Attachments

ANSI/HI 9.6.4-2016

American National Standard for

Rotodynamic Pumps

for Vibration Measurements and Allowable Values

Sponsor
Hydraulic Institute
www.Pumps.org

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9.6.4 Rotodynamic pumps for vibration measurements and allowable values

9.6.4.1 Introduction and scope

9.6.4.1.1 Introduction

This standard pertains to evaluation of vibration when the vibration measurements are made on stationary parts associated with bearings (bearing housings) of rotodynamic pumps. It provides specific maximum allowable vibration values measured on bearing housings of rotodynamic pumps in field and factory test environments.

Vibration measurements can be useful for many purposes, such as acceptance tests, diagnostic or analytical investigations, and operational monitoring. The principal purpose of this standard is to establish vibration measurement methodology and maximum allowable vibration values for acceptance testing of new equipment. A general description of the principles to be applied for the measurement and assessment of vibration on rotodynamic pumps is given for vibration on stationary parts associated with bearings.

This standard is based on experiences from pump users and manufacturers as well as vibration measurements by many companies. Vibration data from both factory test and field test environments have been incorporated into the maximum allowable vibration values. Values are applicable when the pump is installed per Hydraulic Institute Standards or the manufacturer's specifications.

For certain vertical pump types, the vibration transducers shall be located near the top of the motor support (refer to Figure 9.6.4.2.3.1, Measurement locations and directions). For vertical pump types, the reference to "bearing housing" refers to this location.

Since the last revision of this standard the recommended default initial field alarm and trip settings are now referenced in ANSI/HI 9.6.5 *Rotodynamic Pumps – Guideline for Condition Monitoring.* In addition, Appendix C has been revised to include vibration criteria at the top of the motor for vertical pumps.

9.6.4.1.2 Scope

This standard applies to the evaluation of vibration on rotodynamic pump applications absorbing more than 2 kilowatts (kW) (3 horsepower [hp]) and of the types as indicated in Figure 9.6.4.2.3.1. It pertains to evaluation of vibration when the vibration measurements are made on stationary parts associated with bearings (bearing housing vibration).

The general evaluation criteria are included for acceptance tests in field environments or at the manufacturer's test facility, as appropriate and as defined in the standard.

This standard applies to tests conducted within the rated speed ±10%. Tests conducted at speeds exceeding these limitations (such as variable-speed pumps or 50-cycle pumps tested with 60-cycle power for factory tests) shall be mutually agreed upon by the user and manufacturer due to the possibility of objectionable resonance effects.

This standard is applicable to solids-handling pump types. A *solids-handling pump* is defined as a pump designed to ensure maximum freedom from clogging when handling liquids containing organic solids or stringy materials.

This standard is applicable to slurry pump types. A *slurry pump* is defined as a pump suitable for pumping a mixture of abrasive solids with specific gravity greater than 1 and concentration by volume greater than 2% in a liquid carrier, usually water. For more information on slurry pump types, refer to the latest edition of ANSI/HI 12.1–12.6 *Rotodynamic Centrifugal Slurry Pumps for Nomenclature, Definitions, Applications, and Operation*. If an ASME B73.1-type pump is used as a slurry pump, the acceptable vibration levels for slurry pumps as provided herein shall be used.

The following types of pumping equipment and associated equipment are **excluded** from this standard:

- Submersible pumps (refer to ANSI/HI 11.6 *Rotodynamic Submersible Pumps for Hydraulic Performance, Hydrostatic Pressure, Mechanical, and Electrical Acceptance Tests*)
- Submersible vertical turbine pumps
- Wet pit cantilever belt-driven pumps with overhung motors
- Pumps purchased to be in compliance with API 610
- Reciprocating engine-driven pumps
- Drivers (except for guidance on vibration on vertical motor, refer to Appendix C)
- Right-angle gear drives
- Maritime applications
- Solids-handling pumps with single-vane impellers

For these pumping equipment types, refer to other industry standards, if available, or the pump manufacturer.

Torsional vibration is not dealt with in this standard.

Information for assessing shaft vibration measured on rotating shafts is **excluded** from the scope of this document. The user is referred to the ISO 10816-7 standard for information on this topic.

9.6.4.2 Bearing housing vibration measurement

9.6.4.2.1 Measurement procedure and units

For rotodynamic pumps operating at all speeds, measurement readings of overall velocity shall be measured on stationary parts associated with bearings in accordance with Section 9.6.4.2.3 and recorded in units of millimeters per second (mm/s) root mean square (RMS) or inches per second (in/s) RMS. In addition, for rotodynamic pumps operating at speeds equal to or less than 600 rpm, measurement readings of overall displacement shall be measured on stationary parts associated with bearings in accordance with Section 9.6.4.2.3 and recorded in units of micrometers (μm) peak-to-peak or mils peak-to-peak.

9.6.4.2.1.1 Speeds above 600 rpm

For speeds above 600 rpm, the sole measurement quantity to be used for measuring the vibration of stationary parts associated with bearings of rotodynamic pumps is velocity in millimeters per second RMS or inches per second RMS.

A velocity or acceleration transducer is used to measure vibration at various frequencies, and the measurements are integrated in an electronic circuit as agreed upon by the user and the pump manufacturer to determine the overall RMS vibration in the appropriate units.

Overall RMS vibration is a measure of the total RMS vibration magnitude obtained using instruments that integrate the vibration within a fixed frequency range over a fixed period of time.

Measurement of vibration filtered to discrete frequencies is not applicable for acceptance testing of pumps according to this standard. Such methodologies, including complete frequency analysis, may be useful in diagnosing vibration problems, should they occur.

9.6.4.2.1.2 Speeds of 600 rpm and below

In addition to velocity measurements, the peak-to-peak displacement vibration on bearing housing(s) shall be measured.

9.6.4.2.2 Vibration measurement instrumentation and transducers

9.6.4.2.2.1 General

For all speeds, a 6-decibel (dB) per octave filter shall be used to filter out frequencies outside the measurement range to reduce the electronic noise. This filter is typically built into dedicated vibration data collection instruments. The filter may not be present when using software processing alone.

For speeds above 600 rpm, the measurement instrumentation shall be capable of measuring the RMS vibration velocity for a minimum frequency range of 5 hertz (Hz) to 1000 Hz.

For pumps with speeds of 600 rpm and below, the measurement instrumentation shall be capable of measuring RMS vibration velocity and peak-to-peak displacement, both overall, for a minimum frequency range of 2 Hz to 1000 Hz.

The manufacturer and the purchaser should agree on the type of data collector and the data collector settings for frequency range, frequency resolution, filter settings, the number of readings to average, and any other instrument settings that may affect the measured vibration values.

9.6.4.2.2.2 Precautions

Personnel conducting vibration tests should take precautions to eliminate sources of errors in the measurements potentially caused by transducer mountings, transducer cable lengths, transducer orientation, magnetic fields, temperature variations, and sound fields.

The vibration transducers should be mounted in such a way as to not adversely affect the accuracy of the measurements. If magnetic vibration transducers are used, the surface of the measured equipment should be prepared in accordance with the transducer manufacturer's instructions at the point of contact to avoid measurement errors. Appropriate mounting methods are shown in Figure 9.6.4.2.2.2 and described in Appendix E.

The manufacturer and the purchaser should agree on the type of measurement transducer to be used. In the absence of any specific recommendation from the vibration transducer manufacturer, the following should be applied:

> For permanently mounted transducers, the machined mounting surface should be a minimum of 1.1 times the diameter of the transducer. Mounting surfaces should be flat to within 0.025 mm (0.001 in) with a surface roughness of less than 3.2 μm (125 microinches).
>
> For temporary mounting of the transducer using a magnetic mount, the surface should be flat, preferably using a machined area specifically intended for the purpose, of a diameter at least equal to the diameter of the mounting surface of the transducer. The paint should be removed at the point of contact to allow contact of the mount with bare metal for most accurate vibration readings.
>
> For temporary mounting of the transducer using a dimple, the dimple should conform to the dimensions shown in Figure 9.6.4.2.2.2. The dimple may be formed by machining or casting. The paint should be removed at the point of contact to allow contact of the mount with bare metal. Surface roughness should be less than 3.2 μm (125 microinches).

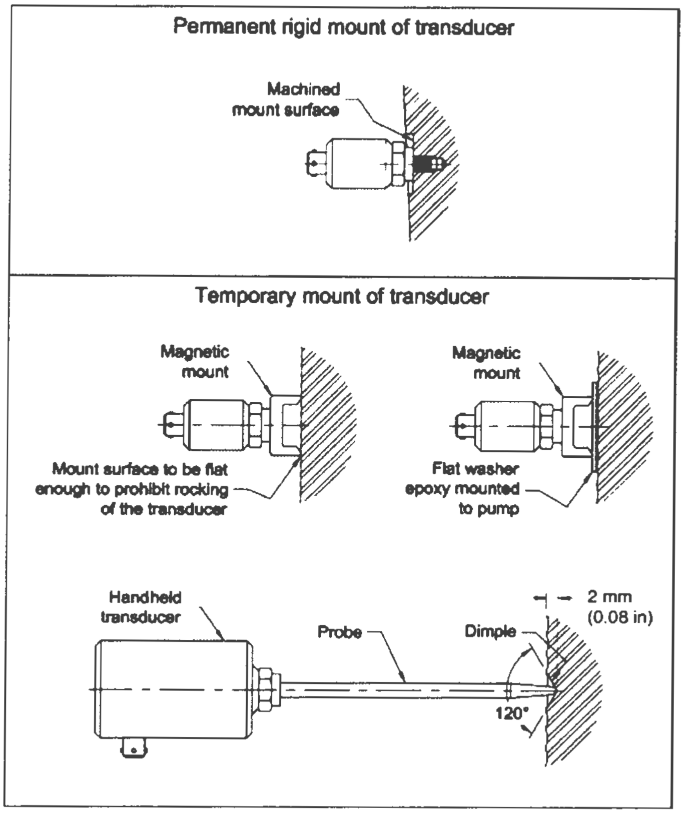


Figure 9.6.4.2.2.2 — Mounting methods for vibration transducers

9.6.4.2.3 Measurement locations and directions

9.6.4.2.3.1 Bearing housing measurements

In general, the vibration transducers should be located approximately at the center of the radial bearing location on bearing housings or the motor mounting flanges of vertical pumps, perpendicular to the plane of measurement as shown in Figure 9.6.4.2.2.2. Designated measurement locations for specific pump types within the scope of this standard are provided in Figure 9.6.4.2.3.1. Transducers must not be located on the flexible panels, nameplates, or motor end covers.

> **NOTE: This ANSI/HI standard uses a method of pump identification similar to ISO 13709/API 610. It should be noted that the limits of acceptable vibration performance are different. This standard does not apply to ISO 13709 or API 610 applications. For ISO 13709 or API 610 applications, refer to those standards (see Section 9.6.4.1.2). For a more complete description of pump types, refer to ANSI/HI 1.1-1.2 *Rotodynamic Centrifugal Pumps for Nomenclature and Definitions* and ANSI/HI 2.1-2.2 *Rotodynamic Vertical Pumps of Radial, Mixed, and Axial Flow Types for Nomenclature and Definitions*.**

9.6.4.2.4 Vibration acceptance tests

Vibration acceptance tests are performed if required by the job specifications or contract. Details such as location, instrumentation, and procedures may involve variations as mutually agreed on by the parties involved. This standard provides details that shall apply if not superseded by other specification requirements.

The maximum vibration magnitude observed at the designated measurement locations (refer to Figure 9.6.4.2.3.1) is to be used in comparison to the maximum allowable vibration values indicated in the graph for the specific pump type, applicable test location (field [in situ] or factory), and pump input power at the test point considered. Note that

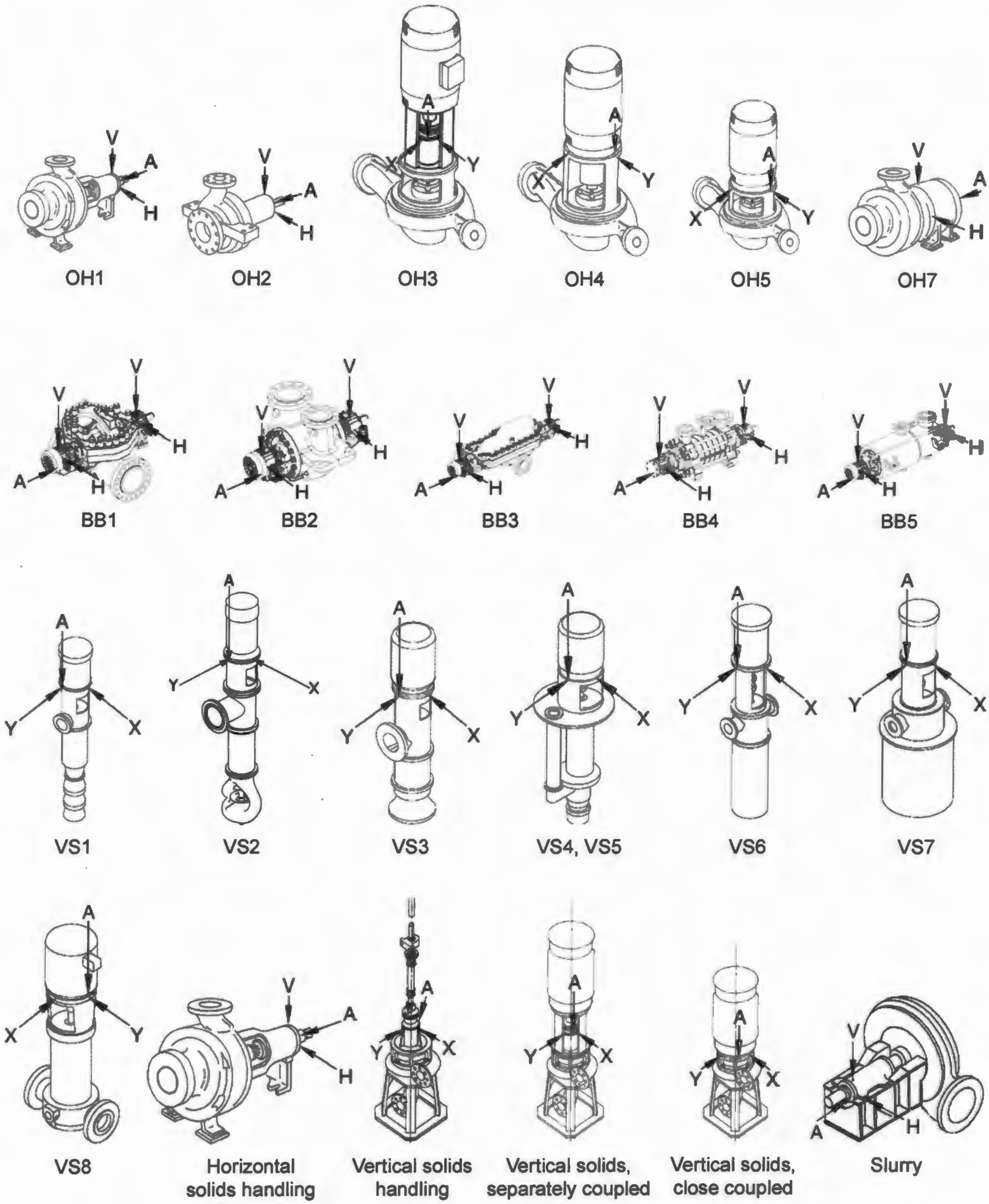


Figure 9.6.4.2.3.1 — Measurement locations and directions (For a more complete description of pump types, refer to ANSI/HI 1.1-1.2 and ANSI/HI 2.1-2.2.)

the pump input power will be affected by the specific gravity of the fluid being pumped during the test, which will in turn determine what acceptance levels are to be used. Applicable instrumentation, installation requirements, and operating requirements for the test are provided herein.

9.6.4.2.4.1 Pump location for acceptance tests

By default, vibration acceptance tests shall be conducted in the field location. Factory vibration acceptance tests are performed if required by the job specifications or contract and with mutual agreement of the parties involved. For some pump types, factory vibration tests are regularly used for acceptance.

The acceptable vibration-level graphs indicate both field and factory vibration levels for most pump types. When factory levels are not provided for certain pump types, factory test acceptance levels for those pump types shall be mutually agreed on by the parties involved.

9.6.4.2.4.2 Factory acceptance test

A factory test, if specified, is performed in the manufacturer's test facility or a facility mutually agreed on by the parties involved, using a temporary test setup that may not be equivalent to the permanent conditions in the field installation. The factory test may also possibly necessitate using a different fluid with different properties (i.e., specific gravity, viscosity) that can affect vibration and can also result in different acceptance levels because of the resulting different pump input power values. Generally, higher vibration is to be expected on temporary test setups than that realized for the same equipment on permanent foundations in the installation.

If the values at the factory test facility do not fulfill the requirements of this standard, the manufacturer shall investigate to clarify the reason for the deviation and resolve the matter as agreed by mutual consent.

9.6.4.2.4.3 Field acceptance test

The field acceptance test conditions apply to pumps that are installed on-site according to the latest standards of the Hydraulic Institute and the manufacturer's instructions.

9.6.4.2.4.4 Acceptance test installation and operating conditions

The following general conditions apply to the use of this standard (factory tests and field tests):

- Pump impellers shall be balanced (typically a single-plane spin balance) in accordance to ISO 1940 balance quality grade G6.3 (see Figures B.1 and B.2). For balance of slurry pump types, refer to the latest edition of ANSI/HI 12.1–12.6. When the ratio of the largest outside diameter of the component divided by the impeller width at the outside of the shroud(s) is less than 6 (see Figures B.3 and B.4), a two-plane balance may be required (refer to ISO 1940). Other grades may be used as agreed on by the user and manufacturer. Note: In the specific case of impellers, the width is measured at the periphery, including the thickness of any shrouds, but not the back vane.

- Pumps should be supported on the test setup and on the permanent foundation in the installation in a manner to avoid resonances of structural natural frequencies during operation. See ANSI/HI 9.6.8 *Rotodynamic Pumps – Guideline for Dynamics of Pumping Machinery* for more information on this topic.

- Operation shall be under steady state conditions at the rated speed ±10% (applies to field tests). This requirement may not always be practicably achievable for factory tests (i.e., 50-cycle pumps tested with 60-cycle power), therefore the operating speed for factory tests shall be mutually agreed on by the user and manufacturer.

- The coupling alignment shall be in accordance with the pump manufacturer's recommendations.

- The bearing housing vibration level recorded shall be the maximum of measurements taken in each plane as indicated by the illustrations in Figure 9.6.4.2.3.1.
- To the fullest extent practicable, no other equipment should be operated during the test in the vicinity of the pump being tested; otherwise, the effects of the other equipment on the vibration test should be considered.

The following conditions apply to the use of this standard with regard to field tests:

- Field measurements on pump bearing housings with antifriction or fluid film bearings shall be performed when the bearing housings have reached their normal steady state operating temperatures.

  NOTES:
  This requirement does not apply to sleeve bearings used on vertically suspended pumps, because such bearings are normally inaccessible for temperature monitoring.

  Additionally (unless otherwise agreed) this requirement does not apply during factory testing because the time for bearing temperature stabilization may be excessive.

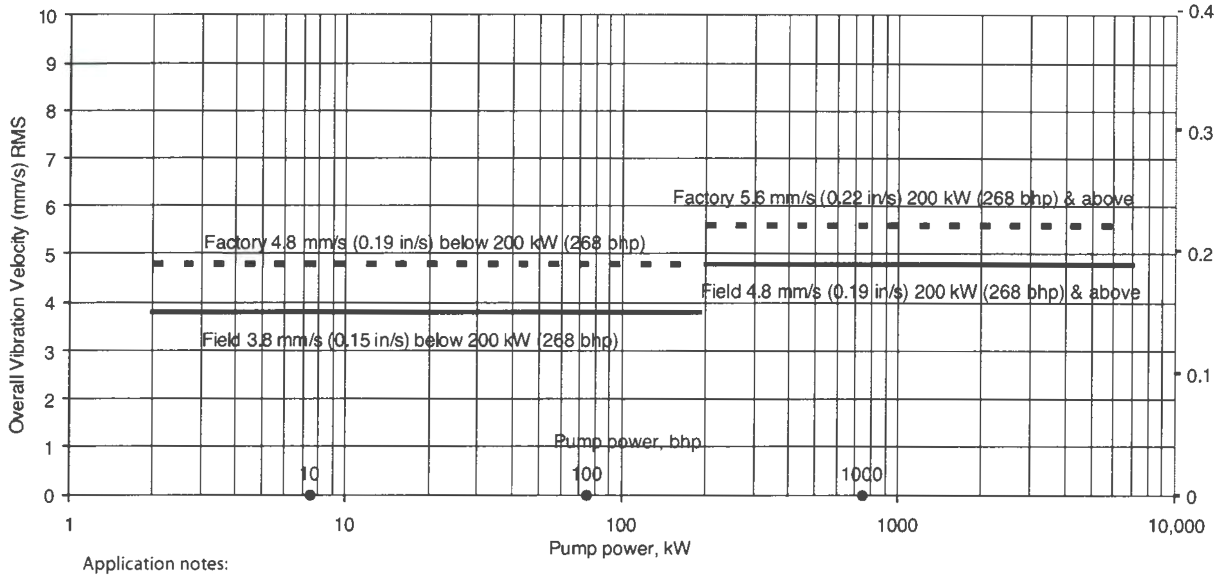
- The field-tested pump shall be operated at the specified or rated operating conditions (rate of flow, head, and speed). Acceptable vibration levels for specified operating conditions within the preferred operating region (POR) are provided in graphs herein. Values to use for specifed operating conditions outside the POR but within the allowable operating region (AOR) are indicated on the graphs for the specific pump type. For more information on operation within the pump POR and AOR, refer to the latest edition of ANSI/HI 9.6.3 *Rotodynamic (Centrifugal and Vertical) Pumps - Guideline for Allowable Operating Region*.
- Pump shall be installed so that nozzle loads do not exceed the loads within ANSI/HI 9.6.2 *Rotodynamic Pumps for Assessment of Applied Nozzle Loads* (if applicable) or the manufacturer's recommendations. When there is a difference between the values of ANSI/HI 9.6.2 and the manufacturer, the values of the manufacturer shall be used unless otherwise agreed on by the parties involved (applies to field acceptance tests).
- Prior to a field test it shall be established that the vibration measured with the pump not running does not exceed 25% of the vibration level established for acceptable operation. In any situation where this limit is exceeded, all necessary steps shall be taken to find and eliminate the source of this vibration, otherwise limits for acceptable vibration must be mutually agreed on by the manufacturer and the user.
- The field test conditions shall represent actual in-service operation as closely as practicable. Site conditions such as temporary flow loops, enhanced inlet pressure, special test setups for hardware, and other abnormal operating configurations may have a significant effect on vibration and are to be avoided or otherwise agreed on by the manufacturer and the user.
- There shall be no suction-related adverse hydraulic phenomena (submerged vortices, free-surface vortices, preswirl, nonuniform velocity distributions at the impeller eye, entrained gas, cavitation, or flow field variations with time) present to an extent significant enough to adversely influence the vibration measurements. For best practice, refer to the latest edition of ANSI/HI 9.8 *Rotodynamic Pumps for Pump Intake Design* or ANSI/HI 9.6.6 *Rotodynamic Pumps for Pump Piping*, as applicable.

9.6.4.2.5 Allowable pump bearing housing vibration

For all speeds, use Section 9.6.4.2.5.1. For speeds 600 rpm and below, use Sections 9.6.4.2.5.1 and 9.6.4.2.5.2.

9.6.4.2.5.1 Allowable pump bearing housing vibration

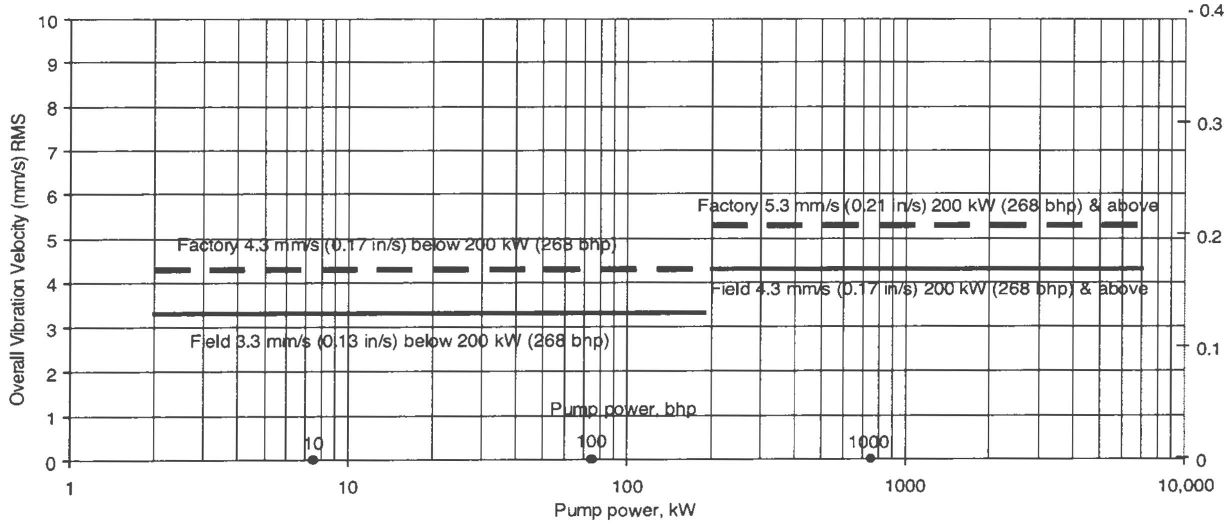
The vibration values shown in the following graphs are for RMS velocity readings. When using the figures, the abscissa refers to the power the pump is drawing at the time the vibration measurement is made.



Application notes:

1) The factory criteria are applicable for new pumps with either a factory or new motor. The field criteria are intended for use when both the pump and motor are in new condition.
2) For operation outside the POR but within the allowable operating region (AOR), increase the values shown by 30%.
3) Pump types refer to Figure 9.6.4.2.3.1.

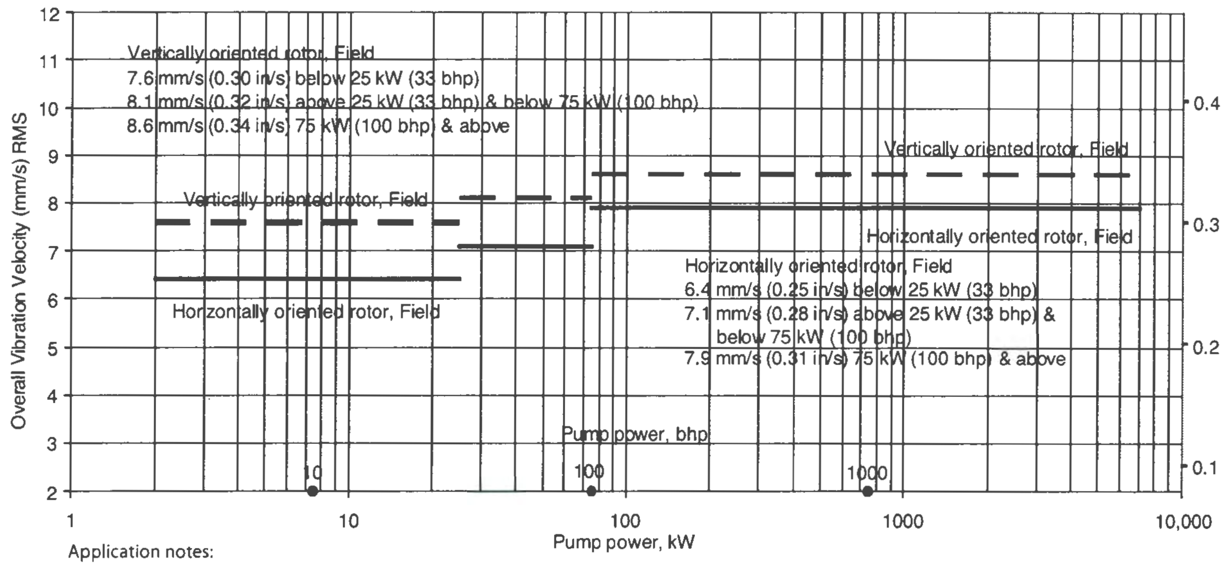
Figure 9.6.4.2.5.1a — Allowable pump vibration, pump types BB and OH (For a more complete description of pump types, refer to ANSI/HI 1.1-1.2 and ANSI/HI 2.1-2.2.)



Application notes:

1) The factory criteria are applicable for new pumps with either a factory or new motor. The field criteria are intended for use when both the pump and motor are in new condition.
2) For operation outside the POR but within the allowable operating region (AOR), increase the values shown by 30%.
3) For solids-handling versions of VS pump types, increase the values for AOR and POR, respectively, by 50% (tested free of clogging conditions).
4) Pump types refer to Figure 9.6.4.2.3.1.
5) Allowable pump values are based on historic data and, as more test data become available, limits will be subject to change.

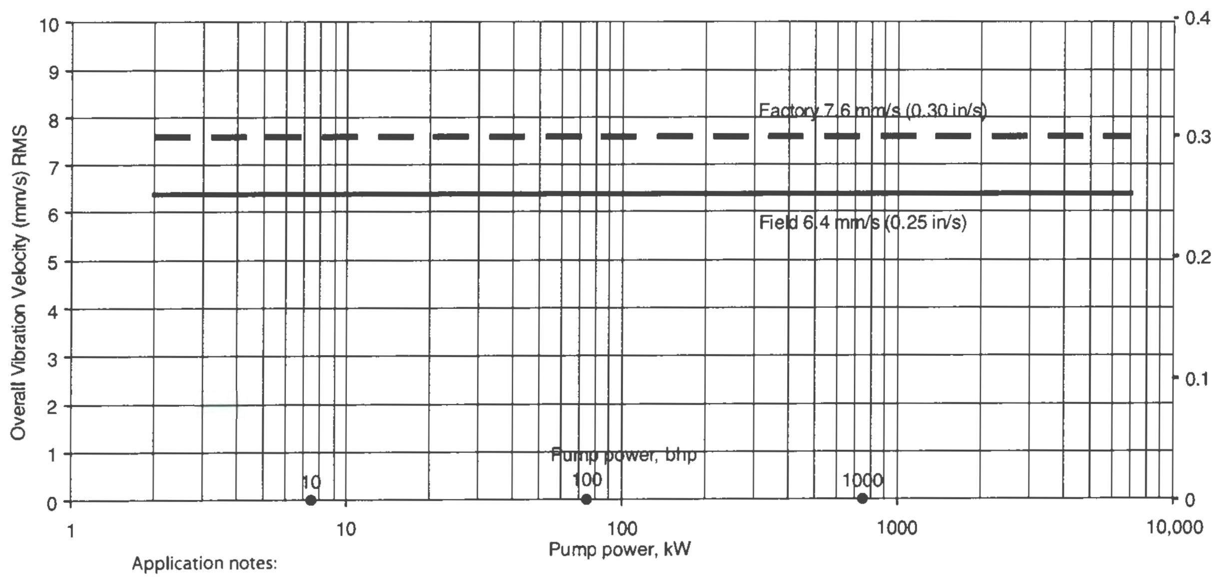
Figure 9.6.4.2.5.1b — Allowable pump vibration, pump types VS1, VS2, VS3, VS4, VS5, VS6, VS7, and VS8 (For a more complete description of pump types, refer to ANSI/HI 1.1-1.2 and ANSI/HI 2.1-2.2.)



Application notes:

1) Field tests (factory tests not applicable), new pumps, operation in the preferred operating region (POR) tested free of clogging conditions. (Maximum, any plane. For measurement locations indicated in Figure 9.6.4.2.3.1.)
2) For operation outside the POR but within the allowable operating region (AOR), increase the values shown by 30%.
3) Pump types refer to Figure 9.6.4.2.3.1.
4) Solids-handling pumps with single-vane impellers are excluded from this standard. The user and the manufacturer should agree on some increased allowable pump vibration criteria for these excluded pumps.

Figure 9.6.4.2.5.1c — Allowable pump vibration, solids-handling pump types



Application notes:

1) The factory criteria are applicable for new pumps with either a factory or new motor. The field criteria are intended for use when both the pump and motor are in new condition.
2) For operation outside the POR but within the allowable operating region (AOR), increase the values shown by 30%.
3) Pump types refer to Figure 9.6.4.2.3.1.

Figure 9.6.4.2.5.1d — Allowable pump vibration, horizontal and vertical slurry pump types (excluding wet pit cantilever belt-driven pumps with overhung motors)

9.6.4.2.5.2 Allowable pump bearing housing vibration for speeds of 600 rpm and below

For speeds of 600 rpm and below, both the allowable velocity vibration criteria shown in Figures 9.6.4.2.5.1a-d and the allowable displacement vibration criteria selected from Table 9.6.4.2.5.2a and adjusted by Table 9.6.4.2.5.2b shall be met.

Table 9.6.4.2.5.2a — Additional acceptance criteria for pumps operating at 600 rpm and below[1]

Operating Conditions & Application Data	Field peak-to-peak at running speed	Factory peak-to-peak at running speed
Operation within the POR	80 μm (3.0 mils)	100 μm (4.0 mils)
Operation within the AOR	100 μm (4.0 mils)	125 μm (5.0 mils)

[1] Adjust these values using the applicable additive values in Table 9.6.4.2.5.2b.

Table 9.6.4.2.5.2b — Additive values to Table 9.6.4.2.5.2a

Application Data	Field or Factory peak-to-peak at running speed
An additive value will only be applied when the measurement location per Figure 9.6.4.2.3.1 is greater than 1.5 m (5 ft) above the foundation. In this case, the additive value is determined per meter of height that exceeds 1.5 m (5 ft) above the foundation. Example: Measurement location = 2 m above the foundation Additive value = 50 μm (2.0 mils)/m exceeding 1.5 m above foundation Additive value = 2.0 (mils/m) × 0.5 (m) = 1 mil	50 μm (2.0 mils)
Additive value for slurry pumps	100 μm (4.0 mils)
Additive value for solids-handling pumps	50 μm (2.0 mils)

Appendix A

Test report (informative)

This appendix is not part of the standard, and is presented for informative purposes only.

A suggested test report form is provided on the following page.

Vibration Test Report

Subject Pump	
Manufacturer	
Pump Type Designation (Ref. Fig. 9.6.4.2.3.1)	
Model	
Size & Type	
Serial Number	
No. of Stages	
Driver Size & Description	
Speed (Rated)	
Rate of Flow (Rated)	
Total Head (Rated)	
Power (Rated)	
Pumped Liquid	
Specific Gravity	
Viscosity	
Temperature	

Test Conditions	
Test Location	
Test Speed	
Rate of Flow	
Discharge Head	
Suction Head	
Pumped Liquid	
Liquid Specific Gravity	
Viscosity	
Liquid Temperature	
Inboard Bearing Housing Temperature	
Outboard Bearing Housing Temperature	
Ambient Temperature	
Power	

Instrumentation			
Description	Model	Serial	Date Calibrated

Data					
Pump Shaft Orientation	Measurement Location Description (Ref. Figure 9.6.4.2.3.1)	Direction (Ref. Figure 9.6.4.2.3.1)	Measured Values (Units =___)	Maximum Allowable (Units =___)	Pass/Fail
Vertical		X			
		Y			
		A			
Horizontal		H			
		V			
		A			
		H			
		V			

Tested By: ______________________________ Date: ______________________

Reported By: ____________________________ Date: ______________________

indicator mounted to a convenient stationary surface on the discharge head/driver stand and slowly rotate the pump's shaft. If the runout is within acceptable tolerances, check the tightness of the driver hold-down bolts. If dowels are used to secure the driver location, then it should be noted that redoweling is required after disassembly/reassembly, since tolerance buildup in the multiple vertical joints results in alignment variation.

A.4.8.1.2 Vertical hollow shaft drivers

Remove the clutch or coupling from the top of the hollow shaft, and mount the driver on top of the discharge head/driver stand. For designs requiring the pump head shaft to be installed prior to mounting the driver, lower the hollow shaft driver with care over the head shaft to be sure the latter is not damaged. Check the driver for correct rotation, as given in the manufacturer's installation instructions. Install the head shaft, if not already done, and check it for centering in the hollow shaft. If off-center, check for runout in head shaft, misalignment from discharge head to driver, or out-of-plumbness of the suspended pump. Shims can be placed under the discharge head to center the head shaft, but shims should not be placed between the motor and the discharge head unless recommended by the manufacturer.

The head shaft should be centered within the motor hollow shaft by using a close-fitting steady bushing. This bushing is pressed into or is fastened to the hollow shaft and rotates with the hollow shaft and head shaft. Steady bushings should be installed by the motor manufacturer.

For motors with lower oil-lubricated bearings, the motor manufacturer should install the steady bushing. This is because the steady bushing will usually be located well up inside of the hollow shaft above the stationary oil sleeve. On the grease-lubricated lower motor bearing designs, the steady bushing is usually located at the bottom of the hollow shaft, which is more accessible.

Install the driver coupling or clutch, and check the anti-reverse rotation device for operability, if furnished. Install the coupling gib key and the adjusting nut, and raise the shaft assembly with the impeller(s) to the correct running position in accordance with the manufacturer's instructions. Secure the adjusting nut to the clutch, and double-check the driver hold-down bolts for tightness.

Most hollow shaft drivers have register fits. Further centering of these drivers is, therefore, normally not required, nor are dowels recommended.

A.4.8.1.3 Special driver considerations for submersible units (type VS0)

While it is important to comply with the manufacturer's installation instructions for all equipment, this is imperative for submersible pumps in order to avoid start-up failure, since the unit cannot be observed at this stage. Submersible motors vary greatly in basic construction, so only a few general guidelines can be provided.

For storage prior to installation, the manufacturer will specify whether the motor should be kept in a horizontal or vertical position.

For motors filled with either oil or other special fluid, check for leakage at the shaft seal prior to installation. Check the fluid level in the motor and refill with the manufacturer's recommended fluid per the instructions, if required.

If the power cable is to be connected to the motor terminal box in the field, make sure the connection is dry and the gaskets undamaged before bolting up the joint.

Keep the reel with the power cable close to the wellhead so that the cable insulation does not become damaged by being dragged over the ground or over the well casing flange when the unit is lowered into the well. Similarly, clamps for securing the cable to the discharge pipe should not have sharp edges and should be properly spaced to keep the cable closely attached to the discharge pipe. Small VS0 pumps suspended from plastic pipe should have slight slack in the cable between clamps to prevent stressing of the cable and any spliced connections as the pipe elongates under pressure. Additionally smaller VS0 pumps suspended from plastic pipe require a torque arrestor head resulting from surging. Therefore, knowledge of the surging characteristics of the pipeline is essential for determining the runaway speed. This is particularly important in case of long lines.

A.5 Commissioning, start-up, operation, and shut-down

A.5.1 Lubrication

CAUTION: Proper lubrication is critical to trouble-free, long-term operation of the equipment! Lubrication methods and frequency vary with bearing type, application, equipment, environment, and the unique operating characteristics of the individual equipment.

(Manufacturer will include information in this section regarding lubrication requirements.)

A.5.2 Rotation

Anti-reverse rotation devices are furnished as an integral part of the motor or right-angle gear when reverse rotation from backflow in the pump may cause damage. While the motor or gear is still disconnected from the pump, rotate the motor or gear by hand in both directions to check proper functioning of the ratchet. The rotation of the complete drive train should also be checked at this time.

Before starting the pump, check the direction of rotation. The proper direction is usually indicated by a direction arrow on the discharge head or on the driver stand when the discharge is located below the mounting level. When electric motors are used as drivers, the rotation should be checked with the motor uncoupled from the pump.

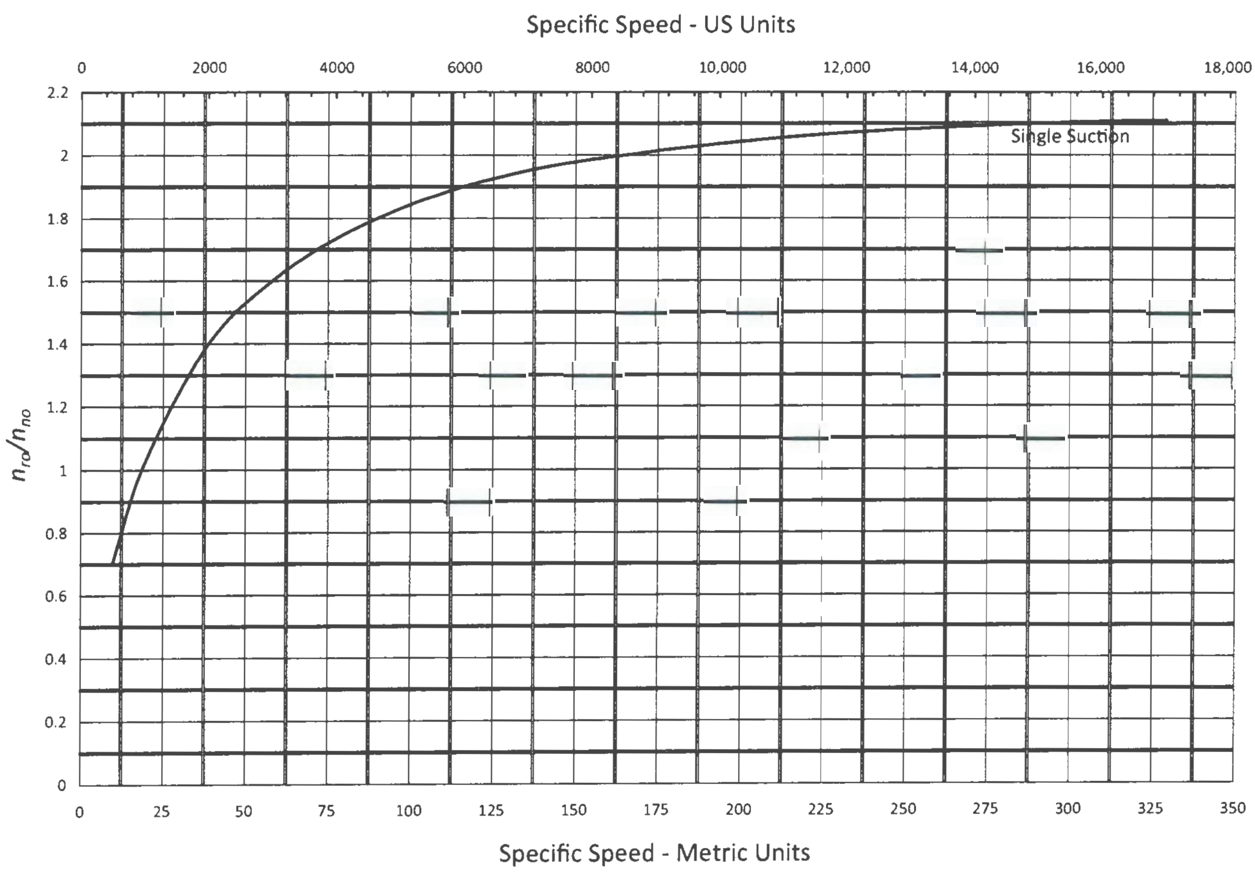


Figure A.6 — Reverse runaway speed ratio versus specific speed (metric and US customary units)

The rotation of submersible units can normally be checked by comparing the pump output against the guaranteed performance curve. Check the manufacturer's start-up instructions.

A.5.3 Guarding

All guards must be in place and secure per the manufacturer's instructions prior to start-up.

A.5.4 Start-up considerations

A.5.4.1 System flushing

When the pump is installed in the completed piping system, it is recommended that the system be back-flushed to remove debris such as stubs of welding rod, welding slag, and loose scale. The pump and other sensitive equipment should be protected with start-up strainers, which should in turn be removed on completion of the flushing cycle. For can pumps, it is recommended to remove the pump and let the barrel become the receptacle for the debris for subsequent cleanout.

Before starting the pump, adequate submergence should be provided for lineshaft pumps and submersible pumps, and the barrel and suction line should be filled with liquid for can pumps. Minimum required submergence to prevent vortices is specified by the manufacturer. See also ANSI/HI 2.1-2.2 *Rotodynamic Vertical Pumps of Radial, Mixed, and Axial Flow Types for Nomenclature and Definitions*, ANSI/HI 9.8 *Rotodynamic Pumps for Pump Intake Design*, and ANSI/HI 2.3 *Rotodynamic Vertical Pumps of Radial, Mixed, and Axial Flow Types for Design and Application*.

The pump should not be run unless it is completely filled with liquid or is provided with the minimum required submergence, as there is danger of damaging some of the pump components. Typically, bowl and impeller rings and internal sleeve bearings depend on liquid for their lubrication and may seize if the pump is run dry.

For pumps mounted in a suction barrel or can, typically for critical NPSH applications, a continuous vent line should be provided from the highest point in the barrel to the vapor phase of the suction source. This prevents inadvertent vapor locking and dry-running of the pump. The vent line should be continuously rising to preclude liquid traps, and be fully airtight.

When the required submergence is provided, all submersible units, and most vertical turbine pumps, can be started without concern for the nonsubmerged part of the pump. However, for vertical lineshaft pumps, this depends on the column length and bearing construction, such as metallic and nonmetallic material.

Most vertical pumps have the first stage below the liquid level. Therefore, they are automatically primed by proper venting. When required, as for barrel pumps, priming may be accomplished by ejector/exhauster or vacuum pump.

For VS8-style pumps, a vent valve is usually installed in the motor bracket and can be used for positive suction applications. A fill port or connection for a priming device is also provided. Starting a VS8-style pump not properly primed can cause serious mechanical seal damage.

A.5.4.2 Priming by ejector or exhauster

When steam, high-pressure water, or compressed air is available, the pump may be primed by attaching an air ejector to the highest point on the discharge nozzle or discharge pipe, close to the discharge valve. This will remove the air from the pump, suction piping, and can for barrel-mounted pumps, provided the discharge valve forms a tight seal. Prime is obtained when a steady stream of fluid flows from the ejector or discharge vent connection. The pump can then be started. A foot valve is unnecessary when this kind of device is used. Note that when the pump discharge nozzle is located above the suction source, and a foot valve is not used, the discharge valve should not be opened until the driver has been started, since this may result in loss of prime.

A.5.4.3 Priming by vacuum pumps

When neither of the above methods are practical, the pump may be primed by the use of a vacuum pump to exhaust the air from the pump, suction can, and piping, if applicable. A wet vacuum pump is preferable, as it will not be damaged if water enters. When a dry vacuum pump is used, the arrangement should preclude liquid from being drawn into the air pump. The manufacturer's instructions should be followed.

A.5.4.4 Shaft sealing settings and adjustments (mechanical seals, packing, etc.)

A.5.4.4.1 Packed stuffing box (types VS1, VS2, VS3, VS6, and VS7)

The stuffing box may or may not be filled with packing before shipment. If the stuffing box is not packed, it should be carefully cleaned and packed once the motor is mounted and connected to the head. Instructions may be found with the box of packing. If not, the following may be used as a guide.

The stuffing box should be carefully cleaned. Make sure the packing rings are of proper cross section and length. When installed, the rings should butt tightly but not overlap at the joints. The joints should be staggered 90° apart.

Packing rings should be tamped down individually, but not too tightly, as this may result in burning the packing and scoring of the shaft sleeve. Where compatible, lightly lubricate the packing inside diameter (ID) and outside diameter (OD) with a suitable lubricant. When a lantern ring is required, be sure that sufficient packing is placed in below the lantern ring so that the liquid for sealing is brought in at the lantern ring and not at the packing.

The pipe supplying the sealing liquid should be fitted tightly so that no air enters. This is particularly important for vertical barrel pumps mounted in a system where a vacuum must be maintained (see Figure A.7). If the liquid to be pumped is dirty or gritty, clean sealing liquid should be piped to the stuffing box to prevent damage to the packing and shaft sleeves. Clear sealing liquid is also required if the stuffing-box materials are not completely compatible with the pumpage. Sealing liquid should be at a pressure sufficient to ensure flow of clean liquid into the pump, but not so high as to require excessive tightening of the packing.

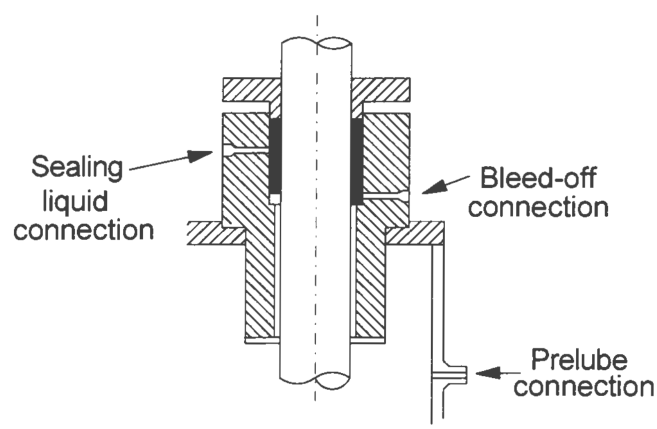


Figure A.7 — Packed-type stuffing box

When a pump is first put into operation, the packing should be left quite loose. After the pump has been found to operate properly, the stuffing-box gland may be tightened very slowly if the leakage is excessive. A leakage of about 8 to 10 drops per minute per 25 mm (1 in) of shaft diameter from the stuffing box is necessary to provide lubrication and cooling. When the leakage can no longer be controlled by adjusting the gland, all rings of packing should be replaced. The addition of a single ring to restore gland adjustment is not recommended.

If the pump is to be left idle for a long period, it is recommended that the packing be replaced prior to starting up the pump.

A.5.4.4.2 Mechanical seals

Mechanical seals for vertical pumps are of two basic types, depending on whether mounting is to be external or internal. Externally mounted seals are easily adjusted for correct positioning after the impeller(s) is set for correct running clearance. Mechanical seals mounted internally in the stuffing box, unless of the cartridge type, must be mounted on a shaft sleeve and the sleeve correctly positioned and locked to the shaft after the impeller(s) is lifted for proper running clearance. For vertical pumps equipped with a mechanical seal and a vertical hollow shaft (VHS) motor, it is recommended that a steady bushing be installed in the motor.

There are two features that can simplify change-out of worn seals. The first is the use of a spacer coupling in the head shaft of the pump. This allows removal of the seal/sleeve assembly without removing the driver. The second is use of an axially split mechanical seal. Change-out of this design does not require any disassembly of the pump.

Because mechanical seals are made in a wide variety of designs, the instructions for the specific seal must be carefully studied and followed. A mechanical seal is a precision device and must be treated accordingly. Mechanical seals normally require no adjustment during operation. Except for possible slight initial leakage, the seal should operate with negligible leakage.

CAUTION: Mechanical seals should not be run dry. Seals require a continuous supply of flush and/or cooling fluid.

If seal damage due to system uncleanliness is expected, it may be advisable to operate the pump with packing or temporary seals and sleeves until the system is clean and start-up problems are resolved. Packing or temporary seals are normally used on systems where the start-up pumpage is different from the final process pumpage, and are replaced once the process pumpage is introduced.

All VS8-style pumps are equipped with mechanical seals. Mechanical seals on vertical multistage pumps (VS8) are typically factory installed. Some configurations will require alignment and are clearly marked.

A.5.5 Start-up, operation, and shut-down

A.5.5.1 Minimum continuous flow

See ANSI/HI 9.6.3 *Centrifugal and Vertical Pumps for Allowable Operating Region*.

A.5.5.2 Minimum thermal flow

See ANSI/HI 9.6.3.

A.5.5.3 Lubrication system settings

A.5.5.3.1 Primary and secondary drivers

Before running the driver, either separately or connected to the pump, check lubrication requirements in the manufacturer's instruction manual. Inspect and make sure that:

- Grease-lubricated bearings have been properly greased with the manufacturer's recommended grade
- Oil-lubricated bearings on drivers and gears, as well as oil sumps on gears, have been filled to the required level with the recommended oil
- All automatic oilers are functioning properly

A.5.5.3.2 Pumps

Vertical pumps are either furnished with product-lubricated, oil-lubricated, or grease-lubricated sleeve bearings. The following provisions should be made for the respective bearings:

a) For product-lubricated bearings (bearings lubricated by the pumped liquid), prelubrication with clean liquid should be provided for all pump bearings above static liquid level when the distance from the mounting floor to the minimum liquid level exceeds 15 m (50 ft), or as recommended by the manufacturer. The manufacturer may permit a greater distance without prelubrication for bearings made of self-lubricating materials.

b) For pumps with oil-lubricated bearings, it is recommended to pour one or more quarts of oil, depending on pump setting, down the shaft enclosing tube prior to start-up. Next, make sure that the oil reservoir is filled and, if a solenoid valve is supplied, that it is functioning properly with the correct amount of oil being gravity-fed into the shaft enclosing tube.

c) For pumps with grease-lubricated bearings, make sure the correct grade of grease is available. For manual grease injection, make sure the grease nipples are properly connected, clean, and accessible. Inject per the manufacturer's instructions.

For motorized grease injection, make sure the grease lines are all securely fastened to the reservoir. Fill the reservoir with grease, energize the grease pump, and check the functioning per the manufacturer's instructions. Proceed in accordance with the pump manufacturer's instruction manual.

A.5.5.3.3 Type of lube filtration

When required to inject water, either for flushing or lubrication of pump components, clean filtered water should be provided. If such quality water is not available at the site, then process water may be filtered, using either a cyclone separator, a mechanical filter, or a tank with a filter bed. When liquids other than water are handled, such liquids can similarly be filtered and used for injection. The pressure drop across the filter should be monitored to ensure that the required injection pressure is available, and filter maintenance should be performed when required. Additional bearing protection can be provided by installing a flow switch in the injection line, set for the minimum flow requirement.

A.5.5.4 Drive system settings

(Manufacturer will include information in this section regarding drive system settings.)

A.5.5.5 Valve settings and operation (timing)

A.5.5.5.1 Across-the-line start

When squirrel cage induction motors having line starting controls are used, it is permissible to have the discharge valve open when the pump is being started. However, the length of time of the high starting current may be shortened if the discharge valve remains closed until the pump comes up to full speed.

A.5.5.5.2 Reduced voltage start

Except for pumps with specific speeds above 100 (5000), pumps using squirrel cage induction motors with reduced voltage starting control should always be started with the discharge valve closed or partially opened.

A.5.5.5.3 Warning against closed valve operation

⚠ CAUTION

The pump should not be operated with the discharge valve closed. The fluid in the pump may boil, with risk of explosion and steam burns to anyone near. If there is any danger of the pump running against a closed discharge valve, install a pressure-relief or bypass valve in the discharge pipe to allow the specified minimum flow through the pump. Minimum liquid flow through the pump is needed for cooling and lubrication of the pump. Run the bypass/relief valve and discharge pipe to a floor drain or a tank for collection.

Brief shut-off operation of most vertical pumps may be necessary. The necessity may arise from system start-up or shut-down requirements and is normally met by closure of the discharge valve for the minimum possible time. Prolonged operation of the pump under this condition may prove harmful to the structural integrity of the pump because of:

- Increased vibration levels affecting the stuffing boxes, mechanical seals, and areas with close running fits
- Increased axial thrust and resultant stresses in the shafts and bearings
- Heat buildup resulting in a dangerous temperature rise of the liquid being handled and pump components in contact with it
- Damage resulting from internal recirculation and flow separation

When a pump has been started against a closed discharge valve, it should be opened slowly as soon as pressure develops at the pump side of the valve. Abrupt valve opening can result in surges damaging to the pump and piping.

Pumps with specific speed over 100 (5000) often have high zero flow horsepower. Running such a pump with the discharge valve closed can result in serious mechanical overloads as well as motor overload.

Operation of a pump with the suction valve closed may cause serious damage and should not be attempted. Operation with both valves closed for even brief periods of time is an unacceptable and dangerous practice. It can rapidly lead to a violent pump failure.

A.5.5.5.4 Water (hydraulic) hammer

Water hammer is an increase in pressure due to rapid changes in the velocity of a liquid flowing through a pipeline. Water hammer may be controlled by regulating valve closure time, using relief valves or surge chambers, and certain other means. See ANSI/HI 2.3.

It is recommended that specialized engineering services be engaged for water hammer analysis.

A.5.5.5.5 Parallel and series operation

Pumps should not be operated in series or in parallel unless specifically designed for this purpose, since serious equipment damage may occur.

For parallel operation, the pumps should have approximately matching shut-off heads. Otherwise, the system operating head may exceed the shut-off head of one or more pumps, resulting in the pump(s) operating with zero output flow. This would have the same effect as operating against a closed discharge valve. Mismatched shut-off heads could also cause one pump to operate below the allowable operating region.

For series operation, the pumps should have approximately the same rate-of-flow characteristics. Because each pump takes suction from the preceding pumps, the stuffing boxes and all pressure-containing components should be designed for the corresponding pressure, and the thrust bearing requirements may also change. The discharge pressure of the first pump must be sufficient to provide adequate net positive suction head available (NPSHA) to the suction of the second pump.

A.5.5.5.6 Valve setting at start-up

A.5.5.5.6.1 Position of discharge valve on starting, high or medium head pumps

Normally, pumps with specific speed below 100 (5000), when primed and operated at full speed with the discharge valve closed, require less power input than when operated at the rated flow rate and head with the discharge valve open. For this reason, it is advantageous to have the discharge valve closed when starting the pump. Note, however, that with pumps of 100 (5000) specific speed and higher, closing of the discharge valve at starting leads to an increased horsepower requirement.

A.5.5.5.6.2 Position of discharge valve on starting, mixed or axial flow pumps

Pumps of the mixed flow type usually require greater input power with the discharge valve closed than open. Axial flow type pumps nearly always require substantially more power and produce more pressure at shutoff than at rating and should be started with the discharge valve open or with the opening of the valve sequenced with starting of the pump. Flap valves are commonly used for these purposes. The manufacturer's instructions should be consulted for the characteristics of such pumps.

A.5.5.5.6.3 Reduced flow/minimum flow discharge bypass

When operating at reduced flow, noise and vibration levels typically increase. This may lead to reduced bearing life and mechanical seal life as well as potential damage to other components.

If it becomes necessary to operate a pump for prolonged periods below the flow rate specified by the manufacturer as permissible continuous minimum flow, then a bypass line should be installed from the pump discharge to the suction source. See ANSI/HI 9.6.3 *Centrifugal and Vertical Pumps for Allowable Operating Region*. The bypass line should be sized so that the system flow plus the bypass flow is equal to or larger than the manufacturer's specified minimum.

A.5.5.6 Condition monitoring

See ANSI/HI 9.6.5 *Rotodynamic (Centrifugal and Vertical) Pumps for Condition Monitoring*.

A.5.5.7 Vibration (alarms and trip points)

See ANSI/HI 9.6.4 *Rotodynamic Pumps for Vibration Measurements and Allowable Values*.

A.5.5.7.1 Noise in pumping machinery

Sound is energy and may be produced by movement within machinery. This is also true for pumps. Sound is produced by liquid flowing within the pump, the bearings within the pumping unit, the coupling, and the unit driver. Some sound is expected during normal operation. Sound may be transmitted in three ways:

a) Airborne within the machinery room.

b) Liquidborne by the liquid being pumped.

c) Structureborne through the attached piping and support system.

Two of the most important factors in minimizing sound in pump installations are the correct selection of the pump type for the operating conditions and the equipment installation. To ensure minimum sound, the pump should be chosen for operation near the point of best efficiency and proper suction conditions should be provided.

The prevention of excessive noise is greatly dependent on the pump installation. Proper alignment of the pump and the driver is essential, as well as the support of the suction and discharge piping. The manner in which the pump is installed and in which the piping is supported may contribute to objectionable noise and vibration. A greater degree of noise prevention may be obtained when the pumping unit is supported free of building structures by the use of vibration isolators and flexible piping and conduit connectors. Noise emanating from the motion of high-velocity liquids within the piping system, particularly from partly opened valves, should not mistakenly be attributed to the pumping unit. Further discussion of noise and sound is contained in ANSI/HI 9.1-9.5 *Pumps – General Guidelines*.

A.5.5.7.2 Hydraulic resonance in piping

Severe vibration problems are often caused by a resonant condition within the pump/piping system that amplifies normal pump-induced pulsations. Such a condition is referred to as a *hydraulic resonance*.

Hydraulic resonance is defined as a condition of pulse reinforcement in which pulses reflected by the piping system are repeatedly added in phase to the source pulse, producing large pulsation amplitudes. Hydraulic resonance in piping may result in unacceptable noise or vibration, or, if uncorrected, can ultimately result in mechanical fatigue failures in either the piping or pump components.

In cases where the existence of a hydraulic resonance is known to be a problem, experience has shown that the following solutions aimed at alleviating the resonant condition may prove effective:

a) Alter the resonant piping.

b) Change the pump speed.

c) Change the internal design characteristics of the pump.

d) Insert a pulsation damper on the pump/piping system.

Modifications to the pump or piping, including the supporting structures, which do not change the pulsation response of the pump/piping system, will not affect the resonant condition and therefore will not be effective.

A.5.5.8 Performance testing/verification

Once the unit is energized, check operating speed, rate of flow, suction and discharge pressure, and power input. While it may not be possible to exactly repeat the factory performance, initial field-test data become a valuable baseline for future checking to determine possible wear and need to perform maintenance. Vibration levels should be checked for the same reason. Auxiliary piping and gasketed joints should be checked for leaks and proper makeup.

A.5.5.9 Bearing temperature

See Section A.7.2.2.

A.6 Maintenance

A.6.1 Schedule

To ensure satisfactory operation of the pumping equipment, frequent inspection and periodic maintenance are required. An inspection and maintenance log should be kept and the inspector is to immediately report any problems. A suggested guide for preventative maintenance for normal applications is given below. Unusual applications with abnormal heat, moisture, dust, etc., may require more frequent inspection and service.

Item	Action required	Frequency
Packing, Packing box	Inspect for excessive leakage. Adjust gland and replace packing.	150 hours of operation As necessary
Pump/Motor alignment	Check for change in alignment.	Annually
Vibration	Check for change in vibration.	Refer to ANSI/HI 9.6.5 *Condition Monitoring.*
Bearings	Lubricate (grease).	Refer to manufacturer for proper lubrication intervals.
Bolting	Check for loose bolting.	Annually