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# PIP PCERE001
## Rotating Equipment Monitoring Guidelines

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**Process Industry Practices**

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1. **Scope**

This Practice provides guidance for the application of instrumentation to monitor rotating equipment for machinery protection, enhanced performance, and predictive maintenance.

This Practice describes the following:

a. Typical applications for continuous on-line monitoring of rotating equipment
b. Types of monitoring that could be provided and where they are typically applied
c. Installation considerations specific to type of monitoring equipment
d. General calibration and functional checkout considerations
e. Documentation recommendations

Types of rotating equipment covered in this Practice include centrifugal compressors, centrifugal pumps, gears, steam turbines, gas turbines, electric motors and generators, and other shaft driven equipment.

This Practice does not cover the design of anti-surge controllers, performance controllers, seal gas systems, and other equipment auxiliary systems. For information on surge detection and anti-surge control, refer to *API 670*.

2. **References**

Applicable parts of the following Practices and industry codes and standards shall be considered an integral part of this Practice. The edition in effect on the date of contract award shall be used, except as otherwise noted. Short titles are used herein where appropriate.

2.1 **Process Industry Practices (PIP)**

- PIP PCCGN002 - *General Instrument Installation Criteria*
- PIP PCSPS001 - *Packaged Equipment Instrumentation Specification*

2.2 **Industry Codes and Standards**

- American Petroleum Institute (API)
  - API 670 - *Machinery Protection Systems*

3. **General**

3.1 This Practice should be used in conjunction with *API 670*.

3.2 Condition Monitoring System (CMS) instrumentation is used to capture and display vibration waveforms for spectrum analysis in support of predictive maintenance and plant optimization. This Practice includes references to CMS procedures and technologies that, if implemented properly, can provide a lower total cost of ownership.

3.3 *PIP PCSPS001* should be referenced for general information on level, temperature, flow, and pressure instrumentation.
3.4 To avoid unnecessary trips, the number of initiating devices in automatic shutdown systems should be kept to a minimum. Automatic shutdowns protect critical and essential machinery in the event of malfunctions that could cause significant personnel hazard or rapid and extensive equipment damage. Consequences of machine trip on the process should be considered.

3.5 Purchaser’s PIP PCSPS001D Data Sheet should be referenced for requirements for alarms, safety shutdowns, and power supplies.

3.6 The key phase angle (i.e., the rotational position, typically in degrees, of a rotating part at any instant with respect to a fixed zero degree point where phase angle is the vibration direction) should be monitored. Each shaft on each equipment train should be provided with a permanently mounted phase angle sensor and target to indicate speed and to provide phase reference pulses vital for diagnostics using vibration waveform spectrum analysis and other dynamic motion information. See API 670, Figures H-1, H-2, and H-3, for installation locations.

3.7 Redundant devices in a voting-to-trip scheme may be considered for increased reliability. In a voting system, sensors typically are installed in pairs (2oo2) or triplicated (2oo3). When either signal reaches its alarm setpoint, an alarm is given. If two or more signals reach the critical danger setpoint, a trip interlock is initiated, an alarm is activated, and the machine is shut down.

3.8 Sensors, instruments, and associated electrical equipment should be in accordance with the electrical classification of the area.

3.9 Special attention should be given to signal wire shields and grounding to minimize noise and ensure reliable readings. See the manufacturer installation instructions for specific information. CMS instrumentation should use buffered output signals from the protection devices.

4. Level of Protection

4.1 Although monitoring of rotating equipment provides information that aids in diagnosing problems and identifying and preventing failures, the high cost to implement and maintain this instrumentation requires economic justification. To ensure an efficient design, plant assets are prioritized on the basis of criticality to limit the level of instrumentation on rotating equipment to the essential for operation and maintenance. Critical and essential applications require that monitoring equipment be provided. These applications are detailed as follows:

a. Single equipment item upon which system, unit, or plant production depends
b. Any equipment item, if loss would result in reduced production
c. Any equipment item, if failure of a component would present a potentially hazardous condition for personnel
d. Any equipment item, if loss of the equipment item would cause expensive repairs
e. Any equipment item, if failure of a component would have serious environmental impact.

4.2 The process control engineer, rotating equipment engineer, and the owner’s operations representative should consult with each other and agree on the level of machine protection required.
4.3 The following method should be used to determine the level and complexity of machine protection recommended for asset prioritization:
   a. Use Table 1 to determine the points for each of the five categories listed.
   b. Add the points from each category to determine applicable machine protection level.
   c. Use Table 2 to select the level of recommended machine protection.

4.4 Machine protection levels should be determined in accordance with Table 2.

Table 1 – Machine Complexity

<table>
<thead>
<tr>
<th>1. EFFECT ON PRODUCTION</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% - single train</td>
<td>100</td>
</tr>
<tr>
<td>50% - dual trains</td>
<td>50</td>
</tr>
<tr>
<td>30% - multiple trains</td>
<td>30</td>
</tr>
<tr>
<td>10% - peripheral only</td>
<td>10</td>
</tr>
<tr>
<td>2. EXPENSE AND COMPLEXITY OF REPAIR</td>
<td></td>
</tr>
<tr>
<td>Expensive and complex</td>
<td>150</td>
</tr>
<tr>
<td>Expensive and noncomplex</td>
<td>100</td>
</tr>
<tr>
<td>Moderate expense and complex</td>
<td>50</td>
</tr>
<tr>
<td>Moderate expense and noncomplex</td>
<td>10</td>
</tr>
<tr>
<td>3. ENVIRONMENTAL, HEALTH, AND SAFETY RISK</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>80</td>
</tr>
<tr>
<td>Low</td>
<td>20</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>4. OPERATOR PRESENCE</td>
<td></td>
</tr>
<tr>
<td>No local operator</td>
<td>80</td>
</tr>
<tr>
<td>Control room monitored</td>
<td>50</td>
</tr>
<tr>
<td>Dedicated operator</td>
<td>0</td>
</tr>
<tr>
<td>5. LOCATION</td>
<td></td>
</tr>
<tr>
<td>Offshore or Remote</td>
<td>40</td>
</tr>
<tr>
<td>Onshore</td>
<td>10</td>
</tr>
</tbody>
</table>

Examples:
   a. 4000-hp gas turbine = expensive and complex = 150 points for Category 2
   b. 1000-hp electric motor = moderate expense and noncomplex = 10 points for Category 2
   c. 100% single train means that loss of the machine shuts down the process = 100 points for Category 1
Table 2 – Machine Protection Levels

<table>
<thead>
<tr>
<th>Total Points from Table 1</th>
<th>Level</th>
<th>Description of Required Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>290 – 450</td>
<td>1</td>
<td>Provide the applicable alarm and shutdown functions defined in Appendix A for all rotating components in the machine train. These functions should be specified and installed in accordance with this Practice and API 670. Depending upon the size, complexity, and criticality of the machine train, a dedicated system of alarm and shutdown functions should be considered with separation for each machine train.</td>
</tr>
<tr>
<td>190 – 280</td>
<td>2</td>
<td>System equipment may vary in sophistication, complexity, and redundancy, depending on the service application of the machinery. The system should be capable of monitoring several machines, e.g., pump drivers, within the framework of one protection system. The applicable alarm and shutdown functions defined in Appendix A should be considered.</td>
</tr>
<tr>
<td>110 – 180</td>
<td>3</td>
<td>Provide a bare minimum of protection. Applicable alarms defined in Appendix A should be considered. As a minimum, a case-mounted vibration transducer should be mounted on the coupling end of the driven machine. Automatic shutdown may not be required.</td>
</tr>
<tr>
<td>30 – 100</td>
<td>4</td>
<td>Provide periodic monitoring using portable instruments.</td>
</tr>
</tbody>
</table>

4.5 The level of protection for any given machine may be increased but not decreased. The values indicated here are for demonstration purposes only. The owner should verify actual values.

4.6 Typical requirements for alarm and shutdown functions of Levels 1 and 2 machines for various types of rotating machinery are shown in Appendix A.

4.7 See Appendix B, Figures 1, 2, and 3 for typical drawings that show protective instrumentation on centrifugal compressors, gearboxes, turbines, and motors.

4.8 If considering retrofitting instruments on existing installations, historical maintenance costs should be considered to determine the level of machine protection required.

5. Design Considerations

5.1 Monitoring refers to the on-line continuous monitoring of important machine parameters (e.g., bearing temperature, radial shaft and case vibration, axial position (thrust), case and differential expansion, speed, and phase reference) whether for protection or performance.

5.2 The following items should be given consideration, and reference made to the equipment manufacturer’s requirements when defining monitoring instrumentation for rotating equipment:

   a. Location and quantity of process and machinery instruments required for start-up, operation, and maintenance
b. A clear line of sight from the local control panel containing monitors (if provided) to the primary equipment location

c. Conditions under which the machine cannot be permitted to start (i.e., permissive start circuit) (e.g., low lube oil pressure and/or low seal oil differential pressure)

d. Time after measurement limits are exceeded before damage to the machine can occur

e. Time required for the operator to respond to an event to prevent damage to the machine or hazard to personnel

f. Conditions under which the machine automatically shuts down (see Appendix A)

g. Requirements for safe manual shutdown

h. Requirements for safe automatic shutdown

i. Equipment to be attended or unattended for startup and shutdown

j. Equipment to have a spare, and if so, whether installed or uninstalled

k. Replacement or repair costs

l. Alarm requirements from owner’s alarm and safety standards (see Appendix A)

m. Requirements for monitoring vibration level of the shaft or case (frame)

n. Requirements for monitoring axial displacement

o. Requirements for monitoring temperature of the following:
   (1) Bearings
   (2) Stator windings in electric motors or generators

p. Requirements for monitoring pressure, temperature, and/or flow of the following:
   (1) Suction
   (2) Discharge
   (3) Gas turbine exhaust
   (4) Steam turbine inlet and exhaust
   (5) Lube oil
   (6) Fuel gas
   (7) Oil filter (differential pressure)
   (8) Seal oil or seal gas
   (9) Seal flush media
   (10) Cooling systems
   (11) Compressor inlet air filter (differential pressure)

q. Requirements for and location of speed (rpm) indications and/or phase angle sensors

r. Necessary precautions to consider if a machine is tripped or shut down include the following:
   (1) Cool down
(2) Slow-roll data

Comment: Slow-roll data is collected from proximity probes observing a rotating shaft when the rotational speeds are too slow to contribute any meaningful rotor dynamic effects in the signal. In addition to electrical and mechanical shaft surface imperfections (known as runout) (e.g., scratches and residual magnetism), certain machinery problems (e.g., misalignment and bows) manifest themselves at slow-roll speeds, permitting them to be distinguished from other malfunctions that yield nearly identical data at full-speed conditions.

(3) Process normalization
(4) Bearing overheating
(5) Engaging a turning gear
(6) Isolation

s. Conditions under which any spare or backup machine can be automatically or remotely activated or deactivated

t. Items provided and installed by the rotating equipment manufacturer. Typically, the manufacturer provides and installs the following:

(1) Proximity probes or vibration sensors
(2) Extension cables between the sensor and transducer, if required
(3) Signal transducers (i.e., oscillator-demodulator)
(4) Temperature sensors for bearings and motor stators
(5) Signal wiring from field devices to skid-mounted local control panel or junction boxes
(6) Skid or frame-mounted junction boxes. Depending upon the location of the main control panel, requirements for wiring and terminations from the junction boxes to the main control panel should be determined and clearly specified for each equipment package on a project.

(7) All skid-mounted instrumentation

u. Devices and components to be provided by the manufacturer for installation by others

v. Instrumentation response time and control system actuation time

5.3 Documentation requirements should be reviewed and clearly stated within the equipment package requirements (e.g., instrument data sheets, calculations, P&ID, etc.).

6. Local Instrumentation

6.1 The development of P&IDs is recommended to define rotating machines and associated lube oil systems in accordance with applicable code, standard, and owner requirements. P&IDs should be reviewed with the process and operating departments before finalizing requirements for local instrumentation.
6.2 P&IDs and/or equipment specifications should indicate preferences for local instrumentation installation:
   a. On the process piping and/or the machine (e.g., pressure gauges, temperature gauges, level gauges, and miscellaneous switches)
   b. In gauge boards on the machine baseplate
   c. In panels located on or near the machine baseplate

6.3 The manufacturer’s standard control panel offering should be reviewed to determine the level of customization required to meet project requirements. Local instrumentation panels may be provided by the rotating equipment manufacturer or by the purchaser.

6.4 Operators should have a clear line of sight to local indicators and gauges from a normal operating position.

7. Protective Instrumentation – Vibration, Axial Displacement, and Speed

7.1 General
   7.1.1 Sensor type, mounting location, installation details, and integration with the machinery should be coordinated with the machinery manufacturer to ensure a reliable signal and measurement within an effective range for the sensor to provide the necessary machinery protection. Reference the appropriate API Practice and the sensor manufacturer installation instructions for additional information.

   7.1.2 Proximity (i.e., non-contacting, eddy current type) probes are used to measure shaft radial vibration, axial displacement (thrust), and speed. Proximity probes are typically used for sleeve bearing applications.

   7.1.3 Vibration sensors that measure acceleration (e.g., accelerometers) and those that measure velocity (e.g., seismic transducer) are used to monitor case/frame vibration. These may require special machining of the case or frame for mounting that is most effectively done when included within the machinery manufacturer’s scope of supply. Vibration sensors are typically used for rolling element bearing applications, case monitoring on sleeve bearing machines, and sleeve bearing applications where the probes should not pierce the casing.

   7.1.4 Vibration limits should be set to achieve a level of protection that meets or exceeds the equipment manufacturer’s recommendations.

   7.1.5 The minimum performance requirement (calibration) and system linearity for a complete vibration-monitoring system (i.e., transducer, power supply, monitors, and interconnecting cables) should be in accordance with API 670.

7.2 Proximity Probes
   7.2.1 Two axial position (thrust) proximity probes should be provided on each machine in an equipment train to monitor axial rotor position relative to the machine casing. The probes should send a signal to a thrust monitor. The thrust monitor should be a dual voting logic type that could trip the machine if both axial position probes reach or exceed a preset level of axial movement in either the active or inactive direction. Such an occurrence could result from a thrust bearing
failure. The probes should be mounted no further than 12 inches (30 cm) from the thrust bearing and should be sensing a surface integral to the machine shaft. If the probes have to be mounted inside the machine and are not accessible from the outside with the machine on-line, an installed (third) spare probe should be provided that can be activated in the event of a probe failure.

7.2.2 Each machine in the train should be provided with two proximity-type vibration probes for each journal bearing. The probes should send a signal to a vibration monitor. The vibration monitor should provide information to enable operators to better determine the mechanical and operating condition of the equipment. Monitor displays should simulate or mimic the geometry of the equipment train if possible.

7.2.3 Two proximity probes should be provided for each bearing to measure radial shaft vibration. The two probes mounted at each bearing should be 90 ± 5 degrees apart and 45 degrees from the top vertically. See API 670, Chapter 6 & Annex H for typical proximity probe mounting arrangements.

7.2.4 Proximity probes used for speed or phase angle measurement should measure a shaft surface that is independent of the shaft surfaces measured by axial displacement sensors.

7.2.5 All proximity probes should be removable without disassembly of the bearing housing.

7.3 Key-Phasors

7.3.1 A one-event-per-revolution mark and a corresponding key-phasor (i.e., phase reference transducer) should be provided for each shaft speed in the machinery train.

7.3.2 The key-phasor should have the option of being mounted axially, sensing a hole or notch in the end of the shaft.

7.3.3 The key-phasor probe should not interfere with the thrust position probes.

7.4 Acceleration Sensors

7.4.1 Acceleration sensors should be piezoelectric accelerometers with internal amplifiers and low output impedance.

7.4.2 Ground isolation should be provided, and the connector should mate with a standard API 670 connector.

7.4.3 The acceleration sensor should be:
   a. Monitoring horizontal and vertical vibration perpendicular to the axis of the shaft
   b. Located where they are not subject to resonant frequencies.
   c. Installed on the bottom section of the case in the event that the machine case is horizontally split
   d. Installed on a single stud
   e. Appropriate frequency range for the equipment being monitored
   f. Placed parallel to the shaft on the thrust bearing in rolling element machines.

7.4.4 The acceleration sensor should be protected using a conduit outlet body with the center milled out. A typical housing is shown in API 670.
7.5 Speed Sensors

7.5.1 Tachometers operate on a signal that may be pulse, square, or sine wave. Tachometer signals can also vary in amplitude as a machine operates throughout the speed range. Design of the tachometer circuit should include signal compatibility of tachometer with the sensor selected.

7.5.2 Speed sensors that generate tachometer signals can be either of the following:
   a. A proximity probe with the associated oscillator-demodulator, extension cables, and monitor
   b. A self-powered magnetic pick-up

7.5.3 It is preferred that speed be measured on all turbine or mechanical variable speed drives using a sensor and target integral to the machine shaft or a gear permanently attached to the shaft.

7.5.4 Toothed sensor wheels provide higher resolution signals for low speed applications. Selection and installation of targets should be by the rotating equipment manufacturer.

7.5.5 On critical service applications, redundant sensors with a loss of signal alarm should be considered.

7.5.6 If the equipment is a turbine, a digital rpm readout should be provided in both the control room and in a local display near and visible from the throttle control valve.

7.5.7 Where a hole, notch, or single projection on the shaft is used as a target with a proximity probe-type speed sensor, speed indication is based on one event per revolution.

7.5.8 If a toothed-wheel, target, or gear is used to measure speed, the number of teeth determine the number of sensed pulses required for each revolution. 30- and 60-tooth gears are typically selected as targets for ease in calculating and configuring rpm readouts.

7.5.9 For overspeed protection refer to API 670.

7.6 Signal Transducers

7.6.1 General

7.6.1.1 Signal transducers may be of various types (e.g., oscillator-demodulators, drivers, etc.).

7.6.1.2 The manufacturer’s installation instructions for cable type, shielding, and grounding requirements should be followed. Shielded, twisted pair/triad instrument cable should be used.

7.6.1.3 Except if coax or triplex cables are used, the cable shield should not be used as the common return line.

7.6.1.4 Electrical noise degrades millivolt-level signals (e.g., thermocouples and bridges) more than volt-level signals. If a low-level voltage signal needs to be measured, the signal should be amplified as close to the sensor as possible to boost the signal well above the noise.
7.6.1.5 An ungrounded shield provides little protection from noise. More than one ground on a cable shield can cause ground loop interference. The ground shield should be grounded nearest to the power source but alternative grounding points for best signal response may be required.

7.6.2 Housing and Mounting

7.6.2.1 All enclosures, housings, and junction boxes should be watertight and dust-tight, as a minimum. Installations where unsupported enclosures are subject to excessive vibration should be avoided.

7.6.2.2 Where device or cable maintenance is anticipated, sufficient space should be provided to permit two-handed work within the enclosure. Space for coiling excess extension cable should be provided in the transducer enclosure.

7.6.2.3 Where space within a sensor/probe housing is limited and special tools are required for maintenance, the rotating equipment manufacturer should provide the special tools.

7.6.2.4 Spare panel space should be considered for future expansion only where applicable.

7.6.2.5 Where an oscillator-demodulator is required to be isolated from ground, manufacturer instructions should be followed.

7.6.2.6 Where an enclosure or housing contains inputs to a shutdown system, the enclosure should be labeled to indicate it is part of a shutdown system.

7.7 Extension Cables

7.7.1 Proximity probe extension cables should either be armor-sheathed coaxial or installed within rigid metal conduit to protect against mechanical abuse.

7.7.2 Consideration should be given for permanently securing the armored cable or conduit to the equipment frame without obstructing access to, or removal of, any instrument, component, or access panel.

7.7.3 Cable installation should follow original equipment manufacturer’s installation requirements.

7.7.4 Prefabricated extension cables are often supplied at predetermined lengths with connectors attached. Conduit, fittings, and junction boxes should be selected to provide adequate space for coiling excess cable. Openings and internal dimensions of fittings and hardware should permit installation and removal of the cable with attached connector.

7.7.5 The cable selection from the junction box on the equipment baseplate to the readout device should be approved by the probe manufacturer.
8. **Protective Instrumentation – Temperature**

### 8.1 General

8.1.1 Temperature sensors should be the 100-ohm platinum (DIN 43760) resistance temperature detector (RTD) type, in accordance with *API 670*, and should be ungrounded.

8.1.2 Use of thermocouples should be approved by the owner.

8.1.3 Temperature sensors should be removable during operation with the exception of embedded bearing sensors and stator temperature sensors. Bearing thermal elements embedded within the thrust pads and extending through the bearing housing should be provided as dual elements with armored extension cable and terminated at a junction box mounted on the frame of the equipment. Sensor penetration should be on the top half of the bearing housing.

8.1.4 The temperature sensor location in bearings should be in accordance with *API 670*.

8.1.5 If sensors are not removable while on line, installed spare sensors should be provided.

8.1.6 Temperatures should be monitored in the control room.

8.1.7 Temperature alarms should be provided, as appropriate, for each point monitored.

### 8.2 Thrust Bearings

8.2.1 A minimum of two points should be measured on both the active thrust bearing and the inactive thrust bearing.

8.2.2 Sensor leads should be connected to a terminal strip mounted inside the machine case, and from that terminal strip to a junction box which can be easily accessed outside the machine case. Routing leads through the machine case may require the installation of compression fittings to seal the pass-through connection.

### 8.3 Journal Bearings

8.3.1 Two points per bearing are preferred, a minimum of one point should be measured on each journal bearing. If only one point is measured it should be in bearing’s load zone.

8.3.2 If the temperature of journal bearings in electric motors is being measured, a test for electrical isolation of the sensor from the bearing should be performed with the rotor removed from the motor.

8.3.3 Temperature sensors in electrically isolated bearings should be similarly electrically isolated.

8.3.4 Sensor leads should be connected to a terminal strip mounted on the inside of the machine case and from that terminal strip to a junction box which can be easily accessed outside the machine case.
8.4 Motor Stator

8.4.1 Two sensors should be installed in each of the three phases of the stator windings to monitor motor temperature. A temperature protection relay located within the switchgear may be provided for additional protection.

8.4.2 Sensors that measure temperature in the same phase should be as far apart as possible.

8.4.3 Connections between sensor leads and readout device should be accessible with the motor running. A separate enclosure should be provided to terminate sensors outside the motor if sensors are routed through the motor lead termination box.

9. Protective Instrumentation – Monitors

9.1 General

9.1.1 The term monitor as used in this Practice refers to the electronic device that accepts machine transducer/sensor signal inputs, scales the signals to the correct engineering unit, compares the measured signal to predetermined set-points, and initiates an output for process control, interlock, and/or alarm. Monitor types are designed specifically to a measured machinery variable with configurable parameters and options to customize the device for each installation.

Comment: This Practice covers stand-alone multipoint monitoring systems that are capable of shutting down the rotating equipment being monitored and providing information to the process control system or other monitoring equipment. This Practice does not cover single point vibration transmitters and switches that can be connected directly to a process control system.

9.1.2 Monitors should be compatible with, and configurable to, the input devices that are connected to them. The type of sensor (e.g., proximity probe, accelerometer, seismic, RTD, thermocouple), its characteristics, and specifications of each sensor model used should be considered.

9.1.3 Each monitor should have minimum features in accordance with API 670.

9.1.4 The monitor system should have capability provided for digital communication with Programmable Logic Controllers (PLC), and Basic Process Control Systems (BPCS).

9.1.5 The monitoring system design should include data communication equipment necessary to interface with data monitoring/collection equipment (e.g., as used in analysis for predictive maintenance, asset economic optimization, maintenance management, etc.) that may be available as an existing system or designed and integrated with the protection monitoring system. Provisions should be included in the design if this equipment is planned for addition at a later date.

9.1.6 Monitors may be hard-wired directly to an external control system through isolated Inputs/Outputs and form-C contacts when applicable.

9.2 Vibration

Each monitor should have minimum features in accordance with vibration section of API 670.
9.3 Axial Position

Each monitor should have minimum features in accordance with axial position monitoring section of *API 670*.

9.4 Temperature

Each monitor should have minimum features in accordance with temperature monitoring section of *API 670*.

9.5 Speed Monitors (Tachometers)

The measurement range of the speed monitor should be suitable for the machine being monitored including potential overspeed and slow roll. A local tachometer/digital speed indicator supports local operation of a turbine drive.

9.6 Power Supplies and Relays

9.6.1 Each power supply should be capable of supplying power and simultaneously resetting all alarm functions in all monitors associated with the power supply. See *API 670*, for minimum requirements on power supplies.

9.6.2 Output relays available on most monitoring systems are as follows:

- a. Electromechanical – provides a dry contact for interfacing to third party devices.
- b. Hermetically Sealed – electromechanical relay that is sealed for environmental or electrical area classification considerations.
- c. Solid State – may require an interposing relay to interface with a third party device.

9.6.3 The relay control circuit should be “fail-safe” (i.e., de-energized to shutdown or alarm) and should be of the single- or double-throw type with all contacts available for wiring. See *API 670*, for minimum requirements for relays.

9.7 Electrical Considerations

9.7.1 Conduit should be rigid type. Armored cable should be used in offshore installations.

9.7.2 All instrument and electrical wiring should be brought to the edge of the equipment baseplate and terminated in junction boxes.

9.7.3 Bottom entry for conduit is preferred on junction boxes to prevent liquids from penetrating and corroding the box.

9.7.4 The junction box for instrumentation should be separate from the junction box for electrical power.

9.7.5 Signal wiring should maintain minimum separation from power circuits in accordance with the National Electrical Code (NEC) or local codes and be run in separate conduit from power wiring.

9.7.6 All wiring should be properly labeled and identified on the elementary drawings.

9.7.7 See *PIP PCSPS001* should be referenced for electrical requirements.
10. **Installation**

10.1 Proper installation of monitoring equipment is essential for long-term system reliability.
10.2 *API 670* should be referenced for general physical installation requirements and applications.
10.3 *PIP PCCGN002* should be referenced for instrumentation electrical installation requirements and applications.
10.4 All parts of the system should be installed in accordance with *API 670*.
10.5 The equipment manufacturer should be required to install monitoring equipment probes in accordance with *API 670*, this Practice, and any additional specified requirements.
10.6 The owner should approve the design of the proposed monitoring system before fabrication.
10.7 Flexible metal conduit from the machine to the first conduit fitting should only be long enough to permit maintenance of bearings and seals without removing the conduit or junction boxes.
10.8 Signal cable shield should be grounded in accordance with instrument manufacturer instructions (typically at the monitor and not at the field device).
10.9 Each probe/sensor lead extension cable should be plainly marked at each end to indicate the location and service of its associated probe or sensor.
10.10 Each transducer, converter, and oscillator-demodulator should be clearly labeled to indicate the machinery location and functional position.
10.11 Each monitor should have a permanent tag indicating the identification number and description of the sensor point in relation to the machine. Tags should be securely mounted and displayed.
10.12 Plastic connector covers or heat shrink tubing should be applied at the probe to extension cable connection to prevent intrusion of foreign material and ensure an insulated, tight connection. This covering should not obstruct identification tags.

11. **Calibration and Functional Checks**

11.1 All systems and monitoring equipment should be calibrated and functionally checked in accordance with *API 670*, manufacturer recommendations and requirements, and any owner facility operating procedures.
11.2 The owner should approve the final calibration and functional checkout of each system.
11.3 Monitoring systems should be verified from the field sensor through the local and remote displays and controls to verify system functionality.
11.4 The owner has responsibility for any shutdown system associated with the equipment that may have inputs from the monitoring system.
11.5 The owner should clarify and resolve contradictory statements and requirements among all applicable referenced standards.
11.6 For installing and maintaining dual-voting thrust shutdown probes and to determine actual alarm and shutdown setpoints, appropriate machinery manufacturer’s recommendations and owner procedures should be referenced.
Appendixes

Appendix A: General Guidelines for Alarms and Shutdown

Appendix B: Figures

Figure 1. Typical drawing showing protective instrumentation sensors for gas turbine-driven high- and low-pressure centrifugal compressors

Figure 2. Typical drawing showing protective instrumentation sensors for an electric motor-driven compressor with gear

Figure 3. Typical drawing showing protective instrumentation sensors for a steam turbine driven generator
## Appendix A: General Requirements for Alarms and Shutdown

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<thead>
<tr>
<th></th>
<th>Alarm</th>
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<tbody>
<tr>
<td><strong>Centrifugal Compressors</strong></td>
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<tr>
<td>High shaft radial vibration (Note 6)</td>
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<td>X (Note 1)</td>
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<tr>
<td>Low lube oil pressure (Note 2)</td>
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<tr>
<td>High axial displacement</td>
<td>X</td>
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<tr>
<td>High thrust bearing temperature</td>
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<td>High journal bearing temperature</td>
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<td>High discharge temperature</td>
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<tr>
<td>High discharge pressure (Note 11)</td>
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<tr>
<td>High stage suction drum level</td>
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<tr>
<td>Low suction pressure (Note 11)</td>
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<tr>
<td>Low seal fluid differential pressure or low seal fluid overhead tank level</td>
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<tr>
<td>High primary seal leakage flow (for tandem Dry Gas Seals)</td>
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<tr>
<td>Low buffer gas flow</td>
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<tr>
<td>High lube oil console filter differential pressure</td>
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</table>

| **Reciprocating Compressors** (Note 4) |       |                    |
| Low lube oil pressure (Note 2)     | X     |                    |
| Low suction pressure or high differential pressure | X | X |
| High discharge pressure            |       |                    |
| High discharge temperature        |       |                    |
| High suction drum level            | X     |                    |
| High frame vibration (Frame Velocity) | X | X (Note 1)         |
| High Cross Head Vibration (Acceleration) | X | X (Note 1)         |
| Rod drop or rod runout sensors (Note 12) | X | X |
| Valve temperature (suction and discharge) |       |                    |
| High main bearing temperature      |       |                    |
| Cylinder oil low pressure or lubricator low cycle counter | X | |
| High/Low cylinder jacket coolant temperature (Note 13) | X | |
| High lube oil console filter differential pressure | X | |
| Oil header supply temperature Hi  |       |                    |

<p>| <strong>Centrifugal Pumps</strong> (Note 4) |       |                    |
| High thrust bearing temperature  | X     |                    |</p>
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<thead>
<tr>
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<tbody>
<tr>
<td>High journal bearing temperature</td>
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<tr>
<td>High shaft vibration (Note 6)</td>
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<td>High axial displacement</td>
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<tr>
<td>Casing vibration (anti-friction bearings)</td>
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<td>Seal failure (Note 14)</td>
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**Gears (Note 4)**

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<td>High shaft radial vibration (both shafts) (Note 6)</td>
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<tr>
<td>High axial displacement (on shaft(s) with thrust bearing)</td>
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<td>High case vibration (acceleration)</td>
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<td>Low lube oil pressure</td>
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**Electric Motors/Generators (Note 5)**

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<td>High shaft radial vibration (Note 6)</td>
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<tr>
<td>High stator (windings) temperature</td>
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<td>Cooling water leak (Note 7)</td>
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<td>High motor amps (electrical overload implemented in motor protection relay system)</td>
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**Steam Turbines (Note 4)**

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<tr>
<td>High journal bearing temperature</td>
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<td>Low lube oil pressure (Note 2)</td>
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<tr>
<td>High exhaust pressure</td>
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<tr>
<td>High Surface Condenser Level</td>
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<tr>
<td>Low Surface Condenser Level</td>
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<tr>
<td>Speed Sensor Failure</td>
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<td>Operating speed deviation from setpoint</td>
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**Gas Turbines**

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<tr>
<td>Flame failure</td>
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<td>Alarm</td>
<td>Alarm and Shutdown</td>
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**Internal Combustion Engines**

- **Overspeed**: X, X
- **High frame vibration**: X, X
- **High jacket water temperature**: X
- **Low lube oil pressure (Note 2)**: X, X
- **Low crankcase oil level**: X

**Lube Oil Systems and Seal Oil Systems (Note 8)**

- **Low level in oil reservoir**: X
- **Auxiliary lube oil pump running**: X
- **Auxiliary seal oil pump running**: X
- **High differential pressure across oil filter**: X
- **High oil temperature (downstream of cooler)**: X
- **Low oil header pressure (Note 2)**: X, X (primary equipment (Note 10))
- **Low seal oil differential pressure or low level in overhead tank (Note 9)**: X, X (primary equipment (Note 10))
- **High level in overhead tank**: X

**Seal Gas Systems**

- **Buffer gas low pressure**: X
- **High differential pressure across seal gas filter**: X
- **High seal gas differential pressure across seal**: X, X (primary equipment (Note 10))

**Air-Cooled Exchangers**

- **High fan (Frame) vibration (Note 6)**: X, X

**Cooling Tower Fans**

- **High gear box vibration (Note 6)**: X, X
NOTES:

1. Shutdown functions are assigned on an individual, case-by-case basis, at the option of the owner and/or the machinery manufacturer. Dual voting (2oo2) on radial vibration (X and Y) are recommended. If shutdown is required, the alarm should be connected to shutdown system.

2. Each item of rotating machinery should be protected from low lube oil pressure. Normally, protection is accomplished by sensing pressure of the lube oil header.

3. A “voting” system should typically be used to initiate a shutdown on high axial displacement. See this Practice, Section 3.7.

4. Applies to large, heavy-duty equipment (e.g., 1,000 hp and larger) and to equipment in un-spared or high consequence of failure service. Protective instrumentation need not be furnished for gears unless either the driver or the driven equipment requires protective instrumentation. Additional instrumentation per API 670, current edition, may be considered for efficiency monitoring or machinery analytics.

5. Applies to electric motors 1,000 hp and larger.

6. Accelerometers providing continuous reading are preferred over vibration switches. Proximity sensors to be used for fluid film bearings. Accelerometers (wired or wireless) to be used for case or frame vibration or rolling element bearings.

7. Applies to water-cooled electric motors/generators only.

8. The same requirements apply whether the consoles are combined or separate, and whether an overhead tank is used.

9. If an overhead oil tank is used, the following requirements should be applied as referenced within the applicable API Practice:
   a. The overhead tank should have a minimum total capacity equal to 10 minutes of seal oil supply.
   b. A low-level alarm should sound and the auxiliary pump should start when the volume of seal oil in the tank falls to a 10-minute supply plus the volume allowed for coast-down and block-in (typically 2-minute supply minimum).
   c. A low-low alarm should sound and a shutdown should be initiated once the overhead tank level drops to a point that only the volume allowed for coast-down and block-in remains.
   d. See API 614 for more information.

10. “Primary equipment” is defined as the machinery train’s major equipment items (e.g., turbine, compressor, gearbox, etc.).

11. Surge control and surge protection system shall be specified for centrifugal compressor in variable flow and mole weight gas applications.

12. Key phasor shall be used for synchronizing rod drop or rod runout sensors with crank angle. Unsynchronized rod drop or rod runout readings are of limited value for predicting machine conditions.

13. Low coolant temperature alarm shall be employed in gas service containing condensables – refer to API 618, current edition

14. Seal failure alarm and shutdown will depend on seal piping plan employed – refer to API 682, current edition for recommended piping plans instrumentation.

15. Refer to API 670, 611 and 612 and NEMA SM 23 and 24 for overspeed system requirements. Overspeed protection system must be independent of governing system. Electronic overspeed protection systems should be used and replacement of mechanical overspeed protection systems should be considered.
Appendix B: Figures

Figure 1. Typical drawing showing protective instrumentation sensors for gas turbine-driven high- and low-pressure centrifugal compressors

Figure 2. Typical drawing showing protective instrumentation sensors for an electric motor-driven compressor with gear

Figure 3. Typical drawing showing protective instrumentation sensors for a steam turbine driven generator

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<tr>
<th>Sensor and Symbol Identification</th>
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</table>
Figure 1 - Typical protective Instrumentation for gas-turbine driven centrifugal compressor train.
Figure 2 - Typical protective Instrumentation for Electric Motor-driven compressor with Gear.
Figure 3 - Typical protective instrumentation for Turbine-Generator