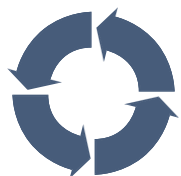




American National Standard for

Rotary Pumps

— Guidelines for Condition Monitoring



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Rotary Pumps – Guidelines

for Condition Monitoring

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Approved December 4, 2018
American National Standards Institute, Inc.

American National Standard

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Published By

Hydraulic Institute
6 Campus Drive, First Floor North
Parsippany, NJ 07054-4406
www.Pumps.org

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Printed in the United States of America
ISBN 978-1-935762-80-5



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Contents

	Page
Foreword	vii
9.6.9 Guidelines for condition monitoring	1
9.6.9.1 Introduction	1
9.6.9.1.1 Purpose	1
9.6.9.1.2 Scope	1
9.6.9.2 Monitoring and control system concepts	1
9.6.9.2.1 Calibration	3
9.6.9.2.2 Monitoring interval	3
9.6.9.2.3 Control limits	4
9.6.9.2.3.1 Alert limit settings	4
9.6.9.2.3.2 Alarm limit settings	4
9.6.9.2.3.3 Shutdown limit settings	5
9.6.9.2.3.4 Definition of baseline used in alarm set point limits	5
9.6.9.3 Power monitoring	5
9.6.9.3.1 Introduction	5
9.6.9.3.2 Means of power monitoring	5
9.6.9.3.3 Power monitoring frequency	6
9.6.9.3.4 Power control limits	6
9.6.9.4 Temperature monitoring	7
9.6.9.4.1 Introduction	7
9.6.9.4.2 Means of monitoring temperature	7
9.6.9.4.3 Specific applications of temperature monitoring	7
9.6.9.4.3.1 Motor-winding temperature	7
9.6.9.4.3.2 Temperature-sensitive liquids	7
9.6.9.4.3.3 Rolling element and sleeve bearing temperatures	7
9.6.9.4.3.4 Liquid film bearing and seal faces temperatures	7
9.6.9.4.3.5 Pumped liquid temperature rise	8
9.6.9.4.4 Sealless pump liquid temperature	8
9.6.9.4.4.1 Sealless pump temperature damage	8
9.6.9.4.5 Temperature monitoring frequency	9
9.6.9.4.6 Temperature control limits	9



9.6.9.5	Leakage monitoring	9
9.6.9.5.1	Introduction	9
9.6.9.5.2	Means of monitoring leakage	9
9.6.9.5.2.1	Leakage by visual inspection	9
9.6.9.5.2.2	Leakage by sniffer inspection	9
9.6.9.5.2.3	Leakage by catch tank	9
9.6.9.5.2.4	Leakage by pressure buildup	10
9.6.9.5.2.5	Leakage by change in barrier fluid flow	10
9.6.9.5.3	Submersible pump leakage	10
9.6.9.5.3.1	Seal leakage in submersible pumps	10
9.6.9.5.4	Leakage monitoring frequency	11
9.6.9.5.5	Leakage control limits	11
9.6.9.6	Pressure monitoring	11
9.6.9.6.1	Introduction	11
9.6.9.6.2	Means of pressure monitoring	11
9.6.9.6.3	Pressure monitoring frequency	11
9.6.9.6.4	Pressure control limits	12
9.6.9.7	Vibration monitoring	12
9.6.9.7.1	Introduction	12
9.6.9.7.2	Means of vibration monitoring	12
9.6.9.7.3	Vibration monitoring frequency	13
9.6.9.7.4	Vibration control limits	13
9.6.9.8	Lubricant analysis	13
9.6.9.8.1	Introduction	13
9.6.9.8.2	Measuring metal particles from wear	14
9.6.9.8.2.1	Evaluating wear rates	14
9.6.9.8.3	Measuring contamination of lubricant	14
9.6.9.8.3.1	Organic contamination of lubricant	14
9.6.9.8.3.2	Inorganic contamination of lubricant	15
9.6.9.8.4	Measuring lubricant degradation	15
9.6.9.8.5	Lubricant sampling techniques	15
9.6.9.8.6	Lubricant monitoring frequency	15
9.6.9.8.7	Lubricant control limits	15

9.6.9.9	Rate-of-flow monitoring	15
9.6.9.9.1	Introduction	15
9.6.9.9.2	Measuring rate of flow	16
9.6.9.9.3	Rate-of-flow monitoring frequency.	16
9.6.9.9.4	Rate-of-flow control limits	16
9.6.9.10	Shaft position monitoring.	16
9.6.9.10.1	Introduction	16
9.6.9.10.2	How to monitor shaft position	16
9.6.9.10.3	Shaft monitoring frequency	16
9.6.9.10.4	Shaft control limits	17
9.6.9.11	Speed (rpm) monitoring	17
9.6.9.11.1	Introduction	17
9.6.9.11.2	Speed measurement methods	17
9.6.9.11.3	Speed monitoring frequency	17
9.6.9.11.4	Speed control limits	17
9.6.9.12	Maintenance inspection	17
9.6.9.12.1	Introduction	17
9.6.9.12.2	Maintenance inspection practice	18
9.6.9.12.2.1	Maintenance inspection of keys and keyways	18
9.6.9.12.2.2	Maintenance inspection of coupling flexible elements	18
9.6.9.12.2.3	Maintenance inspection for shaft bending fatigue.	19
9.6.9.12.2.4	Maintenance inspection for shaft torsional fatigue	19
9.6.9.12.2.5	Maintenance inspection for torsional overload	19
9.6.9.12.2.6	Maintenance inspection for fatigue and breakage	19
9.6.9.12.2.7	Maintenance inspection for erosion wear from the action of flow, abrasion, and/or corrosion	19
9.6.9.12.2.8	Maintenance inspection for cavitation erosion	20
9.6.9.12.2.9	Maintenance inspection for hydraulic performance.	20
9.6.9.12.3	Maintenance inspection frequency	20
9.6.9.13	Corrosion monitoring.	20
9.6.9.13.1	Introduction	20
9.6.9.13.2	Means of corrosion monitoring	20
9.6.9.13.2.1	Corrosion monitoring by visual/dimensional inspection	20

9.6.9.13.2.2	Corrosion by electrical resistance (ER)	21
9.6.9.13.2.3	Corrosion by linear polarization resistance (LPR)	21
9.6.9.13.2.4	Corrosion by ultrasonic thickness measurement (UTM)	21
9.6.9.13.3	Corrosion monitoring frequency	21
9.6.9.13.4	Corrosion parameter control limits.	21
9.6.9.14	Wireless data transmission technology.	22
9.6.9.14.1	Condition-based monitoring (CBM): transmission schemes for wireless systems.	22
9.6.9.14.2	Wireless communication for CBM sensor systems	23
9.6.9.14.3	Wireless communication standards.	24
9.6.9.14.4	References	24
Appendix A	Condition monitoring failure modes.	25
Appendix B	Condition monitoring indicators.	32
Appendix C	Vibration analysis.	36
Appendix D	Condition-based maintenance (CBM).	38
Appendix E	Condition monitoring as a tool to manage asset reliability.	41
Appendix F	Definitions	43
Appendix G	Index	45
Figures		
9.6.9.2a	— Typical monitoring control system.	2
9.6.9.2b	— Typical fixed speed rotary pump monitoring devices	2
9.6.9.14.1	— Example of a vibration diagnostic system network (star topology)	22
C.1	— Typical vibration waveform.	37
C.2	— Typical waveform over time	37
D.1	— Summary of condition-based monitoring (CBM) strategies	38
Tables		
9.6.9.2.2a	— Severity levels.	3
9.6.9.2.2b	— Frequency of monitoring	4
9.6.9.3.2.5	— Application guidelines for leakage monitoring systems' mechanical seals.	10
A.1	— Condition monitoring failure modes	25
B.1	— Condition monitoring indicators	32

Foreword (Not part of Standard)

Purpose and aims of the Hydraulic Institute

The purpose and aims of the Hydraulic Institute are to promote the advancement of the pump manufacturing industry and further the interests of the public and to this end, among other things:

- a) Develop and publish standards.
- b) Address pump systems.
- c) Expand knowledge and resources.
- d) Educate the marketplace.
- e) Advocate for the industry.

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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 standard will be appreciated, to help the Hydraulic Institute prepare even more useful future editions. Questions arising from the content of this standard may be directed to the Technical Director of the Hydraulic Institute. If appropriate, the inquiry will then be directed to the appropriate technical committee for provision of a suitable answer.

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American National Standards 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 are reaffirmed using the ANSI canvass procedure.

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Units of measurement

Metric units of measurement are used, and corresponding US customary units appear in parentheses. Charts, graphs, and sample calculations are also shown in both metric and US customary units. Because 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 standard. If no such statement is provided, metric units shall govern.

Consensus

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

Brown and Caldwell	Parametrix
Camtrack, LLC	Colfax Fluid Handling
Kemerovo Inc.	Pumps, Parts & Service
Leistritz Advanced Technologies Corp	Stantec
Las Vegas Valley Water District	Syncrude Canada
mwi pump	

Committee list

Although this standard 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 – Kenneth Patton, CIRCOR Pumping Technologies
Vice-Chair – Scott Wild, Leistritz Advanced Technologies Corp.

Committee Members

Timothy Albers
Henri Azibert
Randy Bennett
Jeff Bergman
Jeffery Sietsema

Company

Nidec Motor Corporation
Fluid Sealing Association
Leistritz Advanced Technologies Corp.
ABB LV Drives US
Blackmer, Inc.

9.6.9 Guidelines for condition monitoring

9.6.9.1 Introduction

This guideline is intended to give the pump user a tool for condition monitoring of rotary positive displacement pumps, but does not directly address process management systems.

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. Additional appendices are provided to help the user of this guideline. Appendix C provides an overview of vibration analysis that is commonly used for condition monitoring, Appendix D provides condition-based maintenance strategies, Appendix E provides guidance on using condition monitoring to manage asset reliability, and finally Appendix F provides definitions to clarify terms used in this guideline.

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

- Power absorbed
- Temperature change
- Leakage
- Pressure (suction, discharge, differential)
- Vibration
- Lubricant analysis
- Rate of flow
- Shaft position
- 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 can be subjective in nature.

9.6.9.1.1 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.

9.6.9.1.2 Scope

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

9.6.9.2 Monitoring and control system concepts

A typical control system and typical monitoring devices are shown in Figures 9.6.9.2a and 9.6.9.2b, 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 after the pump is put in service and is operating in a stable condition. 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.

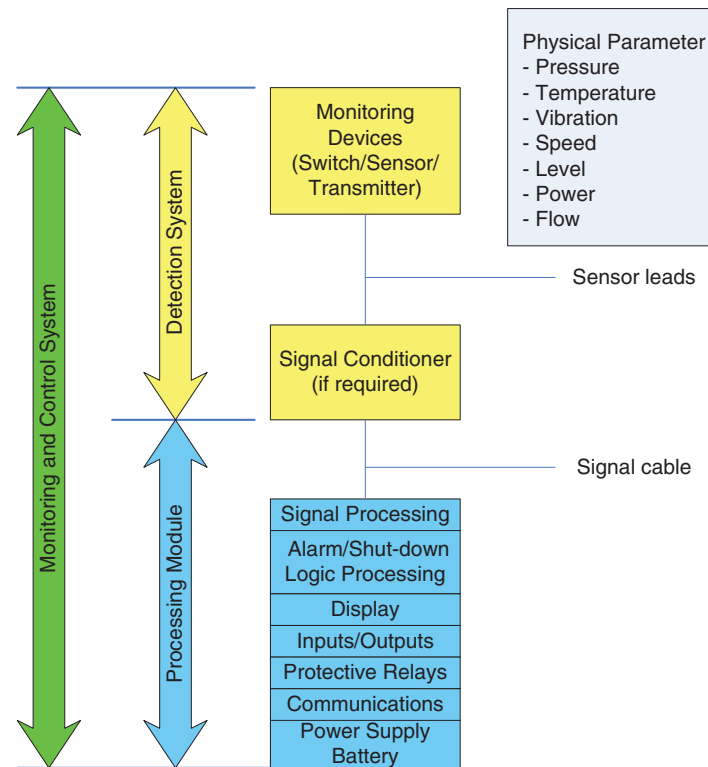
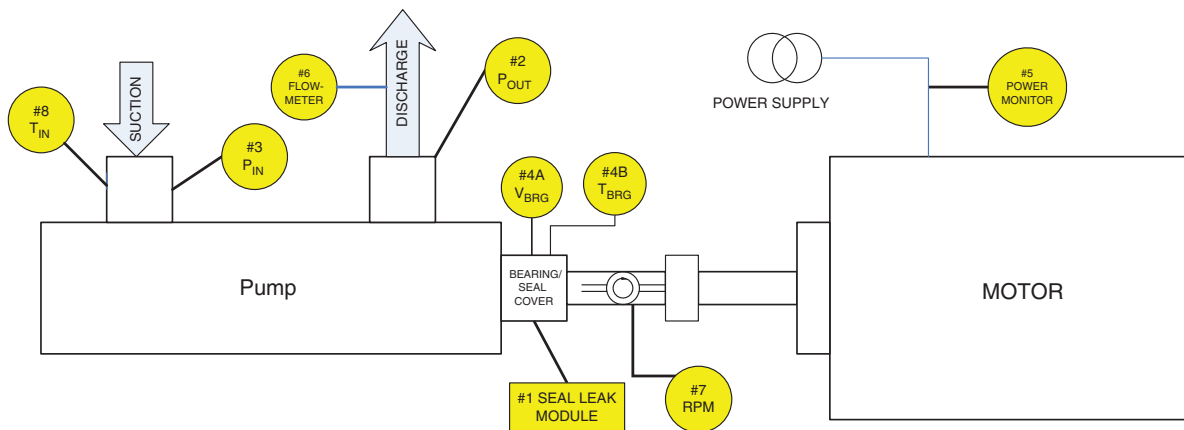


Figure 9.6.9.2a Typical monitoring control system



- #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 suction pressure; filter
condition, NPIPA, etc.
- #4 Bearing housing; misalignment; coupling wear
#4A: Velometer/Accelerometer: high vibration shut-down
#4B: Bearing temperature RTD
- #5 Power monitor
- #6 Flowmeter
- #7 Tachometer/Encoder – rotational speed
- #8 Inlet temperature: over temperature shut-down, monitor fluid temperature

Figure 9.6.9.2b Typical fixed speed rotary pump monitoring devices



9.6.9.2.1 Calibration

This document covers the measurement of many variables, each requiring a measurement instrument. The continued accuracy should be checked and maintained through calibration to ensure reliable and consistent data. The calibration interval depends on the type of instrument and use of the instrument. The instrument manufacturer will typically provide information on how the instrument should be calibrated and how often the instrument should be calibrated. The user of this guideline should follow the recommended calibration procedures and intervals provided by the instrument manufacturer.

9.6.9.2.2 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, damage to other system components, and correcting the failures

Table 9.6.9.2.2a 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 9.6.9.2.2a 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 9.6.9.2.2b. 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 shut-down 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 9.6.9.2.2b 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

9.6.9.2.3 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. In this guideline, the following approach is introduced. For the alarm limit setting, two different levels are recommended: (1) alert limit and (2) alarm limit. More details of each level are discussed in the alert and alarm limit settings sections. 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.

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 section 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.

9.6.9.2.3.1 Alert limit settings

An alert limit is 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 to determine whether a repair will be needed or if preventative maintenance should be initiated. The repair planning process should also start at this level, and, most importantly, spare parts should be ordered when the machine is in alert.

9.6.9.2.3.2 Alarm limit settings

An alarm limit is 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.

9.6.9.2.3.3 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?

9.6.9.2.3.4 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. It should be noted that any subsequent data points measured need to be taken at the same operating conditions to accurately compare the data to the baseline measurement.

9.6.9.3 Power monitoring

9.6.9.3.1 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.

9.6.9.3.2 Means of power monitoring

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

- 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.
 - Note that standard power meters located on the electrical supply to a motor from a variable frequency drive (VFD) may not be suitable for use due to the altered characteristics of the voltage and current supplied to the motor from a VFD.

- 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 properly designed pressure relief valve system.

9.6.9.3.3 Power monitoring frequency

Refer to Table 9.6.9.2.2b.

9.6.9.3.4 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.

9.6.9.4 Temperature monitoring

9.6.9.4.1 Introduction

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

9.6.9.4.2 Means of monitoring temperature

Thermocouple probes or resistance temperature detectors (RTDs) are primarily used for monitoring temperature. Special care must be taken when monitoring temperatures at locations where there can be rapid changes (e.g., vaporization of cooling flow or bearing rubs). 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.

9.6.9.4.3 Specific applications of temperature monitoring

9.6.9.4.3.1 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.

9.6.9.4.3.2 Temperature-sensitive liquids

Temperature sensors are used to measure temperature of liquids to ensure that the material is maintained within the operating temperature range that corresponds to the operational viscosity range of the pump. 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).

9.6.9.4.3.3 Rolling element and sleeve bearing temperatures

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

- 1) Thermocouples or tip-sensitive RTDs immersed in lube oil active flow areas to measure lubricant temperature.
- 2) Thermocouples or tip-sensitive RTDs touching the outside raceway of the bearing.
- 3) 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.

9.6.9.4.3.4 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.

9.6.9.4.3.5 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 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 fluid power 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.

9.6.9.4.4 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.

9.6.9.4.4.1 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 metal on metal contact that will lead to rapid expansion 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.

9.6.9.4.5 Temperature monitoring frequency

Refer to Table 9.6.9.2.2b.

9.6.9.4.6 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.

9.6.9.5 Leakage monitoring

9.6.9.5.1 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.

9.6.9.5.2 Means of monitoring leakage

9.6.9.5.2.1 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.

9.6.9.5.2.2 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.

9.6.9.5.2.3 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.