



American National Standard for

Rotodynamic Pumps

Guideline for Condition Monitoring



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Approved December 16, 2022
American National Standards Institute, Inc.

American National Standard

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Published By

Hydraulic Institute
300 Interpace Parkway Building A, Third Floor
Parsippany, NJ 07054-4406
www.Pumps.org

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Printed in the United States of America

ISBN 978-1-954671-17-1

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Foreword [Not part of American National Standard (ANSI)]

Purpose and aims of the Hydraulic Institute

The purpose and aims of the Hydraulic Institute are to drive all Pump System stakeholders towards a sustainable future by:

- a) Advancing Solutions for Pump System Performance and Efficiency
- b) Developing Standards and Technical Resources
- c) Educating the Global Marketplace
- d) Advocating for the Industry

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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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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.

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LAS VEGAS VALLEY WATER DISTRICT
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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 – Michael Cugal, Weir Minerals North America

Vice-chair – Steve Rose, Specialty Pumps - Dean, Fybroc, & Sethco

Committee Member

Timothy Albers
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Mechanical Solutions, Inc.
Xylem Inc. - Applied Water Systems
Xylem Inc. - Applied Water Systems
Dodge Industrial
Grundfos USA
Flowserve Corporation
Plymon Vibration Consultants

Committee Alternates

Maki Onari

Company

Mechanical Solutions, Inc.

9.6.5 Rotodynamic Pumps for Condition Monitoring

9.6.5.1 Introduction

9.6.5.1.1 Scope

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

9.6.5.1.2 Purpose

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

9.6.5.1.3 Use of This Document

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

9.6.5.2 Condition-Based Maintenance Fundamentals

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

9.6.5.2.1 Overview of Potential-to-Failure Curves and Intervals

Every machine has a unique path to failure that condition monitoring can track. Potential-to-failure (P-F) intervals are commonly used to help establish the right maintenance to perform at the right time.

P-F intervals vary by type of monitored machine and type of detection technology in use. The P-F interval defines the time between when equipment degradation can be detected and the functional failure of the machine. However, it is important to remember there is no guarantee of continued operation through the typical P-F interval. Conversely, there is also no guarantee that the failure will indeed occur at the failure point identified in the P-F curve. Experience and equipment history can inform the creation of a P-F Interval, but it should never be viewed as a guarantee of timelines when potential failures are detected using CBM.

Furthermore, when employing P-F curves in CBM, it is important to remember that in some cases the technology does not provide enough lead time for the detection to be of practical use.

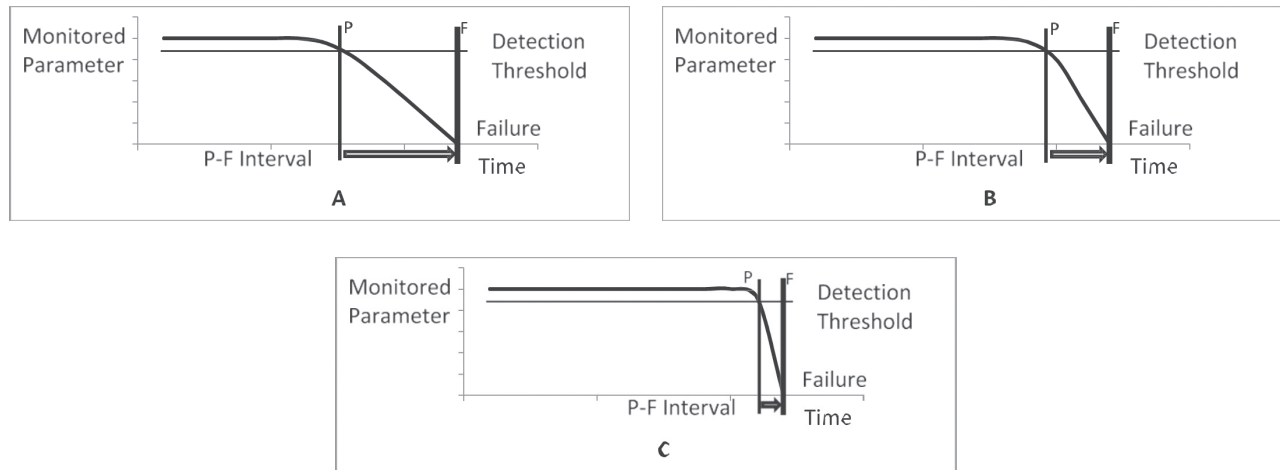


Figure 9.6.5.2.1 Typical P-F Curves

The three P-F Curves shown in Figure 9.6.5.2.1 demonstrate that the P-F interval can vary even for a single monitored parameter based on a given diagnostic test and failure mode combination. Curve A shows a long P-F interval, and in this case the organization may opt to wait for a second measurement before taking action. Curve B shows a shorter P-F interval but still provides sufficient warning to execute repairs in advance of a failure. Curve C shows a short P-F interval, which might not allow enough time to execute repairs prior to failure.

P-F Curves can help inform a CBM program by:

- Informing maintenance scheduling, planning, and prioritization
- Allowing for assessment of risk
- Maximizing asset lifecycles

For example, if an organization detects a fault on a machine, they can either pull the machine out of service immediately, affecting production, or wait after the first indication of fault, in which case failure may occur and more maintenance is required. CBM can help inform the decision of when and how to perform maintenance using a P-F interval.

9.6.5.2.2 Asset Management Overview

Various strategies for asset reliability management are shown in Table 9.6.5.2.2 as stated in the US Department of Energy (DOE) Energy Efficiency & Renewable Energy *Operations & Maintenance Best Practices* guide. Reactive maintenance is simply allowing the machine to fail before repairing it, a strategy usually employed for noncritical machines. These are usually easily replaceable machines whose failure is unlikely. The next stage is preventive maintenance, which is applied to machines considered essential to a plant's operation. The maintenance is periodic (via route-based monitoring) or nearly continuous (wired or wireless online monitoring). Predictive maintenance focuses mainly on expensive machines that are critical to the plant's operation. Decisions to shut down upon reaching the critical alarm set points of the machine condition are based on models that provide fault or failure modes that can be compared with time and frequency data extracted from the continuous monitoring records. A detailed description of using condition monitoring as a tool to manage asset reliability or risk management is provided in sections 9.6.5.18.5 to 9.6.5.18.6.

Table 9.6.5.2.2 — Asset reliability management strategies

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

9.6.5.2.3 Rotodynamic Pump Failure Modes

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

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

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

- Power consumption
- Temperature change
- Corrosion or erosion
- Leakage
- Pressure (suction, discharge, differential)
- Vibration
- Noise (sound) characteristics
- Lubricant condition
- Total indicated runout (periodic)
- Rate of flow
- Speed (rpm)
- Bearing wear

9.6.5.3 Monitoring Strategies

9.6.5.3.1 Monitoring Frequency

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

In all cases, monitoring frequency should be less than half the P-F interval. If the P-F interval is unknown, it is advisable to consult with experts who have experience with the type of machinery under study. When an alert condition is detected, it is often prudent to increase monitoring frequency.

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

9.6.5.3.2 Control Limits

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

In this guideline, the following approach is introduced. For the alarm limit setting, two levels are recommended: (1) alert limit and (2) alarm limit. More details of each level are discussed in sections 9.6.5.3.2.1 Alert Limit Settings and 9.6.5.3.2.2 Alarm Limit Settings. 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 or 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 section 9.6.5.3.2.3 Shutdown Limit Settings.

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

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

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

9.6.5.3.2.1 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 be 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, end user preferences, or both may be used. If the organization has access to the historical data for this or other similar machines, alert limits can be set to average plus one standard deviation. The subsequent action for this level can be to alert the operators to investigate the status of the equipment. The repair planning process should also start at this level. Most importantly, spare parts should be ordered when the machine is in alert.

9.6.5.3.2.2 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 or repair process. Further actions should be discussed based on the nature of the system and process. If the organization has access to the historical data for this or other similar machines, alarm limits can be set to average plus two standard deviations.

9.6.5.3.2.3 Shutdown Limit Settings

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

Further discussions on the system design review process are available in 9.6.5.16.2.4 Operating Procedure Review.

9.6.5.3.2.4 Definition of Baseline Used in Alarm Set Point Limits

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

9.6.5.3.2.5 Definition of Field Acceptance Level or Industry Standard Level

For some critical indicators, the set points for shutdown limits are set at certain deviation levels from the industry-standard field-acceptance levels at commissioning. An example is the vibration field acceptance level as per ANSI/HI 9.6.4 *Rotodynamic Pumps for Vibration Measurement and Allowable Values*. For the leakage indicator, this could be a governmental regulatory requirement on seal leakage.

9.6.5.4 Power Monitoring

9.6.5.4.1 Introduction

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

9.6.5.4.2 Means of Power Monitoring

There are several ways to monitor the power used by a pump. Several instrumentation types and systems are outlined in this section. Some of these measure mechanical power and some electrical power. For example, the torque

meter and strain gauges are used to measure mechanical power, whereas the power meter and electrical current meter measure electrical power.

Use caution when applying electrical power monitoring techniques to pumps exhibiting flat power curves—that is, where power changes little over the operating range. In these cases, setting alarm points can be difficult because of the detection of small power changes that result from operating point changes. Discriminating between these changes and power changes due to other causes, such as temperature changes in the motor or pump and normal process fluctuations, can be difficult.

Along with power measurements, the operating condition of the pump needs to be monitored, or as a minimum, the pump must be operated under the same conditions when data are recorded. To monitor the operating condition of the pump, one or more of the following performance or process parameters need to be determined from measurements:

- Rate of flow
- Total head
- Net positive suction head available (NPSHA)
- Suction and discharge temperatures
- Pumpage viscosity
- Specific gravity

When variable-speed devices are used, speed should also be measured.

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

9.6.5.4.2.1 Torque Meter

The most direct measurement 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.

9.6.5.4.2.2 Power Meter

This measurement is useful if the pump is driven by an electrical motor either directly coupled to the pump or through a gearbox, belt, or hydraulic coupling. Electrical transducers are typically installed in the electrical motor starter to measure voltage, current, and phase angle. These measured values are used in the calculation of the power supplied to the motor. This approach will not only monitor the power increase or decrease in the pump as parts deteriorate or drag, but also will indicate other changes that could be happening to the electrical motor and/or, the gearbox, belts, or hydraulic coupling.

9.6.5.4.2.3 Electrical Current Meter

This is 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.

9.6.5.4.2.4 Strain Gauges

Strain gauges applied to either the pump shaft near the coupling or the drive output shaft with proper telemetry or slip ring equipment will give an indication of the torque required to drive the pump. This approach is similar to using a torque shaft except that a longer baseplate is not required to accommodate the length of the torque shaft. Some accuracy is sacrificed. If the pump speed is constant or known, the power required by the pump can be calculated. Relating torque to a strain gauge measurement requires a fore knowledge of the stiffness of the torque shaft. Generally, this specification on the torque shaft (assuming linearity) is difficult to identify since the torque loading is often complicated by shaft misalignments.

9.6.5.4.2.5 Variable Frequency Drive

A variable frequency drive (VFD) and reduced voltage soft starter (RVSS) can be programmed to provide power monitoring.

9.6.5.4.2.6 Measurement Practice

Monitoring the pump power usage alone will indicate only whether the power is changing. Power changes can also result from changing the hydraulic operating conditions and from mechanical or hydraulic deterioration.

9.6.5.4.3 Power Monitoring Frequency

Refer to section 9.6.5.3.1.

9.6.5.4.4 Power Control Limits

Before selecting alarm and shutdown limits, evaluate the accuracy, repeatability, and stability of the power measurements. Similarly, evaluate the accuracy, stability, and repeatability with which the pump's operating condition can be set. Also consider the power level—higher-power pumps require tighter tolerances.

Setting the alarm (combining alert and alarm) control limits at a 5% to 10% change from baseline is recommended. These levels should be coordinated with any control-limit settings on power equipment.

9.6.5.5 Temperature Monitoring

9.6.5.5.1 Introduction

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

9.6.5.5.2 Means of Monitoring Temperature

Primarily thermocouple probes and strip resistance temperature detectors (RTDs) are used for monitoring. Non-contact infrared (IR) temperature measurement can also be considered.

Two types of IR measurement are common: (1) thermography and (2) IR spot thermometers.

1. Thermography involves the measurement of variations in IR radiance using visual imaging. IR cameras determine the surface temperature levels over a broad area of the pump and motor, including the coupling and bearings. An image is provided showing the profile of temperatures within the image.
2. IR spot thermometers are pointed at a specific location and measure IR emissions. Unlike in the case of thermography, these devices provide a temperature readout of the area being measured.

When monitoring temperatures at locations where there can be rapid changes (e.g., vaporization of cooling flow or bearing rubs), care must be taken. Temperature at the source of heat input may be up to several hundred degrees higher than 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 machine condition.

9.6.5.5.3 Specific Applications of Temperature Monitoring

9.6.5.5.3.1 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 RTDs located either in the motor stator slot or at the center of the end turns. Thermocouples and thermistors are also used as alternate sensor methods. Motors are often fitted with thermostats that shut off power when a preset temperature is reached.

9.6.5.5.3.2 Temperature-Sensitive Liquids

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

9.6.5.5.3.3 Rolling Element Bearing Temperatures

Rolling element 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. Technologies measuring the temperature on the outside surface of the bearing housing. This is the least reliable method of measurement and is not recommended

9.6.5.5.3.4 Fluid-Film Bearing and Seal-Face Temperatures

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

9.6.5.5.3.5 Pumped-Liquid Temperature Rise

Measurement of liquid temperature at suction and discharge can indicate temperature rise accurately when rate of flow is sufficient to avoid recirculation and suction heating (above 10% or so of best efficiency point flow). At lower rates of flow, fluid mixing from discharge to suction can result in a relatively low indicated temperature rise. In these cases, the suction temperature may have increased so that NPSHA has been reduced, and flashing may be occurring. Locating the suction thermocouple 20 diameters or more upstream will also avoid suction recirculation heating error. The recirculation backflow extends upstream 2 or more X inlet diameters. Significant increase in temperature rise across the pump indicates a drop in flow that is likely to cause flashing.