Electric Motor Predictive Maintenance

Draft Guidelines

TR-108773-V1

Final Report, September 1997

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REPORT SUMMARY

Predictive Maintenance can enhance the early detection and avoidance of incipient equipment failures in electric motors. This report provides draft guidelines to support the development of electric motor predictive maintenance (EMPM) programs at utility sites.

Background

Electric motor maintenance has been a time-based function for many years, often driven by vendor recommendations requiring excessive and sometimes unnecessary preventive maintenance practices. Unexpected motor failures can lead to lost generation and necessitate time-consuming corrective maintenance. Responding to a need for increased motor reliability and more efficient maintenance practices, EPRI initiated a Tailored Collaboration program to implement a predictive maintenance program for electric motors.

Objectives

To provide assistance in the development of Electric Motor Predictive Maintenance programs at utility sites, including the data collection, storage, evaluation, and communication needed to establish a successful program; to develop a software database to provide basic data and retrieval capabilities for EMPM programs.

Approach

The project team collected data and produced draft guidelines on electric motor condition monitoring. The team also created a beta version of a software database to provide basic data and retrieval capabilities for EMPM programs.

Results

These draft guidelines provide basic instruction for applying various electrical and condition monitoring tests on 3-phase induction motors of 4kV and above. The guidelines introduce each testing method, describe test equipment, provide basic instructions for performing the test, and discuss and evaluate available acceptance criteria. Electrical testing techniques covered include:

- Insulation resistance
- Polarization index

- DC step voltage test
- Winding resistance
- Dissipation factor and capacitance test

Condition monitoring tests include:

- Vibration analysis
- Thermography inspection
- Lube oil analysis
- Motor current analysis for broken rotor bars

The guidelines also discuss the criteria for choosing which electric motors should be selected for initial inclusion in a predictive maintenance program.

EPRI Perspective

These are draft guidelines only and should be considered experimental. Data is still being collected and will be published at the end of the project as a second volume of this report. Input from those utilities that wish to use these guidelines should be referred to Jan Stein at EPRI (jstein@epri.com) or by mailing the suggestion card. The EMPM database program will be upgraded to include expert system analysis capabilities that can automatically and consistently assess the type and extent of maintenance needed to preserve equipment life.

TR-108773-V1

Interest Categories

Fossil steam plant O&M cost reduction
Motors and pumps

Key Words

Predictive maintenance
Electric motors
Reliability-centered maintenance

ABSTRACT

Predictive maintenance (PM) programs provide a strategy to condition monitor equipment to enhance early detection and avoidance of incipient equipment failures. In a Tailored Collaboration project among EPRI and a number of electric utilities, draft guidelines were prepared to support a predictive maintenance program for electric motors at utility sites. Besides discussing the criteria for choosing which motors to include in a PM program, the guidelines give basic instructional information for performing a wide range of electrical and condition monitoring tests, including several new technologies such as vibration analysis, thermographic inspection, and lube oil analysis.The guidelines are preliminary and should be considered experimental. Additional data is being collected to produce finalized guidelines.

ACKNOWLEDGMENTS

The principle investigators would like to thank the following people for their contributions to the draft guidelines.

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Robert Hammaker

Steve Braden

Robert Woyshner

Rick Leonard

Jeff Evans

John Niemkiewicz

IRIS Power Engineering

Greg Stone

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INTRODUCTION AND OVERVIEW

Utilities and industrial users are optimizing maintenance and operations strategies to reduce Operation and Maintenance (O&M) costs and avoid forced outages. Reliability-Centered Maintenance (RCM) program studies have been adopted to identify cause and effects, while providing better direction to preventive maintenance activities. Predictive Maintenance (PDM) programs provide the strategy to condition monitor equipment to further enhance early detection and avoidance of incipient equipment failures. Published studies report a significant (98%) reduction in equipment breakdowns, 30-50% reduction in maintenance costs, and reduced manpower requirements. One report identified savings 10-50 times the cost of implementation. Another demonstrated that, at one plant, the implementation of various monitoring and diagnostic techniques resulted in annual savings of $5.3 million. Still another utility saved $516,000 by adopting RCM for a condensate pump motor which prevented a unit forced outage.

Electric motor maintenance was for many years a time-based function, often driven by vendor recommendations that required excessive, and sometimes unnecessary, preventive maintenance practices. A great deal of time was also being spent on corrective type maintenance which was due to unexpected failures often causing manpower problems and loss of generation. Recognizing the need to operate more efficiently and increase motor reliability, a Tailored Collaboration program was initiated by EPRI to implement a predictive maintenance program for electric motors.

This program addressed the programmatic aspects of effective communication of information which are a result of the Predictive Maintenance (PDM) activities. Various electrical condition monitoring techniques were performed such as:

- Insulation Resistance (IR)
- Polarization Index (PI)
- DC step voltage test (4kV only)
- Winding resistance
- Dissipation factor and capacitance test

- Heater testing

In addition, various new condition monitoring technologies were also included, where applicable, such as:

- Vibration analysis
- Thermography inspection
- Lube oil analysis
- Motor current analysis for broken rotor bars

The program began in late 1994 and for almost two years has collected data, produced draft guidelines, created a beta version EMPM software database and investigated new technology applications for electric motor condition monitoring. To date, 131 anomalies have been detected as a result of this program. Benefit calculations performed on the first 10% of those anomalies has resulted in a cost savings in excess of $1 million dollars.

Objective

The project objective was to provide assistance in the development of Electric Motor Predictive Maintenance (EMPM) programs at utility sites which include data collection, storage, evaluation, and communication needed to establish a successful program. Another objective was to enhance the software database that provides the basic data storage and retrieval capabilities. A final goal was to provide software functions with this database that automates the process of evaluating motor condition from the input data. This would include expert system analysis capabilities which will automatically and consistently assess the type and extent of maintenance needed, consistent with preservation of equipment life and cost minimization.

As an extension to the ongoing project , new utilities that continue to join the TC project have evaluated and enhanced existing project tasks and objectives by providing additional motor data and software development evaluation.

These draft guidelines were developed as part of the original project effort. The guidelines are for performing electrical and condition monitoring tests on large 3-phase induction motors (4kV and above). The guidelines address the specific testing method and test equipment as well as providing basic instructional information for performing the test. Acceptance criteria, as available, are applied; and, an evaluation of the acceptance criteria is being performed. The draft guidelines provide basic instruction for applying various electrical and condition monitoring tests. The Final Guidelines will be developed prior to the completion of the project.

These are draft guidelines only, and as such, should be considered as experimental. The data is still being collected and will be published as a Final Report at the completion of the project. Input from those utilities that wish to use these guidelines should be referred to Jan Stein at EPRI (jstein@epri.com) or by mailing the suggestion card found in the back of the report.

Selection of Motors

The selection of motors to be included in a monitoring program is based on a combination of factors. The first consideration involves understanding the motor's impact on the plant in both the areas of safe operation and production. Secondly, if this motor is expensive to repair or replace, it should be considered for selection into the program. An additional consideration is the motor maintenance history which involves some research of past repairs and the parts used. There may also be other factors to be considered before selection - ease of data collection, age and/or environment. Each plant will have different concerns and may factor motor selections differently as well.

As an aid to troubleshooting it may be helpful to choose similar motors; for instance, all of the feedpump motors or draft fan motors. This approach will provide direct comparisons of data to determine uncharacteristic vibration conditions.

Motors, therefore, should be selected for initial inclusion in a predictive maintenance program based on one or more of the following criteria:

- Equipment critical to plant safety
- Equipment critical to power generation
- Equipment of high initial cost
- Equipment with high corrective maintenance costs

Note: *These criteria are meant as guidelines and are not intended to be all-inclusive.*

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ELECTRICAL TESTING OF MOTOR STATOR WINDINGS

The purpose of this guideline is to provide instruction for an effective and consistent method of performing the electrical field tests of induction three phase medium and high voltage motor stator windings. ***These instructions are to be used as guidelines only and are intended for use on most form wound, three phase, medium and high voltage motors. All test data should be reviewed by the appropriate personnel before re-energizing the equipment.***

Project Objectives

The objectives of this guideline are to provide general guidance to perform the following electrical tests, and to assure that the test data is acquired in a consistent manner.

- Motor Winding Resistance Measurements
- Motor Capacitance/Dissipation Factor Test
- Insulation Resistance Test
- Absorption Test
- DC Step Voltage Test

The above tests were chosen to evaluate their effectiveness when included as part of an electric motor predictive maintenance program. An evaluation of the test data will be performed, and the results will be correlated with other predictive maintenance data acquired from the application of technologies in the Electric Motor Predictive Maintenance (EMPM) Program.

Precautions and Limitations

The precautions and limitations of this guideline shall be based on each site's electrical safety practices; and, on each site's training requirements for the individuals involved with the EMPM program.

Prerequisites

The amount of equipment, personnel, and information necessary to maximize the effectiveness of this guideline are identified.

Equipment Required

Table 2-1 includes the test equipment required for an effective program. It also serves as a data sheet to record the test equipment manufacturer, model and/or serial number, and the calibration date.

Table 2-1
Equipment Matrix

Description	Manufacturer	Model	Calibration Date
Megohm Meter, Electronic or Motor Driven			
High Voltage DC Test Set			
Wheatstone Bridge, Kelvin Bridge			
Digital Low Resistance Ohmmeter (DLRO)			
Capacitance/Dissipation Bridge			
Timing Device			
Psychrometer or any other humidity Indicator			
Thermometer			
R.T. D. Thermocouple Bridge			

If at all practical, the same test equipment should be used as was used in prior testing to ensure the best correlation of data.

Personnel Required

Experienced Electrical Maintenance personnel who are qualified to operate the necessary test equipment should be selected to conduct the tests.

Information Required

Prior to testing, the three-phase motor amps should be recorded; and, any significant unbalances should be noted.

On the appropriate tables and Appendices, record the plant and motor operating conditions at the time of electrical testing, including the following:

a) The station and unit number being surveyed

b) The component tag number of the motor

c) The motor nameplate data

d) The date and time of the survey

e) The test technician's name

The original motor factory test sheet should be reviewed; and, the original polarization index and stator winding resistance information should be noted.

Electrical Tests

Test Set-Up

Step 1: Ensure that all appropriate safety blocking, tagging, and lock-out procedures are in place (per each site's electrical safe practices).

Step 2: Visually inspect the motor under test for signs of obvious damage or required maintenance and document these observations on the test report.

Step 3: All testing should be done from the MCC (Motor Control Center).

Step 4: When the test results are questionable, disconnect all cables and retest from the motor leads.

Step 5: Record all nameplate data (Refer to Figure 2-1).

Step 6: Isolate any motor power factor or surge capacitors, and surge arrestors.

Step 7: Short out and ground all winding RTDs and current transformers.

Step 8: Perform all of the test equipment self diagnostics; and, ensure the integrity of the lead insulation and the continuity of the leads and connections.

Step 9: If a test truck or dummy breaker is used, ensure that it is clean, then record its resistance shown in Table 2-2 as part of the test results. (Its resistance is measured by performing a 30 second spot test with all three poles grouped together.)

Note: *A test truck or dummy breaker should be stored under a cover to assure its cleaniness, as the cleaniness of this device affects its resistance which will be reduced if contaminated. If the insulation resistance is not extremely high, service the test truck prior to performing the motor insulation tests. A low resistance would be an indication of a dirty or contaminated test truck and this condition should be addressed before continuing.*

Table 2-2
Test Truck or Dummy Breaker

Test Truck or Dummy Breaker		
Insulation Resistance	____________	M-OHMS

Company:____________
Station:____________
Date:____________

Drawing No:____________
Identification No:____________
Equipment:____________
Equipment No:____________

MOTOR

Manufacturer:____________
Serial No:____________
Frame:____________
Type:____________
Model:____________
Duty:____________
Frequency:____________
Code:____________
Design Letter:____________
Temperature Rise:____________
Class:____________
Original Mfg. Date:____________

Service Factor:____________
HorsePower:____________
R.P.M.____________
Amperes:____________
Volts:____________
Phase:____________
Temperature Ambient:____________
Insulation:____________
Rewind Date:____________

BRAKE

Manufacturer:____________ Model:____________
Torque:____________
Volts:______ Phase:______ Duty:______ Ser. No.____________
Comments:

Data Taken By:____________ Date:____________

Figure 2-1
Motor Name Plate Data Sheet

Motor Winding DC Resistance Measurements

Three-Phase.

For resistance measurements of three-phase medium and large voltage form-wound motor windings, perform the following:

Step 1: Short and ground all windings for one minute.

Step 2: Remove the ground from the windings to be tested.

Step 3: Connect a Kelvin Bridge, Wheatstone Bridge, or DLRO across the terminals to measure the resistance of the motor windings.

Step 4: Record the motor winding temperature.

Step 5: Measure the resistance of the windings and record this information on the data sheet.

Step 6: Disconnect the Bridge or DLRO from the winding terminals.

Step 7: Correct the resistance to 40°C using the following formula and record the value in Table 2-3:

$$Rt = \frac{274.5}{234.5 + Tm} \times Rm$$

Rt = Corrected Resistance at 40°C

Rm = Measured Resistance

Tm = Measured Temperature in Centigrade

Note: This formula will yield slight variations if the motor cable temperature is different than the motor temperature, or if the motor cable is not copper.

Step 8: Repeat Steps 2 through 6 as necessary for the remaining windings.

Table 2-3
Resistance of Winding Data Sheet

TERMINALS	READING (OHMS)	CORRECTED TO 40°C
A-B		
B-C		
C-A		

Motor Winding Temperature ☐

☐ With Motor Cable ☐ Without Motor Cable

Interpretation

The three temperature-corrected DC resistance measurements between the phase leads should all be within ± 5% of each other. If one phase is more than 5% higher than the other phases, visually inspect the connections.

Compare the present test results with those from earlier tests performed using the same test equipment. If there has been an increase of more than 5% in the resistance since the previous measurement, inspect the connections.

High DC resistance is an indication that the connections may have oxidized or loosened. In addition, high DC resistance may indicate that some strands or coil connections within the winding may have cracked. In addition to visual inspections of the electrical connections, the user may want to scan the connections with thermovision equipment to locate overheating connections during motor operation.

Motor Capacitance/Dissipation Factor Test

AC motor

IF testing an AC motor rated at **480 volts or greater**, **THEN** perform the following:

Step 1: Ensure that any surge packs or power factor surge capacitors are disconnected from windings, if applicable.

Step 2: Short and ground the motor windings for one minute.

Step 3: Remove the ground.

Step 4: Connect a capacitance bridge between the phases and ground.

Step 5: Measure the winding capacitance and insulation dissipation factor of the combined phases and record this data in Table 2-4.

Step 6: Disconnect the capacitance bridge.

Step 7: **IF** the single-phase capacitance/dissipation test data is **NOT** desired, **THEN** proceed to Step 15.

Step 8: **IF** the motor leads are disconnected **AND** the neutral connection is open, **THEN** short and ground each winding.

Step 9: Isolate one winding.

Step 10: Connect a capacitance bridge between the winding and the frame/ground.

Step 11: Measure the winding capacitance and insulation dissipation factor **AND** record this data in Table 2-4.

Step 12: Disconnect the capacitance bridge.

Step 13: Short and ground the winding just tested.

Step 14: Repeat Steps 9 through 13 as necessary for each winding.

Step 15: Remove the shorts and grounds from the windings.

Table 2-4 Capacitance Test/Dissipation Test

	TEST METHOD	CAPACITANCE (MicroFarad)	DISSIPATION (%)
1	Windings Grouped		
2	Windings Isolated Phase A		
	Windings Isolated Phase B		
	Windings Isolated Phase C		

Conditions

Wet Bulb	________	Psychrometer	________
Dry Bulb	________		
Relative Hum.	________	Dew Point	________
Thermometer	________		

☐ With Motor Cable ☐ Without Motor Cable

Interpretation

The basic interpretation of capacitance and dissipation factor data is based on the fact that the capacitance of thermally deteriorated insulation decreases over time, whereas the dissipation factor increases. In contrast, if the winding has been contaminated with partly conductive oil or water, both the capacitance and dissipation factor increase. Windings in good condition will have a stable capacitance and dissipation factor over time.

Capacitance

A single measurement of the capacitance conveys no information on the condition of the winding at all. It is the trend in capacitance over time that is meaningful. The change in capacitance over time due to winding deterioration is usually small; however, a change of capacitance of only 2 or 3% indicates that severe deterioration may be present. Thus, the capacitance measuring device must be accurate and precise, if useful information is to be collected. If the capacitance test is done from the MCC, the capacitance of the power cable may dominate the readings and, therefore, little diagnostic information on the condition of the motor is obtained. Usually, the capacitance test is only sensitive to winding condition, if the test is performed at the motor terminal box.

Dissipation Factor

A single dissipation factor measurement may provide information on the condition of the stator winding insulation, if the type of insulation is known. The dissipation factor should not exceed 1% for epoxy-mica windings, 3% for polyester mica windings, or 5% for asphaltic mica windings, when measured at room temperature.

The trend in the dissipation factor over time is a more sensitive way of determining winding condition. If the dissipation factor increases by more than 5% (for example from 0.540% to 0.570%) from a previous measurement, then thermal deterioration or winding contamination may have occurred. This small change requires that the dissipation factor test be done with the same measurement equipment that is accurate and precise. The dissipation factor of a motor can be reliably measured from the MCC if the power cable connecting the MCC to the motor is insulated with polyethylene or EPR. Cables made with oil-paper or butyl rubber have such a high natural dissipation factor, that the motor winding dissipation factor cannot be measured.

Insulation Resistance Test Preparation

Note: A Motor Winding Resistance check should be performed prior to this test, and the winding temperature should be above the dew point.

Step 1: Calculate minimum acceptable resistance at 40ºC using the following formula:

Megohms = kV + 1

where,

Megohms = insulation resistance in Megohms

kV = motor voltage rating in kilovolts

Step 2: Record the minimum acceptable resistance on the test sheet form shown in Figure 2-2.

Step 3: Short all three phases together

Step 4: Perform the following Test

1. Using a Volt-Ohm Meter, measure the motor insulation resistance to frame/ground to determine that it exceeds the minimum value recorded in Step 2.

2. If the motor passes the above test, then proceed with the Insulation Test.

Insulation Resistance Test

Step 1: Apply the test voltage as specified in Table 2-5 and record this voltage on the test sheet form shown in Figure 2-2.

Step 2: Measure the motor insulation resistance to ground for a period of one minute and record this information on the test sheet form shown in Figure 2-2.

Step 3: Record the winding temperature on the data sheet shown in Figure 2-2.

Step 4: Correct the resistance to 40°C using the correction factor (Kt) from the Temperature Correction Chart (Refer to Figure 2-3).

Step 5: Record the test conditions on the data sheet shown in Figure 2-2.

Step 6: Record whether or not the test was performed with or without cables on the data sheet shown in Figure 2-2.

Step 7: Proceed with the polarization index test.

Figure 2-2
Preliminary Insulation Resistance Test Sheet

Minimum Acceptance Resistance Corrected to 40°C______________ Megohms

Measured Resistance Reading _______________ Megohms

Corrected Resistance Reading _______________ Megohms

(Corrected Reading @ 40°C = Measured Reading x Kt)

(One Minute Duration)

Conditions

Wet Bulb: _________________

Psychrometer: _________________

Dry Bulb: _________________

Relative Humidity: _________________

Thermometer: _________________

Winding Temperature _________________

Applied Test Voltage _________________

☐ With Motor Cable ☐ Without Motor Cable

Table 2-5
Motor Voltage to Megohmeter Voltage

Motor Voltage	**Test Voltage**
Less than 600 volts	500 volts
2.3KV to 13.1 KV	2500 volts
13.2 KV and higher	5000 volts

Interpretation

The minimum acceptable one minute insulation resistance (IR_1) depends on the stator winding insulation material. If the IR_1 corrected to 40°C is greater than (kV+1) megohms, then this is acceptable for asphaltic mica windings. If the corrected IR_1 is greater than approximately 100 megohms (for any voltage class), then this is acceptable for epoxy mica and polyester mica windings. Readings lower than these thresholds indicate that the winding has been contaminated with a partly conductive film of oil or moisture, or that the winding insulation has cracked, exposing the copper conductors. The winding should be dried, cleaned, or at least inspected, before being returned to service.

If the insulation resistance test has been used over the years, and the readings have always been made at temperatures above the dew point, then the trend in IR_1 may indicate that gradual deterioration from pollution or moisture absorption is occurring. Increased deterioration is indicated by a decrease in IR_1 over time.

Absorption Test (Polarization Index)

Note: *Perform the Insulation Test prior to performing the Absorption Test. This will determine if the motor will withstand the Absorption Test.*

Step 1: Momentarily short and ground the windings.

Step 2: Connect between winding(s) to be tested and frame/ground.

Note: Time requirements on the Data Sheet should be reviewed prior to commencement of the next step to allow timely data collection.

Step 3: Apply the test voltage as specified in Table 2-5, and record this value on the data sheet shown in Figure 2-4.

Step 4: Record the winding temperature on the data sheet shown in Figure 2-4.

Step 5: Record the test conditions on the data sheet shown in Figure 2-4.

Step 6: Record on the data sheet shown in Figure 2-4 whether or not the test was performed with or without cables.

Step 7: Record the readings in Figure 2-4 at the time intervals indicated.

Step 8: Disconnect the equipment.

Step 9: Ground the windings for a period of time equal to four times the test time, or one hour, whichever is greater.

Step 10: Correct all measured resistance to 40°C using the correction factor (Kt) from the Temperature Correction Chart (Refer to Figure 2-3).

Step 11: Calculate the Polarization Index (PI) by dividing the 10 minute reading by the 1 minute reading. Record on data sheet.

Winding Temp °C	Correction Factor Kt	Winding Temp °C	Correction Factor Kt	Winding Temp °C	Correction Factor Kt	Winding Temp °C	Correction Factor Kt	Winding Temp °C	Correction Factor Kt
-10	0.031	13	0.154	36	0.758	59	3.73	82	18.40
-9	0.033	14	0.165	37	0.812	60	4.00	83	19.70
-8	0.036	15	0.177	38	0.871	61	4.29	84	21.10
-7	0.038	16	0.189	39	0.933	62	4.59	84	22.60
-6	0.041	17	0.203	40	1.00	63	4.92	86	24.30
-5	0.044	18	0.218	41	1.07	64	5.28	87	26.00
-4	0.047	19	0.233	42	1.15	65	5.66	88	27.90
-3	0.051	20	0.250	43	1.23	66	6.06	89	29.90
-2	0.054	21	0.268	44	1.32	67	6.50	90	32.00
-1	0.058	22	0.287	45	1.41	68	6.96	91	34.30
0	0.063	23	0.308	46	1.52	69	7.46	92	36.80
1	0.067	24	0.330	47	1.62	70	8.00	93	39.40
2	0.072	25	0.354	48	1.74	71	8.57	94	42.20
3	0.077	26	0.390	49	1.87	72	9.19	95	45.30
4	0.082	27	0.406	50	2.00	73	9.85	96	48.50
5	0.088	28	0.435	51	2.14	74	10.60	97	52.00
6	0.095	29	0.467	52	2.30	75	11.30	98	55.70
7	0.102	30	0.500	53	2.46	76	12.10	99	59.70
8	0.109	31	0.536	55	2.64	78	13.00	100	64.00
9	0.117	32	0.574	55	2.83	78	13.90	*	*
10	0.125	33	0.616	56	3.03	79	14.90	*	*
11	0.134	34	0.660	57	3.25	80	16.00	*	*
12	0.144	35	0.707	58	3.48	81	17.10	*	*

$$R_c = K_t \times R_t$$

R_c = Resistance at 40°C

K_t = Correction Factor

R_t = Resistance at Measured Temperature

Figure 2-3
Temperature Correction Chart (Kt)

TEST DATE________________
TEST VOLTAGE____________

	MEASURED READING (Megohms)	CORRECTED READING - 40°C (Megohms)
Minutes		
.25		
.50		
.75		
1.0		
2.0		
3.0		
4.0		
5.0		
6.0		
7.0		
8.0		
9.0		
10.0		
PI=10/1		
REMARKS		

Conditions

Wet Bulb ______Psychrometer __________
Dry Bulb ________________________
Relative Humidity ________________
Thermometer _____________________
Winding Temperature _____________

☐ With Cable ☐ Without Cable

________________ **Minimum Acceptable Insulation (MEGOHMS @ 40°C)**

Figure 2-4
Motor Winding Polarization Index Test Sheet

Interpretation. For asphaltic mica windings and the older (pre 1970) polyester mica windings, the polarization index can be interpreted as follows:

PI<1	The winding is very deteriorated by the absorption of moisture; and/or, the end windings have been polluted with partly conductive moisture, oil or other contaminants.
1<PI<2	Some deterioration is occurring due to moisture or pollution.
2<PI<7	The winding is clean and dry.
PI>7	The insulation may be brittle due to thermal aging of the insulation.

For modern epoxy and polyester windings, the PI can be interpreted as follows:

PI<1	The winding is contaminated with moisture or oil.
1<PI<2	Some contamination of the winding by moisture or oil is present.
P>2	The winding is clean and dry.

If the IR_1 is greater than 1,000 megohms when testing an epoxy or polyester mica winding, many users may not perform the 10 minute test, since it is clear that the winding is clean and dry.

DC Step Voltage Test

CAUTION

Insulation, PI, and Capacitance/Dissipation Test results should be reviewed before performing the DC Step Voltage Test. Site procedures on Test Voltage Limits must be adhered to, since this test can possibly cause winding insulation failure. The impact of a winding failure should be carefully considered.

Step 1: Record all test conditions as shown in Figure 2-5.

Step 2: Determine the maximum test voltage. Momentarily short and ground the windings for one minute.

Step 3: Short and ground all windings not under test.

Step 4: Connect a High Voltage DC Test Set between the windings to be tested and ground.

CAUTION

At any time during this test, if the winding insulation appears to be failing due to a sudden increase in current, then the test should be discontinued immediately.

Step 5: Increase the voltage to the first step value in Figure 2-5, and maintain for a specified time interval.

Step 6: After the time duration specified, record the stabilized current on the data sheet shown in Figure 2-5. For very large motors, a longer time may be needed for the readings to stabilize.

CAUTION

If the test current continues to rise or decrease sharply while voltage is being maintained, an insulation failure may be pending.

Step 7: Increase the voltage to the next step value as indicated in Figure 2-5.

Step 8: After the duration specified, record the current in Figure 2-5.

Step 9: Repeat Steps 6 and 7 as necessary until the maximum test voltage has been obtained.

Step 10: Slowly reduce the test voltage to zero and allow the winding(s) to discharge through the test set.

Step 11: Ground the windings with a resistive loaded ground stick until the test instrument indicates zero volts.

Step 12: Disconnect the test set from the winding.

Step 13 Short and ground the winding(s) under test.

Step 14: Allow the windings to discharge for a time duration equal to the duration of the test.

Step 15: Remove any shorting and grounding devices that were installed.

Step 16: Using the test voltage and corresponding leakage current, calculate the insulation resistance for each voltage step (Insulation Resistance = Test Voltage / Leakage Current). Record these calculations on the data sheet shown in Figure 2-5.

Interpretation. The main purpose of the DC step voltage test is to apply a high dc voltage to the stator insulation, while at the same time reducing the risk of insulation breakdown from a major insulation defect.

While the test is being conducted, plot the current (on the vertical scale, measured at the end of the one minute stabilization period) versus the applied voltage (on the horizontal scale) on linear scales. In a good winding, the current versus voltage plot should produce a straight line. If, as the voltage increases, the current starts increasing faster than normal (i.e. the plot is curving up, rather than being a straight line), then incipient insulation breakdown may be occurring. The test should then be stopped immediately, to prevent complete breakdown, even though the maximum test voltage has not been reached. This warning of incipient failure usually only occurs if the insulation defect is in the endwinding portion of the coils. If the defect is in the slot, usually no warning of impeding breakdown is given.

Assuming that breakdown or current instability does not occur, the stator winding has successfully withstood a hipot test. This implies that there are no major defects in the insulation, and several more years of successful service can be expected. The plot of current versus voltage should be retained for future reference. If the plots are the same (± 50%) from test-to-test, then deterioration from moisture or pollution is not occurring. (Note: The high variability of ± 50% can be expected due to the humidity of the air). If more current is needed at each voltage in each successive test, then deterioration may be occurring.

Station________________ Date ________________

Step	Test Voltage * (KV)	Time Interval * (minutes)	Leakage Current (microAmps)	Insulation Resistance (Mohms)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

Voltage Steps to Maximum Voltage

* Above 600 volts-1000V steps at 1 minute intervals.
* Below 600 volts- 200V steps at 1 minute intervals

Typical Maximum Voltage Applied: 2E+1000V (conform to plant practice)

Conditions

Wet Bulb ______________________Psychrometer__________

Dry Bulb ____

Relative Humidity ________________________________

Thermometer ______________________________________

☐ With Cable ☐ Without Cable

Figure 2-5
DC Step Voltage Test Data Sheet

Equipment Restoration

Step 1: **IF** this procedure is **not** being performed in conjunction with a surveillance procedure, **THEN** remove the test equipment.

A 1 minute Insulation Resistance check could be made at this time to confirm the integrity of the windings.

Step 2: Ensure that any shorting and grounding devices that were installed during the test have been removed from the winding-imbedded temperature devices.

Step 3: **IF** no further testing is required, **THEN** notify the appropriate plant personnel that the testing is complete and they can restore any power leads, splices or surge capacitors that were disconnected for the performance of this test.

Step 4: **IF** any other leads were removed, **THEN** reconnect them in accordance with applicable work instructions.

Note: All test data should be reviewed by the appropriate plant personnel before re-energizing the equipment.

3

BEARING OIL SAMPLING FOR MOTORS

For many years, oil analysis has been used to monitor and diagnose the condition of lubricants and the oil-wetted components they lubricate. In order to accurately diagnose how a machine is operating and the condition of its internal components, extreme care must be taken in obtaining the sample. There are many different lubrication methods being utilized in plant machinery including forced oil systems, oil baths, ring systems, wick feed, drip systems, etc. For electric motors, three predominant methods are typically found: forced oil systems which pump oil to and from the bearings; ring oil systems; and, oil bath systems. The optimal method for sampling from these different types of lubrication systems depends on the type of lube oil system, and the location of the internal components being lubricated. The key to obtaining a representative sample is to acquire a sample of the oil which is circulating in and throughout the moving components (i.e. bearing races, etc.).

This guideline will provide some general instructions for how to determine the optimal location for sampling, and specific instructions on sampling different types of electric motors. *Since the validity of the oil analysis testing data will only be as good as the sample taken, emphasis will be placed on obtaining a representative sample.*

The Basics of Particle Generation and Removal

All machines generate wear. The key to understanding whether or not a machine is operating properly is to analyze the wear particles being generated from the lubricated surfaces, and correlate this data to the physical condition of the internal components. The wear particles exist as a separate phase in the oil, and are often not uniformly distributed throughout the system. As a result, extreme care must be taken in selecting the location to sample, and in the actual steps taken in obtaining the sample.

During normal operation of lubrication systems, particles are continually generated and removed from the oil. The particles being generated typically come from the bearings, slingers, shafts, reservoir housings and/or piping, and other internal components which come in contact with the oil. Likewise, particles are continually being removed from the oil due to filtration, settling, adhering to the reservoir sides and/or lube oil piping, etc. An equilibrium level is achieved based on the amount of particle generation and removal occurring in the system. It is this equilibrium rate (i.e.

wear particle concentration) we desire to trend over time to monitor and diagnose internal problems.

The wear particle concentration achieved, once a machine has reached equilibrium, has two main constituents. One is the amount of small wear and contamination present in the system. These small wear particles (typically less than 5 microns in size) tend to stay suspended in the lube oil and often pass through most filters (if present). As a result, they are generally distributed evenly throughout the lube oil reservoir/system and tend to increase over time. However, the larger particles being generated in the lube oil reservoir/system are typically not distributed uniformly due to their tendency to settle out or adhere to the bearing reservoir and piping. These larger wear particles provide the most valuable information regarding the present condition of the internal components since they typically indicate an abnormal wear condition. As a result, the location and method of sampling must be carefully selected to ensure a representative sample (of both small and large wear and contamination) can be obtained.

Effects of Oil Changes

The equilibrium rate (i.e. wear particle concentration) of particle generation and removal is affected by oil changes. In order to ensure that an oil change is effective, the bearing reservoir should be thoroughly cleaned and flushed with an approved, commercially available solvent before installing the new lubricant. Proper flushing will ensure that all of the unwanted contaminants and wear particles are removed, and new sample data taken after oil changes are not tainted with particulate from the previous lubricant installed. Following an oil change, the amount of particle generation will increase, causing the amount of particle removal to increase until an equilibrium rate is achieved. The time it takes a machine to reach its equilibrium level varies depending on the type of machine, the filtration system installed (if applicable), and the type of flow and circulation within the lube oil system. In most cases, an equilibrium wear particle concentration will be achieved within a couple of hours, but could take up to a couple of days. It is recommended that an oil sample be taken shortly after an oil change to re-establish baseline data, and to ensure that the proper oil was installed.

Oil Changes versus Oil Sampling

Many companies get involved in routine oil sampling and analysis to help reduce the costs associated with maintaining lubrication systems. The most significant costs involve periodic oil changes based on a time schedule as recommended by the equipment specific manufacturer. Recommended oil change frequencies can range from weekly to yearly depending on the equipment, its operating environment, the duty cycle of the equipment, and many other factors. To help reduce and possibly eliminate the need to perform time-based oil changes, a well designed oil sampling and analysis program can help. One of the biggest concerns in implementing an oil analysis program is to determine which equipment should be sampled. For larger systems (i.e. greater than 10-15 gallons), it is usually more cost effective to establish a condition-based oil change program, rather than a time-based one. For smaller reservoirs (i.e. less than 10 gallons), there may or may not be a financial benefit from performing oil analysis versus oil changes. A lot of determination on whether or not to sample smaller reservoirs depends on the criticality of the equipment, and the resultant effects on production or operation, if the equipment or lubrication fails in service. A complete plant survey should be performed to adequately evaluate the equipment, the reservoir size(s), the equipment's function as related to plant production and safety, accessability for obtaining samples, etc.

Equipment Required for Oil Sampling

The equipment required for obtaining oil samples depends on the equipment being sampled and the method of sampling. A partial list of equipment which may be needed includes:

- Sample Bottles with Labels
- Sample Pump (hand-held vacuum)
- Tygon Tubing (at various lengths)
- Waste Oil Container
- New Oil for Re-Filling Reservoirs
- Probe-On Assemblies for Sample Fittings (if applicable)
- Appropriate Wrenches
- Oil-Absorbent Cloths and Rags

A typical sample pump and fittings are illustrated in Figures 3-1 and 3-2.

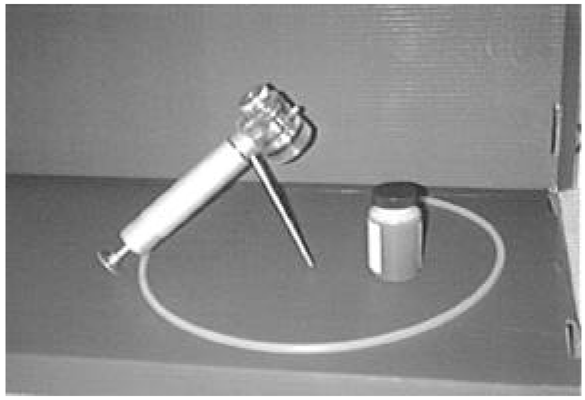


Figure 3-1
Pump with Tygon Tubing Assembly

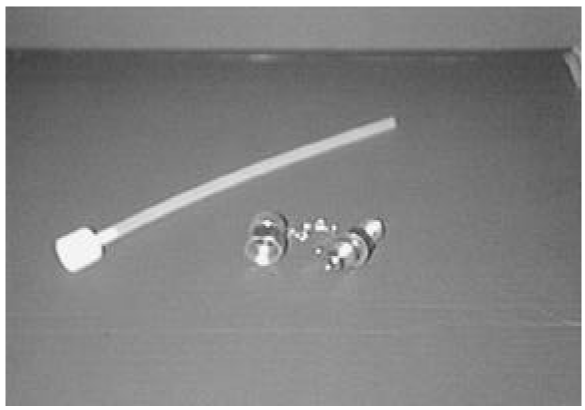


Figure 3-2
Oil Sample Fitting with Probe-on

Sampling Bearing Reservoirs

In order to obtain a representative sample from a bearing reservoir, one must have an understanding of the location of the internal components and the flow or circulation of oil within and through the reservoir. A review of bearing internal schematics, or visual inspections (utilizing fiber optic equipment), will help to identify the location of the critical internal components and the circulation flow of lubrication inside the reservoir. The actual sample location and method should be chosen based on the point which will provide the most representative sample of particles being generated from the lubricated surfaces. Depending on the type of motor and bearing, there may be more than one option available for obtaining a sample. For pressurized lube oil systems, samples should be taken either directly from the bearing sump, or at some downstream location prior to any filtration. For non-pressurized (or static) systems, the sample should be taken from an area in the lube oil reservoir where there is adequate circulation of the oil within and throughout the bearing surfaces. In many cases, this can be achieved by sampling midway between the top oil level and the bottom of the sump, in close proximity to the actual bearings.

Precautions

For all sampling methods, there are some general precautions which should be followed, regardless of which method is used.

- Always check the oil level before and after taking the oil sample.
- Take the samples while the motor is running, or within 15 minutes after a shutdown.
- Take the samples from the same location, using the same method, every time.
- Stay clear of all moving/rotating parts of the machine while sampling.
- Do not sample from a stagnant area of the reservoir where there is no oil circulation.
- After sampling, ensure there are no leaks present from all potential exit sources.
- Ensure that the sample bottle is clean & labeled properly for the reservoir being sampled.
- Sampling from a bottom drain plug is never recommended.

Sampling from a Bearing Oil Fill Plug

To obtain an oil sample from a bearing oil fill plug, a sample pump and tygon tubing will be necessary. After removing the oil fill plug, insert the tygon tubing into the bearing reservoir until it bottoms out on the bottom of the sump. Then, pull back the tubing slightly to remove it from the bottom, still keeping it immersed under the top oil level. Using the vacuum pump, draw an oil sample from the reservoir (Refer to Figures 3-3 through 3-5 for equipment-specific examples with illustrations).

This sampling method is probably the easiest to perform, but it often results in the most errors. Because the location of the tygon tubing can vary from one sample to another, and from one person to another, the results may not provide an accurate trend over time.

The use of a “stand-off” rod (i.e. a stainless steel rod with open clips which can be attached to the tygon tubing) may help ensure that the tubing is placed in the same area of the reservoir for each sample, but care must be taken to ensure that the rod can be safely inserted into the bearing reservoir without making contact with any of the moving internal components.

Sampling from a Bearing Oil Sightglass

To obtain an oil sample from a bearing oil sightglass, a sample pump and tygon tubing will be necessary. After removing the top cap on the sightglass, insert the tygon tubing into the sightglass until it bottoms out. Then, pull back the tubing slightly to remove it from the bottom, still keeping it immersed under the top oil level. Using the vacuum pump, fill the sample bottle with oil. Dispose of the oil in the sample bottle (since this is stagnant oil which was not circulating in the reservoir), and resample. Repeat this process until the entire sightglass and sightglass line has been thoroughly flushed (and oil which was circulating in the reservoir is now present in the sightglass). Fill the sample bottle with oil (Refer to Figures 3-6 and 3-7 for equipment-specific examples with illustrations).

This sampling method is quite easy to perform, but care must be taken to ensure that the sightglass and sightglass line are thoroughly flushed. In addition, it is critical that the sightglass tube remain seated during the entire process. If the sightglass tube becomes unseated, it may be difficult to reseat it properly, and may result in an oil leak.

MOTOR TYPE GE 4kV (600 hp) Induction Motor Vertically Mounted APPLICATION Core Spray Pump Motor	BEARING TYPES Angular Contact Ball Bearing: Upper & Lower Reservoir LUBE SYSTEM Oil Bath
SAMPLING LOCATIONS Upper Motor / Lower Motor Bearings	**SAMPLING METHOD** Bearing Fill Plug

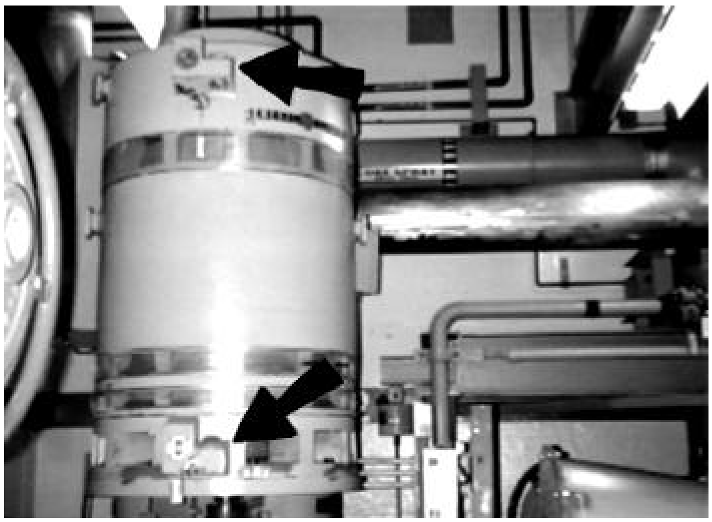


Figure 3-3 Sampling from Bearing Fill Plug - Angular Contact Ball Bearing

Equipment Needed:

Sample bottles with labels, Sample Pump, Tygon Tubing, Refill Oil

Precautions:

Ensure proper oil levels before and after sampling.
Samples should be taken with machine running or within 15 minutes after shutdown.
Use separate piece of tygon tubing for each bearing reservoir sample.

Instructions for Sample Collection:

The following instructions are to be followed for sampling from both the upper & lower motor bearing reservoirs:

Remove bearing-fill plug and insert tygon tubing into reservoir until it bottoms out. Pull tubing back slightly to remove it from the bottom while still keeping it under the top oil level. Using suction pump, obtain sample. Refill with appropriate oil to proper level. Re-install bearing fill plug.

MOTOR TYPE GE 2.3kV (800 hp) Induction Motor Horizontally Mounted APPLICATION Service Water Pump Motor	BEARING TYPES Ball Bearing: Outboard Motor Reservoir LUBE SYSTEM Bath / Ring
SAMPLING LOCATIONS Outboard Motor Bearing	**SAMPLING METHOD** Sample Fitting or Bearing Fill Plug

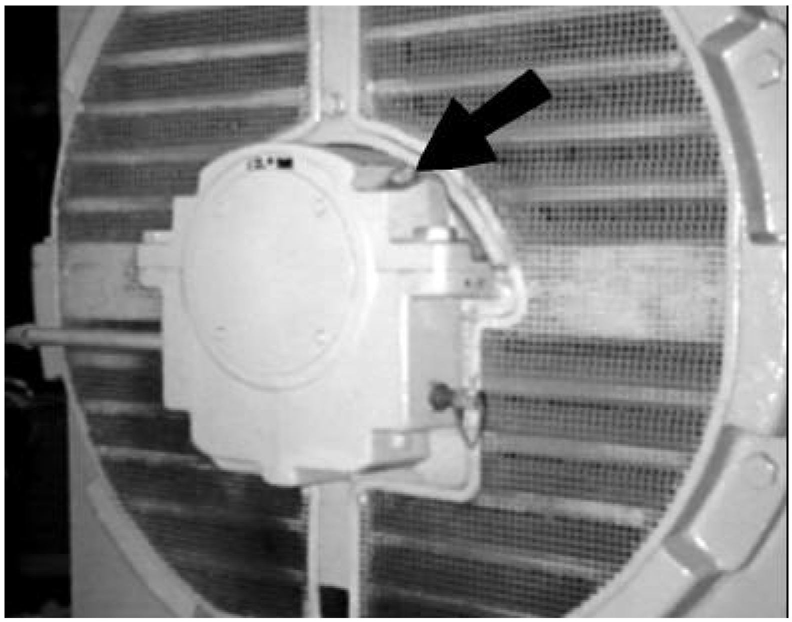


Figure 3-4 Sampling from Bearing Fill Plug - Ball Bearing, Outboard Motor

Equipment Needed:

Sample bottles with labels, Sample Pump, Probe-on Assembly or Tygon Tubing, Refill Oil

Precautions:

Ensure proper oil levels before and after sampling.
Samples should be taken with machine running or within 15 minutes after shutdown.
Use separate probe-on assembly or separate piece of tygon tubing for each bearing reservoir sample.

Instructions for Sample Collection:

For sampling from the bearing fill plug:

Remove bearing-fill plug and insert tygon tubing into reservoir until it bottoms out. Pull tubing back slightly to remove it from the bottom while still keeping it under the top oil level. Using suction pump, obtain sample. Refill with appropriate oil to proper level. Re-install bearing fill plug.

For sampling using the installed sample fitting:

Remove sample fitting cap and insert probe-on assembly into fitting to actuate valve. Using sample pump, draw sample from bearing reservoir. Refill with appropriate oil to proper level. Re-install sample fitting cap.

MOTOR TYPE GE 2.3kV (800 hp) Induction Motor Horizontally Mounted **APPLICATION** Service Water Pump Motor	**BEARING TYPES** Ball Bearing: Inboard Motor Reservoir **LUBE SYSTEM** Bath / Ring
SAMPLING LOCATIONS Inboard Motor Bearing	**SAMPLING METHOD** Sample Fitting or Bearing Fill Plug

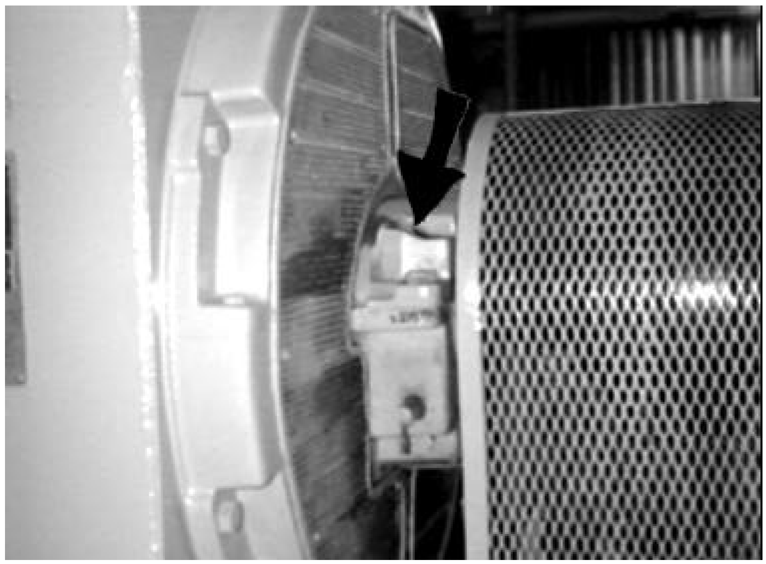


Figure 3-5 Sampling from Bearing Fill Plug - Ball Bearing, Inboard

Equipment Needed:

Sample bottles with labels, Sample Pump, Probe-on Assembly or Tygon Tubing, Refill Oil

Precautions:

Ensure proper oil levels before and after sampling.
Samples should be taken with machine running or within 15 minutes after shutdown.
Use separate probe-on assembly for each bearing reservoir sample, if sampling from fitting.

Instructions for Sample Collection:

For sampling from the bearing fill plug:

Remove bearing fill plug, and insert tygon tubing into reservoir until it bottoms out. Pull tubing back slightly to remove it from the bottom while still keeping it under the top oil level. Using suction pump, obtain sample. Refill with appropriate oil to proper level. Re-install bearing fill plug.

For sampling using the installed sample fitting:

Remove sample fitting cap and insert probe-on assembly into fitting to actuate valve. Using sample pump, draw sample from bearing reservoir. Refill with appropriate oil to proper level. Re-install sample fitting cap.

MOTOR TYPE Allis Chalmers 4kV (600 hp) Induction Motor Vertically Mounted **APPLICATION** River Water Pump Motor	**BEARING TYPES** Ball Bearing: Upper & Lower Bearings **LUBE SYSTEM** Oil Bath
SAMPLING LOCATIONS Upper Motor / Lower Motor Bearings	**SAMPLING METHOD** Sightglass

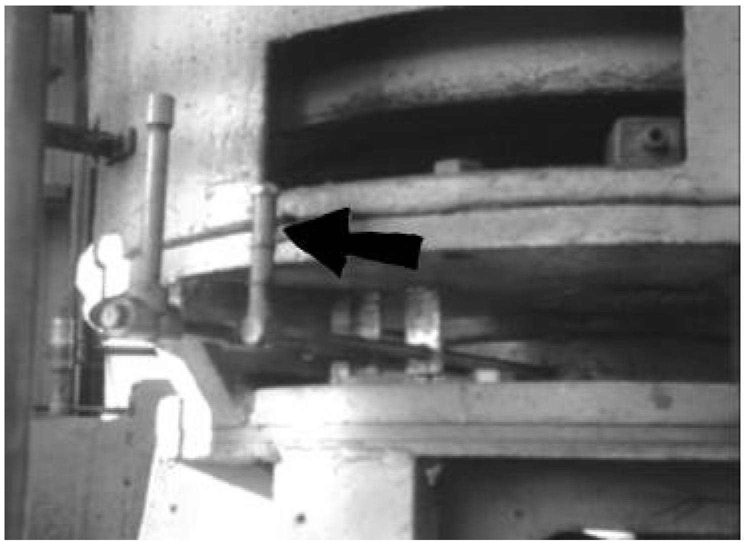


Figure 3-6 Sampling from Bearing Sightglass - Ball Bearing, Upper/Lower

Equipment Needed:

Sample bottles with labels, Waste Container, Refill Oil, Wrench

Precautions:

Ensure proper oil levels before and after sampling.
Sightglass lines must be thoroughly flushed prior to obtaining sample.
Samples should be taken with machine running or within 15 minutes after shutdown.

Instructions for Sample Collection:

The following instructions are to be followed for sampling from both the upper and lower motor bearing reservoirs:

Remove sightglass cap and insert tygon tubing into sightglass. Withdrawl sample from sightglass using suction pump. Flush the sightglass line “dead leg” until hot and foamy oil is coming out of the sightglass. Multiple bottles of waste oil will be generated depending on how long the line is from the bearing reservoir to the sightglass. Ensure the sightglass tube does not come unseated from its base during sampling. After obtaining sample, refill with appropriate oil to proper level. Re-install sightglass cap and ensure no leaks exist.

MOTOR TYPE Allis Chalmers 4kV (200 hp) Induction Motor Horizontally Mounted APPLICATION Cooling Water Pump Motor	BEARING TYPES Ball Bearing: Inboard & Outboard Bearings LUBE SYSTEM Oil Bath
SAMPLING LOCATIONS Outboard Motor Bearings	**SAMPLING METHOD** Sightglass

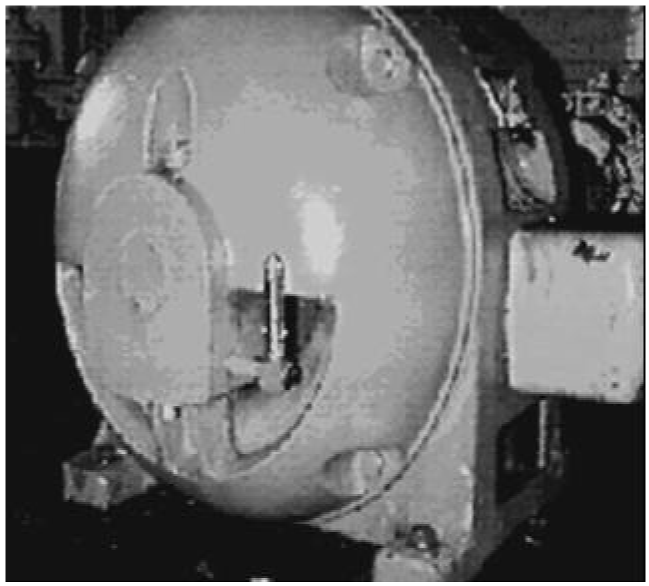


Figure 3-7 Sampling from Bearing Sightglass - Ball Bearing, Inboard/Outboard

Equipment Needed:

Sample bottles with labels, Waste Container, Refill Oil, Wrench

Precautions:

Ensure proper oil levels before and after sampling.
Sightglass lines must be thoroughly flushed prior to obtaining sample.
Samples should be taken with machine running or within 15 minutes after shutdown.

Instructions for Sample Collection:

The following instructions are to be followed for sampling from both the upper and lower motor bearing reservoirs:

Remove sightglass cap and insert tygon tubing into sightglass. Withdrawal sample from sightglass using suction pump. Flush the sightglass line "dead leg" until hot and foamy oil is coming out of the sightglass. Multiple bottles of waste oil will be generated depending on how long the line is from the bearing reservoir to the sightglass. Ensure the sightglass tube does not come unseated from its base during sampling. After obtaining sample, refill with appropriate oil to proper level. Re-install sightglass cap and ensure no leaks exist.

Sampling from a Bearing Oil Drain Line

To obtain an oil sample from a bearing which has an oil drain line, the only equipment required is a waste oil container for draining the "dead-leg", and some basic piping tools. Remove the drain line pipe cap and open the drain valve. Drain enough oil out of the piping to properly flush out the stagnant oil in the line. While the oil is still flowing out of the line, insert the sample bottle under the flow of oil to obtain the sample. As a general rule, it can be assured that the line has been adequately flushed when the oil coming out of the line is warm and foamy (indicating it was circulating within the bearing reservoir).

Care must be taken when draining the oil out of a reservoir, especially if the bearing reservoir is small. In some applications, the bearing reservoir may have to be completely drained in order to flush the line and obtain an accurate sample. For sleeve bearings, this is never recommended, and samples should be obtained shortly after the equipment is shut down. For anti-friction bearings, a sample may be obtained while the equipment is running, as long as the person sampling the reservoir immediately refills the reservoir (to ensure that the bearing is not without proper lubrication for an extened period of time). The safest method of sampling for small reservoirs is to obtain the sample right after the equipment has been shutdown (i.e. within 15 minutes after shutdown), to ensure that the lubricant film is not lost during operation. After an adequate sample has been obtained, close the drain valve and re-install the drain line pipe cap (Refer to Figure 3-8 for an equipment specific example with illustrations).

Sampling from a Bearing with an Oil Sample Fitting

To obtain an oil sample from a bearing with an oil sample fitting, a sample pump and probe-on assembly will be necessary. Remove the sample fitting cap, and insert the probe-on assembly to actuate the fitting's valve. Using the vacuum pump, fill the sample bottle with oil. Re-install the sample fitting cap (Refer to Figures 3-9 through 3-13 for equipment-specific examples with illustrations). This sampling method is the easiest to perform, and results in the most accurate and representative sample. However, the location of the sample fitting must be carefully chosen to ensure that the particles being generated are accurately represented in the sample. Instructions for the installation of oil sample fittings will be described later in this section.

MOTOR TYPE	BEARING TYPES
Allis Chalmers 13.2kV (3500 hp) Induction Motor Vertically Mounted	Journal (Babbit) Bearing: Upper & Lower Reservoir Kingsbury Thrust Bearing in Upper Bearing Reservoir
APPLICATION Circulating Water Pump Motor	**LUBE SYSTEM** Oil Bath
SAMPLING LOCATIONS Upper Motor / Lower Motor Bearings	**SAMPLING METHOD** Drain Line

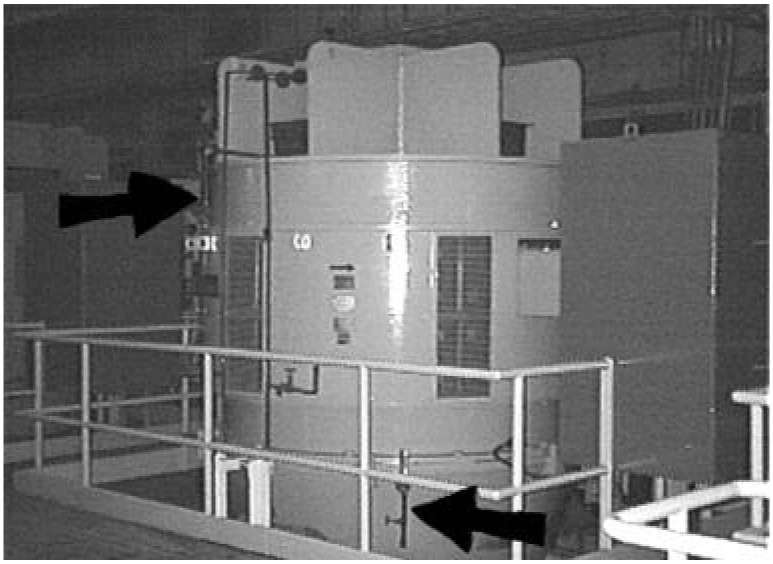


Figure 3-8 Sampling from a Bearing Drain Line

Equipment Needed:

Sample bottles with labels, Waste Container, Refill Oil, Pipe Wrench

Precautions:

Ensure proper oil levels before and after sampling.
Drain lines must be thoroughly flushed prior to obtaining sample.
Samples should be taken with machine running or within 15 minutes after shutdown.

Instructions for Sample Collection:

The following instructions are to be followed for sampling from both the upper & lower motor bearing reservoirs:

Remove pipe cap and slowly open drain valve to obtain moderate oil flow. Flush bearing drain line until hot and foamy oil is coming out of the line. While keeping oil flow constant, insert sample bottle under the flow of oil and fill sample bottle. Close drain valve. Refill with appropriate oil to proper level. Re-install drain line pipe cap.

MOTOR TYPE GE 4kV (600 hp) Induction Motor Vertically Mounted APPLICATION Core Spray Pump Motor	BEARING TYPES Angular Contact Ball Bearing: Upper Reservoir LUBE SYSTEM Oil Bath
SAMPLING LOCATIONS Upper Motor Bearing	SAMPLING METHOD Sample Fitting

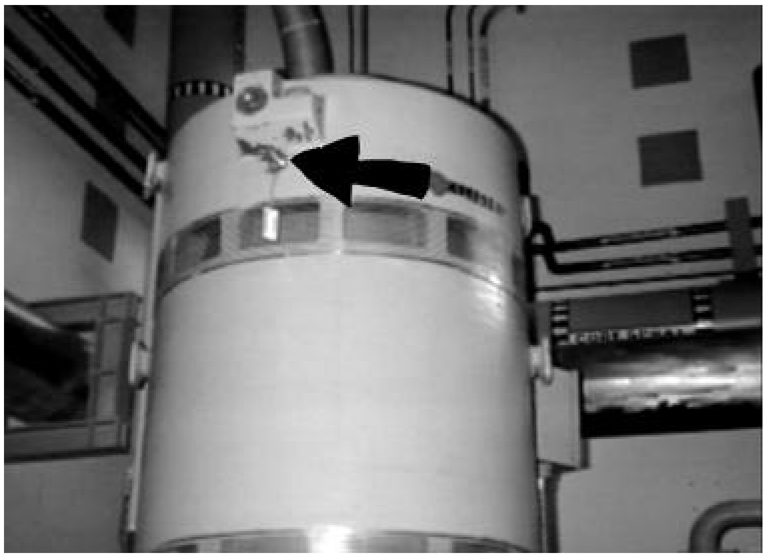


Figure 3-9 Sampling from Oil Sample Fitting

Equipment Needed:

Sample bottles with labels, Sample Pump, Probe-on Assembly, Refill Oil

Precautions:

Ensure proper oil levels before and after sampling.
Samples should be taken with machine running or within 15 minutes after shutdown.
Use separate probe-on assembly for each bearing reservoir sample.

Instructions for Sample Collection:

The following instructions are to be followed for sampling from both the upper & lower motor bearing reservoirs:

Remove sample fitting cap and insert probe-on assembly into fitting to actuate valve. Using sample pump, draw sample from bearing reservoir. Refill with appropriate oil to proper level. Re-install sample fitting cap.

MOTOR TYPE GE 13.2kV (4500 hp) Induction Motor Horizontally Mounted	BEARING TYPES Journal (Babbit): Outboard Motor Bearing Reservoir
APPLICATION Motor Generator Set for Recirc Pump Motor	**LUBE SYSTEM** Forced Oil / Bath
SAMPLING LOCATIONS Outboard Motor Bearing	**SAMPLING METHOD** Sample Fitting

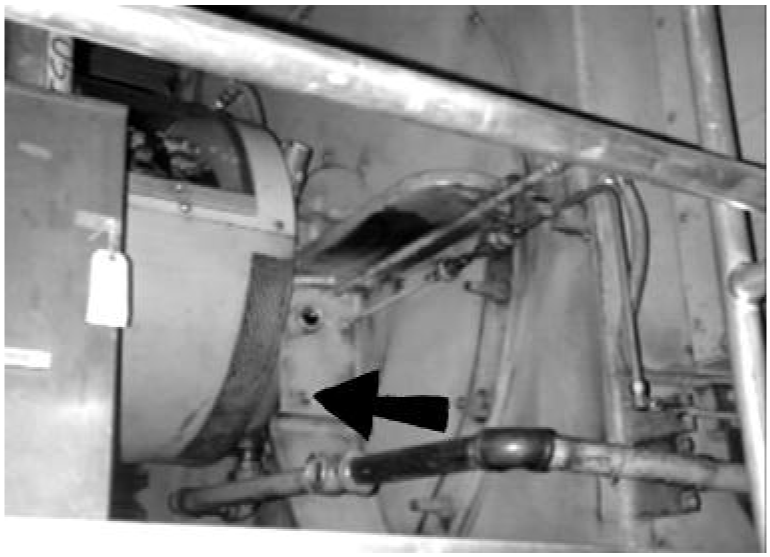


Figure 3-10 Sampling from Oil Sample Fitting

Equipment Needed:

Sample bottles with labels, Sample Pump, Probe-on Assembly, Refill Oil

Precautions:

Ensure proper oil levels before and after sampling.
Samples should be taken with machine running or within 15 minutes after shutdown.
Use separate probe-on assembly for each bearing reservoir sample.

Instructions for Sample Collection:

The following instructions are to be followed for sampling from both the inboard & outboard motor bearings:

Remove sample fitting cap and insert probe-on assembly into fitting to actuate valve. Using sample pump, draw sample from bearing reservoir. Refill with appropriate oil to proper level. Re-install sample fitting cap.

MOTOR TYPE GE 4kV (800 hp) Induction Motor Horizontally Mounted APPLICATION Primary Air Fan Motor	BEARING TYPES Journal (Babbit): Inboard Motor Bearing Reservoir LUBE SYSTEM Bath
SAMPLING LOCATIONS Inboard Motor Bearing	**SAMPLING METHOD** Sample Fitting

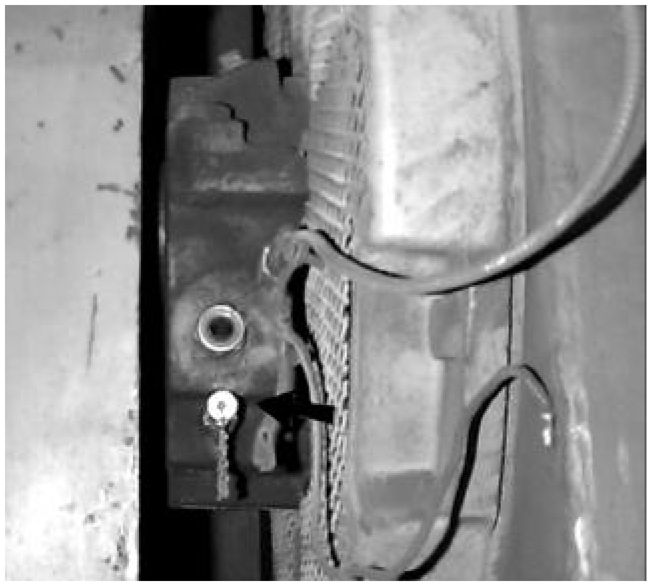


Figure 3-11 Sampling from Oil Sample Fitting

Equipment Needed:

Sample bottles with labels, Sample Pump, Probe-on Assembly, Refill Oil

Precautions:

Ensure proper oil levels before and after sampling.
Samples should be taken with machine running or within 15 minutes after shutdown.
Use separate probe-on assembly for each bearing reservoir sample.

Instructions for Sample Collection:

The following instructions are to be followed for sampling from both the inboard & outboard motor bearings:

Remove sample fitting cap and insert probe-on assembly into fitting to actuate valve. Using sample pump, draw sample from bearing reservoir. Refill with appropriate oil to proper level. Re-install sample fitting cap.

MOTOR TYPE GE 4kV (800 hp) Induction Motor Horizontally Mounted APPLICATION Primary Air Fan Motor	BEARING TYPES Journal (Babbit): Outboard Motor Bearing Reservoir LUBE SYSTEM Bath
SAMPLING LOCATIONS Outboard Motor Bearing	**SAMPLING METHOD** Sample Fitting

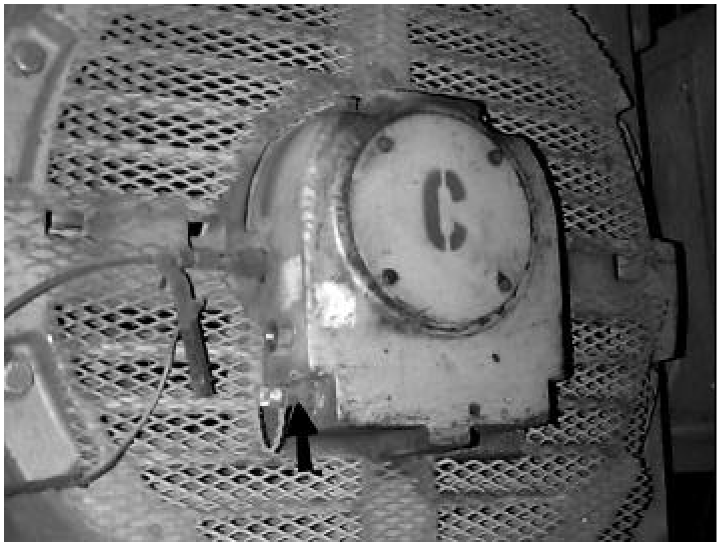


Figure 3-12 Sampling from Oil Sample Fitting

Equipment Needed:

Sample bottles with labels, Sample Pump, Probe-on Assembly, Refill Oil

Precautions:

Ensure proper oil levels before and after sampling.
Samples should be taken with machine running or within 15 minutes after shutdown.
Use separate probe-on assembly for each bearing reservoir sample.

Instructions for Sample Collection:

The following instructions are to be followed for sampling from both the inboard & outboard motor bearings:

Remove sample fitting cap and insert probe-on assembly into fitting to actuate valve. Using sample pump, draw sample from bearing reservoir. Refill with appropriate oil to proper level. Re-install sample fitting cap.

MOTOR TYPE GE 4kV (800 hp) Induction Motor Horizontally Mounted	BEARING TYPES Journal Bearing: Inboard Motor Reservoir
APPLICATION Induced Draft Fan Motor	**LUBE SYSTEM** Bath
SAMPLING LOCATIONS Inboard Motor Bearing	**SAMPLING METHOD** Sample Fitting

Figure 3-13 Sampling from Sample Fitting - Journal Bearing

Equipment Needed:

Sample bottles with labels, Sample Pump, Probe-on Assembly or Tygon Tubing, Refill Oil

Precautions:

Ensure proper oil levels before and after sampling.
Samples should be taken with machine running or within 15 minutes after shutdown.
Use separate probe-on assembly for each bearing reservoir sample, if sampling from fitting.

Instructions for Sample Collection:

For sampling using the installed sample fitting:

Remove sample fitting cap and insert probe-on assembly into fitting to actuate valve. Using sample pump, draw sample from bearing reservoir. Refill with appropriate oil to proper level. Re-install sample fitting cap.

Sampling from a Bearing Return Line

This sampling method is generally applicable for bearings which are part of a common forced-oil system. If a sample valve is not installed in the lube oil line downstream from the bearing reservoir, an oil sample fitting may have to be installed either on the bearing reservoir or on the downstream piping, to obtain a representative sample. It is highly recommended that the oil sample be taken from the discharge line before any filtration. If a sample is taken from a bearing return line after going though the filtration portion of the system, most of the larger wear particles and contaminants will be removed. Since the larger particles provide the most valuable information regarding the condition of the lubricated surfaces (i.e. they indicate an abnormal wear condition), obtaining a sample after filtration will not provide a true indication of the machine's condition (Refer to Figure 3-14 for an equipment-specific example with illustrations).

The sampling method to be used depends on whether a drain line valve or a sample fitting is used. The methods previously outlined for these sampling methods will be adequate to ensure that a representative sample is obtained.

The Use and Installation of Oil Sampling Fittings

Purpose of Oil Sample Fittings

In order for an oil analysis program to be effective, a representative sample must be obtainable from each specific lubricated component. In a forced oil system, with common lube oil circulating through multiple bearings, it is very hard to accurately assess the condition of any one bearing by sampling from one common point in the system. Furthermore, for isolated bearing reservoirs, errors can be introduced by "fishing" tygon tubing to some unknown area of the bearing reservoir. To overcome these shortcomings and improve the overall effectiveness of an oil analysis program, the use of oil sample fittings has become a popular alternative for sample acquisition. By carefully selecting a location to install an oil sample fitting, the following benefits can be realized:

- More representative samples
- Minimal errors from improper sampling
- Increased efficiency in obtaining samples
- Reduced waste oil generation
- More repeatable and trendable oil analysis data
- Sampling of bearings which would normally be unsafe and/or impractical

MOTOR TYPE GE 4kV (1500 hp) Induction Motor Horizontally Mounted APPLICATION Boiler Feed Pump Motor	BEARING TYPES Journal Bearing: Outboard Motor Reservoir LUBE SYSTEM Bath
SAMPLING LOCATIONS Outboard Motor Bearing	**SAMPLING METHOD** Sample Fitting or Drain Valve (Installation Required on Example Below)

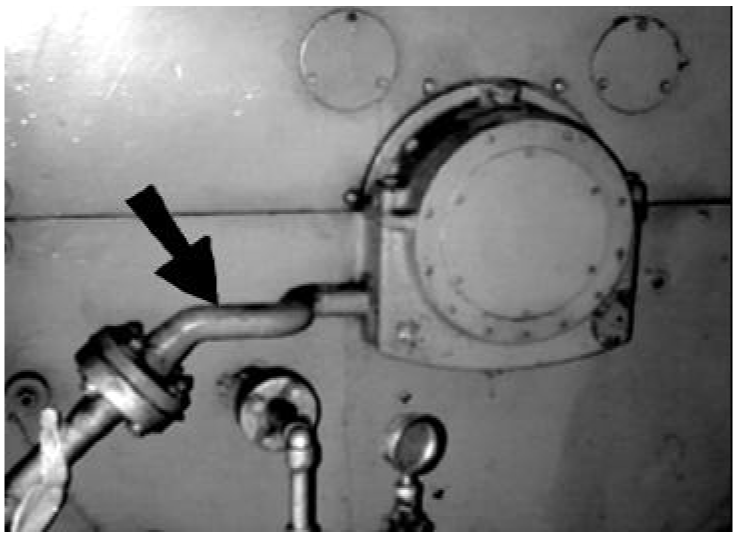


Figure 3-14
Sampling from Bearing Return Line

Equipment Needed:

Sample bottles with labels, Sample Pump, Probe-on Assembly or Tygon Tubing, Refill Oil

Precautions:

Ensure proper oil levels before and after sampling.
Samples should be taken with machine running or within 15 minutes after shutdown.
Use separate probe-on assembly for each bearing reservoir sample, if sampling from fitting.

Instructions for Sample Collection:

For sampling using the installed sample fitting (requires installation of sample fitting):

Remove sample fitting cap and insert probe-on assembly into fitting to actuate valve. Using sample pump, draw sample from bearing reservoir. Refill with appropriate oil to proper level. Re-install sample fitting cap.

For sampling from return line drain valve (requires installation of drain valve):

Remove pipe cap and open drain valve. Flush drain line and while keeping flow of oil running, insert bottle and obtain oil sample. Close drain valve and re-install pipe cap. Ensure no leaks exist.

The following sections discuss the use of oil sample fittings in electric motor applications, and the different installation methods which can be used. The end user must decide which option is most practical, balancing the cost of installation with the value added in obtaining a more representative sample.

Types of Oil Sample Fittings

There are many different types of oil sample fittings available today. For most types, the fitting is actually a valve which is typically actuated with some sort of probe device attached to a piece of tygon tubing. Two popular styles of valve fittings are the needle valve (similar to the ones found on many bicycle tires), and the ball-check valve. The operation of an oil sample fitting is rather simple. When the probe device is inserted into the fitting, the valve is opened and the sample can be obtained. In a pressurized system, the oil pressure is sometimes great enough to allow the flow of oil into the sample bottle. However, in most cases a vacuum pump is required to draw the oil out through the fitting and probe assembly, and into the sample bottle. After the sample is taken and the probe assembly is removed, the valve automatically closes to stop the flow of oil. Most sample fittings are also equipped with a sealed cap that is threaded on the end of the sample fitting which acts as a back-up to prevent oil leaks.

Determining Where to Install a Sample Fitting

The most difficult part of utilizing oil sample fittings is determining where to install the fitting to achieve optimal performance. There are a few general steps which should be taken BEFORE any action is taken. First, the PDM engineer should obtain an internal schematic of the bearing reservoir with dimensions and locations of the bearings, slingers, and other internal components. If this information cannot be obtained, discuss the installation of the sample fittings with a maintenance mechanic or someone who may have a familiarity with the internal "layout" of the components inside the bearing reservoir. Also to be considered is an internal fiber optic inspection when the motor is in service, to not only identify where all the critical components are, but also to understand the flow and circulation of oil within the bearing reservoir.

For forced oil systems, a detailed review of the lube oil system and components will also be necessary to identify piping information, filter locations, etc. Once all of this information is obtained, then an accurate determination can be made as to where the optimal location for the sample fitting should be. Remember, the objective is to install the sample fitting in a location where an accurate representation of the wear particles being generated from the internal components can be obtained. In many situations, there may be a number of options available for sample fitting location and installation. The location which provides the most representative sample is the one which should be chosen, not the easiest to install. The following sections detail different installation options for oil sample fittings in electric motor applications:

Installing Oil Sample Fittings in Place of Existing Drain Plugs

Many electric motors have oil drain plugs installed either on the side or on the bottom of each bearing reservoir. Depending on where the drain plugs are located, the installation of an oil sample fitting in place of the drain plug may be a feasible alternative to sampling from bearing fill plugs. It is not recommended to install oil sample fittings in drain plugs which are mounted on the bottoms of the bearing reservoirs. The bottom of the reservoir usually contains many large particles which have been generated over the life of the oil, and have settled out due to their abnormally large size. The information obtained from the wear and contamination on the bottom of a bearing reservoir is “ancient history” and does not provide an accurate indication of the present wear rates of the lubricated surfaces. However, if there is a drain plug located on the side of the bearing reservoir, or a plug exists for some other reason (i.e. future cooling water lines, thermocouples, etc.), this may be a good location for installing a sample fitting. The only precaution which should be considered is whether or not this side drain plug is far enough off of the bottom of the reservoir to obtain a representative sample of the oil circulating within the internal moving components.

One must know the location of the internal components and the general flow and circulation of oil inside the bearing reservoir to accurately determine where the optimal location is for a sample fitting. If it is determined that an existing drain plug can be used, the old drain plug should be removed and the sample fitting should be installed in its place (with the use of reducing and /or increasing bushings as needed). This installation option is the most easiest to perform and the most inexpensive to implement.

Installing Oil Sample Fittings by Drilling & Tapping Bearing Reservoirs

If there is no existing drain plug on the bearing reservoir, or it is determined that the drain plugs present are not feasible locations for a sample fitting, a second alternative is to drill and tap the bearing reservoir. This installation is the most accurate because the user can carefully select where the oil sample fitting should be located, based on the configuration of the internal components and the oil circulation patterns. Typically, the bearing reservoirs are drilled and tapped to fit the size of the fitting installed, and the location is between the middle and the bottom third of the oil level. Careful review of internal bearing schematics and/or fiber optic inspections must be performed *before* drilling and tapping, to ensure that the optimal location is selected. Additionally, extreme care must be taken to remove all of the debris which will be introduced from drilling the bearing housing. If possible, the bearing housing should be removed so that all drilling debris can be adequately removed prior to re-installation. If this is not feasible, then as a minimum, the bearing reservoir should be thoroughly flushed with an approved solvent to remove as much of the debris as possible.

Installing Oil Sample Fittings in Bearing Return Lines: (Forced-Oil)

In order to obtain a representative sample from a bearing which is part of a common forced oil lubrication system, an oil sample fitting can be installed in the bearing return lines which return the oil to a common reservoir. The location of the fittings should be before any filtration devices which may be present, so as not to remove much of the larger wear particles and contaminants. The actual installation involves cutting out a section of the return line piping and installing a 'tee' connection. The oil sample fitting can then be installed in the open end of the tee. When performing this type of installation, again care must be taken to remove any wear particles and contamination which may have been generated as a result of cutting out a section of the piping. It is recommended that the tee connection be installed at a 45° angle from horizontal to facilitate the flow of wear particles and contaminants through the fitting.

4

INFRARED THERMOGRAPHY SURVEY GUIDELINES

The purpose of performing an Infrared Thermography (IRT) survey on large induction motors is to acquire data pertaining to the thermal profile of that motor to assist in determining its on-line condition over a period of time. The purpose of this document is to provide the guidelines for an effective method of locating, documenting, and tracking the thermal profile data of large induction motors using Infrared (IR) Thermography imaging equipment.

Objectives

The Objectives of this Guideline are as follows:

- Provide general guidance to perform an Electric Motor IRT Survey.
- Provide specific guidance for identifying "Hot Spots" on motor bearings, casings, and couplings.
- Provide a method for documenting and trending data.
- Identify or develop methods for verification of deficiencies.
- Provide data to assist facility personnel in evaluating and implementing corrective actions.

Prerequisites

The amount of equipment, personnel, and information necessary to maximize the effectiveness of this guideline is identified as follows:

Equipment

- Field-portable thermal imaging radiometer with a minimum accuracy of ±2 °C or 2% of scale, to include: video tape compatibility; power supply; and accessories (Refer to Figures 4-1 & 4-2).

- Visible light camera (e.g. Video camcorder, still video camera, digital camera) for obtaining visible light images.
- Contact Thermometer with a ±2°C accuracy.
- 50 Ft. Tape Measure
- Computer with applicable hardware & software, for producing reports, such as:
  - 90Mhz, Pentium Processor
  - 1 GB hard drive
  - Frame Grabber Software
  - Report Generation Software (i.e. Word Processing Program, IRT Camera software, IR-SIP, etc.)

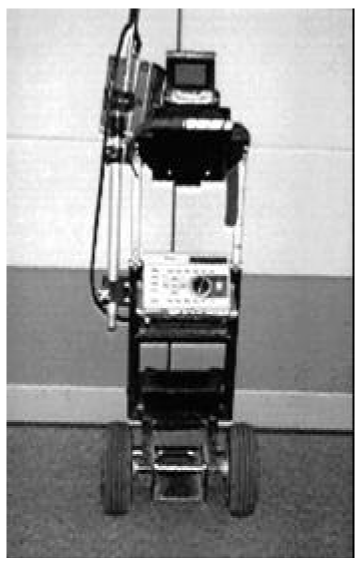


Figure 4-1 Cart Mounted IRT Camera

Figure 4-2 Hand Held IRT Camera

Personnel

- An experienced Infrared Thermographer who is proficient in the use of thermal imaging radiometers.
- Site personnel familiar with the motors being surveyed.

Information

- When performing an EMPM IR Thermography Baseline Survey, or a Follow-Up Survey, all of the information shown on the data sheet of Figure 4-3, should be recorded. The following is a list of the plant and motor operating condition required data:

    1. Station & Unit number being surveyed
    2. Component ID of Motor
    3. Motor Load (Amps)
    4. Motor Horse Power rating
    5. Ambient Air Temperature (i.e. the IR camera's background temperature setting)
    6. IR camera's emissivity setting
    7. RTD and/or Thermocouple Motor Winding Temperature indication from computer point, if available
    8. Date and time of the survey

General Instructions for a Baseline Survey

Step 1: A walk-down of each of the motors being surveyed is suggested.

Step 2: A Baseline IR Thermography Survey consists of a complete observation of the motor, as shown on Table 4-3. The following is a list of information to be taken as part of an EMPM Baseline Survey:

a) Left Side Inboard Bearing and Casing

b) Left Side Casing

c) Outboard Bearing and Casing

d) Right Side Casing

e) Right Side Inboard Bearing and Casing

f) Coupling (if available) or Shaft (if available)

g) Conduit and Motor Lead Box

h) Breaker Compartment

i) Air Inlet & Outlet Vent surface temperature

Step 3: A Baseline survey is considered the first IR Thermography survey performed on the selected motor. The appropriate EMPM Infrared Thermography Baseline Field Data Sheets (Tables 4-1 and 4-2) shall be used during these surveys.

Step 4: A Baseline survey requires that a **Visual** and a **Thermal Image** be taken for items numbered 'a' through 'g' in Step 2, (see Table 4-3 thru 4-6 for examples of thermal & visual images). Ensure that the image numbers are recorded on the data sheet and in the appropriate location.

Step 5: A Baseline survey also requires that the "Highest" temperature indicated for each of the surveyed items be recorded in the proper location on the appropriate data sheet drawing (Refer to Table 4-1 or Table 4-2).

Table 4-1
Horizontal Motor Baseline Field Data Sheet

EMPM INFRARED THERMOGRAPHY BASELINE FIELD DATA SHEET

Utility Name ______ Date ______

Station & Unit # ______ Time ______

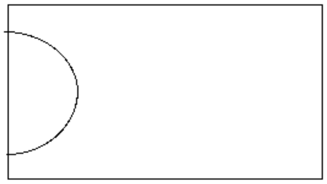
IR Thermographer ______ Emissivity Setting ______

Ambient Air Temp. ______ Motor HP Rating ______

Motor Identification ______ Breaker Compartment Surveyed: YES NO

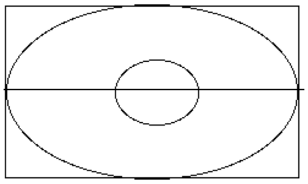
Motor Load (Amps) Phase "A" ______ Phase "B" ______ Phase "C" ______

NOTES: Left & Right Side references are with respect to the Motor End Cap. Indicate Temperature Engineering Units
On the drawings below, record and indicate where the "Highest" temperature is indicated. Always record Distance From Object (DFO).



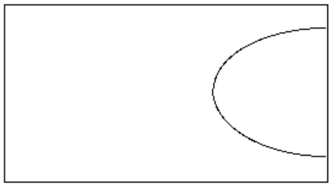
T#: V#: ______ Left Side Inboard Bearing/Casing
DFO = ______

T#: V#: ______ Left Side Casing
DFO = ______

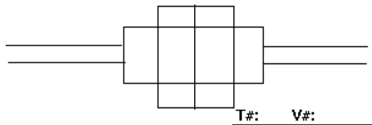


Outboard Bearing/Casing T#: V#: ______
DFO = ______

Right Side Casing T#: V#: ______
DFO = ______



Right Side Inboard Bearing/Casing T#: V#: ______
DFO = ______



Coupling Center Flange Joint Temp. T#: V#: ______
DFO = ______

Air Inlet Vent *Surface* Temp. = ______ Air Outlet Vent *Surface* Temp. = ______

Motor RTD Temperature as indicated on Plant Computer: ______

ANOMALIES (Circle applicable items)

Motor - Casing/Bearings	Thermal Image #	______	Visual Image #	______
Breaker Comp./Motor Lead Box	Thermal Image #	______	Visual Image #	______
Coupling - Center Flange Joint	Thermal Image #	______	Visual Image #	______

Motor Lead Box T#: V#: ______
DFO = ______

Comments: ______

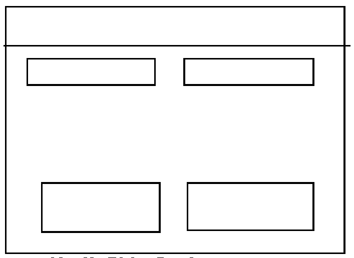
Table 4-2
Vertical Motor Baseline Field Data Sheet

EMPM VERTICAL MOTOR IR THERMOGRAPHY BASELINE FIELD DATA SHEET

Utility Name	______	Date	______
Station & Unit #	______	Time	______
IR Thermographer	______	Emissivity Setting	______
Ambient Air Temp.	______	Motor HP Rating	______
Motor Identification	______	Breaker Compartment Surveyed: YES NO	

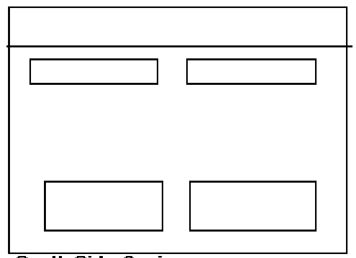
Motor Load (Amps) Phase "A" ______ Phase "B" ______ Phase "C" ______

NOTE: On the drawings below, record and indicate where the "Highest" temperature is indicated.
Please, indicate temperature Engineering Units. Always record Distance From Object (DFO).



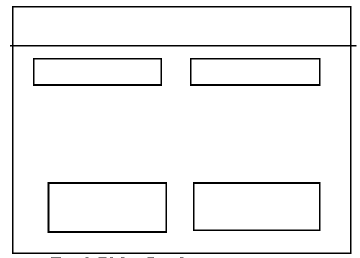
North Side Casing

T#:
V#: DFO =



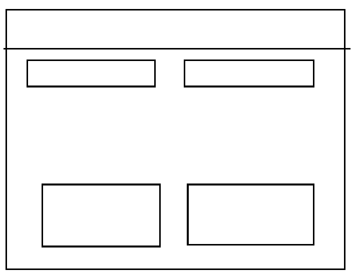
South Side Casing

T#:
V#: DFO =



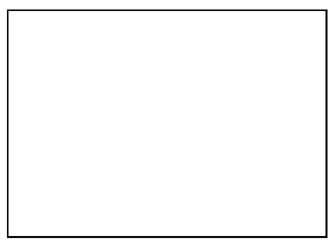
East Side Casing

T#:
V#: DFO =



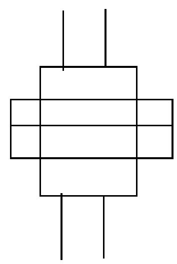
West Side Casing

T#:
V#: DFO =



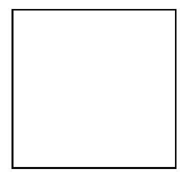
Top Casing

T#:
V#: DFO =



Coupling

T#:
V#: DFO =



Motor Lead Box

T#: ______
V#: ______
DFO= ______

Air Inlet Vent *Surface* Temp. = ______ Air Outlet Vent *Surface* Temp. = ______

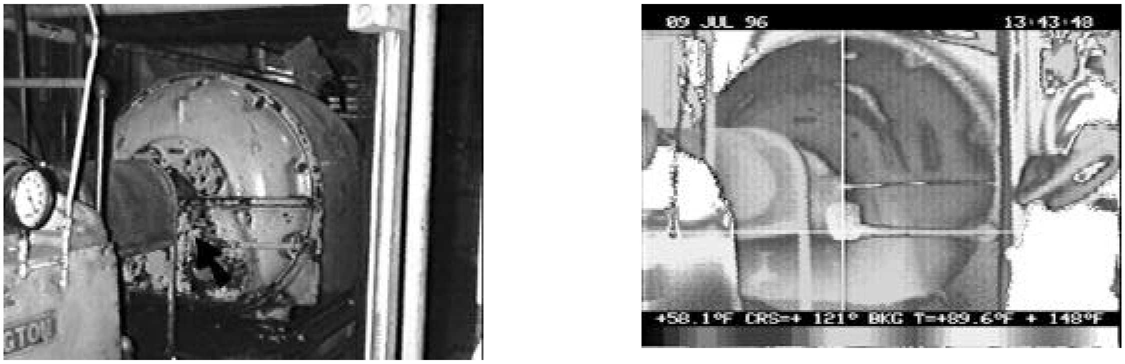
Motor RTD Temperature as indicated on Plant Computer: ______

ANOMALIES (Circle applicable items)

Motor - Casing/Bearings	Thermal Image # ______	Visual Image # ______
Breaker Comp./Motor Lead Box	Thermal Image # ______	Visual Image # ______
Coupling - Center Flange Joint	Thermal Image # ______	Visual Image # ______

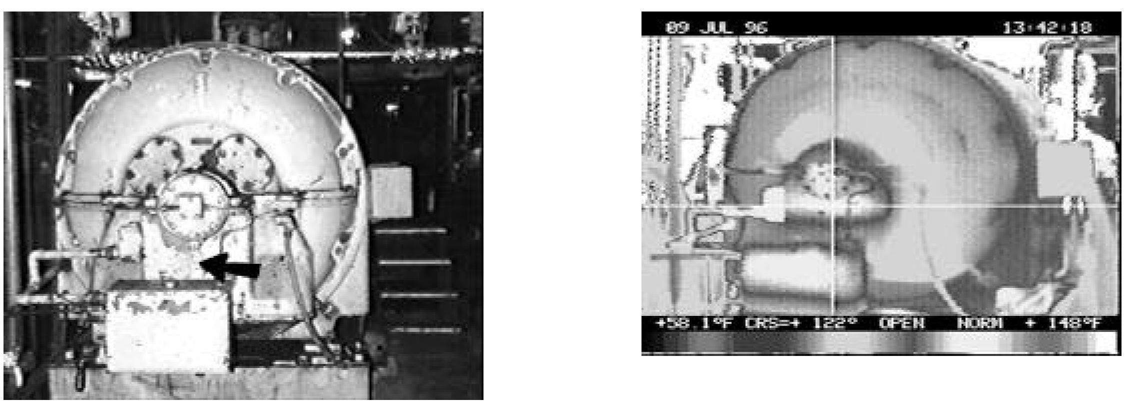
Comments:

Table 4-3
Visual and Thermal Images for Baseline Reference, Horizontal Motor



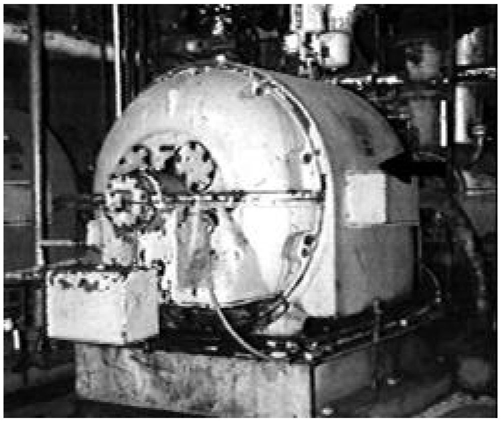
Left-Side Inboard

Left-Side Casing

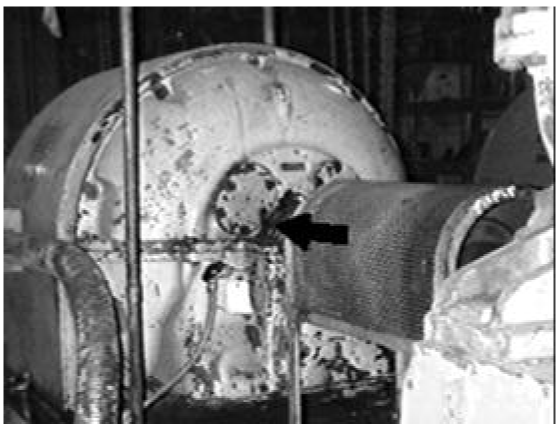


Outboard

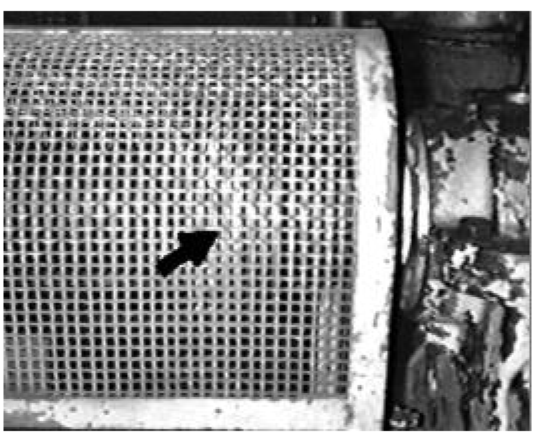
Table 4-4
Visual and Thermal Images for Baseline Reference, Horizontal Motor

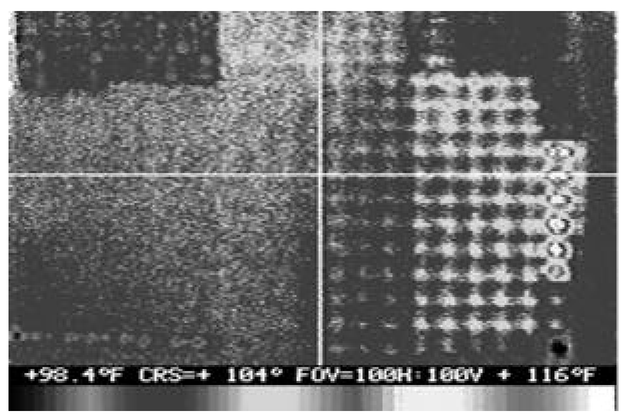


Right-Side Casing



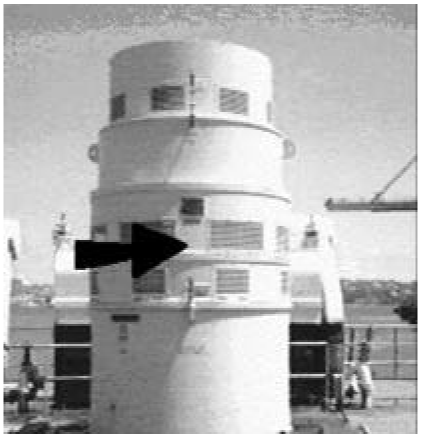
Right-Side Inboard

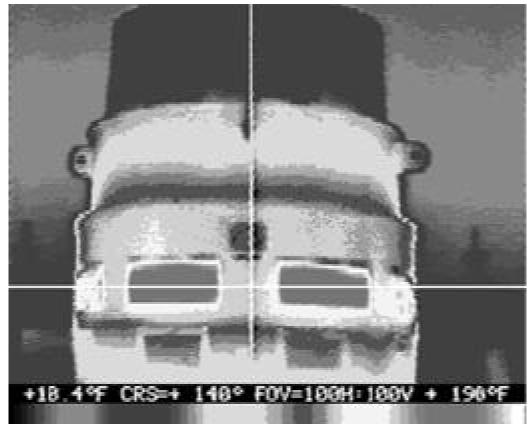




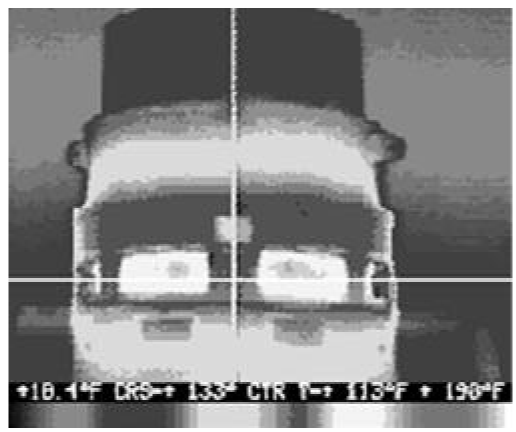
Coupling

Table 4-5
Visual and Thermal Images for Baseline Reference, Vertical Motor

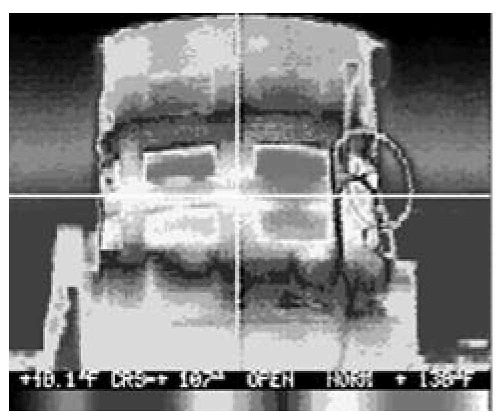




North-Side Casing

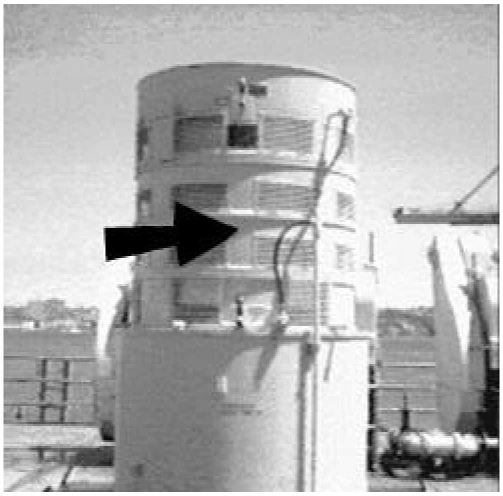


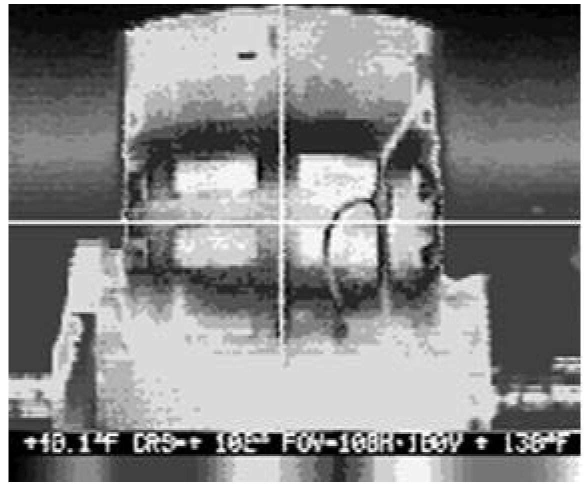
South-Side Casing



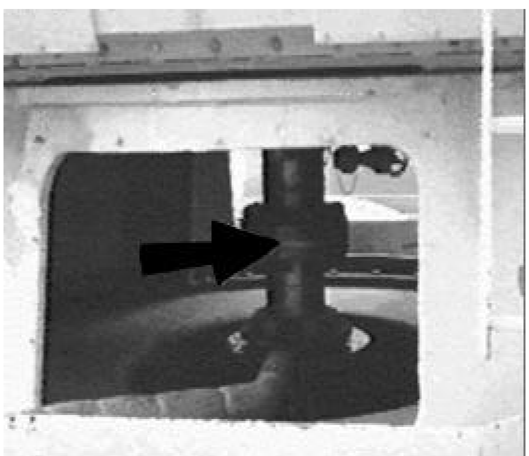
East-Side Casing

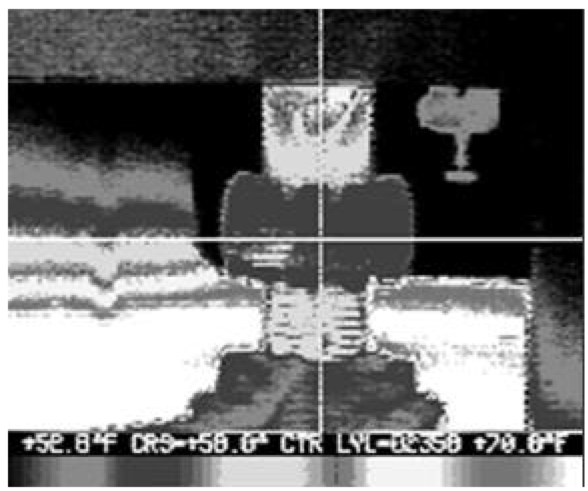
Table 4-6
Visual and Thermal Images for Baseline Reference, Vertical Motor





West-Side Casing





Coupling

Step 6: Determine specific temperatures on a Horizontal Motor's Air Inlet Vent Surface (Refer to Figures 4-3 and 4-4).

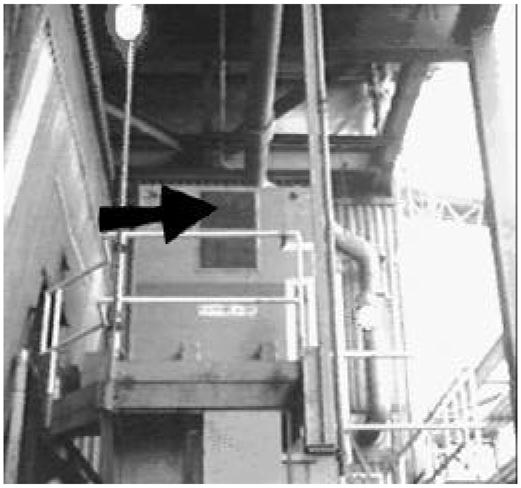


Figure 4-3 Visual Image

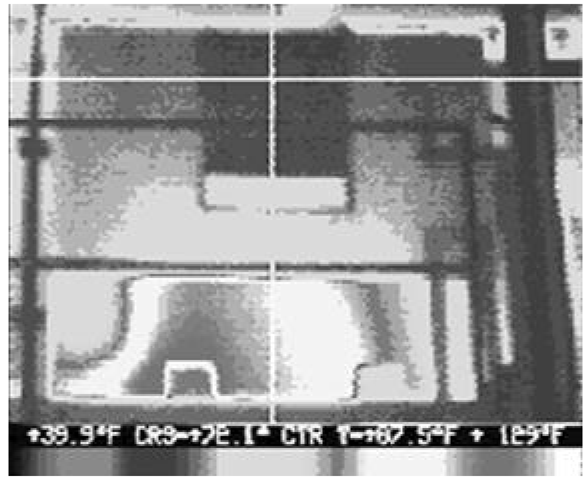


Figure 4-4 Thermal Image

Step 7: Determine specific temperatures on a Horizontal Motor's Air Outlet Vent Surface (Refer to Figures 4-5 and 4-6).

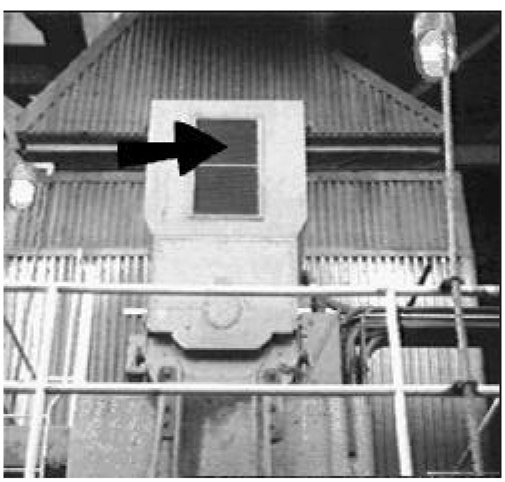


Figure 4-5 Visual Image

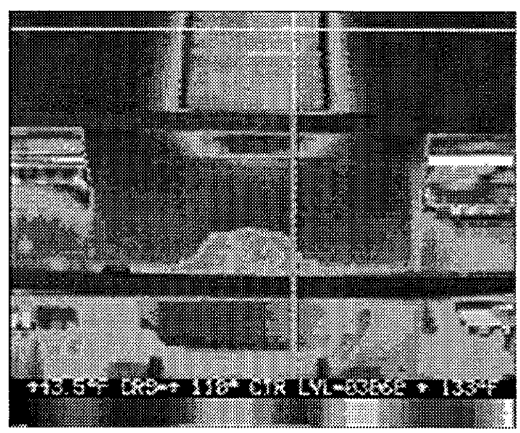


Figure 4-6 Thermal Image

Step 8: Determine specific temperatures on a <u>Vertical Motor's Air Inlet Vent Surface</u> (Refer to Figures 4-7 and 4-8).

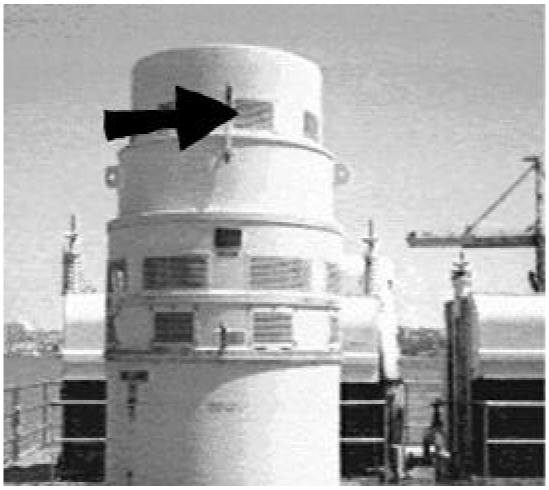


Figure 4-7 Visual Image

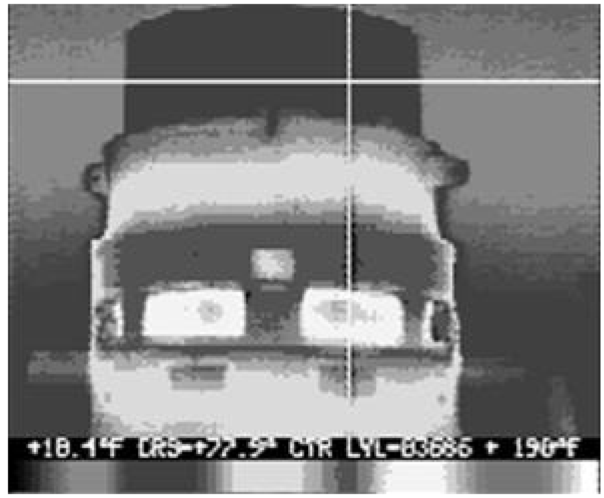


Figure 4-8 Thermal Image

Step 9: Determine specific temperatures on a <u>Vertical Motor's Air Outlet Vent Surface</u> (Refer to Figures 4-9 and 4-10).

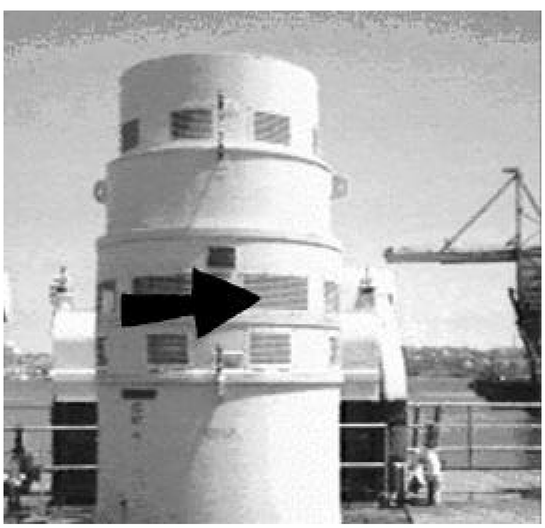


Figure 4-9 Visual Image

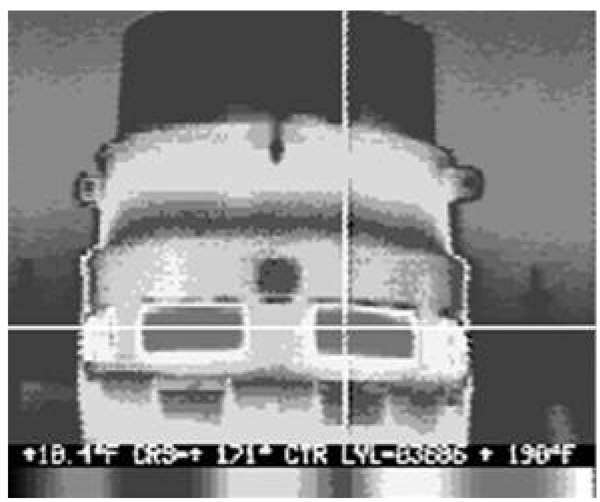


Figure 4-10 Thermal Image

Step 10: Determine specific temperatures on a Motor Lead Box Surface (Refer to Figures 4-11 and 4-12).

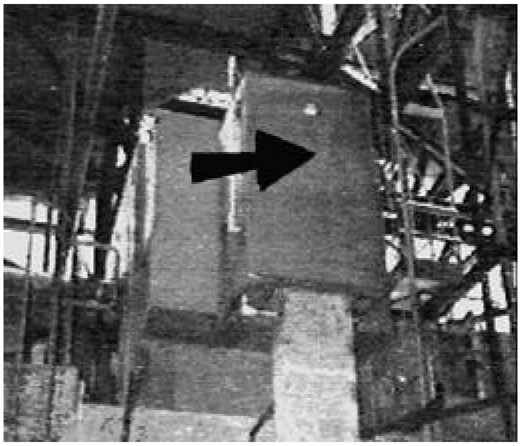


Figure 4-11 Visual Image

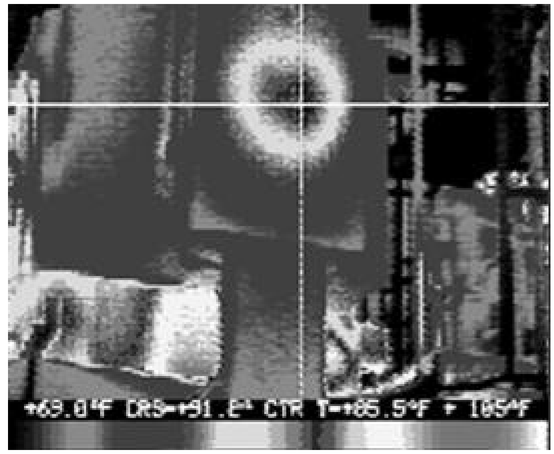


Figure 4-12 Thermal Image

Step 11: The appropriate distance from the IR camera to the item being surveyed is required and shall be recorded in the "Distance From Object-DFO" location on the data sheet (Refer to Tables 4-1 and 4-2). This information may provide assistance during analyses.

Step 12: Indicate that the Breaker Compartment was surveyed on the data sheet (Refer to Tables 4-1 and 4-2).

Step 13: All baseline images, both infrared and visual, shall be retained as a hard copy printout (a report) and on diskettes.

Step 14: It is suggested that a Temperature Comparison Chart (Tables 4-7 and 4-8) be created for all the items being surveyed for easier comparison of the items during the Follow-Up surveys.

Step 15: It is also suggested that a Distance From Object Chart (Tables 4-9 and 4-10) be created for all items being surveyed for ensuring a comparative DFO during the subsequent surveys.

Step 16: If a "Hot Spot" is noted and has been evaluated as an anomaly, the **Anomalies** portion of the data sheet can be used and "**Hot Spot Instructions"** of this guideline shall be followed.

Table 4-7
Temperature Comparison Summary Chart - Horizontal Motors

Utility Name & Station/Unit #
EMPM IR Thermography Survey Data Of Horizontal Motors
Temperature Comparison Summary Chart

(Note all temperatures in degrees F; HT= Highest Temp., NA = Not Accessible)

		LEFT SIDE			OUTBOARD		RIGHT SIDE			COUPLING			
Station/Unit #	Motor ID	IB Bearing HT	IB Casing HT	Casing HT	Bearing HT	Casing HT	IB Bearing HT	IB Casing HT	Casing HT	Center Flange Joint Temp.	Motor Lead Box Temp.	Date	Ambient Temp.

Table 4-8
Temperature Comparison Summary Chart - Vertical Motors

Utility Name & Station/Unit #
EMPM IR Thermography Survey Data of Vertical Motors
Temperature Comparison Summary Chart

(Note all temperatures in degrees F; HT= Highest Temp., NA = Not Accessible)

Station/Unit #	Motor ID	North Side Casing	South Side Casing	East Side Casing	West Side Casing	Top Side Casing	COUPLING Center Flange Joint Temp.	Motor Lead Box Temp.	Date	Ambient Temp.

Table 4-9
Distance from Object Summary Chart - Horizontal Motors

Utility Name & Station/Unit #
EMPM IR Thermography Survey Data of Horizontal Motors
Distance From Object Summary Chart

(Note all measurements in feet.)

		LEFT SIDE			OUTBOARD		RIGHT SIDE					
Station/Unit #	Motor ID	IB Bearing	IB Casing	Casing	Bearing	Casing	IB Bearing	IB Casing	Casing	Coupling Center Flange Joint	Motor Lead Box	Date
		Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	

Table 4-10
Distance from Object Summary Chart - Vertical Motors

Utility Name & Station/Unit #
EMPM IR Thermography Survey Data of Vertical Motors
Distance From Object Summary Chart

(Note all measurements in feet.)

Station/Unit #	Motor ID	North Side Casing	South Side Casing	East Side Casing	West Side Casing	Top Side Casing	COUPLING Center Flange Joint	Motor Lead Box	Date

General Instructions for a Follow-Up Survey

A Follow-Up Survey is a survey that is performed subsequent to the initial Baseline Survey. It is recommended that when starting an IRT PDM Program that quarterly surveys be performed on the selected equipment. The survey frequency may be reduced to three times per year and less, as the reduction in the number of anomalies found during each survey decreases. The Follow-Up Survey ***does not*** require ***infrared*** or ***visual images***, unless an anomaly is found. The Follow-Up Survey utilizes the data sheets identified as the "EMPM Infrared Thermography Follow-Up Field Data Sheets" (Tables 4-11 and 4-12).

Step 1: The Follow-Up survey also consists of an entire survey of the motor, which includes the following specific items:

a. Left Side Inboard Bearing and Casing

b. Left Side Casing

c. Outboard Bearing and Casing

d. Right Side Casing

e. Right Side Inboard Bearing and Casing

f. Coupling (if possible) or Shaft

g. Conduit and Motor Lead Box

h. Breaker Compartment

i. Air Inlet & Outlet Vent surface temperature

Step 2: A Follow-Up Survey requires that the "Highest" temperature indicated for each of the surveyed items be recorded in the proper location on the appropriate data sheet drawing. However, a Visual and Thermal Image is not required of any item, unless an anomaly is found or a new motor has been installed. If a new motor has been installed, baseline data is required to be taken in accordance with **"General Instructions for a Baseline Survey".**

Step 3: When performing the Follow-Up survey, compare the thermal images being viewed on the camera with the thermal images in the report from the Baseline survey.

Step 4: If a "Hot Spot" is noted and has been evaluated as an anomaly, the **Anomalies** portion of the data sheet can be used and **"Hot Spot Instructions"** of this guideline shall be followed.

Table 4-11
Follow-up Field Data Sheet - Horizontal Motor

EMPM INFRARED THERMOGRAPHY FOLLOW-UP FIELD DATA SHEET

Utility Name ____________________ Date ____________

Station & Unit # ____________________ Time ____________

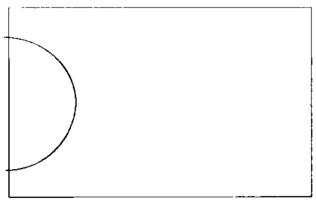
IR Thermographer ____________________ Emissivity Setting ____________

Ambient Air Temp. ____________________ Motor HP Rating ____________

Motor Identification ____________________ Breaker Compartment Surveyed: YES NO

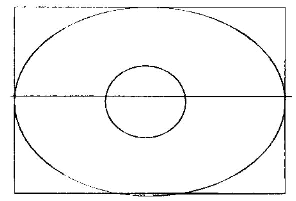
Motor Load (Amps) Phase "A" ________ Phase "B" ________ Phase "C" ________

NOTES: Left & Right Side references are with respect to the Motor End Cap. Indicate Temperature Engineering Units
On the drawings below, record and indicate where the "Highest" temperature is indicated. Always record Distance From Object (DFO).



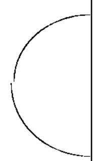
T#: V#: Left Side Inboard Bearing/Casing
DFO =

T#: V#: Left Side Casing
DFO =

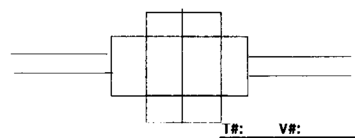


Outboard Bearing/Casing T#: V#:
DFO =

Right Side Casing T#: V#:
DFO =



Right Side Inboard Bearing/Casing T#: V#:
DFO =



Coupling Center Flange Joint Temp. T#: V#:
DFO =

Air Inlet Vent Surface Temp. = ________ Air Outlet Vent Surface Temp. = ________

Motor RTD Temperature as Indicated on Plant Computer: ________

ANOMALIES (Circle applicable items)

Motor - Casing/Bearings Thermal Image # ________ Visual Image # ________

Breaker Comp./Motor Lead Box Thermal Image # ________ Visual Image # ________

Coupling - Center Flange Joint Thermal Image # ________ Visual Image # ________

Motor Lead Box T#: V#:
DFO =

Comments:

Table 4-12
Follow-up Field Data Sheet - Vertical Motor

EMPM VERTICAL MOTOR IR THERMOGRAPHY FOLLOW-UP DATA SHEET

Utility Name ____________________ Date ____________

Station & Unit # ____________________ Time ____________

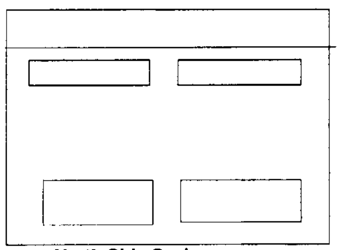
IR Thermographer ____________________ Emissivity Setting ____________

Ambient Air Temp. ____________________ Motor HP Rating ____________

Motor Identification ____________________ Breaker Compartment Surveyed: YES NO

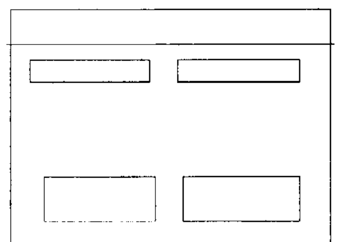
Motor Load (Amps) Phase "A" ________ Phase "B" ________ Phase "C" ________

NOTE: On the drawings below, record and indicate where the "Highest" temperature is indicated.
Please, indicate temperature Engineering Units. Always record Distance From Object (DFO).



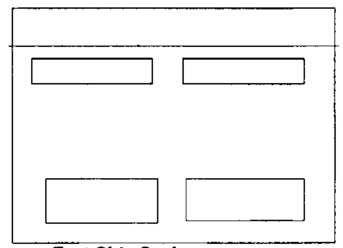
North Side Casing

T#:
V#: DFO =



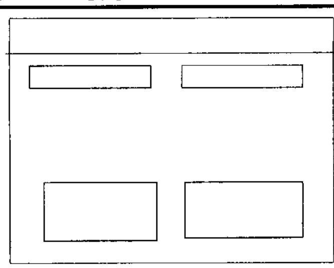
South Side Casing

T#:
V#: DFO =



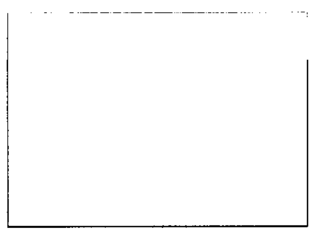
East Side Casing

T#:
V#: DFO =



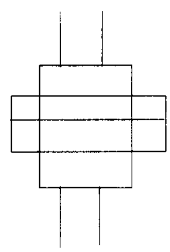
West Side Casing

T#:
V#: DFO =



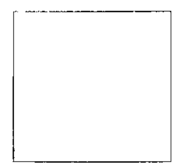
Top Casing

T#:
V#: DFO =



Coupling

T#:
V#: DFO =



Motor Lead Box

T#: ________
V#: ________
DFO= ________

Air Inlet Vent Surface Temp. = ________ Air Outlet Vent Surface Temp. = ________

Motor RTD Temperature as indicated on Plant Computer: ________

ANOMALIES (Circle applicable items)

Motor - Casing/Bearings Thermal Image # ________ Visual Image # ________

Breaker Comp./Motor Lead Box Thermal Image # ________ Visual Image # ________

Coupling - Center Flange Joint Thermal Image # ________ Visual Image # ________

Comments:

Hot Spot" Instructions

A "Hot Spot" is defined as an area on the component being viewed that has a surface temperature that is greater than the surrounding surface temperature.

Caution

Ensure that the "Thermal" image is recorded within the dynamic range so that hottest spot can be measured.

NOTE: It may be necessary to take two (2) thermal images:

- one to provide a thermal image of the entire portion of the motor being surveyed for identification purposes, which may not allow the “Hot Spot” to be within the dynamic range; and,
- one for measurement purposes to ensure that the “Hot Spot” is within the dynamic range. Dynamic range means the “Hot Spot” temperature can be measured, and does not appear as a white or black spot on a color image.

Step 1: Record "Thermal" image(s) of the "Hot Spot" and note the Thermogram number(s) in the **Anomalies** portion of the data sheet (i.e. Baseline or Follow-up Tables).

Step 2: Record the distance from the IR camera to the motor in the appropriate location on the data sheet.

Step 3: Record a "Visual" image of the component and the "Hot Spot" and note the image number in the **Anomalies** portion of the data sheet.

Step 4: Calculate the Temperature Rise of the "Hot Spot" by subtracting the "Reference" temperature from the "Hot Spot" temperature and record it in the **Comment** section on the data sheet.

Step 5: Visually inspect the "Hot Spot" area for discoloration, noise, or movement, etc. and note them on the data sheet.

Step 6: If this is a first occurrence of a "Hot Spot", at this location, note it on the data sheet.

Step 7: If this is recheck of a previously recorded "Hot Spot" note on the data sheet how much the temperature has increased or decreased since the last survey.

Step 8: If a previously recorded "Hot Spot" is repaired, Follow-Up Surveys of that previous "Hot Spot" should continue so that the repair work can be tracked for effectiveness.

Step 9: Also, after a previously recorded "Hot Spot" has been repaired, the information related to the repair (i.e. materials cost, labor cost, etc.) should be maintained with the EMPM motor file for trending each anomaly, for calculating cost benefits of each finding and for tracking the severity of each anomaly.

Step 10: Each "Hot Spot" that has been identified, along with the pertinent information for that "Hot Spot", shall be recorded on an **Exception Report** (Refer to "**Report Requirements"** of this guideline).

Report Requirements

NOTE: A hard copy report is required for both Baseline and Follow-Up Surveys.

Baseline Survey Report

The following are the Baseline Survey Report Requirements.

- A visual and thermal image with a location description for each of the required motor shots.
- A copy of all the completed field data sheets associated with each motor (Table 4-1 and/or Table 4-2).
- A copy of the Temperature Comparison Charts and Distance From Object (Tables 4-7 through Table 4-10).
- A complete Exception Report for all anomalies found (Refer to **"Exception Report"**).

Follow-up Survey Report

The following are the Follow-Up Survey Report Requirements.

- A copy of all the completed field data sheets associated with each motor (Table 4-11 and/or Table 4-12).
- A copy of the Temperature Comparison Charts and Distance From Object (Tables 4-7 through Table 4-10).
- A complete Exception Report for all anomalies found (Refer to **"Exception Report"**).

Exception Report

The following are the Exception Report Requirements (Refer to Tables 4-13 and 4-14).

- A visual and thermal image of each "Hot Spot" with a location and "Hot Spot" description.
- Visual and thermal images and data from the "Baseline" survey for comparison with the new survey motor data.
- A copy of the "Baseline" data sheets for the motor(s) associated with each "Hot Spot" shall be included in the Exception Report.
- A calculation of the differential temperature from the Baseline survey to the Follow-Up survey, with respect to ambient temperature during both surveys, shall be included in the Exception Report.

Table 4-13
EMPM Exception Report

EMPM Exception Report

Utility Name
Utility Station

Thermogram No.	Survey Date	TEMPERATURE	
		Rise °F	Severity
10	8/26/96	44	***

Location: Grade Floor

Equipment ID No.:

Equip. Description: #2 Primary Air Fan Motor

Specific Item: Air Outlet Vent Surface indicates a higher temperature as compared to Baseline Survey Data and compared to #3 PA Fan motor.

Probable Cause: Unknown, possibly clogged Air Inlet screens

Recommendations: Inspect Air inlet screens for clogging and rework as necessary.

Comments: Baseline to Follow-Up: Ambient temp. differential = 26° F, Air Outlet Surface temp differential = 68° F, therefore temperature rise = 68° - 26° = 44°F

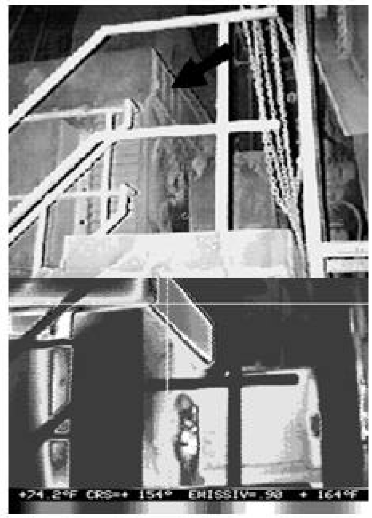


Table 4-14
Severity Guidelines Medium & Large Induction Motors Rated 4KV and Above

Classification	Symbol *	Comments
Minor Problem	*	Repair as a part of regular maintenance. Little probability of physical damage.
Intermediate Problem	* *	Repair in the near future (2-4 weeks). Watch load and change accordingly. Inspect for physical damage. There is probability of damage in the component, but not in surrounding components.
Serious Problem	* * *	Repair in the immediate future (1-2 days). Inspect the surrounding components for probable damage.
Critical Problem	* * * *	Repair immediately. Inspect surrounding components. Repair while IR camera is still available to inspect after correction.

Note: Severity is indicated by the number of asterisks assigned. Findings such as motor bearing surface temperatures, motor casing surface temperatures, temperature variations in heat transfer or cooling equipment, etc., are classified according to normal versus abnormal temperatures, or according to the severity of the problems found and how important that piece of equipment is to power generation.

5

MOTOR CURRENT MONITORING FOR THE DETECTION OF BROKEN ROTOR BARS

The purpose of this guideline is to instruct the user in the application of the Motor Current Monitoring technology as it applies to the detection of broken rotor bars in large induction motors rated 4kV and above. This technology is one of several used in the Electric Motor Predictive Maintenance Program (EMPM); and, it focuses on the application of the technology and provides instruction on its use. It also addresses some of the concerns and precautions which should be taken when specifically applying this technology in a periodic, walk-around, data collection program.

Rotor Bar Failure Mechanism

Broken rotor bars and cracked end rings can cause an induction motor to spark, vibrate, and emit excessive noise, thus impairing motor efficiency and contributing to the premature failure of other motor components. A single broken bar in an operating motor is frequently undetectable by sound or other non-analytic means, and analytic detection methods often give false readings. Further, vibration and excessive noise are typical of other motor problems as well, so it is difficult to reliably troubleshoot the cause of poor performance while a motor is on-line. Moreover, increased vibration is often attributed to motor imbalance rather than to broken rotor bar breakage. In such cases, attempts to rebalance the motor are futile, and they lead to delays which can cause the fault to propagate further.

Rotor bar cracking and subsequent failure occur most commonly in machines that are started often or that drive rapidly fluctuating loads, thereby subjecting the bars to repeated forces of acceleration and deceleration. Rotor bar fatigue fractures usually occur first where stress is at a maximum - in the region where the end ring joins the rotor bars. The stresses in those areas are greatest during startup of the machine, when rotor currents may be six to ten times full load current, when rotor temperatures as a consequence become quite high, when the mechanical strength of the rotor bars is reduced, and when vibration is also at a maximum.

After rotor bar cracking has started, the cracked bar typically overheats around the crack. The bar eventually breaks redistributing the current path and arcing often occurs (refer to Figure 5-1). Adjacent bars are forced to carry more current than normal and are therefore subjected to increased thermal and mechanical stresses during startup. This leads to the cracking and breaking of more bars and the damaging of rotor laminations around the broken rotor bars. In addition to damaging adjacent bars, broken rotor bars also affect the rest of the machine. For instance, increased vibration may damage the stator and cause excess bearing wear; and, high temperatures may reduce the service life of insulation materials. In fact, if use continues, broken bars may eventually lift, contact the stator, and destroy an entire motor.

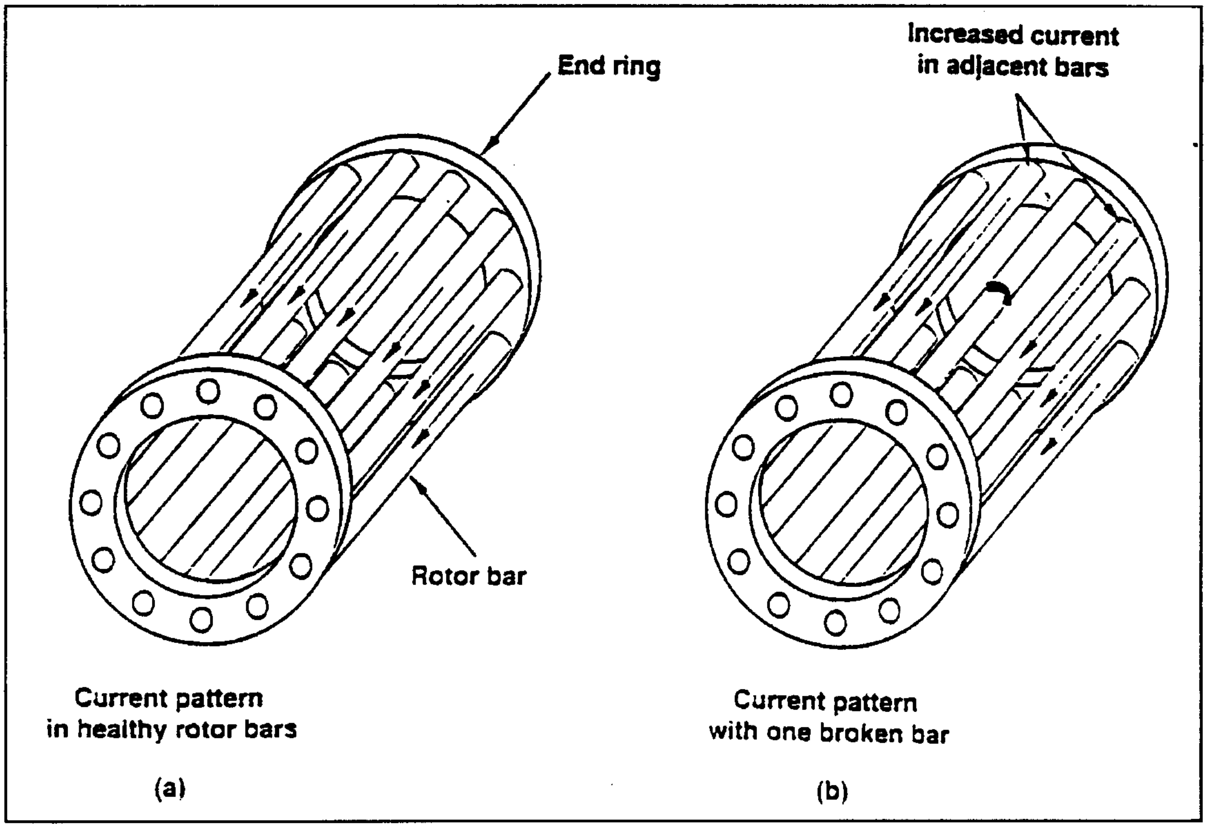


Figure 5-1
Current patterns in an induction rotor (a) with all bars intact and (b) with one broken bar

Test Set-up

Current monitoring can be implemented inexpensively by utilizing current transformers already in place in motor control centers. Typically, current transformers are designed for line frequency operation only, but they can pass signals well into the kHz range, if the signals are small and superimposed on a large line frequency component. The analog signals from these existing current transformers can be digitized and subjected to computerized signal processing. Utilities can take advantage of these current-sensing capabilities without retrofitting motors.

To generate the current input signal, the user need only use a clamp-on current probe that supplies (or is modified to supply) a voltage output. The current probe may simply be attached to the secondary side of an existing current transformer located in the control room or on the Motor Control Center panel (refer to Figure 5-2).

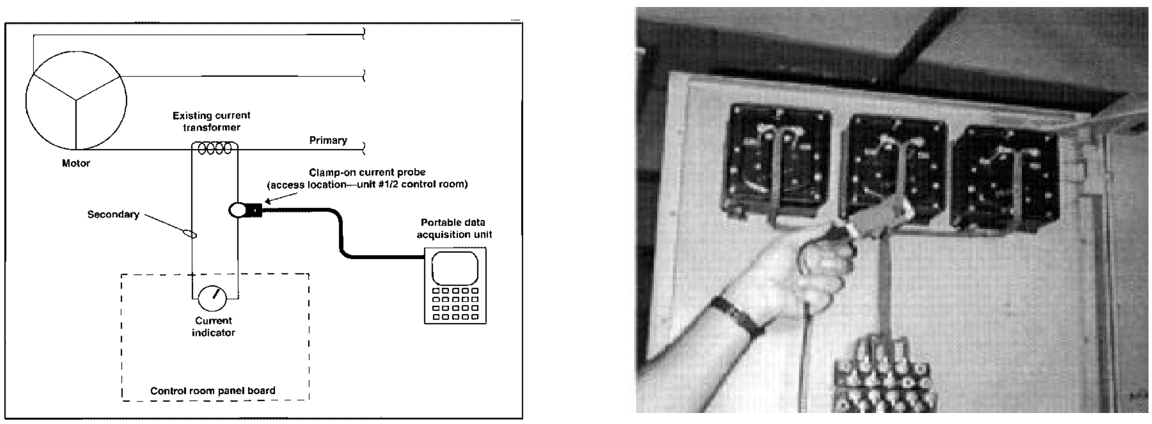


Figure 5-2
Schematic and visual of motor current data collection process

Then, a portable vibration monitor or data collector with spectrum analysis capabilities can be configured to receive the voltage output of the current probe and display the data in a logarithmic, high-resolution spectrum centered around the 60-Hz line frequency (refer to Figure 5-3). This process will be further discussed in Sections 'Data Collection' and 'Data Analysis'.

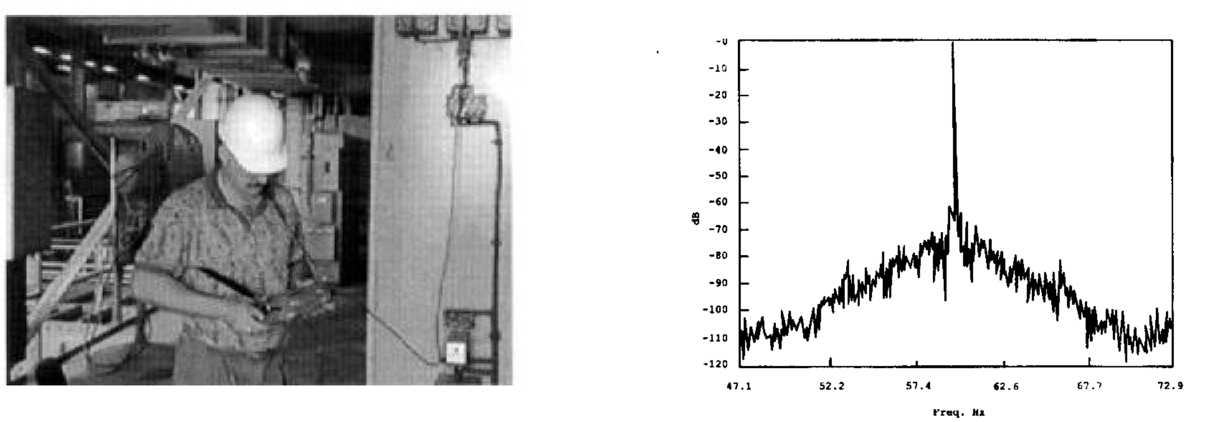


Figure 5-3 Data collector being used for data collection and a high resolution stator current spectrum for a healthy motor.

Current Probes

Current probes are available from a number of different manufactures and come in various sizes and output capabilities. In many cases, these probes are readily available from the plant's Electrical Department. An example of a typical current probe is shown in Figure 5-4. Two important factors must be considered when selecting a current probe to be utilized for motor current data collection.

The first factor is the output of the probe. It is important that the probe output be in volts and the proper range is selected. Many probes produce a current output which is often not readily acceptable to many of the portable vibration analyzers or data loggers. If this type of current probe is to be used, the output must first be shunted with a resistor, thus converting the output from current to voltage. If this is not done, the data collector may not recognize the input signal; or, the analyzer may be damaged. It is also important to note that the input voltage to the analyzer should not exceed the defined manufacturers limits.

The second factor to be considered when selecting a current probe is the physical size of the jaws which are used to clamp around the wire. Careful thought should be taken as to where data will be collected and what size probe jaws may be required. In some cases, more than one current probe may be necessary due to the thickness of the wire or the lack of space in which to clamp-on a different size probe that may be required.

Figure 5-4
Current probe used for motor current monitoring

Motor Current Data Collection Points

Motor Current data can be collected at various locations in the plant. The most common place is on the secondary side of existing current transformers where the voltage and current values are not excessive. Often, these values are a few amps or less. One such location is on the MCC panel where there may be an over current protection relay device with hard-wired terminations. Another location is the back of an ammeter in the control room. The current probe may be placed on the primary or secondary side of the circuit as the data obtained will be the same except for a different scale factor.

After selecting the location where data will be collected for each motor, it is recommended that the electrical wires be prepared and tagged for future data collection. This preparation may require that the wire ties be removed and the wire be looped to enable the jaws of the current probe to be placed around the wire. This will eliminate the possibility of data being collected on the wrong wire, and also will facilitate the data collection process. This is especially true if several different personnel will be acquiring data.

Caution: *Extreme care must be exercised when opening MCC cabinet doors or working around electrical connections. Plant personnel safety precautions must be addressed when working in these areas.*

In addition to personnel safety, the possibility exists to trip the motor and/or plant by jarring the cabinet door or inadvertently shorting the terminals with the current probe.

Required Conditions for Data Collection

When collecting motor current data, it is important that the motor be as fully loaded as possible. The magnitude of the rotor bar fault frequencies or "sidebands" (refer to Data Evaluation) around the line frequency component in the current signal are affected by the load on the machine as well as by the number of broken rotor bars. Load variations also affect the line frequency component, but as the load varies from zero to full the change in the line frequency component is typically far less than that in the sideband magnitude. Thus, at full load, tell-tale sideband changes are more readily detected than at lesser loads; and, tests should be performed when the motor is operating at full load or as close to full load as is practical. It is also important that the shaft speed be constant during the data collection process. Speed fluctuations can lead to confusing and possibly erroneous data interpretations.

To accurately locate the rotor bar fault frequencies in the current spectra, the actual speed of the motor must be known. However, when obtaining the motor current spectra by taking a reading at a motor control center, the user is often far from the motor and cannot easily obtain the motor speed at the same time. When periodic data is collected on a motor running at or near full load, nameplate speed may be used as the estimated running speed. When one or more broken bars are indicated, a high resolution vibration spectrum or a strobe light can be used to confirm the actual motor speed. Large motors often have tachometers that may be utilized for speed data. Also, an axial leakage flux coil may be used as described in the report.

Data Collection

Data can be collected by taking the output signal of the current probe and inputting it to one of several commercially available data collection devices. The data may be also be input to a tape recorder for future data processing or, in some cases, the data collection process may be on-line and hard-wired to a computer that stores and trends large amounts of data.

Data Loggers/Portable Vibration Analyzers

The data collection device commonly used for motor current monitoring in predictive maintenance programs is a portable vibration analyzer or data logger. These devices generally have spectral analysis and storage capabilities and in most cases interface with optional software programs. The software helps facilitate the data collection process and is used to further analyze the data. It also provides several report functions and in some cases applies an expert system or automated evaluation process. The software resides on a computer which interfaces with the data logger via external cables.

The most important feature of the data collector is its ability to receive and process the output signal (generally in volts) from the current probe, and display this information in the form of a spectrum. The spectrum is the result of transforming a signal from the time domain to the frequency domain. This process, known as Fast Fourier Transform (FFT) analysis, allows the user to view the frequency content of the signal. By viewing the data in this format, the user can determine if broken rotor bars or high resistance joints are present in the rotor. The method used to perform this analysis is further explained in ‘Data Evaluation’.

Some data collectors and most portable vibration analyzers can be configured to display spectrums in a “real-time” mode on a screen and require no additional software. This information can also be saved for later use. This option allows the user to perform an immediate evaluation while in the field. This method is generally used when evaluating a single motor because of the time required to configure the data logger.

When motor current data is to be collected on several motors, as part of routine data collection, optional software can be used to enhance the process. Data loggers are a natural fit due to the similarities in vibration data collection methods. In many cases, the software and data logger currently being used for vibration data collection, can also be used to collect motor current data; thereby, no additional costs to the PDM program are incurred. The only additional cost may be the purchase of a current probe.

Software

As previously stated, optional software is often used to facilitate the data collection process for several reasons. The first reason is the software can be used to automate the data collection. This is done by setting up predetermined parameters[1] in the software so the data is collected in the precise manner required for each data point. These parameters need to be set up one time and can be quickly downloaded to the data logger when data is to be collected. This is much quicker than configuring the data logger for each point. Data collection routes can also be set up in the software instructing the user as to which order the data should be taken.

Another advantage of using optional software is the management and display of the data. Numerous data points can be taken quickly by personnel who may not have the expertise to do the analysis. The data can then be downloaded to the computer and reviewed by qualified personnel at a later date. Many of the commercially available software packages also have the capability of performing trend plots and use other techniques such as alarming, which alert the user to abnormal conditions.

Expert or knowledge-based software systems are also available which automates the data analysis process and delivers an automated report with specific findings. Several of these systems also provide additional information such as rotor eccentricity.

When using expert systems, it is important to note that specific motor information must first be entered into the system before it can be used. This information includes, but is not limited to, motor nameplate data. If this data is not correct, the possibility exists that the analysis will not be correct. One typical area of concern is the exact motor speed at the time the motor current data was taken, versus the motor nameplate speed, which was entered into the system. If there is a large difference, the analysis could be in error. The reason for this is that the calculation performed to do the analysis is directly related to the motor speed. Motors which experience broken rotor bars tend to slow in speed as the deteriorating condition worsens. For this reason, the motor speed may not be the same as originally entered into the system. This is not a limitation of the expert system, because the motor speed is a variable that can be changed at any time; however, it is a concern that the user should be aware of. Some systems have enough "smarts" built into them to recognize this and may prompt the user to confirm the correct running speed.

[1] Predetermine parameters are specific criteria set by the vibration software user. These parameters are frequency limits, engine units, overall values, etc.

Another reason expert system software is used is that it has the ability to perform the analysis automatically and alert personnel to an abnormal condition. In some cases, the software produces a report including recommended action. In other cases, it may recommend additional testing be performed. Although this is an automated process requiring little expertise by the user, it is important to have a basic understanding of the way the analysis is performed.

Configuring the Data Logger/Software

Before motor current data can be collected, the data logger must be configured to receive the input signal from the current probe. If using the data logger without supporting software, this is generally accomplished in the data logger set-up menu. If the data logger is used with supporting software, this can be done by utilizing the configuration menu in the supporting software. This configuration process matches the output parameters of the current probe (volts) with the input parameters of the data logger. This is simply done by selecting volts in the set-up menu on the data collector or in the supporting software. As stated earlier, it is important not to exceed the input limits of the collector.

The data logger and software must also be configured to display the data in a logarithmic, high resolution spectrum. This is required because the amplitude of the line frequency is much higher than the rotor bar sideband frequencies and it would be difficult to distinguish them in a linear spectrum.

A high resolution spectrum is also required in order to view the spectral data and distinguish between peaks that are sometimes only a few RPM difference. This can be done by either setting the frequency span on the X-axis of the spectrum or by increasing the number of lines of resolution for the spectrum.

Data Analysis

Rotor Fault Sidebands

Fourier transformation of any signal containing narrow peaks results in series of periodic functions or "harmonics" of all frequencies. The motor harmonics are related to machine design. Most 'healthy' induction motors will generate harmonics that are 5^{th}, 7^{th}, etc. multiples of line frequency. The presence of a broken bar in a rotor creates a disturbance in the rotor flux pattern which transforms into the stator as a sideband signal or spectrum component.

If a rotor bar is broken, the 60 Hz current component and harmonics are modulated by rotating and time-varying contributions from the rotor anomaly. In the frequency spectrum, this modulation shows up as lower pairs of sidebands of the motor harmonics. The detection scheme relies on this phenomenon. Motor current monitoring in the frequency domain can detect the presence of one or more broken rotor bars or end rings, without the benefit of previous testing; however, periodic trending of this information will provide the greatest sensitivity to pending problems. When a fault such as a broken rotor bar or high-resistance joint occurs, harmonic fluxes are produced that induce currents in the stator windings. This defect is detectable in the current spectrum, because the current is induced at:

$$\text{Frequency of sidebands} = (1 \pm 2s)F1$$

where s = per unit slip = $\dfrac{\textit{Synchronous rpm} - \textit{actual rpm}}{\textit{Synchronous rpm}}$

and, F1 is the supply-current frequency in Hz.

An example using an induction motor with a synchronous RPM of 1200 actually running at 1185 RPM is as follows:

where s = per unit slip = $\dfrac{1200 - 1185}{1200} = 0.0125$

Frequency of sidebands = $(1 \pm 2(0.0125))3600 = (1 \pm 0.025)3600$

If there are broken rotor bars, the sidebands will be located at 3510 and 3690 rpm, respectively, in the frequency spectrum.

Another way to determine the location of the rotor bar side bands in the frequency spectrum is to multiply the **slip speed** of the motor by the number of poles in the motor. This will result in the spacing of the sidebands around the line frequency:

(Slip speed) (# of poles) = Rotor bar sideband spacing around 3600 rpm

where slip speed **=** (synchronous RPM - actual RPM)

An example using same motor as above:

Slip speed = (1200 - 1185) = 15 rpm

Rotor Bar Sideband Spacing around 3600 rpm = (15)(6) = 90 rpm

Rotor bar sidebands will be located at 3510 and 3690 rpm in the frequency spectrum.

Regardless of which method is used, the result will be the same; however, it is important to note that the first example refers to "**per unit slip**" while the second example refers to the actual "**slip speed**" of the motor. Both methods are shown because they are often confused with each other.

Spectral Evaluation

When evaluating spectral data to determine if broken rotor bars or high resistance joints are present, it is first necessary to determine where the sidebands should be located in the frequency spectrum utilizing one of the above methods. As stated earlier, the user should confirm actual motor speed.

Once the location of the rotor bar expected frequencies have been determined, the spectral data should be examined to see if there are any peaks at those frequencies. If peaks are located, the next step is to determine their amplitude in relation to the line frequency peak. The mere presence of rotor bar sideband peaks does not necessarily mean that the motor has broken rotor bars or high resistance joints. It is the amplitude of the sideband peaks in relation to the amplitude of the line frequency peak that is used to evaluate the condition.

As stated earlier, motor current data is viewed utilizing a high resolution, logarithmic spectrum. In most cases the "log" scale used is the decibel or dB scale. This is actually a ratio scale which relates the measured amplitude level to a reference level.

When using this scale, the line frequency level is the reference level and is usually set to zero dB. The amplitude level of the spectral peaks are then compared to the reference level or line frequency level and are read directly in dB values. This is often referred to as the number of **dB down**, or, how many **dB down** are the peaks from the reference value.

Sometimes, the amplitude values are only given in Amps or Volts and the exact **dB down** value can be calculated by using the following expression:

$$L_{dB} = 20 Log10 \frac{l_1}{l_{ref}}$$

l_1 = amplitude of sideband

l_{ref} = amplitude at 60 Hz

or, the **dB down** value is equal to:

> The rotor bar fault peak value divided by the line frequency peak value. Then take the log function of the result and times by 20. This will give the **dB down** value.

A spectrum for a motor with no problems consist of a clear peak at the line frequency and sidebands equally spaced on either side. The magnitude of the sidebands may be over 60 dB down from the magnitude of the line frequency (Figure 5-5). The spectrum for a motor with a known fault will have a distinct peak at line frequency and elevated sidebands at the rotor bar fault frequencies (Figure 5-6).

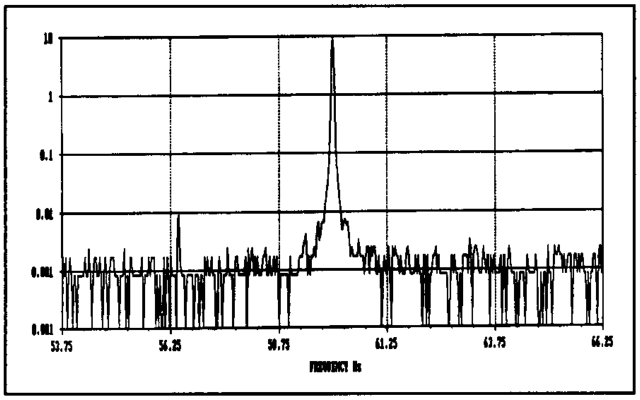


Figure 5-5
Motor with no problems

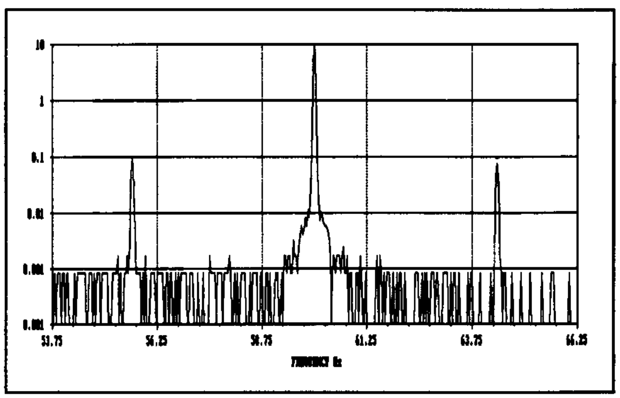


Figure 5-6
Motor with a known fault

An empirically-established threshold for amplitude of the rotor fault sidebands allows "single look" identification of probable rotor bar problems. If the lower sideband peak is 53 to 45 dB down from the peak current value at line frequency, a high resistance joint or broken rotor bar may be present and further testing should be performed. If the lower sideband peak is less than 45 dB down from the peak current value, one or more rotor bars are probably broken.

The above criteria should be used to help assess the overall condition and severity of the problem rather than determining the exact number of broken rotor bars. In some cases, the presence of high resistance joints or 1 broken rotor bar indicated by a 53 or 52 dB down value may not require immediate attention and the recommended action may be to increase data collection and trend the values. In other cases, a value of 40 dB down indicates that the problem may be more severe and may require a different course of action such as pulling the rotor for inspection.

In all cases, the motor current data should be correlated with other available motor data and parameters such as vibration data, motor amp swings, reduced operating speed, etc. The long term trending of the motor current and supporting data will provide valuable information when a decision must be made as to the operability of the motor.

References / Further Reading

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6

VIBRATION MONITORING FOR PERIODIC DATA COLLECTION ON MEDIUM & LARGE INDUCTION MOTORS

The purpose of this guideline is to provide an overview of the application of a periodic vibration monitoring program utilizing portable data collection equipment. *The instructions contained are intended as a guide for use on medium and large induction motors.*

This guideline is to provide general instruction on the application of a periodic vibration monitoring program which yields data that is consistent and trendable. The data produced will be correlated with other technology data used as part of the Electric Motor Predictive Maintenance program.

Overview of Periodic Vibration Monitoring

The reason for a vibration monitoring program is to aid in determining the condition of the machinery, or in this case, the motor involved. Once the motor's condition is known accurate maintenance planning is possible.

Vibration monitoring is the systematic acquisition, measurement and evaluation of the motor's physical movement. This motor movement can usually be attributed to mechanical or electrical-mechanical forces acting upon its mass.

This systematic acquisition of data should involve data collection on a periodic basis. Two time frames are useful for periodic monitoring: (1) a time period for motors in good machinery health, usually monthly or quarterly; and, (2) a shorter time frame for motors with identified adverse conditions that require closer observation.

Motor vibration data should be collected as close to the bearing as possible. In order to obtain this information, a vibration sensor is used to convert the physical movement into an electrical signal that is stored in a portable data collection box and ultimately uploaded into a computer. This information is then trended over time. Any deviation in the trend data can then be evaluated for a possible cause.

Vibration Monitoring Equipment

Periodic vibration monitoring would not be possible if it were not for the availability of low cost portable equipment. Some of the equipment involved are sensors and a battery powered analyzer or datalogger. A personal computer is the best means to store all the acquired data, and to provide a method of displaying and trending the data. Figure 6-1 shows an example of typical data collection equipment.

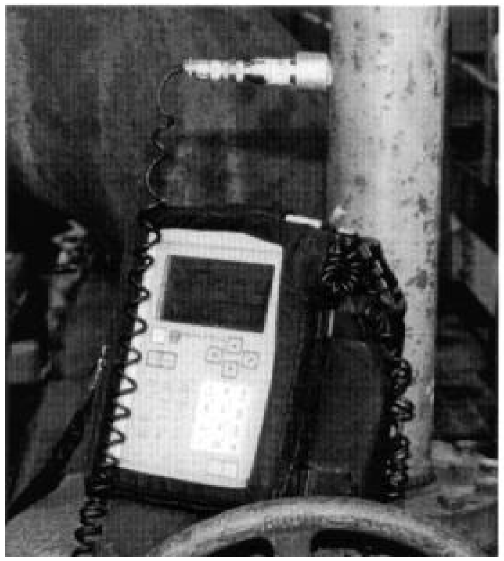


Figure 6-1
Typical Data Collector

Vibration Sensor Overview

All vibration sensors or transducers convert the physical movement of the motor into an electrical signal. This signal is a representation or signature of that motor which is then stored in the datalogger.

Three different types of sensors are commonly used in a vibration monitoring program. One type of sensor is the velocity probe which has an output in units of inches per second. Another type of sensor is the accelerometer which produces a signal in the units of g's. The third commonly used vibration sensor is the proximeter (prox) probe and it converts shaft displacement to mils.

Note: *The accelerometer is usually the sensor of choice due to its light weight, ease of use and its wide frequency response. It is also important to note that most accelerometers today are of the ICP type which means that they include, internally, an integrated circuit preamplifier.*

Velocity Probe

One of the earliest vibration sensors is the velocity sensor which is still widely used today. Its construction is simple and rugged. A velocity sensor consists of a coil of wire and a magnet in a non-conductive housing. As motion causes the magnet to move, it induces a flux in the coils which produces a signal that is proportional to the initial movement or vibration.

Accelerometer

The accelerometer is another type sensor that is commonly used for vibration monitoring. An accelerometer utilizes a piezo-electric crystal. In its simplest form, the piezo-electric crystal is placed between its base and a pre-determined amount of mass. As physical movement is applied to the sensor the mass squeezes and exerts pressure on the crystal, and this action produces an electrical signal. Accelerometers are very light with a linear response range that lend themselves to the tasks required in a periodic vibration monitoring program. Another reason for its broad acceptance in this type of program is because of its wide frequency response; normally 2Hz to 10kHz. For special applications, however, sensors are available that have a lower or higher frequency capability outside of this range. For example, accelerometers are available to monitor the lower frequencies of a 90 rpm motor, or the higher frequencies associated with rolling element bearing defects.

Proximity Probe

The proximeter probe or displacement probe is used to measure the distance between the probe tip and the motor shaft. This is a permanently installed sensor and, due to the added expense of installation, usually only monitors critical plant equipment. The proximeter or prox probe operates by generating a flux field that is sensitive to the relative position of the shaft. As the shaft changes position the flux field at the probe tip senses this change and produces an output that is proportional to that position change. Figure 6-2 shows a typical proximeter probe installation.

Figure 6-2
Typical Proximeter Probe Installation

The proximeter probe is valuable for monitoring shaft vibration. They are inexpensive, durable (not affected by lubricating oil) and possess a frequency response of up to 1000Hz. A major disadvantage in the prox probe is that it will respond to shaft scratches or other imperfections, and to variations in rotor eccentricity and shaft metallurgy.

Note: *It is important to remember that the proximeter probe monitors shaft motion relative to its mounting. If the probe is mounted inside a bearing, then the shaft motion is said to be relative to the bearing housing.*

Shaft Stick

The shaft stick is not a sensor but an attachment to a sensor. In most cases a shaft stick, or sometimes called a fish-tail, is attached to an accelerometer. When using the shaft stick, the V-shaped end of the stick is placed against the rotating shaft which allows the accelerometer to sense the shaft's movement. This method of detecting shaft vibration is used when proximeter probe installation is cost prohibitive. (refer to Figure 6-3 in Data Collectors for a view of a shaft stick).

Safety tip: *Be sure to check the shaft beforehand for keyways and unnoticed shaft coupling bolts, or any other rotating parts that can cause injury. Also, to further avoid injury, it is wise to take your vibration readings on an area of the shaft where the surface is rotating away from you.*

Strobe Light

The strobe light in a periodic vibration monitoring program is useful in determining motor rpm and for shaft inspection. This device has the capability of visually 'freezing' the motor's shaft. Some of the reasons for 'freezing' the shaft are to find the exact rotating speed of a motor, and checking the shaft for keyways and other obstructions. Motor fans can also be checked for cleanliness and damage.

Note: *The strobe light also has uses in troubleshooting and balancing of equipment, but those applications are beyond the scope of this guideline.*

Tachometer Pulse

The purpose of a tach pulse is to act as a timing reference. Commonly, a prox probe is used to obtain a tach pulse for motor speed indication that can be transmitted to the control room. The prox probe is usually positioned to sense the keyway of a shaft. As the keyway passes in front of the prox probe a pulse signal is generated which becomes the reference point for determining speed and other vibration related events on that motor. In lieu of a keyway, any other distinct disruption in the rotating surface that occurs once per revolution can be used as a reference. *These techniques produce what is termed a 'once per rev pulse.'* Tach pulses are mostly used when performing advanced analysis techniques.

Data Collectors

At the center of any periodic vibration monitoring program is the FFT or Fast Fourier Transform analyzer. The FFT data collector is used to view and store the vibration signal. The FFT analyzer converts a time domain signal into a frequency domain signal. This frequency domain signal, or spectrum, is what is termed the motor's vibration signature.

In a periodic vibration monitoring program the data collector is commonly used to gather and store the data until it is convenient to upload it to the host computer. (Figure 6-3 shows a data collector with a shaft-stick attachment). It is this ability to process and store the vibration signals that is precisely the feature that allows for a periodic monitoring program.

Note: *Although an FFT is commonly used for periodic vibration monitoring, it can also be used for troubleshooting purposes by viewing the spectrum and analyzing the data immediately.*

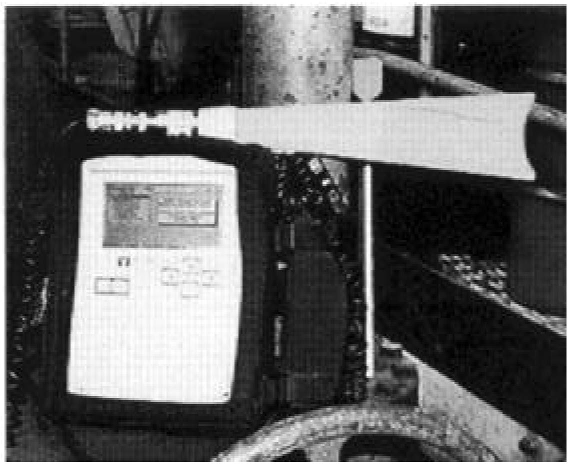


Figure 6-3
Data Collector with Shaft-Stick Attachment

The data collector should have the ability to display a high amount of resolution and be capable of identifying fractions of a hertz in the range from 1X to 5X of operating speed.

Lines of Resolution

This is the amount of detail that is shown on the FFT analyzer display. As an example, if it is desired to monitor a motor with a running speed of 60Hz up to 5 times its running speed (5X), or 300 Hz, the proper way to monitor this motor is for the analyzer to show clarity up to at least 300 Hz. Most FFT analyzers are capable of at least 400 lines of resolution which translates into a 300 Hz range divided by 400 lines of resolution. Thus the analyzer will show information every 0.75 Hz. However, by increasing the lines of resolution to 800, the analyzer will show information every 0.375 Hz.

CPM vs. Hz

It is important to understand the relationship between Cycles Per Minute (CPM) and Hertz (Hz). When converting Hz to CPM simply multiply by 60. Therefore, a motor with an operating speed of 60 Hz will rotate at 3600 CPM. C*ycles per minute and revolutions per minute, RPM, are interchangeable terms.*

Software

The most important function of the software is to serve as a database manager. Database management is the organization, storage and retrieval of data; in this case, the vibration spectrums.

Note: *The software and data collector must be compatible.*

In explaining the role of the software it is necessary to first explain how the motor's collection points are organized into routes, also referred to as lists, and how the software is responsible for the coordination of those routes.

Routes

Each motor has a standard amount of data points to be monitored. These points may be placed into a group of points called a route. In some cases it may be convenient to place several motors into the same route.

The software provides a means to coordinate the routes and sets the order in which data is to be acquired. The user may then select separate routes or a route that combines more than one motor. Once the route is organized, it is downloaded into the data collector where the user is encouraged to systematically step through the data collection process.

At the beginning of the day, one or several routes may be placed or downloaded into the data collector for the motors to be monitored. Starting at the beginning of the route, each point is taken in order (if possible) until the route is completed. At this time, each point contains a vibration sample that is stored until connection to the host computer is possible.

Host Computer

The host computer can be a main frame, mini or personal computer. The principal criterion is having enough power and capability to maintain a large database, and to provide the means for adequate data evaluation.

Organizing the spectrums that have been processed by the data collector is done by the software. Upon upload from the data collector to the host computer, the spectrums are placed into memory (hard-drive) for later retrieval. Once these vibration samples, or spectrums, are entered into the computer, permanent storage and condition analysis becomes an option.

Database management is the software's primary use, although other features are also beneficial. Most vibration software programs will offer features that aid in the analysis process by incorporating trending, alarms and reports.

Data Acquisition

The requirement of a periodic monitoring program is to gather accurate data on a consistent basis. The importance of this is to ensure that the ability to trend motor health is not distorted by false or erroneous data. Figure 6-4 shows the data collection process with a portable data collector.

The considerations to assure proper data acquisition are as follows:

- Measurement point locations.
- Proper sensor mounting techniques.
- Data collection sequence.

Figure 6-4
Example of Data Acquisition

Measurement Point Location

Vibration data should be taken on the bearing casing or housing, using portable data collection equipment. The bearings offer a good transmission path to the bearing housing. As the rotor vibrates, vibration energy will be transferred to the bearings and bearing housing.

It is important to know the location of the radial bearings, the type of bearings and the location and type of thrust support before determining measurement point locations and attempting to acquire data on a motor. On sleeve bearings, the location of the 'load zone' is also desired. Once this information is known, data can then be gathered in the appropriate locations and directions.

Note: *A cross-section mechanical drawing of the machine is helpful if the bearing locations are not obvious.*

Every bearing should be monitored for vibration in each supporting plane. For example, a radial bearing supports the rotating member in two planes, horizontal and vertical. The thrust bearing or collar will support the rotating member in one plane or direction; therefore, only one vibration reading is required. The basic premise is to take two vibration readings on each radial housing , as shown in Figure 6-5, and one in the direction of the thrust support.

Note: *Ideally, the vertical and the horizontal probes are 90 degrees apart*

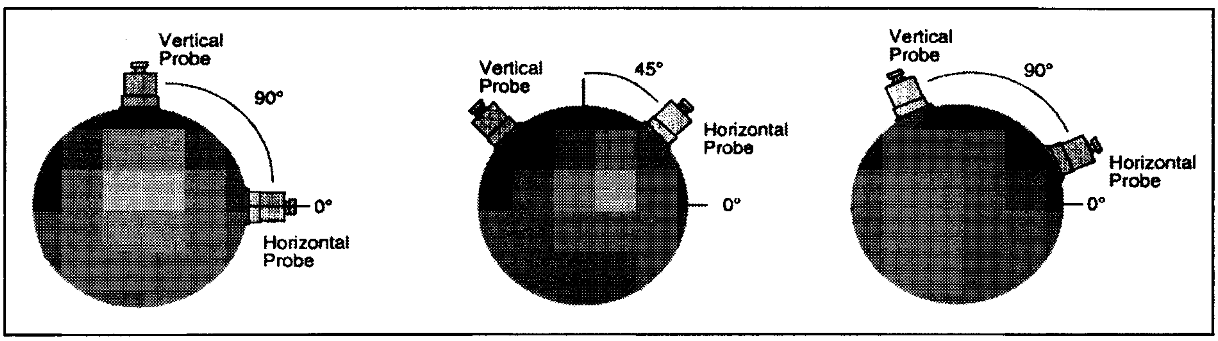


Figure 6-5
Typical Probe Configuration

Note: *Although it is ideal to space the probes 90 degrees apart, it is not always possible. In these cases, place the probes as close to a 90 degree orientation as achievable.*

Measurement Point Labeling

The accepted practice for collecting data is to record vibration readings starting from the outboard bearing and ending with the inboard bearing. The accepted sequence for gathering data at each bearing is horizontal, vertical and axial (H,V,A). A typical motor point designation would be MOH for Motor Outboard Horizontal. Another possibility is numbering the bearings. For instance, starting at the outboard end of the motor, begin numbering the bearings 1,2,3,.etc. until all bearings are numbered. A typical point designation using this method would be 1H for # 1 bearing - horizontal direction. Regardless of whichever designation method is adopted, the important thing is to be consistent.

Identifying this data point location at each bearing varies and can be as elementary as using a paint stick dot, or as high tech as labeling with bar code strips. The goal of either method, again, is to produce consistently identifiable data collection points.

Sensor Mounting

Note: *Vibration sensors are very sensitive to mounting; therefore, a reasonable amount of care is required to ensure accurate vibration readings.*

The collection of accurate vibration data depends upon the quality of the transmission path to the sensor. This fact makes accelerometer mounting vital to data collection. *Most periodic vibration monitoring programs employ the use of transducers that are either magnetically-mounted or hand-held*. These mounting methods are satisfactory for the majority of locations; but, in certain cases alternatives need to be applied, such as for motors that are completely enclosed by an external housing. In these cases, the sensors would be permanently mounted under the enclosure using one of the following methods:

- Stud Mounting.
- Machined Surface Mounting.
- Cyroacetic Glue (Crazy Glue) Mounting.
- Dental Cement Mounting.
- Epoxy Cement Mounting.

Stud-mounted sensors offer the best vibration transmission characteristics, but may be impractical as the number of data collection points increase. Use of magnetically-mounted sensors on a machined surface is another good method for acquiring accurate data; but, this method can also become cost prohibitive as the number of machined surfaces increase.

Note: *The most practical and economical choices of sensor mounting in a periodic vibration monitoring program is the magnetically-mounted sensor or the hand-held sensor used on standard motor surfaces.*

Note: *When properly applied, the hand-held sensor offers a good conduit for data transmission. Practicing to gain experience with this technique will help result in consistently repeatable readings.*

Collecting the Data

Example:
This horizontal motor will have two radial bearings with thrust support incorporated within the outboard bearing. Therefore, at least five data points are required- three on the outboard bearing casing (H,V,A), and two (H,V) on the inboard bearing casing.

The diagram (Figure 6-6) shows the typical configuration for data collection locations on a horizontal motor. Note also the Motor Inboard Axial (MIA). Its location is labeled, if needed; but, it is not required in this example since the thrust movement is detected at the outboard location.

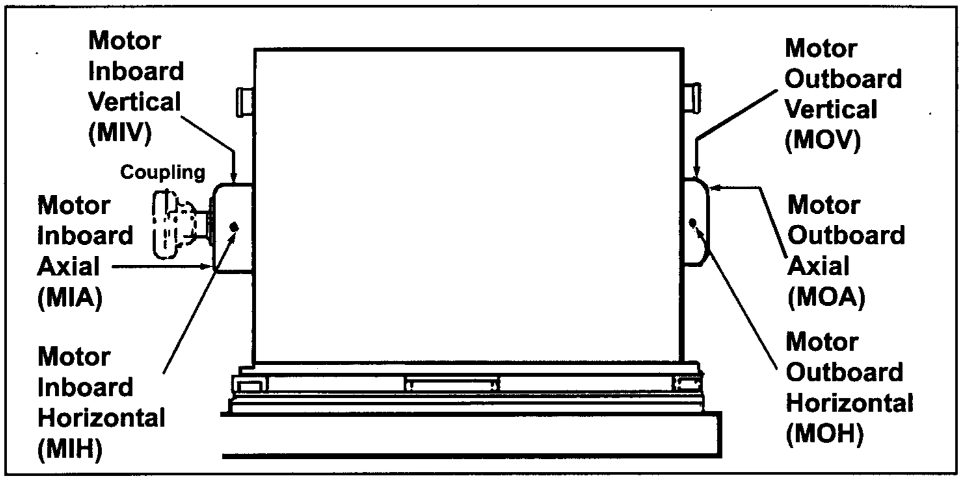


Figure 6-6
Horizontal Motor Configuration

The sequence for acquiring vibration data on this motor is as follows:

a) proper route is downloaded to datalogger.

b) proceed to motor and perform visual inspection.

c) place sensor on Motor Outboard Horizontal (MOH) location and gather data.

d) move sensor to Motor Outboard Vertical (MOV) location and gather data.

e) move sensor to Motor Outboard Axial (MOA) location and gather data.

f) move sensor to Motor Inboard Horizontal (MIH) location and gather data.

g) move sensor to Motor Inboard Vertical (MIV) location and gather data.

h) upload route to host computer

Note: *The recommended method to obtain trendable data is to follow a set sequence that is the same each time data is collected.*

Vertical Motor Label Variations

Vibration monitoring test points on vertical motors can be labeled in a variety of ways. The bearing locations can remain labeled as 'outboard' and 'inboard', or could be changed to 'top' and 'bottom' or 'upper' and 'lower'. These locations can also be numbered, in which case no changes are required between vertical and horizontal motors.

The test point orientation at these bearing locations can be labeled north, south, east or west (N,S,E,W); or, in relation to the pump flow direction, such as 'in-line' or 'perpendicular to flow'. Labeling these points can also be as simple as X,Y,Z relating to their dimensional planes.

The example included in Figure 6-7 shows the bearings labeled as Outboard and Inboard. The outboard bearing usually contains the thrust support and will require an axial reading in addition to the standard horizontal and vertical data planes. In this case the horizontal plane is in the same direction as the discharge piping and is thus in-line with the flow.

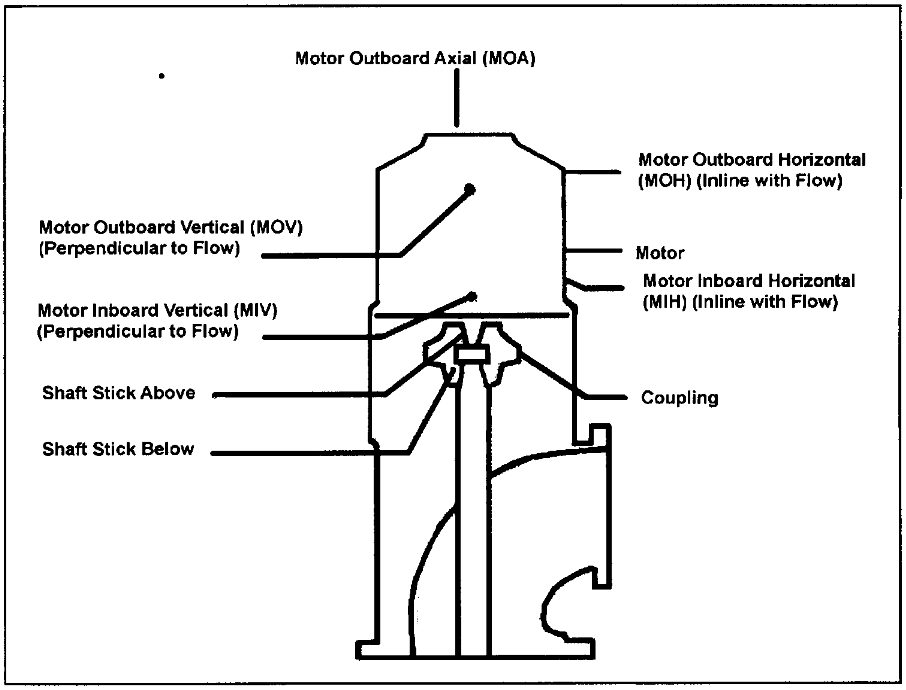


Figure 6-7
Vertical Motor Configuration

Note: *The most important factor in labeling data points is consistency.*

Motor Casing vs. Shaft Vibration

In a periodic vibration monitoring program most data is gathered at the bearing casing or on the nearby housing. This is possible when the bearing is easily transmitting the rotor vibration to the casing. However, certain bearing designs inhibit this vibration transmission.

Anti-friction bearings offer a good vibration transmission path. Rolling element bearings, one type of an anti-friction bearing, allows some metal-to-metal contact between the bearing and the rotor, as well as the bearing and the casing. This fact forms a direct path for vibration transfer which allows the data to be collected on the casing.

Sleeve bearings, a type of hydrodynamic fluid bearing, on the other hand impedes this transmission path. These bearings are designed to have the rotor shaft ride on a film of oil as it rotates. This oil film dampens the shaft movement and thus lessens the amount of vibration transmitted to the bearing casing.

Some of the factors that affect vibration dampening are: the type of bearing, the bearing design, the mass of the motor housing or, possibly, the bearing clearance and the oil film viscosity and thickness.

Note: *In cases where the rotor vibration is not being transferred to the motor casing, a shaft displacement measurement may be required.*

Shaft Stick Vibration Data

A shaft vibration measurement is recommended on vertical motors. This measurement is obtained by attaching a wooden fishtail stick to an accelerometer, then holding this fishtail against the rotor shaft. This technique is demonstrated in Figure 6-8.

Figure 6-8
Shaft-Stick Measurement

If possible, take two shaft vibration measurements, one above the coupling and the other below.

The method used to take shaft vibration with a shaft stick is as follows:

a) ensure good connection between the sensor and the fishtail.

b) check the shaft with a strobe light for safety concerns.

c) place a few drops of light oil on the 'V' of the fishtail.

d) place the fishtail against the shaft with sufficient force to gather data - without bouncing or wavering up and down the shaft.

e) allow ample time for the FFT to acquire data.

Note: *A section of cardboard can be used to clean the shaft of light dirt. The shaft can also be burnished with a piece of emery cloth to remove grime and some corrosion.*

The fishtail method of gathering shaft vibration data is used when proximeter probes have not been installed. The proximeters can give much more accurate data and allow the data to be gathered faster and safer. Another advantage with proximeters is that they may be orientated in both the X and Y planes, whereas the fishtail is usually limited to one plane because of the housing structure.

Note: *A rough or scratched shaft surface can adversely affect the accuracy of the shaft-stick measurement.*

The Vibration Database

After the data is collected, it is uploaded into the host computer. The host computer offers data storage, data retrieval and database management.

Data Storage and Retrieval

Once the vibration data is collected it is downloaded onto the computer's hard drive where it resides until retrieval is necessary. Data retrieval is instrumental in viewing vibration trends and signatures.

Database Management

Long term storage is necessary for the data to be trended easily. The computer is the most convenient method for this storage need and, in addition, offers a good means for data retrieval. This allows easy access for data trending and motor vibration analysis. Database management is also convenient in this format.

Hints for maintaining a reliable database:

- Ensure that the data is in the proper routes.
- Delete unwanted or erroneous samples.
- Back up files at frequent intervals.

Vibration Trending of Overall Values

Trending is the comparison of vibration samples that have been taken at periodic intervals. Increasing vibration levels are an indication of a developing problem or a deterioration of motor health. Figure 6-9 is an example of an overall trend plot versus time.

Baseline Data

The baseline survey is the basis for data comparison in trending. Subsequent data is compared to the baseline survey, as a reference for the developing vibration trend. The initial data sample is the first vibration data taken and can be used as the baseline survey.

Note: *The most valuable baselines are those gathered on new motors, after a rebuild, or any other time that the motor condition is known.*

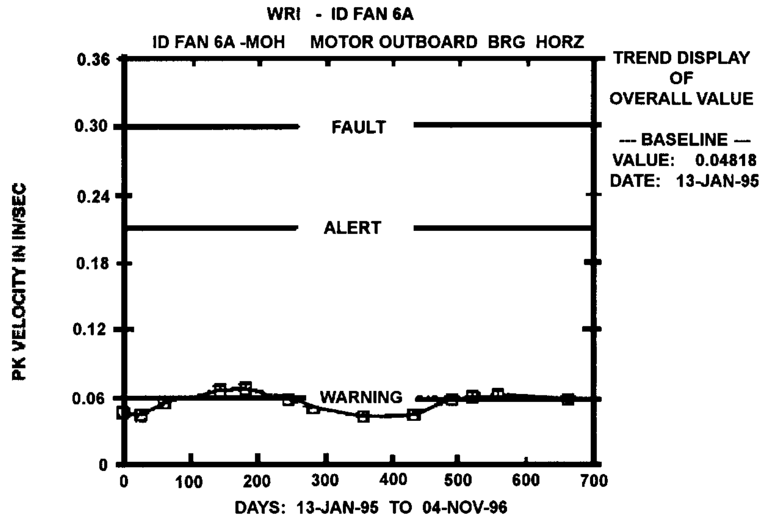
Motor Condition Assessment

The ability to assess motor condition is based on many factors. Some of these include experience, technology, motor knowledge, testing time and training. Over time, the ability to accurately analyze motor condition will increase as the working knowledge of vibration analysis and machinery operation is increased.

Note: *Many faults look similar. The assessments need to include other technologies such as motor current analysis, lube oil analysis, thermography and electrical testing data to form a knowledgeable opinion.*

Note: *The monitoring interval should be increased for any motor that has indicated a problem. This is because some machinery faults increase at an exponential rate, leading to a shorter time to failure.*

Note: *Vibration data should be reviewed frequently to enhance early detection. This early detection will help prevent production loss, minimize motor damage and reduce its repair cost.*



<u>List of Trend Points</u>

Station: WR1 → Wabash River Unit 1
Machine: ID Fan 6A → ID Fan 6A
Meas Point: MOH → Motor Outboard Brg Horz
Parameter: Overall Value (Pk Velocity in In/Sec)

Date	Time	Value	Date	Time	Value
13-Jan-95	15:48	0.0482	05-Jan-96	15:44	0.0436
09-Feb-95	15:47	0.0454	22-Mar-96	13:43	0.0452
15-Mar-95	13:59	0.0550	16-May-96	14:06	0.0590
06-Jun-95	13:09	0.0670	18-Jun-96	10:11	0.0606
11-Jul-95	15:21	0.0676	25-Jul-96	10:19	0.0619
15-Sep-95	14:48	0.0581	04-Nov-96	11:22	0.0590
21-Oct-95	10:20	0.0512			

Baseline	Stored Mean	Stored Deviation
0.0482	0.0573	0.0082

Figure 6-9
Overall Trend Example

Vibration Alarms and Severity Charts

The use of vibration alarms is a software feature that alerts to a change in levels from the previous sample, or as being above a pre-set level. For example, some software packages feature an enveloping option which places an alarm level at 10% above a previous spectrum, then produces an alarm when any peak exceeds that level. Another example is the pre-set alarm level that may be set at 0.3 inches per second of overall vibration, and then alarm when this level is exceeded. Both alerting methods offer reliable indications of increasing levels of vibration. The first alarm method is for spectrums and the latter is for overall vibration levels.

Severity charts are used as aids in determining motor condition. Once the data is collected and uploaded into the computer it becomes necessary to analyze the condition of the motor. It is very important to remember that there are many severity charts in use, some are specific to machinery designs and others are very generalized. For instance, there are in use different severity charts for horizontal motors, as opposed to those used for vertical motors. Figure 6-10 is an example of a widely used general severity chart.

Note: *The Electric Motor Predictive Maintenance Program uses 0.3 inches per second as the alarm point for determining excessive vibration levels.*

Frequency Analysis

Machinery assessment can be divided into two major components. The first is assessing its condition by measuring the overall levels. This is used as a general indication of machinery health. A more intensive approach is frequency analysis. This is a detailed study of the vibration peaks occurring in the collected spectrums. Each peak may correlate to a basic physical property of the motor. For instance, a peak at running speed (1X) is a good indicator of rotor mass unbalance.

Some general rules for analysis follow but are not by any means all-inclusive:

a) the first step in an assessment is having knowledge of the motor.

b) obtain information on how the data was collected.

c) use overall vibration levels as a general indicator of motor condition.

d) use spectrum analysis for a more detailed investigation.

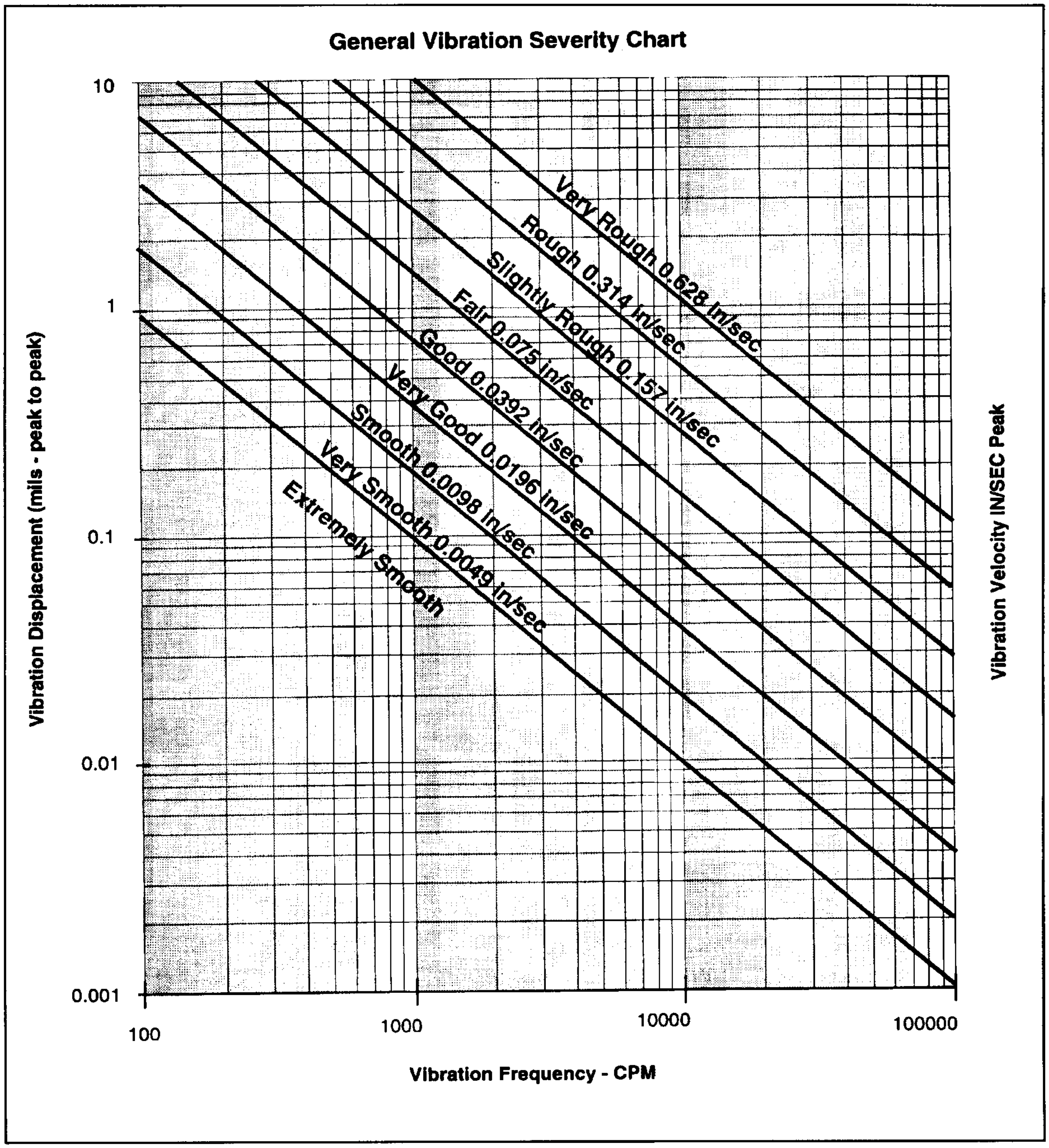


Figure 6-10
Severity Chart

Frequency Banding Analysis

This method of analysis divides the vibration spectrums into defined sections, then each section is averaged. An example of how this method would be incorporated on a motor-driven pump with seven (7) vanes is as follows:

Five frequency bands:

1X-2X	Unbalance and Misalignment Band
3X-5X	Bearing Impacting Band
6X-8X	Vane Pass Band
9X-30X	Rolling Element Bearing Condition Band
0-20kHz	Overall Acceleration Level Band

Severity limits are assignable for each frequency band; and, there are usually three limits for each band. The first limit would be an alert of an emerging problem, the second limit would be a caution of a deteriorating condition, and the third would warn of an impending failure.

Setting up these severity limits requires a good working knowledge of the dynamics of the machine being monitored. *Over time, the trended data will disclose valuable information for use in modifying these severity limits.*

Mechanical Faults

Some of the more common mechanical faults include rotor mass unbalance, coupling misalignment and bearing defects. These three are the majority of machinery faults that will be encountered using a periodic vibration monitoring program.

Rotor mass unbalance may be caused by dirt accumulation, loss of rotating parts, or possibly a lost balance weight. Coupling misalignment can be due to coupling wear, temperature growth of the driver or driven component; and, perhaps it was not aligned to the proper specifications during installation. Bearing defects or degradation may be due to a manufacturing flaw, excessive load or improper lubrication.

A few precautions will lessen the impact of these three faults. One, make sure that the balancing specifications for a motor returning from rebuild are satisfactory. Two, ensure that the motor is aligned properly during the coupling process. Three, bearing problems can be lessened by using care during installation, and ensuring an adequate lubrication program.

Note: *As a troubleshooting aid, run a motor uncoupled, then run it coupled. This will determine if the problem exists with the driven component instead of the motor. This technique is especially useful for motors returning to service*

Table 6-1 gives a short list of the major mechanical problems found during a periodic vibration monitoring program.

Table 6-1
Mechanical Fault Diagnoses Chart

Problem	Symptom	Comments
Unbalance	1X Running Speed	Unsupported radial plane
Misalignment	1X,2X Running Speed	Radial or axial plane
Bearing Faults	Resonance frequencies of bearing components	Calculated from bearing details

Electrical Faults

In addition to mechanical faults, motors can also show indications of electrical-mechanical abnormalities. Although electrical faults are diagnosed less often than their mechanical counterparts, they do exist. The difficulty is in determining that the fault is electrical in nature instead of mechanical.

Note: *Some electrical faults are indicated by a multiple of line frequency, such as 60 Hz and 120 Hz. In certain cases it is possible to differentiate between mechanical and electrical faults by removing power from the motor and allowing a coastdown. If the indication is electrical in origin it will usually disappear when power is removed. If the fault is mechanically based it will still be evident, although it may diminish in severity as the speed decreases.*

Table 6-2 gives a short list of some electrical faults that may be encountered in a periodic vibration monitoring program.

Table 6-2
Electrical Fault Diagnoses Chart

Problem	Symptom	Comments
Uneven Air Gap	2X Line Frequency	Always 120Hz
Eccentric Rotor	1X Running Speed	Beat frequency present
Broken Rotor Bar	1X Running Speed	Beat frequency present

Discussions

As with any program that encompasses a large variety of machinery, some special considerations are involved. Some areas that require particular attention are discussed below.

Low Speed Motor Discussion

This type of motor can present a challenge to acquiring useful data. The reason is that the motor is slow in turning and its casing is normally very large. This situation hinders the relatively low level of rotor vibration from reaching the sensor. The best means to acquire data on this type of motor is to install proximity probes. If this is not possible, be sure to acquire shaft stick vibration readings. The shaft vibration readings will yield more accurate and useful motor information, as compared to the casing readings.

Low speed motors (less than 900rpm) require that the data acquisition equipment have good low frequency capability. An accelerometer with a minimum frequency range of 1 Hz is adequate for identifying the mechanical anomalies that usually occur in this type of motor. Additional time is required to gather these low frequency, high resolution vibration samples.

Note: *Consider using stud-mounted or magnetically-mounted accelerometers for these low frequency measurements. In this application it is difficult to gather accurate data using hand-held sensors due to the interference of hand motion on the desired low frequency data.*

Bearing Discussion

It is very important to know what types of bearings are installed in the motor being monitored. There are two major bearing types for this application: anti-friction and sleeve. Anti-friction bearings include roller and ball bearing designs, and sleeve bearings are of the hydrodynamic fluid design.

Anti-friction bearings will transmit the shaft vibration to the motor housing with little hindrance. The bearings balls or rollers may exhibit frequencies related to the races and their number and speed. Small defects in these bearings will exhibit defined acceleration peaks which are easily detected. *Trending of these peaks and their overall acceleration levels will offer a good indication of the bearing's condition.*

Sleeve bearings will dampen the shaft's movement and thus the casing will exhibit less vibration. A shaft stick reading or mounted proximeter may be useful on a motor with this type of bearing. Sleeve bearing faults are better defined with the aid of proximity probes. These sensors can detect shaft movement that will potentially contact the babbitt material. *If the bearing clearances are known, the actual shaft displacement is a good indicator for determining if the bearings need replacement.*

Note: *When the bearings are removed from the motor it is a good idea to count the number of balls or rollers and record the bearing type and manufacturer. This is also an ideal time to photograph the bearings, both pre-installation and post-installation, for future reference.*

Summary

The goal of a vibration monitoring program is to know the condition of the motor at all times. Once the condition of the motor is known, accurate planning becomes possible. Accurate data is required to assess motor condition; and accurate data on a consistent basis is required to trend motor condition.

The goal of a vibration monitoring program is to reduce equipment risks and its economic impact. Early problem detection will help prevent production loss, minimize motor damage and thus reduce its repair cost.

The realm of vibration data collection and analysis is continuously changing. As a result, an attitude of progressive learning is required to maintain pace with the changes in both technologies and techniques.

References

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A

GLOSSARY

Anti-friction bearing: There are two main types of anti-friction bearings, roller and ball bearings.

Bearings: A bearing is a mechanical device used to reduce friction and wear while supporting rotating elements. For a motor, bearings provide a relatively rigid support for the rotor shaft. There are two main types of bearings, anti-friction and sleeve-type.

Beat Frequency: This is a term which describes a pulsation effect that results when two frequencies in close approximation add and subtract in amplitude. This effect can be displayed on an analyzer as a rise and fall of the observed frequency's amplitude.

CPM: Cycles per minute.

Hertz(Hz): A unit of frequency where one hertz is equal to one cycle per second. (When converting Hertz to RPM simply multiply by 60).

Resolution: The degree of clarity shown in an FFT spectrum expressed as a number of lines.

Route: The assembly of vibration data collection points into one grouping.

RPM: Revolutions per minute.

Sleeve-type bearing: A sleeve bearing is a babbitt-lined tubular shell in which the shaft rides on an oil film. Some bearings of this type are split and are thus called split-sleeve bearings.

Vibration sensor: A device that converts vibration to an electrical signal.

Vibration trend: The observation of vibration data over a period of time.