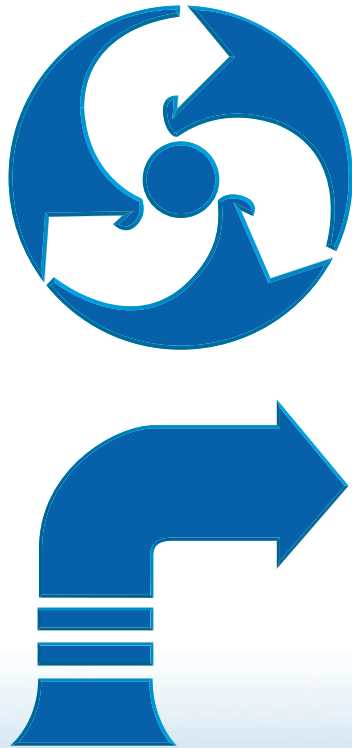




American National Standard for

Rotodynamic Pumps

Guideline for Condition Monitoring

ANSI/HI 9.6.5-2016



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American National Standard for

Rotodynamic Pumps

— Guideline for Condition Monitoring

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American National Standards Institute, Inc.

American National Standard

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Foreword (Not part of Standard)

Purpose and aims of the Hydraulic Institute

The purpose and aims of the Institute are to promote the continued growth and well-being of pump manufacturers and further the interests of the public in such matters as are involved in manufacturing, engineering, distribution, safety, transportation, and other problems of the industry, and to this end, among other things:

- a) To develop and publish standards and guidelines for pumps;
- b) To collect and disseminate information of value to its members and to the public;
- c) To appear for its members before governmental departments and agencies and other bodies in regard to matters affecting the industry;
- d) To increase the amount and to improve the quality of pump service to the public;
- e) To support educational and research activities;
- f) To promote the business interests of its members but not to engage in business of the kind ordinarily carried on for profit or to perform particular services for its members or individual persons as distinguished from activities to improve the business conditions and lawful interests of all of its members.

Purpose of standards and guidelines

- 1) Hydraulic Institute Standards and Guidelines are adopted in the public interest and are designed to help eliminate misunderstandings between the manufacturer, the purchaser, and/or the user and to assist the purchaser in selecting and obtaining the proper product for a particular need.
- 2) Use of Hydraulic Institute Standards and Guidelines is completely voluntary. Existence of Hydraulic Institute Standards does not in any respect preclude a member from manufacturing or selling products not conforming to the Standards.

Definition of a Hydraulic Institute Guideline

A Hydraulic Institute Guideline is not normative. The guideline is tutorial in nature, to help the reader better understand the subject matter.

Comments from users

Comments from users of this guideline will be appreciated, to help the Hydraulic Institute prepare even more useful future editions. Questions arising from the content of this guideline may be directed to the Hydraulic Institute. It will direct all such questions to the appropriate technical committee for provision of a suitable answer.

If a dispute arises regarding contents of an Institute publication or an answer provided by the Institute to a question such as indicated above, the point in question shall be sent in writing to the Technical Director of the Hydraulic Institute, who shall initiate the Appeals Process.

Revisions

The Standards and Guidelines of the Hydraulic Institute are subject to constant review, and revisions are undertaken whenever it is found necessary because of new developments and progress in the art. If no revisions are made for five years, the standards and guidelines are reaffirmed using the ANSI canvass procedure.

Units of measurement

Metric units of measurement are used and corresponding US customary units appear in brackets. Charts, graphs, and sample calculations are also shown in both metric and US customary units. Since values given in metric units



are not exact equivalents to values given in US customary units, it is important that the selected units of measure to be applied be stated in reference to this guideline. If no such statement is provided, metric units shall govern.

Consensus

Consensus for this guideline was achieved by use of the Canvass Method. The following organizations, recognized as having an interest in the standardization of rotodynamic pumps, were contacted prior to the approval of this revision of the guideline. Inclusion in this list does not necessarily imply that the organization concurred with the submittal of the proposed guideline to ANSI.

Black & Veatch (B & V)
Brown and Caldwell
DuPont Company
Dyna Tech
Flowserve Corporation
Fluid Sealing Association
Kemet Inc.
Leistritz Advanced Technologies Corp.
Las Vegas Valley Water District (LVVWD)
Paterson Pump Company
Pentair - Berkeley
Pentair - Fairbanks Nijhuis
WEG Electric Corp.
Weir Floway, Inc.

Committee list

Although this guideline was processed and approved for submittal to ANSI by the Canvass Method, a working committee met many times to facilitate its development. At the time it was developed, the committee had the following members:

Chair – Mike Cugal, Weir Minerals North America
Vice-Chair – Greg Case, TACO

Committee Members

Tim Albers
Jack Bagain
Randal Ferman
Thomas Grove
Mark Heiser
Gary Koopman
William Marscher
Scott Wilde

Alternate Members

Eric DeWilde

Company

Nidec Motor Corporation
John Crane Inc.
Ekwestrel Corp
AESSEAL Inc.
Xylem Inc. - Applied Water Systems
KCF Technologies, Inc.
Mechanical Solutions, Inc.
Leistritz Advanced Technologies Corp.

Company

Weir Minerals North America

9.6.5 Rotodynamic Pumps for Condition Monitoring

9.6.5.1 Introduction

9.6.5.1.1 Scope

This guideline is for rotodynamic pumps, including both sealed and sealless pump designs as stated in each section.

9.6.5.1.2 Purpose

This document is intended to give the pump user a tool for condition monitoring of the pumps in his or her systems, but does not directly address process management systems.

9.6.5.1.3 Use of this document

It is the user's responsibility to identify the need for implementing pump condition monitoring practices. The user is also responsible for identifying those parameters he or she wishes to monitor. *This document does not require any specific monitoring be done on the pumping system*, but will provide a guideline and information relevant to making such decisions, and provides suggestions for carrying out the monitoring process.

Condition-based maintenance (CBM) of machines by monitoring the output of various sensors and/or indicators as diagnostics tools allows technicians to assess the condition of a machine while in operation. Successful application of CBM enables identification of existing, impending, or potential problems prior to component failure. CBM not only helps plant personnel reduce the possibility of catastrophic failure, but also allows them to order parts in advance, schedule manpower, and plan other repairs during the downtime.

Every machine has a unique path to failure that condition monitoring can track. The potential-to-failure interval (P-F Interval) is commonly used to help establish the right maintenance to perform at the right time.

The P-F intervals vary by type of machine and type of detection technology employed. Once a problem has been identified using a diagnostic technology, there is no guarantee of continued operation through the typical P-F interval. In addition, there is no guarantee that the failure will indeed occur at some specified time in the future. Experience tells us that there is a potential for failure based the basic physics behind the diagnostic technology. The basis for this comes from the many case studies that have related diagnostic indication to machine defects. When employing P-F logic in specifying monitoring intervals, it is important that we recognize that in some cases the technology does not provide enough lead time for the detection to be of practical use.

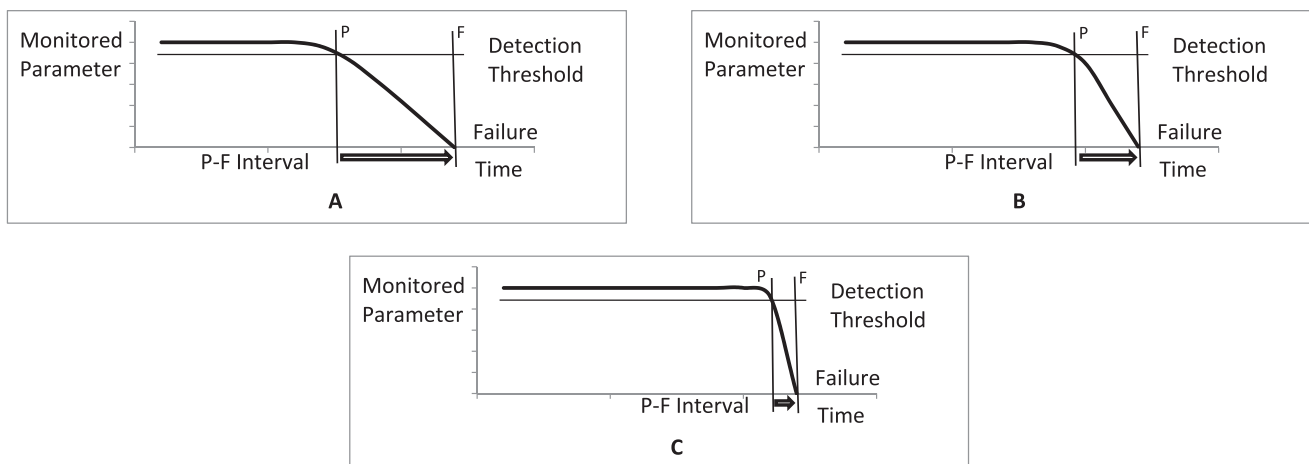


Figure 9.6.5.1.3 — Typical P-F interval curves

The three curves shown in Figure 9.6.5.1.3 demonstrate that the P-F interval can vary and is specific to a given diagnostic test and failure mode combination. Curve A shows a long P-F interval and the organization may opt to wait for a second measurement before taking action. Curve B shows a shorter P-F interval, but still gives sufficient

warning to execute repairs in advance of a failure. Curve C shows a very short P-F interval which, in some cases, does not allow enough time to execute repairs prior to failure.

In each case, the interval can vary. If an organization waits for a period of time after the first indication of fault, they risk larger scope repairs from an unscheduled shutdown as well as wasted monitoring efforts. Unless the organization has prior experience with a particular failure mode, response should be more immediate.

Various strategies for asset reliability management are shown in the chart below. Beginning with noncritical machines, reactive maintenance is simply allowing the machine to fail before repairing it. These are usually easily replaceable machines whose failure is unlikely. The next stage is preventative maintenance and is applied to machines considered essential to a plant's operation. Here the maintenance is periodic (via route-based monitoring) or nearly continuous (wired or wireless online monitoring). Predictive maintenance focuses mainly on highly expensive machines that are critical to the plant's operation. Here, decisions to shut down upon reaching the critical alarm set points of the machine condition are based on models that provide fault/failure modes that can be compared with time/frequency data extracted from the continuous monitoring records. Table 9.6.5.1.3 summarizes the various strategies, reactive, preventive, and predictive as stated in the U.S. Department of Energy (DOE) EERE O&M Best Practices Guide. A detailed description of using condition monitoring as a tool to manage asset reliability or risk management is provided in Appendix G.

Table 9.6.5.1.3 — Asset reliability management strategies

Reactive	Preventive	Predictive
• Small parts	• Wear	• Random failure
• Noncritical	• Consumable	• Critical
• Redundant	• Failure well understood	• Incorrect maintenance
• Failure unlikely		

This guideline discusses the indicators that can be monitored or reviewed on rotodynamic pumps to assess machinery condition, identify changes in machinery condition or impending failure. Common means of measuring those indicators have been defined. Alarm set point limits have been recommended, where appropriate, for those indicators whose limits are not defined in other Hydraulic Institute Standards.

There are a number of potential failure modes for rotodynamic pumps. For each failure mode, there can be several possible causes. One or more of the following 12 indicators may be monitored to assess pump condition and anticipate and identify the source of a failure. The failure modes, causes, and indicators are listed in Appendix A. The inverse, namely indicators, causes, and failure modes, are listed in Appendix B.

There are definitions included in Appendix F to clarify terms used in this standard.

Once baseline values have been established, machinery condition may be assessed by monitoring the following indicators.

- Power consumption
- Temperature change
- Corrosion/erosion
- Leakage
- Pressure (suction, discharge, differential)
- Vibration
- Noise (sound) characteristics

- Lubricant condition
- Shaft position
- Rate of flow
- Speed (rpm)
- Bearing wear

9.6.5.2 Monitoring Strategies

9.6.5.2.1 Monitoring frequency

The most important aspects of condition monitoring of machinery are that the monitoring is effective and provides a suitable level of risk reduction. As stated in section 9.6.5.1.2 above, P-F intervals are sufficiently well known to detect failures and give sufficient warning so that repairs can be planned (including procurement of replacement parts and scheduling of labor resources to effect the repairs).

In all cases, monitoring frequency should be less than $\frac{1}{2}$ the P-F interval. If the P-F interval is not known, it is advisable to consult with experts who have experience with the type of machinery under study. When an alert condition is detected, it is often prudent to increase monitoring frequency.

It is extremely important that after repairs are completed, new baseline measurements are taken to ensure that repairs were done correctly and the equipment is safe and reliable for long term running.

9.6.5.2.2 Control limits

One part of condition monitoring is establishing a system to indicate the status of the equipment that is being monitored so that appropriate subsequent actions can be executed. In general, two such sets of indications are recommended: the “alarm limit” and the “shutdown limit.” The alarm limit is typically recommended to set at a certain level above a baseline when the equipment is initially installed and operated satisfactorily. The purpose of the alarm limit setting is to notify the operators that some attention should be paid to the equipment in question. The shutdown limit should usually be set at a certain preset level above the baseline value where if the measured level exceeded the setting, the equipment in question would automatically shut down.

In this guideline, the following approach is introduced. For the alarm limit setting, two different levels are recommended: (1) alert limit (2) alarm limit. More details of each level are discussed in the alert and alarm limit settings sections. For the shutdown limit setting, stopping the operation of the machine is recommended to avoid collateral damage. However the recommendation is not to use an automatic shutdown in general unless a system/process review is performed and a well-planned shutdown procedure for the entire system is in place. Details of the shutdown limit setting are described in the Shutdown limit settings section.

These are overall guidelines, but do not necessarily apply to all indicators that are being monitored. Each indicator being monitored may have its own alarm/shutdown limit criteria as described in each chapter in this guideline.

In subsequent sections of this document, each indicator is discussed. Each section includes an introduction discussing the reasons for monitoring, methods of monitoring, frequency of monitoring, and control limits.

Appendix B contains a cross-reference between indicators, causes, and failure modes. Statistics can also be used to set alert, alarm and shutdown limits.

9.6.5.2.2.1 Alert limit settings

Alert limit: A preset level of some margin of the measured value over an established baseline value that was recorded after a successful start-up. This level could end up being well below the industry standard equipment

acceptance criterion for new equipment installation. In the absence of industry standards criteria, the alert set points suggested by the pump manufacturer and/or end user preferences may be used. If the organization has access to the historical data for this or other similar machines, alert limits can be set to average plus one standard deviation. The subsequent action for this level can be to alert the operators to investigate the status of the equipment. The repair planning process should also start at this level, most importantly spare parts should be ordered when the machine is in alert.

9.6.5.2.2.2 Alarm limit settings

Alarm limit: A preset level of some margin of the measured value over the maximum value of the established accepted criteria. In some cases the alert limit and the alarm limit could be the same value (if the trend baseline is equal to the maximum allowable acceptance criteria set by an industry standard). The subsequent action for this level should be to start the maintenance/repair process. Further actions should be discussed based on the nature of the system and process. If the organization has access to the historical data for this or other similar machines, alarm limits can be set to average plus two standard deviations.

9.6.5.2.2.3 Shutdown limit settings

Shutdown limits: In most system processes, shutting off a pump without careful provisions in place could result in damage to other critical equipment downstream, severe breach of personal safety, and significant loss of production. Except in very specific and special cases, most equipment and process production can be protected by using the recommended alarm settings for condition monitoring. If the organization has access to the historical data for this or other similar machines, shutdown limits can be set to average plus three standard deviations. When shutting down a pump becomes necessary, the following items should be considered before installing an automatic shutoff system:

1. What impact will it have on other equipment upstream and/or downstream in the system?
2. What impact will it have on the system process and production?
3. Will it eventually cause a greater danger to the safety of personnel?

Further discussions on the system design review process are available in Section 9.6.5.12.

9.6.5.2.2.4 Definition of baseline used in alarm set point limits

To set the alarm warning level, some percentage value change from “baseline” or “trend baseline” is used. The baseline is set after the pump has been successfully commissioned, and the process system has been fully stabilized. The indicator measurement values at the trend baseline level could be lower than the industry standard acceptance levels at commissioning. To establish the baseline value, any steady state data fluctuations should be considered. The baseline set level is used to study the trend changes in the monitored equipment.

9.6.5.2.2.5 Definition of field acceptance level or industry standard level

For some critical indicators, shutdown limit set points are set at certain deviation levels from the industry standard field acceptance levels at commissioning. An example is the vibration field acceptance level as per ANSI/HI 9.6.4. For the leakage indicator, this could be a governmental regulatory requirement on seal leakage.

9.6.5.3 Power monitoring

9.6.5.3.1 Introduction

Monitoring the power consumed by a pump can give advanced indication of the following failure modes: rolling element bearing failure, coupling failure, shaft breakage, and excessive wear in the hydraulic components of the pump affecting changes in performance.

9.6.5.3.2 Means of power monitoring

There are several ways of monitoring the power used by a pump. Some of the instrumentation/systems are outlined below. It should be noted that some of these measure mechanical power and some electrical power. For example, the torque meter and strain gauges are used to measure mechanical power, whereas the power meter and electrical current measure electrical power. Caution must be used when applying electrical power monitoring techniques to pumps exhibiting “flat” power curves, i.e., where power changes very little over the operating range. In these cases, setting alarm points can be difficult due to the detection of small power changes resulting from operating point changes and discriminating them from power changes due to other causes, such as temperature changes in the motor or pump and normal process fluctuations.

- **Torque meter:** The most direct method is to install a torque meter with integral speed pickup between the driver and the pump. This system will directly sense the speed and torque required by the pump. Some torque meter readouts will even calculate the actual power transmitted.
- **Power meter:** This measurement is useful if the pump is driven by an electrical motor, either directly coupled to the pump or through a gearbox, belt, or hydraulic coupling. Electrical transducers are typically installed in the electrical motor starter to measure voltage, current, and phase angle. These measured values are used in the calculation of the power supplied to the motor. This approach will not only monitor the power increase or decrease in the pump as parts deteriorate or drag, but also indicates other changes could be happening to the general health of the electrical motor and/or the gearbox, belts, or hydraulic coupling.
- **Electrical current:** Similar to a power meter, but only the motor current is monitored. The line voltage and power factor are assumed to remain constant, allowing one to calculate the power supplied to the motor. While this method monitors the condition of the pump and motor, it is susceptible to error caused by variations in the electrical supply grid.
- **Strain gauges:** Strain gauges applied to either the pump shaft near the coupling or the drive output shaft with proper telemetry or slip ring equipment, will give an indication of the torque required to drive the pump. This approach is similar to using a torque shaft except that a longer baseplate is not required to accommodate the length of the torque shaft. Some accuracy is sacrificed. If the pump speed is constant or known, the power required by the pump can be calculated. Relating torque to a strain gauge measurement requires a fore knowledge of the stiffness of the torque shaft. Generally, this specification on the torque shaft (assuming linearity) is difficult to identify, since the torque loading is often complicated by shaft misalignments.
- **Variable frequency drive (VFD):** A variable frequency drive could be programmed to provide the power monitoring.
- **Measurement practice:** Monitoring the pump power usage alone will only indicate whether or not the power is changing. Power changes can also result from changing the hydraulic operating conditions and mechanical or hydraulic deterioration.

Along with power measurements, the operating condition of the pump needs to be monitored, or as a minimum, the pump must be operated at the same conditions when data are recorded.

To adequately monitor the operating condition of the pump; rate of flow, total head, net positive suction head available (NPSHA), and pumpage viscosity and specific gravity need to be measured. When variable-speed devices are used, speed should also be measured.

Once it has been determined that changes in the power consumed by a pump are not the result of changes in its operating conditions, then the changes can be attributed to a pump or motor failure mode. Note that flow rate, operating speed, fluid density, and viscosity are all operating conditions that will impact the absorbed power. Further study of the changes in power and other failure causes will be required to determine the exact mode of failure.

9.6.5.3.3 Power monitoring frequency

Refer to section 9.6.5.2.1.

9.6.5.3.4 Power control limits

Before selecting alarm and shutdown limits, the accuracy, repeatability, and stability of the power measurements must be evaluated. Similarly, the accuracy, stability, and repeatability with which the pump's operating condition can be set must also be evaluated. Consideration should also be given to the power level, with higher-power pumps requiring tighter tolerances.

The following control limits are recommended:

Alarm (combining alert and alarm) – 5% to 10% change from baseline

The above levels should be coordinated with any power equipment control limit settings.

9.6.5.4 Temperature monitoring

9.6.5.4.1 Introduction

Temperature is a relatively simple and inexpensive parameter to monitor. It can be used to monitor the following failure modes: bearings, seal faces, NPSHA variation, cooling-loop blockage, decoupling of magnetic couplings, VFD, and motor-winding insulation breakdown.

9.6.5.4.2 Means of monitoring temperature

Thermocouple probes or strip resistance temperature detectors (RTDs) are primarily used for monitoring. Also, noncontact, infrared (I-R) temperature measurement could be considered. Thermography involves the use of I-R sensors, often in the form of an I-R camera that determines the surface temperature levels over a broad area of the pump and/or motor, including the coupling and bearings. When monitoring temperatures at locations where there can be rapid changes (e.g., vaporization of cooling flow or bearing rubs), care must be taken. Temperature at the source of heat input may be up to several hundred degrees higher than measured temperature of liquid, gas, or metal a short distance away. There is also a time delay between temperature rise at the hot spot as heat flows toward the measurement spot. With proper attention to locating the sensor near the heat input, and minimizing the thermal inertia of the sensor and heat transfer path, temperature changes (temperature rise) can be used as an indicator of machine condition.

9.6.5.4.3 Specific applications of temperature monitoring

9.6.5.4.3.1 Motor-winding temperature

Motor insulation deteriorates faster at higher temperatures. Temperature is dependent on load, frequency of starts, and cooling effectiveness. Winding temperature is more often measured by thermocouples located at the center of the end turns. Strip RTDs and thermistors are also used as alternate sensor methods. Motors are often fitted with thermostats that shut off power when a preset temperature is reached.

9.6.5.4.3.2 Temperature-sensitive liquids

Temperature sensors are used to measure temperature of liquids to ensure that the material is maintained in the liquid state. For high-freezing-point liquids, care must be taken to locate the sensor in the least heated area and allow time for temperature stabilization. For polymerizing liquids, the sensor must be mounted in potential hot spots (areas of high liquid shear or near external heat inputs).

9.6.5.4.3.3 Rolling element bearing temperatures

Rolling element bearing temperatures can be measured by one of three methods:

- Thermocouples or tip-sensitive RTDs immersed in lube oil active flow areas to measure lubricant temperature
- Thermocouples or tip-sensitive RTDs touching the outside raceway of the bearing
- Technologies measuring the temperature on the outside surface of the bearing housing. This is the least reliable method of measurement and is not recommended

9.6.5.4.3.4 Liquid-film bearing and seal faces temperatures

Temperatures of contacting surfaces of sleeve bearings, thrust bearings, and mechanical seal faces can change rapidly when the liquid film is not supporting the load correctly. For hydrodynamic radial bearings, even thermocouples installed in drilled holes as close to the radial bearing surface as possible are often too slow in showing excessive temperature rise to be able to shut down before bearing failure. Use of proximity probes to detect radial shaft position and motion is preferred. For thrust bearings and mechanical seal faces, thermocouples located very near the contact surfaces can frequently detect distress before failure.

9.6.5.4.3.5 Pumped liquid temperature rise

Measurement of liquid temperature at suction and discharge can indicate temperature rise accurately when rate of flow is sufficient to avoid recirculation and suction heating (above 10% or so of BEP flow). At lower rates of flow, fluid mixing from discharge to suction can result in relatively low indicated temperature rise. In these cases, the suction temperature may have increased so that NPSHA has been reduced and flashing may be occurring. Locating the suction thermocouple 20 diameters or more upstream will also avoid suction recirculation heating error. Significant increase in temperature rise across the pump indicates a drop in flow that is likely to cause flashing.

9.6.5.4.4 Sealless pump liquid temperature

Avoidance of liquid flashing in the bearing area of sealless pumps is critical because the bearings are liquid lubricated. Reduced cooling flow can result in an increase in cooling-liquid temperature and flashing. Slow increases in temperature can be detected by well-placed thermocouples. Rapid increases may not be sensed quickly enough to avoid bearing damage.

Liquid is also often used as a coolant in the magnetic gap between the inner magnet and the containment shell. If flashing occurs, heat removal capacity is greatly reduced and excessive heating may take place. The flashing of highly volatile liquids inside a sealless pump can cause rapid expansion that leads to distortion of internal components that can result in failure.

9.6.5.4.4.1 Sealless pump temperature damage

Magnets in magnetic couplings lose strength at elevated temperatures. If excessive heating occurs, the magnets will weaken until they are no longer strong enough to transmit the torque. Process liquid temperature changes as well as coolant-loop blockages may result in elevated coupling temperatures. Temperature sensors may be installed on the outside of the containment shell or in the containment shell cooling loop to monitor the magnetic coupling environment.

The following are some of the situations that may be encountered:

- Dry run: with no liquid to dissipate heat, temperature will rise rapidly
- Running against a closed discharge valve, temperature will rise slowly

- Decoupling of magnetic drive. In this case, the slippage of the inner magnet ring relative to the outer will generate eddy currents in the inner rotor and resulting heating can damage the magnets both thermally and mechanically. Coupling temperature will rise quickly
- Internal flow holes blocked by solids/polymerized pumpage. Coolant temperature will rise at a rate depending on the amount of blockage
- Solids between the inner magnet ring and the containment shell. Containment shell temperature will rise slowly
- Internal and external rubbing on containment shell. Containment shell temperature will rise rapidly
- Excessive temperature can damage the insulation of canned motor wiring

9.6.5.4.5 Temperature monitoring frequency

Refer to section 9.6.5.2.1.

9.6.5.4.6 Temperature control limits

Alarm (combining alert and alarm) – +10% to 20% change from baseline

Shutdown – +50% change from baseline. Only with considerations discussed in 9.6.5.2.2.3

These limits should be considered as initial guidelines. Specific process parameters may dictate more or less restrictive limits.

9.6.5.5 Corrosion monitoring

9.6.5.5.1 Introduction

Pumps may be monitored for corrosive attack to prevent pressure boundary failure, and corrosion monitoring is therefore an important aspect of maintaining a pump's reliability. Because of the difficulty in monitoring, potential for catastrophic failures, and the insidious effects of corrosion, it is imperative that proper materials are selected. Difficult or unusual pumpages may require the reselection or changes in materials based on the results of monitoring corrosion rates. Choosing the right materials for a service should be done by consulting with knowledgeable corrosion engineers, and when done correctly, some of the burden for corrosion monitoring can be eliminated, or at least reduced.

9.6.5.5.2 Means of corrosion monitoring

9.6.5.5.2.1 Corrosion monitoring by visual/dimensional inspection

Visual inspection is the easiest and most economical method of monitoring corrosion, and most forms of corrosion can be detected by this method. However, stress corrosion cracking usually occurs without any visible signs, thus resulting in a sudden and sometimes catastrophic failure. Visual inspection of pump internals can reveal the degree of general corrosion occurring as well as signs of localized corrosion, such as pitting and crevice corrosion. Particular attention should be given to complete inspection of fasteners as corrosion often takes place in areas hidden from view. Pressure boundary leakage may expose nonwetted fasteners to corrosive pumpage.

Visual inspection can be supplemented with dimensional checks of key components, which can then be used to calculate the amount of general corrosion that the pump is experiencing.

Because most pump manufacturers provide a corrosion allowance in the design of their equipment, the amount of dimensional change over a given time increment can be projected into the remaining life of the pump.

9.6.5.5.2.2 Corrosion by electrical resistance (ER)

The basic principle of this method is the measurement of the increasing ER of a metal probe as its cross section is reduced by corrosion. The probe should be the same alloy as the pump. However, probes will typically be wrought alloys, whereas most pump components will be cast alloys, which can result in some small degree of error. ER probes can provide a reasonable degree of accuracy for general corrosion but they are not useful for localized forms of corrosion, such as pitting.

9.6.5.5.2.3 Corrosion by linear polarization resistance (LPR)

This method involves measurement of a current response to an applied potential through probes that are inserted in the system. There is commercially available equipment that can do this automatically. A small known pulse of direct current (DC) voltage is supplied to a test electrode and the resulting current is measured. The current generated is proportional to the corrosion rate, which can be determined by electrochemical principles. Although there is a time lag involved with ER measurements, the advantage of LPR is that it can give instantaneous corrosion readings. To use LPR, a conductive liquid is required.

9.6.5.5.2.4 Corrosion by ultrasonic thickness measurement (UTM)

Although not as accurate as the other methods, UTM can also be used to monitor corrosion on a periodic basis. To use this method, a baseline reading should be obtained at a specific location on the pump casing or cover plate. Then a series of measurements can be made at this same location over time and the metal loss per unit time calculated. To use UTM, the metal surface must be bare metal (i.e., no paint). Temperature extremes may influence readings. One effect of temperature is choice of the couplant (material used to acoustically couple the sensor to the surface). High temperature will require a couplant other than water.

9.6.5.5.3 Corrosion monitoring frequency

The ER, LPR, and UTM methods lend themselves to continuous monitoring or frequent checks by use of small portable data acquisition devices.

The visual/dimensional checks are difficult to do on a very frequent basis because this method requires that the pump be shut down and opened in order to gather the data. The frequency of inspection by this method will then be determined by the importance of the pump. In the absence of experience, the first inspection by this method should be no longer than 3 months. The findings of these first inspections can then determine when subsequent inspections need to be made. Of course, data generated by this method should be obtained anytime a pump is opened for maintenance. Another sign as to when visual/dimensional inspection should be done is when a drop-off in pump performance is noted, i.e., rate of flow and total head. Corrosion monitoring is also recommended shortly after any significant process changes are made, such as temperature, concentrations, or any changes in corrosives being handled (unless experience dictates otherwise).

Also see section 9.6.5.2.1.

9.6.5.5.4 Corrosion parameter control limits

Pump casing or pressure boundary components are designed with a corrosion allowance. This corrosion allowance varies by component. Casings and rear cover plates may have up to 3 mm (1/8 in) allowance, while components such as sleeves and containment shells may be as low as 0.25 mm (0.01 in). The pump manufacturer should be consulted for specific corrosion allowances.

Alarm (combining alert and alarm) – 50% of corrosion allowance

9.6.5.6 Leakage monitoring

9.6.5.6.1 Introduction

Leakage from installed pumps is detected in a number of ways depending on the hazard posed by the liquid being pumped and the surrounding environment. Leakage is monitored to identify the failure of the seal or pressure boundary. These leaks may be in the form of liquid or vapor.

It should be noted that the presence of leakage does not always indicate seal failure or poor performance. Most seals require lubrication at the seal face contact area to prevent excessive wear and heat generation. Consult with the manufacturer for more details about the specific design.

9.6.5.6.2 Means of monitoring leakage

9.6.5.6.2.1 Leakage by visual inspection

For less-hazardous liquids, leakage is often detected visually from joints or seal drains. Larger leaks of volatile light hydrocarbons such as propane may form ice deposits on the outside surface of the seal gland plate. Visual monitoring is commonly used for single seals and the outboard seal of a dual seal arrangement. Visual inspection is also important for equipment using alternate methods of sealing equipment such as mechanical packing, expellers, etc.

9.6.5.6.2.2 Leakage by organic vapor analyzer (OVA) inspection

OVA's are used to detect minute leakage of volatile organic compounds (VOCs). Typical locations monitored are joints, flanges, connections, and seal drains. Concentrations can be measured to determine the severity of the leak. The proper device must be used for the compound pumped.

The OVA inspection method, Environmental Protection Agency (EPA) method 21, is typically used for detection of VOC emissions from single seals.

9.6.5.6.2.3 Seal leakage in submersible pumps

Submersible pumps are typically fitted with a dual unpressurized seal system and a separate containment volume that accepts leakage accumulations from the outer seal. If this volume is allowed to fill up, the contained fluid will leak past the inner seal and into the submersible motor. Some motor designs have an additional interior cavity that will collect this leakage before any damage is done to the motor.

The two principal places for leakage monitoring are at the bottom of the motor (for vertical shaft motors) or in the seal barrier fluid containment volume. For reasons not discussed here, most designs place the leakage sensing device in the motor housing. Two sensor types dominate the market, the conductivity probe and the float switch. Leakage sensors installed in the seal oil chamber will respond sooner to leakage resulting from a mechanical seal failure, but because of the location, they are unable to detect water intrusion from other entry points in the equipment. A sensor installed in the bottom of the dry motor compartment can detect liquid intrusion from all possible areas, including from the top of the motor.

The float switch contains a small floating element that is loosely mounted on a pin or shaft. Under normal conditions, the float element remains at rest at the bottom. When liquid enters, the float will rise and this can be detected by several electrical methods. Although simple and reliable by design, float style leakage detectors are position sensitive and as a result are not usually used in submersible equipment that may be subject to inclined operation such as portable pumps.

The conductivity probe senses the conductance of an oil–water mixture, beyond a threshold water limit, that reaches the sensor. It works with a “relay” usually located in the control panel.

9.6.5.6.2.4 Leakage in an inner seal of dual unpressurized seal arrangements

Leakage monitoring at the seal support system may serve as a method to establish alarms, which will assist with condition monitoring of the equipment. Leakage through the inner seal of a dual unpressurized seal arrangement may be detected by a change in seal reservoir pressure and/or a change in the seal reservoir buffer fluid level (commonly referred to as a Plan 52).

Change in the seal reservoir pressure can be detected by either blocking off the reservoir from the flare (vent) and noting the increase in pressure or using a pressure transmitter or switch. Normally, the reservoir is vented through an orifice to a vapor collection system, which allows detection of excessive vapor leakage by an increase in pressure in the buffer fluid reservoir. This increase in pressure can be monitored by a transmitter or a switch can be set to activate at a predetermined pressure. Detection can also be accomplished by blocking off the reservoir from the flare (vent) for a short period of time and noting the increase in pressure. When performing the measurement, do not allow the buffer fluid pressure to exceed the inner sealed pressure.

Change in the seal reservoir fluid level can be monitored visually with a sight-gauge or by using a level transmitter or switch. Since the process fluid will be at a higher pressure than the buffer fluid, an inner seal leak will result in an increase in fluid level in the reservoir.

9.6.5.6.2.5 Leakage in an inner seal of dual pressurized seal arrangements

Leakage monitoring at the seal support system may serve as a method to establish alarms, which will assist in condition monitoring of the equipment. Leakage through the inner seal of a dual pressurized seal arrangement may be detected by a change in pressure and/or a change in the barrier fluid level (commonly referenced systems include plan 53A, 53B, 53C, and 54).

Change in the seal support system pressure can be detected by using a pressure transmitter or switch. Dual pressurized seals use a higher pressure barrier fluid. This means alarms will be set to indicate decreases in pressure (if the pressure source is isolated).

Change in the seal support system fluid level can be detected by using level transmitters, switches or visually if the system has a sight-gauge. Since the process fluid will be at a lower pressure than the barrier fluid, an inner seal leak will result in a decrease in fluid level of the system.

9.6.5.6.2.6 Double-walled system

For extremely hazardous fluids such as phosgene, double-walled pipe with double sealing flange surfaces and inert purge gas arrangement is used to minimize the chance of leakage to the atmosphere. Pumps with double-walled leakage protection are often used. Sniffers are used to detect the presence of any hazardous gas in the purge gas.

For liquids that do not flash when leaking into the lower-pressure collection areas, liquid detectors may be used to indicate leakage past the primary boundary into the collection area.

Table 9.6.5.6.2.6 provides an application guideline for the above methods.

Table 9.6.5.6.2.6 — Application guidelines for leakage monitoring systems' mechanical seals

Monitoring Method	Seal Arrangement				
	Single	Dual			
		Pressurized (Double)		Unpressurized (Tandem)	
		Inner	Outer	Inner	Outer
Visual	X		X		X
Organic vapor analyzer	X				X
Level increase or pressure buildup in seal reservoir				X	
Level decrease or pressure decline in seal reservoir		X	X		X

9.6.5.6.3 Leakage monitoring frequency

Refer to section 9.6.5.2.1.

9.6.5.6.4 Leakage control limits

Leak monitoring is one way for the user to understand the health of the mechanical sealing system. A change in leak rate can be an indicator of the health of the sealing device and an increasing rate is often a sign of impending failure. It is recommended that the user consult with the seal manufacturer to develop the best strategy for leak monitoring and how to interpret this data.

As stated in the *Hydraulic Institute Mechanical Seals For Pumps Application Guidelines* (Para. 1.4), it is not recommended to operate seals at leakage levels that are unacceptable by plant site standards and the applicable local, state, or federal regulations. Seal failure increases risks with safety, and environmental or product contamination. The list of regulating bodies that specify limits of hazardous compounds to the atmosphere in the form of liquid or vapor emissions varies within cities, counties, states, and countries and is increasing in number. Volatile hazardous air pollutants (VHAP) as defined by Title 1, Part A, Section 112 of the US National Emission Standards for Hazardous Air Pollutants (NESHAPS, or the Clean Air Act) lists specific limits of emissions to the atmosphere. The European Union also continues to implement directives regulating pollutants.

With the exception of regulated fluids, acceptable leakage levels are normally dictated by site or by site operating units based on the process fluid. The user is encouraged to define the acceptable limits of leakage based on regulatory requirements and considering safety and housekeeping requirements. Items to consider when determining leakage control limits:

Single seals

- What leak rate can be tolerated and contained safely? And for how long?
- What leak rate constitutes a significant safety concern for the facility?
- What leak rate indicates a change in seal performance from baseline?
- What leak rate indicates that the seal is not performing correctly?