ANSI/HI 9.6.9-2013

Approved American National Standard

ANSI

American National Standard
for

Rotary Pumps

– Guidelines for Condition Monitoring

ANSI/HI 9.6.9-2013

Hydraulic Institute

6 Campus Drive
First Floor North
Parsippany, New Jersey
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www.Pumps.org

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Rotary Pumps – Guidelines for Condition Monitoring

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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 of the 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;

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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 sent to the Technical Director of the Hydraulic Institute. The inquiry will then be directed to the appropriate technical committee for provision of a suitable answer.

If a dispute arises regarding the contents of an Institute Standard or Guideline, or an answer provided by the Institute to a question such as indicated above, the point in question shall be referred 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 or guidelines are reaffirmed using the ANSI canvass procedure.

Units of measurement

Metric units of measurement are used; 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 for this guideline was achieved by use of the Canvass Method

The following organizations, recognized as having an interest in the standardization of rotary 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.

A.W. Chesterton Company
Albemarle Corporation
Bechtel Power Corporation
Black & Veatch
Brown and Caldwell
Colfax Fluid Handling
DuPont Company
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Leistritz Corporation
Mechanical Solutions, Inc.
Patterson Pump Company
Peerless Pump Company
Sulzer Pumps (US) Inc.
Summit Pump, Inc.
Tennessee Valley Authority
WEG Electric Corp.

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 – Randy Bennett, Leistritz Corporation
Vice-Chair – Jessica Phillips, Flowserve Corporation

Committee members	**Company**
James Casey	Milton Roy, LLC
Trygve Dahl	Intelliquip, LLC
Adam Downey	NOV Mono Pumps
Gregory Duncan	Wilden Pump & Engineering LLC
James Farley	PSG-GT
Richard Foster	Blackmer, Inc.
Ken Patton	Colfax Fluid Handling
Tino Senon	MWH Americas, Inc.
Larry Stanley	ABB Ltd.
Thiru Veeraraghavan	A.W. Chesterton Company
Alex Vitou	Baldor Electric Company
Don Weidemann	Neptune Chemical Pump Co., Inc.

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Scott Wild	Leistritz Corporation
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Other contributors	Company
John Owen	Colfax Fluid Handling

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9.6.9 Guidelines for condition monitoring

9.6.9.0 Scope

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

9.6.9.0.1 Purpose

This document is intended to be used as a guide for pump monitoring and failure detection techniques as elements of safety and general pump availability programs. It does not directly address process management systems.

9.6.9.0.2 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 they wish to monitor. *This document does not require any monitoring be done*, but will provide information relevant to making such decisions, and provides suggestions for carrying out the monitoring process.

This guideline discusses some of the indicators that can be monitored or reviewed on rotary pumps to predict and identify pump failure modes. Common means of measuring those indicators have been defined. Control 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 rotary pumps. For each failure mode there can be several possible causes. To anticipate the occurrence of each cause, one or more of the following seven indicators may be monitored or reviewed. 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 C to clarify terms used in this standard.

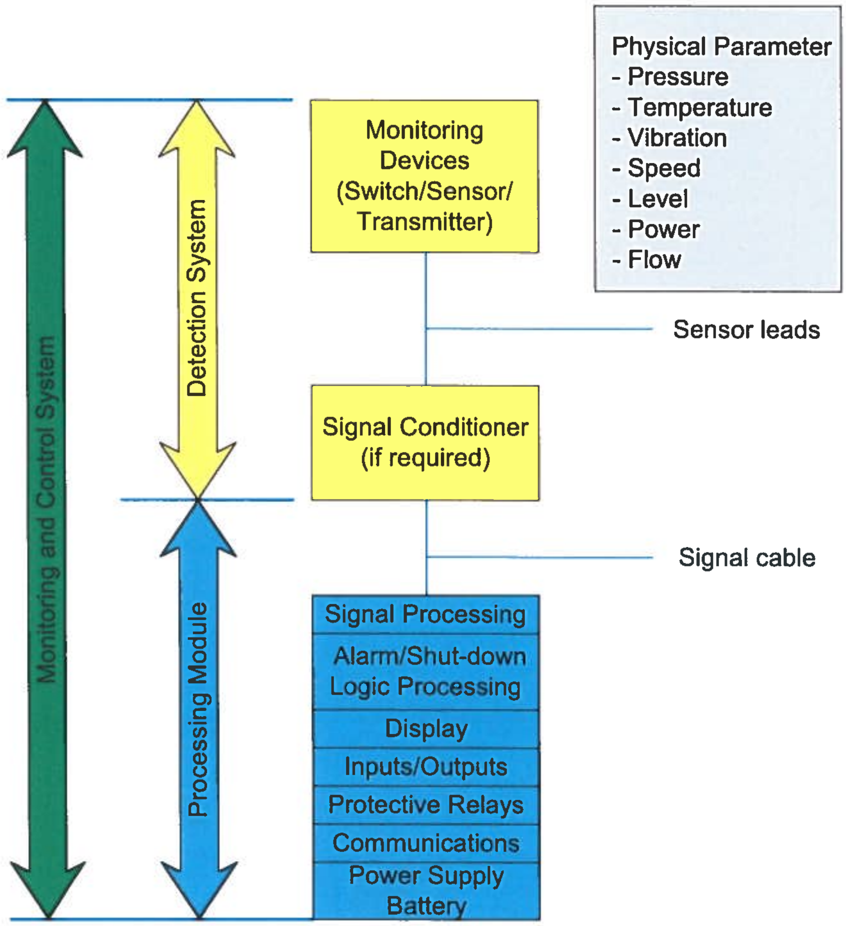
Various failure modes can be characterized by the following observations and processes:

- Power absorbed
- Temperature change
- Leakage
- Pressure (suction, discharge, differential)
- Vibration
- Rate of flow
- Speed (rpm)

In addition to the indicators listed above, changes in pump sound can sometimes be used to indicate some changes in pump performance. However, interpretation of change in sound is usually subjective in nature.

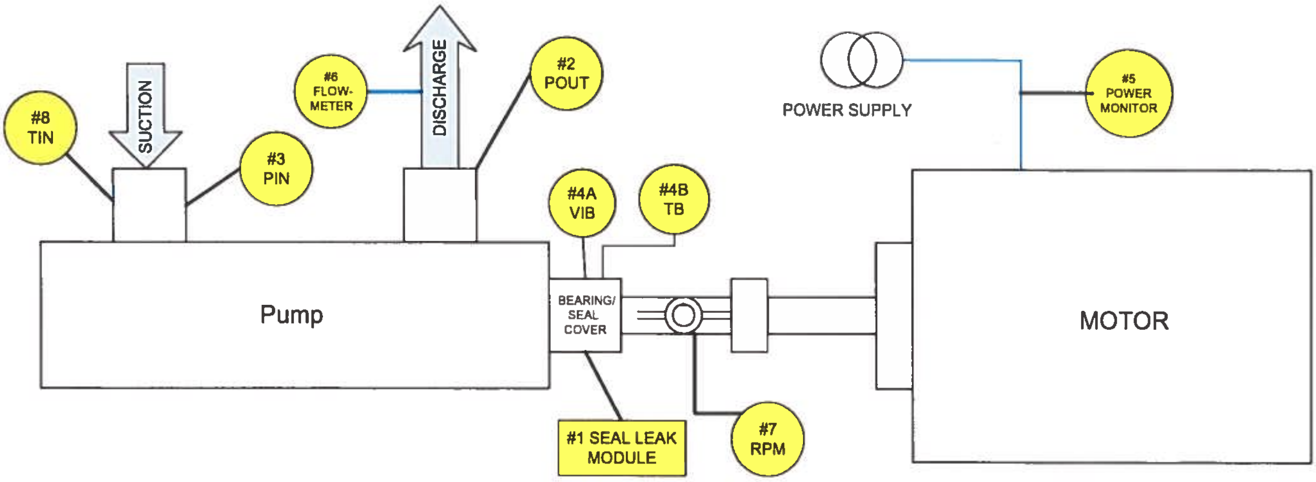
9.6.9.0.3 Monitoring and control system concepts

A typical control system and typical monitoring devices are shown in Figures 9.6.9.0.3a and 9.6.9.0.3b, respectively. When monitoring a pump, it is important to establish a baseline to which all future measurements can be compared. This applies to both new and reconditioned equipment. Trending and the absolute level of the indicator are important. A baseline should be established soon after the pump is put into service. The indicators that are chosen to be monitored at an established frequency can then be compared to the previously established baseline. The change and rate of change of the trended indicator will give the user indications of the pump's current state, and how much longer it will continue to operate.



Adapted from API 670, Figure 1.

Figure 9.6.9.0.3a — Typical monitoring control system



#1 Seal leak detection device – custom; may combine multiple devices

#2 Discharge pressure sensor:
For overpressure or loss of pressure in event of case failure; shaft/coupling failure; internal seizure

#3 Inlet pressure sensor – monitor boost pressure; filter condition, NPIPA, etc.

#4 Bearing housing; misalignment; coupling wear
#4a: Velometer: high vibration shut-down
#4b: Bearing temperature RTD

#5 Power monitor

#6 Flowmeter

#7 Tachometer – rotational speed

#8 Inlet oil temperature: overtemperature shut-down, monitor fluid temperature

Figure 9.6.9.0.3b — Typical fixed speed rotary pump monitoring devices

9.6.9.0.4 Monitoring interval

The frequency at which an indicator should be monitored is determined by the severity of the consequences of failure (severity level) and the probability of failure. The suggested monitoring frequencies are based on continuous operation of the pump system. There are three factors considered in the severity level: safety, environmental, and economic.

- Safety consequences include those effects on immediate employees as well as others in the community
- Environmental consequences may involve local regulations and national or company standards
- Economic consequences include the costs of lost production and correcting the failures

Table 9.6.9.0.4a suggests three levels for each factor: low, medium, and high. Users should assign a severity level for each factor based on its circumstances. The severity level for an application is determined by the highest individual level.

Table 9.6.9.0.4a — Severity levels

Safety consequences	Low	Medium	High
Environmental consequences	Low	Medium	High
Economic consequences	Low	Medium	High

In determining the probability of a pumping system failure, the following factors should be considered:

- Historical data
- Indicator levels at start-up
- Recent trends
- Pumped fluid characteristics
- Equipment redundancy
- Severity of operating conditions

It should be recognized that the probability of failure may be revised at any time, particularly if trends change.

The user should categorize the probability as low, medium, or high.

A monitoring frequency can be determined by looking at Table 9.6.9.0.4b. The user should consider monitoring more frequently than monthly for pumps that are rated as "high" probability of failure and "high" severity level. The frequency should be determined based on the user's evaluation of specific risks and consequences of failure. For critical applications, the frequency may range from twice a month to continuous monitoring with alarm and shutdown control. The use of installed monitoring equipment should be considered for these applications. The installed monitoring equipment should provide alarm indication based on set operating parameters. The monitoring equipment may also be set up to periodically record and store operating parameters. These data are useful for reviewing pump condition trends and evaluating and scheduling service.

Table 9.6.9.0.4b — Frequency of monitoring

Severity Level	Probability of Failure		
	Low	Medium	High
Low	Annually	Annually	Semiannually
Medium	Annually	Semiannually	Monthly
High	Semiannually	Monthly	Twice a month to continuous

9.6.9.0.5 Control limits

Separate control limits are recommended for alarm and shut-down conditions.

Alarm limit is defined as the indicator value at which one wants to be notified of changes (either increase or decrease) in the measured indicator level. The alarm limit for each indicator should be set as a change from the baseline value and not from established commissioning acceptance levels. The pump does not need to be shut-down, but more detailed and/or increased frequency of monitoring should be instituted.

The *shut-down limit* is defined as the indicator value at which the unit needs to be shut-down and secured immediately. Continued pump operation at indicator levels in excess of the shut-down limit will shorten the mean time between failures of the unit and greatly increase the likelihood of a catastrophic pump failure.

The alarm and shut-down limits suggested in this document are guidelines. The best knowledge base for each pump installation is the user's experience and knowledge. Experience may warrant higher or lower alarm/shut-down limits, depending on the design of the equipment, system requirements, past indicator history, and failure record. Detailed information on pump operation and shut-down is contained in ANSI/HI 3.1-3.5 *Rotary Pumps for Nomenclature, Application, and Operation*.

Each indicator is discussed in subsequent sections of this document. 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.

9.6.9.1 Power monitoring

9.6.9.1.1 Introduction

Monitoring the power consumed by a pump can give an indication of the following failure modes: rolling element bearing failure, sleeve bearing failure, coupling failure, shaft breakage, pump wear, system blockage, magnetically driven pump decoupling, and pressure-retaining component failure.

9.6.9.1.2 Means of power monitoring

There are several ways of monitoring the power used by a pump. Some of the instrumentation/systems are outlined below.

> 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. Under controlled operating conditions, torque measurement can sometimes be used to detect internal component rubbing and wear in rotary pumps.

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. The product of these values results in 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 if anything is happening to the general health of the electrical motor and/or the gearbox, belts, or hydraulic coupling. This type of device may not be suitable for use with motors controlled by variable frequency drives (VFDs), which alter the characteristics of the voltage and current supplied to the motor.

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 and when motors are running at low load.

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. However, some accuracy is sacrificed. If the pump speed is constant or known, the power required by the pump can be calculated.

Caution must be used when applying electrical power monitoring techniques to rotary pumps. Monitoring the pump power usage alone will only indicate whether or not the input electrical power is changing. Power changes can also result from changing hydraulic operating conditions, changing fluid conditions, and deterioration of the pump or driver. 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.

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

Failure of a drive component (coupling, shaft, etc.) or sudden loss of pressure due to failure of a pressure-retaining component or discharge piping will cause sudden loss of power. Therefore, power monitoring of rotary pumps may require high power and low power detection.

Warning: A power monitoring device must not be used as an overpressure protection device for a positive displacement pump. The pump must be suitably protected by a pressure relief valve.

9.6.9.1.3 Power monitoring frequency

Refer to Table 9.6.9.0.4b.

9.6.9.1.4 Power control limits

Before selecting alarm and shut-down 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 also must 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 — 5% to 10% change from baseline

Shut-down — 10% to 30% change from baseline

The above levels should not fall below the normal minimum power required by the pump or above the normal maximum power levels determined by the user based on expected operating power range.

NOTE: It may be necessary to use a start-up timer to avoid tripping the control during start-up, when inrush current can be very high and when torque can be low, until pressure is applied by the system. It may also be necessary to use trip delay timers to avoid nuisance trips from short transient changes in power level.

9.6.9.2 Temperature monitoring

9.6.9.2.1 Introduction

Temperature is a relatively simple and inexpensive parameter to monitor. It can be used to monitor the following failure modes: bearings, seal faces, corrosion, net positive inlet pressure available (NPIPA) variation, cooling-loop blockage, and decoupling of magnetic couplings.

9.6.9.2.2 Means of monitoring temperature

Thermocouple probes or resistance temperature detectors (RTDs) are primarily used for monitoring temperature. When monitoring temperatures at locations where there can be rapid changes (e.g., vaporization of cooling flow or bearing rubs), special care must be taken. Temperature at the source of heat input may be higher than the 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 pump condition.

9.6.9.2.3 Specific applications of temperature monitoring

9.6.9.2.3.1 Temperature-sensitive liquids

Temperature sensors are used to measure temperature of liquids to ensure that the material is maintained in the liquid state. For liquids that must be maintained at high temperature to control viscosity, 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).

9.6.9.2.3.2 Rolling element and sleeve bearing temperatures

Rolling element and sleeve 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.
- Sensors attached to or touching the external surface of the bearing housing. This is the least reliable method of measurement and is not recommended due to the potential temperature difference between the bearing and the bearing housing external surface.

9.6.9.2.3.3 Liquid film bearing and seal faces temperatures

Temperatures of contacting surfaces of sleeve bearings, thrust bearings, pumping elements (such as between rotor and stator of a progressing cavity pump), and mechanical seal faces can change rapidly when the liquid film is not supporting the load correctly or not providing proper lubrication to the parts. 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. For thrust bearings and mechanical seal faces, temperature sensors located very near the contact surfaces can frequently detect distress before failure.

9.6.9.2.3.4 Pumped liquid temperature rise

The maximum allowable pump temperature is often determined by the materials of construction or elastomers contained within the pump. Rotary pump performance is a function of the viscosity of the pumped liquid. If the viscosity and temperature characteristics of the pumped liquid and the maximum temperature capability of the pump are known, then measurement of the temperature of the pumped liquid at suction and discharge can be used to monitor the following potentially harmful conditions listed below.

Low viscosity: In most fluids, viscosity decreases with increasing temperature. Maximum allowable pump or fluid temperature set point can be used to prevent a pump from operating beyond minimum allowable conditions.

Low volumetric efficiency: When internal recirculation or slip in a rotary pump approaches 50% of its displacement (typically from low-speed operation, internal wear, or both), the pump differential temperature will not stabilize and the pumped liquid temperature can exceed maximum allowable pump or fluid temperature.

Vapor pressure: Vapor pressure increases with increasing temperature. For volatile fluids, increasing temperature may cause the pumped fluid to vaporize in the pump inlet and the pump to cavitate.

Relief valve, system recirculation, or bypass valve open: Rotary pumps require the use of relief valves for overpressure protection. Recirculation valves are used to maintain fluid system pressure. Bypass valves are often used to control flow to the system. If the relief valve or bypass valve is partially or fully open, then the temperature of the exhaust increases proportionately to the oil horsepower bypassed. If the exhaust recirculates to the inlet side of the pump, then the pumped liquid temperature can quickly exceed the maximum allowable pump or fluid temperature, resulting in catastrophic pump failure.

Dry run: with no liquid to dissipate heat, temperature will rise rapidly. Pump failure is likely.

9.6.9.2.4 Sealless pump liquid temperature

Sealless pumps are manufactured as magnetically coupled with synchronous magnets. Most sealless pumps rely on cooling by the pumped liquid to maintain temperature within normal operating limits. The temperature measurement points will be designated by the pump manufacturer and vary with the type of sealless pump design configuration. This section deals generically with the impact of temperature on sealless pumps.

9.6.9.2.4.1 Sealless pump temperature damage

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.

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 also 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 rubbing can result in penetration of the liquid containment shell.

9.6.9.2.5 Temperature monitoring frequency

Refer to Table 9.6.9.0.4b.

9.6.9.2.6 Temperature control limits

Alarm — 10% from baseline

Shut-down — 20% from baseline

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

9.6.9.3 Leakage monitoring

9.6.9.3.1 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.

9.6.9.3.2 Means of monitoring leakage

9.6.9.3.2.1 Leakage by visual inspection

For less-hazardous liquids, leakage is often detected visually from static joints (gaskets/O-rings) 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. Continued operation will cause the ice to melt and be replaced by carbon wear debris from the seal faces. Visual monitoring is commonly used for single seals and the outboard seal of a dual seal arrangement.

9.6.9.3.2.2 Leakage by sniffer inspection

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

The sniffer inspection method can be used for detection of VOC emissions from single seals.

9.6.9.3.2.3 Leakage by catch tank

Leakage from single mechanical shaft seals may be detected by collecting the seepage from the seal drain connection into a small reservoir. Fluid level sensors in the reservoir can be used to detect seal leakage and signal an alarm if the leakage becomes severe.

9.6.9.3.2.4 Leakage by pressure buildup

Leakage through the inboard seal of a dual unpressurized seal arrangement may be detected by a change in pressure in the seal reservoir containing the buffer fluid. This is accomplished by blocking off the reservoir from the vent for at least 10 minutes and noting the increase in pressure.

Pressure buildup in secondary containment areas of sealless pumps may also be used to indicate leakage past the primary containment.

9.6.9.3.2.5 Leakage by change in barrier fluid flow

Leakage through the inboard seal of a dual unpressurized seal arrangement may be detected by monitoring the gas/liquid flow from the seal to the vent system or collection system.

Leakage through the inboard seal of a dual pressurized seal arrangement may be detected by measuring the change in level of barrier liquid from the circulation system and reservoir.

Table 9.6.9.3.2.5 provides an application guideline for the above methods.

Table 9.6.9.3.2.5 — Application guidelines for leakage monitoring systems' mechanical seals

	Seal Arrangement				
		Dual			
		Pressurized (Double)		Unpressurized (Tandem)	
Monitoring Method	Single	Inboard	Outboard	Inboard	Outboard
Visual	X		X		X
Sniffer	X				
Catch tank	X				
Pressure buildup in seal reservoir				X	
Barrier fluid flow increase or change in reservoir level		X	X	X	

9.6.9.3.3 Leakage monitoring frequency

Refer to Table 9.6.9.0.4b.

9.6.9.3.4 Leakage control limits

Allowable leakage of hazardous materials is often established by government regulations. For monitoring purposes, the following limits are recommended:

Alarm — 50% increase over baseline or based on government regulations, whichever is less

Shut-down — 100% increase over baseline or based on government regulations, whichever is less

9.6.9.4 Pressure monitoring

9.6.9.4.1 Introduction

Pump pressures may be monitored for at least two reasons. The pump or seal static pressure can be monitored to guard against an overpressurization of the casing that may cause the casing joint seal or mechanical seal to leak. Pressure may also be monitored as an indication of the operating point of the pump.

9.6.9.4.2 Means of pressure monitoring

Monitoring for pump performance is accomplished through the use of a pressure gauge or a pressure transducer. When monitoring pressure for hydraulic performance, both the discharge pressure and the suction pressure must be monitored or a differential pressure device can be used. Follow ANSI/HI 3.6 *Rotary Pump Tests* for tap location and design. Gauges at other locations and/or with other tap designs will provide data that can be trended, but may have a very poor correlation to the manufacturer's published performance data. This discrepancy is because of flow distortion and/or additional piping losses at the entrance and exit of the pump.

The mounting location of a gauge used to measure the discharge pressure of a pump is less critical and should be on the discharge side of the pump before any valve. Mounting pressure gauges in the seal cavity of a pump should be discussed with the pump manufacturer to prevent disturbances in the flow field and/or formation of a collection point for debris.

Mounting a pressure gauge to a seal pressure reservoir should be done only after consulting with the reservoir manufacturer. If a pump is being used on the seal flush system to circulate the fluid through the seal cavity, then the pressure gauge should be mounted between the discharge of the circulation pump and the seal cavity.

9.6.9.4.3 Pressure monitoring frequency

Refer to Table 9.6.9.0.4b.

9.6.9.4.4 Pressure control limits

Control limits will vary with the type of service. Typical control limits will be based on the following:

Suction pressure

- NPIP of the pump/system
- Pressure limits of the pump and/or seals
- Operating pressure range

Discharge pressure

- Mechanical limits of the pump or piping system
- Operating pressure range
- Product viscosity range
- Relief valve setting

Differential pressure

Mechanical limits of the pump rotating elements

If pressure monitoring is being used to monitor the overpressurization of the casing, seal pot, or seal cavity, then a shut-down limit can be set at the manufacturer's maximum allowable working pressure for the unit.

9.6.9.5 Vibration monitoring

9.6.9.5.1 Introduction

Monitoring pump vibration is by far the most widely used method to determine the condition of pumps. Presently there are many manufacturers of equipment that will measure the vibration of rotating equipment. However, because many different failure modes can cause an increase in the pump vibration, it is difficult to pinpoint the failure mode by vibration alone. Bearing failure, seal leakage, coupling failure, shaft breakage, and hydraulic degradation are some of the failure modes that can be detected by vibration monitoring.

9.6.9.5.2 Means of vibration monitoring

Depending on the pump construction, there are different vibration sensors commonly used to measure vibrations.

Bearing housing vibrations: Pumps that have rolling element bearings are commonly monitored using an accelerometer or velocity transducer. The vibrations are usually measured on the bearing housings in the vertical, horizontal, and axial positions. For rolling element bearing equipped pumps operating between 100 and 5000 rpm, velocity is the preferred unit of measure, although displacement is sometimes used. If an accelerometer transducer is used, most vibration analyzers can integrate the signal to velocity.

Filtered high-frequency signal processing is a means to obtain early warning of rolling element bearing defects. When traditional vibration parameters (such as velocity and acceleration) are measured, bearing defects would not be detected until the latter stage of bearing failure when the vibration of a pump unit reaches a detectable level. This is because the normal amplitude of high-frequency vibration is relatively small compared to the amplitude of lower-frequency vibrations at pump running speed. The lower-frequency vibrations are normally analyzed to detect unbalance, misalignment, looseness, etc. Relying on lower-frequency vibration analysis may not leave sufficient time to schedule an economic repair or replacement of the bearing. The incipient bearing defect (microscopic cracks and spalls in the bearing) is typically unnoticeable without using the filtered high-frequency signal processing technique. The most meaningful use of this technique is to measure the baseline data at normal operating conditions and then trend future measurement data as discussed in the measurement practice section.

Shaft vibrations on pumps with sleeve bearings: Vibration measurement is commonly taken using a velocity transducer mounted on the bearing housing. On sealless pumps where access to the shaft is not readily available, bearing housing acceleration is also used.

Measurement practice: It is important that baseline and subsequent vibration measurements are taken at the same locations, using the same analysis procedures, and with the pump at the same operational conditions. Indelible ink markers, stickers, or drilled dimples can be used to identify the location of each vibration measurement point. The vibration analysis procedure (i.e., bandwidth, number of filters, type of filter, type of average, number of averages, pass filters, etc.) should be standardized. To ensure that the pump is operating at the same hydraulic condition, the rate of flow, speed, differential pressure, power, NPIPA, and pumpage temperature should be recorded. If it is not possible to duplicate operating conditions, then measurement results may need to be adjusted.

9.6.9.5.3 Vibration monitoring frequency

Refer to Table 9.6.9.0.4b.

9.6.9.5.4 Vibration control limits

Overall unfiltered vibration levels are the most commonly used indicator of pump integrity. For VFD controlled devices, vibration levels can vary depending on operating speeds. This variation should be taken into consideration. While acceptance levels at commissioning are beyond the scope of this document, several industry standards and the pump supplier can provide guidelines.

The following control limits are recommended for bearing housing vibration:

Alarm — 30% above baseline

Shut-down — 50% above baseline

9.6.9.6 Rate-of-flow monitoring

9.6.9.6.1 Introduction

In some field installations, it may be difficult to accurately measure rate of flow. However, problems such as plugging of flow passages, air entrainment, insufficient NPIPA, and increased internal pump clearances can be detected by flow monitoring using less accurate devices of sufficient sensitivity.

For example, in transfer applications, the rate of flow can be monitored based on the amount of time to transfer the pumpage or empty the vessel. From baseline measurements, increased amount of time to transfer or empty could be caused by corrosion, erosion, or some other damage/wear to the pump internals.

9.6.9.6.2 Measuring rate of flow

Monitoring rate of flow may be accomplished by fixed in-line devices, such as rotameters, turbine flowmeters, orifices, venturi meters, magnetic flowmeters, or nutating disc meters. Noninvasive devices such as ultrasonic meters may also be used.

Those devices that cause losses or flow distortion should be placed on the discharge side of the pump. Manufacturer's directions should be followed to obtain the specified accuracy of the flow-measuring device. Particular attention should be given to the piping configuration immediately before and after the flowmeter, and the recommendations of the flowmeter manufacturer should be followed.

9.6.9.6.3 Rate-of-flow monitoring frequency

Refer to Table 9.6.9.0.4b.

9.6.9.6.4 Rate-of-flow control limits

Control limits will vary with the type of service. Process controls must dictate these settings.

Typical control limits for fixed speed applications are:

Alarm — 10% from baseline values

Shut-down — 20% from baseline values

9.6.9.7 Speed (rpm) monitoring

9.6.9.7.1 Introduction

Pump speed is monitored to check for speed changes that may cause the rate of flow to change. Also, excessive speed will cause the pump to draw more power and may cause the motor to be overloaded. There are two types of systems that drive pumps: constant speed and variable speed.

Constant-speed systems: It is unlikely that the motor speed will change significantly unless a major electrical problem has occurred. While the load of a rotary pump varies with differential pressure, the changes in speed associated with the load changes are normally relatively slight (less than 2% of full load speed for NEMA Design B motors). However, changes due to high or low voltage, or loss of power to one phase on a three-phase motor, may be significant.

Variable-speed systems: These systems rely on speed change to control the rate of flow. These systems can have the same problems as the constant-speed systems, but can also have unintended speed changes. These changes can be due to a faulty drive or speed control problems.

9.6.9.7.2 Speed measurement methods

Common methods of measuring speed are strobe light, revolution counter, tachometer, or electronic counter. Any of these devices should be able to measure within 0.1% accuracy.

9.6.9.7.3 Speed monitoring frequency

Refer to Table 9.6.9.0.4b.

9.6.9.7.4 Speed control limits

Alarm — 2% from baseline (constant-speed unit)

Shut-down — 5% from baseline (constant-speed unit)

The recommended control limits for variable-speed systems should be determined based on individual system component limitations and application requirements.

Appendix A

Condition monitoring failure modes

This appendix is not part of the standard, but is included to inform the user of relationships between failure modes, causes, and indicators related to condition monitoring. Reference the Hydraulic Institute *Mechanical Seals for Pumps: Application Guidelines* for additional information on mechanical seals. Many causes may be detectable by several indicators and are therefore grouped together for ease of using the table.

Table A.1 — Condition monitoring failure modes

Failure Mode	Causes	Indicators
Bearing Failure (rolling element)		
Pitting and spalling of races	Overload	Bearing temperature
	Insufficient lubrication Contamination Overload Improper mounting	Vibration (high frequency) Bearing temperature Inspection - cage breakage
Seizure	Overload Excessive speed Insufficient lubrication Contamination Shaft misalignment	High temperature Inspection - cage breakage Vibration
Skidding	Insufficient bearing load	Inspection - marks on outer race
Electric fluting	Improper shaft grounding	Inspection - speckling and visual marks on outer race Vibration
Brinneling	Shaft vibration during transportation or storage	Inspection - visual marks High temperature Vibration
Inner/outer race rotation	Incorrect bearing fit	Vibration High temperature

Table A.1 — Condition monitoring failure modes (*continued*)

Failure Mode	Causes	Indicators
Seal Leakage - Single Mechanical Seal		
Seal face heat checking	Insufficient vapor pressure margin Improper installation Loss of cooling flow Process upset Overpressurization Incompatible process fluid Lack of product/dry running	High face/chamber temperature Catch tank level Leakage observation Sniffing
Face blistering	Lack of product/dry running Incompatible process fluid High-viscosity fluid	High face/chamber temperature Catch tank level Sniffing Leakage observation
Face wear	Lack of lubricant/dry running Loss of cooling flow Improper installation Overpressurization Fluid vaporization Contaminated product	High face/chamber temperature Catch tank level Leakage observation Sniffing
Spring failure	Excessive deflection Improper installation Improper material selection Hang up/clogging due to contamination	Vibration Leakage observation Sniffing Catch tank level
Metal bellows failure	Excessive deflection Improper installation Improper material selection Overheating due to dry running	Vibration Leakage observation Catch tank level Sniffing
Rubber bellows failure	Excessive deflection Improper installation Improper material selection Blistering due to heat/incompatible process liquid	Vibration Leakage observation Catch tank level Sniffing

Table A.1 — Condition monitoring failure modes (*continued*)

Failure Mode	Causes	Indicators
Dynamic secondary seal hang up	Solids in pumpage Incompatible process fluid Improper gap dimension Pressure reversal	Leakage observation Sniffing Catch tank level
Dynamic or static seal degradation	Improper material selection Long idle period between operation Excessive temperature	Leakage observation Sniffing Catch tank level High face/chamber temperature
Dynamic or static seal compression set	Excessive temperature Excessive pressure Improper installation Improper groove design Long idle period between operation	Leakage observation Sniffing Catch tank level High face/chamber temperature High pressure Inspection
Static seal breach	Cut O-ring Improper surface finish Improper size	Leakage observation Sniffing Catch tank level Inspection
Drive pin wear/breakage	Sticking faces due to high polishing Sticking faces due to high viscosity Sticking faces due to insufficient fluid film Product buildup on atmospheric side of seal faces High vibration Improper material selection	Leakage observation Sniffing Catch tank level High face/chamber temperature Inspection Vibration

Table A.1 — Condition monitoring failure modes (*continued*)

Failure Mode	Causes	Indicators
Seal Leakage - Double Mechanical Seal [a]		
Seal face heat checking	Insufficient vapor pressure margin Lack of lubricant/dry running Improper barrier fluid selection	High face/chamber temperature Reservoir tank level Leakage observation (outboard seal only) Reservoir pressure buildup (unpressurized seal only)
Face blistering	Lack of lubricant/dry running Improper barrier fluid selection	High face/chamber temperature Reservoir tank level Leakage observation (outboard seal only) Reservoir pressure buildup (unpressurized seal only)
Face wear	Lack of lubricant/dry running Improper installation Overpressurization Fluid vaporization Contaminated barrier/process fluid	High face/chamber temperature Reservoir tank level Leakage observation (outboard seal only) Reservoir pressure buildup (unpressurized seal only)
Spring failure	Excessive deflection Improper installation Hang up/clogging due to contamination	Vibration Leakage observation (outboard seal only) Reservoir tank level Reservoir pressure buildup (unpressurized seal only)
Metal bellows failure	Excessive deflection Improper installation Improper material selection Overheating due to dry running	Vibration Leakage observation (outboard seal only) Reservoir tank level Reservoir pressure buildup (unpressurized seal only)
Dynamic secondary seal hang up	Solids in pumpage Incompatible process fluid Improper gap dimension Pressure reversal	Reservoir tank level Leakage observation (outboard seal only) Reservoir pressure buildup (unpressurized seal only)

Table A.1 — Condition monitoring failure modes (*continued*)

Failure Mode	Causes	Indicators
Dynamic or static seal degradation	Improper material selection	Reservoir tank level Leakage observation (outboard seal only) Reservoir pressure buildup (unpressurized seal only)
	Excessive temperature	High face/chamber temperature
Dynamic or static seal compression set	Excessive pressure Improper installation Improper groove design Long idle period between operation	Reservoir tank level Leakage observation (outboard seal only) Reservoir pressure buildup (unpressurized seal only)
	Excessive temperature	High face/chamber temperature
Static seal breach	Cut O-ring Improper surface finish Improper size	Reservoir tank level Leakage observation (outboard seal only) Reservoir pressure buildup (unpressurized seal only) Inspection
Drive pin wear/breakage	Sticking faces due to high polishing Sticking faces due to high viscosity Sticking faces due to insufficient fluid film High vibration Improper material selection	Reservoir tank level Leakage observation (outboard seal only) Reservoir pressure buildup (unpressurized seal only) Inspection Vibration
Reverse pressurization of inboard seal (pressurized system only)	Loss of seal system pressure Improper tracking of process pressure Electrical equipment failure	Reservoir tank level Pressure Power measurement Temperature
[a] These are the most common double seal failure modes. Depending on seal design, some single seal failure modes may apply.		
Coupling Failure		
Hub loose (set screws)	Improper installation Worn shaft/hub	Vibration Inspection - shaft fretting

Table A.1 — Condition monitoring failure modes (*continued*)

Failure Mode	Causes	Indicators
Key shearing	Overloaded key	Power measurement (torque)
	Improperly sized key Wrong material Worn key/keyway	Inspection Vibration
Flexible element failure	Excessive misalignment	Vibration
	Overload	Power measurement (torque)
	Corrosion/wear	Inspection - pitting, cracks, broken segment(s)
	Runout Torsional natural frequency Lack of lubrication	Vibration Inspection
	Incorrect selection	Design review
Shaft Breakage		
Bending fatigue	Excessive pressure	Power measurement
	Thermal growth	High temperature
	Structural natural frequency Incorrect material Incorrect manufacture Corrosion	Vibration Inspection
Torsional fatigue	Corrosion Torsional natural frequency Incorrect manufacture Incorrect material	Vibration Inspection
Torsional overload	Excessive load (pressure, viscosity)	Power measurement
	Incorrect material Material defect	Inspection

Table A.1 — Condition monitoring failure modes (*continued*)

Failure Mode	Causes	Indicators
Hydraulic		
Insufficient flow rate	Excessive solids Incorrect pump Air entrainment Cavitation Electrical equipment failure System (piping/valves/filter) issues Insufficient NPIPA Excessive fluid temperature Speed change Manufacturing error Increased clearances	Rate-of-flow measurement Power measurement Vibration Temperature measurement Speed measurement
	Incorrect pump System (piping/valves/filter) issues	Design review Rate-of-flow measurement
High power	Changes in system pressure Changes in fluid properties Change in speed Binding - mechanical Internal rubbing	Pressure measurement Temperature measurement Speed measurement Power measurement
Pressure Boundary Leakage		
Gasket	Cut gasket Installation error Extrusion Gasket degradation Excessive pressure	Leakage observation Power measurement

Table A.1 — Condition monitoring failure modes (*continued*)

Failure Mode	Causes	Indicators
O-ring	Incorrect surface finish	Leakage observation
	Insufficient O-ring compression	Pressure measurement
	O-ring degradation	Temperature measurement
	Process upset	
	Excessive temperature	
	Cut O-ring	
	Extrusion	
	Installation error	

Appendix B

Condition monitoring indicators

This appendix is not part of the standard, but is included to inform the user of relationships between indicators, causes, and potential failure modes related to condition monitoring. Many causes can result in multiple failure modes and are therefore grouped together for ease of using the table.

Table B.1 — Condition monitoring indicators

Indicators	Cause	Potential Failure Mode
Power		
High power	Excessive pressure	Coupling failure Motor trip Shaft breakage Pump seizure
	Internal rubbing Foreign object ingestion	Coupling failure Motor trip Shaft breakage Pump seizure
	Increased viscosity	Motor trip Coupling failure Shaft breakage Cavitation
	Excessive speed	Motor trip Coupling failure Cavitation Excessive flow
Low power	Excessive air/gas	Low flow Vibration
	Insufficient NPIPA No pump shaft rotation	Low flow Cavitation Vibration Coupling failure
	Reduced speed	Low flow

Table B.1 — Condition monitoring indicators (*continued*)

Indicators	Cause	Potential Failure Mode
Vibration		
High-frequency vibration rolling element bearings	Insufficient or contaminated lubrication oil Excessive load Excessive speed Electric fluting Brinneling	Pitting/spalling of bearing races Cage breakage Cage wear Seizure
High vibration level	Incorrect bearing fit or excessive differential pressure	Bearing race rotation Bearing failure Rotating element/liner wear
	Cavitation	Bearing failure Seal failure Low flow Excessive audible noise
	Improper installation of coupling	Coupling failure Bearing failure
	Loose coupling hub Shaft runout	Coupling failure
	Rotor imbalance Structural natural frequency	Pump mechanical component failure
	Incorrect shaft manufacturing Corrosion	Shaft bending fatigue Shaft torsional fatigue
Temperature		
Excessive process fluid temperature	Process upset	Liner/rotor wear or corrosion Seal face wear/heat checking Bearing failure Pressure boundary failure O-ring failure

Table B.1 — Condition monitoring indicators (*continued*)

Indicators	Cause	Potential Failure Mode
Excessive seal face/chamber temperature	Loss of cooling Excessive face loading Lack of face lubrication Incompatible process fluid	Corrosion of seal springs/bellows Seal face blistering Seal face wear/heat checking Static/dynamic O-ring failure Seal face wear O-ring compression set
High bearing temperature	Excessive static or dynamic loads Incorrect bearing fit Improper lubrication Misalignment	Pitting/spalling of bearing races Inner/outer race rotation Bearing seizure
Low process fluid temperature	Process upset/Cold start	High Power Vibration Cavitation
High stator temperature (PC pump)	Dry running	Stator failure
Leak Detection		
Leak observation at seal	Improper installation Improper material selection Lack of lubrication Overpressurization of seal	Seal spring or bellows failure Seal face wear Cut O-ring Dynamic/static secondary seal degradation Dynamic secondary seal hang up Seal face heat checking Drive pin wear O-ring compression set/extrusion
Leak observation pressure boundary joint	Insufficient gasket/O-ring load	Gasket/O-ring leakage
	Cut gasket or O-ring	Gasket/O-ring failure
	O-ring degradation	O-ring failure

Table B.1 — Condition monitoring indicators (*continued*)

Indicators	Cause	Potential Failure Mode
Pressure		
Excessive differential pressure	Change in the piping system Change in the process Pump overspeed Blockage in discharge High liquid viscosity	Casing/cover leakage Rotating element/liner wear Bearing failure Motor trip/high power
Insufficient inlet pressure or NPIPA	Excessive air/gas Blocked inlet High liquid viscosity Dry running	Cavitation Rotating element/liner wear Bearing failure Seal failure
Rate of Flow		
Decreased rate of flow	Speed change Increased clearances Insufficient vapor pressure margin Cavitation	Electrical equipment fault Rotating element/liner wear Vibration
Speed (rpm)		
Change in speed	Electrical equipment failure Coupling failure	Change in flow High power Low power

Appendix C

Definitions

This appendix is not part of the standard, but is included to help the user with factors referenced in the standard.

Accuracy A measure of how closely the measured value agrees with the true value or how closely the controlled (actual) value agrees with the target (set point) value.

Baseline The baseline is the beginning. In condition monitoring, baseline measurements are the values measured at the beginning of the monitoring process. Baseline condition is the condition at the beginning of the monitoring process. Baseline condition may be compared with current condition to detect changes and to predict and prevent failure.

Cause A reason for a condition, such as a failure condition.

Condition The condition of a rotary pump is its status, and is indicated by measurable parameters. For example, vibration amplitude is a measurable parameter; high vibration amplitude may indicate a condition of imbalance.

Condition monitoring A process of monitoring measurable parameters, i.e., indicators, to determine the condition of a rotary pump. The measured values are the process inputs. Condition of the pump is the process output.

Control limits Upper and lower bounds allowed by the condition monitoring process.

Failure Failure of a rotary pump is a condition in which the pump does not satisfy specified operating limits. For example, if the pump must operate with bearing temperature below 65 °C (150 °F) and actual bearing temperature is 93 °C (200 °F), the bearing has overheated and the pump is a failure.

Failure mode A general description of the manifestation of the failure.

Indicators Parameters identified by this standard as especially important to monitor because their measured values may be used to anticipate, predict, and/or prevent pump failure conditions.

Informative The informative portion of a standard is reference information not mandatory for compliance.

Monitoring A process of measuring or observing over a period of time. The monitoring process has a beginning and an end.

Normative The normative portion of a standard is prescriptive in nature and thereby mandatory for compliance.

Parameters Measurable or observable physical properties that may be used to describe the condition of a rotary pump.

Process A process that converts inputs into outputs. For example, a condition monitoring process may convert a millivolt (mV) thermocouple signal, as an input, into an output. The output will vary depending on the logic of the process. If the input value exceeds limits allowed by the process, then the process output may be an alarm or automatic equipment shut-down.

Repeatability A measure of variation among a set of measurements taken at the same conditions, with the same equipment, and, if possible, by the same person.

Stability A measure of changeability over time. A process is said to be stable when all of the response parameters used to measure the process have both constant means and constant variances over time, and also have a constant distribution.[1]

Tolerance Limits allowed for variation in measured values. Measured values falling out of tolerance indicate nonconformance with specified requirements.

Trending Baselining combined with monitoring. Trending shows trends, i.e., change and rate of change over the period of time monitored. Trends enable prediction of future performance, prevention of future problems, and help with troubleshooting of problems.

[1] *NIST/SEMATECH e-Handbook of Statistical Methods, http://www.itl.nist.gov/div898/handbook/.*

Appendix D

Index

This appendix is not part of this standard, but is presented to help the user with factors referenced in the standard.

Note: an f. indicates a figure, and a t. indicates a table.

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