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Plant Engineering: Large Horizontal Pump End-of-Expected Life Report

2011 TECHNICAL REPORT

Plant Engineering: Large Horizontal Pump End-of-Expected Life Report

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Report Summary

Background

The Electric Power Research Institute (EPRI) conducted this study at the direction of the Plant Engineering Advisors to evaluate the point in the life of large horizontal pumps when a contingency plan for pump refurbishment or replacement is desirable to prevent an unexpected end-of-life failure. This report identifies methods that utilities can use to mitigate or counteract the approach of end-of-expected life failures.

Objective

- To assist nuclear power plant managers and component or system engineers in the development of life cycle management plans for large horizontal pumps (LHPs)

Approach

This document provides data that will aid in the identification of the approach of end-of-life conditions for LHPs. LHPs are generally trouble-free over the life of a facility if fundamental maintenance practices are in place and performed. EPRI Nuclear Maintenance documents and the EPRI Preventive Maintenance Basis Database outline best practices and recommendations for the implementation of maintenance and condition-based monitoring of LHPs. The objective of this report is to identify the point during the LHP's life cycle at which end of life is approaching. Although large pumps are designed for a long life, there have been many examples of unanticipated plant outages and deratings due to aging issues.

Industry operating experience, EPRI technical reports, and industry failure data form the foundation for this study. A search of the Institute of Nuclear Power Operations (INPO) Equipment Performance Information Exchange (EPIX)* database was performed to identify end-of-life failures and review failure causes. Sources other than EPIX (such as INPO Topical Reports) were also reviewed to validate the EPIX results. (INPO materials are available only to INPO members and participants.) This report describes conditions that accelerate pump life and methods to identify these conditions.

* INPO materials are available only to INPO members and participants; they are not publicly available.

A brief description of the logistics associated with pump repair is also included. Finally, the report describes the use of performance data in pump maintenance planning.

Results

The expected life of LHPs varies widely, depending on design applications, operating conditions, and other stressors such as cycling, starts and stops, and so on. Monitoring operating performance trends and pump characteristics such as oil, vibration, and alignment; documenting and reviewing detailed inspection results; and understanding plant history and pump criticality are essential elements in managing the life cycle. An area that is often overlooked is the importance of initial detailed baseline inspections and performance runs, including vibration, current, and critical dimension checks of wear parts and clearances. This practice applies, as well, to newly overhauled or refurbished LHPs. It is with this data that initial operating trends are compared with current data to assess component condition and the approach to maintenance or failure.

One should consider not only the technical aspects of when to replace or refurbish but also the economic point at which preventive maintenance is no longer cost effective. Important to this decision are the facility's strategic long-range plan and the implications for the extended demand of the LHP over the lifetime of the facility—that is, how long the facility will operate, whether the facility is being uprated, whether the expected facility lifetime is being extended beyond design, and what the extended LHP operating demand is.

LHPs are robust components and can provide long, trouble-free service if appropriate preventive maintenance is applied. Wear and aging of major subcomponents determine the end of useful life. When developing LHP life cycle management plans, one should consider the criticality of the pump, lost generation, availability and lead time for spare parts, out-of-service timing to replace the pump, expected lifetime of the facility and LHP, methods of repair or refurbishment, the cost associated with repair, and the capital cost for replacement or refurbishment.

Keywords

Component reliability
End of life
Expected life
Large horizontal pump
Life cycle management
Nuclear asset management

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Section 1: Introduction

1.1 Purpose

Large horizontal pumps (LHPs) are robust components that are used in numerous nuclear plant applications, including feedwater, chilled water, closed or component cooling water, condensate, service water, emergency core cooling, emergency core cooling systems, fuel pool cooling, and suppression pool makeup and purification systems.

The current focus on plant life, including license renewal, creates challenges associated with ensuring that systems and components function properly to meet 60 years of plant operation and beyond. The life of LHPs varies throughout the industry, depending on factors associated with each specific pump, such as operating conditions, design application, and preventive maintenance practices; however, it is unreasonable to expect any pump to provide 60 years of failure-free operation with no pump refurbishment. Although consequences vary for specific applications, each pump will eventually reach a point at which unexpected end-of-life failure becomes a concern, with associated safety, generation, cost, and regulatory implications.

End of life of a component is the point at which the preventive maintenance (PM) regime transforms to one of major refurbishment or replacement. Typically, this point arrives due to materials aging of major subcomponents. For LHPs, end of life includes failures of major subcomponents such as impellers, shafts, and the pump casing. Failures not considered are manufacturing defects and personnel error, which are not precursors to end of life. Economic end of life is achieved when the present worth cost of anticipated repairs of the component equals or exceeds the cost of replacement.

This technical report was developed to assist nuclear plant personnel in the development of LHP life cycle management plans for their facilities. It provides information related to LHP failures and associated precursors, a summary of methods to predict end of life, and factors to consider in developing a refurbishment or replacement plan (such as logistics). Much of the information contained in this report was gleaned from a synthesis of historical data and plant and subject matter expert experience. The Electric Power Research Institute (EPRI) has developed an extensive library of technical reports that describe LHP

maintenance practices and condition monitoring guidelines, many of which are referred to in this report. No new methods are detailed in this report, and there are no changes to any recommended preventive or condition-based maintenance methods.

1.2 Abbreviations and Acronyms

The following abbreviations and acronyms are used in this report:

- **BEP**. Best efficiency point
- **EPIX.** Equipment Performance and Information Exchange System
- **EPRI.** Electric Power Research Institute
- **LHP.** Large horizontal pump
- **INPO.** Institute for Nuclear Power Operations
- **PM.** Preventive maintenance

1.3 Scope

The focus of this report is on recognizing the approaching end of life of LHPs used in nuclear power plants. Only the pump is included in the scope of this report; the pump driver (motor, turbine, and so on), support equipment (such as lube oil pumps), bearings and shaft seal and packing are excluded. However, if a failure of one of these support items led to rebuilding or replacing the pump, it was included in the failure analysis. Items that require extensive maintenance or replacement of major parts (for example, impellers, shafts, and pump case) are the focus of this report because they are the most costly and they drive the greatest cost impact on plant availability.

This report defines *large pumps* as those with a flow rate of at least 500 gpm (1893 L/m) and an inlet size of at least 6 in. (15.24 cm). These thresholds provide a reasonable sample size while excluding smaller pumps that are typically replaced rather than being rebuilt.

Section 2: Expected Life Considerations

This section describes factors that could affect pump life, methods to monitor these factors, and typical end-of-life failure modes seen in the field.

2.1 Conditions That Affect Pump Life

Various conditions that can affect pump life are described in the following EPRI reports:

- *Centrifugal and Positive Displacement Charging Pump Maintenance Guide* (TR-107252) [1]
- *Condensate Pump Application and Maintenance Guide* (1000052) [2]
- *Fossil Maintenance Applications Center: Combined-Cycle Combustion-Turbine Segmented-Casing Feedwater Pump Maintenance Guideline* (1020274) [3]
- *Main Feedwater Pump Maintenance Guide* (TR-105933) [4]

Typical conditions that are frequently encountered include the following:

- **Alignment.** Establishing proper internal clearances and proper alignment of pump to driver are critical to maximize the life of a pump.
- **Balance.** This includes the initial balance of the pump as well as balances due to changes that occur during operation caused by wear, debris, erosion, cavitation, and so on.
- **Cavitation.** Pump design, location, variations in suction pressure, multiple-pump operating variations, pump operating conditions, liquid levels, and temperature can affect pump cavitation. Small changes in the pump (operating speed, impeller design, and so on) can significantly affect the amount of cavitation-related damage.
- **Environment.** The quality of the fluid can be difficult to manage, but it can have a tremendous effect. Chemistry control (affecting corrosion), sandy or brackish environment (affecting erosion), biologics, and so on can notably affect the life of the pump.
- **Hydraulic instability.** The hydraulic conditions of the system can change, depending on the fluid quality and temperatures, shape of the pump's head-flow curve in relation to its point of operation, presence of large debris, silt deposition, pump degradation, and so on. This also includes vortex formation at the pump suction caused by piping design, low sump water levels, filter and screen condition, and so on.

- **Manufacturing defects.** Flaws in the manufacture of a pump can go unnoticed for several years. However, in the presence of additional stressors, manufacturing defects can result in major pump failures.
- **Manufacturing tolerances.** Inadequate tolerances in the pump design can result in an increased severity of many of these listed conditions.
- **Mechanical looseness.** Looseness can occur from human error, corrosion, thermal cycles, vibration, or normal pump operation.
- **PM effectiveness.** The frequency, extent, and type of PM performed can either enhance or reduce the life of a pump. Each time the pump is disassembled, opportunities are created to allow other factors (misalignment, looseness, imbalance, and so on) to become more or less prevalent than they otherwise would have been.
- **Resonance.** Pump resonant frequencies can change over the life of the pump as a result of normal wear, corrosion, or changes in the environment. Structural resonant frequency aligning with pump rotational frequency is a common problem in the industry and must be considered.

Unless they are addressed in a timely manner, each of these factors can eventually lead to premature degradation of the pump. The resulting degradation could range from the pump operating beyond its normal parameters to catastrophic damage. Table 2-1 lists typical failure indications and failure mechanisms.

Table 2-1
Typical Failure Indications and Mechanisms

Failure Indication	Failure Mechanism
High motor current	Misalignment (severe)
	Internal rubbing
	Manufacturing defect
	Operation outside the intended flow range
High vibration	Balance
	Misalignment
	Mechanical looseness
	Resonance
	Hydraulic instability
	Cavitation
	Environment
	Internal rubbing
	Manufacturing defect
Loss of performance	Hydraulic instability
	Pump clearance changes
	Cavitation
	Impeller wear

2.2 Normal Aging Mechanisms and Effects

Although the effect of the failure mechanisms can be mitigated through corrective actions, there comes a point at which it becomes too costly to pursue corrective measures. Aging effects, mechanisms, and diagnostic methods are identified in the EPRI *Preventive Maintenance Basis Database* [5] and are listed in Table 2-2, with some additional information based on experience. Details on pump diagnostic methods can be found in the following EPRI reports:

- *Centrifugal and Positive Displacement Charging Pump Maintenance Guide* (TR-107252) [1]
- *Condensate Pump Application and Maintenance Guide* (1000052) [2]
- *Fossil Maintenance Applications Center: Combined-Cycle Combustion-Turbine Segmented-Casing Feedwater Pump Maintenance Guideline* (1020274) [3]
- *Main Feedwater Pump Maintenance Guide* (TR-105933) [4]
- *Pump Troubleshooting, Volume 1* (TR-114612-V1) [6]
- *Pump Troubleshooting, Volume 2* (TR-114612-V2) [7]

When replacement or major refurbishment of the pump's major components (impellers, shafts, case, or bowl) would be required to correct these effects, the pump is considered to approach its end of life. (See Section 2.3, Primary End-of-Life Failure Modes.)

Table 2-2
Aging Mechanisms and Effects

Pump Subcomponent	Aging Effect	Aging Mechanism	Diagnostic Methods	Diagnostic Effectiveness	Repairability	Repair Time	Repair Issues
Balancing device	Wear	Process fluid quality	Thrust bearing temperature, balance line leakoff pressure, vibration measurement, inspection	Methods for trending and inspection are well established.	Replace if out of round or not square to shaft. Surface scratches can be repaired by skim cut machining. Out-of-specification clearances or interference fits are repaired by chrome plating.	Planned: 2–7 days Unplanned: 3–30 days	Components should be carried as spare parts for quick turnaround.
		Vibration or wear of other components					
		Distortion due to improper pump warm-up					
		Distortion due to pipe strain					
		Improper assembly or materials					
		Off-best efficiency point (BEP) operation or flashing in leakoff system					

Table 2-2 (continued)
Aging Mechanisms and Effects

Pump Subcomponent	Aging Effect		Aging Mechanism	Diagnostic Methods	Diagnostic Effectiveness	Repairability	Repair Time	Repair Issues
Diffusers, volutes, and channel rings	Erosion or damage to diffuser or volute inlets	Process fluid quality Normal wear Improper installation Incorrect material Loss of protective coating Off-BEP operation	Thrust bearing temperature, performance test, vibration measurement, inspection	Methods for trending and inspection are well established.	Surface damage can be repaired by hand grinding to a smooth finish. Excessive clearance between impeller vane outlets and diffuser or volute inlets can degrade performance and should be checked. Weld buildup and grinding can be an option, depending on component materials and severity of the pump duty.		Planned: 2–6 days Unplanned: 3–14 days	Spare components should be on hand for timely turnaround.
	Erosion of interstage sealing	Normal wear Casting defect or incorrect material Frequent pump cycles Improper installation Tie rod or stay bolt failure Warping from thermal shock	Performance test, vibration measurement, inspection	Methods for trending and inspection are well established.	Replace badly worn or distorted parts. Normal wear can be repaired by a skim cut and chrome plating to restore clearances or snug fits.		Planned: 2–7 days Unplanned: 3–30 days	Spare parts should be on hand for timely turnaround.
	Failure of balancing relief line	Rotor wear Vibration	Vibration measurement, thrust bearing temperature, inspection	Methods for trending and inspection are well established.	Repair as needed.		Planned: 2–6 days Unplanned: 3–14 days	Materials used in repair work should match the existing.

Table 2-2 (continued)
Aging Mechanisms and Effects

Pump Subcomponent	Aging Effect	Aging Mechanism	Diagnostic Methods	Diagnostic Effectiveness	Repairability	Repair Time	Repair Issues
Pump casing, horizontal split	Corrosion, erosion, or damage to internal flow passages (casing or rotor)	Process fluid quality Run time Improper installation or incorrect material Off-BEP operation	Inspection, performance test, vibration measurement, thrust bearing temperature	Methods for trending and inspection are well established.	If corrosion or erosion has violated minimum wall thickness replace casing. Localized erosion can be weld-repaired if base material is suitable.	Planned: 2–7 days Unplanned: 3–20 days	If the horizontal joint is machined, internal flow passages will be reduced and can degrade performance. Excessive machining should be avoided for performance and structural strength. Joint surface can be restored by weld buildup and machining.
	Erosion of Interstage Sealing and Horizontal Joint	Run time Casting defect Frequent pump cycles Improper installation or gasket material Joint bolt failure Warping from thermal shock	Performance test, vibration measurement, inspection	Methods for trending and inspection are well established.	Damaged horizontal joint can be skim machined. Wire-drawn areas can be weld-repaired and ground. Internal seal erosion can be machined and oversize rings installed.		
	Deformation of casing	Improper bolting Pipe stress Thermal shock	Performance test, vibration measurement, inspection	Methods for trending and inspection are well established.	A deformed case can be repaired with head treatment or machining if not severe. Otherwise, it must be replaced.		
	Failure of equalizing line	Vibration	Inspection	Methods for trending and inspection are well established.	Replace equalizing line with one that has a different natural frequency.		

Table 2-2 (continued)
Aging Mechanisms and Effects

Pump Subcomponent	Aging Effect	Aging Mechanism	Diagnostic Methods	Diagnostic Effectiveness	Repairability	Repair Time	Repair Issues
Wear rings and surfaces	Wear or galling	Process fluid quality Excessive mechanical or hydraulic loading Improper installation, fits, clearances, alignment, or materials	Performance test, motor current monitoring, pump hand rotation, vibration measurement, inspection	Methods for trending and inspection are well established.	Wear rings should be replaced when the diametric clearance approaches twice the as-built clearance. If the pump has both casing and impeller wear rings, both should be replaced. The impeller ring can be trimmed smooth and an oversized case ring installed. If the pump has only a casing wear ring, the mating impeller surface should be trimmed smooth and an oversized casing ring installed to restore proper clearance.	Planned: 2–6 days Unplanned: 3–14 days	If wear on the stationary part is elliptical shaped, misalignment is indicated.

Table 2-2 (continued)
Aging Mechanisms and Effects

Pump Subcomponent	Aging Effect	Aging Mechanism	Diagnostic Methods	Diagnostic Effectiveness	Repairability	Repair Time	Repair Issues
Pump casing (barrel) and closure head	Discharge nozzle erosion	Run time, design, fatigue	Inspection	Methods for inspection are well established.	Internal surfaces that have localized erosion can be weld-repaired if the base metal is suitable. Cracked inlay material should be ground out and reapplied to a thicker dimension. Warped head can be machined true, if minimum wall thickness is not violated.	Planned: 2–7 days Unplanned: 3– 20 days	Significant permanent distortion of barrel or head should indicate a need for thorough dimensional inspection to determine whether components are salvageable.
	Damage to casing penetration						
	Erosion of casing penetration						
	Leaks	Cracked head (stainless insert or weld inlay)	Inspection, performance test	Methods for trending and inspection are well established.			
		Improper torqueing					
		Warped head					

Table 2-2 (continued)
Aging Mechanisms and Effects

Pump Subcomponent	Aging Effect	Aging Mechanism	Diagnostic Methods	Diagnostic Effectiveness	Repairability	Repair Time	Repair Issues
Shaft	Loss of shaft diameter	Packing wear	Vibration measurement, inspection, oil sample	Methods for trending and inspection are well established.	Worn or corroded surfaces should be ground smooth. If the remaining diameter is acceptable to the manufacturer, the shaft can be reused.	Planned: 2–7 days Unplanned: 3–20 days	Straightness of the shaft should be checked as possible collateral damage.
		Corrosion					
		Misalignment					
		Wear or failure of other components					
	Cracked	Number of cycles or torsional or thermal fatigue	Include dye penetrant and ultrasonic inspection	Methods for trending and inspection are well established.	Surface cracks can usually be tolerated, but they should be ground smooth. Penetrating circumferential cracks require replacement of the shaft.		If cracks occur at corners of fillets, keyways, or ring grooves, the radius of the corner should be increased by machining to reduce stress concentrations.
		Manufacturing defect					
		Off-BEP operation					
		Stress corrosion cracking					
	Bent	Debris	Vibration measurement, inspection, oil sample	Methods for trending and inspection are well established.	If the bend is a fairly uniform bow and has not caused cracks, the shaft can be straightened and stress relieved. If it remains straight, it can be reused. A sharp bend typically causes cracks and requires shaft replacement.		Collateral damage to bearings, wear rings, shaft seal, sleeves, and bushings should be checked.
		Improper layup or warm-up					
		Improper storage or installation					
		Misalignment - rubbing at bearing, seal, impeller wear rings					
		Thermal shock or water hammer					

Table 2-2 (continued)
Aging Mechanisms and Effects

Pump Subcomponent	Aging Effect	Aging Mechanism	Diagnostic Methods	Diagnostic Effectiveness	Repairability	Repair Time	Repair Issues
Impeller	Wear from vane thinning or erosion	Normal wear, process fluid quality	Performance test, inspection	Methods for trending and inspection are well established. Trending vane measurements provides the most accurate indication.	If the amount of thinning is less than the corrosion allowance, no action is needed. Replace impeller if corrosion allowance is violated.	Planned: 2–7 days Unplanned: 3–15 days	Except for use of borescope, the entire pump internal assembly might require removal and dismantling for the inspection and repair.
		Improper axial positioning or material					
		Off-BEP operation					
	Physical damage	Debris	Hand rotation of pump, vibration measurement, inspection, borescope	Methods for trending, inspection, and nondestructive evaluation are well established.	If cracks or breakage exist, replace impeller.		
		Fatigue from corrosion					
		Manufacturing defect					
		Pressure pulsations					
	Loose	Improper installation, material, or fit tolerances	Performance test, vibration measurement, motor current monitoring	Trending methods are effective only after loosening starts.	Restore fit to shaft by skim machining and chrome plating. Grind to size.		
		Pressure pulsations or vibration					

Table 2-2 (continued)
Aging Mechanisms and Effects

Pump Subcomponent	Aging Effect	Aging Mechanism	Diagnostic Methods	Diagnostic Effectiveness	Repairability	Repair Time	Repair Issues
Impeller (continued)	Wear from cavitation	Low net positive suction head available or off-BEP operation System configuration	Inspection, vibration measurement, audible noise, performance test, borescope	Methods for trending and inspection are well established.	Can be weld-repaired if base metal is suitable. Replace impeller if wear is extensive.		
	Improper outside diameter	Manufacturing or personnel error	Performance test, inspection, vibration measurement, motor current monitoring	Methods for trending and inspection are well established.	If impeller is too large, it can be trimmed. If it is too small, it must be replaced.		
	Wear from recirculation	Off-BEP operation	Inspection, vibration measurement, audible noise, performance test, borescope	Methods for trending and inspection are well established.	Can be weld-repaired if base metal is suitable. Replace impeller if wear is extensive.		

Table 2-2 (continued)
Aging Mechanisms and Effects

Pump Subcomponent	Aging Effect	Aging Mechanism	Diagnostic Methods	Diagnostic Effectiveness	Repairability	Repair Time	Repair Issues
Discharge and suction flanges	Erosion	Process fluid quality Casting defect Design Flashing to steam	Inspection	Methods for inspection are well established.	Wire-drawing can be weld-repaired and machined.	Planned: 2–7 days Unplanned: 3–15 days	Minor erosion can be tolerated using extra thick gaskets.
	Deformation	Pipe stress	Check for cracks using dye penetrant	Methods for inspection are well established.	Cut, bend, weld, and stress relieve to restore fit-up of motor to pump, if base metal is suitable.	Planned: 2–7 days Unplanned: 3–20 days	Cause of the deformation should be determined. Additional stiffeners might be needed on the discharge head, or the discharge might need to be restrained. Look for collateral damage at the bearings and sleeves.

2.3 Primary End-of-Life Failure Modes

2.3.1 Identification of Failures

Industry failure data from the Institute for Nuclear Power Operations (INPO) Equipment Performance and Information Exchange System (EPIX)* database for January 1997 to April 1, 2011, were reviewed to identify the major failures experienced by LHPs at nuclear plants. (INPO materials are available only to INPO members and participants.) Because EPIX failures are typically related only to systems within the scope of the Maintenance Rule [8] or those that cause power reductions or transients, the reported failures might be fewer than actual. However, the types of failures are expected to be representative of all LHPs. Results of the EPIX searches were filtered to ensure that only relevant failures were reviewed. Failures were filtered out based on the following criteria:

- Pumps that were not horizontal or centrifugal
- Pump with flow <500 gpm (1893 L/m) or pump inlet <6 in. (<15.24 cm)
- Failures that affect the operation of a pump but that were not pump failures (failures associated with pump drivers, instrumentation, valves, procedural issues, and so on)
- Support equipment (such as control linkages, lube oil coolers, and so on) failures
- Mechanical seal or packing failures
- Pump bearing failures (bearing failures attributed to age-related issues that also led to rebuilding the pump were not filtered)

This review and filtering identified 22 failures pertaining to LHPs (see Table 2-3). Each of these failures required either replacement or major rebuilding to return the pump to service.

* INPO materials are available only to INPO members and participants; they are not publicly available.

Table 2-3
Results from the Equipment Performance and Information Exchange System Search

Industry Standard System	Number of End-of-Life Failures	Continuous or Standby System	Years from In-Service to Failure	Component Causing Failure	Manufacturer	Failure Cause
Auxiliary or emergency feedwater system	1	Standby	32.3	Impeller/casing	Pacific Pumps	Inadequate clearance
Closed or component cooling water system	3	Continuous	12.2 20.7 24.3	Bearing/bushing Bearing/bushing Not identified	Ingersoll Rand	Lack of PM, improper reassembly
Condensate system	2	Continuous	0.2 35.8	Impeller	Byron Jackson	Defective material or manufacturing
Condensate storage and transfer system	1	Continuous	1.8	Bearing/shaft	Ingersoll Rand	Loss of lubrication
Containment spray system	1	Standby	0.1	Wear ring	Gould	Alignment
Feedwater system	8	Continuous	1 0.8 15.1 15.6 16.1 24.3 32.4 34.7	Impeller Shaft Vanes Impeller Wear ring Casing Casing Bearing	Byron Jackson, Delaval, Ingersoll Rand	Major cause: cavitation causing flow-accelerated corrosion, erosion
Heat rejection system	1	Standby	12.3	Bearing	Gould	Inadequate PM

Table 2-3 (continued)
Results from the Equipment Performance and Information Exchange System Search

Industry Standard System	Number of End-of-Life Failures	Continuous or Standby System	Years from In-Service to Failure	Component Causing Failure	Manufacturer	Failure Cause
High-pressure safety injection system	1	Standby	15.8	Shaft	Pacific Pumps	Fatigue
Residual heat removal system	1	Standby	0.2	Bearing	Ingersoll Rand	Defective material
Service water system	3	Continuous	4.7 13.3 16.2	Impeller Casing Not available	Gould, Johnston, Worthington	Normal wear, clogging, normal aging
Total	**22**					

Figure 2-1 shows the progression in numbers of cumulative pump failures versus pump life. Figures 2-2 and 2-3 show the progression in number of pump failures versus pump life for high-duty-cycle pumps and low-duty-cycle pumps, respectively.

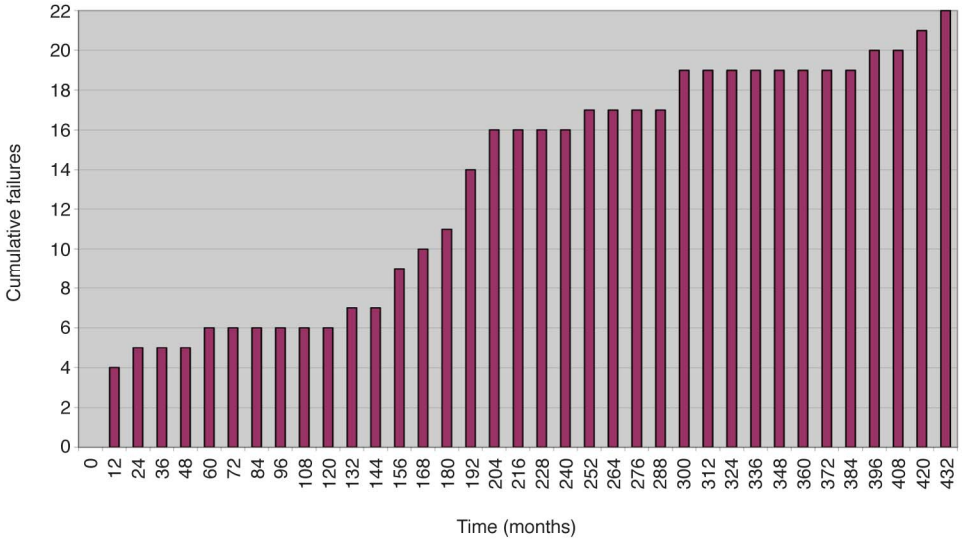


Figure 2-1
Number of Cumulative Failures

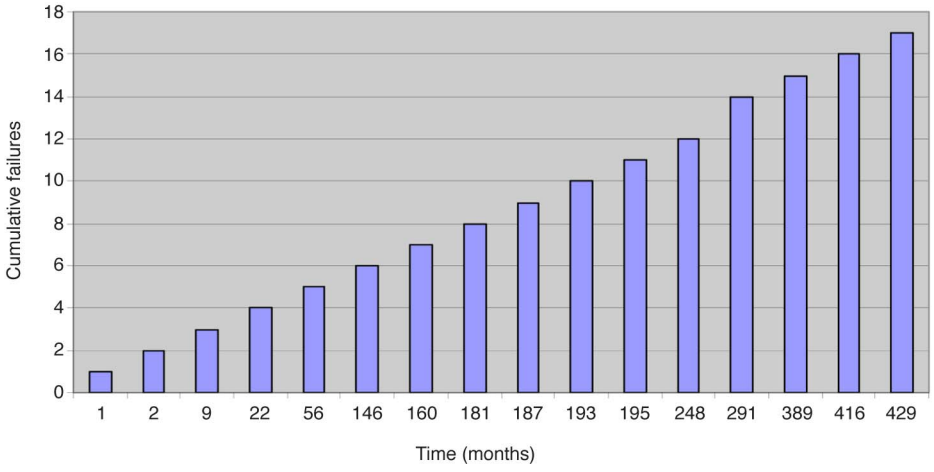


Figure 2-2
High-Duty-Cycle Cumulative Failures

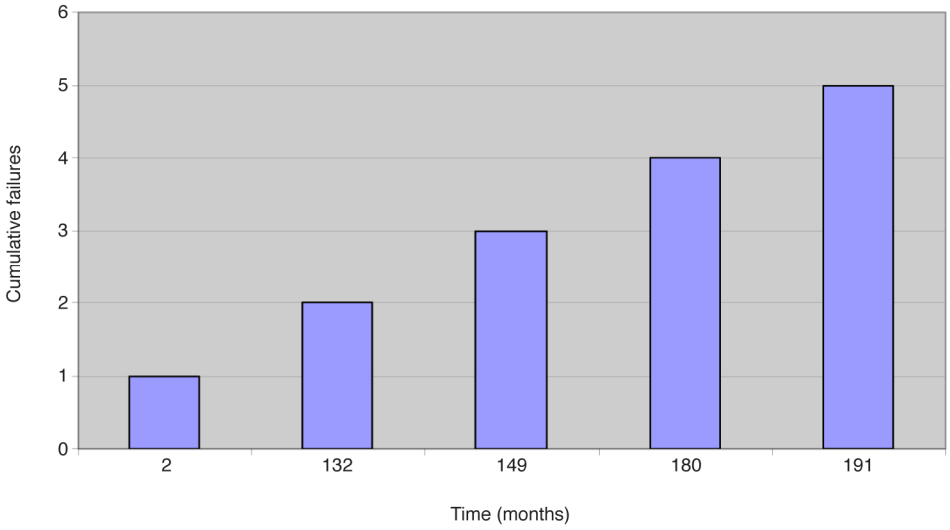


Figure 2-3
Low-Duty-Cycle Cumulative Failures

2.3.2 Failure Analysis

The failures identified in Table 2-3 were reviewed to determine the cause. A review of the results shows that the largest number of failures—one third of the failures (10 of 22)—occurred between 12 and 17 years of pump life. This equates to a failure rate of two pumps per year. Four failures occurred in the first year; all of these failures were attributed to special causes such as manufacturing quality or material defect, and they are considered infant mortality (not indicative of pump life). Between 1 and 12 years, the end-of-life type failure rate for the entire industry was approximately 0.2 failures per year (2 failures in 11 years). Between 17 and 36 years, the end-of-life type failure rate was approximately 0.3 failures per year (6 failures in 19 years). A common mode of failure was not identified (each pump failed in a different way).

Duty cycle is a critical factor for determining end-of-life failures for the large components (impeller, shaft, and pump casing) that are the focus of this report (see Table 2-3). Only one failure was identified in a pump located in a standby system (low duty cycle). One failure of a high-pressure safety injection pump shaft was attributed to fatigue. The number of pump starts could influence the determination of pump duty cycle more than time of operation would, with respect to shaft failures.

For high-duty-cycle pumps, the life of the casing and impeller depend on the suction head, minimum flow rate, and quality and temperature of water. In feedwater systems, two of the failures were due to the erosion or corrosion of the pump casing after a service of 28–32 years. In one service water system, one failure was due to wear of the impeller after 4.5 years of service. Because both feedwater and service water systems are continuous duty, depending on the spare installed

capacity, erosion and wear are to be expected in these systems. Other failures in both continuous duty and standby applications (high- and low-duty-cycle) were due to factors such as lack of lubrication or lack of preventive maintenance.

The failures are summarized in Table 2-5, which includes the time for the failure to occur (based on pump installation or last refurbishment). The failed pumps had a wide range of lifetimes. However, based on the trend between 12 and 17 years of pump life, it would be prudent to perform detailed pump inspections and possible refurbishment (depending on plant specifics) when an LHP reaches 10 to 12 years in service. Otherwise, the failure data show that unless special conditions (design or application flaw, personnel error, or harsh environment) exist, LHPs are highly reliable with extremely low industry failure rates (overall, 0.5 pumps per year, excluding infant mortality).

2.3.3 Determining Pump Life

A significant number of failures occurred between 12 and 17 years of pump life. However, the following major factors must be considered:

- Only 22 end-of-life type failures were identified in the entire industry.
- The EPRI report *Main Feedwater Pump Maintenance Guide* (TR-105933) recommends a six-year major overhaul [4].
- Vendor recommendations for overhauls vary.

Therefore, it is inaccurate to conclude a specific pump life on the basis of 10 failures when there are many more LHPs in service in the industry and major overhauls can occur much more frequently than the sharp trend in failures. However, performing a detailed inspection at the beginning of life and then again between 10 and 12 years of pump life (or earlier, during overhauls recommended by pump manufacturers) allows the data collected (performance, vibration, current, and dimensions of all critical wear parts, pressure-retaining parts, and clearances) to provide correlation between diagnostic test method results and pump condition. This would allow a prediction of expected life for that specific pump.

Performing the inspection at 10 to 12 years, or earlier if recommended by pump manufacturers, is based on the significant increase in failure rate (see Figure 2-1). If pump internals are replaced, inspection of the remaining parts would still be beneficial.

The beginning-of-life inspection can use vendor data; however, the data should be actual measurements and not nominal values. Using nominal values for new pumps can lead to erroneous trends with regard to wear rates. For pumps that have been installed for long periods and for which measurements of the original (new) pump installation are not available, current measurements could be compared to original nominal values to obtain a general trend; however, the margin for error is higher.

The correlation developed between these inspections allows for a higher confidence that condition monitoring results provide an indication of pump condition and remaining life. The trend developed by these diagnostic methods could allow for a prediction of the point at which parameters would reach their limits from normal operation (wear, flow, pressure, vibration, and so on). At this predicted point, the pump would be considered to be approaching its end of life because increased maintenance inspections, and possibly refurbishment or replacement, would be required to keep the pump operating within specifications. If the estimated cost of maintenance or repairs meets or exceeds the cost of replacement, the pump is considered to have reached the end of its feasible life. Each plant must perform its own analysis of operating conditions and history to identify an expected life related to an individual pump.

Condition monitoring and correlation of pump inspection data should not replace detailed internal inspections or vendor-recommended overhauls throughout the life of the pump. Some degradation parameters are not detectable through condition monitoring techniques. A balance between the frequency and extent of detailed inspections must be achieved by evaluating condition monitoring trends, pump environment, inspection results, pump history, and criticality of the pump to establish a point at which detailed inspections are implemented.

2.3.4 Monitoring Effectiveness

Table 2-4 contains valuable information related to the effectiveness of methods to help evaluate pump condition. A review of the failures shows that condition monitoring (such as vibration monitoring, performance monitoring, motor monitoring, and oil analysis) would not have had an effect in predicting half of the failures (excluding infant mortality). Degradation leading to many of these failures could have been seen only by performing detailed internal pump inspections. For example, item 11 in Table 2-4 was identified by a shift in pump clearance. Although changes in pump clearances can be observed during pump performance testing (as a change in performance), the specific clearance issues related to that failure did not cause a change in performance. Had a detailed inspection of the pump been performed (including a check of the specific clearances), the degradation might have been evident, and repairs could have been made before the pump failed.

Table 2-4
EPIX Failure Summary

Item Number	System	Failed Component	General Failure	Failure Indication	Description of Cause	Contributing Factors	PM Supporting Expected Life	Time from In-Service to Failure (months)	Failure Predictable Using Vibration, Performance, Motor Current, or Thermography?
1*	Feedwater	Impeller and diffuser	Operated, but not within specified parameters	Pump performance parameter monitoring indicated diverse flow trend during operation. Internal inspection of the pump showed significant damage to impeller and diffuser.	Poor manufacturing quality led to fatigue failure of impeller.	Inadequate inspection prior to installation	Visual inspections, performance monitoring, vibration monitoring	1	No
2*	Condensate	Impeller	Operated, but not within specified parameters	Pump exhibited abnormal parameters during operation.	Failure attributed to manufacturing defect in impeller casting.	Normal operation, inadequate inspection of new parts	Visual inspections, performance monitoring, vibration monitoring	2	No

Table 2-4 (continued)
EPIX Failure Summary

Item Number	System	Failed Component	General Failure	Failure Indication	Description of Cause	Contributing Factors	PM Supporting Expected Life	Time from In-Service to Failure (months)	Failure Predictable Using Vibration, Performance, Motor Current, or Thermography?
3*	Residual heat removal	Bearing	Operated, but not within specified parameters	During operation, pump exhibited loud noises. Further analysis indicated excessive vibration levels.	Bearing failure occurred due to a defect present during manufacturing or shipping.	Normal operation	Performance monitoring, vibration monitoring	2	No
4*	Feedwater	Shaft	Pump tripped during operation	Reactor trip due to low stem generator level.	Failure attributed to cracked pump shaft due to improper metallurgical treatment of part.	Normal operation	Visual inspections, performance monitoring, vibration monitoring	9	No

Table 2-4 (continued)
EPIX Failure Summary

Item Number	System	Failed Component	General Failure	Failure Indication	Description of Cause	Contributing Factors	PM Supporting Expected Life	Time from In-Service to Failure (months)	Failure Predictable Using Vibration, Performance, Motor Current, or Thermography?
5	Condensate	Bearing and pump shaft	Operated, but not within specified parameters	During in-service testing, pump exhibited high vibrations, with levels above safe operating limits.	Lack of bearing lubrication.	Bearing design	Lubrication, periodic replacement, vibration monitoring	21.6	Yes
6	Service water	Impeller	Operated, but not within specified parameters	Pump differential pressure was in required action range during operation for testing.	Failure attributed to wear of the impeller and wear ring due to normal operation	Age, installation of new pump controller	Performance monitoring, visual inspection	56	Yes
7	Containment spray	Impeller wear ring	Failed to start on demand	Pump seized during operation for testing.	Failure attributed to shift in pump alignment during pump start	Tolerance of parts out of specification, bolt relaxation due to age	Visual inspection, vibration monitoring	132	No

Table 2-4 (continued)
EPIX Failure Summary

Item Number	System	Failed Component	General Failure	Failure Indication	Description of Cause	Contributing Factors	PM Supporting Expected Life	Time from In-Service to Failure (months)	Failure Predictable Using Vibration, Performance, Motor Current, or Thermography?
8	Auxiliary cooling water	Pump	Pump tripped during operation	Pump tripped during normal operation.	Failure attributed to bearing wear due to age	Normal operation	Visual inspection, vibration monitoring	146	Yes
9	Heat rejection	Bearing	Operated, but not within specified parameters	During operation, operator noticed that pump bearing was hot and emitting smoke.	Inadequate maintenance led to various pump issues, including bearing failure	Insufficient work instructions, vendor information, and lubrication	Lubrication, visual inspection, periodic replacement	148.6	Yes
10	Service water	Impeller	Pump tripped during operation	Inadequate flow and high vibration while pump was operating.	Failure attributed to foreign material lodged in impeller.	Normal operation	Performance monitoring, visual inspection	160	Yes

Table 2-4 (continued)
EPIX Failure Summary

Item Number	System	Failed Component	General Failure	Failure Indication	Description of Cause	Contributing Factors	PM Supporting Expected Life	Time from In-Service to Failure (months)	Failure Predictable Using Vibration, Performance, Motor Current, or Thermography?
11	Auxiliary feedwater	Casing	Pump tripped during operation	Pump emitted sparks while operating for testing.	Failure attributed to contact between components due to inadequate control of clearances.	Normal operation, age	Visual inspection	180	No
12	Feedwater	Impeller and diffuser	Operated, but not within specified parameters	Pump flow was significantly lower than expected during operation.	Failure attributed to high stress at impeller vanes due to operation below the minimum flow requirement.	Failure of minimum flow valve	Performance monitoring, vibration monitoring	181	No
13	Feedwater	Impeller and casing	Pump tripped during operation	Pump exhibited excessive noise while operating.	Failure attributed to impeller becoming free from shaft due to flow instability.	Abnormal conditions (low flow)	Performance monitoring, vibration monitoring	187	No

Table 2-4 (continued)
EPIX Failure Summary

Item Number	System	Failed Component	General Failure	Failure Indication	Description of Cause	Contributing Factors	PM Supporting Expected Life	Time from In-Service to Failure (months)	Failure Predictable Using Vibration, Performance, Motor Current, or Thermography?
14	High-pressure safety injection	Pump shaft	Operated, but not within specified parameters	Received low flow alarm while pump was operating.	Pump shaft sheared as a result of high cycle fatigue. Vendor changed the standard shaft material to improve strength; however, the existing shaft had not been replaced.	Pump operating at low efficiency points	Visual inspections, performance monitoring, vibration monitoring	190.2	No
15	Feedwater	Impeller and wear ring	Operated, but not within specified parameters	Pump exhibited high vibrations during operation for testing.	Failure attributed to inadequate clearance between impeller and wear ring.	Normal operation	Performance monitoring, vibration monitoring	193	Yes

Table 2-4 (continued)
EPIX Failure Summary

Item Number	System	Failed Component	General Failure	Failure Indication	Description of Cause	Contributing Factors	PM Supporting Expected Life	Time from In-Service to Failure (months)	Failure Predictable Using Vibration, Performance, Motor Current, or Thermography?
16	Service water	Pump	Operated, but not within specified parameters	During in-service testing, pump discharge pressure and flow were inadequate.	Inadequate detail in failure report to determine specific cause of failure. Failure attributed to aging of pump from normal operation.	Normal operation	Visual inspections, performance monitoring, vibration monitoring	194.9	Yes
17	Component cooling water	Shaft	Unable to run for mission time	Pump emitted sparks while operating for testing.	Failure attributed to shaft misalignment to casing due to inadequate instructions.	Normal operation	Visual inspection	248	Yes

Table 2-4 (continued)
EPIX Failure Summary

Item Number	System	Failed Component	General Failure	Failure Indication	Description of Cause	Contributing Factors	PM Supporting Expected Life	Time from In-Service to Failure (months)	Failure Predictable Using Vibration, Performance, Motor Current, or Thermography?
18	Component cooling water	Thrust bearing	Operated, but not within specified parameters	Pump seal was leaking excessively.	Failure attributed to misalignment of the seal due to excessive thrust resulting from normal wear of pump internals.	Normal operation, age	Visual inspection	291	No
19	Feedwater	Casing	External leakage	During operation, operator noted leakage from pump.	Failure attributed to various casting defects that grew together, creating a through-wall leak.	Casting defect, operating fluid chemistry	Visual inspections, fluid chemistry monitoring	291.0	No
20	Feedwater	Casing	External leakage	Pump leakage through casing during operation.	Failure attributed to erosion, corrosion.	Fluid parameters, normal operation	Periodic inspection, periodic replacement	389	No

Table 2-4 (continued)
EPIX Failure Summary

Item Number	System	Failed Component	General Failure	Failure Indication	Description of Cause	Contributing Factors	PM Supporting Expected Life	Time from In-Service to Failure (months)	Failure Predictable Using Vibration, Performance, Motor Current, or Thermography?
21	Feedwater	Bearing and pump shaft	Operated, but not within specified parameters	Pump bearing high-temperature alarms were received while pump was in operation.	Oil supply hose material degraded over time, leading to momentary blockage of oil flow.	Age	Visual inspections, fluid chemistry monitoring	416	No
22	Condensate	Impeller	Operated, but not within specified parameters	Inadequate flow and high vibration while pump was operating.	Failure attributed to manufacturing defect in impeller casting.	Normal operation, inadequate inspection of new parts	Visual inspections, performance monitoring, vibration monitoring	429	Yes

* Items 1–4 represent end-of-life type failures that are not indicative of typical pump life; failures were caused by operation in the presence of a stressor such as a manufacturing defect, improper application, or environment that does not typically exist. The data associated with these failures are included in the analysis to help identify the point at which infant mortality failures are less prevalent; in this case, less than 12 months (see Figure 2-1).

This does not imply that condition monitoring is ineffective. Half the failures likely could have been predicted by a rigorous condition monitoring program. A combination of pump preventive maintenance, inspections, and condition monitoring are necessary to fully understand the life of each pump.

2.3.5 Example of Determining End of Life

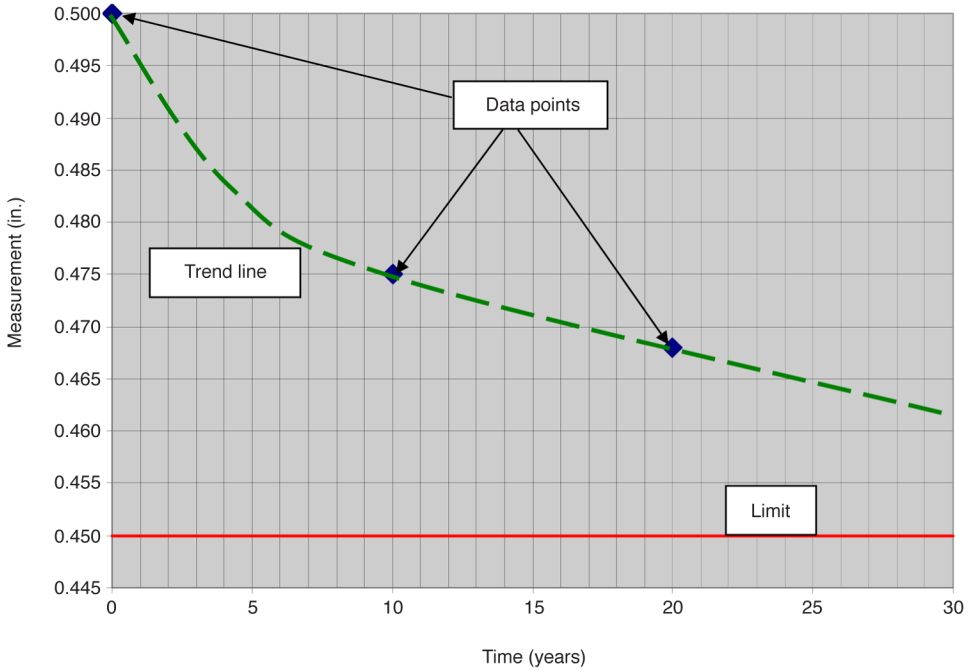
The following example uses hypothetical data to illustrate a method for estimating end of life. The example is greatly simplified. For instance, during a 10-year period, numerous performance tests will provide results of flow. By the time of the 10-year inspection, the trend for flow might be better represented by the numerous data points collected.

Data collected at the beginning of life included measurement of the casing thickness and the pump flow at rated speed. Additional data, such as impeller vane and shroud thicknesses, running clearances at bearings, bushings, and wear rings, and so on should also be measured, but those are ignored for simplicity of the example. These data were collected again at 10-year frequency inspections. Results (see Table 2-5) were analyzed to evaluate the expected life of the pump.

Table 2-5
Hypothetical Measurements

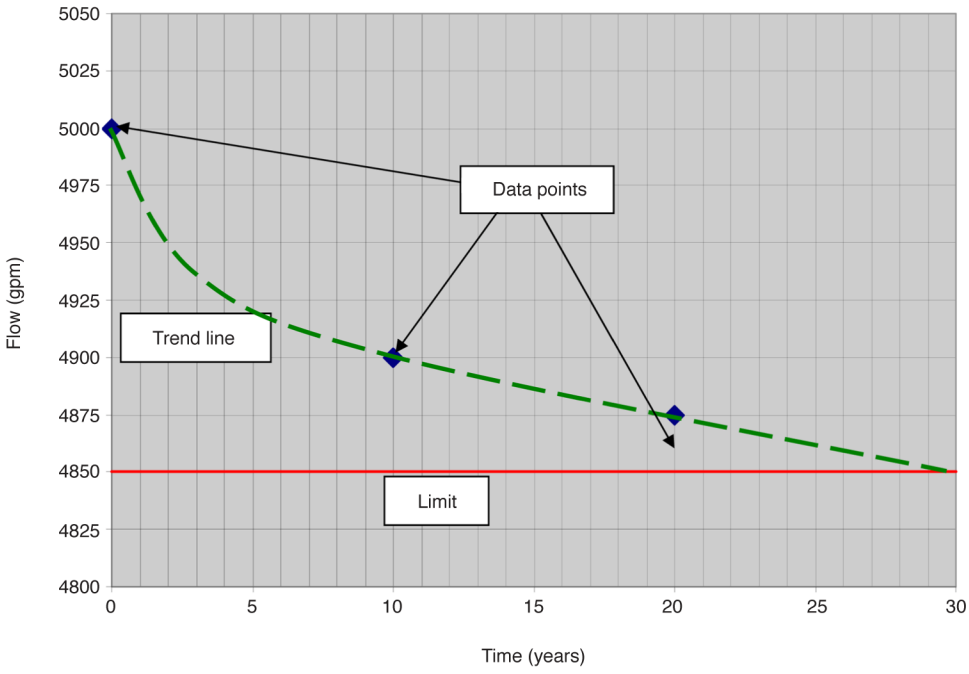
	Data at Beginning of Life	Data at 10 Years	Data at 20 Years	Limit
Casing thickness	0.500 in. (1.27 cm)	0.485 in. (1.23 cm)	0.468 in. (1.19 cm)	0.450 in. (1.14 cm)
Flow at rated speed	5000 gpm (18,927 L/m)	4900 gpm (18,459 L/m)	4875 gpm (18,454 L/m)	4850 gpm (18,359 L/p)

These data can be plotted and a trend can be developed to evaluate when the parameter would reach its limit for an estimation of the life of the pump. Figures 2-4 and 2-5 show the plots from the data in Table 2-5. The data points (shown as diamonds) represent the measurements, the dashed line represents the trend, and the thick, solid line represents the limits. The figures show that the life based on casing thickness is well in excess of 30 years, whereas the flow limit is reached at 29.5 years. Based on these results, a plan should be developed to perform a major pump refurbishment or replacement before 29 years of service have elapsed.



1 in. = 25.4 mm

Figure 2-4
Casing Thickness Example



1 g = 3.79 L

Figure 2-5
Flow Measurement Example

In addition to the trends viewed in the data, additional relationships should also be reviewed. For instance, the casing thickness in this example reduced by 0.032 in. (0.08 cm) or 6.4%, whereas flow reduced by 125 gpm (473 L/m) or 2.5%. If the casing wear could be related directly to flow, another method exists to determine when the casing reaches its limit of a 10% reduction (0.050 in. [0.127 cm] wear). In developing this relationship, the data between the 10-year point and 20-year point are much more linear and would provide more reliable predictions. However, periodic replacement of certain pump internals (such as the wear ring) could skew this relationship; therefore, the effect of replacement parts must be considered.

2.3.6 Comparison to Current EPRI Documents and Other Sources

Additional searches were performed to validate the results of the INPO EPIX* database review. Sources included the following EPRI and INPO reports:

- *Centrifugal and Positive Displacement Charging Pump Maintenance Guide* (TR-107252) [1]
- *Condensate Pump Application and Maintenance Guide* (1000052) [2]
- *Fossil Maintenance Applications Center: Combined-Cycle Combustion-Turbine Segmented-Casing Feedwater Pump Maintenance Guideline* (1020274) [3]
- *Main Feedwater Pump Maintenance Guide* (TR-105933) [4]
- INPO TR4-39, *Review of Auxiliary Feedwater System Events* [9]
- INPO TR4-41, *Review of Main Feedwater (MFW) System Related Failures* [10]
- INPO TR4-41, Addendum 1, *Review of Main Feedwater (MFW) System Related Failures* [11]
- INPO TR6-55, *Review of Large-Pump-Related Events Resulting in Scrams, Shutdowns, and Outage Extensions* [12]

As indicated by the limited number of failures identified through the INPO EPIX database, failure of the actual pump was rare when compared to the number of total failures. Typical failures were related to many factors, including the following:

- Bearing or bushing failure
- Coupling failure
- Mechanical seal failure
- Human performance (maintenance induced, procedure related, and so on)

Based on this review, it can be concluded that LHPs are quite robust.

* INPO materials are available only to INPO members and participants; they are not publicly available.

Section 3: Condition Monitoring

3.1 On-Line Monitoring

Effective methods of condition monitoring have been developed and described in various EPRI documents. A brief summary of these methods is provided in Table 3-1. Descriptions of the data collection and analysis can be found in the following EPRI reports:

- *Centrifugal and Positive Displacement Charging Pump Maintenance Guide* (TR-107252) [1]
- *Condensate Pump Application and Maintenance Guide* (1000052) [2]
- *Fossil Maintenance Applications Center: Combined-Cycle Combustion-Turbine Segmented-Casing Feedwater Pump Maintenance Guideline* (1020274) [3]
- *Main Feedwater Pump Maintenance Guide* (TR-105933) [4]
- *Pump Troubleshooting, Volume 1* (TR-114612-V1) [6]
- *Pump Troubleshooting, Volume 2* (TR-114612-V2) [7]

Table 3-1
Typical Condition Monitoring Techniques

Condition Monitoring Technique	Factors Affecting Severity	General Cause
Vibration monitoring and trending	Unbalance	Inadequate dynamic balance of subcomponents (after maintenance/refurbishment/commissioning of new pump)
		Component material loss or damage
		Bowing of the shaft
	Misalignment	Dimensional clearance and concentricity of alignment fits
		Perpendicularity of alignment faces to the shaft axis
		Parallelism of the alignment faces to each other

Table 3-1 (continued)
Typical Condition Monitoring Techniques

Condition Monitoring Technique	Factors Affecting Severity	General Cause
Vibration monitoring and trending (continued)	Mechanical looseness	Rabbet fits loose
		Loose or inadequate bolting
		Loose pump foundation joint (improper or broken grout)
		Lack of crush between the bearing and its support
		Increased clearance between the bearing and journal
	Resonance	Pump or structural issues
Vibration monitoring and trending	Hydraulic instability	Cavitation
		Flow separation at the impeller inlet; often accompanied by cavitation
		Recirculation at the impeller outlet and casing inlet
		Impact loading of the exiting impeller flow on the stationary casing vanes
		Flow separation at the discharge elbow
		Operation in the unstable portion of the pump curve
		Hydraulic resonance in the piping system
	Sump-induced vibration	Inadequate sump design
Pump performance testing and trending	Head and flow rate variation	Incorrect initial specifications
		Wear
		Operation at unstable point on head or flow curve
		Subcomponent damage
Motor current trending	High motor current	Operation at lower flow rates
		Increased motor thrust bearing friction
		Internal rubbing
		Packing adjusted incorrectly
Thermography (if bearing accessible) or direct temperature measurement (if available)	High temperature	Inadequate lubrication/cooling to bearings
		Increased bearing load
		Improper bearing materials

Other methods of monitoring include external and internal inspections. These methods require the pump to be taken out of service to allow adequate access. Maintenance and inspection methods have been developed over the years. It is key to trend the results of inspections (especially dimensions, presence of pitting, and so on) through the use of databases, photographs, videos, and so on, and to compare these results with the trending data from condition monitoring results. Correlation between the results obtained in condition monitoring and inspections must be developed to provide the best indication of the pump's overall condition and prediction of pump life.

3.2 Off-Line Monitoring

Off-line monitoring consists primarily of inspections, but it can consist of specific pump testing and condition monitoring for some plants. Several plants have the flexibility to take one pump out of service at a time, with no effect on plant operation. However, many configurations require either plant shutdown or entry into limited conditions for operation to allow access.

If detailed on-line pump inspections cannot be performed, detailed off-line inspections are highly recommended. Internal inspections can confirm or diagnose indications seen in condition monitoring, quantifying the extent of the condition and identifying deterioration that is not shown in condition monitoring. As shown in Table 2-5, half the failures reported were not predicted by normal condition monitoring methods. Although some failures showed indications that were identified by normal condition monitoring, the failure was not predicted. Internal inspections would have been required to identify the degradation mechanism. A combination of condition monitoring (such as vibration, performance, motor current, and thermography monitoring) and internal inspection provides the best approach for predicting failures and evaluating pump life.

Section 4: Logistics of Component Replacement

The main aging effects in large pumps are wear and erosion or cavitation. Unfortunately, these mechanisms apply to a majority of the pump subcomponents. Plant history would be a decent indicator of which subcomponents are most limiting for a given application. History and criticality of the pump should be considered when evaluating the need for spare parts or spare pumps and the overall approach to take concerning the end of life for the pump.

4.1 Part Availability and Obsolescence

Availability of parts is a major issue when repairs are needed on LHPs. Some subcomponents might be stocked by vendors. However, as vendors for a variety of industries operate, the larger, more expensive subcomponents are typically manufactured as needed, and spares are not readily available. Lead times for new subcomponents could be several months to more than a year. Although costly, an agreement could be reached with a vendor to expedite the order and reduce the lead time by a few weeks. Reliance on expediting parts should be avoided because it cannot always be accomplished. This applies to complete pump assemblies as well, especially for less-common pumps. Because pump manufacturers typically obtain subcomponents from other vendors, they also have lead time issues, which would cause even longer lead times for a plant to order a new pump than to obtain subcomponents. Many pump vendors, both original equipment manufacturers and aftermarket shops, offer reverse engineering services. Long lead times and high costs can be reduced by using the reverse engineering option. The same quality standards required of the original equipment manufacturer should be applied to reverse-engineered options.

A variety of pumps are in service in the nuclear power industry. That being said, a pump of the same manufacturer and model installed at one plant is quite possibly in service at a different plant. When responding to a pump failure, the fastest way to obtain parts might be to purchase used parts, purchase parts from a different facility, or refurbish the current parts.

4.2 Repair Times

Repair times for end-of-life failures can range from days to months. Long repair times might be acceptable, depending on the pump application. If an excess capacity (both physical excess and according to technical specifications) exists, there might be no direct plant impact other than the increased risk associated with a train being out of service.

Table 4-1
Repair Time Considerations

	Planned Repair	Unplanned Repair
Lead time for parts	Up to several months. Parts procured in advance of maintenance to eliminate impact on repair time.	Up to several months. Repairs delayed while awaiting parts. If possible to expedite, cost of parts for repair is greatly increased.
Maintenance qualification	Sufficient time exists for maintenance personnel to review work instructions and become familiar with infrequent items by walkdowns, or training, or both.	Although qualified maintenance personnel and vendors are typically available, due to an aging workforce, experienced personnel are being lost to retirement. This is a factor in planned work, as well; however, time for preparation does not exist. This lack of preparation time can increase the time required to perform the actual work.
Plant impact	Minimal impact. Work planned as required to prevent impact to generation.	Unknown until failure occurs and extent of condition is evaluated.
Repair location	Several plants have the capability to perform an in-house refurbishment of any pump. However, depending on the work required, a larger number of plants ship the pump to a vendor for complete refurbishment.	
Rigging equipment	Equipment readily available either on site or through leasing.	If leasing is required, equipment is typically available, but it might be more costly.
Vendor support	Vendor support is available.	Vendor support is difficult to obtain and more costly.
Work instructions	Sufficient time for creation of work instructions.	Although work instructions can be completed in a relatively short time for emergent issues, an increased risk of error is created. One way to minimize risk is to plan emergent work items based on plant history and industry operating experience.

4.3 Shipping and Storage Issues

Spare parts and pumps should be maintained on site, depending on pump criticality and plant history. Several parts can be stored with the intention of never using them. Long-term storage presents challenges associated with various factors such as temperature, humidity, dust, damage from adjacent parts, damage due to improper support, and so on. While in storage, parts should still be maintained (lubricated, cleaned, rotated, elastomer replaced, and so on).

Shipping parts (subcomponents and pumps) presents the same challenges as long-term storage—and then some. In addition to providing physical support for storage, additional physical support must be provided during shipping to account for increased load from the transit (turns, bumps, acceleration, and so on). When pumps have been installed in contaminated systems, radiological controls add increased complexity. This must be considered both in shipping and in the facility's ability to handle the radiological components on receipt.

4.4 Refurbishment

Refurbishment of pumps brings up several considerations related to cost and risk. Some of these items, such as where the repairs will be performed and who will perform the repairs, are described in Section 4.2, Repair Times. Additional consideration should also be given to the parts used. A determination must be made whether to use new parts, refurbishing existing parts, or re-use used parts. Methods of repair for parts (such as welds, epoxy, and so on) already exist and are described in the following documents:

- *Centrifugal and Positive Displacement Charging Pump Maintenance Guide* (TR-107252) [1]
- *Condensate Pump Application and Maintenance Guide* (1000052) [2]
- *Fossil Maintenance Applications Center: Combined-Cycle Combustion-Turbine Segmented-Casing Feedwater Pump Maintenance Guideline* (1020274) [3]
- *Main Feedwater Pump Maintenance Guide* (TR-105933) [4]
- *Pump Troubleshooting, Volume 1* (TR-114612-V1) [6]
- *Pump Troubleshooting, Volume 2* (TR-114612-V2) [7]

Used parts introduce risk from the unknown condition and previous operating history of the parts. This risk should be carefully considered before using these parts in critical pumps that could affect plant safety or operation. Inspection, testing, and nondestructive evaluation can be used to reduce the risks associated with used parts.

Section 5: Conclusions

The INPO EPIX failure information was reviewed to identify failures that are typical of end of life of LHPs. Table 2-5 shows the results of this search and indicates that end-of-life type failures could occur 1–40 years into the pump life. This wide range is due to a variety of aging factors (see Table 2-1) as well as periodic overhauls, as recommended by vendors. Methods that are useful in evaluating the pump condition are identified in Table 3-1; they should be reviewed and implemented to aid in evaluating the pump's condition. The pump maintenance methods, condition monitoring techniques, and troubleshooting techniques are described in the following EPRI documents:

- *Centrifugal and Positive Displacement Charging Pump Maintenance Guide* (TR-107252) [1]
- *Condensate Pump Application and Maintenance Guide* (1000052) [2]
- *Fossil Maintenance Applications Center: Combined-Cycle Combustion-Turbine Segmented-Casing Feedwater Pump Maintenance Guideline* (1020274) [3]
- *Main Feedwater Pump Maintenance Guide* (TR-105933) [4]
- *Pump Troubleshooting, Volume 1* (TR-114612-V1) [6]
- *Pump Troubleshooting, Volume 2* (TR-114612-V2) [7]

Since EPIX became effective in 1997, only 18 end-of-life type failures have occurred (22 were reported; 4 of those were considered infant mortality). The existing maintenance and condition monitoring methods are effective, but it is recommended to perform a detailed visual inspection within the first 10–12 years (or sooner, based on vendor-recommended maintenance) of pump operation to evaluate pump life and develop a correlation between actual pump condition and condition monitoring parameters. This correlation can be useful in estimating the individual pump life expectancy. In addition, because half of the end-of-life type failures that occurred would have had no direct indication from condition monitoring alone, additional detailed inspections should be scheduled at some point, based on condition monitoring trends, pump environment, initial inspection results, plant history, and criticality of the pump.

LHPs seem to be highly robust components. Most pump failures are actually failures of the pump's seals or bearings and not the actual pump. However, each pump will eventually reach the end of its life. The point at which a plant should shift from basic condition monitoring to more detailed monitoring, including internal inspection and measurements, varies from plant to plant and from pump

to pump. This point depends on trends established through condition monitoring, presence of aging factors (pump environment), and plant history. When the pump life expectancy is determined, more detailed maintenance should be scheduled (such as more frequent detailed inspections or more frequent condition monitoring) as that time approaches.

In addition, a contingency plan and pump refurbishment or replacement plan should be developed, along with arrangement for parts based on the criticality of the pump and the cost associated with each path.

Section 6: References

1. *Centrifugal and Positive Displacement Charging Pump Maintenance Guide*. EPRI, Palo Alto, CA: TR-107252. 1996.
2. *Condensate Pump Application and Maintenance Guide*. EPRI, Palo Alto, CA: 1000052. 2000.
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10. *Review of Main Feedwater (MFW) System Related Failures*. Institute of Nuclear Power Operations, Atlanta, GA: TR4-41.
11. *Review of Main Feedwater (MFW) System Related Failures, Addendum 1*. Institute of Nuclear Power Operations, Atlanta, GA: TR4-41, Addendum 1.
12. Review of Large-Pump-Related Events Resulting in Scrams, Shutdowns, and Outage Extensions. Institute of Nuclear Power Operations, Atlanta, GA: TR6-55.

Appendix A:Translated Table of Contents

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Ingénierie de centrale : Rapport sur la fin de durée d'utilisation prévue des grandes pompes horizontales

Novembre 2011

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Ingénierie de centrale : Rapport de fin de durée d'utilisation prévue des grandes pompes horizontales
EPRI, Palo Alto, CA : 2011.
1022970.

Résumé du rapport

Historique

Electric Power Research Institute (EPRI) a conduit cette étude d'après les directives de Plant Engineering Advisors afin d'évaluer à quel moment de la durée utile des grandes pompes horizontales un plan d'urgence de remise en état ou de remplacement s'avère nécessaire afin d'éviter une panne inattendue de fin de durée d'utilisation. Ce rapport identifie les méthodes que les producteurs d'électricité peuvent utiliser afin d'atténuer ou de répondre à l'approche de pannes attendues de fin de durée utile.

Objectif

- Assistance aux directeurs de centrales nucléaires et à l'ingénierie des composants et des systèmes dans le développement de plans de gestion de la durée d'utilisation des grandes pompes horizontales (LHP)

Approche

Ce document présente des données qui aideront à l'identification de l'approche des conditions de fin de durée utile des grandes pompes horizontales. Celles-ci sont généralement à l'abri d'incidents pendant la durée d'utilisation d'une installation si des pratiques fondamentales de maintenance sont en place et mises en œuvre. Les documents de maintenance nucléaire d'EPRI et la base de données de référence de maintenance préventive d'EPRI présentent les grandes lignes des meilleures pratiques et des recommandations de mise en œuvre d'une maintenance et d'une surveillance en fonction de l'état des grandes pompes horizontales. L'objectif de ce rapport concerne l'identification de « l'instant » pendant la durée utile des grandes pompes horizontales qui déclenchera une procédure de fin de leur durée utile. Même si les grandes pompes sont conçues pour une longue durée d'utilisation, les exemples d'arrêts imprévus de centrales et de réduction des caractéristiques de fonctionnement en raison du vieillissement sont nombreux.

L'expérience de l'exploitation dans le domaine, les rapports techniques EPRI et les données sur les pannes sont à la base de cette étude. Une recherche sur les bases de données de l'Institute of Nuclear Power Operations (INPO) (Institut des opérations électronucléaires) et de Equipment Performance Information Exchange (EPIX)* (échanges d'informations sur les performances des équipements) a été réalisée afin d'identifier les pannes de fin de durée utile et d'en examiner les causes. Des sources autres qu'EPIX (comme les rapports thématiques de l'INPO) ont aussi été étudiées afin de valider les résultats EPIX. (Les documents INPO ne sont disponibles qu'à ses membres et participants.) Ce rapport décrit les conditions d'accélération de la durée utile d'une pompe et des méthodes d'identification de ces conditions.

* Les documents de l'INPO ne sont disponibles qu'à ses membres et participants ; ils ne sont pas mis à la disposition du public.

Une brève description de la logistique associée à la réparation des pompes est aussi incluse. Pour terminer, le rapport décrit l'utilisation des données de performances dans la planification d'une maintenance de pompes.

Résultats

La durée prévue d'utilisation des grandes pompes horizontales varie largement en fonction des applications conceptuelles, des conditions d'exploitation et d'autres facteurs stressants, comme les cycles successifs, le démarrage des arrêts, etc. La surveillance des tendances des performances opérationnelles et les caractéristiques de la pompe comme l'huile, les vibrations et l'alignement, la documentation et l'examen des résultats détaillés d'inspection ainsi que la connaissance de l'historique de la centrale et la criticité de la pompe, constituent les éléments essentiels de la gestion du cycle de vie. Un élément souvent oublié concerne l'importance des inspections initiales détaillées de base et des épreuves fonctionnelles, notamment les vibrations, le courant et les vérifications des dimensions critiques des pièces d'usure et les jeux. Ces pratiques s'appliquent aussi aux grandes pompes horizontales nouvellement révisées ou remises en état. C'est avec ces données que les tendances fonctionnelles initiales sont comparées aux données courantes afin d'évaluer l'état des composants et l'approche pour la maintenance ou en cas de panne.

Chacun doit considérer non seulement les aspects techniques, c'est-à-dire de savoir quand procéder à la remise en état ou au remplacement, mais aussi de déterminer le seuil économique d'une maintenance préventive qui ne s'avère plus rentable. Les plans stratégiques sur le long terme d'une installation et les implications relatives à une demande d'extension de la durée d'utilisation des grandes pompes horizontales au-delà de la durée utile de l'installation sont importants vis-à-vis de cette décision, c'est-à-dire quelle est la durée prévue de fonctionnement de l'installation, peut-elle bénéficier d'améliorations, sa durée utile prévue peut-elle être étendue au-delà de sa conception et quelle est la demande d'extension sur les grandes pompes horizontales en fonctionnement ?

Les grandes pompes horizontales sont des composants robustes qui peuvent fournir un service de longue durée et sans incident si une maintenance préventive appropriée est appliquée. L'usure et le vieillissement des sous-composants principaux déterminent la fin de la durée utile. Lors du développement de plans de gestion du cycle de vie des grandes pompes horizontales, il est important de considérer la criticité de la pompe, les pertes de production, la disponibilité et les délais d'approvisionnement des pièces détachées, la planification, la durée d'immobilisation due au remplacement de la pompe, la durée utile prévue des installations et des grandes pompes horizontales, les méthodes de réparation ou de remise en état, le coût des réparations et le coût d'investissement du remplacement ou du reconditionnement.

Mots clés

Fiabilité des composants
Fin de durée utile
Durée utile prévue
Grandes pompes horizontales
Gestion du cycle de vie
Gestion des biens de production nucléaire

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プラントエンジニアリング:
大型水平ポンプ予想耐用年数
報告書

2011 年 11 月

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EPRI, Palo Alto, CA: 2011.
1022970.

報告書の要約

背景

Electric Power Research Institute（EPRI）は、プラントエンジニアリング アドバイザーの指示のよりこの研究を行っており、耐久年数（寿命）超過による故障を防ぐため、ポンプの改修または交換が必要になった場合のためのコンティンジェンシープラン策定の際に、大型水平ポンプの寿命の時期を評価しています。この報告書は、電力会社が寿命の接近に対して、軽減または対抗するために利用できる方法を特定します。

目的

- 大規模水平ポンプ（LHP）のライフサイクル管理計画の作成において、原子力発電所マネージャーおよび構成部品またはシステムエンジニアを支援することです。

方法

この文書は、LHP の寿命の終わりが近づいたことを識別する上で役立つデータを提供します。LHP は、基本的な保全実践が適切に行われている場合、通常施設の寿命にわたって故障がありません。EPRI 原子力保全文書および EPRI 予防保全ベースデータベースは、LHPs の保全の実施および状態監視のための最優良事例および推奨事項の概要を示しています。この報告書の目的は、寿命の終わりが近づいているときに、LHP のライフサイクル中の時期を特定することです。大型ポンプの寿命は長くなるように設計されていますが、長年の使用による予期せぬプラント停止や出力低下など多くの事例があります。

業界の運転経験、EPRI 技術報告書、および業界の故障データは、この研究の基盤になります。Institute of Nuclear Power Operations（INPO）Equipment Performance Information Exchange（EPIX）*データベースの調査は、耐用年数による故障を特定し、故障の原因を確認するために実行されました、また、EPIX（INPO トピックレポートなど）以外のソースは、EPIX のデータを検証するために確認されます。（INPO 情報は INPO メンバーおよび参加者のみ利用可能です。）この報告書はポンプ寿命を促進させる条件と、これらの条件を特定する方法を説明しています。

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ポンプの修理に関連する手配業務の簡潔な説明も含まれています。最後に、この報告書ではポンプ保全計画におけるパフォーマンスデータの使用法を説明しています。

結果

LHP の予想寿命は、設計アプリケーション、運転状況、およびサイクリング、起動、停止などのその他の負荷によって大幅に異なります。オイル、振動、配置など、運用パフォーマンス傾向およびポンプの特徴を監視します。詳細な検査結果を文書化し確認します。発電所の履歴を理解して、ポンプの重大性がライフサイクルの管理において重要な要素であることを理解します。摩耗部品や間隙の振動、電流および重要な寸法の確認を含む、最初の段階での詳細なベースライン検査およびパフォーマンス実行の重要性をしばしば見過ごしてしまう場合があります。この実践は同様に、新しく総点検または改修された LHP に適用されます。構成要素の状態、および保全または故障への取り組みを評価するために、最初の段階での運転の性向を現在のデータと比較するためにこのデータを使用します。

交換または改修の際の技術面だけではなく、予防保全がコスト的に効率的ではない場合の経済面も考慮する必要があります。この決定には、施設の戦略的長期計画と施設の寿命にわたって LHP を長期間必要とするとの暗黙の事項が重要になります。つまり、その稼働時間、施設が増強されたか、予想される施設の耐久年数が設計以上に伸びたか、または LHP の運転上の要求事項がどのようなものであるかということです。

LHP は堅固な構成部品であり、適切な予防保全が行われている場合、長期間トラブルの無いサービスを提供します。主要なサブコンポーネントの磨耗および老朽化が有効寿命の終了を確定します。LHP ライフサイクル管理計画を立案する場合、ポンプ、喪失、予備部品の入手可能期間と納期、ポンプの交換における使用停止のタイミング、施設および LHP の予想耐用年数、交換または改修の方法、修理に関するコスト、および交換または修理の資本コストの重要性について考慮する必要があります。

キーワード

構成部品の信頼性
耐用年数
予想耐用年数
大型水平ポンプ
ライフサイクル管理
原子力資産運用

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Ingeniería de centrales: Informe sobre el fin de la vida estimada de las bombas horizontales grandes

Noviembre de 2011

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Esta publicación es un documento corporativo que se debe citar en la literatura de la manera siguiente:

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RESUMEN DEL INFORME

Antecedentes

Electric Power Research Institute (EPRI) ha realizado este estudio a indicación de los asesores de ingeniería de centrales para evaluar el momento del ciclo de la vida de las bombas horizontales grandes en el que sería deseable disponer de un plan de contingencia para la reconstrucción o sustitución de la bomba con el fin de evitar un fallo inesperado antes del fin de la vida útil. En este informe se identifican métodos que las compañías eléctricas pueden utilizar para mitigar o contrarrestar el enfoque de fallos al final de la vida útil prevista.

Objetivo

- Ayudar a los ingenieros de sistemas o componentes y a los directivos de las centrales eléctricas nucleares a desarrollar planes para la gestión del ciclo de vida de las bombas horizontales grandes (Large Horizontal Pumps, LHP)

Enfoque

Este documento incluye datos que ayudarán en la identificación del enfoque de las condiciones de fin de vida de las LHP. Las LHP normalmente no presentan problemas durante la vida de unas instalaciones si se dispone de prácticas fundamentales de mantenimiento y se llevan a cabo. Los documentos de mantenimiento nuclear de EPRI y la base de datos de mantenimiento preventivo de EPRI describen las mejores prácticas y recomendaciones para la implementación de sistemas de mantenimiento y supervisión en función de las condiciones de las LHP. El objetivo de este informe es identificar el punto del ciclo de vida de la LHP en el que se aproxima al final de su vida. Aunque las bombas grandes están diseñadas para una vida larga, se han dado muchos casos de paradas imprevistas de centrales y reducciones de potencia debido a problemas de envejecimiento.

La experiencia operativa de la industria, los informes técnicos de EPRI y los datos de fallos de la industria constituyen las bases de este estudio. Para identificar fallos de fin de vida y revisar sus causas se realizó una búsqueda en la base de datos de intercambio de información de rendimiento de equipos (Equipment Performance Information Exchange, EPIX)* del Instituto de Operaciones de Energía Nuclear (INPO). También se revisaron otras fuentes distintas a EPIX (como los informes temáticos del INPO) para validar los resultados de EPIX. (Los materiales del INPO sólo están disponibles para sus miembros y participantes.) En este informe se describen las condiciones que acortan la vida de la bomba y los métodos para identificarlas.

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También se incluye una breve descripción de la logística asociada a la reparación de las bombas. Por último, el informe describe el uso de datos de rendimiento para la planificación del mantenimiento de la bomba.

Resultados

La vida útil prevista de las LHP varía significativamente en función de las aplicaciones de diseño, las condiciones operativas y otras tensiones, como las ocasionadas por el funcionamiento cíclico, los arranques y las paradas, etc. Supervisar las tendencias de rendimiento operativo y características de la bomba como el aceite, la vibración y la alineación, documentar y revisar los resultados de inspecciones detalladas, y conocer el historial de la central y la criticalidad de la bomba, son elementos esenciales para la gestión del ciclo de vida. Un área que con frecuencia se pasa por alto es la importancia de las inspecciones iniciales y detalladas de línea base y los ciclos de rendimiento, incluyendo comprobaciones de vibración, corriente y dimensiones críticas de los elementos de desgaste y las holguras. Estas prácticas se aplican también a las LHP recientemente revisadas o reconstruidas. Estos datos se utilizan para comparar las tendencias operativas iniciales con los datos actuales para evaluar el estado de los componentes y el enfoque de mantenimiento o fallo.

No solo se deben considerar los aspectos técnicos de cuándo sustituir o reconstruir, sino también el punto a partir del cual el mantenimiento preventivo ya no resulta económicamente rentable. Para tomar esta decisión, es importante el plan estratégico de las instalaciones a largo plazo y las implicaciones de la ampliación de uso de la LHP a lo largo de la vida de las instalaciones, es decir, cuánto tiempo estarán operativas, si se realizarán aumentos de potencia, si la vida esperada de las instalaciones se ampliará más allá del tiempo establecido en el diseño original, y cuál será la demanda operativa de la LHP.

Las LHP son componentes robustos y pueden funcionar sin problemas durante mucho tiempo si se realiza un mantenimiento preventivo adecuado. El desgaste y el envejecimiento de los principales subcomponentes determinan el fin de la vida útil. Al desarrollar planes de gestión del ciclo de vida de la LHP, se debe tener en cuenta la criticalidad de la bomba, la generación perdida, la disponibilidad y el tiempo de adquisición de repuestos, el tiempo fuera de servicio necesario para sustituir la bomba, la vida prevista de las instalaciones y la LHP, los métodos de reparación o reconstrucción, el coste asociado a la reparación, y el coste de capital de la sustitución o reconstrucción.

Palabras clave

Fiabilidad de los componentes
Fin de vida
Vida prevista
Bomba horizontal grande
Gestión del ciclo de vida
Gestión de activos nucleares

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- 핵 발전소 관리자 및 구성부품 또는 시스템 담당 엔지니어들의 대형 수평 펌프 (LHP)용 라이프 사이클 관리 계획 수립을 돕기

접근방식

본 문건에서는 LHP 용의 사용 수명 종료 시점이 가까워지고 있음을 확인하는 데 도움이 될 데이터를 제공합니다. LHP 들은 기본적인 유지 관리 관행들을 마련하여 시행하고 있을 때는 일반적으로 설비를 사용하는 동안 문제를 일으키지 않습니다. EPRI 핵발전소 유지관리 문서 자료들과 EPRI 예방적 관리 기초 데이터베이스에서는 LHP 의 유지 관리 및 상태에 따른 모니터 작업을 실행하기 위한 최선의 관행 및 권고사항들을 간략히 설명합니다. 이 보고서는 LHP 의 라이프 사이클에서 사용 수명이 끝나가는 시점을 확인하는 데 목표를 두고 있습니다. 대형펌프들은 장기간 가동하도록 설계되었지만, 노후 문제로 인한 예상외의 발전소 가동 중지 및 출력 용량 저감 사태가 여러 차례 발생해 왔습니다.

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결과

LHP 의 기대 수명은 설계 적용, 가동 조건 및 사이클링, 시동 및 정지 등의 기타 스트레스 요인에 따라 크게 달라집니다. 가동 성능 상의 경향과 오일, 진동, 조정 같은 펌프 특성을 모니터하고; 자세한 점검 결과들을 기록, 검토하고; 발전소 이력 및 펌프의 임계상태(criticality)를 이해하는 일은 라이프 사이클 관리의 필수 요소들입니다. 세밀한 초기 기본 점검과 진동, 전류 및 마모성 부품과 간극에 대한 중요한 규격 점검을 비롯한 성능 시험 (performance run)의 중요성이 자주 간과되곤 합니다. 이 점은 새로 정밀검사를 실시했거나 재생된 LHP 들에도 적용됩니다. 이 데이터를 이용하여 초기 가동 경향을 현재의 데이터와 비교하여 구성부품의 상태와 유지관리 또는 고장을 처리하기 위한 접근법을 평가합니다.

작업자는 교체 또는 재생 작업 시기에 관한 기술적 측면은 물론 예방 목적의 유지관리 작업이 더 이상 비용 효율적이지 못한 경제적 시점도 함께 고려해야 합니다. 이러한 결정을 내릴 때 중요한 것은 발전소의 전략적 장기 계획과 발전소의 사용기간 전체에 걸친 LHP 에 대한 장기간에 걸친 요건이 갖는 의미—즉, 얼마나 오래 발전소를 가동할 것인가, 발전소 출력 등급을 높일 것인가, 예상되는 발전소 가동 기간을 설계 조건보다 연장시킬 것인가, 그리고 LHP 가동 기간을 늘리려면 무엇이 필요한가—입니다.

LHP 는 견고한 구성부품으로서 적절하게 예방 차원의 유지관리를 실시하면 장기간 고장 없는 이용이 가능합니다. 마손 및 주요 하위 구성 부품들의 마손과 노후화는 이용 가능한 기간을 결정합니다. LHP 라이프 사이클 관리 계획을 세울 때는, 펌프의 임계상태(criticality), 발전 손실 (lost generation), 예비 부품의 공급 여부 및 공급 소요 기간, 펌프 교체에 소요되는 서비스 중지 시간, 발전소 및 LHP 의 기대 수명, 수리 또는 재생 방법, 수리 비용 및 교체 또는 재생에 드는 자본 비용을 고려해야 합니다.

주요 어휘

구성부품 신뢰도
수명 종료 시점
기대 수명
대형 수평 펌프
라이프 사이클 관리
핵 자산 관리

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Engenharia de usinas: Relatório sobre a expectativa do fim da vida útil de bomba horizontal de grande porte

Novembro de 2011

Este documento **NÃO** atende os requisitos do Anexo B da 10CFR50, 10CFR Parte 21, ANSI N45.2-1977 e/ou a intenção da norma ISO-9001 (1994)

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Reconhecimentos

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Resumo do relatório

Informações básicas

O EPRI (Electric Power Research Institute) desenvolveu este estudo atendendo à solicitação dos Consultores de engenharia da usina para avaliar o momento na vida útil das bombas horizontais de grande porte onde é desejável um plano de contingência para o recondicionamento ou reparo dessas bombas para prevenir uma falha inesperada devido ao fim da vida útil. Este relatório identifica métodos que as concessionárias de energia podem usar para mitigar ou neutralizar a ocorrência de falhas de fim de vida útil.

Objetivo

- Auxiliar os gerentes de usinas de energia nuclear e engenheiros de componentes ou sistemas no desenvolvimento de planos de gerenciamento do ciclo de vida útil para LHPs (bombas horizontais de grande porte)

Abordagem

Este documento fornece dados que ajudarão na identificação da aproximação das condições de fim de vida útil das LHPs. As LHPs normalmente não apresentam problemas durante a vida útil de uma instalação se as práticas fundamentais de manutenção estão em vigor e são executadas. Documentos de manutenção nuclear do EPRI e a Base de dados da manutenção preventiva básica delineiam as melhores práticas e recomendações para a implementação da manutenção e monitoramento baseado em condições de LHPs. O objetivo deste relatório é identificar o momento durante o ciclo de vida das LHP em que se aproxima o fim de sua vida útil. Embora as bombas de grande porte sejam projetadas para terem uma longa vida útil, observam-se muitos exemplos de interrupções e redução de eficiência devido a problemas de envelhecimento.

A experiência das operações do setor, relatórios técnicos do EPRI e dados de falhas observadas formam os fundamentos deste estudo. Foi realizada uma pesquisa pelo INPO (Institute of Nuclear Power Operations) na base de dados EPIX* (Intercâmbio de informações sobre o desempenho de equipamentos) para identificar as falhas causadas por fim de vida útil e avaliar as causas dessas falhas. Outras fontes além da base EPIX (tal como Relatórios de tópicos do INPO) também foram analisadas para validar os resultados do EPIX. (O material do INPO está disponível apenas para membros e participantes do instituto). Este relatório descreve as condições que reduzem a vida útil de uma bomba e os métodos para identificar essas condições.

_____

* O material do INPO está disponível apenas para membros e participantes desse instituto; não está disponível para o público em geral.

Inclui-se também uma breve descrição da logística associada ao reparo de bombas. Ao final, o relatório descreve o uso de dados de desempenho no planejamento da manutenção de bombas.

Resultados

A expectativa da vida útil das LHPs varia largamente, dependendo das aplicações do projeto, condições de operação e outros fatores estressantes como, ciclos de operação, inícios e paradas, e assim por diante. O monitoramento das tendências do desempenho operacional e de características das bombas como óleo, vibração e alinhamento; a documentação e avaliação dos resultados detalhados de inspeções e a compreensão crítica do histórico da usina e das bombas são elementos essenciais no gerenciamento do ciclo de vida útil. Uma área que frequentemente é negligenciada é a importância das inspeções detalhadas básicas iniciais e das operações de desempenho, incluindo vibração, corrente e verificações de dimensões críticas de peças sujeitas a desgaste e folgas. Esta prática aplica-se, também, a LHPs recém revisadas ou recondicionadas. Com base nestes dados as tendências iniciais da operação são comparadas com os dados atuais para avaliar a condição dos componentes e a abordagem para a manutenção ou falha.

Devem ser levados em consideração não só os aspectos técnicos de quando substituir ou recondicionar, mas também o momento econômico em que a manutenção preventiva não é mais viável do ponto de vista do custo-benefício. Importante nesta decisão é o plano estratégico de longo prazo da usina e as implicações da demanda estendida da LHP ao longo da vida útil da unidade. Ou seja, por quanto tempo a usina irá operar, se as instalações estão sendo ampliadas, se a expectativa de vida útil da usina está sendo acima da projetada e qual é a demanda operacional estendida da LHP.

As LHPs são componentes robustos e podem operar longamente sem problemas se a manutenção preventiva adequada for aplicada. O desgaste e envelhecimento dos principais subcomponentes é que determinam o fim da vida útil. Ao desenvolver planos de gerenciamento do ciclo de vida das LHPs, deverá ser considerada a criticidade da bomba, geração perdida, disponibilidade e tempo de suprimento de peças sobressalentes, período de interrupção de serviço para substituição da bomba, vida útil estimada da usina e da LHP, métodos de reparo ou recondicionamento, o custo associado ao reparo e o custo de capital para reposição ou recondicionamento.

Palavras-chave

Confiabilidade do componente
Fim de vida útil
Bomba horizontal de grande porte
Gerenciamento de ciclo de vida
Gerenciamento de ativos nucleares

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