performed every time when cognizant persons are physically at the valve. Such informal inspections should not replace the scheduled inspection.

Functional Valve Stroke Test

Stroke the valve to verify that the valve operates as a complete unit, in accordance with the manufacturer's component-specific operating requirements.

Stroke Time Test may include:

- Timed stroke
- Limit switch actuations
- SOV actuations

Task Justification and Degradation Progression

Calibration of Accessories

Although this task addresses calibration of accessories, the details of the calibrations are to be found in the relevant sections under the corresponding I&C component. The accessories that can be accessed in this way are booster, E/P and I/P transducers, pneumatic switches, positioners (including position transmitters), and pressure regulators. The task also includes calibration of limit switches and speed control valves, as well as other inspection items.

Calibration measures the dynamic response of individual accessories (e.g., E/P, positioner, and booster) to a control input. The intent is to ensure that each accessory is functioning correctly within design tolerances (e.g., start and stop points, travel, timing). Calibration thus focuses on design specifications of the accessories. It provides assurance that the process is being controlled properly, at least as far as the inputs to the actuator and valve are concerned.

Calibrations are useful in providing information on accessory condition. Persistent, significant calibration drifts can be used to identify the need for accessory replacement. No other information might be available for this purpose, as it is not cost-effective to internally examine the condition of accessories.

Valve or operator internal degradation can occasionally be inferred from calibration data, but not with any precision as to location or quantification of the degradation mechanism. It is more likely that persistent accessory drift might suggest the potential for internal damage to the valve and would be factored into the decision process to investigate further. For example, calibration drifts that suggest a valve has been improperly seating over an extended period could raise the question of erosion of the seat. Timely correction of calibration drifts is therefore important in preventing degradation of internals.

Trended accessory calibration data should be used as justification to adjust PM frequencies. This could consist of as-found and as-left data on I/P (E/P) and positioner. Other factors such as duty cycle may influence the interval decision.

Wear may commonly cause drift of positioners and E-P/I-P transducers within 3 years, and random failures of positioners, position transmitters, limit switches, and E-P/I-P transducers on timescales of a few years. There are also many other common random and wearout failure mechanisms on somewhat longer timescales. This means that relatively short term degradation should be expected.

Functional Valve Stroke Test

A Functional Valve Stroke Test is done to verify that the valve operates as a complete unit. A simple stroke test can be done as a failure-finding task to ensure that a valve has not already failed. However, it provides practically no assurance that the valve is not about to fail.

Failure finding tasks such as stroke tests may be applied to any critical valve that may fail undetected. This task addresses a large number of common failure mechanisms, mainly random but including some wearout mechanisms longer than 5 years in couplings and position transmitters.

Stroke Time Test

A Stroke Time Test is performed to verify that the valve operates as a complete unit, including the solenoid valve. A timed stroke test, combined with visual external inspection, provides some additional assurance that the valve system is operating within overall tolerance, especially if the data is trended over time. A time response outside tolerance requires further investigation to ascertain whether the problem is in the valve or the actuator.

This task addresses a large number of common and random failure mechanisms, mainly in the actuator, but also in accessories.

Example Worksheets

Measurement Worksheet				
Measurement	**Specification**	**As-Found**	**As-Left**	**Notes**

AOV – Diaphragm – Calibration of Accessories (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Accumulators, if present	Cannot be calibrated
	Accumulators, if present	Out of tolerance
	Check Valves - Air Line	Cannot be calibrated
	Check Valves - Air Line	Out of tolerance
	External Air Filter	Clogged
	External Air Filter	Leaking
	Limit Switches	Cannot be calibrated
	Limit Switches	Out of tolerance
	Pneumatic Tubing	Cannot be calibrated
	Pneumatic Tubing	Out of tolerance
	Seat (Moving Part)	Excessive wear or erosion
	Speed Control Valves	Cannot be calibrated
	Speed Control Valves	Out of tolerance
	Valve Body Seat	Cannot be calibrated
	Valve Body Seat	Out of tolerance

AOV – Diaphragm – Functional Valve Stroke Test (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Coupling: Direct	Improper operation
	Coupling: Fixed Moment Arm	Improper operation
	Coupling: Scotch Yoke	Improper operation
	Limit Switches	Improper operation
	Packing	Improper operation

AOV – Diaphragm – Stroke Time Test (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Actuator	Failed hand wheel
	Actuator	Improper operation
	Actuator	Mispositioned hand wheel
	External Air Filter	Clogged
	External Air Filter	Leaking
	Packing	Improper operation
	Speed Control Valves	Improper operation
	Valve Stem	Improper operation

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #28 AOV – Diaphragm (Diagnostic Testing)

Task Overview

Task Timing and Objective

This task should be performed on an as-required basis. The main intent of diagnostic testing is to check the operability of all the accessories, the actuator, and the valve as a single integrated unit.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Diagnostic Testing could include:

- Total friction
- Seat load
- Travel
- Available actuator thrust / torque
- Accessory signatures
- Air pressures
- Spring rate
- Spring preload

Task Justification and Degradation Progression

Diagnostic testing checks the operability of all the accessories, the actuator, and the valve as a single integrated unit. As a minimum it provides a verification of the calibration data and the calibration process. This verification includes being within overall tolerances for the complete valve as a system.

For example, if valve timing or travel data indicate a problem, the diagnostic testing can usually indicate if the source is inappropriate friction, possibly from a packing problem or from internal damage, or if it is a result of worn springs.

Travel and seat load information on the seating area can raise the likelihood of internal leakage, which can often be confirmed by acoustic or thermographic techniques. There are limits to these capabilities. For example, although leakage may be confirmed, the extent of the leakage can only be assessed by an inspection of the seat, i.e., an overhaul. The techniques may not always be applicable. For example, a cold water valve in a noisy environment may not be assessable by thermography or acoustics. A control valve that needs to shut off in an emergency may not be able to be tested for leakage in realistic shut-off conditions.

Nevertheless, diagnostic testing can be used to decide if the source of a problem is the operator or the valve, and whether the problem can be corrected without tearing down the whole valve.

Diagnostic test results allow trending of useful valve parameters. These parameters may include travel, total friction, air pressures, spring rate, seat load, etc., and may be used to adjust PM intervals.

Because the diagnostic test data can be trended it is possible to use the data, with some qualification, to defer overhauls and replacements when the condition of the equipment appears to be good and stable over time, or to decide if an overhaul is appropriate. However, there is one major exception to this claim. Diagnostic testing does not provide information on the condition of the diaphragm if there is no leakage. The condition of other soft goods can be inferred from diagnostic information because they typically deteriorate gradually and give signs of progressive leakage. For example, O-ring piston seals degrade this way. Similarly, soft goods in accessories typically show degradation over time through increasing calibration drift.

Diagnostic Testing addresses a very large number of common, random failure mechanisms as well as many common wearout phenomena. Although the majority of these mechanisms are also adequately addressed by the calibration of the actuator and its accessories, these two tasks do not address the wear of bushings and cylinders in the actuator, or the wear of valve guides and valve body bearings. Provided that the actuator overhauls are performed as recommended, the need for diagnostic testing is reduced to an as-required basis.

Example Worksheets

Measurement Worksheet				
Measurement	**Specification**	**As-Found**	**As-Left**	**Notes**

AOV – Diaphragm – Diagnostic Testing (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Actuator	Degraded diaphragm
	Actuator	Failed handwheel
	Actuator	Improper operation
	Actuator	Mispositioned handwheel
	Coupling: Direct	Improper operation
	Coupling: Fixed Moment Arm	Improper operation
	Coupling: Rack and Pinion	Improper operation
	Coupling: Scotch Yoke	Improper operation
	External Air Filter	Clogged
	External Air Filter	Leaking
	Packing	Excessive friction
	Packing	Excessive leakage
	Pneumatic Tubing	Improper operation
	Seat (Moving Part)	Improper operation
	Valve Body Bearing/Bushing, if present	Improper operation
	Valve Body Seat	Improper operation
	Valve Guides	Improper operation
	Valve Stem	Improper operation

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #29 AOV – Diaphragm (Packing Inspection/Adjustment)

Task Overview

Task Timing and Objective

This task should be performed every two years. Packing Inspection/Adjustment is intended to detect unacceptable leakage from the packing area, and to adjust gland nut torque according to site procedures. The interval is not well determined from the failure mode data.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Inspect packing for signs of degradation, embrittlement, cracking, damage, or physical deformation that could lead to leakage of the process fluid. Adjust the pressure on the packing as necessary to prevent leakage of the valve.

Task Justification and Degradation Progression

Inspect for unacceptable leakage from the packing area and adjust gland nut torque according to site procedures. Degradation of the packing occurs randomly from several commonly encountered causes.

Example Worksheets

Measurement Worksheet				
Measurement	**Specification**	**As-Found**	**As-Left**	**Notes**

AOV – Diaphragm – Packing Inspection/Adjustment (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Packing	Excessive leakage
	Packing	Gouged stem
	Packing	Improper gland torque

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #30 AOV – Piston (Calibration of Actuator)

Task Overview

Task Timing and Objective

This task should be performed approximately every six (6) years, but does not necessarily have to coincide with outage events associated with other plant equipment. The focus of this task is on the design specifications of the actuator to provide assurance that the valve is capable of performing its design function. The interval is suggested but not strongly determined by the failure mode data, except for the scotch yoke type of coupling where wearout may be expected in about 5 years.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Calibration of the actuator should include:

- Spring preload (uncoupled) / bench set
- Check for air leakage from pneumatic components
- Stroke length
- Inspection of coupling and proper torquing, as required
- Verify correct position of the handwheel, if applicable

The visual inspection should include:

- Structural integrity
- Subcomponent damage
- Loose, broken, missing fasteners, especially in high vibration areas
- Damaged or loose electrical connections
- Observe obvious process fluid leaks
- Actuator shaft condition
- Condition of the valve stem and coupling

It is recommended that an informal external inspection should be performed every time when cognizant persons are physically at the valve. Such informal inspections should not replace the scheduled inspection.

Task Justification and Degradation Progression

Calibration of the actuator verifies that the overall valve is functioning within design tolerances. Focus on the design specifications of the actuator provides assurance that the valve is capable of performing its design function. A large number of random failure mechanisms is addressed, including many that occur commonly, some of which are expected to occur sometime in a 5-year time frame. The scotch yoke type of coupling is also susceptible to wear from several influences with an expected time to failure of about 5 years.

Example Worksheets

Measurement Worksheet				
Measurement	**Specification**	**As-Found**	**As-Left**	**Notes**

AOV – Piston – Calibration of Actuator (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Actuator	Cannot be calibrated
	Actuator	Failed hand wheel
	Actuator	Mispositioned hand wheel
	Actuator	Out of tolerance
	Coupling: Direct	Cannot be calibrated

AOV – Piston – Calibration of Actuator (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Coupling: Direct	Out of tolerance
	Coupling: Fixed Moment Arm	Cannot be calibrated
	Coupling: Fixed Moment Arm	Out of tolerance
	Coupling: Rack and Pinion	Cannot be calibrated
	Coupling: Rack and Pinion	Out of tolerance
	Coupling: Scotch Yoke	Cannot be calibrated
	Coupling: Scotch Yoke	Out of tolerance

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #31 AOV – Piston (Calibration, Inspection, and Test)

Task Overview

Task Timing and Objective

This task should be performed approximately every three (3) years, but does not necessarily have to coincide with outage events associated with other plant equipment. Calibration, Inspection, and Test consists of the Calibration of Accessories, a Functional Valve Stroke Test, and a Stroke Time Test.

The intent of Calibration of Accessories is to ensure that each accessory is functioning correctly within design tolerances (e.g., start and stop points, travel, timing).

A Functional Valve Stroke Test is done to verify that the valve operates as a complete unit, and has not already failed.

A Stroke Time Test is performed to verify that the valve operates as a complete unit, including the solenoid valve.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Calibration of Accessories should include:

- Set limit switches
- Pressure regulator set point (see I&C - Pressure Regulator)
- I-P / E-P transducer (see I&C - I to P and E to P Transducer)

- Positioner (see I&C - Positioner)
- Booster tuning (see I&C - Booster)
- Pressure switches (see I&C - Pressure Switch)
- Position transmitter (see I&C - Positioner)
- Speed control valves
- Air leakage check, e.g., a delta P test

The visual inspection should include:

- Structural integrity
- Subcomponent damage
- Loose, broken, missing fasteners, especially in high vibration areas
- Damaged or loose electrical connections
- Observe obvious process fluid leaks
- Actuator shaft condition
- Condition of the valve stem and coupling

It is recommended that an informal external inspection be performed every time when cognizant persons are physically at the valve. Such informal inspections should not replace the scheduled inspection.

Functional Valve Stroke Test

Stroke the valve to verify that the valve operates as a complete unit, in accordance with the manufacturer's component-specific operating requirements.

Stroke Time Test may include:

- Timed stroke
- Limit switch actuations
- SOV actuations

Task Justification and Degradation Progression

Calibration of Accessories

Although this task addresses calibration of accessories, the details of the calibrations are to be found in the relevant sections under the corresponding I&C component. The accessories that can be accessed in this way are booster, E/P and I/P transducers, pneumatic switches, positioners (including position transmitters), and pressure regulators. The task also includes calibration of limit switches and speed control valves, as well as other inspection items.

Calibration measures the dynamic response of individual accessories (e.g., E/P, positioner, booster) to a control input. The intent is to ensure that each accessory is functioning correctly within design tolerances (e.g., start and stop points, travel, timing). Calibration thus focuses on design specifications of the accessories. It provides assurance that the process is being controlled properly, at least as far as the inputs to the actuator and valve are concerned.

Calibrations are useful in providing information on accessory condition. Persistent, significant calibration drifts can be used to identify the need for accessory replacement. No other information might be available for this purpose, as it is not cost-effective to internally examine the condition of accessories.

Valve or operator internal degradation can occasionally be inferred from calibration data, but not with any precision as to location or quantification of the degradation mechanism. It is more likely that persistent accessory drift might suggest the potential for internal damage to the valve and would be factored into the decision process to investigate further. For example, calibration drifts that suggest a valve has been improperly seating over an extended period could raise the question of erosion of the seat. Timely correction of calibration drifts is therefore important in preventing degradation of internals.

Trended accessory calibration data should be used as justification to adjust PM frequencies. This could consist of as-found and as-left data on I/P (E/P) and positioner. Other factors such as duty cycle may influence the interval decision.

Wear may commonly cause drift of positioners and E-P/I-P transducers within 3 years, and random failures of positioners, position transmitters, limit switches, and E-P/I-P transducers on timescales of a few years. There are also many other common random and wearout failure mechanisms on somewhat longer timescales. This means that relatively short term degradation should be expected.

Functional Valve Stroke Test

A Functional Valve Stroke Test is done to verify that the valve operates as a complete unit. A simple stroke test can be done as a failure-finding task to ensure that a valve has not already failed. However, it provides practically no assurance that the valve is not about to fail.

Failure finding tasks such as stroke tests may be applied to any critical valve that may fail undetected. This task addresses a large number of common failure mechanisms, mainly random but including some wearout mechanisms longer than 5 years in couplings and position transmitters.

Stroke Time Test

A stroke time test is performed to verify that the valve operates as a complete unit, including the solenoid valve. A timed stroke test, combined with visual external inspection, provides some additional assurance that the valve system is operating within overall tolerance, especially if the data is trended over time. A time response outside tolerance requires further investigation to ascertain whether the problem is in the valve or the actuator.

This task addresses a large number of common and random failure mechanisms, mainly in the actuator, but also in accessories.

Example Worksheets

Measurement Worksheet				
Measurement	**Specification**	**As-Found**	**As-Left**	**Notes**

AOV – Piston – Calibration of Accessories (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Air Pump	Cannot be calibrated
	Air Pump	Out of tolerance
	Check Valves - Air Line	Cannot be calibrated
	Check Valves - Air Line	Out of tolerance
	Check Valves - Piston/Actuator	Cannot be calibrated
	Check Valves - Piston/Actuator	Out of tolerance
	External Air Filter	Clogged
	External Air Filter	Leaking
	Limit Switches	Cannot be calibrated
	Limit Switches	Out of tolerance
	Pneumatic Tubing	Cannot be calibrated
	Pneumatic Tubing	Out of tolerance
	Speed Control Valves	Cannot be calibrated
	Speed Control Valves	Out of tolerance
	Valve Body Seat	Cannot be calibrated
	Valve Body Seat	Out of tolerance

AOV – Piston – Functional Valve Stroke Test (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Coupling: Direct	Improper operation
	Coupling: Fixed Moment Arm	Improper operation
	Coupling: Scotch Yoke	Improper operation
	Limit Switches	Improper operation
	Packing	Improper operation

AOV – Piston – Stroke Time Test (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Actuator	Failed hand wheel
	Actuator	Improper operation
	Actuator	Mispositioned handwheel
	External Air Filter	Clogged
	External Air Filter	Leaking
	Packing	Improper operation
	Speed Control Valves	Improper operation
	Valve Stem	Improper operation

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #32 AOV – Piston (Diagnostic Testing)

Task Overview

Task Timing and Objective

This task should be performed on an as-required basis. The main intent of diagnostic testing is to check the operability of all the accessories, the actuator, and the valve as a single integrated unit.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Diagnostic Testing could include:

- Total friction
- Seat load
- Travel
- Available actuator thrust / torque
- Accessory signatures
- Air pressures
- Spring rate
- Spring preload

Task Justification and Degradation Progression

Diagnostic testing checks the operability of all the accessories, the actuator, and the valve as a single integrated unit. As a minimum it provides a verification of the calibration data and the calibration process. This verification includes being within overall tolerances for the complete valve as a system.

For example, if valve timing or travel data indicate a problem, the diagnostic testing can usually indicate if the source is inappropriate friction, possibly from a packing problem or from internal damage, or if it is a result of worn springs.

Travel and seat load information on the seating area can raise the likelihood of internal leakage, which can often be confirmed by acoustic or thermographic techniques. There are limits to these capabilities. For example, although leakage may be confirmed, the extent of the leakage can only be assessed by an inspection of the seat, i.e., an overhaul. The techniques may not always be applicable. For example, a cold water valve in a noisy environment may not be assessable by thermography or acoustics. A control valve that needs to shut off in an emergency may not be able to be tested for leakage in realistic shut-off conditions.

Nevertheless, diagnostic testing can be used to decide if the source of a problem is the operator or the valve, and whether the problem can be corrected without tearing down the whole valve.

Diagnostic test results allow trending of useful valve parameters. These parameters may include travel, total friction, air pressures, spring rate, seat load, etc., and may be used to adjust PM intervals.

Because the diagnostic test data can be trended it is possible to use the data, with some qualification, to defer overhauls and replacements when the condition of the equipment appears to be good and stable over time, or to decide if an overhaul is appropriate. However, there is one major exception to this claim. Diagnostic testing does not provide information on the condition of the diaphragm if there is no leakage. The condition of other soft goods can be inferred from diagnostic information because they typically deteriorate gradually and give signs of progressive leakage. For example, O-ring piston seals degrade this way. Similarly, soft goods in accessories typically show degradation over time through increasing calibration drift.

Diagnostic Testing addresses a very large number of common, random failure mechanisms as well as many common wearout phenomena. Although the majority of these mechanisms are also adequately addressed by the calibration of the actuator and its accessories, these two tasks do not address the wear of bushings and cylinders in the actuator, or the wear of valve guides and valve body bearings. Provided that the actuator overhauls are performed as recommended, the need for diagnostic testing is reduced to an as-required basis.

Example Worksheets

Measurement Worksheet				
Measurement	**Specification**	**As-Found**	**As-Left**	**Notes**

AOV – Piston – Diagnostic Testing (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Actuator	Failed handwheel
	Actuator	Improper operation
	Actuator	Mispositioned handwheel
	Coupling: Direct	Improper operation
	Coupling: Fixed Moment Arm	Improper operation
	Coupling: Rack and Pinion	Improper operation
	Coupling: Scotch Yoke	Improper operation
	External Air Filter	Clogged
	External Air Filter	Leaking
	Packing	Excessive friction
	Packing	Excessive leakage
	Pneumatic Tubing	Improper operation
	Seat (Moving Part)	Improper operation
	Valve Body Bearing/Bushing, if present	Improper operation
	Valve Body Seat	Improper operation
	Valve Guides	Improper operation
	Valve Stem	Improper operation

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #33 AOV – Piston (Packing Inspection/Adjustment)

Task Overview

Task Timing and Objective

This task should be performed every two years. Packing Inspection/Adjustment is intended to detect unacceptable leakage from the packing area, and to adjust gland nut torque according to site procedures. The interval is not well determined from the failure mode data.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Inspect packing for signs of degradation, embrittlement, cracking, damage, or physical deformation that could lead to leakage of the process fluid. Adjust the pressure on the packing as necessary to prevent leakage of the valve.

Task Justification and Degradation Progression

Inspect for unacceptable leakage from packing area and adjust gland nut torque according to site procedures. Degradation of the packing occurs randomly from several commonly encountered causes.

Example Worksheets

Measurement Worksheet				
Measurement	**Specification**	**As-Found**	**As-Left**	**Notes**

AOV – Piston – Packing Inspection/Adjustment (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Packing	Degraded packing
	Packing	Excessive leakage
	Packing	Gouged stem
	Packing	Improper gland torque
	Packing	Improper packing configuration

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #34 MOV – AC Limitorque (Diagnostic Test)

Task Overview

Task Timing and Objective

This task should be performed approximately every six (6) years, but does not necessarily have to coincide with outage events associated with other plant equipment. The objective of the Diagnostic Test task is to measure key parameters to assess the health of the valve-actuator assembly as a combined unit.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Diagnostic Test may include the following:

- Direct stem force and or torque measurement
- Spring pack displacement
- Torque and limit actuation
- Motor current, voltage, and power
- MCC testing (electrical force testing). Note: MCC testing can be useful provided that a correlation is first established with the parameters from the other measurements list above.
- Stem position

Task Justification and Degradation Progression

For the task acting alone under CHM conditions, the dominant degradation mechanisms addressed by this task are hardening of the valve stem lubricant from age and high temperatures, and loss of or poor conduction of control signals through the torque and limit switch contacts from normal wear of the contact and loss of the contact spring tension.

Diagnostic tests address the valve-actuator assembly as a combined unit. The electrical thrust diagnostics provide the most reliable qualitative indication of a change in conditions within either the valve or the actuator. Most of the sources of degradation and failure can be picked up by the diagnostic tests, with the electrical tests providing somewhat better and certainly more efficient coverage than the direct thrust diagnostics. This is because the electrical tests can be performed at the motor control center and do not require personnel to be physically present at the valve. Consequently, the electrical tests can be performed much more frequently than the direct force tests.

In fact, the effectiveness of the electrical diagnostic tests is also the key to avoiding the need for tasks focused specifically on the valve, other than packing adjustments. Cracked or bent valve stems, stem to stem nut thread damage, and worn valve guides are the situations in which the effectiveness of electrical diagnostics enables a detailed internal valve inspection to be avoided altogether. Direct thrust diagnostics also play a role in defending against these problems, but that task is performed at the valve, and therefore on a much longer interval than the electrical diagnostics.

For the task acting alone under CHM conditions, the dominant degradation mechanisms addressed by this task are hardening of the valve stem lubricant from age and usually will not take place for about 5 to 10 years if proper lubricants and lubricating techniques are used. The stem lubricant can begin to show signs of hardening and loss of lubricity as early as 3 to 5 years in high temperature applications where the valve stem is exposed to high temperature process fluids, or very high external temperatures, which is somewhat rare. Special high temperature lubricants have been shown to be effective to extending the useful life of the lubricant if used properly. Loss of or poor conduction of control signals through the torque switch and limit switch contacts from normal wear of the contact and loss of contact spring tension has a failure free period of 10 years.

Example Worksheets

Measurement Worksheet				
Measurement	**Specification**	**As-Found**	**As-Left**	**Notes**

MOV – AC Limitorque – Diagnostic Test (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Drive Train	Improper test result or failed test
	Lubricant - Limit Switch	Improper test result or failed test
	Lubricant - Valve Stem	Improper test result or failed test
	Lubricant - Valve Stem, Gearbox, Limit Switch Compartment	Improper test result or failed test
	Packing	Improper test result or failed test
	Seat	Improper test result or failed test
	Spring Pack	Improper test result or failed test
	Switch - Limit	Improper test result or failed test
	Switch - Torque	Improper test result or failed test
	Valve Stem	Improper test result or failed test
	Valve Stem - Stem Nut	Improper test result or failed test

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #35 MOV – AC Limitorque (Functional Tests)

Task Overview

Task Timing and Objective

This task should be performed approximately every three (3) years, but does not necessarily have to coincide with outage events associated with other plant equipment. Functional Tests consist of performing a functional test of the stroke time, stroke verification, and valve obturator (i.e., actuator) movement.

The objective of the Functional Test – Stroke Time task is to assure that the MOV will open and close within timing specifications. The objective of the Functional Test – Stroke Verification task is to verify that the actuator will change position as required. The objective of the Functional Test – Valve Obturator (i.e., actuator) Movement task is to ensure that the valve operator remains connected to the stem and changes position as required when the valve is stroked.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

The MOV Functional Tests are expected so that the MOV will operate when needed and should include:

- Timing of the valve stroke from full open to full close and from full close to full open for comparison to baseline and historical values, looking for deviations and degradations over time.
- Verification that the valve opens when the open signal is given to the actuator.
- Verification that the valve changes position in both the open and closed direction. There are no work instructions for the three functional tests included in this task.

Task Justification and Degradation Progression

Functional Test – Stroke Time

For the task acting alone under CHM conditions, the dominant degradation mechanism addressed by this task is primarily the loss of or poor conduction of control signals through the torque and limit switch contacts from normal wear of the contact and loss of contact spring tension. Other degradations that may affect stroke time are hardening of the limit switch's lubricant from age and high temperatures, and to a much lesser degree are worn drive train worm gear bearings from normal use.

Note: In general, timed stroke tests against predetermined stroke times for valves subject to in-service-testing (IST) requirements are able to determine the effect of degraded valve stem lubricant, as well as the more directly acting subcomponent failures that prevent the valve from operating.

For the task acting alone under CHM conditions, the dominant degradation mechanism addressed by this task is primarily the loss of or poor conduction of control signals through the torque and limit switch contacts from normal wear of the contact and loss of contact spring tension, which is not expected to occur much before 10 years. Hardening of the limit switch's lubricant from age and high temperatures has an expect failure free period of 20 to 40 years unless exposed to very high external temperature, which is not very likely. Worn drive train worm gear bearings from normal use, even in high duty cycle operating conditions, is a very long term mechanism, at 40 years.

Functional Test – Stroke Verification

For the task acting alone under CHM conditions, the dominant degradation mechanisms addressed by this task are loss of or poor conduction of control signals through the torque and limit switch contacts from normal wear of the contact and loss of contact spring tension, and damage to the drive train's soft clutch mechanism, which is caused by wear of the clutch's elastomers from normal use.

For the task acting alone under CHM conditions, the dominant degradation mechanism addressed by this task, such as loss of or poor conduction of control signals through the torque switch and limit switch contacts from normal wear of the contact and loss of contact spring tension, has a failure free period of 10 years. Damage to the drive train's soft clutch mechanism, if present, is very long term even in high duty cycle operating conditions, which are expected to be at least 15 to 20 years, if not longer.

Functional Test – Valve Obturator (i.e., Actuator) Movement

For the task acting alone under CHM conditions, the dominant degradation mechanisms addressed by this task are loss of or poor conduction of control signals through the torque and limit switch contacts from normal wear of the contact and loss of contact spring tension, and damage to the drive train's soft clutch mechanism, which is caused by wear of the clutch's elastomers from normal use.

For the task acting alone under CHM conditions, the dominant degradation mechanism addressed by this task, such as loss of or poor conduction of control signals through the torque switch and limit switch contacts from normal wear of the contact and loss of contact spring tension, has a failure free period of 10 years. Damage to the drive train's soft clutch mechanism, if present, is very long term even in high duty cycle operating conditions, which are expected to be at least 15 to 20 years, if not longer.

Example Worksheets

As-Found Worksheet – MOV Functional Test Stroke Time (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Drive Train	Improper test result or failed test
	Lubricant - Limit Switch Compartment	Improper test result or failed test
	Switch - Limit	Improper test result or failed test

As-Found Worksheet – MOV Functional Test Stroke Verification (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Drive Train	Improper test result or failed test
	Switch - Limit	Improper test result or failed test
	Switch - Torque	Improper test result or failed test

As-Found Worksheet – MOV Functional Test of Obturator (i.e., actuator) Movement (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Drive Train	Improper test result or failed test
	Switch - Limit	Improper test result or failed test
	Switch - Torque	Improper test result or failed test
	Valve Stem	Improper test result or failed test

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #36 MOV – AC Limitorque (Inspection and Lubrication)

Task Overview

Task Timing and Objective

This task should be performed approximately every three (3) years, but does not necessarily have to coincide with outage events associated with other plant equipment. The Inspection and Lubrication consist of an external visual inspection of the actuator and lubrication of the valve stem.

The objective of the Actuator – External Visual Inspection task is focused mainly on the actuator, to evaluate a sample of gearbox grease and to look for general contamination and corrosion; missing, loose, or damaged parts; and leaks, including valve packing leaks. In a full PM program for CHM conditions, the failure rate is not sensitive to the task interval. The objective of the Valve Stem Lubrication task is to help ensure that the valve stem lubricant is present and has the required lubricity to maintain the specified coefficient of friction.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

The MOV external visual inspection task should include the following activities:

- Inspect drive train for drive sleeve / gear case O-ring seal failure
- Inspect fasteners for broken or missing fasteners
- Inspect fasteners for loose fasteners

- Inspect handwheel for loose or mispositioned condition
- Inspect lubricant - gearbox for contaminated condition / loss of lubricity, which results in reduced efficiency and output torque
- Inspect lubricant - gearbox for hardened condition / loss of lubricity, which results in reduced efficiency and output torque
- Inspect lubricant - valve stem for contaminated condition / loss of lubricity, which results in reduced thrust output (becomes significant sooner for low margin valves)
- Inspect lubricant - valve stem for hardened condition / loss of lubricity, which results in reduced thrust output (becomes significant sooner for low margin valves)
- Inspect lubricant - valve stem for inadequate application of lubricant
- Inspect lubricant - valve stem for loss of lubricant
- Inspect lubricant - valve stem, gearbox, and limit switch compartment for incorrect or inadequate lubricant
- Inspect packing for leakage

The valve stem lubrication task should include lubricating the stem and performing the following activities:

- Inspect lubricant - valve stem for contaminated condition / loss of lubricity, which results in reduced thrust output (becomes significant sooner for low margin valves)
- Inspect lubricant - valve stem for hardened condition / loss of lubricity, which results in reduced thrust output (becomes significant sooner for low margin valves)
- Inspect lubricant - valve stem for inadequate application of lubricant
- Inspect lubricant - valve stem for loss of lubricant
- Inspect lubricant - valve stem, gearbox, and limit switch compartment for incorrect or inadequate lubricant
- Inspect valve stem - stem nut for stem or stem nut thread damage, i.e., low output thrust

Task Justification and Degradation Progression

Actuator – External Visual Inspection

For the task acting alone under CHM conditions, the dominant degradation mechanisms addressed by this task are hardening of the valve stem lubricant from age and high temperatures, and leakage of the valve stem packing from normal wear and use.

The visual inspection that can be performed with the equipment on-line is limited to looking for general contamination and corrosion; missing parts; or packing leaks; apart from the latter, the main focus is on the actuator.

For the task acting alone under CHM conditions, the dominant degradation mechanisms addressed by this task are hardening of the valve stem lubricant from age and usually will not take place for about 5 to 10 years if proper lubricants and lubricating techniques are used. The

stem lubricant can begin to show signs of hardening and loss of lubricity as early as 3 to 5 years in high temperature applications where the valve stem is exposed to high temperature process fluids, or very high external temperatures, which is somewhat rare. Special high temperature lubricants have been shown to be effective at extending the useful life of the lubricant if properly applied. Packing leaks are affected by duty cycle and normal wear or use. Today's packing materials have a fairly long life, and packing failure is not expect to occur for at least 10 to 20 years even if the operation of the valve is high duty cycle. Low duty cycle valves can expected packing to last twice as long as the high duty life.

Valve Stem Lubrication

For the task acting alone under CHM conditions, the dominant degradation mechanism addressed by this task is hardening of the valve stem lubricant from age and exposure to high temperatures, either from the process fluid or steam controlled by the valve, or continued exposure to very high external temperatures above the temperature rating of the lubricant.

Lubricating the valve stem and stem nut helps to prevent excessive friction between these two subcomponents. Correct valve operation is extremely sensitive to the condition of the valve stem and stem nut and their lubrication.

For the task acting alone under CHM conditions, the dominant degradation mechanism addressed by this task is hardening of the valve stem lubricant from age and usually will not take place for about 5 to 10 years if proper lubricants and lubricating techniques are used. The stem lubricant can begin to show signs of hardening and loss of lubricity as early as 3 to 5 years in high temperature applications where the valve stem is exposed to high temperature process fluids, or very high external temperatures, which is somewhat rare. Special high temperature lubricants have been shown to be effective at extending the useful life of the lubricant if used properly.

Example Worksheets

As-Found Worksheet – MOV – AC Limitorque – Actuator External Visual Inspection (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Fasteners	Broken or missing
	Lubricant - Gearbox	Audile or unusual noise when gearbox operates
	Lubricant - Gearbox	Valve will not move
	Lubricant - Valve Stem	Dirty stem lubrication
	Lubricant - Valve Stem	Hardened stem lubrication
	Lubricant - Valve Stem	No evidence of stem lubricant
	Packing	Leakage

As-Found Worksheet – MOV – AC Limitorque – Valve Stem Lubrication (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Lubricant - Valve Stem	Contaminated lubricant
	Lubricant - Valve Stem	Hardened lubricant
	Lubricant - Valve Stem	Inadequate application of lubricant
	Lubricant - Valve Stem	No evidence of lubricant present
	Lubricant - Valve Stem, Gearbox, Limit Switch Compartment	Incorrect or inadequate lubricant
	Valve Stem - Stem Nut	Damaged stem or stem nut thread

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #37 Solenoid Operated Valve (Functional Test – Leak Tests)

Task Overview

Task Timing and Objective

The Functional Test – Leak Tests for Solenoid Operated Valve should be performed every two years. These tests detect internal leaks that occur as a result of changes in spring constant, crud buildup, and damaged seat(s).

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

Conduct leak test to ensure that there is no leakage due to changes in spring constant, or leakage due to crud buildup and/or damage to the seat.

Task Justification and Degradation Progression

These tests detect internal leaks that occur as a result of changes in spring constant, especially in models where the springs are normally compressed. They also detect leaks at the valve / plunger seat area due to crud buildup, and those due to damage to the seat(s).

Changes in spring constant are likely to develop continuously in time, influenced mainly by the local temperature (both ambient and process fluid medium), degree of compression, and the number of cycles of the valve. At least 10 years of trouble free service are anticipated under moderate conditions, but the period is sensitive to the service conditions.

Both the buildup of crud and physical damage to the seat area are a function of the quality and cleanliness of the process fluid medium; physical damage to the seat is also sensitive to the flow conditions. These degradation processes may proceed continuously or be precipitated by a sudden change in fluid quality or an influx of debris, or by a change in system operation. Even when degradation is continuous, the failure time is likely to be random, owing to lack of knowledge and control of the process. Consequently, even if a leak is within design limits these tests are essentially failure-finding tasks with little predictive capability.

Example Worksheets

As-Found Worksheet – Solenoid Operated Valve Functional Test – Leak Tests (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Springs	Leaking
	Valve Seat	Leaking

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

Job Plan #38 Solenoid Operated Valve (Valve Body Bonnet – Elastomer Replacement)

Task Overview

Task Timing and Objective

Valve Body Bonnet – Elastomer Replacement for Solenoid Operated Valve should be performed approximately every six (6) years, but does not necessarily have to coincide with outage events associated with other plant equipment. This task is driven by the need to change elastomers before they wear out.

Pre-Job Considerations

The maintenance supervisor should determine if there is a need to conduct a pre-job brief with craft personnel prior to the start of this maintenance activity. Specific to this task, consideration should be given to a review/discussion of the following maintenance support documents and issues:

- Applicable procedures, including:
  - Lockout/tagout (LOTO)
  - Calibration procedure
  - Foreign material exclusion (FME)
- Identification of clearance/tagout boundary
- Identification of FME potential and mitigation
- Environmental considerations (reference MSDS)

Contingency Considerations

The maintenance supervisor should determine necessary parts, consumables, special tools, and/or equipment needed by the craft personnel prior to the start of this maintenance activity.

Work Instructions

SOV Valve Body and Bonnet Elastomer Replacement should include:

- Inspect for external evidence of leaks or damage
- Inspect plunger and valve seat area for evidence of damage and wear
- Inspect for build-up of crud and plugged equalization ports
- Measure spring dimensions and compare to original specifications; springs may need replacement if SOV is in severe service conditions or it has been greater than 10 years since they were last replaced
- Inspect magnets for damage, positioning, and retention of magnetic properties
- Clean and inspect all surfaces

- Replace all O-rings and diaphragm (if present)
- Lap seat and disk area to required finishes
- Inspect the coil, all electrical wiring and connections, and any electronic components for damage and any evidence of overheating
- Adjust switch assembly for proper stroke, positioning, and function
- Lubricate any surfaces where required
- Check for proper fit on bolted bonnet assemblies

Task Justification and Degradation Progression

O-rings are subject to aging and sliding wear (but not all are exposed to sliding wear). Diaphragms are subject to cracking and sticking. The replacement task is driven by the need to change these components before they wear out. However, the task also serves as an internal inspection during which the condition of other subcomponents can be ascertained. All the degradation mechanisms for elastomers are influenced by temperature and radiation. The number of wear cycles is also a factor for O-rings subject to sliding wear. In mild conditions and low duty cycles, a minimum trouble free period of 5 years is expected, which may be extended to 10 years if the condition is invariably good at replacement.

Example Worksheets

As-Found Worksheet – Solenoid Operated Valve Valve Body Bonnet – Elastomer Replacement (check off any unacceptable conditions)		
Unsatisfactory	**Failure Location**	**Reportable Condition**
	Coil	Insulation breakdown
	Diaphragms	Degraded
	O-rings	Degraded
	Plunger	Clogged ports
	Plunger	Stuck
	Springs	Loss of spring constant
	Switches	Misadjusted
	Valve Seat	Crud buildup on plunger / seat
	Valve Seat	Damaged
	Wiring, Insulation, or Connectors (Component: Actuator)	Improper crimp
	Wiring, Insulation, or Connectors (Component: Actuator)	Pinched insulation

Feedback Mechanisms

Identify mechanism to provide work order feedback for improvements and errors

A. Perform post-job review.

B. Initiate any corrective action program documents necessary to resolve any problem areas that were identified.

Post-Maintenance Testing

This section should include any post-maintenance testing performed subsequent to the MMP PM tasks described above.

References

A. Industrial Safety Manual

B. Foreign Material Control Procedure

C. Material Safety Data Sheets

D. Vendor Technical Manual

6
PERSONNEL SAFETY ISSUES

The purpose of this section is to provide safety guidance for operations and maintenance personnel working on or around a typical combustion turbine installed at a combined cycle facility. Guidance is also provided for CTCC owners that may be beneficial for enhancing their existing site-wide worker safety programs.

6.1 General

Safety is a basic factor that must be considered at all times during the installation, operation, and maintenance of mechanical equipment. Through the use of proper tools, clothing, and procedures, serious injury and property damage can be prevented. Any accident, regardless of the situation, is generally the result of someone's carelessness or neglect. No amount of training or instruction can replace common sense, sound judgment, and acceptable work practices.

6.2 Safety Guidance for Maintenance Personnel

The following section describes safety guidelines for maintenance personnel working on or around the combustion turbine, performing either the preventive or corrective maintenance activities described in this report.

6.2.1 Personal Protective Equipment (PPE)

6.2.1.1 General

PPE includes clothing and other accessories designed to create a barrier between the user and workplace hazards. It should be used in conjunction with engineering work practices and/or administrative controls to provide maximum employee safety and health in the workplace. All contractors are responsible for providing training and ensuring the proper use of required personal protective equipment.

6.2.1.2 Hard Hats

All contract employees, subcontractors, visitors, and delivery personnel should be required to wear hard hats while at the CTCC facility.

6.2.1.3 Hearing Protection

All contract employees, subcontractors, visitors, and delivery personnel should be required to wear appropriate hearing protection to reduce time-weighted average exposure levels on noise within Occupational Safety and Health Administration (OSHA) permissible exposure limits.

6.2.1.4 Eye and Face Protection

All contract employees, subcontractors, visitors, and delivery personnel should wear, at a minimum, safety eyeglasses with side shields. More specialized eye protection should be required by the contractor as the work being performed demands. All eyewear should meet ANSI Z87.1-1968 standards.

6.2.1.5 Respiratory Protection

Respiratory protection that conforms to OSHA regulations should be used when engineering controls are not adequate to protect maintenance personnel from exposure to air contaminants. No technician may be assigned to wear a negative pressure respirator unless they have first been evaluated by a physician to determine their physical ability to wear the respirator and have been fit-tested.

6.2.1.6 Foot Protection

Steel-toe safety shoes are recommended for all workers. Sneakers, sandals, or canvas shoes are not permitted.

6.2.2 Safety Harnesses and Safety Nets

Safety harnesses, lifelines, and lanyards should be used only for employee safeguarding. Lifelines should be secured above the point of operation to an anchorage or structural member capable of supporting a minimum dead weight of 5,400 pounds. A lanyard should be a minimum of ½-in. nylon rope, or equivalent, with a maximum length to provide for a fall of no greater than 6 ft, or to keep the employee from contacting the next lower level.

Safety harnesses should be worn when working on any structure, member, or device that is of a height greater than 4 ft above the next lower level, except when working on an approved scaffold.

Safety nets should be provided when work places are more than 25 ft above the ground, water surface, or other surfaces where the use of ladders, scaffolds, catch platforms, temporary floors, safety lines, or safety harnesses is impractical.

6.2.3 Fire Protection and Prevention

Maintenance personnel in the permanent plant facility should be responsible for the following:

- Reporting all fires, no matter how small, in accordance with site-specific procedures
- Providing the appropriate manager(s) with the locations and types of all combustible or flammable materials brought onto the CTCC facility

Regarding fire prevention, maintenance personnel working on or around the combustion turbine should consider the following safety guidelines:

- Practice good housekeeping and do not let combustible scrap or refuse accumulate in the areas for which they are responsible.
- Obey all posted "no-smoking" notices and do not smoke in areas where combustible or flammable material is in use.
- Store oily, paint-soaked, or solvent-soaked rags in covered metal containers.
- Cut or weld only when permitted to do so. Welding or cutting should not take place near locations where flammables are present. An approved fire extinguisher should be located in each welding or cutting area. Refer to the Welding and Cutting section for more details.
- Store combustible or flammable liquids in proper containers, and use proper bonding and/or grounding when transferring fuels.
- Report all fire hazards to the appropriate site-management personnel.
- Do not permit open fires of any kind.
- Ensure that gas cylinders are transported and stored in an upright position. When stored, keep them at least 25 ft from oxygen cylinders.
- Ensure that no material is stored within 3 ft of an electrical panel, outlet, or fire-suppression system.
- Prohibit smoking within 100 ft of any plant enclosure or gas piping and in the Maintenance Building and Substation Control Building.

6.2.4 Housekeeping and Foreign Material Exclusion

Maintenance personnel should adhere to the following guidelines when working on or around combustion turbines:

- Keep aisles clear for the safe passage of people and material.
- Clean up slippery substances, such as grease or oil, spilled on floors or other work surfaces. Cover with sand or other non-slip material.
- Keep tools in boxes, racks, or trays when not in use.
- Do not leave nails, pieces of wood with protruding nails, or other sharp objects on floors and walkways. Store them where they cannot be stepped on.
- Keep exits clear. Keep fire extinguishers readily accessible and free of obstruction.
- Do not let materials such as scrap lumber, metal, and debris that might create a tripping hazard accumulate.
- Dispose of empty bottles, cans, paper, and other containers by depositing them in the receptacles provided.
- Clean the job site daily and ensure that debris is disposed of on-site, or off-site, in accordance with all EPA regulations.

6.2.5 Material Handling

The following safety guidelines regarding material handling should be considered by maintenance personnel working on or around the combustion turbine:

- Proper lifting techniques must be used when handling materials. Lift heavy objects as instructed, with leg muscles and not with the back.
- Stored materials must not block exits, aisles, fire-protection equipment, breakers, or passageways.
- Liquid containers should be labeled.
- Material stored inside buildings or structures under construction must not be placed within 6 ft of any hoist-way or other inside floor opening or within 10 ft of an interior wall that does not extend above the top of the material stored.
- Pipe, conduit, and bar stock should be stored on racks or stacked and blocked to prevent movement.
- The quantity of materials stored on scaffolds, platforms, or walkways must not exceed what is required for 1 day's operation.
- Materials must never be thrown or dropped from a distance of more than 20 ft. The drop area must be barricaded to protect personnel from being struck by falling materials. Trash chutes are required for dropping materials from heights above 20 ft.
- Protruding nails must be bent or pulled when stripping forms or uncrating material.
- All ropes, chains, cables, slings, and other hoist equipment must be inspected each time before use.
- A load should never be lifted and left unattended.
- Safety gloves must be worn when handling materials.
- All materials must be properly stacked and secured prior to lifting or moving to prevent sliding, falling, or collapse.

6.2.6 Rigging

In addition to the guidelines listed below, maintenance personnel should consider the guidance provided in EPRI report 1007914, *Lifting, Rigging, and Small Hoist Usage Program Guide*, and EPRI report 1009706, *Rigger's Handbook*.

- Rigging equipment should be inspected prior to use on each shift. Defective rigging should be removed from service.
- Rigging equipment should not be loaded in excess of recommended working-load limits.
- Wire rope should be removed from service if there is a marked reduction in rope diameter, excessive broken wires, kink damage, or other mechanical damage.
- Never strain wire rope over sharp corners.

- Remember that increasing the angle between the legs of a sling increases the load on each leg.
- Do not paint hooks.
- Only qualified personnel may be assigned to rigging operations.
- Rigging equipment is not permitted for working closer than 10 ft of any power line.
- All rigging devices should have permanently affixed identification stating size, grade, rated capacity, and manufacturer.
- "Shop-made" grabs, hooks, clamps, and other lifting devices are prohibited.

6.2.7 Hand Tools and Power Tools

Maintenance personnel should adhere to the following guidelines regarding the safe use of hand and power tools when working on or around combustion turbines:

- All hand and power tools and similar equipment, whether issued by the employer or furnished by the employee, should be maintained in safe condition and properly stored.
- Wrenches should not be used when jaws are sprung to the point that slippage occurs.
- Impact tools such as drift pins, wedges, and chisels should be kept free of mushroomed heads.
- Wooden handles should be free of splinters and cracks and should be tight in the tool.
- Electric power-operated tools should either be of the approved double-insulated type or grounded in accordance with OSHA requirements.
- Any power-operated tools designed with guards should have the guard in place when in use.
- The use of electric cords for hoisting or lowering tools is not permitted.
- Only trained employees are allowed to operate power-actuated tools.
- All power-actuated tools should be tested daily, and all defects must be corrected before use.
- All power-actuated tools should be of the low-velocity, cushioned-pistol-grip, piston-type design.
- Power-actuated tools should not be used in areas in which hazardous, ignitable dust, gases, or liquids are present.
- All maintenance work on power-actuated tools must be performed according to manufacturer specifications and must be done be qualified persons only.
- All defective tools and equipment must be reported immediately in accordance with site procedures and tagged "out of service." Temporary and makeshift repairs are prohibited.
- Floor-stand and bench-mounted grinders should be provided with properly adjusted work rests and grinding-wheel guards.

- Abrasive wheels and tools should comply with the ANSI B7.1-1970 safety code for the use, care, and protection of abrasive wheels.
- All employees using abrasive wheels should be protected by eye protection equipment appropriate to the equipment and task being performed.
- Gas-powered tools should not be used in unventilated areas, and gas should be dispensed from Underwriters Laboratories (UL)-approved cans only. All gas-powered tools must be turned off before being refueled.

6.2.8 Welding and Cutting and Other "Hot" Work

No "hot" work should be permitted at the CTCC in the presence of flammable or combustible materials. Many facility owners use the Factory Mutual "Hot Work" permitting system for all heat- or spark-producing operations except in those areas designated by the owner as safe areas. Hot-work permits are issued by the CTCC site manager and must be in accordance with site procedures.

6.2.9 Gas Welding and Cutting Safety

Maintenance personnel performing gas welding and cutting should adhere to the following guidelines when working on or around combustion turbines:

- Valve protection caps should be in place when moving, transporting, and storing compressed gas cylinders.
- Cylinders should be secured on a cylinder truck by a chain or other steadying device while in use.
- Cylinders containing oxygen, acetylene, or other fuel gas should not be taken into confined spaces.
- No defective or damaged cylinders should be used.
- Fuel-gas hose and oxygen hose should be easily distinguishable from each other, be without defects, and be fitted with rotary-motion disconnect fittings.
- Torches should be inspected at the beginning of each work shift. Defective torches should not be used.
- All torches should be fitted with approved flashback control devices.
- Torches should only be lighted by friction lighters or other approved devices and not by matches or from "hot" work.
- Employees are required to wear the proper personal protective equipment, such as coveralls, safety goggles, face shield, welding hood, or welding jacket, as demanded by the type of work completed.

6.2.10 Arc Welding and Cutting

Maintenance personnel performing arc welding and cutting should adhere to the following guidelines when working on or around combustion turbines:

- Any faulty or defective machines, cables, or electrode holders must be removed from service and reported to the supervisor.
- All welding, cutting cables, and connectors should be of a completely insulated and flexible type capable of handling the maximum current requirements of the work in progress.
- Only cable that is free from repair or splices for a minimum of 10 ft from the end to which the electrode is connected should be used; insulated connectors or splices whose insulating quality is equal to that of the cable are permitted.
- Maintenance personnel are required to wear the proper personal protective equipment, such as coveralls, safety goggles, face shield, welding hood, or welding jacket, as demanded by the type of work completed.

6.2.11 Electrical Safety

Maintenance personnel should adhere to the following electrical safety guidelines when working on or around combustion turbines:

- All construction electrical installations and temporary wiring should be made in accordance with the National Electric Code ANSI/NFPA latest edition and all federal, state, and local codes.
- Temporary lights should be equipped with guards. Broken or burned-out bulbs should be replaced.
- Temporary electric cords must be covered or elevated. They must be kept clear of walkways where they could be exposed to damage or create tripping hazards.
- Extension cords used with portable electric tools and appliances must be heavy-duty (no less than 12-gauge conductors) of the three-wire grounding type, and must conform to OSHA standards. No flat electrical cords should be allowed on site.
- Voltages must be clearly labeled on all electrical equipment and circuits. Circuits must also be clearly marked for the areas of service they provide.
- Prior to performing any work, electricians must perform “lockout and tagout” of the equipment or machinery. The only exception is when power is required for “megging” circuits.
- All temporary electrical circuits should be periodically inspected and properly maintained.

Note that many CTCC facility owners are subject to the Power Generation and Transmission OSHA standard 29 CFR 1910.269. Contractors working on CTCC premises may also be subject to portions of this regulation.

6.2.12 Lockout and Tagging of Circuits

Maintenance personnel should adhere to the following electrical safety guidelines when lockout and tagging of circuits is required prior to working on or around combustion turbines:

- Controls that are to be deactivated during the course of work on equipment or circuits should be tagged/locked in accordance with site-specific tagging procedures.
- Equipment or circuits de-energized should be rendered inoperative and should have tags and/or locks attached at all points where such equipment or circuits can be energized.

6.2.13 Scaffolding

In addition to the guidelines noted below, maintenance personnel should consider the guidelines provided in EPRI report 1007914, *Lifting, Rigging, and Small Hoist Usage Program Guide*, and EPRI report 1009706, *Rigger's Handbook*.

- All scaffolds should be erected in accordance with appropriate OSHA standards for the type and application used.
- The footing or anchorage for scaffolds should be sound, rigid, and capable of carrying the maximum intended load without settling or displacement.
- Guardrails, mid-rails, and toe boards must be installed on all open sides of scaffolds that are 10 ft or more in height. Guardrails must be 2 x 4 in. or equivalent, supported at intervals of not more than 8 ft. Toe boards should be a minimum of 4 in. in height.
- Where persons are required to work, or to pass under them, the scaffolds should be provided with a screen between the toe board and rail, extending along the entire opening, consisting of #18-gauge U.S. standard wire ½-in. mesh or equivalent.
- Overhead protection should be provided if maintenance personnel working on scaffolds are exposed to overhead hazards.
- Scaffolds and their components should be capable of supporting, without fail, at least four times the maximum load intended.
- Any scaffolding, including all accessories, damaged or weakened from any cause should be immediately repaired or replaced.
- All planking should be scaffold-grade, as recognized by approved grading rules for the species of wood used, and a full 2 x10 in. in thickness.
- An access ladder, or equivalent safe access, should be provided.
- Scaffold planks should extend at least 6 in., but no more than 12 in., over the end of the support.
- All scaffolds must be two planks wide; no employee may work on a single plank.
- Scaffold planks must be visually inspected before use. Damaged planks must be removed from service.
- Scaffolds must be tied to the building or structure at intervals that do not exceed 30 ft horizontally and 26 ft vertically.

- Lean-to scaffolds and makeshift platforms are prohibited.
- All scaffolds over 10-ft high are required to have load footprints and limits that can be obtained from the scaffold manufacturer.
- When erecting and dismantling scaffolds, OSHA's Project Six-Foot Fall Protection Requirements must be followed.
- Ladders must be used to climb scaffolds at all times. Workers should never climb a scaffold's cross bracing. Both hands should be free of tools/materials when ascending or descending a scaffold. Employees should not propel themselves while working on scaffolds.

6.2.14 Floor and Wall Openings

Maintenance personnel should adhere to the following safety guidelines regarding floor and wall openings when working on or around combustion turbines:

- Floor openings should be guarded by a standard rail and toe board or cover. In general, the railing should be provided on all exposed sides, except at entrances to stairways.
- Wall openings from which there is a drop of more than 4 ft and the bottom of the opening is less than 3 ft above the working surface should have a standard guardrail.
- Open-sided floor or platforms 6 ft or more above the adjacent floors or ground level, and runways 4 ft or more above the ground floor level, should be provided with standard handrails and toe boards.
- Stairways having four or more risers should be equipped with standard stair railings on both sides.
- Guardrails and/or covers are not to be removed until other means of fall protection are in place. Employees installing or removing guarding or covers should be protected by alternative fall protection.
- Employees are prohibited in any area that could expose them to a fall unless proper fall protection procedures are in place.
- Stairways should be free of hazardous projections, debris, and other loose materials.

6.2.15 Cranes, Hoist, Elevators, and Conveyors

In addition to the guidelines noted below, maintenance personnel should consider the guidance provided in EPRI report 1007914, *Lifting, Rigging, and Small Hoist Usage Program Guide*, and EPRI report 1009706, *Rigger's Handbook*.

Maintenance personnel should adhere to the following safety guidelines regarding the operation of cranes when working on or around combustion turbines:

- All cranes must be operated and maintained in accordance with established standards, specifications, and limitations.
- Only trained, qualified employees are permitted to operate any crane or rigging equipment. Training includes an in-depth review of the operating characteristics and limitations of the equipment.

- A fire extinguisher is to be kept in the crane's cab at all times.
- "Shop-made" grabs, hooks, clamps, or other lifting devices are prohibited.
- A licensed engineer must inspect all lifting beams and spreader bars to make sure that they are the proper size for the capacity.
- Slings should not be shortened by using knots, bolts, or other makeshift designs.
- Wire rope slings should be padded to protect against damage from sharp corners.
- Hard hats and proper personal protective equipment should be worn while operating or working close to a crane.
- Rated load capacities and recommended operating speeds, special hazard warnings, or instruments should be conspicuously posted.
- Cranes should be inspected prior to each use shift. Records of inspections should be kept as required by law.
- Hand signals to crane operators should be by ANSI standards for the type of crane in use.
- Accessible areas within the swing radius must be barricaded.
- Do not ride hook or load.
- Safety latches are required on all crane hooks.
- Do not operate a crane or bring its loads within 10 ft of electrical distribution lines.
- The use of a crane to hoist employees onto a personnel platform is prohibited, except when the erection, use, and dismantling of conventional means of reaching the work site would be more hazardous or is not possible because of structural design or work-site conditions. The following precautions are required when using cranes to hoist personnel:
  - Hoisting of the personnel platform should be performed in a slow, controlled manner with no sudden movements of the crane platform.
  - Load lines should be capable of supporting without failure at least 10 times the maximum intended load.
  - A trial lift with the unoccupied personnel platform loaded at least to the anticipated lift weight of personnel and material should be made from the ground level with full crane operational tests. The trial lift should be repeated prior to hoisting personnel any time the crane is moved and set up in a new location or returned to a previously used location. In every case, the trial lift must be conducted at the beginning of every shift.

Employees should keep all body parts inside the platform during raising, lowering, or positioning. Employees being hoisted should remain in continuous sight of and in direct communication with the crane operator. Employees occupying the personnel platform should use a body belt/harness system with the lanyard attached to the lower load block, overhaul ball, or structural member within the platform. Finally, hoisting of employees while the crane is traveling is prohibited.

6.2.16 Ladders

Maintenance personnel should adhere to the following safety guidelines regarding ladders when working on or around combustion turbines:

- All ladders should be inspected for defects prior to use. Any defective ladder should be removed from service and reported to the supervisor for repair or replacement.
- Portable ladders should be placed on a substantial base at a 4-to-1 pitch, have clear access at top and bottom, and extend at least 36 in above the landing and be secured against movement when in use.
- Always face the ladder and use both hands when climbing up or down. If you have to raise or lower tools, use a line.
- Do not use metal ladders for electrical work or where they may contact electrical conductors.
- Do not use stepladders as strait ladders.
- Avoid over-reaching when working from ladders.
- Manufactured ladders must comply with OSHA, ANSI, manufacturer, and job specifications.
- The six-foot-fall protection procedure applies when working from a ladder. All ladders should be secured with a rope or other substantial device.
- Ladders should be maintained free of lines, ropes, hoses, wires, cables, oil, grease, and debris. No objects should be left on ladders.
- Never stand or sit on the top rung of a stepladder.
- Never climb or work from the back of a ladder.
- Never work when there is another person on the same ladder.

6.2.17 Compressed-Gas Cylinders

Maintenance personnel should adhere to the following safety guidelines regarding the use of compressed-gas cylinders when working on or around combustion turbines:

- The protective caps of gas cylinders must be kept on all cylinders when not in use.
- All cylinders must be properly secured to prevent tipping.
- All gas cylinders, whether in use or in storage, must be secured in an upright position by some substantial means, such as chains or ropes.
- Oxygen and fuel-gas cylinders in storage must be separated from each other by a separation of 20 ft or by a 5-ft high barrier wall that has a minimum 1-h fire rating.
- Compressed-gas cylinders should not be taken into confined spaces.

6.2.18 Permit-Required Confined Spaces

Only contract employees who have been trained in compliance with OSHA confined-space standard 29 CFR 1910.146 may enter permit-required confined spaces. Only trained attendants should be used to monitor permit-required confined spaces while authorized entrants are inside.

No person should enter a confined space until all preparations for entry have been completed, the permit has been approved, all conditions of site-specific entry procedures have been met, and the entry is authorized. Typically, no person should enter a confined space unless an attendant is on duty. The attendant must maintain visual and/or voice contact at all times with personnel in the confined space.

Personnel using monitoring equipment should be trained in its use and calibration. All electrical shock hazards should be protected by use of low-voltage systems and/or ground-fault protectors. Explosion-proof electrical equipment is required for entry into spaces where potential fire risk and/or explosion risk exists.

No one should enter confined spaces without a permit. The CTCC facility owner should identify all confined spaces by signs, placards, or other appropriate means. Individuals authorized to issue a confined-space permit should be designated and identified to site maintenance personnel. The individual issuing the permit should personally inspect, examine, and evaluate the confined space before entry and should ensure that all hazards have been identified before allowing entry. The individual issuing the permit should also discuss the following with all personnel:

- Emergency procedures
- What the emergency standby person must do
- The fact that all permits are null and void in case of an emergency
- How to request a re-check of the permit
- What the permit does and does not authorize
- The duration of the permit: one shift (or the duration of the entry, whichever is shorter)

The following work rules are unconditionally and automatically required for confined-space entry procedures:

- Ventilation should be of an adequate volume to safely maintain the airflow within the confined space.
- It is the responsibility of maintenance personnel to immediately report unsafe conditions.
- A flashlight should be carried by each person entering a confined space.
- Lighting used must be explosion-proof, a 12-volt system, or a flashlight.
- Welding, cutting, brazing, and purging operations are covered by specific requirements. Consult with the individual issuing the permit and check site-specific requirements.
- Chemicals used or transported inside the confined space are covered by specific requirements. Consult with the individual issuing the permit and check site-specific requirements.

The following locations and structures are typically designated by CTCC facility owners as permit-required confined spaces at the power plant:

- Exhaust-bearing tunnel
- Inlet air duct between the evaporative cooler and inlet silencers
- Inlet air duct between the inlet silencers and compressor
- Electrical vault
- Stack
- EHC skid reservoir
- Gas-filter separator vessel
- Lube-oil reservoir
- Turbine-building ventilation fan and exhaust-hood enclosures
- Evaporative cooler water supply valve pit

6.3 Worker Safety and Health Guidelines for CTCC Facility Owners

6.3.1 General Safety Requirements for CTCC Facility Owners

Owners should provide a workplace free of hazardous, unsanitary, or dangerous conditions for all employees. It should be the responsibility of the owner to initiate and maintain such accident prevention programs, hazardous material programs, and other programs as may be necessary to comply with federal, state, and local regulations applicable to work at the CTCC facility.

It should be the responsibility of the owner to ensure that all subcontractors and contractor employees abide by the safety rules and regulations while on the CTCC facility. Technicians should stay in their assigned work areas.

The owner should ensure that any GT technicians do not bring any explosives, firearms, alcoholic beverages, or drugs on the CTCC property. GT technicians should wear appropriate clothing at all times. Short pants and shirtless attire are prohibited. Sturdy shoes with steel toes must be worn at all times. Safety glasses and hard hats must be worn at all times.

Owners should ensure that the following general work practices are followed during maintenance activities:

- Owners should not permit maintenance personnel to work in proximity to any part of an electrical power circuit such that the employee could contact in the course of work unless the employee is protected against electrical shock by de-energizing the circuit and grounding or guarding it effectively by insulation or other means.
- In work areas where the exact location of underground electrical cables is unknown, employees using jackhammers, bars, or other hand tools that could contact a line should be provided with insulated protective gloves. All insulated protective gloves must be tested prior to use, in accordance with the National Electric Code.
- Before work is begun, the owner should ascertain by inquiry, direct observation, or instruments whether any part of an energized electrical power circuit, exposed or concealed, is located so that the performance of the work could bring any person, tool, or machine into physical contact with the circuit. The owner should post and maintain proper warning signs where such a circuit exists. The owner should advise employees of the location of such lines, the hazards involved, and the protective measures to be taken.

6.3.2 Occupational Safety and Health

Construction, operation, and maintenance activities associated on or around the CTCC facility may expose workers to physical and chemical hazards. Potential worker exposure to these hazards will be minimized through adherence to appropriate engineering design criteria, implementation of appropriate administrative procedures, use of personal protective equipment, and compliance with applicable health and safety requirements.

Formal health and safety procedures and programs should be established and implemented for construction and operations to control the various hazards and provide for a safe workplace. Site-specific injury and illness prevention programs and safety training programs, which are intended to protect worker health and safety during construction and operation of the proposed project, are described in the following sections.

6.3.3 Injury and Illness Prevention Programs

Prior to beginning construction activities, the CTCC facility owner should develop a site-specific construction injury and illness prevention program (IIPP). Once the construction of the proposed project is complete, a site-specific IIPP for operations and maintenance activities will be implemented.

6.3.3.1 Construction Injury and Illness Prevention Programs

Consistent with applicable state and OSHA policy on multi-employer work sites, each CTCC-facility owner should be responsible for the health and safety of its own employees. Periodic health and safety audits should be conducted by facility personnel to verify contractor and subcontractor compliance with contractual health and safety obligations.

6.3.3.2 Operations and Maintenance Injury and Illness Prevention Programs

Upon completion of construction, startup of the proposed project, and implementation of routine operations, the construction IIPPs should transition into an operations-oriented program that reflects the hazards and controls necessary during routine operations and maintenance of the CTCC facility.

Injury and Illness Prevention Plan

The primary mitigation measures for worker hazards during normal plant operation and maintenance are spelled out in the injury and illness prevention plan, as required by state and OSHA requirements, and site-specific procedures. The written plan should designate an individual who is responsible for implementing the program. It also should describe safety training and procedures for tracking safety training. An injury and illness prevention plan should contain the following information and procedures:

- Identity of the person(s) with authority and responsibility for implementing the IIPP
- A system for ensuring that employees comply with safe and healthy work practices
- A system for facilitating employer-employee communications regarding safety
- Procedures for identifying and evaluating workplace hazards, including inspections to identify hazards and unsafe conditions
- Methods for correcting unhealthy/unsafe conditions in a timely manner
- An employee training program that includes:
  - Introducing the program
  - Training of new, transferred, or promoted employees
  - Training on new processes and equipment
  - Supervisor training
  - Evaluation of contractor training
- Methods of documenting inspections and training, and for maintaining appropriate records

Emergency Action Plan

In addition to incorporating various safety and environmental features and design measures to minimize emergencies and their effects on public and worker safety, the CTCC facility should have a site-specific emergency action plan. The emergency action plan should address potential emergencies—including chemical releases, fires, bomb threats, pressure-vessel ruptures, aqueous ammonia releases, and other catastrophic events. It should describe evacuation routes, alarm systems, points of contact, assembly areas, responsibilities, and other actions to be taken in the event of an emergency. The plan will include a layout map, a fire extinguisher list, and a description of arrangements with local emergency response agencies for responding to emergencies.

Hazardous Materials Management Program

The storage and handling of chemicals should follow applicable state and OSHA requirements to minimize risk to workers and the surrounding community. Chemicals should be identified and stored in appropriate chemical storage facilities. Bulk chemicals should be stored in aboveground storage tanks; other chemicals should be stored in their delivery containers. Chemical storage and chemical feed areas should be surrounded by temporary or permanent containment or curbing to contain leaks and spills. The containment areas should be sized to hold an appropriate volume (considering the potential for the local hazard contingencies).

Safety showers and emergency eyewash stations or bottles should be provided at all chemical treatment and storage areas, laboratories, and battery rooms in accordance with state and OSHA requirements (within 50 ft, or 10 s of travel time). Standard personal protective equipment (PPE) for use during chemical handling activities should be provided.

Self-contained breathing apparatus sets should be available in the control room. First-aid kits should be located in work areas around the plant. Fire blankets and evacuation stretchers should be located in the control building. Standard PPE should be readily available for use during minor chemical spill containment and cleanup activities by plant personnel. Adequate supplies of absorbent material should also be available on site for minor spill cleanup. A hazardous material emergency response team, trained in managing the accidental release of the chemicals used and stored at the plant, should be available through contract.

Emergency contact numbers should be available to summon assistance from these contractors and for notification of local agencies. These procedures should be detailed in the emergency action plan.

Personal Protective Equipment Program

PPE requirements for work at the CTCC facility should be identified during the job hazard analysis process. The PPE requirements should be developed and incorporated into the site-specific IIPP. The PPE program should include the following:

- Hazard analysis and prescription of PPE
- Personal protective devices
- Head protection
- Eye and face protection
- Body protection
- Hand protection
- Foot protection
- Safety belts and life lines
- Protection for electric shock
- Respiratory protective equipment

Operations and Maintenance Written Safety Program

Additional written safety programs will be developed and implemented as necessary to address hazards that are identified with operation and maintenance of the CTCC facility. These programs will be made components of the overall operations and maintenance IIPP for the facility. These programs include, but are not limited to, the following:

- Blood-borne pathogens control program
- Hazard communication program
- Hearing conservation program
- Hazardous energy control program
- Confined space entry program
- Safe work practices program
- Ergonomics program
- General facility safety procedures:
  - Compressed-gas safety procedures
  - Heavy equipment safety procedures
  - Hand tools and equipment guarding procedures
  - Hoist and rigging safety procedures
  - Slips, trips, and falls prevention procedures
  - "Hot-work" safety procedures
- Fall protection program
- Contractor safety program
- Risk management plan

6.3.4 Safety Training Programs

To ensure that employees recognize and understand how to protect themselves from hazards at the CTCC facility, comprehensive training programs for construction and operations personnel should be implemented.

Operations and maintenance personnel should be given instructions regarding their responsibility for the safe conduct of their work. These instructions should be given at the time the employee is first hired and as an ongoing training program of hazard recognition and avoidance.

Employees will also be instructed in safety procedures pertinent to their employment tasks. Safe working conditions, work practices, and protective equipment requirements will be communicated in the following manner:

- A new, promoted, or transferred employee will receive safety training orientation.
- Safety meetings will be held with employees.
- "Toolbox/tailgate" safety meetings will be conducted periodically for each crew. General safety topics and specific hazards that may be encountered will be discussed. Comments and suggestions from all employees will be encouraged.
- A periodic staff safety meeting will be held for supervisors.
- Hazard communication training, including state-required hazardous material warnings and discharge prohibitions, will be conducted as necessary when new hazardous materials are introduced to the workplace.
- Material safety data sheets will be available as required for all appropriate chemicals.
- A bulletin board with required postings and other information will be maintained at the plant site.
- Warning signs (for example, "Hazardous Waste Storage Area," "Confined Space Area") will be posted in hazardous areas that comply with applicable regulations (bilingual, readable font size).

Safety training should be provided to each maintenance technician as described below:

- A list of safe work rules for the CTCC facility should be explained to each new employee.
- A copy of the applicable Safe Work Practices documentation should be given to each new employee. The provisions should be incorporated into training for the qualifications programs so that employees will fully understand what the protective provisions mean.
- The hazard communication program and requirements for personal protection for the types of hazards that may be encountered at the CTCC facility site should be explained and documented.
- Unusual hazards that are found on site should be explained in detail to each new employee, including any specific requirements for personal protection.
- Safety requirements for the new employee's specific job assignment will be explained by the foreperson upon initial assignment and upon any reassignment.

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A
LISTING OF KEY POINTS

A.1 Key Human Performance Points



Key Human Performance Point

Denotes information that requires personnel action or consideration in order to prevent personal injury, equipment damage, and/or improve the efficiency and effectiveness of the task.

Page Number	Key Human Performance Point
3-2	As with any shell-and-tube type heat exchanger, there always exists the possibility of fouling or tube leaks, and it is incumbent upon a prudent operator to periodically clean and inspect the tube bundles. This includes performing a representative eddy current evaluation of the tubes, to look for tube wall thinning and cracking.
4-30	This analysis was performed for oil-lubricated horizontal motors. If grease-lubricated horizontal motors are installed at a facility, appropriate tasks should be undertaken to properly maintain the grease in accordance with current industry practice that is consistent with the EPRI PMBD.
5-1	One key attribute associated with the consistent development of high-quality job plans is the *critical task analysis.*
5-2	When planning a job plan or maintenance work package, the planner should search for relevant maintenance experience, and if such information is identified that is relative to the work being performed, then it should be placed in the work package.
5-4	The work planner should typically prepare a pre-job brief traveler for any maintenance activities posing risk to unit operation/generation.
5-5	The work planner should review bill-of-materials, drawings, component maintenance philosophy, and maintenance history to identify parts and consumables that are likely to be needed for the job.
5-7	The job plan should contain a means for the craft labor to provide feedback to the maintenance organization regarding the quality and clarity of the work package.
B-7	If you experience failures in green and yellow, you are currently performing the high-effectiveness tasks, the task scope is correct, and the tasks are being implemented properly, you should examine your training program, personnel qualifications, and quality of procedures.

A.2 Key O&M Cost Points



Key O&M Cost Point

Emphasizes information that will result in overall reduced costs and/or increase in revenue through additional or restored energy production.

Page Number	Key O&M Cost Point
3-2	Given the cost of pulling a fan and/or motor, when the cost of crane rental is factored in, it is often financially advantageous to replace vibration switches with sensors that can be read remotely by portable data collectors that can assist with vibration analysis.
3-3	Failure to maintain proper glycol/water ratios within the system can possibly lead to the corrosion of system piping, as glycol will act as a passivating agent on the carbon steel piping systems. Not only can this cause pipe wall thinning, but the products of corrosion can also create further problems with valves, fouling of condensers, plugging of sensing lines, and other similar issues.
3-4	One of the biggest potential issues with an evaporative cooling system is water quality, and while it is an operational issue, it can and will present maintenance issues such as media fouling and in rare cases possibly even pluggage of instrumentation.
B-11	When contemplating the merits of deferring a PM task, the licensee should also consider the cost if the component associated with this PM fails prior to the PM activity being performed. The cost consequence of deferral of this PM should be acceptable.

A.3 Key Technical Points



Key Technical Point

Targets information that will lead to improved equipment reliability.

Page Number	Key Technical Point
3-1	As with many cross flow towers, one of the most repetitive issues is associated with the distribution boxes, sometimes referred to as splitter valves in cross flow cooling towers, which control the amount of water to each side of the cooling tower cell.
3-1	Inlet chiller manifolds and spray nozzles can also present problems with plugging and breaking and must be inspected routinely as well, to ensure proper flow distribution.
3-2	As with any refrigeration compressor, it is imperative that the system avoid what is referred to as Low Delta T Syndrome, which will cause the compressor to surge and ultimately lead to compressor failure.
3-4	During the annual commissioning of an evaporative cooling system, it is also imperative to inspect the integrity of the sealing system.
4-30, 4-35	*Thermography* is recommended for electrical motors and associated connections, although as the PMBD indicates, the value of this task is minimized by other tasks, such as *System Owner Walkdown* and *Electrical Testing*. *Thermography* does, however, have the capability of detecting affected failure modes much sooner in the degradation process.
5-5	Only replacement parts that are physically identical to the original should be installed unless an alternate replacement item has been determined to be a suitable equivalent.
5-117, 5-121	Perform diagnostics on an old seal, so as to determine the amount of seal face wear for wear rate evaluation, condition of elastomers, presence of any debris, condition of the spring, and extent of the setscrew indentations into the shaft sleeve.
B-4	The key to optimizing maintenance tasks and frequencies is to do more highly effective tasks, not just more tasks.
B-7	If you experience failures in green and yellow and you are performing the high-effectiveness tasks, you may not be performing them effectively. You should be able to improve PM defenses against such failures by modifying your PM program to be closer to the recommendations.
B-7	If you experience failures in green and yellow, and you are currently performing the high-effectiveness tasks, you should suspect that task scope or implementation might be improved.

A.4 Key Supervisory Observation Points



Key Supervisory Observation Point

Identifies tasks or series of tasks that can or should be observed by Maintenance First Line Supervisors to improve the performance of the Maintenance Staff and improve the reliability of the component.

Page Number	Key Supervisory Observation Point
3-4	In general, cleaning of evaporative cooling media should be done by hand, or potentially through the use of a pressure washer utilizing the low-pressure setting, to avoid damaging the media.

B
EFFECTIVE USE OF THE EPRI PMBD VULNERABILITY TOOL

The purpose of this appendix is to provide insight into the use of the vulnerability tool integral to the EPRI PM Basis Database, which should be a key consideration when adjusting any given PM task scope or frequency while transitioning to a condition-based maintenance strategy.

B.1 Overview of the Vulnerability Tool

The PMBD template task information is designed to provide the licensee with more detailed information pertaining to an individual task. It will display the task objectives, the time necessary to perform the task, the amount of time the component will be out of service while the task is performed, the task contents, the principal failure locations and causes the task will cover, the progression of degradation in time, and the support for the task and its relationship to other tasks.

One of the features of the PMBD is the Vulnerability Tool. The vulnerability tab can be used to perform calculations for a component template's baseline tasks versus customized tasks, to determine the effect that omission of tasks or changes in frequency will have on the component's reliability. The tool will also identify any new failure modes that are exposed when a task is omitted or an interval is extended.

B.2 Using Vulnerability to Manage Degradation

In a general sense, the PMBD vulnerability tool allows a licensee to:

- Find strengths and weaknesses in the recommended PM program
- Provide information on what tasks are protecting what piece parts and from what mechanisms
- Provide means to determine "how much is enough"

Figure B-1 illustrates the relationship between equipment reliability, PM costs, and CM costs.

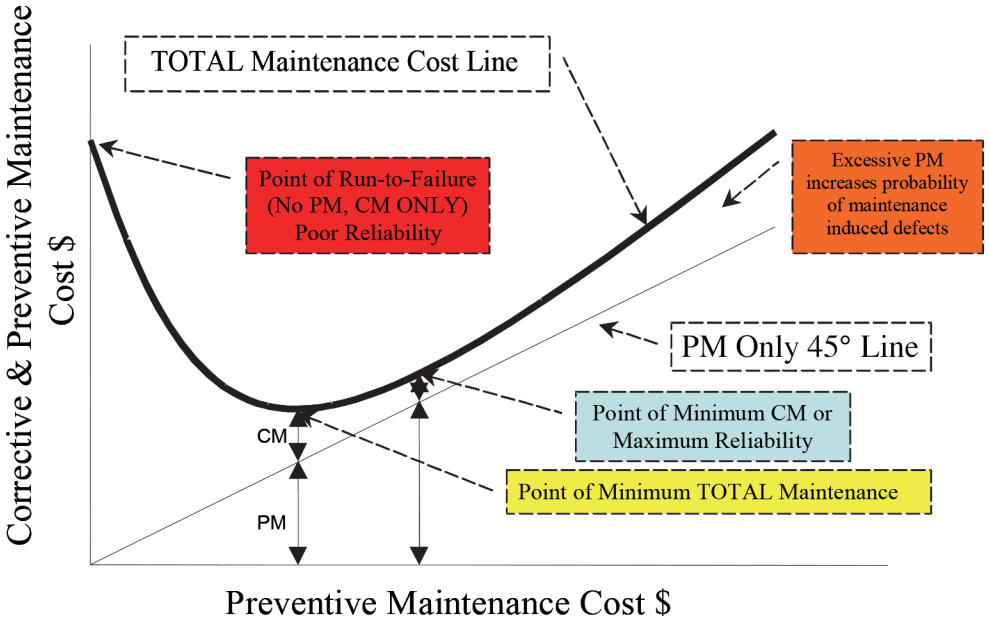


Figure B-1
Relationship Between Equipment Reliability and Maintenance Costs

The point designated by the blue-gray box represents the point where CM costs are minimized and equipment reliability is maximized. The point designated by the yellow box represents the point where total maintenance costs are minimized but equipment reliability is not optimized. The vulnerability tool can assist each licensee in optimizing a given component's maintenance and equipment reliability. The tool can be used to perform one or more of the following tasks:

- Get an overview of recommended PMs
- Understand the technical basis for a given PM
- Address equipment performance issues
  - Failures or poor condition experienced at the licensee's facility
  - Failures or poor performance experienced at other plants
- Conduct a PM assessment by comparing the licensee's plant to the PM Basis
- Adjust the PM frequency or task scope, which may be beneficial when transitioning toward a condition-based maintenance strategy.

B.2.1 Evaluating PM Recommendations for Effectiveness

As noted above, one of the capabilities of the vulnerability tool is evaluating the effectiveness of recommended PM tasks, which enables the licensee to conduct an equipment-focused PM assessment. The maintenance organization is constantly challenged with trying to ascertain whether what they are doing is enough, or too much. The objective of a tiered maintenance approach is to apply maintenance resources to a level commensurate with the component's safety classification, economic significance, and other factors. Industry experience suggests that licensees have defined the various maintenance tiers as follows:

- Minimum maintenance
- Moderate maintenance
- Trendable maintenance
- Extensive maintenance

Intrinsic task effectiveness (H (High), M (Medium), L (Low)) is basic data stored in the component table fields named with the PM Task ID numbers. The intrinsic effectiveness describes how good the task is at detecting the specific degradation mechanism if the task is performed well and on the recommended interval. These values are never changed or overwritten by the code.

Intrinsic task effectiveness, E, connects each PM task to the failure mechanisms it protects against. If E is the probability a degraded condition will be discovered before it becomes a failure, the probability a degraded condition will become a failure before it is detected equals (1 - E), where $0<E<1$ assuming the task is done at the right time.

Overall task effectiveness, E', is the effectiveness of the task on the interval at which it is performed in the specific PM program. Overall task effectiveness is calculated each time the vulnerability tool is run. The overall task effectiveness values additionally take into account the task intervals in relation to the timing of the degradation and are recorded in the component table fields named with the normal names of the PM tasks. Overall task effectiveness is reduced more and more as the task interval exceeds the expected time to the first failure. So H may become M (shown as hM), or L (hL), or zero. M may become L (mL), or zero. The lower case letter indicates the intrinsic effectiveness of the task if it were being performed on the recommended interval. That is, an hM indicates a task that could be highly effective, h, if it were performed on the recommended interval, but is only medium effective, M, on the interval at which it is being performed in the current calculation.

This reduction in task effectiveness is illustrated in Figure B-2.

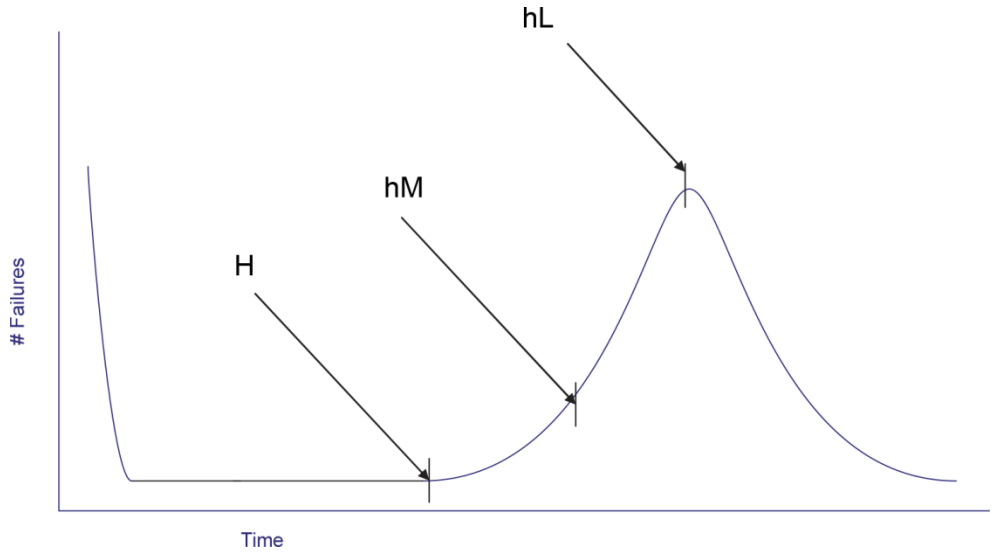


Figure B-2
Reduction of Overall Effectiveness

For one failure mechanism and one PM task, E is modified by changing factors in the algorithm (I, FTime, W, R, etc.) to become E'. The resulting failure rate = degraded rate x (1-E'). If multiple tasks are performed, they are dependent tasks rather than independent tasks, and for a scenario with one failure mechanism and several PM tasks, the factors (1-E') for each task are adjusted to reflect this dependence. In this more complex but common scenario, the failure rate is calculated as follows:

$$\text{Failure rate} = \text{Degraded rate} \times (1\text{-E1'}) \times (1\text{-E2'})^{1/2} \times (1\text{-E3'})^{1/3} \ldots \times (1\text{-En'})^{1/n}$$

For example, if E' is 80% for each of two tasks, the probability of a failure occurring before it is detected is:

$$(1\text{-E1'}) \times (1\text{-E2'})^{1/2} = 0.2 \times (0.2)^{1/2}, \text{ which equates to } 0.2 \times 0.45 = 0.09$$

This is greater than what would be calculated if these were independent events, which would render 0.2 x 0.2 = 0.04. Similarly, for three tasks the result is 0.05, not 0.008.

Key Technical Point

The key to optimizing maintenance tasks and frequencies is to do more highly effective tasks, not just more tasks.

B.2.2 Evaluating Failures for Causes and Corrective Actions

The vulnerability tool helps a licensee analyze how well their PM program protects a component against failures. The color codes provide a quick look at the overall effectiveness and a qualitative level of protection for each failure mechanism. For example:

Red indicates that the PMs provide **poor** protection or none at all.

Orange indicates that the PMs provide **moderate** protection (80% effectiveness).

Yellow indicates that the PMs provide **good** protection (at least one task providing 97% effectiveness).

Green indicates that the PMs provide **excellent** protection (2 or more tasks providing 97% effectiveness).

When evaluating the effectiveness of a given PM, the licensee should use the vulnerability tool to provide an indication of the percentages of total failure modes that are:

- Red
- Red and Common
- Red and Random
- Red and Wear out

The time codes provided in the PMBD should be interpreted as follows:

- Random (R) - Failure can occur at any time
- Wear out (W) - Has a failure-free interval before failures are expected
  - Both are conditional on the degradation mechanism being triggered, i.e., on the existence of the degradation influence
- Unconditional Wear out (UW) - Has a failure-free interval before failures are expected, but Wear out begins at the moment the component is placed in service

Those combinations of color code and time code should then be compared to the percentage of failure modes that are other colors. One could make the following conclusions given the existing conditions:

- >15% Red failure modes means even a good program gives limited protection.
- >5% Red and wear out failure modes are of particular concern. They should be identified, and they probably mean trouble. Note that any Red and wear out failure modes should cause the licensee to consider shorter scheduled task intervals, or adding tasks.
- A large % of Red and random failure modes should cause the licensee to consider shorter condition monitoring intervals, or adding other condition monitoring tasks.

The vulnerability tool can be used to customize a PM by applying various combinations/choices of tasks and intervals. These customized scenarios should prompt the following analysis and questions regarding the effectiveness of the PM and the component's vulnerability to failure:

- Are there more Reds and Oranges than the default?
- What color is the failure experience? (Remember that even the default does not protect everything.)
- Are there Red and wear out failure mode combinations? If so, how do you provide for reliability?
- If there are many Red and random failure mode combinations, then the licensee should question whether predictive PM is sufficient.
- If the hL trending pattern is prevalent, then the licensee should consider checking the intervals.
- Failure modes in Yellow or Green rows suggest the licensee should check task content, implementation, skills, and procedures.

B.2.3 Addressing Failures in Green and Yellow

As noted in the previous section, the EPRI PMBD is set up and color coded to reflect the following levels of protection against failure modes:

Red indicates that the PMs provide **poor** protection or none at all

Orange indicates that the PMs provide **moderate** protection (80% effectiveness)

Yellow indicates that the PMs provide **good** protection (at least one task providing 97% effectiveness)

Green indicates that the PMs provide **excellent** protection (2 or more tasks providing 97% effectiveness)

Each licensee controls the chance of experiencing failures in the following three ways:

- By the number of unprotected failure mechanisms
- By the degree of reliance placed on the tasks that address priority failure mechanisms (i.e., address them with one, two, or more tasks)
- By the choice of task intervals that affect task effectiveness

If failures are still being experienced then, the licensee should consider the root cause to be one of the following:

- The PM is performing the **wrong task.**
- The task contains **inadequate content.**
- The task is being **performed incorrectly.**



Key Technical Point

If you experience failures in green and yellow and you are performing the high-effectiveness tasks, you may not be performing them effectively. You should be able to improve PM defenses against such failures by modifying your PM program to be closer to the recommendations.



Key Technical Point

If you experience failures in green and yellow, and you are currently performing the high-effectiveness tasks, you should suspect that task scope or implementation might be improved.



Key Human Performance Point

If you experience failures in green and yellow, you are currently performing the high-effectiveness tasks, the task scope is correct, and the tasks are being implemented properly, you should examine your training program, personnel qualifications, and quality of procedures.

B.3 Interval Sensitivity

Task effectiveness can be affected by revising the frequency of the task and by stressors. Table B-1 illustrates this relationship.

Table B-1
Interval Sensitivity

	H	hM	hL	h_
For UW (*x*) – (No Stressor Effect)	*Interval* <= *x*	*x* < *Interval* <= 1.5(*x*)	1.5(*x*) < *Interval* <= 2(*x*)	2(*x*) < *Interval*
For UW (*x_y*) – (No Stressor Effect)	*Interval* <= *x*	*x* < *Interval* <= *y*	*y* < *Interval* <= 2(*y*)	2(*y*) < *Interval*
For UW (*x*) – (Stressor Effect)	*Interval* <= 0.5(*x*)	*x* < *Interval* <= 1.5(*x*)	1.5(*x*) < *Interval* <= 2(*x*)	2(*x*) < *Interval*
For UW (*x_y*) – (Stressor Effect)	*Interval* <= 0.5(*x*)	0.5(*x*) < *Interval* <= 0.5(*y*)	0.5(*y*) < *Interval* <= *y*	*y* < *Interval*
W *(x)* – (Both with and without Stressors)	*Interval* <= *x*	*x* < *Interval* <= 1.5(*x*)	1.5(*x*) < *Interval* <= 2(*x*)	2(*x*) < *Interval*
W *(x_y)* – (Both with and without Stressors)	*Interval* <= *x*	*x* < *Interval* <= *y*	*y* < *Interval* <= 2(*y*)	2(*y*) < *Interval*

Table B-2 illustrates the impact of removing or extending the interval of a particular task on the Task Effectiveness/Program Effectiveness (i.e., H/Green).

Table B-2
Impacts of Removing or Extending the Interval of a Particular Task

	L, hL, mL, /gray, [blank]	M, hM	H
Red	Won't Change Program Effectiveness		
Orange	Won't Change Program Effectiveness	Could Have Impact	
Yellow	Won't Change Program Effectiveness	Won't Change Program Effectiveness	Will Have Impact
Green	Won't Change Program Effectiveness	Won't Change Program Effectiveness	Could Have Impact

The vulnerability tool can also be used to evaluate overhaul and refurbishment intervals. The vulnerability tool can calculate annual failures based on program. The failure rate will change as a function of interval by holding everything else constant and changing the interval for refurbishment. Table B-3 illustrates how annual failure rate is affected by changing the refurbishment interval times.

Table B-3
Impacts of Changing Refurbishment Intervals

Refurbishment Interval – Years	Annual Failure Rate
5	0.5359
10	0.6500
12	0.7150
15	0.7154
17	0.7475
20	0.7475
25	0.7761
35	0.7819

The graph in Figure B-3 illustrates the general impact that extending refurbishment intervals has on the annual failure rate of a component.

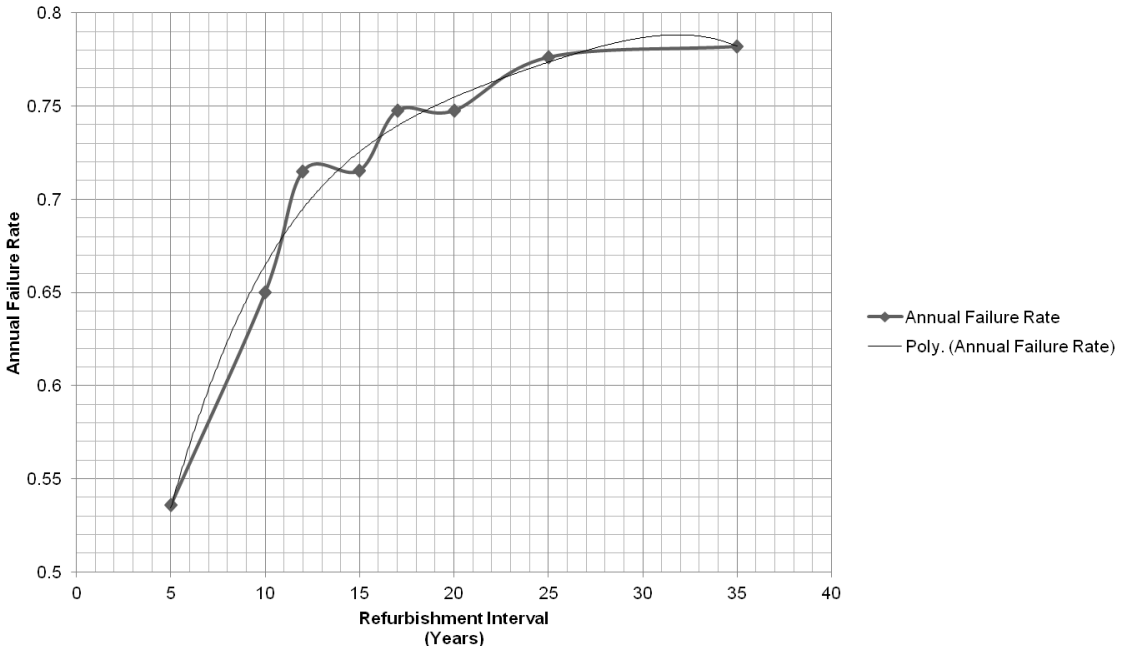


Figure B-3
Impacts of Changing Refurbishment Intervals

B.4 Task Deferral Using the PM Basis

The vulnerability tool can also be used to assess the impact of deferring PM tasks. A deferral is different than changing an interval, because the deferral is meant to be done once, whereas changing the interval implies a permanent change that will remain in effect going forward. The following definitions are provided to help the user understand what is meant by a deferral.

- PM Deferral: (Postponement) Justification to exceed the grace date based on documented evaluation of the equipment condition and requirements
- Grace Period: The allowed frequency extension for a PM task calculated from the due date, not to exceed 25% of the frequency. For PM tasks not allowing grace, such as EQ tasks, the grace date equals the due date.
- Overdue: A PM task is considered overdue when it has exceeded its due date.
- Late Date: (Past Grace) The date when a PM has been determined to have exceeded its due date plus the grace period. Calculated by adding the grace period to the nominal due date.
- Late: A PM has been determined to be late when it has exceeded the Late Date.

Figure B-4 illustrates a timeline of activities and how tasks may be deferred.

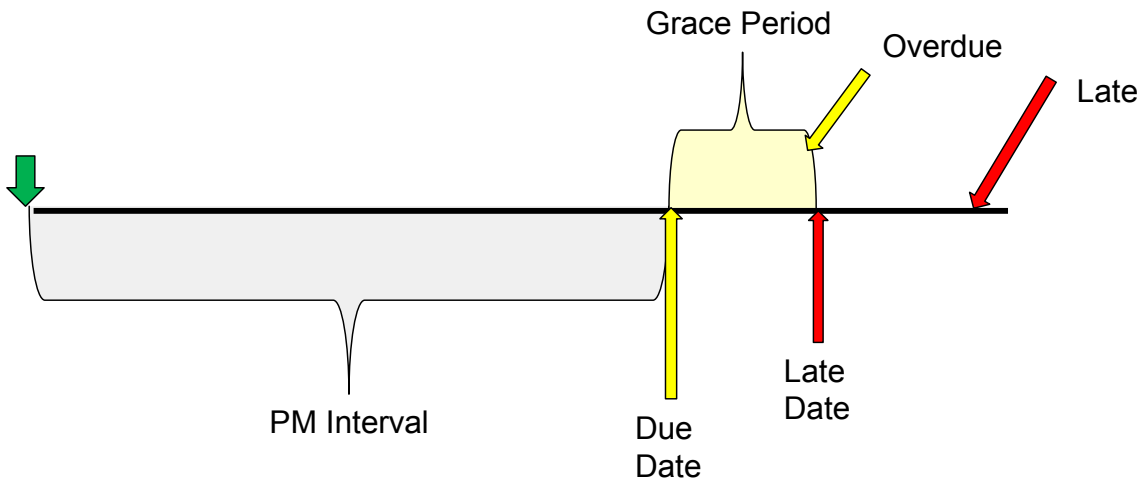


Figure B-4
PM Deferrals, Grace Period, and Late Dates

The following scenarios typically justify when a deferral is warranted:

- A PM Deferral is required when an activity is not going to be performed before the end of its grace period.
- A PM Deferral is not required when a permanent change in PM frequency is more appropriate.
- A PM Deferral is not required for the following types of activities:
  - Support activities, such as installation of scaffolding in support of a PM or refueling outage preparations
  - PM activities that have been "turned off" because the related equipment is out of service and there is no need to perform the PM

The following information is typically needed when justifying a PM deferral:

- Functional importance, duty cycle, and service conditions
- Current scope and basis for the preventive maintenance activity being proposed for deferral
- Previous maintenance feedback for the PM being proposed for deferral
- Previous deferrals of the PM being proposed for deferral
- Status of other PMs on the component being addressed by the PM being proposed for deferral
- Site-specific failure history associated with this and similar components
- Industry operating experience associated with this type of component

The following activities should be performed when conducting a deferral evaluation for any given PM:

- Criticality, duty cycles, and service conditions for the affected component(s) should be documented. The criticality in this step will be used to determine the consequence of failure. Duty cycles and service conditions are used to aid in determination of the probability of failure.
- Review the PM Basis to determine if there is anything in the current PM Basis that would indicate that the PM should not be deferred.
- Are there any commitments that would prevent deferral of this PM?
- Does the PM being proposed address significant and likely failure modes?

By deferring the PM in the vulnerability tool, the following questions will be answered:

- Does previous feedback on this PM indicate degraded conditions that would indicate that the PM should not be deferred? If so, the risk associated with this deferral is higher.
- Has this PM already been deferred? A second deferral of this PM could significantly increase the risk associated with the failure of this component. A second deferral should be treated as a task interval change.
- Are there any performance issues in health reports that would indicate that this PM should not be deferred?
- What is the probability of this component failing after the late date and prior to the planned performance of this PM? (Low, Medium, or High)

After using the vulnerability tool, the licensee can decide if the technical risk of deferral is acceptable. This will be a qualitative decision. The licensee should then document the basis, or thinking, behind this decision.



Key O&M Cost Point

When contemplating the merits of deferring a PM task, the licensee should also consider the cost if the component associated with this PM fails prior to the PM activity being performed. The cost consequence of deferral of this PM should be acceptable.

The following actions should typically be taken after the deferral is approved:

- Alert Operations that this PM activity is being deferred and that closer attention should be paid to this component.
- Use the information from the vulnerability analysis to identify the specific vulnerabilities.
- Consider whether specific additional monitoring information may be appropriate to ensure focused attention on the likely failure mode(s).

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