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Nuclear Maintenance Applications Center: Oil Lubrication Guide for Rotating Equipment

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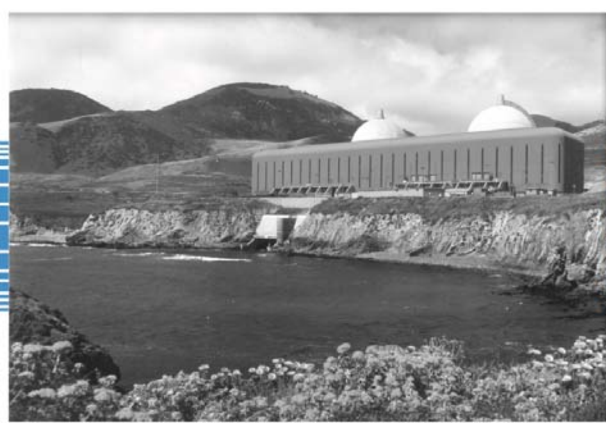

Nuclear Maintenance Applications Center: Oil Lubrication Guide for Rotating Equipment

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REPORT SUMMARY

Background

At a nuclear station, several types of safety-related and non-safety-related equipment rely on lubricating oil systems to provide lubrication to rotating components. These lubricating systems consist of gears, pumps, valves, heat exchangers, and other parts. In the event of a lubrication system failure, the supported equipment can be shut down, which in turn can lead to unanticipated entries into limiting conditions of operation, system degradation, or a unit trip. An understanding of how oil is affected by contamination and operating and environmental conditions as well as what measures can be taken to minimize or prevent these effects can result in better equipment reliability and availability as well as cost savings. The importance of maintenance activities—such as oil change intervals, filtration, and general lubrication system cleaning—will ensure that the rotating equipment is properly lubricated for optimized equipment reliability and availability.

The report provides insights into the previously described issues in addition to corrective, preventive, and predictive maintenance practices and how to troubleshoot lubrication system problems. The information in this report can be used in conjunction with the Electric Power Research Institute (EPRI) reports *Lubrication Guide* (1019518) and *Effective Greasing Practices* (1020247) to provide an overall approach to lubrication fundamentals and systems. Preventive and predictive maintenance techniques are consistent with EPRI preventive and predictive maintenance guidance.

This report can be used by any personnel who monitor or maintain equipment lubrication systems in the plant, including system and component engineers, preventive and predictive maintenance personnel, lubrication engineers and technicians, maintenance personnel, and planners. The report can be applied to various equipment in a plant for a successful and reliable lubricating oil system.

Objectives

- To provide general information and guidance to plant personnel who are involved with lubricating oil systems within the plant that require additional attention (such as main turbines, Terry Turbines, feed pump, diesel generator, motors, and pumps)
- To provide fundamentals of how the lubrication systems operate and function for various plant equipment, including motive sources and cooling mechanisms
- To present information on lubrication system troubleshooting

- To document general, preventive, and predictive maintenance practices
- To describe contamination and contamination control

Approach

Nuclear Maintenance Applications Center: Oil Lubrication Guide for Rotating Equipment is the result of work performed by EPRI. A technical advisory group was formed to provide input on report content, organization, and end-use application. Applicable EPRI documents related to lubrication systems and lubricants were reviewed to ensure consistency of information provided. Also, plant procedures were solicited and reviewed, and from the information collected, a draft report was developed. The draft covered lubrication methods and contamination that can affect the performance of lubrication. The draft was disseminated for review and comment to members of the TAG. Comments and suggestions were subsequently incorporated to produce the final draft, which was also reviewed in-house at EPRI prior to publication.

Results

This report addresses lubrication systems for major pieces of plant equipment that might require additional attention. It includes sections on lubrication methods, constant-level oilers, cleanliness and contamination control, degradation, and guidance and information on major pieces of plant equipment and their lubrication systems. Specific information on major equipment includes basic lubrication system operation, general maintenance guidance, troubleshooting, lubrication system vulnerabilities, and operating experience. A glossary of terms and acronyms used in the report is also included. Resources that were used in the development of this report are listed as a source of additional information.

EPRI Perspective

Knowledge of the lubrication systems in important plant equipment is essential to maintenance personnel in their day-to-day work. This report provides information on maintenance practices (such as general, preventive, and predictive), troubleshooting techniques, and contamination (sources and control) in lubrication systems. Information contained in this report can be useful to personnel developing troubleshooting procedures and reviewing preventive maintenance; it can also help support training instructors. This report addresses recent changes within the lubrication industry related to lubrication formulation and issues that could affect the industry in the future.

Keywords

Filters
Lube oil systems
Lubrication
Rotating machinery

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INTRODUCTION

1.1 Purpose

There are a number of pieces of safety-related and non-safety-related equipment that rely on lubricating oil systems to provide fluid to rotating components. These lubricating systems consist of gears, pumps, valves, heat exchangers, and other parts. In the event that these systems fail, the equipment can be shut down, which in turn can lead to a reactor trip. Single-point vulnerabilities within the system can shut the equipment down or cause detrimental damage. Maintenance activities—such as oil change intervals, oil sampling techniques, and general system cleanliness—would ensure that the rotating equipment is properly lubricated.

1.2 Scope

The lubricating oil system maintenance report addresses the following:

- Lubricating oil systems within the plant that require additional attention, such as the feed pump, Terry Turbine, emergency diesel generator (EDG), and reactor recirculation pump (RRP)
- Fundamentals of how these systems operate and function, including motive sources and cooling mechanisms
- System troubleshooting
- General maintenance practices
- Preventive and predictive maintenance practices

1.3 Report General Information

This report addresses lubrication systems for major pieces of plant equipment that may require additional attention. The report is divided into four major sections. Section 2 provides information on several lubrication methods employed by lubrication systems on major pieces of plant equipment. Section 3 provides information on constant-level oilers (such as basic operation, setup, and problems). Section 4 discusses oil contamination, degradation, and conditioning of oil. Section 5 is the heart of the report; it provides general maintenance information, troubleshooting guidance, and information about vulnerabilities associated with lubrication systems of major rotating plant equipment. A glossary of terms and acronyms used in the report is also included. References that were used in the development of this report are provided as a source for additional information if required.

1.4 Key Points

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

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

The Key Points are organized into three categories: Human Performance, O&M Costs, and Technical. Each category has an identifying icon to draw attention to it when quickly reviewing the guide. The Key Points are shown in the following way:

Key O&M Cost Point

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

Key Technical Point

Targets information that will lead to improved equipment reliability.

Key Human Performance Point

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

The Key Points Summary section (see Appendix B) of this report is a list of all key points in each category. The summary restates each key point and provides a reference to its location in the body of the report. By reviewing this list, users of this report can determine if they have taken advantage of key information that the writers of this report believe would benefit their plants.

2
LUBRICATION METHODS

2.1 Introduction

Every nuclear site has hundreds of pieces of rotating machinery (for example, motors, pumps, turbines, valves, and compressors) that require lubrication in order to function effectively, efficiently, and reliably. The lubricants that are available to accomplish this are oil, grease, and solid lubrication techniques. Oil and grease are the primary lubricants used in nuclear plants for the lubrication of rotating machinery. The choice of lubrication, oil, or grease depends on many factors, including the following:

- Application
- Environmental issues
- Equipment type
- Speed
- Load
- Duty cycle
- Serviceability
- Operating characteristics

There are advantages and disadvantages to any type of lubricant. Table 2-1 provides some of the advantages and disadvantages associated with using oil or grease as a lubricant. Note that the primary lubrication medium in grease is oil. There are other additives, such as thickeners and gelling agents, that are used to immobilize the oil and allow the lubricant to be in various orientations without running out of the machine.

Table 2-1
Comparison of oil and grease lubrication

Lubricant Attribute	Oil	Grease
Lubrication	Very good	Good
Contaminant removal	Easy, simple processes	Difficult, impractical
Sampling	Easy to obtain representative sample	Difficult to obtain a representative sample
Lubricant change	Easy	Troublesome, but possible in some bearing applications
Heat transfer	Good, auxiliary cooling possible with forced circulation	Poor; auxiliary cooling not applicable
Lubricant life	Long; higher oxidation life	Short; reduced oxidation life
Machine speed	Higher limiting speed	Low to moderate speeds
Machine startup	Lubrication film must develop	Immediate lubrication (if grease is still good)
Sealing mechanism	Complicated; requires maintenance	Simple, with little maintenance
External leakage	Higher leakage probability	Minimal leakage

Oil lubrication may be accomplished through a variety of methods, including the following:

- Forced oil circulation
- Oil bath
- Splash (oil-ring or slinger-ring)
- Oil mist
- Drip feed
- Oil/air
- Oil jet

The most predominant methods found in a nuclear power plant include forced oil circulation, oil bath, and splash lubrication.

2.2 Lubricating Methods

The predominant lubricating methods currently in use at nuclear power plants are covered in this section. Additional methods are presented to provide a well-rounded view of lubricating techniques.

2.2.1 Forced Oil Circulation Lubrication

Forced oil circulation is a lubrication method where oil is pumped from a reservoir to the bearing under pressure for lubrication and cooling of the bearing. There are two types of forced lubrication oil systems—one incorporates an external oil storage tank and the other an integral reservoir with a lift pump and cooler. The oil is typically returned to the reservoir by gravity feed, but in some cases, it is pumped back to the reservoir. Because evacuation of circulating oil occurs from the bearing, the drain lines are larger and located opposite the oil supply lines. The oil reservoir must contain a sufficient quantity of oil to allow time for the oil to drain back into the reservoir. This method of lubrication is also referred to as *dry sump* lubrication because the bearing housing is not used to store the oil. This method of lubrication is typically used for high-speed or high-load applications (such as in the main turbine) where cooling of the bearing is of high importance.

Forced oil circulation lubrication is more complex and more expensive than other lubrication methods. It requires pumps, piping, storage tanks, heat exchangers, filtration, and so on. Advantages of this method of lubrication include the use of a centrally located oil supply, the use of cooling heat exchangers, and filtration. Because forced oil circulation is employed on operationally sensitive equipment, backup and redundant equipment is also used to ensure system reliability. This lubrication system typically uses various types of instrumentation systems for level, temperature, and pressure control. A simplified one-line diagram for a forced oil system is provided in Figure 2-1. If it is designed, operated, and maintained properly, a forced oil circulation system will provide maximum bearing life.

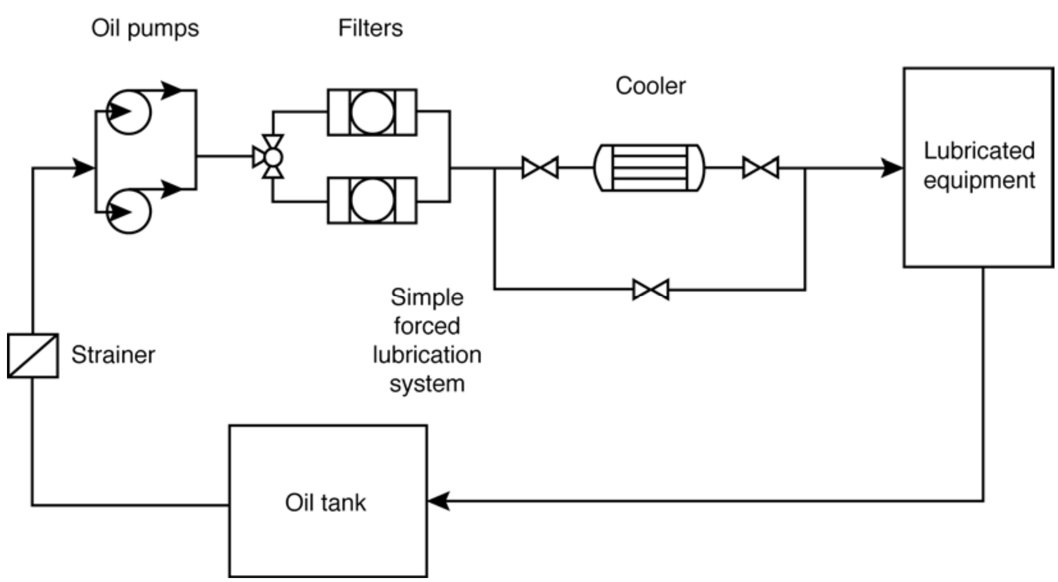

Figure 2-1
Forced circulation lubrication

2.2.2 Oil Bath Lubrication

Oil bath lubrication is one of the simplest and oldest of the lubrication systems. In oil bath lubrication, the bearings or gears operate in an oil bath. The bearings or gears are not completely submerged in the bath, but rather they extend into the bath. For roller element bearings, the oil level is maintained at approximately the center of the ball in the lowest part of the reservoir when the machine is at rest. The movement of the bearing through the oil bath lubricates and cools the bearing. A disadvantage of oil bath lubrication is the frictional heating of the oil as the bearing passes through the oil. This heating occurs primarily at the surface and can result in thermal stratification in the bearing housing pump. Sometimes disks are used to minimize this thermal stratification.

Oil bath lubrication is typically found on low-speed or medium-speed machinery with light loads. Maintaining a proper oil level is necessary for operation of this system. Bearing housing design is important in minimizing wide fluctuations in level. Sight glasses might be installed to allow for easy verification of the oil level. If the oil level is too low, starvation to the bearing will result. This leads to increased wear, heat generation, and premature or catastrophic failure of the bearing. If the oil level is too high, excessive churning of the oil occurs, resulting in foaming, aeration, and an increase in frictional heating as the bearing passes through the oil. High oil level can also result in oil whip and whirl. Level is maintained through the use of a constant-level oiler (see Section 3, "Constant-Level Oilers").

The oil bath lubrication system can be used for horizontally or vertically mounted equipment. For vertically mounted shafts, oil bath lubrication is typically limited to slow speeds and oil levels are maintained higher than (that is, 50–80% of roller bearing element) horizontal equipment. A simple illustration of an oil bath lubrication system is given in Figure 2-2.

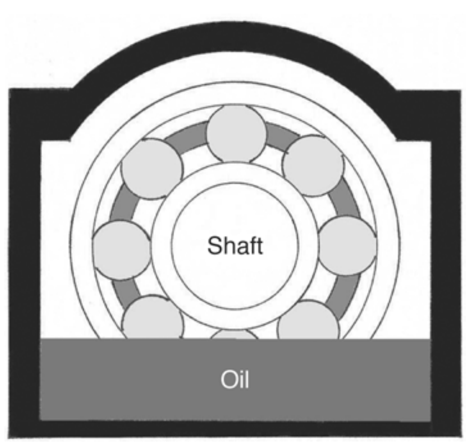

Figure 2-2
Oil bath lubrication

2.2.3 Splash Oil Lubrication (Oil Ring/Slinger Ring)

Oil reservoir/sump lubrication is a low-cost, low-maintenance, and relatively low-risk approach to the lubrication of rotating equipment. Its applications are many, including pumps, blowers, compressors, and gear boxes. This lubrication method provides lubrication, controls temperature, minimizes corrosion, and assists in contamination control. Oil reservoir lubrication is typically accomplished by one of two methods.

One method employs the actual dipping of a bearing or gear into the oil contained in the reservoir/sump. The second method is accomplished by using oil rings (such as slinger rings). The rings ride on the shaft or journal hanging down into the oil in the reservoir/sump. As the shaft rotates, the oil rings rotate, picking up oil and carrying (splashing) it onto the bearings/gears for lubrication. No matter which method of lubrication is used, the oil level in the bearing reservoir must be maintained in a relatively narrow band.

For cases in which the bearing or gear is immersed in the reservoir/sump oil, two rules might apply: 1) for bearings, the oil level should be maintained halfway up the lowest bearing in the bearing assembly when at rest and 2) for gears, the oil level should cover the tooth of the lowest gear when at rest.

For reservoirs in which oil rings are used, a general rule is for the rings to be set with the oil level 1/4–3/8 in. (6.4–9.5 mm) from the bottom inside of the ring. The faster the speed of the machine, the lower the level should be set on the ring. The vendor’s technical manual should be consulted for exact oil ring location for a particular piece of equipment.

Key Technical Point

For reservoirs in which oil rings are used, a general rule is for the rings to be set with the oil level 1/4–3/8 in. (6.4–9.5 mm) from the bottom inside of the ring.

If the oil level is too low or too high, excessive temperatures could occur. Excessive temperatures accelerate the degradation of the oil and shorten bearing/gear life. If the oil level is too low, insufficient oil—which acts as a heat sink—will be delivered to lubricate (establish an oil film to) the bearing/gear. If the oil level is too high, churning will occur. This results in air being whipped or beaten into the oil. Induced heat from the churning increases oxidation rate and effectively shortens the life of the oil.

Splash oil lubrication employs the use of an oil ring or slinger ring that hangs from the shaft or journal and extends into the bearing housing oil reservoir. As the shaft rotates, the oil ring rotates on the shaft, slinging oil onto the bearing for lubrication and cooling. A disk attached to the shaft may also be used.

Similar to oil bath lubrication, the most critical aspect of this type of lubrication is the need to maintain a relatively constant level within a narrow band in the bearing housing reservoir. Too low of an oil level will result in oil starvation to the bearing, leading to increased wear and overheating of the bearing. Too high of a level will result in foaming, aeration, and increased frictional heating. The oil level is maintained within the narrow operating band by a constant-level oiler.

This type of lubrication system is commonly used in horizontally mounted equipment. It may be used on equipment rotating at moderate to moderately high speeds. Though less common, splash lubrication may be used in vertically mounted equipment where a tapered rotor is used below the bearing. As the shaft rotates, the oil climbs up the tapered rotor to the bearing. An example of a slinger rind lubrication system is given in Figure 2-3.

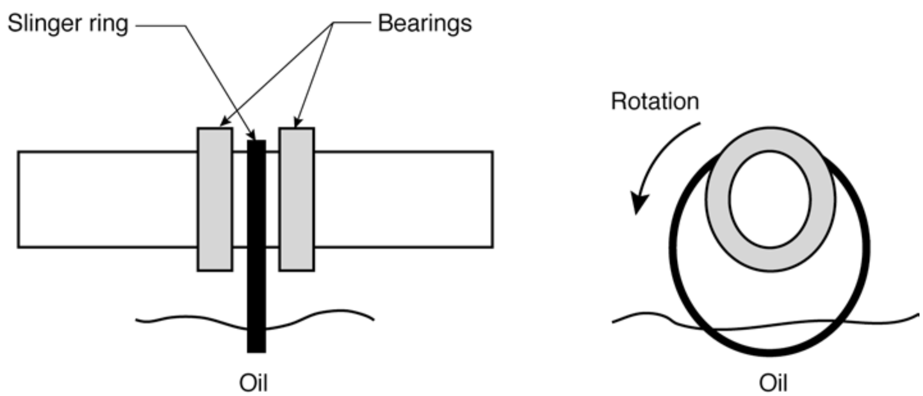

Figure 2-3
Slinger ring lubrication

2.2.4 Additional Lubrication Systems

Oil mist, oil drip, oil-air, and oil jet lubrication systems are not commonly used in the nuclear industry. There may be stations that have unique designs that employ one or more of these systems. It is also possible that these systems may be designed into future plants. A brief description of these designs follows.

2.2.4.1 Oil Mist Lubrication

An oil mist lubrication system uses pressurized air to atomize the oil before it is fed to the bearing. This lubrication system is used in areas of high contamination from water, dirt, and dust. It is used for high-speed lubrication applications and can be used by horizontally or vertically mounted equipment. Advantages of this system include the following:

- Low lubricant resistance.
- Minimal oil consumption.
- New oil is always supplied.
- Several bearings and pieces of equipment can be supplied at the same time.

A disadvantage is that heat removal capacity is not as high as other lubrication methods. This method of lubrication is common in the petrochemical industry.

2.2.4.2 Drip Feed Lubrication

Drip feed lubrication is a system that provides metered drops of oil to a lubricated system. It is used in small, lightly loaded bearing systems (such as conveyer systems). It is a once-through system where the waste oil is either collected in cups that are emptied periodically or routed to an oil waste system.

2.2.4.3 Oil/Air Lubrication

This system differs from the oil mist system. A precise measure of oil is supplied to the bearings at a predetermined frequency or interval by air to the oil nozzle. In the oil mist system, the oil appears more like a fog or smoke. This system has the advantages of high-quality oil supplied to the bearing, cooling from the air, and low oil consumption.

2.2.4.4 Jet Lubrication

Oil jet lubrication provides pressurized oil to the bearing by injecting directly into the side of the bearing (that is, between the inner and outer races). This system of lubrication is used under extreme high-temperature and speed applications (such as in jet engines and gas turbines).

3
CONSTANT-LEVEL OILERS

One of the most widely used methods for maintaining proper oil level in bearing reservoirs/sumps is the constant-level oiler. These oilers have been used in lubrication systems for over half a century. Constant-level oilers are designed to maintain oil level in a reservoir/sump at a given level. When installed and maintained properly, they will maintain the proper oil level for years. The use of constant-level oilers can improve maintenance efficiency, minimize maintenance costs, and assist in the prevention of equipment downtime or production loss. The constant-level oiler is simple in design and replenishes oil that may be lost through seals, vents, breathers, plugs, pipe fittings, and so on.

3.1 Description

Constant-level oilers are generally categorized as vented or non-vented. Vented oilers are vented to atmosphere and are the most common type in use. Vented oilers are designed to maintain oil quantity but not quality. Because they are vented to atmosphere, they can be an intake source for contaminants (such as moisture, dirt, or particles). Contamination intake can occur through the vent by the following dynamics:

- Pressure differential between the bearing reservoir and oiler reservoir (for example, ventilation, and motor fans)
- Process fluid temperature changes
- Bearing reservoir temperature changes

Figure 3-1 provides an example of a vented constant-level oiler.

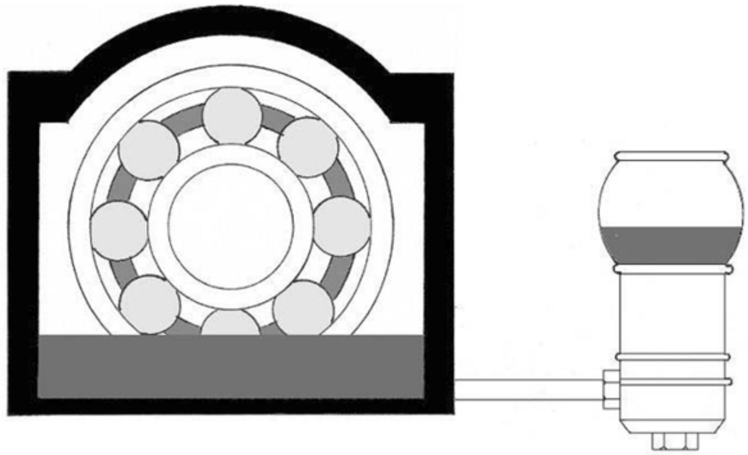

Figure 3-1
Constant-level oiler

Non-vented oilers do not exchange air with the surrounding environment. A non-vented oiler has an equalizing line that connects the base of the oiler to the bearing reservoir atmosphere. Other than the equalizing line, the vented and non-vented oilers operate the same.

The type of oiler that should be used for a given application may depend on one or more of the following factors:

- Operating environment (for example, outside, high humidity, dirty, water, and ventilation)
- Shaft oil seals
- Vents/breathers
- Bearing reservoir/sump design

3.2 Basic Operation

The operation of the constant-level oiler is based on a liquid seal principle. When the fluid level in a bearing reservoir/sump decreases, the seal on the inside of the oiler is broken (that is, the seal and stem rise). This permits air to enter the oiler reservoir through the air vent on the oiler. All oilers—vented and non-vented—require air for proper operation. Oil gravity feeds from the oiler reservoir filling the bearing reservoir/sump. As the bearing reservoir/sump level rises, the oil seal on the oiler closes until the seal is fully closed and the oil level in the bearing reservoir/sump is returned to normal.

3.3 Operation and Maintenance

The keys to proper operation of a constant-level oiler are proper installation and maintenance. If the reservoir oil level cannot be maintained by the oiler, one or more of the following may be the cause:

- Improper/incorrect oiler settings/setup
- Oiler location/setup
- Blocked fittings
- Poor or inadequate filling/sampling practices
- Differential pressure (d/p) (vented oilers)

3.3.1 Settings and Setup

In order to set up an oiler properly, the oil level in the reservoir/sump must be known. The easiest method is by sight glass if installed. If a sight glass is not installed, either the volume of oil required must be known or the level determined by measurement. The normal level should be marked on the outside of the bearing reservoir/sump when determined. Considerations for installation or setup include the following:

- Verify that the oiler is level and parallel in all four directions.
- Connections to the reservoir should be short and rigid to minimize vibration.
- The oil level adjuster mechanism should be adjusted to match the level on the reservoir or by sight glass. (This may require several iterations to obtain the proper level of operation.)
- The bearing reservoir/sump should be filled to normal level (if being filled from the top, allow sufficient time for the oil to drain from internal components to prevent overfilling).
- After oiler installation, the equipment should be run and monitored for proper operation of the oiler. Adjustments should be made as necessary.
- If the oil level is too high, the oiler must be adjusted and the bearing reservoir/sump must be drained to the proper level.

A constant-level oiler is designed to raise the oil level in the bearing reservoir/sump if the level is low, but it will not adjust the oil level lower if it is too high.

3.3.2 Oiler Location

For new constant-level oiler installations, it is important to ensure that the oiler is located properly with respect to shaft rotation. Side-mounted oilers should be placed on the side facing the direction of flow. This protects the oiler from oil reservoir surges that occur during startup and prevents overfilling. The oil is pushed toward the oiler rather than pulled away from the oiler, causing it to open and admit oil. Oil rings or submerged bearings/gears that rotate at high speeds have the potential to form eddy currents or oil turbulence. These can also cause inadvertent operation of the oiler. If either of these two conditions exists, bottom-mounted fittings may be warranted.

3.3.3 Blocked Fittings

When oil oxidizes or becomes contaminated, it is possible for the connection piping to become blocked. This would be especially true for bottom-mounted fittings. During oil changes or equipment overhauls, it is recommended that the oilers be removed and connection ports and piping verified to be clear of obstructions.

3.3.4 Filling and Sampling

When the oil level operating bands are narrow, it is important to have good filling and sampling practices. Filling errors can occur whether filling from the top of the bearing reservoir/sump or oiler surge body or filling too frequently. As it is added from the top of the reservoir/sump, oil may adhere to internal surfaces (such as the bearings, gears, shaft, or oil rings). If oil is added to the normal level mark, an overfill condition may exist after the residual oil drains off these surfaces. If a sight glass is installed, filling through the oiler surge body may be preferred. Without a sight glass, it is possible to overfill the reservoir/sump using this method. An overfill condition can be detected once the oiler reservoir is installed, as indicated by oil flowing out the surge body.

Excessive filling frequencies of the oiler reservoir can also lead to overfill conditions in the bearing reservoir/sump. Each time the oiler is removed, a small amount of oil enters the bearing reservoir/sump. A rule of thumb is to add oil when the oiler reservoir level is less than one-third of the reservoir capacity. Operations and maintenance personnel should be aware of the possibility of this overfilling condition.

Key Technical Point

Each time the oiler is removed, a small amount of oil enters the bearing reservoir/sump. For constant-level oilers, a good rule to follow is to add oil when the oiler reservoir level is less than one-third of the reservoir capacity.

Sampling can also have an adverse effect on the bearing reservoir/sump level and lubrication of the internal components. If a significant quantity of oil is removed quickly, the oiler may not be capable of responding rapidly enough to return the oil level in the bearing reservoir/sump to normal. If this potential exists, it is better to sample the equipment immediately after shutdown (within 15 minutes). If the sample must be taken while the equipment is operating, immediately add the amount removed through the oiler to the bearing reservoir/sump.

Key Technical Point

Sampling can also have an adverse effect on the bearing reservoir/sump level and lubrication of the internal components. If a significant quantity of oil is removed quickly, the oiler may not be capable of responding rapidly enough to return the oil level in the bearing reservoir/sump to normal.

3.3.5 Pressure Differentials (Vented Oilers)

When using a vented oiler, particular care should be taken with respect to pressure differential that may be generated from ventilation or motor coolers. Ventilation systems or motor coolers can establish differentials between the bearing reservoir and oiler reservoir. This can result in over-feeding the bearing reservoir/sump. If the potential for this condition exists, a non-vented oiler may be required.

If the oiler is equipped with a stem that protrudes through the adjustment disks and is capable of being removed, ensure that this stem is installed. This stem breaks the meniscus at the bottom of the oiler reservoir, allowing it to feed properly.

3.4 Routine Maintenance

Constant-level oilers are essentially a low-maintenance component. If maintained properly, they can provide years of satisfactory operation. When the lubrication system receives maintenance, the following activities are recommended to help ensure proper operation of the oiler:

- Inspect/clean reservoir and seals of film and particulate buildup
- Remove oiler surge body and fittings, inspecting ports and piping for any signs of blockage
- Ensure that all oiler parts are installed (for example, the oiler stem and reservoir set screw)

The most likely failure mechanism on the oiler is the failure of the seals. If the seals are determined to be faulty, it is recommended that they be replaced.

4
OIL CLEANLINESS AND CONTAMINATION CONTROL

When components move relative to one another, they require lubrication to operate efficiently and effectively with long life. This also requires that the lubricant be contaminant-free. Contaminants can cause a breakdown in the health of the lubricant and interact with the moving components, causing wear, degradation, and eventual component failure. It is important to know what contaminants can be introduced into the lubricant, how they are introduced into the lubricant, how contaminants are formed, and how they can be removed.

4.1 Measuring the Benefits of Oil Cleanliness

Oil cleanliness plays a significant role in increased production, reliability, and cost savings. When oil cleanliness is properly controlled, a station can expect to extend the life of equipment and components, reduce equipment downtime, and save hundreds of thousands of dollars. Specifically, the benefits include the following:

- Increased equipment availability and reliability
- Reduced maintenance costs (for example, lower cost of oil and less required corrective maintenance)
- Reduction in hazardous waste

In order to achieve these benefits, contamination control must be implemented from the time that the oil enters the station to the end of its life. There are numerous innovative techniques and technologies to control, clean, and monitor oil cleanliness, but none of these is more important than the exclusion of contaminants entering the oil.

The benefits gained from maintaining oil cleanliness are measured in dollars and labor hours. However, it is difficult to measure the cleanliness of oil and the impacts that it may have on the costs and person-hours. Noria has developed several key performance indicators that can be used to assist in determining the ultimate benefits from maintaining oil clean. These key performance indicators include the following:

- **Reliability penalty factor (RPF)**. The RPF rates a piece of equipment based on its criticality to operation, cost of repair (for example, downtime costs and maintenance repair costs), and the effectiveness of oil condition monitoring systems (such as oil analysis). This is a quasi-quantitative measure because it is based on qualitative and quantitative data. Failures are assigned in each of the areas yielding a score between 0 and 10. The RPF is used in the target cleanliness grid (TCG) with the contaminant severity factor (CSF) to determine target cleanliness for a given piece of equipment.

- **CSF**. The CSF is qualitative measure of the sensitivity of a piece of equipment to failure from contamination. The CSF takes into account operating characteristics (such as operating pressure, components, and loading) and contamination that a piece of equipment may be subjected to (such as varnish, water, and particles). The chart is developed for various types of equipment, where each type is rated and a total score of between 0 and 10 is achieved. The CSF is used in the TCG with the CSF to determine target cleanliness for a given piece of equipment.
- **TCG**. The TCG is a matrix with RPF and CSF as its axes. The grid is composed of cleanliness levels established for each RPF/CSF combination between 1 and 10 (for example, RPF = 6 and CSF = 7 would correspond to a target cleanliness of 15/12/9 for a given piece of equipment).
- **Life extension table (LET)**. The LET is devised to determine a multiplication factor for life extension of machinery based on the current oil cleanliness and target oil cleanliness. Each coordinate of the current oil cleanliness and target oil cleanliness provides a life extension multiplier for four different types of machinery or components. The four items are hydraulics/diesel fuel, rolling element bearings, journal bearings/turbo machinery, and gear boxes and other.
- **Overall lubrication effectiveness (OLE)**. OLE is a metric that focuses on variables that constitute effective equipment lubrication—percent compliance to scheduled lubrication PMs (PClpm), percent compliance to contamination control targets (PCcct), and percent compliance to lubricant quality targets (PCqct).

  $$OLE = PClpm \times PCcct \times PCqct$$

  OLE is designed to provide an organization with an overview of how well the organization is lubricating its equipment.

4.2 Oil Contamination and Degradation

4.2.1 Contaminants

Lubricating oils can contain contaminants that are either introduced from the environment or generated within the machine. Contaminants may be in the form of gases, liquids, solids, or semisolids. Regardless of the form, contaminants will have an adverse effect on lubricant performance.

Gases can enter the oil system in different ways and from a variety of sources. The primary gas of concern is air. Potential sources of gas introduction into a lubrication system include air leaks (for example, faulty breathers, fittings, and leaking seals) and process gas.

When gases are present in the oil, the lubrication quality of the oil is affected. A decrease in oil viscosity and an increase in foaming interferes with oil film continuity, which can be observed and lead to bearing failure or other lubrication system problems. If combustible gases are present, the flash point is decreased and the risk of an explosion increases.

The addition of liquid contaminants (water, for example) affects an oil's viscosity, which in turn affects the oil's film thickness, pumping performance, and other properties, depending upon the amount of viscosity change. The simplest method of detection is a viscosity measurement. Liquid contaminants are introduced into the lubrication system by any of the following:

- **Water**. Water contamination comes from two primary sources—leaks in the system and condensation of moisture in the air space. Leaks may be from steam, seals, or gaskets. Water in oil is detrimental to the formation of the oil film and in the promotion of contact fatigue of gear teeth and rolling element bearings. In many systems, water in the oil as low as 0.01% can shorten bearing life substantially. Water contamination may be detected by observing a layer of free water in the bottom of a container of drained oil, or in oil withdrawn from the bottom of a sump. Water may be present if the oil appears hazy or milky.
- **Solvents or process fluids**. Process liquids and solvents interfere with oil film formation similar to water, but most effects are chemical. Process liquid contamination is common in pumps. Initial indication of contamination can be indicated by changes in odor, color, flash point, or viscosity of the oil.
- **Adding the incorrect oil**. The addition of the incorrect oil with a different viscosity will affect oil film thickness, pumping performance, and other properties, depending upon viscosity. The simplest method of detection is a viscosity measurement. If the incorrect oil has different base oil or additives, the initial indication of a problem may be a precipitate due to additive interaction.

Solid particulate may be present in equipment from the operating environment or through oil degradation (wear). Maintenance activities can introduce foreign material into equipment lubrication systems through a variety of activities, such as welding or grinding. Although any solid particulate material can cause damage if the particulate is near oil film thicknesses, they will embed, dent, or abrade surfaces, thus reducing component life.

Semisolid contaminants are usually oxidation and/or thermal polymerization products, carbonaceous material, microorganisms, or oil/additive/water reaction products, and fragments of elastomers. These and other small particulates contribute to varnish and sludge that can collect in pipes, pumps, and orifices, possibly leading to oil starvation.

4.2.2 Oxidation

Oxidation is a chemical aging process of the lubricant that is exacerbated by high temperatures, water, air, and other contaminants. Metal particulate contaminants (such as iron, copper, and lead) increase oxidation rate and attack additives (such as anti-wear, dispersants, and corrosion inhibitors). Oil oxidation is a series of chemical reactions formed within the oil called *free radicals*. As oil degrades, the antioxidant additive package depletes first. The antioxidant additive acts like a sacrificial anode: it is there to protect the base oil from oxidation. The most common antioxidant additive is a phenolic inhibitor that works to neutralize the free radicals that cause oxidation. Following this, the base oil oxidizes.

4.2.2.1 Effects of Oxidation

As the oil oxidizes, it affects the quality of the oil in a variety of ways, including the following:

- The oxidation process produces a number of by-products, including acids. The acid attacks component surfaces, resulting in pitting and surface degradation. This effectively increases the wear rate. Both water as a by-product of oxidation and water from external sources increase the corrosive potential of acid in oil.
- Polymers and oxides are other by-products of the oxidation process that contribute to the formation of varnish. When varnish comes out of solution, it tends to condense onto component surfaces. Varnish deposits that accumulate in the inner surfaces of tanks, pipes, and hoses are chemically active and shorten the life of new oil added to the lubrication system. Particles also tend to stick to the varnish in valves, increasing the valve sticking problem and causing abrasive wear.
- Oxidation affects the physical properties of the oil (such as flow and lubrication characteristics). Oxidation particles suspended in the oil can affect the viscosity of the oil.
- Sludge suspensions produced as a result of oil oxidation provide polar surfaces where active additives (such as anti-wear agents) are adsorbed to the surface of the sludge. This renders the additives unavailable to protect the machine surfaces, which is their intended function.
- As the base oil begins to oxidize and degrade, the interfacial tension properties of the oil start to decline. Oxidation adversely affects the demulsibility properties of the base oil. Water demulsibility is a function of interfacial tension and begins to rapidly decline as the base oil begins to oxidize. Poor demulsibility also adversely influences the filterability of the oil.
- Rapid filter depletion will occur due to varnish deposits and sludge.

Oxidation by-products cannot be filtered directly; however, it is possible to remove oxidation by-products through electrostatic separators or ion exchangers. Removal of these oxidation by-products will slow oxidation. These removal techniques for oxidation by-products can also reduce additives (especially electrostatic separators). If these removal techniques are used, it is likely that the additives will need to be reconstructed. Whether this is possible will depend on the severity of the oxidation problem.

4.2.2.2 Identification of Oxidation

Oxidation has been monitored by oil analysis through trending the acid number (AN), Fourier transform infrared (FTIR) oxidation, and viscosity. As oil oxidizes, organic acids are produced and collect in the oil, causing the AN to rise. FTIR analysis measures the concentration of various organic or metal-organic material present in the oil.

Another method for measuring oxidation is measuring the oil's remaining useful life (RUL). The oil analysis used to determine the RUL was the rotary pressure vessel oxidation test (RPVOT) from ASTM D2272. This test was complex and expensive. As a result, this test was typically only performed on more expensive, critical, or high-volume oil systems or equipment (such as turbines). A newer test that is easier and less expensive to determine RUL is the linear sweep volammetry (see ASTM D6810-02).

The premise behind measuring the RUL of the oil is to be able to take corrective measures before the base oil begins to degrade significantly from oxidation. Before the base oil begins to significantly degrade, measures can be taken to improve the additive package. When the oxidative additives have depleted and significant base oil degradation takes place, the oil must be changed out or significantly treated to prevent the undesired effects of oxidation. If additive replenishment is used before significant base oil oxidation occurs, it should be coordinated with the lubricant manufacturer.

4.2.3 Water

Water in a lubricant is one of the most detrimental contaminants in a lubrication system. It can have significant consequences, reducing machine life by corrosion of materials, and can lead to oil oxidation, varnish, and changes in oil viscosity. It is more complex and intense than other contaminants. Water-induced problems affect both the lubricant and the machine. Failure can occur through numerous mechanisms, and the damage can occur slowly or rapidly. It is a serious problem than can result in significant revenue losses due to lubricant degradation, shortening the life of machine components and equipment downtime. Its effects should not be underestimated.

Water is present to some degree in all lubricants. Some lubricants (or the application of the lubricants) are less tolerable to water than others. Water levels at less than 500 parts per million (ppm) can shorten component (for example, bearing) life. Problems have been noticed at water levels as low as 200 ppm. It is important to recognize when water is present, to take the appropriate corrective actions to address the water in the lubricant, and to take any corrective measures to address all sources of ingress of water into the affected equipment.

Water also introduces oxygen into the lubricant that can increase oxidation rates and contribute to thermal degradation.

It is important to understand the states of water, potential sources of water, water effects on lubricant and machine, tests for water, and the corrective measures that should be taken when water is discovered in the lubrication system.

4.2.3.1 States of Water in Lubricants

It is common knowledge that oil and water do not mix; however, water is present in every lubrication system to some small degree. Dry oil will absorb water if the air is humid. Water may be present in one or more states—dissolved, emulsified, or free. Dissolved water exists in the lubricant at a level below saturation point of the lubricant. Water dissolved in the lubricant is at the molecular level and is not visible to the eye. A lubricant can contain a significant level of water in the dissolved state with little indication that it is present. The amount of water that can be contained by a lubricant in the dissolved state will vary by lubricant base stock, age of the lubricant, additives, and temperature. Higher viscosity oils can have saturation points from 500 ppm to 750 ppm. Extremely low-viscosity oils may have saturation levels below 50 ppm. Extreme pressure additives can increase the amount of dissolved water in oil.

As the amount of water increases in the lubricant, the water content reaches a level where it no longer exists in the dissolved state. The molecular water droplets combine, and the water becomes saturated with small droplets. These droplets will remain suspended in the lubricant. The water lubricant mixture forms an emulsion. This emulsion can also be formed from any free water in the lubricant because of the shearing action of the lubricant in pumps, gears, and so on where the free water is broken into small droplets that again become suspended in the lubricant. This emulsified condition of the lubricant can be determined visually by the lubricant having a cloudy or hazy appearance.

As the water level concentration increases or temperature of the lubricant decreases beyond the saturation level of the lubricant, water droplets form and combine. This results in free water in the lubricant. If the lubricant water mixture is left to stand, the water will fall under the influence of gravity and two distinct layers—water and oil—will be visible. The lubricant can contain a mixture of emulsified and free water. The two most detrimental states of water in a lubricant are emulsified and free water. The determination of how much water is too much before action is required may be subjective; however, if the lubricant is emulsified to the point where it is cloudy, there is too much water in the oil and the water should be removed or the lubricant replaced.

Water must be present for corrosion to occur. Regardless of the state of water in the lubricant, it can pose a problem. Free water will settle on any machinery surface. It will degrade or remove the surface protective oil film and lead to corrosion. Dissolved or emulsified oil can also lead to corrosion. When dissolved or emulsified oil is heated due to process heat, frictional heat, or hot spots, it can vaporize. As the oil is transferred to cooler regions in the lubrication system, it can condense to free water and lead to corrosion in those areas.

4.2.3.2 Sources of Water

The best way to prevent water contamination of a lubricant is to prevent its intrusion into the lubrication system. Trying to completely eliminate water sources would be impractical, but the sources can be controlled and minimized. Water can enter a lubrication system through a variety of sources, and it is important to understand where water intrusion may occur and to control those sources where possible. Some potential water sources or processes are the following:

- Oil storage tanks: these tanks breathe with changing temperatures (for example, day-to-night temperature changes), taking in air that contains moisture that eventually condenses in the lubricant.
- Ventilation openings in tanks (such as vents, reliefs, breathers, and loop seals).
- Operational by-products (such as water vapor from diesel combustion and air compressor blow-by gases).
- Leaking cooling systems (such as heat exchanger tubes, plates, tube sheets, and poor seals).
- Lube oil return line vents.
- Rotating equipment seals (such as oil seals and labyrinth seals).
- Poor lubricant storage practices.

- Poor lubricant transfer practices.
- Malfunction of oil treatment systems.
- Equipment wash-downs.

4.2.3.3 Effects of Water Contamination

Water contamination affects the lubricant, the machine, and its components. The effects that may be observed include lubricant effects—additive depletion, oxidation, increased compressibility, viscosity changes affecting film thickness and lubricating qualities, bacterial growth, hydrolysis, and lubrication starvation due to blockage. Other effects are machine/component ones—corrosion, wear (abrasion, adhesion, or fatigue), hydrogen embrittlement, shortened oil filter life, shortened bearing life, erosion wear, and hard water deposits.

4.2.4 Thermal Effects

Temperature stability is essential to the reliable operation of mechanical systems. Both high and low temperatures may affect mechanical system operation. Temperature stability may be affected by a machine's design or application and operational duty. A machine has sources for generating heat (for example, frictional bearings loads, fluid friction, and orifice restrictions). Thermal degradation is the chemical change in the base stock oil that results when the oil is subjected to high temperatures. High oil temperature also promotes oxidation. When oil gets hot and breaks down, it gets darker in color and will have a distinct odor.

Heat can be introduced into the lubricant by a variety of means, many of which are associated with the normal operation of the machine. These include the following:

- Improper lubricant level (oil or grease)
- Friction heating (fluid, sliding, or rotational)
- Heat conducted from process fluid along the shaft
- Seal failures
- Lubrication cooling system failures

Lubrication cooling systems are used to control the temperature stability of the lubricant. Typically, they are used to remove excess heat generated during operation, but they can also be used to control environmental low-temperature conditions. Heat exchangers—either water or air-cooled—may be used to satisfy temperature stability. Water heat exchangers are more useful over a wider range of temperatures but are susceptible to leaks that may introduce water to the lubrication system if the water pressure is higher than that of the lubrication system. If the oil pressure is higher than the water pressure, there is the potential for environmental concerns unless the system is a closed system. Air-cooled heat exchangers require the oil temperature be at least 10 to 15°F (-12.2 to -9.4°C) higher than the air temperature to be efficient.

Specific mechanisms that can result in thermal degradation of the lubricant include the following:

- Hot spots
- Micro-dieseling
- Electrostatic spark discharge

The temperature at which the lubricant is controlled can have positive and negative results. Temperature control is a critical aspect in maximizing the useful life of bearings. Advantages of running oil (not excessive) include better water shedding and vaporization properties, better foaming (aeration) tendency, and an improved setting rate of particles. Disadvantages include the following:

- Increased oxidation, corrosion, and potential for thermal degradation
- Varnish and sludge formation
- Lower viscosity (reduced film strength)
- Additive depletion

Maintaining the temperature stability of a lubricant is essential to maintaining both lubricant and machine. Temperature stability problems that are not addressed promptly will result in premature aging of the oil and potential damage to the equipment. Temperature effects can occur at low and high temperature. If lubricants are allowed to operate at low temperature, the viscosity will increase. It is possible that the temperature can go low enough to the point that the lubricant congeals and no longer flows. High temperature has several effects, including the following:

- Increased oxidation
- Additive depletion
- Reduced film thickness
- Increased wear rates
- Effect on machine performance (such as high vibration levels)

Low-temperature conditions in the lubricant are a result of a failure in the cooling/heating system of the lubrication system or environmental conditions. As the temperature drops, the viscosity of the lubricant increases. If the temperature is low enough, the lubricant can congeal to the point that it no longer flows. In forced circulation systems, the pumps will not be capable of drawing adequate suction to provide lubrication. This can result in lubricant starvation and lead to high mechanical and frictional loads generating heat. This will lead to damage and/or catastrophic failure of the bearing and journal surfaces.

High temperatures, which typically result from coolant system failures, can lead to poor system performance and the rapid degradation of both the lubricant and the machine. Lubricants that are exposed to high temperatures can suffer irreversible damage. Viscosity changes, oxidation rates, contamination by-products, and increased wear are all affected by temperature changes.

Viscosity changes affect the lubrication film, and loss of this film leads to increased wear. Oxidation rates increase with temperature. A rule of thumb is that oxidation rates double with every 18°F (10°C) of increase in temperature. Increased oxidation produces more insoluble by-products that affect both the base oil stock and the additives package, reducing the effective life of the lubricant.

Key Technical Point

A rule of thumb is that oxidation rates double with every 18°F (10°C) of increase in temperature.

4.2.5 Varnish and Sludge

Varnish and sludge are two by-products of oil degradation caused by oxidation and thermal degradation. These insoluble by-products adhere to any metal surface in the lubrication system (such as pipes, strainers, valves, heat exchangers, bearings, and journals). Turbine applications are less tolerable to varnish buildup than most other lubricant applications. Steam turbines and electrohydraulic control (EHC) systems are sensitive to varnish formation, but gas turbines are especially sensitive to the formation of varnish. The most frequent performance problems with lubricant varnish in gas turbines are startup failures and unit trips. Varnish buildup takes place in the turbine oil systems and will lead to turbine failure if undetected and untreated, resulting in a significant increase in maintenance costs; it might result in unplanned outages. There are several negative effects to turbine lubrication systems, including the following:

- Control valve reliability
- Heat exchanger performance issues
- Premature filter and strainer plugging
- Aggressive wear rates on bearings and valves
- Reduced heat transfer
- Deterioration of the turbine oil

Varnish has the potential to form on all oil-wetted surfaces; however, the most common areas are valves, filters, strainers, heat exchangers, bearing surfaces, and reservoir walls. Varnish buildup on bearing surfaces can result in the lubricant regime transitioning from full-film to boundary lubrication. Other performance problems are decreased cooling capacity of heat exchangers, component corrosion from the acidic nature of varnish, decreased filter life, and plugging of oil orifices.

Varnish is caused by either thermal degradation or oxidation of the lubricant. Varnish is an insoluble film composed of by-products from oxidation and thermal degradation that coats the internal surfaces of a machine. Varnish builds up on surfaces over time. It is easy to identify by its golden color that is evident on piping, calves, journals, bearings, and so forth. It forms as a soft, insoluble material that sticks to metal surfaces and is not typically removed by normal oil system flows. In cooler regions, the film will remain as a soft, sticky grease-like substance. With time this soft sticky film will catch fine particles contained in the oil to form an abrasive surface. As with most oxidation reactions, elevated temperatures increase the oxidation rate. In high-temperature regions, the film can thermally cure to an enamel-type coating.

4.2.5.1 Varnish Detection

The sooner varnish is detected in turbine oils, the better the chance of saving the oil and avoiding expensive equipment wear. Varnish detection is not normally accomplished through routine oil analysis testing. FTIR, colorimetric analysis, and other tests have been successful in determining the potential for varnish formation. A brief summary of what these tests can provide with respect to varnish detection follows:

- The FTIR test is used to detect various degradation by-products found in the oil that cause absorptions in specific regions of the FTIR spectrum. Increasing absorption peaks in the 1630 cm^{-1} region are an indication that oxidation is taking place and that a high potential exists for varnish formation.
- A colorimetric test analyzes for insoluble contaminants in the oil, indicating the severity of the varnish problem.
- An RUL test is used to determine how much life is left in the antioxidant additives. RUL tests can detect a varnish problem before the oil degrades to the point of needing to be replaced.
- The ultracentrifuge test (gravimetric test) uses gravity to force varnish-forming insoluble contaminants to the bottom of a test tube. The amount of contaminants is assigned a rating that corresponds to the varnish-formation tendency.

Another method of determining the susceptibility of a lubricant to varnish is the Quantitative Spectrophotometric Analysis[1] (QSA).

The changes in lubricant quality are similar for both oxidation and thermal degradation. However, thermal degradation does not require oxidation to occur. It requires only excessive heat that can be a result of localized hot spots or micro-dieseling. An FITR analysis can assist in differentiating between oxidation and thermal degradation. Oxidation levels are typically seen in the 1714 cm^{-1} range, whereas thermal degradation is identified by peaks in the 1630 cm^{-1} range (nitration area).

4.2.5.2 Varnish Removal

Varnish that has adhered to surfaces cannot be removed by dumping and recharging the system with new fluid. Not only will the varnish remain within the system, but the varnish may act as a catalyst to oxidize a new fluid charge.

[1] *Quantitative Spectrophotometric Analysis* is a registered trademark of Analysts, Inc.

Electrostatic oil cleaners are capable of removing varnish precursors from oil. They are proven to have a positive impact on the lubricant's ability to resist oxidation, provided that antioxidants are still present in the oil. In addition, electrostatic oil cleaners are capable of removing insoluble oxidation by-products from the internal surfaces within a lubrication system.

Varnish buildup is inevitable in turbine oil lubrication systems. It will occur, even in well-maintained systems using thermally robust oils. With time, varnish will build up on bearings. When bearings are contaminated, they can be cleaned with solvents, kerosene, or mineral spirits. After cleaning, the bearings should be handled carefully because they are susceptible to damage and corrosion and should be lubricated as soon as practical. Observe the following guidelines:

- Do not handle with bare hands.
- Do not spin unlubricated bearings.
- Avoid subjecting unlubricated bearings to vibration.

4.2.6 Air Contamination and Foaming

Foaming, a problem that may exist with oil-lubricated equipment, is often overlooked. Foam is a collection of air bubbles (~ 1 mm in diameter) that accumulate near or on the surface of the lubricant. Air bubbles (~ 0.5 mm in diameter) in the lubricant also contribute to oxidation and reduction in lubricant properties. Foam is also an efficient thermal insulator, making it difficult to control lubricant temperature.

Similar to water, air can exist in three phases—dissolved, entrained, and foam. Air in the dissolved phase exists at the molecular level. Air that is entrained in the oil is in the form of tiny bubbles suspended in the oil. When the air bubbles come out of suspension and accumulate at the surface, they are referred to as *foam*.

Controlling the amount of air contamination in the lubricant will improve the life of the oil and the performance of the lubricated equipment.

4.2.6.1 Causes

There are several paths that can lead to air entering the lubrication system. It is not possible to eliminate all sources, but it is possible to control many of them. Air can enter lubrication systems through in any of the following ways:

- Aeration of lubricant due to mechanical problems (for example, breather caps and loose fittings [suction piping])
- Over agitation (such as high oil levels in bearing reservoirs, oil bath, and splash systems)
- High drain flows (for example, air is pulled into bearing housing)
- Incompatible lubricant mixes (for example, additive depletion; inhibits defoamant from working properly)

- Depleted foaming additive (for example, excessive filtration and electrostatic filtration)
- Excessive defoaming additive (for example, bad formula, sweetening of oil in bearing reservoir, defoaming additive, or silicon leaching from seals)
- Water in the lubricant (alters the surface tension of the lubricant, allowing bubbles to be more easily suspended)
- Particulates in the lubricant
- Temperature impacts (such as when temperature affects viscosity, which can impact foaming)
- Maintenance activities (for example, contaminants introduced through oil changes, poor foreign material exclusion practices, cleaning materials [solvents], transfer operations, and filling and venting of lubrication system)

When considering breather cap selection, several factors should be considered: the operating environment (for example, presence of dirt, dust, or humidity), the contamination history of the lubrication system, and the operational criticality of equipment (consider the consequences of lubricant or equipment failure).

4.2.6.2 Problems with Foaming

Foaming can have an adverse effect on both the lubricant and the machine being lubricated. When foaming is excessive or a stable foam is reached in the lubricant, effective lubrication may not be achieved. Serious foam conditions may lead to premature failure of the lubricant and the equipment lubricated. Foam in the lubricant is a problem that warrants correcting if any of the following conditions exist:

- Equipment is being lubricated by foam versus lubricant (such as reduced heat transfer, increased wear, reduced heat removal, or reduced film strength).
- Temperature control is difficult to maintain as a result of reduced heat transfer capability (this may also contribute to increased lubricant oxidation and thermal fatigue or degradation by micro-dieseling in the presence of large bubbles).
- In a forced circulation lubrication system, foam results in air binding of lubrication lines or pumps.
- Depleting anti-foaming additives.
- Decreasing oil reservoir oil levels or difficulty in controlling level.

4.2.6.3 Resolving Foaming Issues

It is hoped that testing results will narrow the troubleshooting required. Generally, foaming problems are corrected by performing partial or full oil changes. If foaming is a result of contamination, a complete oil change will be required, including a flush of the system prior to refilling the system with new lubricant. The flush is required because a drain will not effectively remove contaminants from piping or other surfaces. This may be a simple and inexpensive process for low-volume oil systems, but for large-volume systems, it can become very time-consuming and expensive. It is also imperative that the source of the contamination be identified and corrected.

If the foaming is not a result of contamination and testing has shown the lubricant to be in relatively good condition, reconditioning of the lubricant may be a viable option. This is not always a beneficial solution. Depending on the reconditioning methods used, the characteristics of the lubricant may change because of removal of additives.

Defoamants are added to the base lubricant stock to inhibit or minimize foaming. A common defoaming agent is silicon. A good defoamant will not dissolve in the lubricant, possesses a surface tension lower than the base lubricant stock, and disperses as small droplets throughout the base lubricant. Always consult the original equipment manufacturer (OEM) before adding defoamants to the lubricant.

4.2.7 Radiation

Lubricants that may be exposed to radiation fields must satisfy the basic requirements of a lubricant and radiolysis. All lubricants undergo some degree of radiolysis when exposed to a radiation field. Lubricants may vary greatly in their ability to resist radiation effects. The resistivity to radiation effects can depend on the base oil stock (such as mineral oil or synthetic) and additives (such as anti-oxidants and anti-wear).

In general, the base oil is the limiting factor with regard to radiation resistance. However, additives suffer radiation damage and can affect the radiation resistance of the base oil. Some additives will break down under radiation at radiation levels lower than the level at which base oil degradation occurs.

Most base oil stocks are capable of performing at radiation levels below 10^8 rads. Some synthetic oils are capable of performing at radiation levels up to 10^9 rads. Greases can provide satisfactory performance at levels up to 10^7 rads. Grease tends to soften initially and then harden when exposed to excessive radiation fields.

More detailed information related to radiation effects on lubricants can be found in the EPRI report *Lubrication Guide* (1019518).

4.2.8 Biological Contamination

Growth of microbes such as bacteria, algae, yeast, and fungi can occur in lubricating oil systems contaminated with water. This contamination would be more typical in oil systems that are in a layup status versus systems in operation. The severity of microbial contamination is increased by the presence of air. Microbes vary in size from 0.2 µm to 2.0 µm for single cells and up to 200 µm for multi-cell organisms. If conditions are favorable, bacteria reproduce exponentially. If biological contamination is not detected early, bacteria may grow into an interwoven mass that will clog the system. A large quantity of bacteria also can produce significant waste products and acids capable of attacking most metals and causing component failure. In the worst situations, the growth of organisms can reach the consistency of a slime or mayonnaise-like material. This can result in plugging filters, small orifices, or clearances, and it can contribute to corrosion in the oil reservoir or sump. To most effectively control biological contamination, remove water from the system.

Lubricating oils are susceptible to biological deterioration if the proper growing conditions are present. Biological contamination is a problem in lubrication systems when the temperature of the lubricant is greater than 104°F (40°C) and less than 68°F (20°C). Between these temperatures, rapid biological attack can occur, especially in the presence of water. Procedures for preventing and coping with biological contamination include cleaning, addition of biocides, frequent draining of moisture from the system, and avoiding dead-legs in system piping. One of the best strategies for controlling biological contamination is to control the water in the lubrication system.

Biological degradation of a lubricant forms acid products that aid in oil oxidation. It can also have an adverse affect on additives. Over time, this may lead to the formation of sludge or other deposits. It can cause premature filter failure and block small lubricant passageways, such as orifices.

4.3 Control Measures

4.3.1 ISO Cleanliness Code

Particulate contaminants that are present in a lubrication system can reduce lubricant efficiency, accelerate component wear, increase operating costs, and cause significant equipment downtime. Equipment lubrication systems will have distinct levels of cleanliness that will achieve optimum life for both the component and the lubricant. Contaminants that are not visible to the naked eye can cause extensive damage if they are not properly controlled.

The best approach to minimizing particulate contamination in the lubricant is to prevent its introduction into the system. It is far easier and more cost-effective to prevent the introduction of contamination than it is to clean up the particulate after it has entered the system. This is best achieved through the proper storage, handling, and transfer of lubricants as well as maintaining equipment components (such as breathers and seals) to minimize the ingress of contaminants into the system.

In 1999, the International Standards Organization (ISO) developed a code system for the measurement of particulate contaminants in a lubricant called the *ISO cleanliness code*. The code is based on the quantification of particulate levels in a milliliter for three distinct sizes—4 µm, 6 µm, and 14 µm. The ISO cleanliness code is a three-number designation—4 µm/6 µm/14 µm. Table 4-1 provides the ISO cleanliness codes and the corresponding particle sizes. From Table 4-1, it can be seen that the particle size doubles for each increase in ISO cleanliness number. It is important to note that it is possible to have very large increases in particle count for a small change in ISO cleanliness number, especially when the ISO cleanliness number is toward the higher ranges (for example, 20 or higher).

Table 4-1
The ISO cleanliness code

ISO 4406:1999 Code Chart		
Range Code	**Particles per milliliter**	
	More Than	**Up to/Including**
6	0.032	0.64
7	0.064	1.3
8	1.3	2.5
9	2.5	5
10	5	10
11	10	20
12	20	40
13	40	80
14	80	160
15	160	320
16	320	640
17	640	1300
18	1300	2500
19	2500	5000
20	5000	10000
21	10000	20000
22	20000	40000
23	40000	80000
24	80000	160000

There are no set cleanliness limits for specific components. Most cleanliness limits are based on OEM recommendations and proactive measures taken to monitor, control, and maintain target cleanliness levels. Table 4-2 provides some general targets for typical components that may be lubricated at a nuclear station. These values are provided for guidance rather than recommendations. When provided, OEM recommendations should be established as a minimum cleanliness target.

Table 4-2
Target ISO codes for components

Component	ISO Target
Ball bearing	15/13/10
Roller bearing	16/14/12 or 16/14/11
Journal bearing	17/15/12 (High or low speed)
Diesel engine	17/16/13
Steam turbine	18/15/12
Gearbox	17/15/12

It is often a “tough sell” to justify the time and expense of a lubrication program, especially when the particles you are controlling cannot be seen. The evidence of their destructive nature follows the equipment downtime, loss of revenue, and increased operating costs. However, the cases for establishing appropriate cleanliness targets for equipment can provide potential benefits in multiple areas. Results may take time, but in the long run, they will be realized. Some benefits may include the following:

- Reduced expenses for parts replacement and lubricant
- Lower maintenance labor costs
- Improved equipment reliability and more effective maintenance control
- Extended service life of lubricants
- Reduced costs for used lubricant disposal
- Minimized unplanned equipment downtime
- Reduced maintenance costs and labor

Keep in mind the objectives, maximizing equipment reliability and safety, minimizing repair and replacement costs, extending useful fluid life, satisfying warranty requirements, and minimizing production downtime are attainable goals. After target ISO cleanliness codes are set, following a progression of steps to achieve that target, monitor it, and maintain will produce the desired effects.

The following steps may be taken when establishing cleanliness levels for lubrication systems:

1. Identify the most limiting or sensitive component in the lubrication system.
2. Set the ISO cleanliness target (using OEM recommendations, operational experience, and so on).
3. Establish a program to monitor lubricant.

4. If targets are met, continue with program.
5. If targets are not met, the program will require modification (such as by changing filter size, increasing filtration flow rate, adding a bypass filtration system, or changing storage, handling, and transfer methods).

All components can accept some degree of contamination before failure may occur. Most OEM vendors will provide guidelines as to the recommended cleanliness standard for their equipment. The following considerations can assist in establishing ISO cleanliness targets:

- What operating pressure of load will be experienced?
- What is the duty cycle of the component—continuous, intermittent, or standby?
- What is life expectancy (for example, of the component or lubricant)?
- What is the replacement cost of the component (in terms of parts, labor, and so on)?
- What is the operational cost or impact of lost generation, replacement power, and so on?
- What is the safety impact (consider regulatory, personnel safety, and so on)?
- What is the operating environment (variables include humidity, water, steam, dirt, and dust)?

4.3.2 Filtration

Filters are the preferred destination for contaminants and wear mechanisms.

Many factors influence the filterability of oil, some of which include the following:

- High viscosity
- Concentration of solid particulate
- Insolubles (oxide and carbon)
- Additives
- Temperature (affects viscosity)
- Flow rate (low flow rates produce lower pressure drops across the filter)
- Filter media type (pore density and fiber diameter size)
- Filter size (surface area)

4.3.2.1 Filter Selection

Selection of the proper filter for a given lubrication system is important to maintaining the cleanliness of the lubrication system within desired specifications. The following sections cover some of the considerations that should be made when selecting filters.

4.3.2.1.1 System Operating Information

Filters should be selected to ensure proper filtration and equipment protection under a variety of operating conditions, such as flow, pressure, and temperature. Filters should be capable of providing sufficient flow capacity and withstanding surge flows at the desired filter micron size. They should also be capable of withstanding viscosity changes as a result of any changes in the lubricant temperature.

Consider the operating environment of the filter. Will it be located in areas with high airborne contaminants, high temperatures, or other adverse conditions? What is the accessibility for maintenance?

In general, a better filter is the best choice when compared to system wear that could result from the use of a poor-quality filter.

4.3.2.1.2 Cleanliness Criteria

A general rule is that new lubricant cleanliness should be at least two ISO cleanliness numbers below the equipment's target level.

Key Technical Point

A general rule is that new lubricants should be at least two ISO cleanliness numbers below the equipment's target level.

4.3.2.1.3 Filter and Housing Size

Filters are generally chosen to meet certain cleanliness criteria that necessitate the size and pore rating of the filter as well as the lubricant viscosity over a range of temperatures.

Filter selection also should consider the filter housing. When choosing a filter housing, several characteristics should be considered—size (larger filter elements), pressure rating (accommodate highest pressure surges), and ease of filter element changeout and connections (flanged or threaded). Other options that may be considered when choosing a filter housing include drains, magnetic particle collectors, and thermal bypasses.

4.3.2.2 Filter Specifications

Filters can be classified by nominal or absolute ratings. A filter with a nominal rating has an efficiency between 50% and 95%, whereas a filter with an absolute rating has an efficiency greater than 98%. An absolute filter or filter medium has an extremely high collection efficiency for sub-micrometer size particles, so that, essentially, all particles of concern are collected. The efficiency of the absolute filter can be 99.95% or higher. The absolute filter is usually a membrane-type filter with an array of holes of nearly identical size. An absolute filter rating specifies the size of particle above which no particle of any size will pass. They are generally a low-capacity filter and clog easily. Most oil filter applications do not require absolute filters.

The most common specifications with regard to filters are the β-ratio and efficiency. The β-ratio, determined by ISO 4572 test procedure, is the ratio of the number of particles upstream of the filter compared to the number of particles downstream of the filter for a given particle size. For example, if a 1-μm filter has a β-ratio of 80, there will be 80 more particles greater than 1 μm in size on average for every 1-μm particle downstream of the filter.

Filter efficiency is calculated from the β-ratio:

Filter efficiency = [(β-ratio – 1)/β-ratio)] * 100

For the preceding example,

Filter efficiency = [(80-1)/80)] * 100 = 79/80 * 100 = 98.75% efficient

The β-ratio does not tell the full story with regard to a filter's operating conditions—temperature and pressure effects are not accounted for by the β-ratio. It also does not take into account that the efficiency of the filter changes during use due to filter loading.

4.3.2.3 Filter Materials

Filters may be made of several different materials. Two of the more common are cellulose and fiberglass. A comparison of these filter materials and some of their desired properties is provided in Table 4-3.

Table 4-3
Cellulose vs. fiberglass filters

Filter Quality	Cellulose	Fiberglass
Particle size	Good	Better
Water removal	Good	Negligible
High temperature	Subject to high-temperature failure	Tolerates high temperature
Pore size	Inconsistent; fewer pores	Consistent; more pores
Dirt-holding capacity	Good	Better

Water absorption filters are typically composed of an element that has the ability to remove particulate as well as water. They are designed to remove only small amounts of water. If there are large amounts of water in the system, other removal techniques should be used. Water filters are sensitive to flow and are more efficient under low-flow conditions. For this reason, water filters are used in off-line filtration systems.

The effectiveness of the filtration system depends on several factors, including the following:

- Quality of lubricants used.
- Storage of lubricants.
- Lubricants are filtered during transfer.
- Contamination control devices are properly installed, properly maintained, and verified to be properly operating.
- External and internal leakage paths are identified and corrected promptly.
- The lubrication system is properly maintained.
- Flushing activities are performed properly and thoroughly.
- Filters used are capable of meeting all OEM specifications.

The oil oxidation reaction results in the addition of oxygen to the base oil molecules to form a number of different chemicals species, including aldehydes, ketones, hydroperoxides, and carboxylic acids. The most noteworthy of the reaction by-products are the carboxylic acids. In strength, they are similar to common household vinegar, containing carboxylic acid, an acetic acid. Because oil oxidation results in the formation of carboxylic acids, the acidity of an oil will increase. The AN test can be used to determine the degree to which an oil has oxidized. A steady increase in the acidity of a lubricating oil is an indication that oxidation is occurring. A sudden increase is an indication of contamination by an outside source.

Organic acids from oil oxidation, if not neutralized, degrade oil properties and cause acidic corrosion. Babbitt bearings and the steel in rolling element bearings are susceptible to this corrosion. When oil analysis indicates a steady rise in AN, an oil change may be required. Oil that is badly oxidized could have an AN two to three times higher than the fresh oil reference.

Although carboxylic acids by themselves are detrimental to the oil causing acidic corrosion, an increase in the AN is typically a precursor to the formation of sludge and varnish. Sludge and varnish form when oxygenated reaction by-products, such as hydroperoxides and carboxylic acids, combine to form larger molecular species.

Antioxidants used in oils to reduce oxidation and minimize sludge and acid formation are usually tin compounds, such as tin dioxide, tin tetraphenyl, and tin ricinoleate. Tin dust alone also has an inhibitory action. Absorption, such as fuller earth or activated alumina, are commonly used to lower acids levels in oil.

4.3.2.4 Filter Changes

Filter elements are typically changed out based on OEM recommendations. How effectively and efficiently a filter is performing its function can be determined by performing a particle count.

In most cases, filters are cleaned or changed out based on the d/p across the filter. Filter d/p limits are chosen to minimize or prevent rupture of the filter element. Filter d/p should be observed during routine inspections and trended. A sudden drop in d/p indicates that the filter has ruptured.

The use of d/p for filter change-out is generally accepted. However, it is not necessarily an indication that the filter is performing properly. Filters can bypass flow for many reasons. For example, the filter may have defects (in end caps, seams, and so on). The filter element may not be seated properly in the housing. Particle analysis should be performed to check for proper filter operation.

It is not possible to completely drain a lubrication system. Some residual amount of old oil will remain in the system. The amount that remains can depend on the size and the configuration of the system. The amount of oil that can be drained can be improved by draining the system while it is still hot.

When changing filter elements, if a drain is supplied on the housing, the housing should be drained through this port prior to removing the filter element. If the element is removed from a housing that is full of oil, partial washing or wiping of particles and debris may occur, leaving this in the housing upon installation of the new element.

When systems are highly contaminated, there may be a desire to change to a coarser filter to minimize filter changeouts. Longer filter life should not try to be achieved by using coarser filters; it is better to use larger filters of the same quality and micron size.

Important information can be gained from a filter after it is removed to assist in determining the state of the lubrication system. If lube oil conditions warrant, the filter should be sectioned and the captured particles recovered for analysis.

Another useful metric is to chart the periodicity of filter changes. If filter changes are replaced based on meeting certain criteria (for example, d/p), changes in filter changeouts may be indicative of degrading lubricant conditions.

4.3.2.5 Filter Systems

After oil passes through a filter unit, the clean oil is sent back to the reservoir or tank, where it mixes with unfiltered oil in the reservoir. Because of this dilution effect, it is necessary for the oil to make several passes through the filter unit. A typical number of passes through the filter skid to ensure that the oil is cleaned to acceptable levels is seven. If the volume of the tank and the flow rate of the filter system are known, it is possible to determine how long it will take to achieve desired cleanliness levels (for example, approximately seven half-lives).

A full-flow/in-line filtration system is a closed-loop, forced-flow system. It is designed to provide a positive flow of oil to all lubricated components under normal and abnormal conditions. The system must maintain an adequate oil volume at the required pressure and flow. All of the lubricating oil passes through the filter media prior to passing to the lubricated components. Oil is drawn from the reservoir by a pump (centrifugal or positive displacement). The oil then passes through a strainer (if installed, it may be installed after the cooler). If a strainer is installed, it is protected by a relief bypass line in the event of high d/p across the strainer. The oil then passes to the filter, which may be of single or duplex design. In many cases, the filter media is of depth design, increasing the surface area for filtration. The filter is also protected by a relief bypass line if filter d/p is too high. Oil then passes through a cooler prior to entering the machinery for lubrication of the machine's components. Oil is returned to the reservoir by gravity feed. The main advantage is that all of the oil going to lubricated parts is filtered. The main disadvantage is the limit on particle size of the particles that are filtered.

Because of the limitation on the particle size that can be removed by the full-flow filtration system, a bypass/kidney loop filtration system is often used to remove finer particle size and to polish the oil.

When full-flow filtration is not an available option, off-line filtration should be considered. Off-line filtration has several advantages, including the following:

- It can be taken in and out of service while equipment is operating.
- Maintenance can be performed without affecting equipment operation.
- It can be used to filter system contents prior to placing the main lubrication system in service.
- Flow can be adjusted and maintained to meet needs without impacting the equipment of the main lubrication system.
- It can be placed in service with equipment shutdown, ensuring clean oil at startup.

Off-line filtration of oil systems is generally performed using a filter cart or skid. Filter carts are a valuable asset in keeping lubricants clean. They are capable of maintaining the oil clean without interfering with the operation of the equipment. It can be used as an economical off-line filter system for tanks or reservoirs, filtration of lubricants during transfer, or filtration of lubricants during emergency situations. Filter carts should contain filters for particle removal, and under certain conditions, water removal filters should be used. If possible, filter carts should be dedicated for each type of lubricant.

A common kidney-loop filtration system used in the nuclear industry is the Turbo-TOC.[2] These filtration units are available in a variety of flow rates (1–100 gpm [4–379 lpm]) and reservoir cleanup capacities (120–12,000 gal [454–45,425 l]). The units are self-contained and can be installed as fixed equipment or used as mobile units. They are used to remove both particulate and water contamination and typically achieve cleanliness levels of ISO 16/13 for particulates and water removal (free and emulsified) to 25 ppm or 150 ppm total water.

Regardless of the size of the filtration skid, all units operate similarly, with only minor differences in components. The filtration unit is described as a kidney-loop pressure coalescence filtration system. A skid-mounted pump takes suction on the oil reservoir where the oil passes through a basket strainer prior to the suction of the pump. The strainers are instrumented to

[2] *Turbo-TOC* is a registered trademark of Kaydon Filtration.

monitor strainer cleanliness with a warning light and automatic shutdown. Flow is also monitored, and the system will shut down on a low flow condition. The oil passes through a heater that is capable of heating the oil and maintaining it above 70°F (21°C). Depending on the size (flow rate) of the filtration unit, two or three can be used in the filtration process. The first filter is a multi-element pressure particulate filter. Each filter element is protected by an internal bypass valve. The second filter is a multi-element filter composed of coalescent and separator elements. Coalesced water settles by gravity to the bottom of the filter vessel. The water level is monitored by sight glass. Water can be drained automatically or manually. A water totalizer is provided to measure the amount of free and emulsified water removed. If a third filter is installed, it is a multi-element pressure particulate polishing filter. The arrangement of this filter is similar to the first filter, with the exception that finer micron filters are installed. The purified oil is returned to the oil reservoir. Sample ports are also provided prior to and after the filters. Each skid incorporates a control panel for control and monitoring critical parameters in the filtration system.

Because Turbo-TOC systems are available in several sizes, they can be used to clean oil on numerous lubrication systems, including the main turbine, main feedwater pump turbine, gas turbine, high-speed gear boxes, or any other turbine reservoir (120–12,000 gal [454–45,425 l]) that require clean, contaminant-free oil.

Centrifuges are used to remove water and large particulates or debris from lubricating oil. They are employed as a bypass filtration unit. Centrifugal force is the operating principle employed by this filtration system. A difference in densities between the oil and the contaminants when acted upon by centrifugal force results in the contaminants being separated from the oil. When water is involved in the purification process, the centrifuge is referred to as a *separator*. The principal contaminant is particulate; the centrifuge is referred to as a *clarifier*.

Two common types of centrifuges are the disk type and the tubular type. The basic difference in design is in the rotating element. The disk type centrifuge rotating element is a bowl device that encloses a stack of disks. The tubular type centrifuge has a long, hollow, tubular rotor. In a disk-type centrifuge, the oil enters the top of the spinning bowl through a regulating tube. The oil flows downward inside a tubular shaft to the bottom of the bowl and into the disk stack. The oil then flows upward and outward through the disk stack. The centrifugal force generated by the bowl causes water and particulate to be slung outward. Particulate contamination collects as a layer on the surface of the bowl. Water that is separated from the oil will commence to fill the bowl. Some water and particulate moves upward and is discharged at the top of the bowl. As the bowl fills with water, the available oil layer for purification is reduced. This causes the oil to pass through the bowl at increasing velocity, therefore spending less time subjected to the centrifugal force. This results in less effective separation of water from the oil. If the bowl were to completely fill with water, no water separation would take place. The purified oil flows inward and upward through the center of the bowl and disk stack, discharging at the top of the bowl back to the reservoir.

The tubular-type centrifuge consists of a long, hollow, tubular rotor. The rotor is typically belt-driven by an electric motor but may be driven by an air-operated motor. The contaminated oil enters the bottom of the bowl. Similar to the disk-type centrifuge, clean oil passes upward through the center of the rotor. Particulate and water move toward the tubular rotor. Particulate is deposited on the rotor, and water moves outward and upward, discharging at the top of the rotor. Inside the rotor is a three-bladed device (three-wing) that rotates with the rotor. The three-wing device assists in bringing the oil to the same speed as the rotor. As the oil enters the bottom of the centrifuge, it strikes against a cone that assists in bringing the oil up to speed evenly, minimizing the potential for emulsification of free water in the oil.

There are several factors that can affect the time required to purify the oil and centrifuge output, including the following:

- Viscosity of the oil
- Particulate size
- Quantity of water in the oil (emulsification)
- Difference in specific gravities of oil versus contaminants

Viscosity affects the length of time required to purify the oil. If the oil is more viscous, it will require more time to purify. Some centrifuges are provided with heaters that will heat the oil to make the oil less viscous to aid the purification process and minimize purification time.

The centrifuge bowl/rotor should be cleaned following each use. Depending on the contamination level of the oil, cleaning may be required more frequently. If large amounts of contaminants are discovered during cleanings, increasing the frequency of cleanings may be warranted. Oil analysis or in-line monitoring devices on the discharge of the centrifuge may also be used to determine whether the centrifuge is performing satisfactorily. Common problems that are seen with centrifuges include the following:

- Oil discharged from the water outlet (bowl improperly sealed or a dirty bowl)
- Bent shafts or defective/worn bearings
- Poor cleaning practices

Electrostatic filtration of air systems has been available for decades. A more recent use of electrostatic filtration is the filtration of oil. Electrostatic filtration has been used in many industries (including paper and plastics) but has only recently migrated into the power industry. It has become a popular filtration method for the removal of varnish and other insoluble contaminants in oil. It is capable of removing insoluble submicron contaminants down to 0.01 μm. Electrostatic filtration is used as a kidney-loop filtration system that works on the principles of electrostatic and electromagnetic attraction.

In the power industry, electrostatic filtration is used primarily on turbine systems (such as steam, hydro, and gas). With regard to steam turbines, it has been especially beneficial because these large lubrication systems are rarely drained and operate in environments that are subject to moisture intrusion, biological growth, and the buildup of particulates, varnish, and sludge. This filtration method aids in reducing the number of oil changes that may be required to maintain oil quality within acceptable limits. It is also applicable to gas turbines that have their own unique challenges. Gas turbines are subject to very high operating temperatures. High operating temperatures result from the heat of combustion that is transferred to the bearings and then to the lubricating oil. Bulk oil reservoir temperatures of 200°F (93°C) can be obtained during operation. This leads to higher oxidation rates and thermal degradation. In addition, the bearing lubricating oil and the control oil for the servo valves come from a shared reservoir. With their close tolerances, servo valves are susceptible to varnish buildup that results in valve stiction.

An effective and efficient electrostatic filtration system must possess the following attributes:

- An electrostatic field (sufficient field strength and number of fields)
- An appropriate system flow rate
- Ample electrode surface area
- Contamination collection media

The electrostatic field strength must be strong enough to impart a charge on contamination particles and oxidation by-products. It must also be strong enough to attract the charged particles through the oil toward the electrodes for collection on the collection media. If the field strength is too low, the charged particles will not move through the oil to the collection media. This will result in the charged particles being dispersed throughout the lubrication system, where they can agglomerate with opposite-charged particles. Eventually, these larger particles may be large enough to collect in areas with close tolerances, ultimately affecting their operation (such as servo valves). High flow rates can have a similar effect.

The number of electrostatic fields is also important. The more electrostatic fields available, the greater the probability that a charged particle will be collected. A charged particle may escape one or more fields only to be collected in another. The number of electrostatic fields will differ by vendor but typically range from 14 to 18 fields.

System flow rate, fast or slow, can influence the effectiveness and efficiency of operation. If the flow rate is too fast, the time spent in the electrostatic field is reduced and may not be sufficient for the charged particle to reach the collection media. If the flow rate is too slow, particulate contamination and oxidation by-products may be generated in the lubrication system at a rate faster than they are removed by filtration.

The electrostatic field surface area is important because the larger the surface area, the greater the electrostatic field that can be generated.

The collection media collects the charged particles. Without the collection media, the charged particles would pass through the filtration system into the lubrication system, where they can agglomerate and cause problems as previously explained. Electrostatic collection media are unique when compared to other filtration media. Electrostatic collection media become more efficient as they collect charged contamination particles. As the charged particles collect, the filed strength increases. This does not mean the collection media can be used forever. There is a limit as to the allowed potential between the electrodes before a current is developed. When this limit is reached, a new collection medium must be installed.

The electrostatic filter is composed of a collection chamber with the electrodes approximately 1 inch (25.4 mm) apart. A high direct current (dc) voltage (10–15 kV) is applied to the electrodes. Between the electrodes is the collection medium. The collection medium is a rough, nonconductive, pleated material with very acute angles at the pleats. The pleated collection material allows for more surface collection area and assists in distorting the electrostatic field in the area of the pleats. The rough surface aids in holding the contaminant particles to the collection medium. The oil is pumped upward between the electrodes, where the electric field imparts a negative or positive charge to the contamination particles, allowing both electrodes to attract the contaminated particles. As the particles move toward the electrodes, they are captured by the collection medium. At the acute angles of the pleats, the electric field is distorted, which causes a higher attraction to particles in this area. Clean filtered oil flows out the top of the chamber.

Some electrostatic filtration units operate based on agglomeration. In these filters, a high dc voltage imparts an electric field through the oil, causing charged particles to agglomerate quickly. These agglomerated particles are then passed through a mechanical filter, where they are trapped. The disadvantages of this system are a need to replace the filter medium once it is loaded and a degree of unpredictability with respect to particle agglomeration. If agglomeration does not occur prior to the mechanical filter, it is possible that it will occur later in the lubrication system, with the resultant agglomerated particles deposited in areas where they are not desired.

It should be noted that particulate material will be charged and collected, provided it is insoluble in the oil. This is of particular concern with respect to additives. In general, additives are soluble in the oil, and therefore are not removed by electrostatic filtration. However, anti-foaming agents are typically insoluble, and the electrostatic filtration will strip these additives from the oil. Additional lubricant properties and the potential effect of electrostatic filtration are described in Table 4-4. These effects are general and can be affected by lubricant type and age. Oil analysis should be performed routinely to ensure that lubricant properties are maintained.

Table 4-4
Effects of electrostatic filtration on lubricant properties

Property	Effect
Viscosity	Negligible; may show slight reduction
AN	New oil: negligible; old oil: decrease due to contaminant removal
Anti-foaming additive	Decrease
Pour point	No effect
Oxidation stability	Slight decrease

Vacuum dehydration oil purification units are used to remove all three types of water (free, emulsified, and dissolved), and entrained air and dissolved gases from contaminated oil. In some cases, particulate filters are also installed on vacuum dehydration skids, either prior to or following the dehydration process. The vacuum dehydration oil purifier operates under the principle of vacuum distillation. At atmospheric pressure water will boil at 212°F (100°C). Under a vacuum, water will boil at a lower temperature. Vacuum dehydration units may be designed to operate under either high or low vacuum conditions. The amount of vacuum will dictate the temperature to which the oil must be heated for the unit to operate effectively.

The operation of the vacuum dehydration purifier is relatively simple. Oil is supplied to the vacuum chamber, either drawn into the dehydrator system vacuum or pumped into the vacuum chamber. Prior to entering the vacuum chamber, the oil is heated to a temperature that will allow the water to vaporize from the oil. Some units may be equipped with a particulate filter prior to entering the vacuum chamber. The oil enters the vacuum chamber, where it is dispersed and exposed to the vacuum. The dispersion process provides for maximum exposure of the oil to the vacuum. Water and dissolved gases are vaporized from the oil. The water vapor, air, and dissolved gases are drawn from the vacuum chamber, where they are condensed by either an air or water condenser. The water is then drained to a condensate tank, where it is ultimately pumped for appropriate disposal. The dehydrated oil falls to the bottom of the vacuum chamber, where it is pumped to the lubrication system. Some units may be equipped with a particulate filter on the discharge of the pump.

When compared to other water removal systems, the vacuum dehydration purifier has advantages as well as disadvantages. The magnitude and type of the water problem should be evaluated prior to determining which water removal system should be used. The best solution is to prevent water intrusion from occurring; if it is occurring, find the source and correct the problem.

Advantages of the vacuum dehydration system include the following:

- Removes dissolved water
- Removes air and dissolved gases
- Can effectively dry oil to less than saturation levels (<50 ppm)

Disadvantages of the vacuum dehydration system include the following:

- Installation costs can be high.
- Unit may increase operational and maintenance costs.
- Does not remove particulate unless particulate filters are installed.
- Cannot handle high concentrations of free water.
- Has high energy consumption.
- Has relatively low output.
- Oil must be heated.

Because of the increased costs that are associated with the procurement, operation, and maintenance of the unit, a cost-benefit analysis should be performed based on the magnitude of the water intrusion problem.

4.3.3 Oil Changes

Oil changes are typically specified in plant procedures based on OEM recommendations. If the oil change information is not specified, EPRI's *Lubrication Guide* (1019518) can be used to assist in developing a frequency. If a lubrication frequency interval exists and there is a desire to change it, the condition of the oil as determined through oil analysis should be used. Operating experience should also be used to assist in changing oil change frequency.

Although on the surface an oil change appears to be a relatively straightforward evolution, there is much more to this evolution than the draining and refilling the equipment with oil. Plant equipment may have small reservoirs of a few quarts or gallons, and some equipment may have reservoirs of thousands of gallons. There are numerous costs that may not be readily apparent. There is also the potential for the work activity to experience problems with unintended results. Cost considerations include the following:

- Cost of replacement oil
- Manpower costs (such as purchasing, handling, storage, planning, scheduling, and maintenance)
- Cost of disposal of waste oil (hazardous waste)
- Oil analysis

The following problematic work activities may result in additional costs:

- Adding the wrong oil
- Adding contaminated oil
- Under/over filling the reservoir
- Spills and cleanup
- Operation of equipment dry

Oil does have a useful life and must be changed when end of life is reached. The question is, when is it necessary to change the oil in a piece of equipment? Oil changes may be performed based on vendor recommendations, preventive maintenance (PM) programs, contamination problems, or equipment degradation. These may be good starting points for determining when to change oil, but the problem with the previously described approaches is that it is very likely that the oil will be changed prior to it reaching its useful end of life. This results in increased costs, ineffective use of resources, and the unnecessary generation of hazardous waste.

A more cost-effective approach for determining when oil should be changed relies on oil analysis. When used properly, oil analysis can determine optimum oil change frequencies for plant equipment. It may not be cost-effective to perform analysis on every piece of plant equipment, especially when the reservoirs are small. PM-based oil changes are time-based and performed without regard to the actual condition of the oil or the operating and environmental conditions of the equipment. If the PM frequency does not take into account the operational and environmental conditions, there is a potential that the equipment could degrade or fail due to poor oil quality. Oil analysis can and should be used to refine PM-based oil changes.

Key O&M Cost Point

When used properly, oil analysis can determine optimum oil change frequencies for plant equipment. However, it may not be cost-effective to perform analysis on every piece of plant equipment, especially when the reservoirs are small.

Oil changes are necessary to ensure that a sufficient quantity of good quality lube oil is maintained in each piece of machinery at all times. Oil change guidelines vary depending on the type of machinery and the quality of the lube oil as determined by oil analysis. To be effective, oil analysis must consider the proper frequency for sampling and appropriate target levels should be set for various oil analysis parameters (such as water, particulate, and AN). Trending can be used to determine oil change frequencies. Sampling frequencies should consider operating duty cycle, operating hours, operating environment, and so on.

4.3.4 Lubricant Compatibility

It is common knowledge that oil and water do not mix. It is less common knowledge that not all lubricants mix—all lubricants are not created equal. Lubricants used in nuclear plant rotating equipment are formulated with select base oil stocks and additives to meet the lubrication requirements of the equipment. Base oil stocks are chosen for their viscosity, oxidation stability, fire resistance, and so on. The base oil stock carries the load and removes heat. Additives are blended into the base stock to provide certain performance features, such as anti-foaming, anti-wear, and corrosion inhibitors.

With respect to mixing lubricants and lubricant incompatibility, two golden rules should be followed. First, do not mix lubricants (especially if they are known to be incompatible). Second, if two lubricants are mixed and compatibility is in doubt, assume that they are incompatible and would cause adverse effects to the lubricant and ultimately the equipment if mixed and used.

When a specific lubricant is recommended or chosen for a piece of rotating equipment, this lubricant should be used for the life of the equipment. If it does become necessary to change to a different lubricant, the oil system must be thoroughly cleaned and then flushed with the new lubricant to minimize problems like foaming, precipitation, or other effects on lubricant properties.

Key Human Performance Point

To avoid the possibility of lubricant compatibility, do not mix lubricants. If the compatibility of two mixed lubricants is in doubt, assume that they are incompatible.

4.3.4.1 How Lubricants Get Mixed

How do lubricants get mixed? In general, it is either a lack of knowledge with regard to mixing lubricants on the part of the personnel handling the lubricants or a lack of attention to detail. Specific activities that could lead to the inadvertent mixing of lubricants include the following:

- Lack of lubricant identification. This includes the lubricant and the lubricated equipment.
- Personnel are inadequately trained or qualified with respect to lubricant/lubrication knowledge and the performance of lubrication duties (such as storage, sampling, re-lubrication, and cleanliness).
- Plant lubrication consolidation practices implemented to reduce the number of lubricants.
- Lubricant vendors/suppliers are changed.
- Refurbishment/overhaul of equipment off-site. (Equipment is shipped with the wrong lubricant, or preservatives [such as corrosion inhibitors] are applied to internal surfaces.)
- Accidental mixing of lubricants.
- Poor inventory control.
- Residual oil from draining activities when lubricant type is being changed.
- Improper labeling by the vendor/supplier/station.

4.3.4.2 Effects of Mixing Lubricants

Mixing lubricants may result in the failure of the lubricant and eventually the equipment being lubricated. Incompatibilities of lubricants can exist for several reasons, including the following:

- Incompatibility of the base stock (for example, additive stability is affected, chemical reactions between base stocks or additives form by-products, or increased oxidation [viscosity and AN] takes place)
- Incompatibility of additives (reactions forming insoluble by-products [sludge and varnish] neutralize or alter the performance of additives [foaming], high particulate, and so on)
- Incompatibility of thickeners

4.3.4.2.1 Lubricant Effects

When lubricants are mixed, the basic functions of the lubricant—friction control, heat control, corrosion control, and contamination control—are affected. The failure of mixed lubricants to perform these basic functions can range from minor variations in the lubricant properties and performance to the catastrophic failure of the equipment. When lubricants are mixed, potential impacts include the following:

- Impaired film strength (viscosity): surface asperities will have a greater potential for making contact, resulting in increased wear, heat generation, and vibration.
- Color changes: excessive color changes may indicate lubricant compatibility issues. (**Note**: minor color changes occur with a lubricant over time due to aging caused by oxidation and temperature.)

- Separation of fluid phases in the lubricant mixture.
- Formation of gel-type material that can clog filters or collect in low-flow areas, such as reservoirs.
- Increased external leakage due to viscosity changes.

4.3.4.2.2 Equipment Effects

Mixing lubricants is a major cause of lubricant and equipment failures. Mixing lubricants is avoidable; if they are mixed accidentally, the problem should be addressed immediately. Some lubricants are chemically incompatible and form insoluble by-products that can deposit on equipment surfaces (such as bearings, journals, piping, and filters). Incompatible lubricants can also affect seals. Seals may shrink, swell, or chemically deteriorate. At one nuclear facility where Fyquel[3] was used as a hydraulic fluid for operation of the main feedwater isolation valves, the wrong O-rings (Buna-N[4]) were used in the system, which resulted in failure of the hydraulic system. In the worst case, this can lead to lubricant starvation and increased wear. Some incompatible lubricants may not exhibit any physical changes, with the problem identified only after the equipment has failed.

4.3.4.3 Prevention of Lubricant Mixing

When it comes to lubricant compatibility, the best strategy is prevention. An understanding of how lubricants can be mixed and the measures that can be taken to minimize the occurrence of mixing should be possessed by all personnel who are involved with lubricants.

Lubricants should be identified. This is especially important in the handling and storage of lubricants. Stations have developed unique color coding or tagging systems for lubricant identification. Lubricant tagging should be performed on storage units (such as tanks, drums, containers, oil cans, and grease guns). Equipment should be identified as to which lubricant is required.

Key Human Performance Point

Proper identification and labeling of lubricants will assist in the prevention of lubricant mixing.

Transfer equipment (such as pumps, containers, hoses, and filter skids/carts) should be marked and, if possible, dedicated to a specific lubricant type. When cross-use equipment must be used, it should be flushed and samples taken prior to using the equipment to transfer lubricant. Although not a lubricant, one nuclear station used vendor-supplied hoses during the receipt of diesel fuel oil (hoses previously used to transfer Bunker-C) and contaminated three of four diesel fuel oil storage tanks before the problem was identified.

[3] *Fyquel* is a registered trademark of AKZO Chemicals.
[4] *Buna-N* is a registered trademark of DuPont Dow Elastomers.

Other prevention techniques that may be used include the following:

- A lubrication program (to include a lubrication manual and procedures for handling, storage, transfer, sampling, and so on)
- Lubrication training (maintenance, operations, engineering)
- Storage facilities (proper labeling and stored separately when possible)

Additional guidance on the prevention of introducing contaminants during lubricant transfers is contained in the EPRI report *Lube Oil Predictive Maintenance Handling and Quality Assurance Guidelines* (1004384).

Another potential area for cross-contamination of lubricants can occur during receipt. Suppliers and vendors might do the following:

- Deliver the wrong lubricant.
- Mislabel a lubricant.
- Change lubricant formulas.
- Provide similar blends that are not compatible.
- Oil receipts should be compared with receipt documents and labeling and, when possible, tested prior to use.

Remember the two golden rules with respect to lubricant compatibility.

5
COMPONENT-SPECIFIC EQUIPMENT

Note: The equipment and components described in this section are provided by many vendors that have numerous differences in type and design. The information provided for the equipment and components in this section is general in nature and may not apply to all types and designs. Specific information on the equipment and components can be obtained from the OEM or from EPRI reports that cover specific types of equipment or components. EPRI reports will be referenced in applicable sections and in the reference sections. Recommendations and guidance should be used in conjunction with OEM recommendations for both equipment and lubricants.

5.1 Turbines

Steam turbines are used to drive several major components in both boiling water reactor (BWR) and pressurized water reactor (PWR) plants. The most common are the main turbine driving the generator, the main feed pump turbine, and the Terry Turbine driving BWR high-pressure coolant injection (HPCI) pumps, BWR reactor core isolation cooling (RCIC) pumps, and PWR auxiliary feedwater (AFW) pumps. All turbines require some form or method of lubrication. The lubrication systems employed range from the simple system (oil rings) to more complex systems with main and backup pumps, oil filtration systems, and cooling systems. The major function of the lubrication system is to provide lubrication to the bearings and accessories. Lubrication systems may also provide control or hydraulic oil to the governor or control valves.

5.1.1 Main Turbines

The main turbine-generator is a complex machine that is essential to the production of electricity. Failure of either the turbine or generator would incur major economic and operational setbacks that would result in the loss of generation, increased maintenance costs, and the replacement of lost generation for a significant period. The turbine-generator machine is supported by numerous auxiliary systems to ensure its efficient and reliable operation. Although it is necessary that all supporting systems function satisfactory to ensure that the turbine and generator are capable of performing their functions, the lubrication system is the most vital. A failure of the lubrication system may result in bearing damage or even catastrophic damage to the rotating elements (such as the turbine, generator, or exciter). The ensuing forced outage would incur extremely high repair costs, long outage duration, and a significant financial burden.

There are numerous OEM suppliers of turbines and generators used throughout the nuclear industry. It is not the intent to discuss each of the various turbine-generators or their lubrication systems. If detailed information related to several turbine-generator lubrication systems is desired, it can be obtained from *Turbine Generator Auxiliary Systems, Volume 1: Turbine-Generator Lubrication System Maintenance Guide* (TR-1010191). OEM technical manuals should also be referred to for additional information.

This section will briefly describe the components of a typical turbine-generator system and provide guidance and recommendations that may be used for general, preventive, and predictive maintenance considerations.

For additional information, consult the EPRI report *Turbine-Generator Auxiliary Systems, Volume 2: Turbine Seal System Maintenance Guide* (1013462).

5.1.1.1 System Operation

The turbine-generator lubrication system's primary purpose is to provide clean oil to the turbine, generator, and exciter bearings. The lubrication scheme is forced-flow circulation. The lubrication system is designed to supply oil at the correct quantity and time and at the proper temperature and pressure. This will ensure that the proper hydrodynamic lubrication exists between the rotating parts and the bearings. In addition, the lubrication will remove heat generated by friction and in some designs, provide control oil to control valves.

The lubrication system is required to be in operation whenever the rotating parts are in motion. (such as in turning gear operation, normal operation, startup, shutdown, and abnormal/ emergency conditions, including a turbine trip). A typical lubrication system consists of the following components (the number of pumps, coolers, and filters will vary by design):

- Main oil reservoir
- Oil pumps (such as shaft-driven, alternating current [ac] motor-driven, and dc motor-driven backup operation)
- Oil coolers/heat exchangers
- Filtration/conditioner systems
- Lubricant
- Instrumentation

During normal operation, oil is supplied from the main oil reservoir by the shaft-driven pump and distributed to the bearings. Oil is returned from the bearings by gravity feed to the main oil reservoir.

The main oil reservoir provides a sufficient volume of oil for lubrication of the bearings, allowing for some delay recycle time in the reservoir and time for the oil to gravity-feed back to the reservoir. Motor-driven oil pumps are mounted on and submerged in the main oil reservoir. The number, arrangement, and functions of the various pumps mounted and the reservoir will vary by OEM supplier. Pumps that may be contained in a turbine lubrication system include a main oil pump, bearing lift pump, turning gear pump, and one or two dc-driven pumps for emergency conditions. (Note that the number of pumps is determined by the specific turbine design.) In some arrangements, pumps may perform more than one function.

The main oil pump delivers the oil to the suction of the shaft-driven oil pump after passing through one or more lube oil coolers (depends on valve lineup—single, series, or parallel). The shaft-driven oil pump is capable of supplying the lubrication system requirements when the shaft is rotating at approximately 70% of rated speed. The main oil pump delivers the oil to an oil header that distributes the oil to the various bearings and other components if installed. The oil exits the bearings by gravity feed. Piping is pitched downward to ensure positive drainage. Upon entering the main oil reservoir, the oil passes through screens that provided rough filtration prior to entering the suction of the operating pump. The screens are accessible at power to allow for inspection, cleaning, and repair. The main oil reservoir bottom may be sloped slightly to allow for water collection and drainage.

A vapor extractor is mounted on the top of the main oil reservoir. The purpose of the vapor extractor is to maintain a slight negative pressure in the main oil reservoir to assist in the drainage of oil from the bearings back to the main oil reservoir. The vapor extractor also aids in the removal of or buildup of any combustible gases and ventilates the air space above the oil. The vapor extractor discharges through a mist eliminator to minimize oil being released to the environment. The mist eliminator traps and collects oil that is eventually drained back to the main oil reservoir. Some stations have also installed collection systems downstream of the mist eliminator to collect any oil that passes through the mist eliminator.

During startup, shutdown, and turning gear operation, a bearing oil lift pump provides lubrication to the bearings by establishing hydrostatic lubrication. Bearing lift pumps are used typically when the turbine is rotating less than 50% of rated speed.

Various types of instrumentation (for example, temperature, pressure, and level) are located throughout the lubrication system for monitoring performance of the lubrication system or to control various pieces of equipment in the lubrication system (for example, oil pumps).

5.1.1.2 Lubrication System Vulnerabilities and Operating Experience

The following describes the vulnerabilities of lubrication systems and plants' operating experience with the systems:

- **Foam in the generator lubrication system**. Foam may be observed in reservoir sight glasses (if installed). Foaming tendency can be determined using ASTM D-892, Foam Test. The addition of anti-foamant can reduce the tendency to foam, but lubricant suppliers do not recommend this. Improper amounts of anti-foamant can actually worsen the foaming condition. Increased foaming may also be a result of dirt contamination and/or air entrapment. If this is the cause of the foaming issue, an anti-foamant will not relieve the foaming problem.
- **Color change as a measure for changing oil**. Color is only one property, and the importance of its change depends on the identity of the lubricant. A black color with an originally light-colored turbine or hydraulic oil is cause for further inspection. If a color change is suspected, follow-up oil analysis can be performed to confirm the cause. Odor and feel should be compared to the original product. For example, a dark used turbine or hydraulic oil may be oxidized and, if so, will smell burnt. If oxidation has indeed occurred, changes in consistency may also have taken place. Oil may have gotten thicker. These changes are often readily discernible in comparisons with fresh products.

- **Freshening turbine oil**. Used turbine oil can be freshened/sweetened/rejuvenated by replacing part of it with new oil or by introducing more additives directly. These methods are only effective provided the oil is not too used (*tired*). The addition of fresh oil or additives should only be undertaken with consultation with the oil supplier. In general, the addition of additives is not recommended. Deterioration of the oxidation inhibitor is a leading indicator of trouble in turbine oils. This is followed by changes in physical properties, such as increases in viscosity, acidity, or filter residue. The process of deterioration depends on the severity of the application conditions (temperature, for example). RPVOT and the remaining useful life evaluation routine are methods used to measure the remaining useful life of turbine oils.
- **Black contamination/sludge in the turbine oil**. Although the sludge contains expected metals from wear, it also contains metals that should not be derivable from turbine oil. These additional metals can come only from contamination that has caused sludge. Oxidation was not a problem. Contamination can be introduced during oil transfer to the system or from preservative materials and/or oils used in the manufacture/assembly/repair of the equipment. Cross-lubricant contamination can also contribute to this result.
- **Vacuum dehydration**. Vacuum dehydration can result in reducing the remaining oil life by stripping oxidation inhibitors. The use of lower grade oil combined with vacuum dehydration can result in decreasing the life of the oil. Top-of-the-line products do better than second-line products in this regard. A main difference between the most modern first-line and older second-line turbine oils is the better high-temperature performance of the first-line products. This improvement is achieved primarily through changes in the oxidation inhibitor package.
- **Turbine startup and shutdown operations**. During startup and shutdown of the turbine, it is a good practice to check the operation of the gland seal regulators. If the regulator pressure is too high, steam can blow by the labyrinth seals into the lube oil system. It is also a good practice to monitor turbine lube oil temperature. It has been observed that high- or low-temperature oil can result in increased vibration in the turbine. Lube oil temperature should be monitored from rollup through full-load operation.

5.1.1.3 General Maintenance Practices

General maintenance activities are developed to effectively organize, plan, and execute various types of maintenance activities for power plant machinery. These maintenance activities may include corrective maintenance, troubleshooting, or planned maintenance, including PM and predictive maintenance. The following sections will focus on preventive, predictive, and troubleshooting activities associated with components of the lubrication system of the main turbine-generator. OEMs' operating and maintenance instructions should be referred to for corrective maintenance guidance and any additional maintenance guidance. Site-specific operating experience may also be used to assist in modifying maintenance frequencies to optimize maintenance resources.

5.1.1.3.1 Routine Inspections/Operational Checks/Performance Monitoring

Routine inspections and operations checks of the lubrication system and equipment in the lubrication system are typically performed by operations personnel during the conduct of rounds. These inspections and checks may range from visual to operational checks. Routine inspections and operational checks performed either on a per-shift or daily frequency may include the following:

- General area: check for evidence of leakage (in valves and piping) and general cleanliness
- Main oil tank: level, pressure
- Oil pumps: suction pressure, discharge pressure, header pressure, abnormal noise
- Bearings: supply temperature, bearing return temperatures, abnormal noise
- Filtration: filter d/p
- Lube oil coolers: inlet temperature, d/p (water side), temperature control valve (TCV) operation

In addition to the daily inspections and operational checks, performance monitoring may be performed by system/component engineers on some prescribed frequency (such as weekly or monthly). Performance monitoring may include pump and motor profiles (temperature, pressure, and vibration analysis), oil analysis results, and bearing temperatures.

5.1.1.3.2 Overhauls

Most turbine-generator maintenance is performed during refueling outages. Results from PM and predictive maintenance activities provide valuable insight into components and equipment that may require corrective maintenance above the maintenance required by OEM suppliers. Frequencies of overhaul maintenance activities should be based on OEM recommendations and operational history from PM and predictive maintenance. Typical maintenance activities included in an overhaul are the following:

- Main oil reservoir: internal cleaning and inspection of reservoir, screen/straining inspections and cleaning
- Oil pumps: Motor and pump inspections, cleaning and overhauls, motor lubrication
- Bearings: inspections, re-babbitt
- Lube oil coolers: inspection, cleaning, flushing
- Valves/piping: re-packs, replacements, clean orifices, system flushes, replace gaskets or O-rings
- Instrumentation (indicators, switches, transmitters, and so forth): calibration and set point verifications
- Lubricant: changeout (with flushes), reconditioning

More detailed information related to inspections, operational checks, monitoring, and overhauls of turbine-generator lubrication systems is provided in *Turbine Generator Auxiliary Systems* (TR-010191).

5.1.1.4 Preventive Maintenance

Main turbine-generator PM with regard to the lubrication system is generally divided into those PM activities that can be performed on-line and those that can be performed off-line. PM is performed on turbine-generator lubrication system components that include the following:

- Oil pumps (shaft- or motor-driven)
- Oil coolers/heat exchangers
- Main oil reservoir
- Filtration system
- Vapor extractor
- Bearings, journals

PM is based on several factors—critical versus non-critical equipment, high or low duty cycle, and severe or mild duty cycle. The dominant factor is the criticality of the equipment. Table 5-1 provides recommended frequencies for various turbine-generator lubrication system major components. These recommended frequencies should be compared with OEM recommendations and equipment operating histories, either of which may shorten or lengthen the recommended periodicity of the PM.

Table 5-1
Turbine-generator lubrication system maintenance

Preventive Maintenance	Equipment Criticality	
	Yes	No
Oil analysis	1–3 M	6 M
Vibration monitoring	Q	6 M
Performance monitoring	AR	AR
Inspection, overhaul	5Y	5–10Y
Inspection, visual	1Y	1Y
Inspection, scheduled	AR	AR
Calibration, scheduled	1Y	1Y

Notes:
M = Months
AR = As required
Y = Years
Q = Quarterly

Detailed information related to the development of these recommendations and expanded bases can be found in *Turbine Generator Auxiliary Systems* (TR-010191).

5.1.1.4.1 Oil Pumps

PM on oil pumps relates to the shaft-driven and the motor-driven oil pumps. Major PMs are developed to detect either seal or bearing wear/failure. With respect to motor-driven oil pumps, PMs are also performed on pump instrumentation (such as oil pressure) to ensure that pumps will start or stop as required under normal or emergency conditions. The primary tasks performed to detect wear or failure of seals or bearings are oil analysis and vibration monitoring. These components are considered critical where oil and vibration analysis is performed on a recommended frequency of quarterly. Performance monitoring may also be performed on these pumps on an as-required basis. This may include pump capacity tests trended by a system or component engineer.

5.1.1.4.2 Oil Coolers/Heat Exchangers

PM tasks on oil coolers are performed to detect leaks or fouling of the coolers. PM tasks that assist in the identification of these potential failure mechanisms include oil analysis, performance monitoring, and inspections. Oil analysis is used to detect tube leaks that may introduce water into the oil and the results of the water introduction (corrosion). Performance monitoring is performed on the coolers with respect to pressure differentials and temperature profiles across the coolers. During major overhaul periods the coolers may be opened to determine the condition of the water and oil sides of the cooler. Cleaning and pressure tests may be conducted to fouling and integrity of the cooler.

5.1.1.4.3 Main Oil Reservoir

The main oil reservoir is not accessible for inspection during normal operations. When conditions exist, it is recommended that the main oil reservoir be inspected for debris and damage. However, there are items that can be monitored to assist in determining the status of the lubrication system. Most reservoirs are designed with a sloped bottom. Drains are provided to detect water buildup. Monitoring the presence and the quantity of water for a given time may indicate abnormal conditions existing in the lubrication system (such as oil cooler leaks, vapor extractor performance, or other ingress sources).

5.1.1.4.4 Filtration System

Filters may be changed out based on OEM recommendations or observed performance based on performance monitoring. Most filters will have some type of differential monitoring instrumentation installed. This may be performed by operator’s rounds or system/component engineers. Using OEM performance criteria, filters can be monitored until these criteria are met or exceeded to determine when filter elements should be changed. Monitoring filter d/p can provide additional information with respect to the lubrication system. Filter d/p should trend up steadily if the quality of the oil is reasonably stable. Unexpected increases in filter d/p may indicate a change in the quality of the oil, and drawing an oil sample may be warranted to determine if the oil has become contaminated. An unexpected decrease in filter d/p may be indicative of a failure of the filter element. This can also be confirmed by oil analysis (particle count). If this has occurred, the filter element should be replaced as soon as practical.

If oil conditions warrant, filters that are replaced should be analyzed rather than discarded. A forensic oil analysis of the material collected on the filter can provide valuable information with respect to the status of the oil's condition or degradation occurring in lubrication system components. The filter is sectioned, and the particles contained within are liberated into a solvent with mechanical and/or ultrasonic agitation for analysis. Filter analysis is typically performed by an oil analysis laboratory, including ferrography and elemental analysis.

Key Technical Point

An unexpected increase in filter d/p may indicate a change in the quality of the oil. An unexpected decrease may indicate a failure of the filter element.

5.1.1.4.5 Vapor Extractor

PM on the vapor extractor involves monitoring the motor and the fan/blower for proper operation. This is generally performed through vibration analysis. Vibration analysis is used to determine the status of the bearings. Performance monitoring can also be used to monitor the negative pressure on the main oil reservoir. Loss of negative pressure can result in ineffective draining of the oil from the bearings back to the mail oil reservoir. This can be accomplished through operator rounds or by system/component engineers.

5.1.1.4.6 Bearings/Journals

Bearings are monitored indirectly and directly through oil analysis. Contaminants such as water, air, oxidation by-products, and other particulates indicate an environment for bearing and journal damage. The presence of babbitt material in filters or strainers provides information that damage is occurring to the bearings. Bearing damage may also be detected to a lesser extent based on vibration analysis. The value of vibration analysis in the detection of bearing/journal damage is largely determined by the magnitude of damage that has already occurred. During refueling or other major turbine generator overhauls, bearings and journals are routinely inspected for damage or degradation. Prior oil analysis may provide the inspector with insights into what type or extent of degradation may be expected. Return oil basket strainers should also be inspected for debris and babbitt when they are changed.

5.1.1.4.7 Instrumentation

The lubrication system has various types of instrumentation installed throughout the system (for example, temperature, pressure, d/p, and level). Instrumentation is routinely monitored by operations personnel during the performance of their rounds or by system/component engineers during their routine inspections. Calibration frequency of these instruments will depend on the instrument type and OEM recommendations. These pressure switches are used to control equipment such as oil pumps during normal and emergency conditions.

5.1.1.5 Predictive Maintenance

Many predictive maintenance activities are performed on a regular frequency within the scope of the PM program. Predictive maintenance activities by their nature are generally nonintrusive. The success of predictive technologies available may have varying degrees of success based on the knowledge and use of the technology, accessibility to components monitored, and the environmental conditions in which the technology is used.

5.1.1.5.1 Oil Analysis

Oil analysis provides the general condition of the lubricant, deterioration of the lubricant due to contaminants, and the general condition of components within the equipment lubricated. Oil analysis should be used in conjunction with equipment operating histories. A variety of standardized oil analysis tests are available to assist in determining the condition and age of the lubricant. Oil analysis recommendations are provided in ASTM D4378, Standard Practice for In-Service Monitoring of Mineral Turbine Oils for Steam and Gas Turbines. The practice is intended to assist in maintaining effective lubrication of all parts of the turbine and guard against the onset of problems associated with oil degradation and contamination. The practice covers the requirements for the effective monitoring of mineral turbine oils in steam and gas turbines. The practice includes sampling and testing schedules to validate the condition of the lubricant through its life.

5.1.1.5.2 Temperature Monitoring

Temperature monitoring maybe employed using a variety of techniques; installed temperature instrumentation, contact thermometers or thermography. There are advantages and disadvantages associated with each. Temperature monitoring has proven to be an effective tool for monitoring most lubrication system components (for example, pumps, lubricant, motors, and bearings). Installed and contact temperature monitoring is easy to trend and in most cases easy to obtain. Thermography is more difficult to trend and can be affected by background temperatures or equipment arrangements or accessibility.

Typical components or parameters that should be considered for temperature monitoring include:

- Bearing temperatures (may be indirectly monitored through oil temperature)
- Oil supply temperature
- Bearing drain temperature
- Oil cooler/heat exchanger temperatures
- Motor temperatures

5.1.1.5.3 Vibration Analysis

Vibration testing is a useful tool for monitoring the health of rotating machinery. Vibration monitoring may employ a variety of techniques (for example, frequency, amplitude, and phase angle). Turbine and generator bearings have installed vibration probes for monitoring frequency and amplitude of vibrations. These instruments are remotely monitored in the control room and have alert and action levels associated with them. The turbine generator bearings are also monitored routinely or as a result of identified adverse trends by vibration technicians.

In addition to turbine and generator bearings, pumps and motors within the lubrication system may be routinely monitored.

5.1.1.6 Troubleshooting

Most stations have detailed troubleshooting procedures that provide general guidance related to the development of an effective troubleshooting plan. The plans encompass all aspects of the troubleshooting process from the identification of the cause(s) to implementation of corrective actions. Troubleshooting of the turbine generator lubrication system may involve one to several pieces of equipment or components. Table 5-2 provides some general information with respect to several components in the turbine generator lubrication system. Table 5-2 addresses only lubrication-related troubleshooting. Mechanical, electrical, or instrumentation problems are not addressed. OEM references and operational history should also be consulted when developing troubleshooting plans.

Table 5-2
Turbine-generator troubleshooting

Symptom	Cause	Action
High vibration in turbine-generator	Oil-induced	Check oil supply temperature. Check operation of TCV. Possible oil whirl or oil whip. (Check vibration frequency spectrum.)
Bearing leakage	Drains blocked	Check individual bearing drain temperatures.
	Loss of pressure control in reservoir	Check suction butterfly damper. Check fan/blower operation. Check for system backpressure (blockage). Verify all tank openings closed.

Table 5-2 (continued)
Turbine-generator troubleshooting

Symptom	Cause	Action
Poor oil pump performance (pressure/flow)	Insufficient flow/pumping capacity	Check oil reservoir level. Check for foaming/air binding. Check suction strainer. Check valve lineup. Check shaft/impeller (sheared).
Water in oil	Heat exchanger leakage	Check heat exchanger for leaks (oil and water sides).
High/low filter d/p	Filter clogging (high d/p)	Check filter for debris buildup. Check d/p indicators. Perform analysis of debris buildup on filter element.
	Filter failure (low d/p)	Check filter element for break-through. Perform particle analysis downstream of filter.
Poor lubricant operating properties (temperature/pressure)	Low oil pressure	See poor oil pump performance. Check relief valves in system. Check for reverse flow through standby pump.
	High oil temperature	Check TCV operation. Check heat exchanger for blockage. Check for proper venting of heat exchanger (oil and water sides). Check for fouling on heat exchanger surfaces.
	Low oil temperature	Check TCV operation. Check cooling water temperature.

5.1.2 Terry Turbines

Terry Turbines are used to drive BWR HPCI pumps, BWR RCIC pumps, and PWR AFW pumps. Depending on the application and the Terry Turbine, one of the following three types of lubrication system may be used:

- Ring-only lubrication (ROL)
- Ring lubrication plus pressure circulation (RLPC)
- Full forced feed lubrication (FFFL)

5.1.2.1 Lubrication System Descriptions

ROL is found in some AFW turbine applications. RLPC is found in RCIC and most AFW applications. FFFL is found in HPCI applications. Detailed descriptions and figures associated with these three types of Terry Turbine lubrication systems can be found in *Terry Turbine Maintenance, HPCI* (1007459), *Terry Turbine Maintenance, RCIC* (1007460), and *Terry Turbine Maintenance, AFW* (1007461).

5.1.2.1.1 Ring-Only Lubrication

In this lubrication method, lubricating oil is contained in each bearing pedestal (governor end and pump end). Oil rings (also called *slinger rings*) are positioned around the journal bearings at each end. The oil rings hang off the journal bearings into the oil contained in the bearing pedestal. As the shaft rotates, the oil ring also rotates picking up oil from the bearing pedestal reservoir and carries it up to the journal bearing.

5.1.2.1.2 Ring Lubrication plus Pressure Circulation

In the lubrication system configuration, the pressure circulation portion of the system is the main oil supply and the ring lubrication is the backup or secondary lubrication system. The ring lubrication system is used to supply oil to the bearings during startup, coastdown, and backup to the pressure circulation system if it were to fail.

Similar to ring-only systems, the oil is contained in the bearing pedestals. However, in the RLPC method, the bearing pedestals are connected through an equalizing header of 2–3 in. (50.8–76.2 mm) in diameter. The equalizer pipe is located at the low point of the oil system and serves as an oil sump. The equalizer pipe is fitted at one end with either a tee or plug to facilitate draining and cleaning. The equalizing pipe may also be flanged (plant-specific) at the bearing pedestals to facilitate dismantling in the event that is necessary.

During startup and coastdown, the lubrication system functions as an ROL system. Pressure circulation is provided when the shaft is rotating by a shaft-driven oil pump. The shaft-driven oil pump takes suction on the equalizer pipe. The pump then discharges the oil through a filter and an oil cooler (filter and cooler are optional based on design). Oil is fed to the bearings through meter orifices in each bearing feed line. Branch lines also provide oil to other turbine accessories.

5.1.2.1.3 Full Forced Feed Lubrication

An FFFL system provides lubrication, control, and hydraulic oil. Oil is contained in a reservoir that is integral to the turbine base. During startup and coastdown, oil is supplied by a motor-driven auxiliary oil pump. During operation at normal speeds, the oil is supplied by a shaft-driven pump. Pressure switches control the startup and shutdown of the auxiliary pump based on the output of the shaft-driven oil pump. Oil is drawn from the reservoir and pumped to the control system for positioning the control valves. A portion of the oil is filtered and then fed to the governor and pressure reducer valve. Some of the oil from the pressure reducer valve is supplied as control oil to the turbine stop valve; the remainder is passed through an oil cooler to the turbine bearings.

5.1.2.2 Lubrication System Vulnerabilities and Operating Experience

Although in many respects the lubrication system is conceptually simple, it is subject to a number of vulnerabilities. Lubrication schemes are subject to a variety of faults. Lubricants will degrade and break down, and individual components will wear out over time. Material compatibility issues can lead to failures. This section explores some of the events that have occurred in lubrication systems.

Lack of attention to detail resulted in the improper level in the oil reservoirs. The oil glass on the constant-level oiler had become obscured, and the markings had worn off. When the glass was cleaned and markings were reestablished, it was determined that the oil level was high. In this case, no adverse effects occurred, but the high oil level could have impacted slinger ring operation. Proper routine inspections from operations personnel could have prevented this problem.

Several stations have observed air in the Terry Turbine oil system. At one station, the air entrainment was confirmed using ultrasonic techniques. One indication was the increase of level in the inboard bearing while the oil level decreased in the outboard bearing. The problem was determined to be air entrained in the drain line of the outboard bearing reduced the drainage flow back to the reservoir. The causes could have been from the pumping action of the overspeed trip device aerating the oil, leaks in the suction side of the oil pump, or oil that was subject to foaming. The air issue was resolved by a couple of means. In one case, the discharge pressure of the oil pump was reduced with vendor concurrence. In another case, an atmospheric vent was installed at the top of the outboard bearing housing.

Many utilities with standby Terry Turbines use the so-called *vapor phase–inhibited* oils for their lubrication as well as turbine control. The mineral oil–based product contains oxidation and foam inhibitors as well as liquid- and vapor-phase corrosion/rust inhibitors. They are specified because a lot of water is present in the turbine lube area (the turbines are steam-driven), and there is a perception that the condition of rusting of non-oil-wetted surfaces especially needs to be protected against. Problems with some turbines using the specified oils have surfaced. These include over-speeding on startup and subsequent trip-out. Inability of the turbine to achieve design speed on startup has also been observed. Several causes have been cited: failure to remove accumulated water from the system, sediment in the fresh oil, deposits forming in the oil in use, and excessive deposits in the non-oil-wetted areas. Each of these can interfere with the mechanism controlling the speed of the turbine.

Precautions that can be taken to eliminate some of these causes include removal of water from the oil system and careful filtration of the fresh oil.

Additional information can be found in Note 6 of *Lube Notes, 1989–2001* (1006848).

5.1.2.3 General Maintenance Practices

General maintenance activities are developed to effectively organize, plan, and execute various types of maintenance activities for power plant machinery. These maintenance activities may include corrective maintenance, troubleshooting, or planned maintenance, including preventive and predictive maintenance. The following sections will focus on preventive, predictive, and troubleshooting activities involved with the Terry Turbine. Manufacturers' operating and maintenance instructions should be referred to for corrective maintenance guidance and additional maintenance guidance.

5.1.2.4 PM/Predictive Maintenance Practices

PM activities are time-based maintenance activities that replace parts or equipment based on the manufacturer's recommendations or equipment operational history. These activities are performed at some fixed intervals without regard to the operating conditions of the equipment. PM can be an expensive program that results in potential premature replacement of components, inefficient use of maintenance resources, and excessive downtime of operating machinery.

Predictive maintenance may include analyses, testing, and inspections—specific examples are oil analysis, vibration analysis, external visual inspection, surveillance testing, and operator rounds. Predictive maintenance is a conditioned monitoring program. Proper conditioning monitoring will assist in determining when maintenance is necessary. Condition-based monitoring may include continuous online monitoring or periodic monitoring to determine the health of the equipment. The most common predictive monitoring techniques used to assist in determining the condition of the equipment are thermography, vibration, ultrasonics, oil analysis, and inspections. These techniques are effective on a wide range of plant equipment, including motors, generators, pumps, turbines, fans, and compressors.

Information from these techniques should be trended and analyzed to assist in determining pending equipment failure, scheduling maintenance, and even the procurement of parts. An effective predictive maintenance program can reduce operational costs.

Conditioning monitoring allows for the collection of data (periodically or continuously) on the operating condition of the motor. With respect to the lubrication system, data can be obtained and trended on both the lubricant and motor, including oil condition, bearing condition, and cooling system. PM/predictive maintenance activities and frequencies are presented in Table 5-3.

Table 5-3
Terry Turbine PM/predictive maintenance

PM/Predictive Maintenance Task	Critical: Low-Duty Cycle	
	Severe Service Condition	Mild Service Condition
Oil analysis	M	Q
Vibration analysis	Q	Q
External visual inspection	Y	2Y
Oil filter change	2Y	2Y
Functional testing	Q	Q
Operator rounds	S	S

Notes:
Y = Yearly
2Y = Every two years (that is, an operating cycle)
Q = Quarterly
M = Monthly
S = Shiftly

Oil analysis provides information about the general condition of the lubricant, deterioration of the lubricant due to contaminants, and the general condition of components within the equipment lubricated. Oil analysis should be used in conjunction with equipment operating histories. A variety of standardized oil analysis tests are available to assist in determining the condition and age of the lubricant. Oil analysis recommendations are provided in ASTM D4378, Standard Practice for In-Service Monitoring of Mineral Turbine Oils for Steam and Gas Turbines. The practice is intended to assist in maintaining effective lubrication of all parts of the turbine and guard against the onset of problems associated with oil degradation and contamination. The practice covers the requirements for the effective monitoring of mineral turbine oils in steam and gas turbines. The practice includes sampling and testing schedules to validate the condition of the lubricant through its life.

Vibration analysis provides a method to monitor for wear in turbine bearings. Vibration readings are generally taken in conjunction with surveillance/functional testing.

External visual inspections are performed on-line and off-line. Online inspections are typically performed during surveillance/functional testing. Inspections may include identification of oil leaks, abnormal noises, coupling leaks, condition of elastomers, coupling leaks, and oilers. When accessible, the oil reservoir should be inspected (joints, fittings, flanges, drains, and so on).

Operator rounds provide frequent opportunities to assess the condition of the Terry Turbine. Operators should identify oil leaks, unusual noises (a possible indication of wear), oil pump pressure, oil cooler flow and d/ps, bearing temperatures, and operation of the control system (hunting).

Functional testing is performed to verify the operability of the start and flow functions of the pump. However, during testing, observations on the performance of the oil systems should be performed (for example, flow, pressures, temperatures, and leaks). During testing, vibration and oil analyses are typically performed.

Additional PM information may be found in *Preventive Maintenance Basis, Volume 36: Terry Turbines—Single Stage* (TR-106857-36).

5.1.2.4.1 Routine Inspections

Routine inspections are typically performed on a daily or at least weekly periodicity. In most cases, these inspections are performed by operators during the conduct of their rounds. They may also be performed by system or component engineers during frequent walkdowns of their systems. These inspections are generally visual inspections observing for external oil leaks, cleanliness, proper oil level(s), and general equipment condition (for example, are breather caps properly installed?).

5.1.2.4.2 Surveillance Testing

Surveillance testing is normally performed as required by the plant's technical specifications. Testing periodicity and requirements will be governed by the technical specifications or a referenced in-service testing (IST) program. Periodicity is typically either monthly or quarterly. The conditions and requirements of the test may include the following plant-specific requirements:

- The turbine is run for a sufficient amount of time to allow the turbine to achieve normal operating temperature. This allows for moisture to be driven from critical areas (such as oil and gland areas). For FFFL, this provides sufficient time to verify proper operation of the TCV for the oil cooler.
- It is preferable to draw an oil sample while the turbine is operating using an approved sampling method for the configuration. If it is not possible to draw the sample while the turbine is operating, the sample should be drawn as soon as possible following turbine shutdown (for example, within 15 minutes) to ensure that a representative sample is obtained (that is, suspended particles are thoroughly mixed). Care should be taken when drawing the oil sample from bearing pedestals during operation to ensure that oil levels remain in required bands.
- Oil levels should be monitored while the turbine is in operation. This is especially relevant for RLPC, where the equalizing pipe is installed. Blockage in the equalizing pipe or foaming problems could result in level changes in the pedestal bearing reservoirs causing improper bearing lubrication.
- For FFFL turbines, verify proper operation of the auxiliary oil pump during startup and shutdown.
- During the surveillance test, pump data requirements are typically specified by the appropriate IST requirements. Turbine data (such as vibration and bearing temperatures) should also be obtained. Additional information may include oil pressures, oil temperatures, inspection for oil leaks, and general operating condition of the turbine.

5.1.2.4.3 Planned Maintenance

Planned maintenance activities are generally performed on a frequency that coincides with refueling outages. Planned maintenance activities that may be performed every refueling outage include the following:

- For the oil reservoir: an oil sample should be taken. Drain, clean, and inspect for debris. For RLPC systems, this includes the equalizing pipe. If debris is found, the system should be cleaned and possibly flushed prior to filling with oil.
- For oil filters: if oil filters are installed, the filter element should be replaced and the filter housing cleaned.
- Bearings (journal and thrust): visually inspect bearings and oil rings (if installed).
- Perform an alignment check.
- Calibrate gauges as required (for example, pressure).

Major inspection activities or overhauls should be performed every three to four refueling cycles.

5.1.2.5 Troubleshooting

Most stations have detailed troubleshooting procedures that provide general guidance related to the development of an effective troubleshooting plan. The plans encompass all aspects of the troubleshooting process, from the identification of the cause(s) to implementation of corrective actions. Troubleshooting of the Terry Turbine generator lubrication system may involve one or several pieces of equipment or components. Table 5-4 provides some general information with respect to several degradation mechanisms that may be observed with the Terry Turbine lubrication system. OEM references and operational history should also be consulted when developing troubleshooting plans. General information associated with the Woodward governor oil is provided in Woodward manuals 25071J and 25075A.

Table 5-4
Terry Turbine troubleshooting

Symptom	Cause	Action
High bearing/oil drain temperature	Low oil pressure	Investigate auxiliary oil pump problem. Investigate shaft-driven oil pump. Check for foaming/aeration.
	Restricted lubrication supply	Check equalizing pipe. Check oil orifices.
	Damaged bearings	Analyze oil for particulates and contaminants. Check oil rings for proper operation. Check lubricant level. Replace bearings.
	Oil rings	Check for proper operation. Check for damage.
High oil supply temperature	Plugged oil cooler	Check oil cooler for blockage.
	High cooling water temperature	Check cooling system operation.
	Restricted cooling water flow	Check water side of heat exchanger for blockage.
	Damaged bearings	Analyze oil for particulates and contaminants. Check lubricant level. Check lubrication system (oil rings, oil pumps, and so on) for proper operation.

Table 5-4 (continued)
Terry Turbine troubleshooting

Symptom	Cause	Action
High oil supply pressure	Plugged oil feed orifices	Unplug oil orifices.
	Improper relief valve setting	Check relief valve setting and adjust as necessary.
	Low oil temperature	Check TCV operation (HPIC only). Check cooling water supply.
	Damaged bearings	Analyze oil for particulates and contaminants. Check lubricant level. Check lubrication system for proper operation (such as oil rings and oil pumps).
	Pressure regulator	Adjust pressure regulator (HPIC only).
Low oil pressure	High oil temperature	Check oil cooling system.
	Oil pump performance (if applicable)	Check auxiliary oil pump. Check shaft oil pump. Check for obstructions in suction piping.
	Relief valve	Check operability of relief valve. Check relief valve setting. Replace or adjust as necessary.
	Pressure regulator (HPIC only)	Adjust or replace as required.
High oil filter d/p	Plugged or dirty filter	Confirm d/p reading. Replace filter. Analyze filter (premature clogging).
	Contaminated oil	Perform oil analysis for contaminants (especially water).

Table 5-4 (continued)
Terry Turbine troubleshooting

Symptom	Cause	Action
Oil contamination	Foaming	Check lubricant level (high). Check for air in-leakage. Restricted or inadequate size of oil drains. Improper oil. Check for water in oil. Perform oil analysis. Drain and refill reservoir if required.
	Contaminated makeup supply	Check makeup supply (analyze, storage, and so on).
	Water	Check oil cooler for leakage. Check pump seals for leakage. Investigate any leakage ingress paths. Drain and refill reservoir if required.
	Particulates	Analyze oil. Check for contaminant ingress paths. Check bearings for wear. Check carbon shaft seals. Drain and refill reservoir if required.
	Oxidation	Perform oil analysis. Investigate operational history. Drain and refill reservoir if required.
	Incompatible lubricants	Perform oil analysis. If required, drain and replace oil.

5.1.3 Main Feedwater Pump Turbines

Turbines are used as prime movers for feedwater pumps, primarily to improve cycle efficiency. They incorporate the use of low-pressure extraction steam as well as high-pressure steam for operation. Turbines used in the nuclear industry may be provided by several OEMs (Westinghouse, General Electric, Asea Brown Boveri, and so on). This section will focus on the typical operation and maintenance of a main feedwater pump turbine lubrication system. OEM operations and maintenance manuals should be referenced for specific information related to installed machinery. *Feedwater Pump Turbine Controls and Oil System Maintenance* (EPRI TR-1003094) can also be referenced for more details related to overall turbine maintenance, especially for General Electric and Westinghouse turbines.

5.1.3.1 System Operation

The main feedwater turbine lubrication system is a full forced flow system. In most applications, the lubrication system supplies both the turbine and the pump. In addition, the lubrication system provides control oil for control valve operation. Lubrication system components and the arrangement of components are vendor-specific but generally include an oil tank, pumps (shaft-driven, motor-driven, or a combination thereof), an oil cooler, a filter, valves, piping, and various types of instrumentation for control, alarm, and monitoring system performance. Some systems may employ an additional oil cleanup system or a vapor extractor.

The oil tank may be located beneath or to the side of the turbine. The oil tank typically contains approximately 900 gal (3407 l) of oil. The oil is used for lubrication and control. The tank has a drain valve that may be used for draining water or drawing a sample. The tank may also contain access covers for inspection and vents.

The oil pumps are mounted to the tank with the pumps immersed in the oil. The number of pumps available and in use varies by vendor design. The most common design alternatives include the following:

- Shaft-driven pump, auxiliary oil pump (ac), emergency oil pump (dc)
- Shaft-driven pump, auxiliary oil pump (ac), emergency oil pump (dc), auxiliary control oil pump (ac)
- Two main oil pumps (ac), emergency oil pump (dc)

Shaft-driven pumps typically have a low-pressure and a high-pressure discharge. The low-pressure discharge is used for lubrication and turbine control. The high-pressure system is used for the governor system. Auxiliary oil pumps are used with shaft-driven pumps to supply oil for lubrication and control during startup and shutdown. The dc-driven auxiliary oil pump is used under emergency conditions. In some cases, it may be used for turning gear operation. Lubrication systems that do not use a shaft-driven pump will use two main oil pumps, each of them capable of supplying 100% of the lubrication and control oil requirements. The second pump is in standby and will start on low oil pressure. Some arrangements also use an auxiliary control oil pump. This pump supplies control oil pressure under conditions where the shaft-driven oil pump high-pressure discharge has not developed sufficient pressure to supply control oil demand.

The lubrication system contains two, 100% parallel oil coolers. The oil coolers use a transfer valve to allow for single cooler operation. The oil cooler capacity and valve arrangement provides for the isolation of a cooler in the event of a cooler leak. The oil coolers are cooled by non-essential cooling water or turbine water systems. A TCV modulates the cooling water flow to maintain a given oil temperature.

Most lubrication systems contain a duplex oil filter. The filter has a transfer valve that allows for single filter operation, allowing for filter element replacement. The filter may incorporate either an internal or external relief valve that will ensure oil supply in the event of excessive d/ps across the filter. The filters are also provided with some type of instrumentation to monitor the d/p across the filter, and the d/p instrumentation may be provided with an alarm function. Coarse strainers are also provided to the suction of each of the oil pumps.

Various types of instrumentation located throughout the system provide indication, control, and alarm functions.

5.1.3.2 Lubrication System Vulnerabilities and Operating Experience

Although in many respects the lubrication system is conceptually simple, it is subject to a number of vulnerabilities. Lubrication schemes are subject to a variety of faults—lubricants will degrade and break down, and individual components will wear out over time. Material compatibility issues can lead to failures. This section will explore some of the events that have occurred to the lubrication system.

At a nuclear station, difficulty was noted in maintaining lube oil temperature. The investigation into the cause determined that biofouling of the heat exchanger had degraded the performance of the cooler. Good performance monitoring techniques may have identified this problem earlier. An increased demand had occurred on the TCV over time. Monitoring of heat exchanger performance would also have assisted in early detection.

5.1.3.3 General Maintenance

The guiding principle for lubrication system maintenance is to keep the oil clean. There is no greater threat to the reliable operation of rotating equipment than failure of the oil or the oil system.

Overhaul of the turbine and its lubrication system is based on OEM recommendations, operating history, performance monitoring, and predictive maintenance results. Turbine overhauls are typically not performed each cycle; however, some maintenance of the lubrication system may be warranted, depending on system operation. In general, overhauls are alternated each refueling outage between the trains of feedwater. Lubrication system and lubricated components that require inspection during the overhaul periods might include the following:

- Thrust bearing inspection (wear, damage, and end play)
- Journal bearing inspection (clearances, dimensions, wear, damage, and babbitt bonding)

- Clean bearings
- Oil seal inspection (clearances, wear, degradation, and replacement of soft goods)
- Shaft-driven oil pump (gears, bearings, and coupling)
- Motor-driven oil pumps (clearances and bearing wear/damage)

Note: Care should be taken with installed vibration and temperature instrumentation during overhauls of the turbine.

5.1.3.4 PM/Predictive Maintenance

Time-based PM on the main feedwater turbine lubrication system consists primarily of analyses, testing, and inspections—specifically, oil analysis, vibration analysis, external visual inspections, and operator rounds.

Oil analysis is performed to help ensure that the quality of the oil is maintained at the highest level. This is especially important since a common oil tank is used in most cases to supply both the lubrication of components and the control oil. Oil analysis can detect the onset of wear from lubricated components as well as oil pump wear. It will also detect signs of oil deterioration either due to contaminants (such as water, air, or dirt) or breakdown due to oxidation or thermal degradation. Oil analyses that should be considered include viscosity, pour point, ferrography, particle count, moisture, total acid, shear stability, and thermal stability.

Oil analysis provides the general condition of the lubricant, deterioration of the lubricant due to contaminants, and the general condition of components within the equipment lubricated. Oil analysis should be used in conjunction with equipment operating histories. A variety of standardized oil analysis tests are available to assist in determining the condition and age of the lubricant. Oil analysis recommendations are provided in ASTM D4378, Standard Practice for In-Service Monitoring of Mineral Turbine Oils for Steam and Gas Turbines. The practice is intended to assist in maintaining effective lubrication of all parts of the turbine and guard against the onset of problems associated with oil degradation and contamination. The practice covers the requirements for the effective monitoring of mineral turbine oils in steam and gas turbines. The practice includes sampling and testing schedules to validate the condition of the lubricant through its life.

Vibration analysis should be monitored and trended for the turbine bearings and the motor-driven oil pump and motor bearings. Most turbines are equipped with installed vibration instrumentation. Vibration analysis used in conjunction with oil analysis is particularly beneficial in the early detection of component wear.

Operator rounds may provide early detection of lubrication system problems before they result in major damage. Operations personnel perform routine inspections during the conduct of operator rounds. Many rounds are now taken using computerized data-loggers making the data easily retrievable for trending. During operator rounds, the operator monitors temperatures, pressures, levels, and the general condition of the machine. Parameters or items monitored may include the following:

- Oil tank level
- Oil temperatures (inlet and outlet temperature of cooler, individual bearing temperatures, bearing drain temperatures)
- Oil pressures (pump discharge, filter d/p, and so on)
- External oil leaks
- Valve operation (pressure-regulating valve, TCV)
- General area and machine (cleanliness, missing hardware)
- Unusual noise (turbine, oil pumps, and so on)

Functional tests are performed to check various control, set point, or trip actions. The frequency of the performance of these tests may be required by OEM recommendations or insurance policies. Functional tests may include the following:

- Emergency pump starts/stops
- Temperature and pressure alarm set points
- Turbine trips (low oil pressure, thrust bearing wear, and so on)

External visual inspections are more extensive than the routine inspections performed by operations personnel. The inspections may involve visual inspections similar to those made by operations as well as inspections using more sophisticated techniques (for example, boroscopes and ultrasonics). Inspections performed may use performance monitoring information that was obtained during the operating cycle to assist in focusing on particular problem areas.

Table 5-5 is a summary of predictive maintenance activities and their proposed frequencies based on *Equipment Condition Monitoring Templates* (1000621) as they relate to the lubrication system. Table 5-5 is based on the premise that the main feedwater pump turbine is a critical component operated under high-duty cycle and severe service conditions.

Table 5-5
Predictive maintenance for the main feedwater pump turbine

Predictive Maintenance	Frequency
Oil analysis	Quarterly
Vibration analysis	Quarterly
Routine inspection (operator rounds)	Shiftly
Routine functional tests	Vendor or operational experience (monthly, for example)
External visual inspection	Refueling outage

5.1.3.5 Troubleshooting

Most stations have detailed troubleshooting procedures that provide general guidance related to the development of an effective troubleshooting plan. The plans encompass all aspects of the troubleshooting process, from the identification of the cause(s) to implementation of corrective actions. Troubleshooting of the main feedwater turbine lubrication system may involve one or more symptoms. Table 5-6 provides general information with respect to several symptoms in the main feedwater generator lubrication system. OEM references and operational history should also be consulted when developing troubleshooting plans.

Table 5-6
Troubleshooting main feedwater pump turbine

Symptom	Cause	Action
Oil contamination	Particulate contamination	Determined by oil analysis. Check breather caps installed. Ensure that access covers or inspection ports are covered. Verify that filters are operating properly. Verify that filter elements are the proper size.
	Gaskets, O-rings deteriorating	Check that materials used are compatible with type of oil. Change gaskets/O-rings as required.
	High operating temperature (Increased oxidation and thermal degradation)	Verify temperatures throughout the lubrication system. Verify oil cooler TCV is functioning properly. Perform oil analysis (varnish/sludge).
	Oil incompatibility	Review past oil change records. Perform oil analysis for proper oil characteristics.
Water in oil	Oil cooler leak	Inspect oil cooler for leaks. Repair leaks.
	Gland seals are leaking	Check gland drains for blockage. Check glands for wear or degradation.
	Openings to atmosphere	Check breather caps in place. Check covers, vents closed. Check oil cooler TCV for proper operation. Check immersion heater operation (if applicable).

Table 5-6 (continued)
Troubleshooting main feedwater pump turbine

Symptom	Cause	Action
Low oil pressure	Shaft-driven oil pump not running	Check coupling. Check gear drive (if applicable).
	Main oil pump not running	Verify backup oil pump functioning properly. Check electrical supply. Check control circuit. Check motor/pump coupling.
	Low oil tank level	Verify proper oil level in tank. Add oil to OEM requirements.
	Clogged filters	Verify filter d/p is normal. Verify proper filter size and/or material. Change filter elements as required.
	Insufficient pump discharge pressure	Oil analysis (sludge). Check system pressures for evidence of blockage. Check pump clearances when available.
	Leaking or stuck open relief valve	Use ultrasonics to detect possible leakage. Check system pressures normal. Repair/replace reliefs as required.
High or low oil temperature	TCV failure	Check operation of TCV. Check temperature of cooling water.
	Immersion heaters	Check power supply to heaters. Check heater control circuit.
Abnormal oil tank level	External leakage (low level)	Check external piping and joints for leaks. Restore level to normal.
	Internal leakage (high level)	Perform oil analysis for water. Check for cooler leaks if water is present. Check if instrumentation is operating properly.

5.1.4 Gas Turbines

Gas turbines are used in aviation, marine, and land-based applications. Land-based applications have been primarily for the production of electrical power. The gas turbine has been adopted by some nuclear stations as a source of supplemental power under emergency situations. They have proven to be a reliable means of generating electrical power, but they do require proper maintenance to perform effectively and efficiently. Gas turbines used in industrial applications are either of the heavy industrial type of a derivative of an aero-engine. General Electric, Pratt and Whitney, and Rolls Royce are a few of the major suppliers of gas turbine engines.

Gas turbine engines operate on the Brayton cycle principle. This involves the compression of gases drawn into the inlet of the engine to increase pressure and temperature. The heated gases are then fed to a combustion chamber with the fuel, where the fuel is ignited, increasing the temperature and pressure further. The hot combustion gases are fed to the turbine section, where they expand and produce mechanical energy to rotate the shaft. The shaft is converted to a desired output device (such as a generator) to achieve the final desired output.

Gas turbines are classified by several design configurations. The gas turbine may be of either the heavy industrial or derivative aero-engine design. They may be further classified by the way exhaust gases are passed through the turbine. An open turbine passes the intake gases through the turbine only once. A closed turbine will return heated exhaust gases to the compressor to increase thermal efficiency. A semi-closed turbine will only bypass a portion of the exhaust gases to the compressor. They may also be classified by where the output is taken from with respect to the engine. A hot-end drive machine has the output shaft attached to the exhaust end of the engine. A cold-end shaft design has the output shaft at the compressor or inlet of the engine. The engine may also be classified by the number of shafts. A single spool shaft has a single shaft driving the turbine. A dual spool shaft has two shafts that drive separate compressors and turbines for low- and high-pressure turbines.

They are several differences in design, operation, and maintenance of the derivative aero-engine and the heavy industrial turbine. Differences are provided in Table 5-7.

Table 5-7
Differences in gas turbines

Characteristic	Heavy-Duty Turbine	Derivative Aero-Turbine
Speed	3,000–12,000 revolutions per minute (rpm)	9,000–20,000 rpm
Size	Large blades and vanes	Medium blades and vanes
Bearings	Journal	Anti-friction (roller element)
Compressor ratios	12:1	30:1
Startup	Slow	Fast
Acceleration	Slow	Fast

Table 5-7 (continued)
Differences in gas turbines

Characteristic	Heavy-Duty Turbine	Derivative Aero-Turbine
Cooldown	Long	Short
Maintenance	Time-intensive	Less time-intensive
Operating oil temperatures	130–160°F (54–71°C)	>400°F (>204°F)
Lubrication system	Large reservoir	Small reservoir
Lubricant	Paraffin-based	Synthetic

5.1.4.1 Lubrication System Description

Whether a heavy industrial or derivative aero-engine, the lubrication systems are similar in design. The lubrication system is designed to meet two requirements—lubricate the rotating and stationary surfaces and remove heat. Lubrication of the turbine and its components is accomplished by a pressurized forced flow lubrication system. The basic components of the lubrication system are the reservoir, oil pump, pressure regulator, filter, oil cooler, and instrumentation.

The reservoir serves three functions: it stores the oil during shutdown, provides an oil supply during operation, and deaerates the oil during operation. The heavy-duty turbine reservoir may be a couple of thousand gallons in size, whereas a derivative gas-engine may be a couple of hundred gallons. If the reservoir is exposed to low-temperature conditions, an immersion heater may be installed. As oil flows through the bearings, air may become entrained in the oil, which can cause foaming. The reservoir is capable of deaerating the oil by increasing the surface area in the reservoir through the use of baffles or screens. The reservoir is also operated at a slight positive pressure to ensure net positive suction head to the oil pump.

The oil pump may be either a centrifugal or positive displacement design. Positive displacement pumps may be of the gear, screw, lobe, or vane type. Because a failure can occur rapidly on loss of lubrication, a backup pump is typically installed. The backup pump may be a direct or indirect drive. Direct drive pumps are driven from the accessory gearbox. Indirect drive pumps are driven by an electric motor or hydraulic motor that receives hydraulic or electric power from the accessory gearbox.

The lubrication system may use both full flow and bypass filter systems. Whether full flow or bypass, redundant filters are installed that can be switched during operation by a three-way valve. The bypass filter system also uses filters that are capable of trapping smaller particles (such as 1 μm). If a positive displacement oil pump is used, filter elements can weaken over time because of the pressure pulses generated by the pump.

A pressure regulator is provided to ensure that the pressure in the lubrication system is maintained at a constant pressure. Although not required for centrifugal pumps, they are generally recommended. They are always used if the oil pump is a positive displacement pump.

Lube oil coolers are provided to remove heat from the oil before it is distributed to the turbine. Heat is introduced to the oil from bearing friction, conductive and convective heat transfer from hot turbine gases, and hot gases from seal leakage. Coolers may be either air- or water-glycol-cooled design. Air coolers use electric fans to draw air across the coolers. In water-glycol designed coolers, the oil pressure is maintained at a higher pressure than the water-glycol mixture to prevent the intrusion of water into the turbine.

5.1.4.2 Lubrication System Vulnerabilities and Operating Experience

5.1.4.2.1 Sludge and Varnish

Sludge and varnish are major lube oil problems in gas turbine engines. Once the additives in turbine oil deplete, the oil becomes saturated with soluble, soft contaminants. As the oil cools, the contaminants come out of solution and form varnish deposits—a process referred to as *autodegradation*. *Autodegradation* of oil is defined as the automatic generation of soft contaminants in a static, cool body of oil. The rate of autodegradation depends on the quality of the oil and the severity of the oil environment, particularly the amount of spark generated in mechanical filters. The lower the quality of a turbine's lube oil, the greater the impact of autodegradation. Varnish deposits will form in low-flow, low-temperature areas of the system, whereas high-flow, high-temperature areas remain varnish-free. Electrostatic oil cleaners, agglomerators, or cellulose filters for varnish removal may be able to keep the oil in the sump very clean, but they cannot stop varnish from forming in low-flow/low-temperature areas. The QSA test and membrane patch colorimetry can be used to measure varnish potential.

Good operating practices remain the best line of defense. These may include the following:

- **Minimize spark discharge**. Filters in gas turbine lube oil systems contribute spark discharge damage. The damage is caused by the buildup of static electricity in the oil and on the filters as high-velocity oil flows through the tight clearances in the filter media. Measures that can be used to minimize spark discharge damage include the following:
  - Use both sides of duplex lube oil filters if possible. This reduces the velocity of the oil through the filters.
  - Increase the micron ratings of the last-chance filters to the maximum allowed by the OEM. Determine if alternative filter media can be used that is less susceptible to buildup and maintaining a static charge.
  - Remove last-chance filters with the recommendation of the OEM.
- **Keep the lube oil warm and moving**. Insulation and heat tracing in areas of low temperature and/or flow can help minimize autodegradation and sticking of valves.

- **Reduce levels of soluble contaminants**. The use of ion-charge bonding (ICB) technology can be used to remove soluble contaminants, such as acids, from the oil. ICB technology uses carefully chosen and treated ion-exchange resins to remove specific soluble products from lube oil.
- **Use lube oil misting**. Lube oil misting from the turbine causes housekeeping problems, environmental problems, and a loss of lube oil. The use of oil mist systems or filters can reduce or eliminate this problem.
- **Monitor wear particulate material**. Wear particulate material can cause extensive damage to rotating surfaces, especially with the high speeds of the gas turbine engine. The new in-line debris detector, which uses electronic intelligence to determine bearing wear, can achieve capture efficiencies as high as 100% compared to a capture efficiency of 25% typical of older, magnetic chip detectors. This provides an earlier warning of potential bearing failures. Many have the ability to set debris threshold size, thus avoiding nuisance alarms from fine ferrous particles. Many of the electronic chip detectors are capable of monitoring metallic and non-metallic particles.
- **Evaluate lube oil quality**. Selecting the right lube oil and maintaining its cleanliness are keys to good gas turbine performance. Localized hot spots in the gas turbine lube oil can initiate oxidation, resulting in the formation of sludge, varnish, and hard carbon deposits. To avoid these problems, vendors have developed lubricants with higher thermal stability and better oxidation control. Testing technology is useful in determining the condition of a lube oil after it has been added to the sump. These tests are used to determine the condition of lubricants and their suitability for continued use, the amount of wear on internal, oil-wetted surfaces, and the presence of contaminants that lead to premature failure. Specific recommendations for choosing and monitoring lube oils include the following:
  - Use Group II or III base oils.
  - Monitor routinely for evidence of oxidation and thermal degradation.
  - Maintain temperatures uniform through the lube system (for example, heat tracing).
  - Increase the flow through the system.
  - Monitor oil for loss of antioxidants.
  - Use electrostatic cleaning units.

5.1.4.3 General Maintenance of Gas Turbines (Lubrication System)

The main objectives in maintaining the lubrication system are to maximize turbine and component performance, minimize turbine downtime, and improve the turbine's overall reliability. Condition monitoring plays an important role in gas turbine maintenance. Particular attention should be given to periodic vibration monitoring and trending, maintenance of the lubrication system, use of on-line monitoring (temperature, pressure, vibration), and an aggressive PM program.

Vibration monitoring should be performed on turbine rotors, bearings, and accessory gearboxes. Turbines are equipped with installed vibration monitoring equipment, but routine vibration monitoring with handheld instrumentation provides valuable information as to the condition of the turbine and components. Vibration can be induced into the turbine from numerous sources, including imbalance, misalignments, poor mounting, oil whirl, gear problems, and mechanical defects.

Maintenance of the lubrication system includes the components in the lubrication system and the lubricant itself. During operation, oil levels, temperatures, and pressure should be monitored. Periodically, these parameters should be trended to detect potential degradation. Pressures should be monitored across filters for loading and filter performance. Pressure drops may also be indicative of leakage. The turbine should be monitored for external oil leaks when shut down and operating. Maintaining a leak-tight system is important—because turbines operate at very high temperatures, there is a potential for fires. Internal oil leaks are not easily identified, but if present, they may appear as smoke from the exhaust of the engine. Oil temperatures should be monitored to ensure that the lubrication system is operating satisfactorily. Increasing temperatures may be indicative of oil cooler problems (it might be plugged or degraded, for example). Bearing temperatures should be monitored to ensure that they are being properly cooled. This may be accomplished by temperature measurements of the oil, leaving the bearings or the oil temperature in the return line prior to entering the reservoir. Some turbines may be equipped with contact temperature instruments, such as theromcouples or resistance temperature detectors. An increase in the oil temperature may also occur if faulty or degraded seals allow hot gases to contact the oil.

5.1.4.4 Condition Monitoring and Inspections

Condition monitoring of the turbine is typically performed with vibration and oil analysis. These should be used together to help support diagnosing the overall status of the turbine and its components. When the unit is shut down, boroscope inspections are also useful in supplementing vibration and oil analysis to assist in the identification of internal engine problems.

5.1.4.5 Troubleshooting

Troubleshooting techniques used for gas turbines use both oil and vibration analysis. Results from these techniques should be monitored and trended to aid in troubleshooting efforts. OEM references and operational history should also be consulted when developing troubleshooting plans.

The lubrication system of gas turbines is subject to lubricant oxidation and thermal degradation that causes varnish and sludge, worn bearings, failed seals, and other contaminant intrusion (water, dirt, dust, and so on).

Varnish and sludge are caused by oxidation and thermal degradation. Oxidation problems can be determined by oil analysis, where viscosity, the AN, and color changes will be identified. This is of particular concern when the control oil system shares the reservoir with the lubrication system. The formation of varnish and sludge can deposit in areas of close tolerance (such as servo control valves), leading to degraded or failed operation. The high temperature of the lubricating oil is conducive to thermal degradation. The lubricants are also subject to electrostatic discharge as a result of molecular friction as oil passes through filters and servo valve surfaces. Electrostatic discharges can achieve extremely high temperatures (thousands of degrees), resulting in instantaneous thermal degradation. Turbine oils should contain additives with superior antioxidation properties.

Water contamination is not as much of a problem as it is in steam turbines, but it does occur. Water must be monitored for oil analyses—water not only affects the lubrication properties of the oil, but can lead to foaming and bacterial growth.

Particulate contamination in a gas turbine may be a result of wear or the introduction of contaminants such as dirt, dust, and so on.

Oil analysis provides the general condition of the lubricant, deterioration of the lubricant due to contaminants, and the general condition of components within the equipment lubricated. Oil analysis should be used in conjunction with equipment operating histories. A variety of standardized oil analysis tests are available to assist in determining the condition and age of the lubricant. Oil analysis recommendations are provided in ASTM D4378, Standard Practice for In-Service Monitoring of Mineral Turbine Oils for Steam and Gas Turbines. The practice is intended to assist in maintaining effective lubrication of all parts of the turbine and guard against the onset of problems associated with oil degradation and contamination. The practice covers the requirements for the effective monitoring of mineral turbine oils in steam and gas turbines. The practice includes sampling and testing schedules to validate the condition of the lubricant through its life. Oil analyses that are used routinely to monitor gas turbine lubricant quality include viscosity, AN, particle count, water, and spectrographic analysis of wear particles.

Bearing problems observed in gas turbines are typically a result of poor lubricant quality, temperature, vibration, and contaminants (wear and intrusion). Heavy industrial gas turbines use journal bearings because of the heavier loads they experience. Bearing problems experienced are similar to those experienced by steam turbines. Derivative aero-engines use anti-friction bearings. Anti-friction bearings have low starting friction but high running friction due to the higher speed of the engine. Vibration monitoring is essential in determining the health of these bearings, especially due to the high speeds that the gas turbines operate. Fatigue and operational wear, poor lubrication, and misalignment contribute to most bearing fault frequencies observed.

5.2 Diesel Engines

The diesel engine is the prime mover of choice for emergency power at most nuclear power stations. The diesel engine is a proven source of standby power because of its performance, reliability, and durability of operation. Diesel engines are also used as the prime mover for pumps (such as fire pumps) and a source of backup power to other systems (such as security systems). This section describes a typical diesel engine lubrication system and explores various maintenance philosophies associated with the maintenance of the lubrication system and its components.

5.2.1 System Operation

The diesel engine lubrication system is an FFFL system. The lubrication system is composed of pumps, valves, piping, filters, strainers, coolers, and instrumentation for monitoring and control. The lubrication system lubricates and cools various engine components. The lubrication system components may be part of an engine package or mounted to or near the engine skid. There are numerous diesel engine OEMs. It is not the intent of this report to encompass all of the available types of diesels used throughout the nuclear industry. However, the general operation is similar, with major differences in the arrangement and number of components and instrumentation available. Maintenance, operational, and EDG Owners Group (if applicable) manuals should be referenced for specific information related to a given engine.

The source of lubrication oil for the diesel is typically the engine sump, generally located beneath the engine. There are a variety of pumps performing various functions. The main lube oil pumps are normally engine-driven pumps. The oil is pumped through an oil cooler, where the temperature is thermostatically controlled during normal operation. The oil also passes through a filtration system. The system is sometimes capable of being bypassed for filter replacements if required. The oil is then circulated to the various system components (the main bearings, cam shaft bearings, camshaft, cylinder head gear, and so on). Oil then gravity-feeds back to the sump. For some applications, some of the oil is diverted to the turbocharger, where it typically first passes through a separate turbocharger oil filter system. Other models of turbochargers have a self-contained oil system, separate from the main oil system.

Pre-lubrication or circulating pumps are sometimes provided to circulate oil during standby conditions to help reduce wear that can be caused by a fast start. Some engines may operate only the pre-lubrication pump just prior to startup of the engine, whereas in others, oil is circulated continuously. Pre-lubrication and circulating pumps can also be used for pre-lubrication of a turbocharger—either continuously, just prior to a start, or with a drip feed system. Some of these systems also help remove the heat from the turbocharger when the engine is in a cooldown cycle.

Some engine makes are designed with a bypass filtration system. The bypass filtration system is especially beneficial in that it is not part of the min FFFL system, allowing it to have much lower flow rates and to use a finer, denser filter medium. This allows the bypass filtration system to remove smaller particulate material.

5.2.2 Lubrication System Vulnerabilities and Operating Experience

Although in many respects the lubrication system is conceptually simple, it is subject to a number of vulnerabilities. EDGs are standby engines with limited hours of operation; however, for some engines, pre-lubrication systems run continuously. Lubrication schemes are subject to a variety of faults—lubricants will degrade and break down, and materials compatibility issues can lead to failures. The following operating experience provides examples of problems that have been related to diesel lubrication systems:

- A station experienced a trip of the diesel engine on low lube oil pressure. The problem identified was water in the lube oil. The water entered the lube oil system through the lube oil cooler. The water vaporized, creating a high crankcase pressure and backpressure in the lube oil supply. This caused low oil pressure and an engine trip. Cooler failure was a result of inadequate corrosion inhibitor resulting in exfoliation type solder corrosion at the tube-to-tube sheet weld (Significant Operational Event Report [SOER] 80-4).
- A station experienced the presence of high silicon concentration in the lubrication oil in a sample drawn following a post-maintenance test run. The silicon was determined to be nonabrasive and did not present a problem to diesel operation. The silicon was determined to come from gasket sealant materials. Although the event did not present a problem to the diesel, it nonetheless highlights the need to be aware of materials incompatibilities and the introduction of foreign material into lubrication systems during maintenance activities (OE 14115-2002).
- Fires due to lubrication oil leaks have led to fires in the diesel engines. From 1974 to 1982, 10 fires were identified on the diesel due to leakage. Most of these fires were small and easily controlled. Although these fires have been experienced in the distant past, this still emphasizes the need for proper housekeeping and careful attention to maintenance activities, such as tightening filters, fittings, and so on. Recently, fires have been experienced at diesel exhaust manifolds due to lube oil leakage past the manifold covers/gaskets (Significant Event Report [SER] 70-82, SER 36-81, SER 55-81, SER 80-81, SER 70-82, and Information Notice [IN] 2008-05).
- Stations have experienced problems with the intrusion of fuel oil into the lubricating oil. Fuel intrusion into the lubrication oil has been experienced for a number of reasons, including loose fittings caused by inadequate maintenance practices or vibration, leaks in fuel oil lines, and failed O-ring seals on fuel injectors. This type of event has resulted in fires, failed bearings, and out-of-service time on a key safety-related component. Between 1978 and 1985, 11 events occurred due to the intrusion of fuel oil into the lubrication system (SER 45-85, Operating Experience [OE] 27913-2008, and IN 2007-27).
- EDG lube oil check valves were installed in the lubrication system with incompatible material. The technical manual drawing allowed both ethylene propylene (EPR) and Viton (FPM) elastomers. EPR material is not compatible with lubricating oil, and FPM material should be used. The vendor manual for the EDGs was a compilation of vendor information (manuals and drawings) for the various components associated with the diesels. The check valves were used in both lube oil and jacket water systems. There was no information in the manual specifying the elastomer material to be used in each system (OE15864-2003).

- Extensive coking has been observed on a station's EDG lube oil pre-circulation heaters used to keep the lube oil warm (see Figure 5-1). The problem was attributed to excessive heater watt density. The problem was resolved using a proportional integral derivative controller scheme versus a thermostatic controller.

Figure 5-1
EDG heaters pre- and post-modification

- A diesel generator jacket water cooling pump motor was determined to have suffered catastrophic bearing failure due to a lack of lubrication of the inboard and outboard motor bearings. Review of the maintenance history revealed that the lubrication PM had been canceled due to component failures on other equipment caused by over-lubrication of double-shielded bearings. The decision was based on industry information and equipment failures due to over-lubrication. This OE points out the need for careful consideration when changing PM activities (OE19895-2005).
- Degradation of the power block assembly of two EDGs caused by an incompatibility of the lubricating oil with fuel oil with a low sulfur content. During pre-operational testing of a new safety-related EDG, sporadic spikes in crankcase pressure and lubricating oil seeping out from the crankshaft seal were observed. Upon disassembly, excessive carbon deposits were observed in all cylinders. The problem was determined to be incompatibility of the lubricating oil with the low-sulfur fuel. With increased use of low-sulfur fuels, stations should be aware that potential incompatibility problems have been observed (IN 96-67).
- Two stations have reported the discovery of cylinder liner scuffing in SACM Model UD45 diesel generators due to excessive combustion chamber deposits. These are the only two plants with SACM diesel generators in the U.S. nuclear fleet. Note that no other make or model of engine has observed similar issues, and SACM engines in other countries have not yet reported similar issues. Investigations concluded that the excessive deposits were due to an incompatibility between the low-sulfur diesel fuel and high ash content/high total base number lube oils used in these engines. A white paper concluded that the root cause of the

combustion chamber deposits and cylinder liner scuffing was a high lube oil consumption rate—inherent to the SACM design—during the break-in period. Use of high ash content lube oil in an engine with high lube oil consumption rates can lead to excessive deposit formation, which in turn can cause stuck piston rings and cylinder liner scuffing. Other stations with other makes and models of EDGs have used low-sulfur fuel and high ash content lube oils for many years without experiencing excessive combustion chamber deposits (MPR white paper).

5.2.3 PM/Predictive Maintenance

Diesel engine PM and predictive maintenance are conducted to optimize diesel reliability and unavailability performance. PM of the lube oil system of diesel engines consists of the following key components:

- Routine inspections
- Lubrication system maintenance
- Surveillance testing
- Oil analysis

Nuclear EDGs are standby engines not subject to long operating hours. Typically, the diesel is subjected to a monthly surveillance run (1–4 hours) and several other 18- to 24-month surveillances, including an EDG endurance and margin run (typically 24 hours). Additional starts may be required to meet post-maintenance testing requirements of the diesels.

EDG maintenance can be time- or performance-based. Many stations' EDG maintenance programs have moved to performance-based, developed considering the run time of the EDGs, OEM recommendations, and station and industry failure history, typically unique to the EDG manufacturer. In some cases, EDG owners groups have worked with manufacturers to develop maintenance programs specific for nuclear EDGs in standby service. For condition-based maintenance, the majority of the maintenance is based on inspections as well as monitoring performance data such as lube oil temperatures and pressures and oil analysis information. Some tasks relating to lube oil, such as filter changes, and strainer cleaning are still performed on a time basis.

Oil analysis provides the general condition of the lubricant, deterioration of the lubricant due to contaminants and the general condition of components within the equipment lubricated. Oil analysis should be used in conjunction with equipment operating histories. A variety of standardized oil analysis tests are available to assist in determining the condition and age of the lubricant. Oil analysis recommendations are provided in ASTM D6224, Standard Practice for In-Service Monitoring of Lubricating Oil for Auxiliary Power Plant Equipment. The practice is intended to assist plants in maintaining effective control over their lubricating oils and lubrication monitoring program. The practice may also be used to perform oil changes based on test results rather than service time or calendar time. The practice provides assistance for monitoring lubricating oils—guarding against excessive component wear, oil degradation, or contamination—sampling and testing schedules, and information on how oils degrade. The practice covers the requirements for the effective monitoring of mineral oil and phosphate ester fluid lubricating oils in auxiliary plant equipment used (for example, gears, hydraulic systems, diesel engines, pumps, compressors, and EHC systems).

5.2.3.1 Routine Inspections

Routine inspection of the diesel engine is performed daily by operations personnel during the performance of their equipment rounds. These inspections are mainly visual in nature, with some equipment operational checks. Visual inspections include the following types:

- Standby oil temperature
- Standby oil pressure (if applicable)
- Oil level
- Filter d/p
- Oil cooler TCV operation
- Turbocharger oil level (if applicable)
- Strainer d/p
- Immersion heater operation (if applicable)
- External oil leaks
- Pre-lubrication or circulating pump operation
- General area cleanliness

5.2.3.2 Surveillance Testing

Surveillance tests or operability checks are performed to meet technical specification requirements. Surveillance testing may be performed using fast or slow starts depending on station technical specifications.

While the engine is operating and loaded, all of the systems (fuel, air, lubrication, cooling, and so on) are monitored to ensure proper performance. With respect to the lubrication system or lubricated components, the following checks or parameters may be monitored:

- Oil manifold pressure
- Crankcase pressure
- Oil temperature (inlet and outlet of cooler)
- Filter d/ps
- Oil level

- Strainer d/ps
- Turbocharger (oil pressures and exhaust temperatures)
- Tubing or other external leaks

Information gained from operating logs is typically used by system or component engineers to monitor and trend various diesel parameters.

5.2.3.3 Routine PM

Routine PM may be either time-based (OEM recommendations) or performance-based (performance monitoring or predictive maintenance analysis), depending on the station EDG program.

General PM on the diesel lubrication system can include the following:

- Routine oil analysis and monitoring
- Changing oil filters (time- and performance-based)
- Cleaning strainers (performance-based)
- Cleaning of oil cooler/heat exchanger (water and oil side; the water side is usually time- and/or performance-based, and the oil side is usually performance-based)
- Thermostatic control valve changeouts

5.2.4 Troubleshooting

Most stations have detailed troubleshooting procedures that provide general guidance related to the development of an effective troubleshooting plan. The plans encompass all aspects of the troubleshooting process, from the identification of the cause(s) to implementation of corrective actions. Troubleshooting plans are typically based on OEM documentation and industry or plant experience. The complexity of a diesel engine and interrelations between systems precludes development of detailed troubleshooting information in this report. When troubleshooting lubrication system problems with the diesel or the turbocharger, the information from the OEM's manual, EDG working groups, and operating experience from time- and condition-based maintenance should be taken into account. Many problems experienced with the oil system can potentially be identified through oil analysis. Table 5-8 provides some generic information with regard to troubleshooting of the turbocharger and diesel oil–related problems. OEM operation/maintenance manuals should be referred to for more detailed information; Table 5-8 is not all-inclusive.

Table 5-8
Troubleshooting lubrication system problems in diesel engines

Diesel		
Trouble	**Possible Cause**	**Recommendation/Action**
Excessive oil usage	Oil leakage from exhaust manifold	Inspect exhaust manifold cover and gasket.
	External oil line leakage	Inspect external oil lines for any evidence of leakage.
	Leakage from lubrication system drains	Check lube system drains. Check air box drains.
	Oil in water expansion tank	For shell-and-tube heat exchangers, inspect for leakage if oil is seen in tank.
	Excessive blow-by	Perform oil analysis.
Oil contamination	Wear, water, foreign material, fuel oil	Perform oil analysis to check for contaminant.
Low oil pressure	Low oil level	Check oil level. Restore oil level to normal band.
	Improper oil viscosity	Verify proper oil grade and viscosity installed in engine. Check for water in oil. Check for fuel in oil. Check fuel jumpers to injectors for cracks. Check fuel manifold piping for leaks. If any of the preceding conditions are found, replace oil.
	Oil circulation problem	Verify filter not plugged. Verify strainers not plugged. Verify pressure regulator/relief valve not malfunctioning. Verify filter bypass valve closed. Verify oil cooler bypass valve not malfunctioning. Check for suction leaks. Check wear on crankshaft bearings. If turbocharger is installed, check turbocharger filter.

Table 5-8 (continued)
Troubleshooting lubrication system problems in diesel engines

Turbocharger		
Most turbocharger failures are a result of conditions external to the turbocharger. If a turbo charger is suspected to be damaged, it should be inspected.		
Trouble	**Possible Cause**	**Recommendation/Action**
Unusual noise (severe humming or metallic distress)	Impeller problem	Check impeller.
	Gear train problem	Check for metallic material under crankshaft gear.
Possible bearing degradation	Excessive play in rotor bearings	Check for external oil leaks. Check diesel smoke (blue smoke).
	Insufficient oil supply	Verify proper turbocharger lube pump operation.
	Turbocharger housing misalignment	Check turbocharger housing alignment.
Gear train failure	Debris intrusion	Check for debris in lube oil system.

5.3 Motors

Every nuclear station has hundreds of electric motors, ranging from fractional horsepower to thousands of horsepower. Regardless of motor size, they all have one attribute necessary to ensure effective, efficient, and reliable operation—lubrication. The majority of motor difficulties begin with bearing problems, and those bearing problems are a result of poor lubrication.

5.3.1 Lubrication System Operation

Industry studies by EPRI and the Institute of Electrical and Electronics Engineers (IEEE) have identified that bearing-related failures are the primary contributor to motor failures. The major cause of motor failures is mechanical damage. The major contributors to mechanical breakage, based on observable conditions that may be detected during routine equipment observations or detailed inspections, are poor lubrication and high vibration. Additional failure information regarding motor failures may be found in *Troubleshooting of Electric Motors* (1000968).

There are two primary lubricants used for electric motors—oil and grease. Electric motors are lubricated with one of the following lubrication methods:

- Forced circulation lubrication (see Section 2.2.1)
- Splash (O-ring/slinger ring) lubrication (see Section 2.2.3)
- Oil bath lubrication (see Section 2.2.2)

There are advantages and disadvantages with respect to the use of oil or grease in motor lubrication. These are illustrated in Table 2-1.

These lubrication methods apply to both horizontally and vertically oriented motors. The choice of lubricant is based on machine application, operating conditions, and desired lubricant characteristics. The choice of lubrication method to use for a given motor depends on several factors, such as the following:

- Motor size
- Bearing type (sleeve or anti-friction)
- Operating environment
- Process medium

5.3.2 Vulnerabilities and Operating Experience

Although in many respects the lubrication system is conceptually simple, it is subject to a number of vulnerabilities and a variety of faults. Lubricants will degrade and break down, and individual components will wear out over time. Materials compatibility issues can lead to failures. This section explores some of the events that have occurred in lubrication systems.

- Recirculation motor generator sets tripped on low lube oil pressure. An infrequent lineup allowed water to back-flow through a check valve into the service air system supplying oil mist eliminators. It was believed that a large amount of sediment entered the system with the water. Filters began to clog more often. The event was compounded because replacement filters were not available in sufficient quantity. An awareness of infrequent operations on systems that interface with lubrication systems should be maintained.
- A condensate pump lower motor bearing failed due to lack of lubrication. The reason for the lack of lubrication was an error in a procedure that identified the bearing as a sealed bearing that did not require lubrication. The error was introduced when several lubrication procedures were combined. Even for sealed bearings, this is a significant period for bearing life. Appropriate PM may have identified this error earlier.
- Addition examples of vulnerabilities where appropriate measures could have prevented the event include the following: 1) An incorrect stock number was listed for an oil in stock. The oil was for the recirculation spray pump motor. Errors in the handling of lubricants can lead to oil incompatibility and worst-case equipment failure. 2) Grease relief plugs were not reinstalled following lubrication. Failure to follow instructions could have led to the ingress of contaminants into the bearing. Attention to detail in operator rounds identified this problem before it could become a larger problem.

5.3.3 General Maintenance Practices

Lubrication system maintenance is a vital part in maintaining electric motor reliability. Motor problems can be minimized with scheduled routine service and maintenance. Whether oil or grease is used as the lubricant will affect the scope of maintenance activities performed. Maintenance activities selected may be based on the following factors:

- Type of motor
- Operational importance of motor
- Failure history
- Operating environment
- Operational duty (continuous/intermittent)
- Lubricant

The periodicity of required motor maintenance may be based on OEM recommendations, the impact to production, the economic consequence of motor loss, safety, and the operating and maintenance histories. No matter what maintenance activities are chosen and performed, they should have a well-founded basis for their performance and be well defined, communicated, understood, and implemented by trained, qualified personnel.

In general, oil-lubricated motors are in the minority with respect to grease-lubricated motors. However, oil-lubricated motors are generally larger and used in more critical operational roles (reactor coolant pumps [RCPs], main feedwater pumps, condensate pumps, and so on). Therefore, it is essential to ensure that good lubrication practices (preventive, predictive, corrective) are implemented.

5.3.4 Routine Inspections

Routine inspections may be implemented shiftly, daily, weekly, or during motor runs. Although most inspections are carried out by operations personnel, maintenance personnel and system/component engineers also perform routine equipment walkdowns and inspections. Inspection may be performed with the motor shut down or operating. The type and degree of information will differ based on when the inspection is performed. Typical inspections that are performed include the following:

- **Lubricant level (operating/shutdown)**. This may be inspected by sight glass or bull's-eye. Constant-level oilers (if installed) should also be checked for proper level corresponding to reservoir level.
- **Lubricant inspection (shutdown)**. This inspection involves the senses. Evidence of color changes (such as abnormal darkening) or cloudiness (such as water or air) may be observed. Also, the smell of the lubricant may indicate certain problems.

- **Temperature (operating)**. When the motor is operating, bearing or bearing oil temperatures should be monitored by installed instruments or contact thermometers or thermography. If contact thermometers or thermography are used, monitored locations should be specified for consistency in comparison of results.
- **Pressure (operating)**. When the motor is in operation and forced circulation lubrication is used, oil pressure(s) should be monitored. Low pressure may indicate leakage paths or pump problems. High pressure may be an indication of blockage. D/p instrumentation may also be installed (such as filters). High d/p may indicate that the filter is reaching its end of life. The time period that the high d/p occurs in should be noted. Filter d/p should change gradually. Sudden increases may indicate buildup of contaminants. If trending shows little d/p change, it is possible that the filter element is defective (for example, has a hole or a tear).
- **General area (operating/shutdown)**. Inspect for signs of leakage. Check for points of potential contaminant ingress into the lubrication system (vent caps, inspection ports, and so on). The motor should be clean of dirt or other debris that may find an ingress path into the lubrication system. Check air exhaust ports to ensure that air is blowing from the ports. If filters are installed, ensure that they are clean. Check for evidence of corrosion that may indicate water ingress paths.
- **Ring inspections (operating/shutdown)**. If inspection ports are provided, inspect oil-ring for proper position (shutdown) or for proper slinging of lubricant to bearings. This also provides an opportunity to inspect for foaming (aeration) of the lubricant.

5.3.5 PM and Predictive Maintenance

Most PM activities for electric motors are specified by the OEM. However, in addition to the OEM recommendations, the operational duty (continuous/intermittent), operating load, environmental conditions, and the operating history of the motor should be included in the PM plan. There are numerous PM activities that are associated with a motor. This section focuses on those associated with the lubrication system, including lubrication, temperature, noise, and vibration.

Lubrication may be performed based on OEM recommendations. Following the OEM recommendations should help ensure optimum bearing life. However, operating history may reveal that lubrication frequency can be increased or shortened. Regardless of these criteria, a bearing should be relubricated whenever it is noisy or running hot. It should be noted that if either of these two conditions requires relubrication, it is likely that some level of damage has occurred with the bearing and further investigation for potential replacement of the bearing should be considered.

Temperature can have an adverse effect on every part of a motor. With respect to the lubrication system, it will result in premature deterioration of the lubricant and shorten the lubricant effective life.

Table 5-9 is provided as guidance for determining condition monitoring/predictive monitoring frequencies for various motor voltages. This guidance is interpolated from *Equipment Condition Monitoring Templates* (TR-1000621).

Table 5-9
PM for motors

Condition Monitoring	High-Voltage Motors (>5-KV)		Medium-Voltage Motors (1-KV and <5-KV)		Low-Voltage Motors (<600-V)		DC Motors	
	Critical	Noncritical	Critical	Noncritical	Critical	Noncritical	Critical	Noncritical
Infrared thermography	6M	6M	6M	6M	6M	1Y	6M	1Y
Vibration analysis	3M	6M	3M	6M	3M	1Y	3M	1Y
Oil analysis	6M	1Y	6M	1Y	6M	NR	6M	NR
Performance monitoring	3M	6M	3M	6M	6M	1Y	6M	1Y
Visual inspection—internal	2Y	3Y	2Y	3Y	AR	AR	6M	6M
Visual Inspection—external	6M	1Y	6M	1Y	6M	1Y	6M	1Y

Notes:
3M – Three-month periodicity
6M – Six-month periodicity
1Y – Yearly
2Y – Every two years
3Y – Every three years
AR – As required
NR – Not recommended

Condition monitoring frequencies are based on three criteria—criticality, service condition, and duty cycles—as follows:

- Critical – failure would directly cause failure of a risk-significant structures, systems, or components
- Noncritical – requires some level of PM rather than allowing motor to fail
- Severe service – excessive environmental conditions (for example, humidity, high/low temperature, radiation, steam, corrosive, and vibration)
- Mild service – Clean area with normal environmental conditions and temperature within OEM specifications
- High-duty cycle – frequent starting, stopping or cycling that may be accompanied by high temperature, vibration or wear. Possible lubricant separation from motor inactivity.

- Low-duty cycle – infrequent starting, stopping or cycling. High temperature, vibration or wear is limited. Possible lubricant separation from motor inactivity.

The most significant criterion affecting condition monitoring frequencies was criticality of the motor. The frequencies provided in this table may be adjusted based on plant specific information related to each particular motor. More specific guidance related to condition monitoring/predictive monitoring can be obtained from this report. This guidance does not apply to run-to-failure motors. Additional information is provided in *Electric Motor Predictive and Preventive Maintenance Guide* (NP-7502).

Thermography is useful in determining the condition of bearings, cooling systems, coupling problems, and so on.

Vibration analysis is useful in analyzing the vibration of the motor (misalignment, imbalance, resonance, and so on) for evaluating bearing or seal performance.

Oil analysis is useful in determining the condition of the oil (contaminants, particles, water, thermal, and so on). Evidence of conditions that may identify bearing failures, cooling system failures, seal failures, and so on can be determined.

Performance monitoring uses either installed instrumentation or handheld instrumentation. Information can be obtained and trended to assist in determining the health and performance of the motor (such as bearing temperatures, lubricant temperatures, oil pressure, cooling water temperature, and filter d/ps).

Internal visual inspections may be used to assess the condition of bearings, journals, oil rings, pumps, orifices, and other components that are not normally assessable during motor operation.

External visual inspections include nonintrusive checks of accessible portions of the motor or support systems (such as cooling water flow, leaks, and alignment checks).

5.3.6 Troubleshooting

Most stations have detailed troubleshooting procedures that provide general guidance related to the development of an effective troubleshooting plan. The plans encompass all aspects of the troubleshooting process, from the identification of the cause(s) to implementation of corrective actions. Troubleshooting of a motor's lubrication system may involve one or more symptoms or conditions. Table 5-10 provides some general information or guidance with respect to troubleshooting motor lubrication systems. OEM references and operational history should also be consulted when developing troubleshooting plans.

Table 5-10
Troubleshooting motors

Symptom	Cause	Actions
High bearing temperature	Under-lubrication	Analyze oil. Add lubricant. Bearing inspection may be warranted based on temperature achieved at next inspection.
	Over-lubrication	If oil lubricated return oil level to normal. If grease lubricated, bearing replacement may be required. Investigate greasing practices if other problems have been seen.
	Water intrusion	Verify by analysis. Correct cause. Drain and add new lubricant.
	Foaming/aeration	Check oil level Verify by analysis Correct cause Drain and add new lubricant
	Excessive wear	Analyze oil for contaminants. Replace bearing.
Noisy/excessive vibration	Alignment (driver/pump)	Check alignment. Soft foot.
	Under-lubrication	Add oil to bearing reservoir. Check slinger ring operation. Grease to bearing.
	Over-lubrication	If oil drain to normal level. If grease, replace bearing.
	High/low temperature	Return temperature to normal band.
	Excessive bearing wear	Analyze oil. Inspect bearing.

Table 5-10 (continued)
Troubleshooting motors

Symptom	Cause	Actions
Low oil pressure	Oil pump problem	Inspect oil pump for proper operation.
	Under-lubrication	Check for proper lubrication. Check for foaming/aeration. Inspect suction line for blockage.
High oil pressure	Clogged filter	Check filter d/p. Replace filter if d/p high. Analyze filter for potential causes.
	Clogged orifices	Check lubrication system pressure. Inspect/clean orifices. Analyze oil for cause.
Shortened bearing life	Alignment (driver/pump)	Check alignment. Soft foot.
	Corrosion	Analyze oil. Drain, flush, refill. If bearing affected, replace.
	Oil deterioration	Analyze oil. Correct causes of identified problems. Inspect/replace bearing.
	Excessive lubrication	If oil, drain to normal level. If grease, replace bearing/lubricate.
	Under-lubrication	Check lube system operation (for example, slinger ring). If oil add oil. If grease add grease. Analyze oil for wear. Replace bearing if warranted.
	Shaft imbalance (driver/pump)	Check vibration levels. Balance shaft.

5.3.7 RCP/RRP Motors

RCPs used in PWRs and RRPs used in BWRs transport water through the reactor vessel for cooling. They are required to run continuously for the duration of a fuel cycle. Generally, they are not accessible at power. RCP and RRP motor lubrication system issues (such as oil leakage, oil collection tanks to collect leakage, and oil degradation [foaming, particulate, sludge]) have been prominent in recent years. Motor maintenance, lack of maintenance, and lubricating oils contribute to many of these concerns.

RCP/RRP motor OEM recommendations (in the form of maintenance manuals and bulletins, for example) should be adhered to at all times. These recommendations often contain specific guidance on lubrication systems, including periodic inspections and part replacements. Often, gaskets and sealing systems—such as O-rings, packing, and seals—have a limited life expectancy, especially considering the harsh environment in which these motors operate. Additional information on RCP/RRP motors is available in the EPRI report *Reactor Coolant Pump/Reactor Recirculation Pump Motor Lubrication Oil Systems Maintenance Guide* (1013456). Additional information on Westinghouse motors is provided in Westinghouse Engineering Memorandum 6665, "Reactor Coolant Pump Motor Bearing Oil Analysis."

5.4 Pumps

5.4.1 Pump Lubrication System Operation

Grease lubrication in pump bearings is widely used for heavily loaded bearings that rotate at low to moderate speeds. It is also widely used for vertically mounted pumps, where it is difficult to maintain a reservoir oil level. Greases are selected as a lubricant for the following reasons:

- Consistency
- Mechanical stability
- Water resistance
- Base oil viscosity
- Temperature stability

Temperature is a major consideration in the selection of the grease to be used. High process fluid temperatures and high environmental temperatures will necessitate a grease with a high melting point.

Pump OEMs typically will specify the type of grease (grade and consistency) required for the pump. Greases come in many forms, and the OEM will specify the correct form for the given application.

The base of the grease is an important consideration for lubrication temperature. If the grease is too soft, it will flow into spaces between moving parts and can lead to excessive friction. If the grease is too hard or stiff, it will not enable the moving parts of the bearing to move. This will be especially noted during startup conditions.

Over-greasing can lead to excessive heating of the bearing and can result in rupture of the bearing seals (shielded bearings). This will allow contaminants to enter the bearing and cause excessive wear, leading to bearing failure.

The duty cycle and operating environment will directly affect the lubrication interval of the bearings. Greased bearings may be required to be relubricated every three to six months depending on operating conditions. OEM recommendations and operating experience should be used to determine the proper regreasing frequency.

5.4.2 Lubrication System Vulnerabilities and Operating Experience

Although in many respects the lubrication system is conceptually simple, it is subject to a number of vulnerabilities. Lubrication schemes are subject to a variety of faults. Lubricants will degrade and break down, and individual components will wear out over time. Material compatibility issues can lead to failures. This section explores some of the events that have occurred to the lubrication system.

At one station, water was identified in the oil of the centrifugal charging pumps. An investigation revealed that the cause of the water intrusion was failure of the oil cooler, where the tube is rolled into the tube sheet. The failure was due to erosion. The cooling medium was river water with entrained silt and sand. High water velocities at this turbulent junction contributed to the failure.

An awareness of the impacts of different system configurations that interface with lubrication systems should also be considered. At one station, the centrifugal charging pump lube oil heat exchangers were plugged following cooling water lineups used for surveillance testing of the cooling water system. The lineups resulted in abnormal flow and pressure transients in the river water system. Mud and silt were transferred to the low elevation in the system, plugging the oil heat exchangers. An awareness of system interactions may have prevented this event.

5.4.3 General Maintenance Practices

Maintenance practices can sometimes reduce the reliability of the operating equipment in the absence of attention to detail and strict adherence to good procedural practices. This is especially true when installing and removing bearings. The following applies during bearing installation or removal:

- Pay careful attention to shaft and bearings during the removal process. Form-fit bearings are sometimes heated or forced onto and off. Heating can result in damage to both shaft and bearings.
- Bearings should not be over-lubricated. Oil or grease do not conduct heat well, and over-lubrication can result in eventual bearing overheating.
- Bearings installed in a shaft in the wrong place could affect radial loading.

Bearings should be stored properly. They should be covered or sealed, coated with a preservative or lubricant to prevent corrosion, and stored in an area not subject to induced vibrations (false brinneling/hardening).

Bearings can fail for any number of reasons, including the following:

- Poor alignment between machine and driver
- Improper bearing fit-up (poor interference fit, misposition on a tapered sleeve, and so on)
- Manufacturing defects (such as bent shafts, imbalance, bearings out-of-round, and bad bearing)
- Operational inducted failures (such as shaft expansion, excessive axial thrust, vibration, cavitation, and water hammer)

Perform the following checks before and after startup:

- Check the lubrication system—its oil level, cleanliness, bearing temperatures, general area, and so on.
- Listen for any abnormal noises or rubs.
- Look for vibration problems.

Oil analysis provides information about the general condition of the lubricant, deterioration of the lubricant due to contaminants, and the general condition of components within the equipment lubricated. Oil analysis should be used in conjunction with equipment operating histories. A variety of standardized oil analysis tests are available to assist in determining the condition and age of the lubricant. Oil analysis recommendations are provided in ASTM D6224, Standard Practice for In-Service Monitoring of Lubricating Oil for Auxiliary Power Plant Equipment. The practice is intended to assist in maintaining effective control over their lubricating oils and lubrication monitoring program. The practice may also be used to perform oil changes based on test results rather than service time or calendar time. The practice provides assistance for monitoring lubricating oils; guarding against excessive component wear, oil degradation, or contamination; sampling and testing schedules; and how oils degrade. The practice covers the requirements for the effective monitoring of mineral oil and phosphate ester fluid lubricating oils in auxiliary plant equipment used (such as gears, hydraulic systems, diesel engines, pumps, compressors, and EHC systems).

Vibration problems observed in vertical pumps are generally contributed to the motor initially. The motor is readily observable, and vibration readings are easily obtained and can be higher than other locations, being on the end of the drive train.

5.4.4 Troubleshooting

There are several reasons that troubleshooting is performed, but the primary reason is to identify and correct a problem that has resulted in the pump not operating at optimum performance, which causes pump downtime, potential loss of production, and an inefficient use of maintenance personnel.

The ultimate goal for pump operation is to have efficient and reliable pump operation. Whether a pump develops problems because of design, installation, or poor or no maintenance each time the pump goes down for repair, undesirable costs are incurred.

Troubleshooting pump lubrication system problems is similar to troubleshooting electric motor lubrication system problems because the lubrication systems employed by each are the same (such as forced flow, oil bath, splash, and grease). The best source of troubleshooting information is the pump OEM—OEM references and operational history should also be consulted when developing troubleshooting plans. General information or guidance is provided in Table 5-11.

Table 5-11
Troubleshooting pumps

Symptom	Cause	Actions
High bearing temperature	Under-lubrication	Analyze oil. Add lubricant. Bearing inspection may be warranted based on temperature achieved at next inspection.
	Over-lubrication	If oil lubricated return oil level to normal. If grease lubricated, bearing replacement may be required. Investigate greasing practices if other problems have been seen.
	Water intrusion	Verify by analysis. Correct cause. Drain and add new lubricant.
	Foaming/aeration	Check oil level. Verify by analysis. Correct cause. Drain and add new lubricant.
	Excessive wear	Analyze oil for contaminants. Replace bearing.
Noisy/excessive vibration	Alignment (driver/pump)	Check alignment. Soft foot.
	Under-lubrication	Add oil to bearing reservoir. Check slinger ring operation. Grease to bearing.
	Over-lubrication	If oil drain to normal level. If grease, replace bearing.
	High/low temperature	Return temperature to normal band.
	Excessive bearing wear	Analyze oil. Inspect bearing.

Table 5-11 (continued)
Troubleshooting pumps

Symptom	Cause	Actions
Low oil pressure	Oil pump problem	Inspect oil pump for proper operation.
	Under-lubrication	Check for proper lubrication. Check for foaming/aeration. Inspect suction line for blockage.
High oil pressure	Clogged filter	Check filter d/p. Replace filter if d/p high. Analyze filter for potential causes.
	Clogged orifices	Check lubrication system pressure. Inspect/clean orifices. Analyze oil for cause.
Shortened bearing life	Alignment (driver/pump)	Check alignment. Soft foot.
	Corrosion	Analyze oil. Drain, flush, refill. If bearing is affected, replace.
	Oil deterioration	Analyze oil. Correct causes of identified problems. Inspect/replace bearing.
	Excessive lubrication	If oil, drain to normal level. If grease, replace bearing/lubricate.
	Under-lubrication	Check lube system operation (such as slinger ring). If oil, add oil. If grease, add grease. Analyze oil for wear. Replace bearing if warranted.
	Shaft imbalance (driver/pump)	Check vibration levels. Balance shaft.

5.5 Gears and Gearboxes

Gears and gearboxes are used in numerous industries and for many applications. Although their use in the nuclear industry may be less widespread by comparison with other industries, gears are used in some applications, including turning gears, motor-operated valves, and valve operators. Gears are used to do the following:

- Provide gear reduction, allowing a rapidly spinning motor to provide a greater output torque at a slower speed
- Provide gearing for slowly rotating motors to increase the speed of the end device
- Provide for a change in the direction of rotation
- Provide for a change in the axis of rotation
- Provide for conversion of rotation into linear motion

Gears accomplish the preceding through several different gear types and arrangements, include the following:

- Spur gears: used to create large gear reductions and to change rotational direction. These gears are very noisy compared to other gear types.
- Helical gears: used to create large gear reductions, less noisy than spur gears, capable of higher loads, generate a thrust load that must be compensated for by the use of thrust bearings.
- Bevel gears: used to change the axis of rotation. Can be noisy, but noise can be reduced through the use of curved teeth similar to helical gears.
- Worm gears: used for large gear reductions. Subject to sliding rather than rotational friction, generating higher temperatures. Tallow or synthetic oil designed for these gears is recommended in the lubrication of worm gears. Ensure that adequate antioxidation additives are in the lubricant to extend the life of the tallow.
- Rack and pinion: used to convert rotation to linear motion.

Like other mechanical devices wherein surfaces are in contact with one another, gears require lubrication to work effectively and efficiently. Lubrication of gears or gear boxes has many of the same requirements of other machines or components. However, gears also have special needs. The purpose of gear lubrication is to ensure effective, slip-free power transfer with good reliability, low maintenance, and long life. Lubrication of gears lubricates gear teeth, removes generated heat, and lubricates bearings that may be used in the gear train.

To ensure that these functions are maintained adequately, gear lubrication should possess the following performance characteristics:

- Thermal and oxidation stability
- Protection against excessive gear and bearing wear
- Cleanliness of gears and bearings

- Compatible with gearbox materials, such as seals and paints
- Protection against extreme pressure, corrosion, foaming, and emulsification

When selecting a gear lubricant, the following should be considered:

- Gear type
- Speed
- Load
- Temperature

Surface fatigue, pitting, and scuffing can occur on the gear teeth at contact points if the lubricant film is insufficient. This ultimately will result in increased temperature and lead to additional surface wear. Because worm gears operate in the boundary layer region under sliding friction, the lubricant must possess good thermal and oxidation stability. Extreme pressure additives are used in gear applications to provide a film on the teeth to protect against scuffing, scoring, and localized welding during boundary lubrication conditions (such as startup, stopping, and high-impact loads). Advances in metallurgical technologies have resulted in smaller gearing and smaller gearboxes. This has presented a challenge to gear lubrication because the gearbox contains less lubricant. Synthetic lubricants have been developed that help meet this challenge. These lubricants are well suited for high- and low-temperature applications and high loads. They possess a relatively high viscosity index (stable viscosity of a wide range of temperature variations), giving the lubricant improved thermal and oxidation properties. Disadvantages of synthetic lubricants are that they cost more and have compatibility issues with some materials, for example, surface materials and elastomers.

Gears or gearboxes are lubricated by grease, splash, or spray lubrication. Grease lubrication can be used for open or enclosed gears, provided that they are operated at low speeds—that is, less than 20 ft per second (fps) (6.1 meters per second [mps]) tangential speed. Grease lubrication is not recommended for gears that experience high loads or operate continuously because of poor heat removal. Care should be taken to prevent over-greasing, which also may affect cooling or result in increased viscous drag and power losses. Splash lubrication is achieved by allowing the gears to dip into the oil reservoir as they rotate. Splash lubrication is used for gears that rotate at moderate speeds (tangential gear speeds between 13 fps and 50 fps [4.0 mps and 15.2 mps]). The gears must have sufficient speed to pick up the lubricant and splash it on all the gear teeth and other components in the gearbox.

Similar to oil ring lubrication systems, the lubricant level must be properly maintained. If the oil level is too high, oil churning and air entrainment can occur. If the level is too low, the gears will suffer lubricant starvation. Splash lubrication is effective for lubrication of spur, helical, bevel, and worm gears. Spray lubrication is generally provided directly to the gear teeth using shaped nozzles. It is generally used on gear systems that have tangential speeds above 40 fps (12.2 mps). With these higher gear speeds, it is important to ensure that the gear teeth are receiving adequate oil because centrifugal forces and air flow from the gear(s) will deflect the oil spray.

Contaminants typically enter a gearbox during operation through the seals or breathers. Contamination may also be introduced to the gearbox during maintenance activities, such as inspections, repair, and lubricant changes. Gearboxes should be equipped with breathers to prevent the introduction of dirt, dust, and other debris. When gearboxes are operated in areas of high moisture, they should be fitted with a desiccant type of breather. Having the proper type of seal aids in the prevention of contaminant intrusion. Lip-type seals are relatively cheap, but they wear out frequently. A labyrinth seal is more costly but provides better sealing against particulate and water contamination.

Filtration systems are rarely used in gearboxes. The size of the gearbox generally prohibits their use and effectiveness. However, larger gearboxes may use a bypass filtration system to maintain lubricant cleanliness standards.

Oil analysis provides information about the general condition of the lubricant, deterioration of the lubricant due to contaminants, and the general condition of components within the equipment lubricated. Oil analysis should be used in conjunction with equipment operating histories. A variety of standardized oil analysis tests are available to assist in determining the condition and age of the lubricant. Oil analysis recommendations are provided in ASTM D6224, Standard Practice for In-Service Monitoring of Lubricating Oil for Auxiliary Power Plant Equipment. The practice is intended to assist in maintaining effective control over their lubricating oils and lubrication monitoring program. The practice may also be used to perform oil changes based on test results rather than service time or calendar time. The practice provides assistance for monitoring lubricating oils; guarding against excessive component wear, oil degradation, or contamination; sampling and testing schedules; and how oils degrade. The practice covers the requirements for the effective monitoring of mineral oil and phosphate ester fluid lubricating oils in auxiliary plant equipment used (such as gears, hydraulic systems, diesel engines, pumps, compressors, and EHC systems).

5.6 Couplings

Couplings are installed on most every piece of rotating equipment at a nuclear station. They come in many types, lubrication methods and installation mechanism from simple to complex. Couplings may be ridged (non-lubricated) or flexible, have self-contained or externally applied lubrication and installed on straight, splined or taper shafts with or without interference fit or with or without keyways. The type of coupling used and lubrication method is dictated by the equipment operational needs and cost effectiveness. Detailed information on the maintenance of flexible shaft couplings is provided in *Flexible Shaft Couplings Maintenance Guide* (1007910).

5.6.1 Lubrication Methods

Coupling lubrication may be self-contained (sealed) or externally supplied (continuous feed). Self-contained coupling lubrication is the most common method used in the nuclear industry. Self-contained couplings may be oil- or grease-lubricated, with grease being the predominant lubricant.

Self-contained/sealed couplings have several advantages over the externally lubricated coupling, including the following:

- May use a wide range of lubricants (oil and grease types)
- Economical
- Easy to maintain
- Simple design and operation
- Can accommodate high tooth loading
- Effective against external contaminants
- Long operating times without requiring services

Disadvantages include the following:

- Seals required for retention of lubricant
- Seals age and wear
- High ambient temperatures may adversely affect the lubricant
- Loss of lubricant (from defective elastomers, loose flange bolting, loose plugs, and so on)

Elastomer or metallic seals are used on self-contained lubricated couplings to maintain the lubricant within the coupling. Elastomer seals are the more common in use. The four basic types are as follows:

- O-ring: commonly used; allows small motion between moving parts
- H-T cross section seal: similar to O-rings but has more surface contact area; small motion between parts; is subject to rolling or twisting under some loads
- Lip seal: accommodates a high degree of misalignment; can be designed for high speeds
- Boot seal: low-speed operation; not commonly used; accommodates large misalignments

5.6.2 Lubricant

The quality and type of grease used in a coupling are specified by the coupling manufacturer. Greases used in coupling applications must be capable of preventing wear of mating teeth at high speeds and loads. Problems may be experienced when using grease as the coupling lubricant, including the following:

- Improper grease used
- Loss of grease due to leakage (at seals, shaft keyways, mating surfaces, plugs, and so on)
- Excessive heat generated due to low grease level, misalignment, or poor heat dissipation
- Grease separation due to high centrifugal forces

The centrifugal forces on the lubricant within the coupling play an important role. Centrifugal force is important to the proper lubrication of the coupling. The centrifugal force generates pressure within the grease. This pressure ensures that all the voids within the coupling fill rapidly and that the grease moves to fill the coupling teeth. At high speeds, the grease may separate into its constituents of base oil and soap. Soaps can gather in tight clearances, forming a sludge-like material.

Oil is not commonly used in self-contained/sealed coupling applications because it requires such a high viscosity that it cannot be easily poured to fill a coupling. When high-viscosity oils are used, they prove to be effective because of the other properties of the oil.

5.6.3 Routine Inspections

When available, the inside surfaces of coupling guards should be observed for lubricant leakage. Not only can leakage be observed, but the area that leaked can be identified. During this inspection, the operator should also look for any evidence of shredded elastomer from the coupling.

For equipment with self-contained/sealed couplings that is stationary for long periods, inspections for lubricant leakage should be performed before operation.

In order for a coupling to perform as designed, it must be installed and maintained properly. Poor dimensional fits is a great contributor to improper operation (poor shaft fit, poor key to keyway fits, and so on). Prior to installing a coupling, the following checks should be considered:

- Perform dimensional checks (of spool length, coupling hub bores, keyways/keys, shaft, and so on).
- Verify the coupling type and that all parts are installed.
- Assemble the coupling prior to installation on the shaft to ensure proper fit of coupling parts.
- If a balanced coupling is used, ensure that match marks are present and properly oriented.
- During regreasing of couplings, grease should be added slowly while slowly rotating the shaft to minimize unbalance in the coupling until the grease is fully distributed within the coupling.

5.6.4 Relubrication

Poor lubrication reduces the coupling reliability and useful life. Couplings require regular maintenance and lubrication to ensure reliability of operation and increased life of the coupling. Lubrication requirements are typically specified by the coupling manufacturer, including type, quality, and amount of lubricant as well as frequency of maintenance. In the absence of these recommendations or to refine the recommendations, operating history and industry experience may be used to determine lubrication frequencies.

If a coupling is to be relubricated, it should be completely disassembled, cleaned, and inspected. Cleaning is important in order to remove soaps that may have separated during operation. Failure to clean or remove old soap buildup could result in improper operation of the coupling.

It is important that the correct amount of lubricant be added to the coupling. Underfilling the coupling results in inadequate lubrication and excessive wear of coupling parts. Overfilling is also undesirable because it can generate high thrust forces in the equipment bearings due to coupling lockup (increased rigidity). This may also result in increased vibration levels.

6
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A
DEFINITIONS AND ACROYNMS

A.1 Definitions

abrasive wear – progressive removal of material from a rubbing surface as evidenced by surface lapping caused by fine particles carried in the lubricant, fuel or air, or embedded in the surface.

aeration – the state of air being suspended in a liquid, such as a lubricant or hydraulic fluid.

anti-foam agent – one of two types of additives used to reduce foaming in petroleum products: silicone oil to break up large surface bubbles, and various kinds of polymers that decrease the amount of small bubbles entrained in the oils. See "foaming."

asperities – microscopic projections on metal surfaces resulting from normal surface-finishing processes. Interference between opposing asperities in sliding or rolling applications is a source of friction and can lead to metal welding and scoring. Ideally, the lubricating film between two moving surfaces should be thicker than the combined height of the opposing asperities.

base stock – crude oil fractions of suitable viscosities and volatilities, generally refined to remove unstable and waxy components, and classified as neutrals and bright stocks.

boundary lubrication – form of lubrication between two rubbing surfaces without development of a full-fluid lubricating film. Boundary lubrication can be made more effective by including additives in the lubricating oil that provide a stronger oil film, thus preventing excessive friction and possible scoring.

cleanliness requirements – plant procedures, industry standards, and regulatory positions that address a cleanliness standard for systems and components in a nuclear power plant.

corrosion – any observed chemical attack on metal parts. Rust is a special case of the corrosion of iron.

corrosion inhibitor – an additive for protecting lubricated metal surfaces against chemical attack by water or other contaminants.

demulsibility – the ability of an oil to separate from water, as determined by test method ASTM D1401 or D2711. Demulsibility is an important consideration in lubricant maintenance in many circulating lubrication systems.

emulsifier – an additive that promotes the formation of a stable mixture, or emulsion, of oil and water. Common emulsifiers are metallic soaps, certain animal and vegetable oils, and various polar compounds (having molecules that are water-soluble at one extremity of their structures and oil-soluble at the other).

erosion – mechanical removal of material by impingement of high-velocity fluid with or without entrained particles.

filterabilty – relates to the ease with which a lubricant passes through a mechanical filter medium.

flush – A process employed to remove known or suspected residue generated during the performance of an operation or maintenance activity from a system or component. This is accomplished by the introduction of a liquid or gas, such as water or air, sufficient to entrain the foreign material and remove it from the system, along with the expelled liquid or gas.

foaming – occurrence of frothy mixture of air and petroleum product (such as lubricant or fuel oil) that can reduce the effectiveness of the product and cause sluggish hydraulic operation, air binding of oil pumps, and overflow of tanks or sumps. Foaming can result from excessive agitation, improper fluid levels, air leaks, cavitation, or contamination with water or other foreign materials.

friction – resistance to the motion of one surface over another. The amount of friction is dependent on the smoothness of the contacting surfaces as well as the force with which they are pressed together. Friction between nonlubricated solid bodies is independent of speed and area. Rolling friction (for example, the motion of a tire or ball bearing) is less than sliding friction (back-and-forth motion over two flat surfaces). Sliding friction is thus more wasteful of energy and can cause more wear. Fluid friction occurs between the molecules of a gas or liquid in motion and is expressed as shear stress. Unlike solid friction, fluid friction varies with speed and area.

full-fluid-film lubrication – the presence of a continuous lubricating film sufficient to completely separate two surfaces, as distinct from boundary lubrication. Full-fluid-film lubrication is normally hydrodynamic lubrication, whereby the oil adheres to the moving part and is drawn into the area between the sliding surfaces, where it forms a pressure, or hydrodynamic, wedge. A less common form of full-fluid-lubrication is hydrostatic lubrication, wherein the oil is supplied to the bearing area under sufficient external pressure to separate the sliding surfaces.

grease – a mixture of a fluid lubricant (usually a petroleum oil) and a thickener (usually a soap) dispersed in the oil. Because greases do not flow readily, they are used where extended lubrication is required and where oil would not be retained.

hydrodynamic lubrication – See “full-fluid-film lubrication.”

hydrostatic lubrication – See “full-fluid-film lubrication.”

inhibitor – an additive that improves the performance of a petroleum product through the control of undesirable chemical reactions.

interfacial tension – (related to surface tension) the physical property that describes the ease with which oil separates from insoluble materials such as air and water.

lubricating oil – compounded or finished oil consisting of base stocks and the additives necessary for providing the required performance.

lubrication – control of friction and wear by the introduction of a friction-reducing film between moving surfaces in contact. The lubricant used may be a fluid, solid, or plastic substance.

oxidation – the chemical combination of a substance with oxygen. All petroleum products are subject to oxidation, with resultant degradation of their composition and performance. The process is accelerated by heat, light, metal catalysts (such as copper), and the presence of water, acids, or solid contaminants. The first reaction products of oxidation are organic peroxides. Continued oxidation, catalyzed by peroxides, forms alcohols, aldehydes, ketones, and organic acids, which can be further oxidized to form high-molecular-weight, oil-insoluble polymers.

particulates – atmospheric particles made up of a wide range of natural materials (such as pollen, dust, and resins), combined with manmade pollutants (such as smoke particles and metallic ash).

pour point – using ASTM D97, the lowest temperature at which the oil can be poured. Also, using FTM 203, the stable pour point is the lowest temperature at which an oil will remain fluid after being subjected to a cyclic temperature variation for six days.

sludge – a deposit, principally composed of engine oil and fuel debris, that does not drain from engine parts but can be removed by wiping with a soft cloth.

varnish – hard, dry, generally lustrous oil insoluble deposit which cannot be removed by wiping with a soft cloth.

viscosity – measurement of a fluid's resistance to flow. The common metric unit of absolute viscosity is the poise, which is defined as the force in dynes required to move a surface 1 cm2 in area past a parallel surface at a speed of 1 cm per second, with the surfaces separated by a fluid film 1-cm thick. For convenience, the centipoise (cp)—one one-hundredth of a poise—is the unit customarily used. Laboratory measurements of viscosity normally use the force of gravity to produce flow through a capillary tube (viscometer) at a controlled temperature. The measurement is called *kinematic viscosity*. The unit of kinematic viscosity is the stoke, expressed in square centimeters per second. The more customary unit is the centistoke (cSt)—one one-hundredth of a stoke. Kinematic viscosity can be related to absolute viscosity by the equation

$$\text{cSt} = \text{cp} - \text{fluid density}$$

viscosity index (VI) improver – lubricant additive, usually a high-molecular-weight polymer, that reduces the tendency of an oil to change viscosity with temperature.

wear – the loss or relocation of material from two or more surfaces in relative motion.

A.2 Acronyms

ac	alternating current
AFW	auxiliary feedwater
AN	acid number
ASTM	ASTM International (formerly the American Society for Testing and Materials)
BWR	boiling water reactor
C	Celsius
cm	centimeter
CSF	contaminant severity factor
dc	direct current
d/p	differential pressure
EDG	emergency diesel generator
EHC	electrohydraulic control
EPRI	Electric Power Research Institute
F	Fahrenheit
FFFL	full forced flow lubrication
fps	feet per second
FTIR	Fourier transform infrared
HPCI	high-pressure coolant injection
IEEE	Institute of Electrical and Electronics Engineers
IN	Information Notice

ISO	International Standards Organisation
IST	in-service testing
kW	kilowatt(s)
LET	life extension table
μm	micron(s)
mm	millimeter(s)
mps	meters per second
OE	operating experience
OEM	original equipment manufacturer
OLE	overall lubrication effectiveness
O&M	operations and maintenance
PM	preventive maintenance
ppm	parts per million
PWR	pressurized water reactor
QSA	Qualitative Spectrophotometric Analysis
RCIC	reactor core isolation cooling
RCP	reactor coolant pump
RLPC	ring lubrication plus pressure circulation
ROL	ring-only lubrication
RPF	reliability penalty factor
RPVOT	rotary pressure vessel oxidation test
RRP	reactor recirculation pump
SER	Significant Event Report

SOER	Significant Operational Event Report
TAG	technical advisory group
TCG	target cleanliness grid
TCV	temperature control valve
TR	technical report

B

KEY POINTS SUMMARY

The following list provides the location of Key Point information in this report.

Key O&M Cost Point

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

Section	Page	Key Point
4.3.3	4-29	When used properly, oil analysis can determine optimum oil change frequencies for plant equipment. However, it may not be cost-effective to perform analysis on every piece of plant equipment, especially when the reservoirs are small.

Key Technical Point

Targets information that will lead to improved equipment reliability.

Section	Page	Key Point
2.2.3	2-5	For reservoirs in which oil rings are used, a general rule is for the rings to be set with the oil level 1/4–3/8 in. (6.4–9.5 mm) from the bottom inside of the ring.
3.3.4	3-4	Each time the oiler is removed, a small amount of oil enters the bearing reservoir/sump. For constant-level oilers, a good rule to follow is to add oil when the oiler reservoir level is less than one-third of the reservoir capacity.
3.4.4	3-4	Sampling can also have an adverse effect on the bearing reservoir/sump level and lubrication of the internal components. If a significant quantity of oil is removed quickly, the oiler may not be capable of responding rapidly enough to return the oil level in the bearing reservoir/sump to normal.
4.2.4	4-9	A rule of thumb is that oxidation rates double with every 18°F (10°C) of increase in temperature.
4.3.2.1.2	4-18	A general rule is that new lubricants should be at least two ISO cleanliness numbers below the equipment's target level.
5.1.1.4.4	5-8	An unexpected increase in filter d/p may indicate a change in the quality of the oil. An unexpected decrease may indicate a failure of the filter element.

Key Human Performance Point

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

Section	Page	Key Point
4.3.4	4-29	To avoid the possibility of lubricant compatibility, do not mix lubricants. If the compatibility of two mixed lubricants is in doubt, assume that they are incompatible.
4.3.4.3	4-31	Proper identification and labeling of lubricants will assist in the prevention of lubricant mixing.

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DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Electric Power Research Institute (EPRI)

核電廠維護應用中心：轉動設備油潤滑指南

1019517

2009 年 12 月總結報告

報告摘要

背景

在核電廠中，幾種與安全相關和不相關的設備均有賴於潤滑油系統來為轉動部件提供潤滑。這些潤滑系統包括齒輪、幫浦、閥門、熱交換器及其他部件。一旦潤滑系統出現故障，其所支援的設備便可能關閉，從而意外導致運轉受限、系統效能降低或機組跳閘。若能瞭解污染、運轉及環境條件如何對潤滑油造成影響，以及將這些影響降至最低或有效預防所採取的措施，將可提升設備的可靠性和可用性，同時還能節省成本。維護作業十分(這包括換油間隔、過濾以及潤滑系統的一般清理)重要，將可確保轉動設備獲得適當的潤滑，以最佳化設備的可靠性和可用性。

報告中除提供糾正性、預防性和預測性維護實務外，還對之前所述的問題及如何排除潤滑系統的故障進行了深入剖析。本報告中的資訊可與美國電力科學研究院 (EPRI) 的報告《潤滑指南》(1019518) 和《有效潤滑實務》(1020247) 相結合，為潤滑基本原理和系統提供了一套綜合的方法。預防性和預測性維護技術包括 EPRI 預防性和預測性維護指引。

本報告可供負責監控或維護核電廠設備潤滑系統的任何人員使用，包括系統和部件工程師、預防和預測性維護人員、潤滑工程師和技術人員、維護人員以及設計人員。本報告可應用於核電廠中的各種設備，使潤滑油系統順利、可靠地運轉。

目的

- 為核電廠中負責需額外維護的潤滑油系統 (如主透平機、Terry 透平機、供油泵、柴油發電機、馬達及幫浦) 之相關人員提供一般資訊和指引
- 提供關於潤滑系統如何工作及如何為各種核電廠設備實施潤滑的基本原理，包括動力來源和冷卻機制

- 提供關於排除潤滑系統相關故障的資訊
- 記錄一般、預防性及預測性維護實務
- 闡述污染問題及污染控制

方法

*核電廠維護應用中心：轉動設備油潤滑指南*由 EPRI 編撰完成。 EPRI
為此特別組成了技術諮詢小組，針對報告內容、組織架構以及最終用途的應用提供意見，並審查與潤滑系統和潤滑劑相關的 EPRI
文件，以確保所提供資訊的一致性。同時，亦針對核電廠流程徵詢意見及審查，並根據所收集的資訊編寫報告初稿。報告初稿中涵蓋了可能影響潤滑效果的潤滑方法和污染問題。初稿分發給 TAG
成員，以供其審核並提出意見。隨後將所收集的意見和建議進行彙整並定稿，而且在發行之前由 EPRI 對終稿進行內部審核校對。

結果

本報告闡述了可能需要額外維護的核電廠設備主要部分潤滑系統的問題。其中包括潤滑方法、恒定油位注油器、清潔度和污染控制及指引章節，並另外提供核電廠設備主要部分及其潤滑系統的相關資訊。關於主要設備的特定資訊包括基礎潤滑系統的操作、一般維護指引、故障排除、潤滑系統的潛在風險以及操作經驗。另外，本報告中使用的術語和縮寫辭彙也包含在其中。編寫本報告時所引用的資料來源亦彙編成額外資訊列表。

EPRI 遠景

重要核電廠設備的潤滑系統知識對於維護人員的日常工作至關重要。本報告提供了關於潤滑系統之維護實務（如一般、預防性及預測性）、故障排除技術及污染（來源和控制）的相關資訊。本報告中包含的資訊對於編寫故障排除流程和審查預防性維護的人員非常實用；它也可由講師用以支援訓練。本報告闡述了與潤滑配方和潤滑議題相關的潤滑業內發生的，對潤滑業的未來有著深遠的影響的最新變化。

關鍵字

過濾器
潤滑油系統
潤滑
轉動機械

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《核电厂维护应用中心》：旋转设备的油润滑指南

1019517

总结报告 2009 年 12 月

报告摘要

背景

在核电站中，与安全相关和不相关的几种类型的设备均依靠润滑油系统来为部件的顺利运转提供润滑。这些润滑系统包括齿轮、水泵、阀门、热交换器及其他部件。一旦润滑系统出现故障，其所支持的设备便可能关闭，从而意外导致运转受限、系统性能降低或设备跳闸。深入理解污染、操作及环境条件对润滑油产生的影响，以及为将这些影响降至最低或有效预防所采取的措施，将能够更好地实现设备的可靠性和可用性，并节约成本。维护工作（如换油间隔、过滤以及润滑系统的全面清理）非常重要，将可确保旋转设备得到适当的润滑，以最大程度地实现设备的可靠性和可用性。

报告中除提供纠正性、预防性和预测性维护实务外，还对之前所述的问题及如何排除润滑系统的故障进行了深入剖析。该报告中的信息可与美国电力科学研究院（EPRI）的报告《润滑指南》（1019518）和《有效润滑实务》（1020247）相结合，从而为润滑基本原理和系统提供了一套综合方法。预防性和预测性维护技术包括 EPRI
预防性和预测性维护指导。

该报告可供监控或维护电厂设备润滑系统的任何人员使用，包括系统和部件工程师、预防和预测性维护人员、润滑工程师和技术人员、维护人员以及设计人员。该报告可应用于电厂中的各种设备，从而使润滑油系统顺利、可靠地运转。

目的

- 为电厂中需额外维护的润滑油系统（如主涡轮机、Terry
  涡轮机、供油泵、柴油发电机、发动机及水泵）之相关人员提供综合信息和指导
- 提供关于润滑系统如何工作及如何为各种电厂设备实施润滑的基本原理，包括动力来源和冷却机制

- 提供关于排除润滑系统相关故障的信息
- 将综合性、预防性及预测性维护实践形成文档
- 阐述污染问题及污染控制

方法

核电厂维护应用中心：《旋转设备油润滑指南》由 EPRI
编著。为此，特组建了技术顾问小组，针对报告内容、组织及最终用途的应用提出意见，并审核与润滑系统和润滑剂相关的适用 EPRI
文件，以确保所提供信息的一致性。同时，针对电厂流程进行征集意见并审核，并根据所收集的信息和编写的报告初稿。报告初稿中涵盖了能够影响润滑效果的润滑方法和污染问题。初稿将分发给 TAG
成员，以供其审查并提出意见。随后将所收集的评论和建议进行汇总，形成草案终稿。在出版发行之前，EPRI 也将对终稿进行内部审核校对。

结果

该报告阐述了可能要求额外维护的电厂设备之主要部分润滑系统的问题。其中包括润滑方法、恒定油位注油器、清洁度和污染控制及指导章节，并另外提供了电厂设备主要部分及其润滑系统的相关信息。关于主要设备的具体信息包括基础润滑系统的操作、综合维护指导、故障排查、润滑系统的潜在风险以及操作经验。另外，本报告中使用的术语和缩写词也包含在内。编写本报告时所引用的资料来源亦作为额外信息来源汇编成表。

EPRI 远景

重要电厂设备的润滑系统知识对于维护人员的日常工作至关重要。本报告提供了关于润滑系统维护实务（如综合性、预防性及预测性）、故障排查技术及污染（来源和控制）的相关信息。本报告中包含的信息对于编写故障排查流程和审查预防性维护的人员非常实用；它也可供讲解员用于培训。本报告阐述了与润滑配方和润滑议题相关的润滑业内发生的，对润滑行业的未来有着深远影响的新变化。

关键词

过滤器
润滑油系统
润滑
旋转机械

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Centre d’applications de maintenance nucléaire : Guide de lubrification pour équipement rotatif

1019517

Rapport final, décembre 2009

SOMMAIRE DU RAPPORT

Historique

Dans une centrale nucléaire, plusieurs types de pièces d'équipements portant ou non sur la sécurité dépendent de circuits de graissage pour fournir une lubrification aux éléments tournants. Ces circuits de lubrification sont composés d'engrenages, de pompes, de vannes, d'échangeurs de chaleur et d'autres pièces. En cas dune défaillance du circuit de graissage, l'équipement supporté peut être mis à l'arrêt, ce qui amène des inscriptions non prévues dans les conditions limites d'exploitation, une dégradation du système ou un déclenchement de l'unité. Une bonne compréhension de la façon dont l'huile est modifiée par la contamination et les conditions d'exploitation et environnementales de même que les mesures à prendre pour minimiser ou éviter ces effets peut permettre d'améliorer la fiabilité et la disponibilité du matériel et de faire des économies. L'importance des activités de maintenance, telles que les intervalles de vidange d'huile, la filtration et le nettoyage général du circuit de lubrification, permettra de s'assurer que l'équipement rotatif est bien lubrifié afin d'en optimiser la fiabilité et la disponibilité.

Le rapport offre un aperçu des problèmes décrits antérieurement en plus des pratiques de maintenance corrective, préventive et anticipée ainsi que la manière de procéder au dépannage des problèmes du circuit de graissage. L'information contenue dans le présent rapport peut être utilisée conjointement avec les rapports de l'Electric Power Research Institute (EPRI) intitulés *Guide de lubrification* (1019518) et *Mesures de graissage efficaces* (1020247) pour offrir une approche globale aux principes fondamentaux et aux circuits de lubrification. Les techniques de maintenance préventive et anticipée sont en accord avec les directives de maintenance préventive et anticipée d'EPRI.

Ce rapport peut être utilisé par toute personne qui surveille ou effectue la maintenance des circuits de graissage du matériel dans la centrale, y compris les ingénieurs système et de composants, le personnel de maintenance préventive et anticipée, les ingénieurs et techniciens chargés de la lubrification, le personnel de maintenance et les planificateurs. Ce rapport touche à divers équipements d'une centrale en vue d'obtenir un circuit de graissage efficace et fiable.

Objectifs

- Offrir des informations d'ordre général et des directives au personnel des centrales qui s'occupe des circuits de graissage qui exigent une attention plus particulière (tels que les turbines principales, les turbines Terry, les pompes d'alimentation, les génératrices diesel, les moteurs et les pompes)
- Offrir des notions fondamentales sur la manière dont fonctionnent les circuits de graissage pour divers équipements de centrales, notamment les sources motrices et les mécanismes de refroidissement
- Présenter des informations sur le dépannage des circuits de graissage

- Documenter les pratiques de maintenance générale, préventive et anticipée
- Décrire la contamination et le contrôle de la contamination

Approche

Centre d'applications de maintenance nucléaire. Le Guide de lubrification pour équipement rotatif est le résultat d'un travail effectué par EPRI. Un groupe de consultation technique a été formé pour fournir des observations sur le contenu, l'organisation et l'application finale du rapport. Les documents applicables d'EPRI pertinents aux circuits de lubrification et aux lubrifiants ont été étudiés pour assurer l'uniformité des informations fournies. Les procédures des centrales ont aussi été requises et étudiées et, à partir des renseignements rassemblés, une ébauche du rapport a été mise au point. L'ébauche portait sur les méthodes de lubrification et la contamination qui peut affecter la performance de la lubrification. L'ébauche a été diffusée pour étude et commentaires aux membres du groupe de consultation technique. Les observations et suggestions ont été par la suite incorporées pour produire une ébauche finale qui a été également étudiée en interne à EPRI avant sa publication.

Résultats

Ce rapport vise les circuits de graissage des principaux éléments du matériel de centrales qui peuvent nécessiter une attention supplémentaire. Il comporte des sections sur les méthodes de lubrification, les graisseurs à niveau constant, le contrôle de la propreté et de la contamination, la dégradation et des directives et des informations sur les principaux éléments du matériel de centrales et sur leurs circuits de lubrification. Des informations précises sur le matériel principal comprennent le fonctionnement du circuit de lubrification de base, des directives générales sur la maintenance, le dépannage, les vulnérabilités du circuit de graissage et l'expérience opérationnelle. Un glossaire des termes et acronymes utilisés dans le rapport est aussi joint à ce dernier. Les ressources qui ont été utilisées dans la mise au point de ce rapport sont énumérées comme source d'information supplémentaire.

Point de vue de l'EPRI

La connaissance des circuits de graissage pour les équipements importants de centrales est essentielle au travail quotidien du personnel de maintenance. Ce rapport offre des informations sur les pratiques de maintenance (générale, préventive et anticipée), les techniques de dépannages et la contamination (sources et contrôle) dans les circuits de graissage. Les informations contenues dans ce rapport peuvent être utiles au personnel qui met au point des procédures de dépannage et qui étudie la maintenance préventive ; elle peut également fournir une aide aux agents de formation. Ce rapport traite des changements récents dans l'industrie de la lubrification, lesquels touchent à la formulation et aux problèmes de lubrification qui pourraient affecter l'industrie dans l'avenir.

Mots-clés

Filtres
Circuits de graissage
Lubrification
Équipement rotatif

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原子力保全アプリケーションセンター：回転機器の油潤滑ガイド

1019517

2009年12月最終レポート

レポート概要

背景

原子力発電所では、回転機器を潤滑する潤滑油系統に依存している安全関連機器および非安全関連機器が数機種ある。これらの潤滑系統はギア、ポンプ、弁、熱交換器、およびその他の部品で構成されている。

潤滑油系統が故障した場合、サポートされている装置を停止することになるかもしれなく、予定しないLCO（制限状態においての運転）に入ったり、系統の劣化、またはユニットのトリップにつながったりすることがある。汚染および運転･環境条件による油への影響やこれらの影響の最小化または防止のための対策を理解すれば、機器の信頼性およびアベイラビリティの向上およびコスト削減をもたらすことができる。油交換の間隔、ろ過、および一般的な潤滑系統のクリーニング等の保全活動を重視することで、回転機器が適切に潤滑され、機器の信頼性およびアベイラビリティが最適化される。

レポートには、事後保全、予防保全、および予知保全に加え、前述の課題に関する見識、および潤滑系統の問題のトラブルシューティング方法に関する情報が記載されている。本レポートの情報は、Electric Power Research Institute（EPRI）のレポート、*潤滑ガイド*（1019518）および*効果的な潤滑プラクティス*（1020247）と共に使用することで、潤滑の基本および系統についての包括的な取組方針が提供される。予防保全および予知保全の技術は、EPRI予防保全および予知保全ガイドと整合性がある。

本レポートは、システムエンジニア、機器エンジニア、予防･予知保全担当者、潤滑エンジニアおよび技術者、保全担当者、およびプランナーを含む発電所の潤滑系統機器を監視または保全する技術者が使用することができる。本レポートは、良好で信頼性のある潤滑油系統を目指し、発電所の様々な機器に適用できる。

目的

- 特に注意を払う必要のある発電所の潤滑油系統（主要タービン、テリータービン、給水ポンプ、ディーゼル発電機、電動機、ポンプなど）に関わる発電所の技術者に一般的情報およびガイドを提供すること
- 駆動装置および冷却装置を含む様々な発電所機器の潤滑系統の運転と機能についての基礎を提供すること
- 潤滑系統のトラブルシューティングに関する情報を示すこと
- 一般的な保全、予防保全、および予知保全のプラクティスを文書化すること
- 汚染および汚染管理について説明すること

アプローチ

*原子力保全アプリケーションセンター：回転機器の油潤滑ガイド*は、EPRIが行った検討の結果によるものである。テクニカルアドバイザリーグループ（TAG）が結成され、レポートの内容、構成、および末端機器での適用に関しての情報を提供している。提供される情報の一貫性を確保するため、潤滑系統や潤滑油に関するEPRIの該当文書がレビューされた。さらに発電所での手順の提供を求め、レビューされ、収集された情報からドラフトレポートが作成された。ドラフトでは潤滑油の潤滑方法およびパーフォーマンスに影響する汚染について触れてある。ドラフトはレビューおよびコメントのためにTAGのメンバーに配布された。その後、コメントや提案が最終ドラフトに盛込まれ、発行前にEPRI社内でもレビューされた。

結果

本レポートでは、特に注意が必要となるような発電所の主要機器の潤滑系統を取上げている。潤滑方法、一定レベルの給油装置、清浄度および汚染管理、劣化、および発電所の主要機器およびそれらの潤滑系統に関するガイドと情報のセクションを含む。主要機器に関する具体的情報には、基本的な潤滑系統の運転、一般保全ガイド、トラブルシューティング、潤滑系統の脆弱性および運転経験が含まれる。レポートで使用されている用語および頭字語も含まれている。本レポートの作成に使用された参考資料は追加情報として記載されている。

EPRIの展望

発電所における重要機器の潤滑系統に関する知識は、保全担当者が日々作業を行う上で必要不可欠である。本レポートでは、潤滑系統の（一般、予防、予知などの）保全プラクティス、トラブルシューティング、技術、および汚染（汚染源と汚染管理）に関する情報を提供している。本レポートに含まれている情報は、トラブルシューティング手順の確立や予防保全のレビューをする人にとって有益であり、トレーニング指導者の支援にも役立つであろう。本レポートでは、潤滑産業界における潤滑成分の最近の変更や今後産業界に影響する可能性のある課題を取上げている。

キーワード

フィルタ
潤滑油系統
潤滑
回転機械

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Nuclear Maintenance Applications Center: 회전 기기 윤활 지침

1019517

최종 보고서(2009년 12월)

보고서 개요

배경

원자력 발전소에서는 윤활유 계통을 통해 일부 안전성 및 비안전성 설비의 회전기기에 윤활유를 공급한다. 이 윤활 계통은 기어, 펌프, 밸브, 열 교환기 및 기타 부품으로 구성된다. 윤활 계통에 고장이 발생하면 해당 기기가 정지되어, 이로 인해 예기치 못한 운전제한조건 진입, 계통 성능 저하 또는 발전소 정지 등이 유발될 수 있다. 오염, 운전 및 환경 조건이 윤활유에 미치는 영향을 이해하고, 또한 이 영향을 최소화하거나 예방할 수 있는 방안들을 이해하면, 비용을 절감하고 기기 신뢰도 및 이용률을 향상시킬 수 있다. 윤활유 교체 주기, 여과 및 일반 윤활 계통 청소 등과 같은 정비 활동의 중요한 역할은 회전 기기를 적절하게 윤활하여 최적의 기기 신뢰도와 가동률을 실현하는 것이다.

본 보고서는 교정 정비, 예방 정비 및 예측 정비 방식과 함께 이전에 기술한 사안들을 제시하며, 윤활 계통 문제점들을 해결하는 방법을 제공한다. 본 보고서의 내용은 윤활 관련 기본 사항과 윤활 계통에 대한 종합적인 이해를 위해 EPRI 보고서 " 윤활 지침(1019518)" 및 " *효율적인 그리스 작업 방법*(1020247)" 과 함께 사용할 수 있다. 예방 및 예측 정비 기법은 EPRI의 예방 및 예측 정비 지침과 일관성이 있다.

본 보고서는 계통 및 기기 엔지니어, 예방 및 예측 정비 담당자, 윤활 담당 엔지니어 및 기술자, 정비 요원, 정비계획 작성자 등을 포함하여 발전소에서 기기 윤활 계통을 감시하고 관리하는 모든 직원이 사용할 수 있다. 본 보고서를 발전소의 다양한 장비에 적용함으로써 원활하고 신뢰도 높은 윤활 계통을 운용할 수 있을 것이다.

목적

- 별도의 관리가 필요한 발전소 윤활 계통(주 터빈, Terry 터빈, 급수 펌프, 디젤 발전기, 모터, 펌프 등)에 관련된 발전소 직원에게 일반적 정보 및 지침을 제공한다.

- 다양한 발전소 장비를 위해 윤활 계통이 어떻게 작동하고 기능하는지에 대한 기본 사항(구동원, 냉각 메커니즘 등)을 제공한다.
- 윤활 계통 문제 해결에 관한 정보를 제시한다.
- 일반 정비, 예방 정비, 예측 정비 기법을 문서화한다.
- 오염 및 오염 통제를 다룬다.

접근 방법

“ Nuclear Maintenance Applications Center: 회전 기기의 오일 윤활 지침” 은 EPRI의 업무 성과이다. 보고서 내용, 구성 및 최종 적용에 관한 정보를 제공하기 위해 기술 자문단이 구성되었다. 윤활 계통 및 윤활유에 관련된 EPRI 문서를 검토하여 제공 정보의 일관성을 확보했다. 또한 발전소절차서를 요청하여 검토하고, 수집한 정보를 통해 보고서 초안을 작성했다. 보고서 초안에는 윤활 성능에 영향을 줄 수 있는 윤활 방법 및 오염 관련 내용을 포함했다. 초안은 기술 자문단 구성원들에게 배부하여 검토를 받고 의견을 수렴했다. 이후 의견 및 제안을 포함하여 최종안을 작성하고 발행 전 EPRI 내부적으로 검토를 거쳤다.

성과

본 보고서는 별도의 관리가 필요한 발전소 내 주요 설비의 윤활 계통을 다룬다. 본 보고서에는 윤활 방법, 일정 유면 오일러(constant-level oiler), 청결도 및 오염 제어, 성능 저하, 발전소 주요 장비 및 그 윤활 계통에 관한 지침 및 정보가 포함되어 있다. 주요설비에 관한 구체적인 정보로는 기본 윤활 계통운전, 일반 정비 지침, 문제 해결, 윤활 계통의 취약점, 운전경험 등이 있다. 본 보고서에 사용된 용어 및 약어 설명도 포함되어 있다. 본 보고서 작성에 사용한 내용들은 추가 정보의 출처에 열거되어 있다.

EPRI의 관점

주요 발전소 장비의 윤활 계통에 대해 이해하는 것은 정비 요원의 일상 업무를 위해 반드시 필요하다. 본 보고서는 정비 기법 관련 정보(일반, 예방 및 예측 정비), 문제 해결 기법, 윤활 계통의 오염(오염원 및 통제)에 관한 정보를 제공한다. 본 보고서의 정보는 문제 해결 절차를 개발하고 예방 정비를 검토하는 직원에게 유용하며 교육 강사에게도 도움을 줄 수 있다. 본 보고서에서는 윤활유 조제와 관련된 윤활 업계의 최근 변화와 향후 윤활 산업에 영향을 줄 수 있는 문제들을 다루었다.

주요 용어

여과기
윤활유 계통
윤활
회전 기계

목차

그림 목록

표 목록

Centro de Aplicaciones de Mantenimiento para Centrales Nucleares: guía de aceites de lubricación para equipos rotatorios

1019517

Informe definitivo, diciembre de 2009

RESUMEN DEL INFORME

Antecedentes

En las centrales nucleares, varios tipos de equipos relacionados y no relacionados con la seguridad dependen de sistemas de aceites de lubricación para lubricar sus componentes rotatorios. Dichos sistemas de lubricación se componen de engranajes, bombas, válvulas, intercambiadores de calor y otras piezas. En caso de fallo de un sistema de lubricación, los equipos asociados pueden sufrir paradas, lo que a su vez puede provocar entradas imprevistas en condiciones de operación limitadas, degradaciones de sistemas o disparos de las unidades. Comprender cómo el aceite se ve afectado por la contaminación y diferentes condiciones operativas y medioambientales y conocer qué medidas pueden adoptarse para minimizar o evitar estos efectos puede mejorar la fiabilidad y disponibilidad de los equipos y reducir costes. Determinadas actividades de mantenimiento importantes como los intervalos de cambios de aceite, la filtración y la limpieza general de los sistemas de lubricación garantizan una lubricación adecuada de los equipos rotatorios y proporciona una fiabilidad y disponibilidad óptima a los mismos.

Este informe proporciona perspectivas sobre los asuntos descritos anteriormente, prácticas de mantenimiento correctivo, preventivo y predictivo, así como técnicas para identificar y resolver problemas en los sistemas de lubricación. La información contenida en este documento puede utilizarse conjuntamente con los informes del Instituto de Investigación de Energía Eléctrica de los EE.UU. (EPRI) *Lubrication Guide (Guía de lubricación)* (1019518) y *Effective Greasing Practices (Prácticas de lubricación eficaces)* (1020247) para conseguir un enfoque general de los aspectos fundamentales de la lubricación y sus sistemas. Las técnicas de mantenimiento preventivo y predictivo proporcionadas en el informe se ajustan a las directrices de mantenimiento preventivo y predictivo de EPRI.

Este informe puede ser utilizado por cualquier miembro del personal que realice la monitorización o mantenimiento de los sistemas de lubricación de equipos de su central, incluidos los ingenieros de sistemas y componentes, el personal de mantenimiento preventivo y predictivo, los ingenieros y técnicos de lubricación, el personal de mantenimiento y los planificadores. Además, el informe puede aplicarse a diferentes equipos de planta para lograr un funcionamiento óptimo y fiable de sus sistemas de lubricación.

Objetivos

- Proporcionar información y directrices generales al personal encargado de los sistemas de lubricación de planta que requieren una atención especial (como por ejemplo las turbinas principales, las turbinas Terry, las bombas de alimentación, los generadores diésel, los motores y las bombas)

- Ofrecer conceptos fundamentales sobre cómo operan y funcionan los sistemas de lubricación de diversos equipos de planta, incluidos los mecanismos de refrigeración y las fuentes motoras
- Presentar información sobre la identificación y resolución de problemas relacionados con los sistemas de lubricación
- Documentar prácticas de mantenimiento general, preventivo y predictivo
- Describir la contaminación y el control de la contaminación

Enfoque

El informe *Nuclear Maintenance Applications Center: Oil Lubrication Guide for Rotating Equipment (Centro de Aplicaciones de Mantenimiento para Centrales Nucleares: guía de aceites de lubricación para equipos rotatorios)* es el resultado del trabajo realizado por EPRI en este ámbito, que incluyó la formación de un grupo de asesoramiento técnico para realizar aportaciones sobre el contenido, la organización y las aplicaciones finales del informe. El grupo revisó los documentos de EPRI relacionados con los sistemas de lubricación y los lubricantes para garantizar la coherencia de la información proporcionada. Además, se solicitaron y revisaron procedimientos de centrales y se elaboró un borrador de informe a partir de la información recopilada. El borrador, que abordó métodos de lubricación y temas relacionados con la contaminación que pueden afectar a la efectividad de la lubricación, se distribuyó entre los miembros del GAT para que éstos lo revisasen y proporcionasen sus comentarios y sugerencias, los cuales se incorporaron posteriormente en el borrador final, que también fue revisado por el personal de EPRI antes de su publicación.

Resultados

El presente informe versa sobre los sistemas de lubricación de componentes principales de equipos de centrales que pueden requerir una atención especial, e incluye secciones sobre métodos de lubricación, engrasadores de nivel constante, limpieza y control de contaminación, así como directrices e información sobre componentes de equipos de centrales y sus sistemas de lubricación. La información específica sobre equipos principales que se proporciona en el documento aborda la operación básica de los sistemas de lubricación, directrices de mantenimiento general, técnicas de identificación y resolución de problemas, vulnerabilidades de los sistemas de lubricación y experiencia operativa. El informe también incluye un glosario de los términos y acrónimos utilizados en él. Los recursos utilizados en la elaboración de este documento se enumeran como fuente de información adicional.

La perspectiva de EPRI

El conocimiento de los sistemas de lubricación de los equipos importantes de las centrales es esencial para las actividades diarias del personal de mantenimiento. El presente informe proporciona información sobre las prácticas de mantenimiento (tanto general como preventivo y predictivo), las técnicas de identificación y resolución de problemas, y la contaminación de los sistemas de lubricación. La información recogida en este documento puede ser de utilidad para el personal encargado de elaborar procedimientos de identificación y resolución de problemas y revisar el mantenimiento preventivo, así como para los instructores de formación. El informe aborda también cambios recientes en la industria de la lubricación relativos a la formulación de los aceites y a problemas que podrían afectar al sector en el futuro.

Palabras clave
Filtros
Sistemas de aceite de lubricación
Lubricación
Maquinaria rotatoria

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Export Control Restrictions

The Electric Power Research Institute Inc., (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent more than 90 percent of the electricity generated and delivered in the United States, and international participation extends to 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

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Program:

Nuclear Maintenance Applications Center

1019517

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