Best Practice
September 2007

Best Practices of Mechanical Drive Steam Turbines

Best Practice document developed by RoMaDyn for Emerson Process Management.

EMERSON Process Management

1.0 Introduction

This Best Practices document is a guide for the application of vibration machinery protection instrumentation on Mechanical Drive Steam Turbines in Boiler Feedwater Pump service. This classification of turbomachinery operates with hydrodynamic or fluid film bearings and is absolutely critical to the process. Machinery vibration measurements must be correlated with process variable measurements in order to obtain a complete understanding of machinery behavior as well as providing adequate machinery protection.

In order to properly monitor critical turbomachinery operating in hydrodynamic or fluid film bearings the shaft relative measurement utilizing proximity (displacement) probes must be a part of a properly engineered offering. XY (orthogonal; i.e. at 90°) proximity probes at each radial bearing are mandatory. There are no exceptions to this rule.

2.0 Overview

2.1 Introduction

Mechanical Drive Steam Turbine/Boiler Feedwater Pumps (MDST/BFP) applications usually consist of a steam turbine and horizontal multi-stage centrifugal pump. The turbine and pump shafts are coupled via a flexible coupling. All of the rotors are supported by multiple radial hydrodynamic bearings and a single hydrodynamic thrust bearing. A MDST/BFP is usually a custom designed pump. The machine train is thus composed of multiple complex mechanical systems which incorporate a wide variety of design features. These pumps are designed to deliver water with pressure up to 3500 psi. At these pressures, heavy machine cases are required along with labyrinth shaft seals. Due to the high pressures, close internal clearances, both radially and axially, must be maintained. MDST/BFP units are typically sized to supply from 33% up to 100% of total feedwater flow. This flow rate can be as high as 5 million pounds per hour (or more). MDST/BFP typical configurations can consist of 2, 3 or 4 pumps for a single generating unit. In some instances, one or more MDST/BFP units are used as spares. Typically MDST/BFP units are supported on a foundation block, which may be a concrete structure or a steel fabrication; in all cases the foundation has a considerable influence on the dynamic behavior of the machine train. This is the preferred arrangement because it minimizes alignment problems between the steam turbine and pump case(s). However, in some instances, MDST/BFP units are installed with the steam turbine and pump on separate foundations or base plates. This situation can lead to potential alignment problems, especially when piping strain issues are present. The whole assembly of rotors, casings, bearing supports and foundation must be considered together as a complete system when addressing the requirements for effective vibration monitoring and diagnostics.

MDST/BFP units are supplied with a set of monitored functions grouped together in a machinery protection and/or machinery management system. These measurements include radial vibration, rotor (axial/thrust) position, journal (radial) bearing metal temperature, and thrust bearing metal temperature. At least two xy proximity probes should be located in each radial bearing as well as at the thrust bearing. Process variables such as pump flow, pressure, temperature, oil supply temperature, steam temperatures and pressures, ambient temperature, etc. should be correlated at the control system level. MDST/BFP units are particularly susceptible to misalignment and fluid-induced instabilities at the bearings and seals. The monitoring transducer suite should be capable of consistently and accurately detecting these machinery malfunctions.

The selection of vibration measurement transducers also requires consideration of the design of individual machines within the MDST/BFP train and the effects of the coupling between their rotors. Traditional methods of vibration measurement are based on manufacturer's preferences influenced by corporate end user preference and sometimes national and/or international standards. Installed systems on older MDST/BFP and newly commissioned units may not be adequate for either the protection of the machines or their management. Installations may be inadequate because of wrong transducer type or insufficient measurement points, or outdated instrumentation technology. Most original protection systems were specified without consideration of the need for continuous acquisition of information for diagnostics.

Any MDST/BFP is an extremely expensive investment. Protection and management of the asset throughout its planned operational life is essential. Information derived from inadequate transducer systems may be inaccurate and misleading. Effective machine protection may not be achieved. Losses of production may occur because a machine is tripped or manually shutdown unnecessarily because indicated vibration levels are spuriously high. A trip may be missed because the indicated vibration level is low and does not reveal the true severity of the dynamic forces applied to the rotor or bearing structure. Similarly, effective management of the asset cannot be achieved if the transducer installation provides insufficient or misleading measurements. Vibration transducer requirements for fully effective machine protection and fully effective diagnostics are similar; it is neither necessary nor desirable to use separate transducer installations for machine protection and machine diagnostics and management. However, Prediction System applications almost always will require additional vibration measurements

2.2 Machine Protection and Prediction - Definitions and Requirements

Machine Protection is implemented when vibration (or other) measurements are installed permanently on a machine and connected to a dedicated monitoring system. The monitoring system has alarm set-points which automatically raise an alarm when the predetermined alarm level is reached. The monitoring system may have alarm relays (typically alert and danger) which can affect automatic shutdown or trip of the machine; alternatively instructions to shutdown the machine may be acted upon by an operator when an alarm occurs. Machine Protection is necessary and valuable since it can prevent machine damage and consequential losses in the event that a sudden machinery or process malfunction occurs. The traditional role of Turbine Supervisory Instrumentation includes a Machine Protection function.

A Prediction System uses the data provided by the Machine Protection System, supplemented by additional machine and process measurements, which enable the true operation state and condition of the machine to be defined and managed. A Machine Protection System provides all of the information necessary to optimize the machinery in terms of operational safety, maximized service life, minimized maintenance cost and energy efficiency.

In the current business environment, it is recognized that Machine Protection alone cannot provide adequate information to ensure that the machinery is operated optimally. There is a considerable amount of valuable information obtained by the transducers and monitoring system which, when used with a Prediction System, can provide early identification of machinery malfunctions before an alarm or trip is caused by the Protection system. In fact, Prediction Systems considerably enhance the utility of a Machine Protection system by providing actionable information to operators and engineers which can prevent a sudden plant trip or requirement for emergency shutdown of the machine or process.

In any event due consideration should be given to the consequences of implementing a trip (either automatically or through operator action) based on high vibration. In many cases the risk to the unit and associated plant is much greater as a result of a sudden trip from high load operation than a short period of operation during which vibration alarms are investigated using a Prediction System.

2.3 Vibration Measurement Types: MDST/BFP

Relative Vibration is vibration measured with respect to a chosen reference. Proximity probes measure shaft dynamic motion and position relative to the probe mounting, usually the bearing or bearing housing.

The fundamental monitored points for MDST/BFP are radial vibration and axial position (thrust). The general recommendation for vibration is to monitor with orthogonal (xy or "at 90°") proximity probes mounted at or near each radial bearing of the turbine and pump. These machines utilize fluid film bearings with a reasonable amount of damping so that shaft relative motion is more significant and informative than casing motion – under most conditions. Prior to the advent of the proximity transducer, these machines were monitored with either shaft-rider transducers mounted only in the vertical plane or seismic transducers on the bearing housings. Orthogonal transducers are always recommended in order to be able to observe the plane of maximum vibration, i.e. Smax. In general single transducers provide inadequate protection because it is impossible to know at what radial angle to install a single transducer so as to observe the maximum vibration. A single transducer only provides very limited diagnostic information about vibration characteristics at each bearing. It is also recommended to install spare proximity probes (radial and thrust) at all internal, non-accessible locations.

Absolute Vibration is vibration of an object as measured relative to an inertial (fixed) reference frame. Accelerometers and velocity transducers measure absolute vibration typically of machine housings or structures; thus they are referred to as seismic transducers or inertial transducers.

Axial position (thrust) measurements are one, if not the most critical, measurements made on any machine train. Usually, radial bearings can sustain high vibration amplitudes for extended periods of time. However, a thrust bearing failure can lead to a catastrophic and immediate failure and unwanted "intermarriage" or potential contact of the rotating and stationary parts. Proximity probes, mounted in the axial direction, are used to make this measurement. They indicate where the rotor is operating within its normal "float zone" as well as providing a warning if the thrust bearing begins to degrade.

Note: Axial position measurements should always be accompanied by thrust bearing metal temperature measurements. It is recommended that at a minimum redundant (two) thrust probes should be installed, with at least two spare probes. Axial position proximity probes should be mounted within 12 inches of the thrust collar. If the thrust collar itself cannot be monitored, then the end of the shaft, and auxiliary collar, or a shoulder or step in the shaft diameter are possible target options. When the thrust position monitor is connected to a machine shutdown circuit, it is usually recommended that "and" logic be used in the protection system which requires that both (redundant) axial position probes observe the event in order to minimize false trips.

A keyphasor® probe(s), providing a once-per-turn timing signal, should be included at some radial location to provide speed, phase angle and timing information for the entire machine train. The keyphasor can be used directly to measure machine speed. It can also be used to measure shaft acceleration (revolutions/minute/minute for those machines where shaft acceleration during start-up may be critical), reverse rotation, and of course provides a means to measure phase angle.

Additionally, proximity probe(s) observing a multi-tooth wheel also can be utilized to more accurately measure machine speed changes as well as measuring "zero speed", so that operators will know exactly when to engage the turning gear after turbine shutdown.

2.4 Recommended Transducer Installation for MDST/BFP

Design Considerations

A well designed MDST/BFP and foundation system will have bearing support characteristics which provide high dynamic stiffness at operating speeds within 20% of rated speed. This ensures that no system resonance which is predominantly a resonance of the bearing support structure or foundation, will result in excessive bearing support flexibility (e.g. low dynamic stiffness) during normal operation or overspeed testing on site. A similar operating margin should apply to the occurrence of rotor balance resonances (critical speeds). The well designed machine will be intended to have effective bearing support stiffnesses which are considerably higher than the bearing oil film stiffness; consequently, for such a well designed machine the shaft relative vibration amplitudes will be in the range 5 to 10 times higher than the bearing housing absolute vibration amplitudes. In the above case, the shaft relative vibration is not equal to the shaft absolute vibration in amplitude and phase, but the difference in the vectors is quite small and can be neglected.

Due to the complexity of the design, especially of the foundation structural dynamics, some MDST/BFP designs exhibit resonance of the foundation structure - bearing support system at frequencies below the rated operating speed of the machine. During start-up and shutdown it is necessary for the machine to run through any resonances which are present. Resonances are particularly apparent with fabricated steel foundations, which may exhibit numerous resonances from low frequencies to frequencies above the operating speed of the turbine generator. For higher frequency resonances close to or above operating speed, foundation resonances tend to be more localized and typically do not involve the entire foundation. It should be noted that although concrete foundation structures appear to be much more rigid in construction than steel fabrications, structural resonances may also be problematical.

It is therefore probable that even for a well designed machine, during start-up or shutdown the dynamic stiffness of the bearing supports will be relatively low due to the presence of a structural resonance. Consequently, bearing absolute (casing) vibration will be higher in amplitude in response to excitation forces at certain operating speeds of the MDST/BFP. Shaft relative vibration amplitude may not change substantially under these conditions; however, shaft absolute vibration may increase significantly.

For MDST/BFP, it is very difficult to verify that bearing absolute vibration will never be of significant amplitude. When bearing absolute vibration is of significant amplitude, it may be necessary to install additional xy bearing casing absolute (seismic) vibration transducers at every bearing. If bearing absolute vibration is significant, the economics and constrained space associated with many MDST/BFP applications can mean that these two factors need to be given additional consideration compared to the need for the additional monitoring.

Almost universally the rotor system in a MDST/BFP set is the predominant source of dynamic forces which cause the rotor to apply excitation forces to the bearing supports and foundation through the bearing oil film. The shaft relative proximity probe is the only type of transducer capable of measuring the modulation of the oil film which represents an accurate indication of the forces which the rotor is applying to the rest of the system at each bearing. If the oil film characteristics are known, the actual dynamic forces applied can be quantified.

It is therefore recommended that for the most effective machine protection, diagnostics and machinery management possible, that xy shaft relative proximity transducers are installed on all Mechanical Drive Steam Turbine/Boiler Feedwater Pump machine trains in addition to single accelerometers on each bearing housing on the boiler feedwater pump.

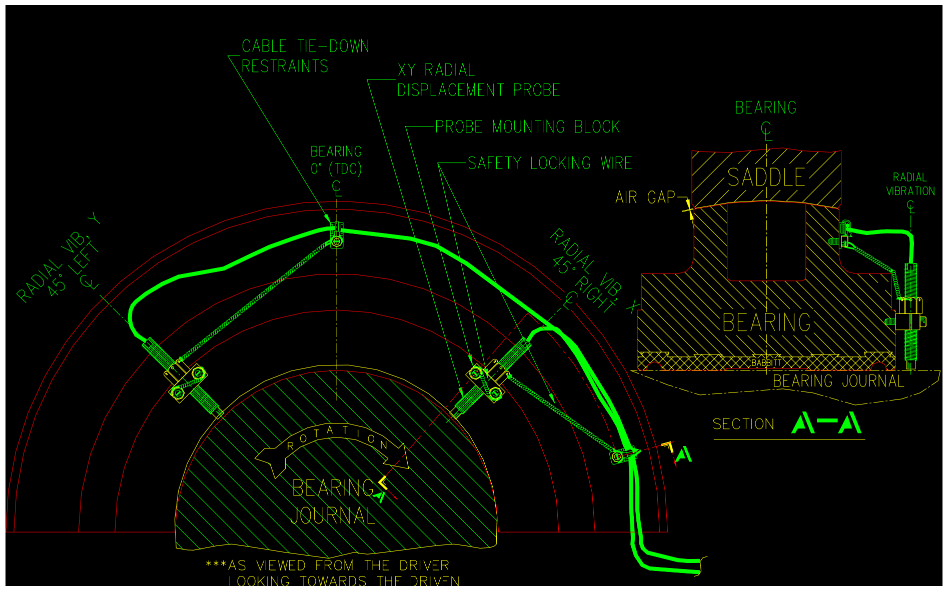


***Figure 1**: Recommended Shaft Relative Vibration Probe Installation Design*

2.5 Summary of Transducer Installation Recommendations for MDST/BFP

1. Essential Requirements for MDST/BFP Protection and Diagnostics - Shaft Relative Proximity Displacement Probes in xy Configuration

   It is recommended that two orthogonally-mounted shaft relative proximity probes be installed at each bearing, using a mounting position directly referenced to the bearing. This position may be on the bearing itself, on the bearing pedestal outer cover. The outer cover may only be used if it is the primary bearing retaining device and is a structurally significant component. Secondary covers which do not retain the bearing are unsuitable for relative shaft vibration of position measurements. Figure 1 illustrates an example of a typical installation. Shaft relative measurements should always be accompanied by bearing metal temperature measurements.

In many instances, MDST/BFP shafts are plated, usually with chrome, to improve wear resistance. Proximity probes are calibrated to the material that they are observing. AISI 4140 steel is used as the primary calibration material because it allows the proximity probe system to respond to many ferrous materials. If the shaft is plated in the probe target area and improperly applied, this can cause excessive electrical run-out to be measured in the vibration signal. This run-out is caused by several factors. Proximity probe RF signals penetrate into the shaft surface through the plating thickness. If the plating is sufficiently thick enough, the proximity probe will only respond to the plating itself. The probe will respond accurately if the proximity probe system is calibrated for the plating material; however, if the plating is not sufficiently thick and/or varies in thickness, the proximity probe RF signal may penetrate through the plating to the parent material of the shaft itself beneath the plating. When the shaft is rotated these material variations will be detected by the proximity probe system and will lead to false probe signals. If shaft plating is applied at or near proximity probe target areas, it must be properly applied and have the proper thickness. Secondly, the proximity probe system must be accurately calibrated for the plating material.

2. Additional Requirements for MDST/BFP Protection and Diagnostics - Shaft Relative Proximity Displacement Probes in Dual Axial Thrust Probe Configuration

   Due to their tight internal tolerances of the pumps, axial position (thrust) measurements are one of the most critical measurements made on MDST/BFP units. A thrust bearing failure can lead to a catastrophic and immediate failure and unwanted “intermarriage” or potential contact of the rotating and stationary parts. Proximity probes, mounted in the axial direction, are used to make axial position measurement. They indicate where the rotor is operating within its normal “float zone” as well as providing a warning if the thrust bearing begins to degrade. Due to thrust loads, dual axial thrust probes must be installed. It is recommended that at a minimum redundant (two) thrust probes should be installed, with at least two spare probes. Axial position proximity probes should be mounted within 12 inches of the thrust collar. If the thrust collar itself cannot be monitored, then the end of the shaft, and auxiliary collar, or a shoulder or step in the shaft diameter are possible target options. When the thrust position monitor is connected to a machine shutdown circuit, it is usually recommended that “and” logic be used in the protection system which requires that both (redundant) axial position probes observe the event in order to minimize false trips. Axial position measurements should always be accompanied by thrust bearing metal temperature measurements.

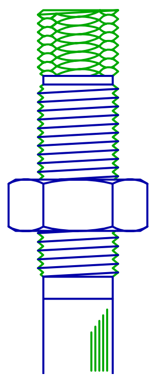
Compensation for changes between cold to hot float zones must also be made. The alert level is frequently adjusted to represent the collar to bearing contact position based upon cold float zone measurements when the machine is down. As the unit heats up while in service, the float zone will also expand. After thermal equilibrium, the alert set point will then occur well within the bearing clearance, even when the thrust collar is not in contact with the bearing. Therefore, an acceptable thrust position change could cause a false alarm. Compensation for temperature changes is very important with MDST/BFP units because of the close internal clearances.

3. Accelerometers mounted on the pump casing are needed for detecting flow rated malfunctions such as cavitation and impeller pass vibration.

   Vibration due to flow cavitation, recirculation, and impeller pass frequencies are more effectively detected by using accelerometers. Accelerometers should be mounted on the pump bearing housings as close as possible to the impeller stages. One accelerometer for suction side and one accelerometer for pressure side should be sufficient for most applications; however, additional accelerometers may be required based on the number of pump stages. Selection of the transducer type, its frequency response, and its dynamic range are important issues to carefully consider. Proper mounting location and mounting technique are essential in order to achieve desired accelerometer performance and to avoid unreliable or unexpected output signals, (see Appendix B). The frequency response of the accelerometer is very important. At the low end of the frequency response, the 1X shaft rotation frequency must be included. At the high end, twice the highest impeller pass frequency must be included as a minimum, with three times the impeller pass frequency being desired. The mounted resonant frequency of the accelerometer itself must be at least twice the highest frequency to be measured. This will ensure a flat frequency response over the measurement range of interest.

APPENDIX A

Proximity Transducer Installation



Proximity Transducer

Introduction

Proximity Transducer is a non-contacting device, which measures the displacement motion (dynamic) and position (static) of an observed surface relative to the transducer mounting location (fixed reference). Typically, proximity transducers used for rotating machinery measurements operate on the eddy current principle and measure shaft displacement motion and position relative to the transducer mounting surface or fixed reference (bearing, bearing housing, machine case etc.).

Proximity transducers sometimes referred to as proximity probes typically measure an array of machine conditions including, but not limited, to the following:

- Shaft Relative Vibration- Shaft dynamic motion measured from a chosen reference (transducer mounting surface) in a direction perpendicular to the shaft centerline or axis.
- Radial Position- Shaft average or static position measured relative to the transducer mounting surface. Provides a good indication or measurement of possible bearing or bearing journal wear.
- Mode (nodal) Identification- Shaft dynamic motion and position measured from a chosen reference (transducer mounting surface) perpendicular to the shaft centerline or axis on the opposite side of normal bearing monitoring points or adjacent to couplings.
- Axial (Thrust or Rotor) position- Average shaft position or change in shaft position measured in the axial direction relative to the transducer mounting surface (fixed reference).
- Keyphasor (once per turn phase reference)- Measures shaft rotative speed and vibration phase lag by observing a single event per revolution marker (notch or projection). It is also an essential element in measuring shaft rotative bow or sagging during slow roll condition (Eccentricity).
- Differential Expansion- Average shaft position or change in shaft position measured in the axial direction relative to the transducer mounting surface (fixed reference). This measurement is the result

of thermal transients between rotating and stationary components, usually during machine startup and shutdown.

- Eccentricity- Average shaft position or change in shaft position measured in the radial direction relative to the transducer mounting surface (fixed reference). This is a measurement of shaft from thermal induced bow or gravity induced sagging with the machine at slow roll.
- Speed- Frequency of which a shaft is rotating at any given time measured relative to the transducer mounting surface (fixed reference). Usually expressed in revolutions per minute (RPM) with the transducer observing multiple events (gear teeth, etc.).

The proximity transducer works in conjunction with a driver, sometimes referred to as a proximitor. The driver is a signal conditioning device which sends a radio frequency to the eddy current proximity transducer, demodulates the transducer output and provides output signals proportional to both the average and dynamic transducer gap distances. Also called an oscillator-demodulator.

General Considerations

Observed Target Area Material

Considerations must be given to the observed target area material (shaft, collar, etc.). The linearity curve of the proximity probe system is similar for most common shaft steel alloys. Standard industry transducer systems are designed to operate with most AISI 1000 and AISI 4000 series carbon steels and most magnetic steels commonly used in rotating machinery. The standard transducer system is calibrated at the factory using an AISI 4140 carbon steel target. However, some materials have different surface compositions which present varying values of resistivity and permeability. This can also introduce a "noise" signal on the driver output.

Proximity transducer systems can be provided to operate with any conductive metal. If the observed metal is other than AISI 1000 and AISI 4000 Series carbon steels, specially calibrated drivers may be required.

Observed target area surface treatments (chrome plating, metallizing, etc.) are also conditions to be aware of when selecting and installing proximity based transducer system. This plating may be thin enough to allow the transducer eddy currents field to penetrate through the chrome or metallized area and view into the parent shaft materials, thus "seeing" two different material resistivities. Compounding this situation are the shaft irregularities between the parent metal (shaft) and the surface treatment. Information concerning the nature of target area material and surface finish should be investigated & well documented prior to purchasing or installing any proximity based monitoring system.

<u>Observed Target Area Contour and Condition (Glitch)</u>

The observed target area or surface *must* be free of all irregularities (i.e. scratches, rust, corrosion, residual magnetism & stress concentrations, metallurgical segregation, non-concentricity, etc.). These irregularities, sometimes called "Glitch", may cause changes in the transducer gap voltage, which is not indicative of a shaft position change, thus introducing a signal error and limiting the transducer system accuracy. If the surface is not free of these irregularities & the transducers cannot be relocated, then ways of dealing with reducing glitch must be considered. Recommendation for observed target area surface finish is a minimum of 0.41 to 0.76 micrometers (16 to 30 micro inches). Additional information is available for dealing with run-out or “glitch”.

<u>Mounting Location Stiffness</u>

Stiffness (rigidity) of the proposed transducer installation, in conjunction with its mounting support, should be evaluated when considering proximity based monitoring system. Stiffness or rigidity of a mounting bracket can be analyzed prior to fabrication and gussets may be incorporated for additional support. Fixed mounting locations such as bearings or bearing housings can be analyzed for stiffness by performing a "ring test". This test will determine the frequency at which the transducer and its support will vibrate, otherwise known as resonant frequency. Recommended resonant frequency specification for proximity transducers and their associated mounting supports (bracket, bearing housing, etc.) are a minimum of ten times the rotative speed (frequency) of the machine.

Example: A 3600 RPM unit has a rotative speed frequency = 3600 RPM/60 or 60Hz. 60 Hz x 10 = 600 Hz. The resonant frequency of the transducer, in its mounted location has to "resonate" at or above 600 Hz.

The test to determine resonant frequency (ring test) should be performed by a qualified individual with past experience in interpreting the results of the data received. On the basis of the data received a conclusion can be made as to the acceptance of the proposed mounting location. If a resonance is identified to be close to rotative speed, additional detailed testing will be required to characterize mounting deflections and develop corrective actions.

When rigidity is in question simply adding a gusset to a weak section of the bracket may solve a low resonant frequency problem associated with that specific bracket. Most brackets can be constructed out of 1/2" AISI 1018 cold rolled carbon steel. This of course is a recommended minimum requirement. Greater thicknesses may be needed to facilitate the specific installation. Remember that increased thickness yields a higher resonant frequency, as will the addition of a gusset.

Target Area Specifications

Transducer target area specifications vary with the size and type of proximity transducer chosen. Projecting outward from the tip of the proximity transducer is an invisible eddy current field. The field size is dictated by the size of the transducer chosen. The larger the tip diameter (50mm) the larger the field, the smaller the tip diameter (8mm) the smaller the field. As the transducer tip moves towards the target area (metallic surface) the field decreases in size. To ensure transducer functionality certain installation constraints must be considered in regard to the eddy current field propagation. Table A1 and Figure A1 depict the minimum target area requirements that should be observed to avoid problems such as *cross talk (cross coupling), side read and back view*.

Note: Table A1 will be used in conjunction with the Figures A1 and A2 for target area specifications and thermal growth considerations.

Table A1

Transducer	A	B	C	D	E	F	G	H
5 mm narrow	1.00	0.35	1.50	1.00	0.45	?	?	?
5 & 8 mm	2.12	0.62	0.90	1.60	0.70	0.35	0.25	0.30
11 mm	3.30	1.30		2.60	0.87	0.43	0.60	0.43
14 mm	3.20	1.70		2.40	1.25	0.53	0.60	0.53
25 mm (Intg)		2.00		4.00	2.00	0.63	0.87	1.50
35mm		2.25		4.00	2.50	1.50	0.87	1.50
50 mm (Intg)		3.00		8.00	5.00	2.50	1.95	1.95

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Dimension "A"= Minimum shaft diameter in inches (assuming xy transducers in same plane).

Dimension "B"= Min. transducer target area in inches (greatest diam. of field) for radial & axial measurements.

Dimension "C"= Minimum center to center distance (inches) for *radially* mounted transducers (x-coupling).

Dimension "D"= Minimum center to center distance (inches) for *axially* mounted transducers (x-coupling).

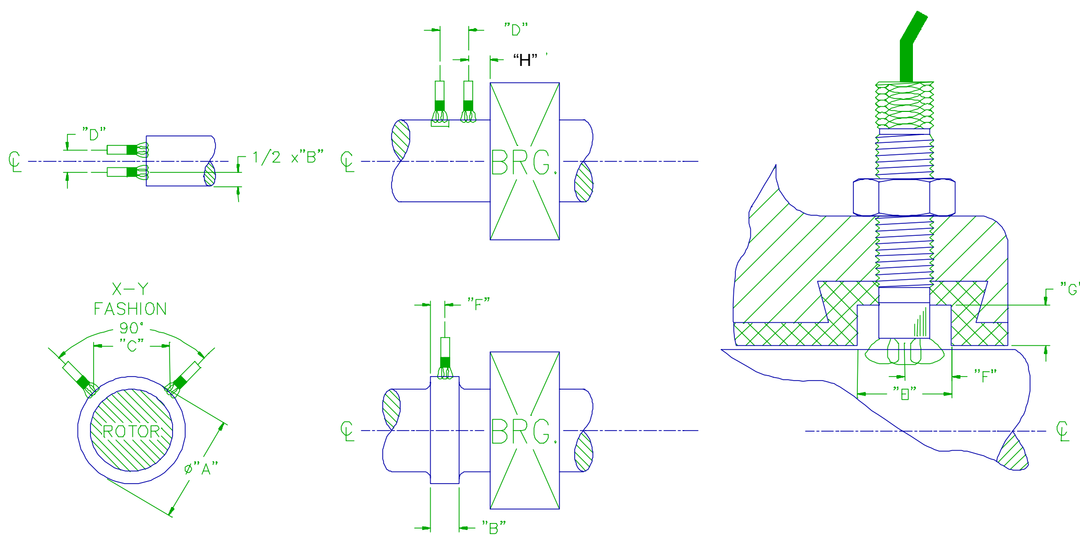
Dimension "E"= Minimum counterbore diameter (inches) for recessed viewing.

Dimension "F"= Minimum lateral obstruction distance (inches), lack of target, removal of steel

Dimension "G"= Minimum rear obstruction distance in inches (back view) from front of probe tip to metal.

Dimension “H”= Minimum lateral obstruction distance in inches (bearing, steel collar) for side read.

Figure A1: *Target Area Specification Illustration*



Thermal expansion or growth is a phenomenon that occurs when an object, regardless of size or mass, is heated. Invariably it will expand. Taking this idea and relating it to typical rotating machinery the following considerations should be observed when choosing a mounting location for a proximity transducer. The observed target area (shaft) and the mounting area (machine case/bearing), because of their different size, material and mass, will expand at different rates. This is referred to as *differential expansion*, and it may be an influencing factor in the proposed location of the transducer. The thermal expansion or growth during machine startup and shutdown (transients) varies from machine to machine and from location to location along the machine train. The transducers eddy current viewing field may be substantially increased or decreased as the observed target area moves due to thermal expansion during machine startup and shut-down. To ensure adequate transducer placement and target area the thermal growth distances for each transducer target area should be determined. Thermal growth information can only be supplied by a qualified source i.e.: The customer or the OEM. However, educated guesses can be formulated by reviewing wear patterns on the rotating components near the proposed target areas. This would be done when the machine is cold, at rest. Performing this visual evaluation will provide a basis for which we determine whether we have enough transducer target area from cold/at rest to hot/online running speed variations.

Refer to Figure A2 for information pertaining to Thermal Expansion.

Note: The scenarios below indicate that the initial transducer target area was acceptable at the time the transducers where initially installed. After startup the target area moved (due to thermal expansion) from beneath the transducer causing the output signal of the transducer system to be false or erroneous.

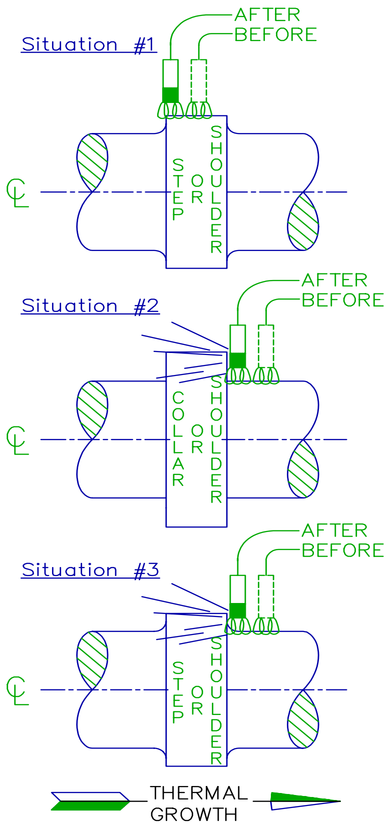


***Figure A2**:*
Thermal Expansion Pitfalls

<u>Situation 1:</u> Results in loss of transducer target area (less metal viewed beneath transducer).

<u>Situation 2:</u> Results in loss of transducer target area (side reading, non-consistent transducer target area or side of collar) and possible damage to rotating component & transducer. No radius at the collar.

<u>Situation 3:</u> Results in loss of transducer target area (non-consistent transducer target area or increase in viewed metal- Note the radius) and possible damage to rotating component & transducer

Transducer Perpendicularity

Care should be taken during the machining and transducer installation phase to ensure that the proximity transducer is installed perpendicular to the target area (surface). If the transducer was threaded all the way down to the target area the face of the transducer tip would be flush against the target surface (assuming a flat surface). This method holds true for flat target areas, described above, and round target areas. The tolerance for transducer perpendicularity is ± 1.5° from the true orthogonal relationship between the transducer centerline and the observed target area surface.

Refer to Figure A3 for information pertaining to Transducer Perpendicularity.

The result of deviation from this tolerance will affect the overall linear range of the transducer system and the transducer gap voltage at 0 mils physical gap.

Specification for the transducer gap voltage for 0 mils physical gap (transducer tip resting on the actual transducer target area) follows.

The voltage at 0 mils physical gap is measured with a test instrument. This value should be between 0.70 and 1.25 Vdc. When the transducer is installed in the actual machine, at 0 mil gap, the output voltage should also be within this limit – thus ensuring perpendicularity.

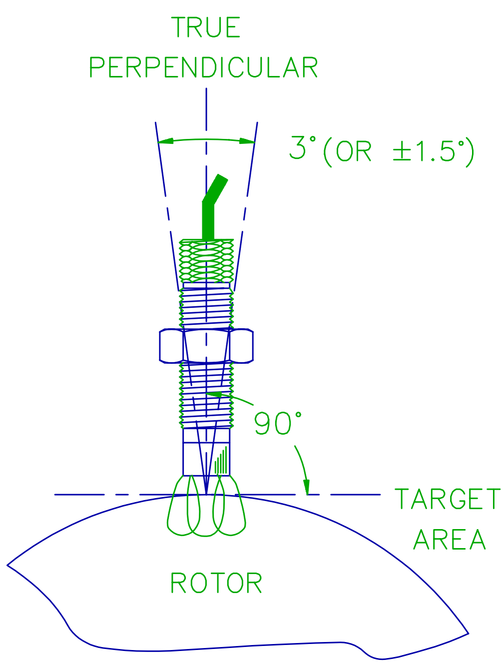


Figure A3: *Transducer Perpendicularity Specifications*

Environmental Considerations

The environment that the transducer is expected to survive in is typically a harsh environment. Temperature, humidity, corrosion, radiation & chemicals are just a few factors that affect the life and reliability of the transducer system. Limiting the exposure to these adversities will decrease the odds of a transducer failure and increase the overall reliability of the transducer system.

Transducer Installation (actual) or Gapping

The actual task of installing the proximity transducer is called setting or gapping. Two methods of gapping proximity transducers are currently being utilized. The first and most preferred method is the electrical method. The second and least preferred method is the mechanical method.

The electrical method is a more precise form of installation plus it will give indications as to wiring errors, shorts etc. The electrical method of installation is performed in conjunction with a DC Mulitmeter. The DC Mulitmeter is connected to the output of the driver. It should be noted that a transducer system linearity curve (mils moved with respect to output voltage) be run prior to installing the transducer. With power connected to the driver/proximitor and with the transducer/extension cable/proximitor connections secured, the DC voltage output of the transducer system, (measured at the proximitor) may be monitored. This voltage is in the form of a negative DC value. With the observed target area not moving or rotating the transducer is threaded (if utilizing a threaded type proximity transducer) through the mounting area/fixture (bracket, bearing, machine case etc.) until the transducer tip gently touches the face of the target area. If this procedure is not done very carefully the transducer coil will be compressed into the casing and ultimately damage the transducer. With the transducer resting flush on target area the output voltage of the transducer system should be below -1.25 Vdc. By performing this preliminary task you are reasonably assured that there are no perpendicularity concerns. At this point the transducer can be turned counterclockwise (backed out) and gapped at the desired final setting.

When installing a keyphasor transducer, observing a notch, it is important that the notch or event not be located under the probe tip. This will place the probe tip too close the target area and cause damage to the target area and transducer. When the shaft is rotating, the keyphasor tip should clear the target area to avoid transducer damage.

The mechanical method of gapping a proximity transducer is not a finite method of installation and therefore is not recommended. However, in some cases where the mechanical method is the only alternative the physical distance between the probe tip and target area should be measured with precision feeler gauges. After reviewing the linearity curve data a correlation between physical gap and proximitor output voltage can be made. This correlation will determine the physical distance (thickness of feeler gauges) at which the probe tip lies from the observed target area.

The most common "mechanically" installed proximity transducers will be Speed and keyphasor transducers observing a projection.

When mechanically gapping a keyphasor transducer that is observing a projection, the leading or trailing edge of the projection (event) should be directly under the probe tip.

Caution: Performing this operation with the machine rotating could result in damage to the rotating components and the transducer and should be avoided whenever possible.

Applications

Shaft Radial Vibration

The first consideration should be "What type of bearing will the transducers be mounted at or near?” The two most common types of radial bearings, for rotating machinery, are rolling element and fluid film bearings. The major difference in the two types of bearings have to do directly with the amount of clearance between the rotating component (shaft, rotor etc.) and the bearing. A rolling element bearing restricts rotor motion due to the absence of clearance between rolling elements & the outer race. This in effect transfers most or all of the forces of the rotor to the outer race and consequently the bearing cover. A fluid film (Babbitt) bearing allows for clearance between the rotor and the bearing contact surface. The characteristics of this type of bearing limit the amount of rotor related motion that is transmitted to the bearing and bearing pedestal cover.

The general recommendation for monitoring fluid film bearings requires a shaft relative measurement made with proximity transducers at the bearing, and bearing or bearing housing-mounted seismic transducers for monitoring rolling element; velocity or acceleration.

Transducer Selection

Transducer selection is based upon the radial bearing clearances and available target area on the shaft. Nearly all fluid film bearing applications will require and accept (have room for) our 8mm (3/8-24), 200 mv/mil transducer system. Nominal bearing clearances for fluid film sleeve, elliptical, cylindrical and tilt-pad bearings are determined by multiplying the bearing journal diameter by an OEM pre-determined value (constant). A common multiplier of (0.0015"/Inch of shaft diameter) is used in the power generation and petrochemical industry for determining nominal bearing clearances. For example, a General Electric fluid film elliptical bearing with a journal diameter of 10" would have a nominal clearance of 0.015" (15mils). Tilt-pad bearings use a value slightly tighter (smaller), like 0.00125"/Inch of shaft diameter.

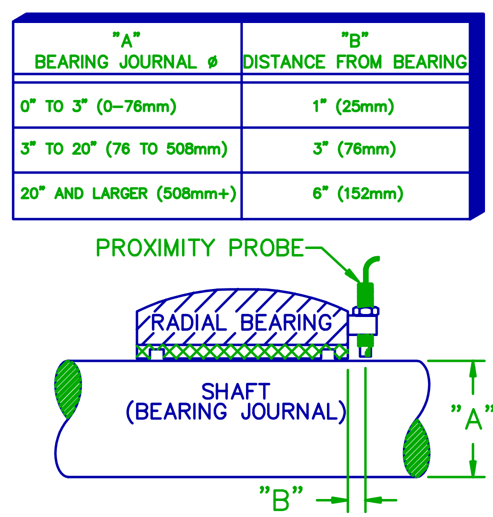


***Figure C4**: Proper Radial Vibration Transducer Mounting Distances*

The installation of xy radial vibration transducers is recommended at each radial bearing, support point, along a given machine train. Radial vibration measurements should be taken as close to the supporting bearing as possible without sacrificing the integrity of the transducers eddy current field (target viewing area). Refer to Figure C4 for the recommended maximum mounting distances away from the bearing face for Transducer Mounting Location (Internal vs. External Installation).

After the determination of bearing type and distance from the bearing a decision has to be made as to the method of transducer installation. The two choices are external or internal. The obvious connotation of the two words indicates accessible & inaccessible, respectively. On the surface this may be true; however, the reliability of the information derived from the transducer systems using these two methods of installation may vary considerably, as well as the associated cost.

The internally installed proximity transducer system offers the following:

- Reliable and accurate data for shaft dynamic motion & shaft centerline position. Rotor motion is faithfully transmitted to the transducer mounting reference, the radial bearing.
- Reduced machining scope of work and subsequent cost (modifications to the radial bearing and a cable exit hole).
- The inaccessibility issue can be overcome by installing a second (spare) set of xy transducers & extension cables back to the junction box/ housing containing the probe drivers.

The externally installed proximity transducer system offers the following:

- When installing a proximity based transducer system externally on a bearing housing/pedestal cover it is imperative that the bearing to bearing pedestal cover relationship have no physical gaps to dampen the movement of the rotor and bearing. Rotor related vibration needs to be faithfully transmitted to the outer bearing pedestal if we are to measure shaft relative motion from this location, i.e. there has to be a pinch or interference fit between the bearing and bearing pedestal cover contact surfaces.
- The externally mounted proximity transducer system, via properly designed probe housing, offers accessibility and external adjustment when the machine configuration doesn't allow for internal transducer installation. However, this installation may be lacking when it comes to the reliability of the information received in some cases/installations, replacing the transducer while the machine is running is a safety concern, and subsequently not recommended.
- Bearing housing resonances, lack of stiffness, need to be considered and identified. Additional support may be required.
- Distance from the transducer mounting surface (the outer circumference of the bearing pedestal cover) to the target area (surface of the rotor) is usually a significant distance and

subsequently a concern. If this distance is 10”-12” or greater, on a 3600RPM machine, the resultant is excessive resonance of the transducer mounting sleeve (31,000 housing sleeve)

- If the transducer system is mounted externally and the distance between the housing and the rotor is excessive then the addition of transducer/sleeve support devices are required. The cost for these appliances as well as the cost for machining the pedestal cover to accept the appliance can be enormous.
- History has shown us that the most cost effective installation is internal on the radial bearing and the most costly installation can be mounting externally. Likewise, the best information for a shaft relative vibration measurement can be achieved by mounting directly on the radial bearing.

<u>Transducer Location (Face of Bearing or “Strongback” vs. Through Bearing)</u>

We have two options when transducers are located internally, on the radial bearing. The probes could be mounted on the vertical face of the bearing (See Figure A8) or mounted through a hole in the bearing (See Figure A7).

In either of the above cases (face of or through bearing) it is highly recommended that the target area on the shaft be an integral part of the rotor. For example, targeting a collar, coupling hub, thrust runner, etc., may induce mechanical runout and glitch in the transducer signal. Typically the bearing journal, native rotor diameter, has little or negligible runout providing the best information to the machinery protection system.

<u>Transducer Location (Inboard vs. Outboard)</u>

The location of the radial vibration transducers from bearing to bearing along a given machine train is important. When choosing the side of the bearing to mount the transducers on we need to take into account the corresponding bearing & how its probes are situated.

Typically you will have two bearings supporting each shaft in a machine train. In the case of the single case steam turbine you would have an outboard (non-drive end) bearing and an inboard (drive-end) radial bearing. Between these two bearings would be the row/s of turbine blading/buckets. If we mount on the outboard side of the outboard bearing we should mount in the outboard side of the inboard bearing. Likewise if we mount on the inboard (blading) side of the outboard bearing we should mount on the inboard side (blading) of the inboard bearing.

<u>Transducer Location (Nodal Points)</u>

Locating the radial vibration transducers at a nodal point (zero motion) should be avoided. Locating the vibration transducers at these nodal points will sacrifice accurate vibration amplitudes for that given location. A nodal point is a point of minimal or no shaft deflection when compared to or measured at the supporting bearing. It is important to note that determining the exact location of a nodal point prior to a permanent transducer installation may be difficult. Nodal points may shift with load & temperature changes and with the operating life & characteristics of the machine. Optimally a second set of xy proximity transducers should be installed on the opposite side of each radial bearing (maintain angular orientation).

<u>Transducer Orientation</u>

Radial vibration measurements are optimally performed with two proximity transducers mounted radially in an xy fashion, with 90° (orthogonal) separation. A typical mounting arrangement would be internally mounted xy probes at ±45° from Top Dead Center (TDC). The following is recommended for standard transducer orientation;

- Transducer orientation is referenced as viewed from the driver end of the machine looking towards the driven, regardless of machine rotational direction.
- Horizontal Machines- Zero degrees (0°) is true vertical, top dead center (T.D.C.), 12 0'Clock.
- Vertical Machines will be referenced in a plan view (top view looking down) where zero degrees (0°) is opposite (180°) the discharge or in the geographical north direction.

From these above references to 0° (zero), transducer orientation is measured in both the clockwise (CW) and counterclockwise (CCW) directions up to, but not inclusive, of 180°. The Vertical or "Y" transducer is always measured CCW from the Horizontal or "X" transducer.

Note: Mounting angles greater than (>) 0° and less than (<) 180° CCW are designated "Left".
Mounting angles greater than (>) 0° and less than (<) 180° CW are designated "Right".

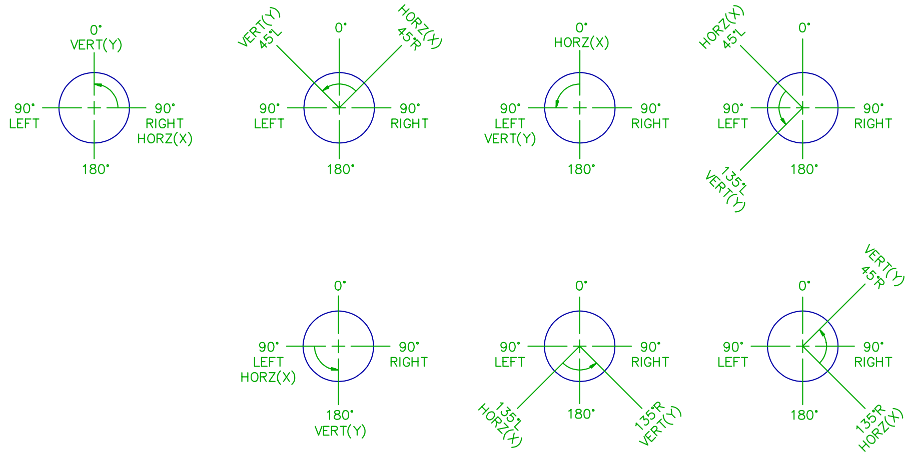


***Figure A5**: Transducer Orientation*

<u>Proximity Transducer Installation</u>

Internal proximity transducer installations require additional care to ensure the integrity and reliability of the system. Due to the inaccessibility of the transducer it is imperative that the transducer be gapped properly, taking bearing clearances and rotor rise into consideration. All jam nuts, brackets and associated hardware should be tightened to their appropriate torque specifications.

When installing internal transducers, associated mounting brackets and fasteners provisions must be made to guard against the loss of these components due to windage, thermal expansion and vibration. All fasteners used in conjunction with the installation of the transducer system need to be captivated (restricted of movement) and guarded against loss. There are a number of ways to accomplish this, the most common is the use of a medium grade removable thread locker (Ex.: Loctite® 242, blue), locknuts and lockwashers. These are minimum requirements for the prevention of loosening fasteners. The use of 0.032" diameter stainless steel locking wire in conjunction with Loctite 242 and lockwashers (where applicable) is recommended for captivating transducer jam nuts and associated fasteners.

An overlooked item of consideration is the transducer lead (probe lead) and extension cable. These two items are the link between the transducer and the driver, damaging these will sacrifice your entire transducer system for that location. Routing and securing the cable should be performed in a manner that does not interfere or sacrifice the integrity of existing machine components, rotating or stationary. Securing the cable can be done by installing a #10 nylon cable tie or similar device that restricts the cable from movement and protects against chaffing and abrasion.

The transducer lead/extension cable API connection can be "made up" inside of the machine/bearing pedestal or outside of the machine. As with the internal vs. the external transducer installation there are benefits and drawbacks to both situations. With the connection made internal to the pedestal you are unable to access the connection for troubleshooting during machine operation. However with the API connection internal to the bearing pedestal the removal of the Low Pressure cable seal assembly (discussed below) and conduit is not required. When bearing disassembly is required, just the transducer will require removal; the extension cable can remain inside of the bearing pedestal.

This decision should be made by the customer, with full understanding of the benefits and drawbacks of each method.

Along with mounting proximity transducers internal to a machine case/bearing pedestal comes the necessity to exit the transducer lead/extension cable. There are many ways to do this, but the recommended method is to exit the cable(s) through the bearing pedestal wall (machine case), below the horizontal joint of the machine, and above the residual oil level in the bearing pedestal. Exiting the cables through the upper and/or removable pedestal cover represents a safety concern as well as a problem when maintenance has to be performed on the machine. The most common form of cable seal used is the Low Pressure cable seal which accommodates environments with less than 25 PSI (1.75 BAR) differential pressure. Other offerings include High-pressure (400 PSI) and Modified High Pressure (999 PSI) Feed Throughs for specific applications involving high differential pressures between pedestal and atmosphere.

After the transducer cable has exited the bearing pedestal wall, through a LP Cable seal, a conduit housing of some nature is recommended to disperse cables and/or to make transducer lead/extension cable connections (where applicable). Use of a junction box (4 hub condulet housing) and a conduit union for the transition between the cable exit & the conduit back to the proximitor housing and ease of maintenance, respectively, is recommended.

The following diagram shows a typical xy internal proximity transducer installation on the face of a bearing with the transducer leads exiting the lower pedestal.

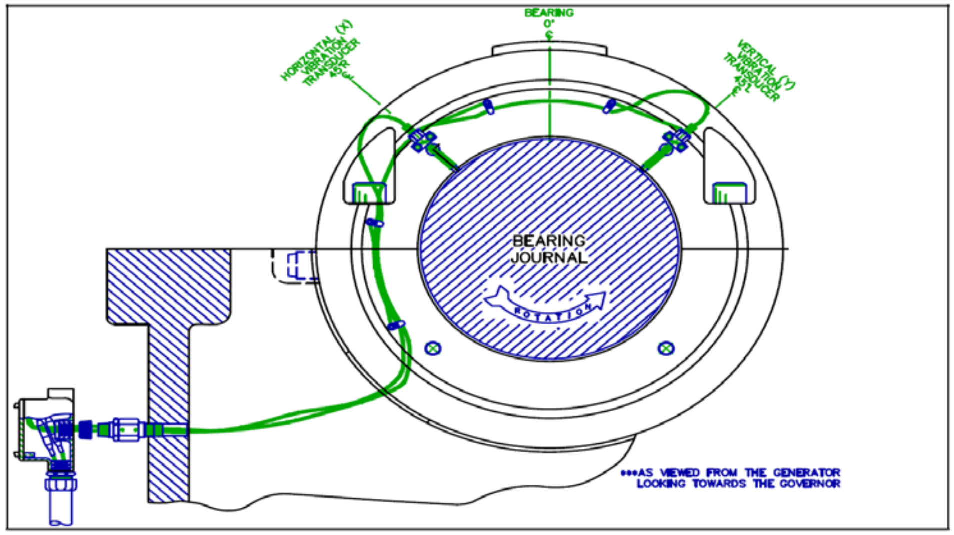


***Figure A6**:*
Typical Internal Vibration Transducer Installation on the face of the bearing.

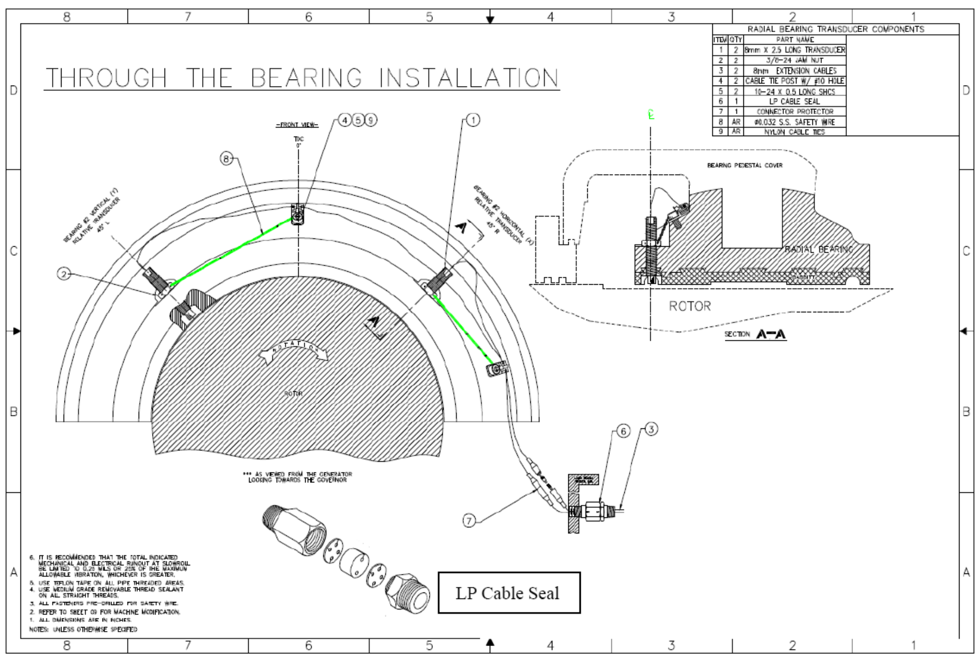


Figure A7

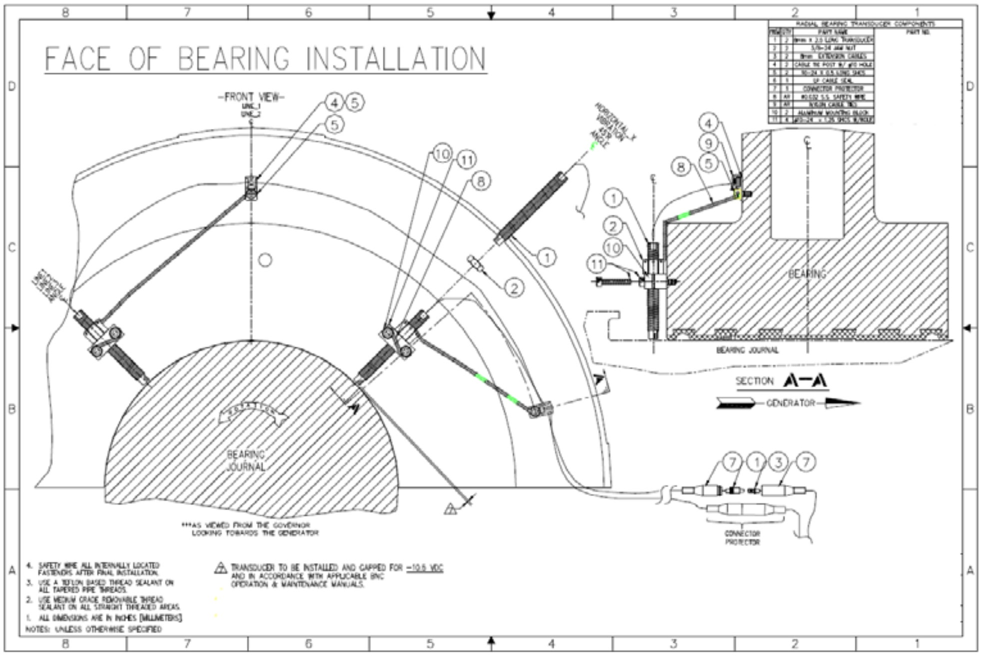


Figure A8

APPENDIX B

Accelerometer Installation

Introduction

An accelerometer is a contacting device, which measures the acceleration motion (dynamic) of a mounting surface relative to an inertial reference (fixed reference). Accelerometers typically use a piezoelectric effect resulting from shearing, compressing or extending of a quartz or ceramic crystal (piezoelectric element) between a known mass and the transducer base to generate an electrical charge proportional to acceleration along the axis of the transducer. Accelerometers come in a variety of internal configurations to measure acceleration.

Selection of the proper type and configuration of accelerometer can be a non trivial matter. Accelerometers can be separated into two categories based upon their mode of operation: internally amplified with microelectronic signal conditioning and charge mode accelerometers which contain only the sensing elements with external signal conditioning.

Typically, the former are used for most measurements while the latter is used for high temperature measurements (environmental temperatures above 350 degrees F).

General Considerations

Frequency Response

One of the most important considerations when using accelerometers is the effect of the mounting technique on the accuracy of the frequency response. Directly stud mounting the accelerometer to a very smooth surface typically yields the highest mechanical mounting resonance frequency and the broadest usable frequency response. Adhesives and magnetic mounting bases lower the mounting resonance frequency of the accelerometer and also decrease the vibration transmissibility from the machine housing to the accelerometer base. A stud mounting is essential in all applications.

Surface Preparation

At high frequencies, best measurement results are achieved by preparing a smooth, machined flat surface for the mounting of the accelerometer. The mounting surface should be free from metal burrs or other foreign particles, like dirt or grit. A thin layer of silicone grease should be applied between the base of the accelerometer and the mounting surface to achieve good high frequency transmissibility and intimate accelerometer contact with the mounting surface.

Stud Mounting

A stud mounting is recommended for all applications. Typically, the first step in preparing the mounting surface is to grind or machine a flat area at least the size of the base of the accelerometer at the mounting location as per the accelerometer manufacturer's specification. The second step is to prepare a tapped hole as per the manufacturers specification and also ensure that the tapped hole is perpendicular to the mounting surface. Accelerometers are installed with the mounting stud such that the stud does not bottom out in either the mounting surface or accelerometer base. Acceleration is transmitted through the mounting surface to the accelerometer base. Therefore, any stud bottoming or other interference between the accelerometer and the mounting surface will inhibit transmission of the acceleration and adversely affect measurement accuracy. Only the recommended torque should be applied when tightening a stud mounting. A thread locking compound or special adhesive can be used on the stud threads to prevent loosening of the accelerometer.

Some accelerometer manufacturers utilize a mounting screw to secure the accelerometer to the mounting surface. This technique can be used, but manufacturers' specifications and the above surface preparations and stud mounting requirements must be followed. In areas where these differ, the manufacturers' requirements and specifications take precedence.

Mass Loading Effects

The vibration characteristics of a machine can be altered by the addition of the mass of an accelerometer. Fortunately, MDST/BFP housing's are massive in comparison to the mass of an accelerometer, so mass loading is not a factor.

Ground Isolation, Noise and Ground Loops

When accelerometers are mounted to the metal surface of a MDST/BFP, ground loops and noise pickup can be a potential problem. Electrical noise from other equipment (motors, ancillary pumps…) that are grounded to the MDST/BFP can enter into the accelerometer signal measurement path through the base of the accelerometer. When the accelerometer is grounded at a different electrical potential than the signal conditioning circuitry, ground loops can occur. Ground loops typically result from the flow of electrical current at power line frequency due to the different grounding electrical potentials. This extraneous signal results in erroneous measurement signals, overload conditions and/or signal drift. When this occurs, the accelerometer must be electrically floated or isolated from the MDST/BFP. This can be done several ways. Some accelerometers can be provided with an integral ground isolated base. Isolating mounting studs and other insulating materials can be used to isolate the accelerometer and break the ground loop. Isolating techniques must be used carefully due to their impact on high frequency response of the accelerometer.

Accelerometer Cabling and Connectors

It is recommended that all accelerometer cabling be securely fastened to the MDST/BFP and protected by hard and or flexible conduit. Securing cabling minimizes cable whip and connector strain. Cable whip can induce noise (triboelectric effect) into the accelerometer signal, especially when high impedance cabling is used. Cable motion can also cause unwanted cable strain at either cable connector which might eventually lead to intermittent or broken connections and loss of accelerometer signals. It is also recommended that all accelerometer connectors should be sealed to protect against moisture and contamination.

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