



American National Standard for

Rotodynamic Pumps

for Assessment of Applied Nozzle Loads



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American National Standard

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Contents

Page

Foreword	v
9.6.2 Rotodynamic pumps for assessment of applied nozzle loads	1
9.6.2.1 Introduction	1
9.6.2.1.1 Purpose	1
9.6.2.1.2 Scope	1
9.6.2.2 Relevance of nozzle loading evaluations	1
9.6.2.2.1 Piping loads on pumps — practical insights	2
9.6.2.2.2 General nozzle loading effects on pumping equipment	4
9.6.2.3 Horizontal end suction pumps (ANSI/ASME B73.1 and B73.3)	7
9.6.2.3.1 Scope	7
9.6.2.3.2 Nomenclature and definitions	7
9.6.2.3.3 Criteria for loading allowances	8
9.6.2.3.4 ANSI/ASME B73.1 pump assessment of applied nozzle loads	9
9.6.2.3.5 ANSI/ASME B73.3 sealless pump assessment of applied nozzle loads	13
9.6.2.3.6 Nozzle load adjustment factors	13
9.6.2.4 Vertical in-line pumps (ANSI/ASME B73.2)	15
9.6.2.4.1 Scope	15
9.6.2.4.2 Nomenclature and definitions	15
9.6.2.4.3 Criteria for loading allowances	15
9.6.2.4.4 ANSI/ASME B73.2 pump assessment of applied nozzle loads	16
9.6.2.5 Axially split one- and two-stage pumps (BB1)	17
9.6.2.5.1 Scope	17
9.6.2.5.2 Definitions	17
9.6.2.5.3 Criteria for loading allowances	18
9.6.2.5.4 Axial split case pumps (single-stage double suction and two-stage single suction) assessment of applied loads	20
9.6.2.6 Vertical turbine short set pumps (VS1 and VS2)	21
9.6.2.6.1 Scope	21
9.6.2.6.2 Definitions	21
9.6.2.6.3 Methodology	22
Appendix A Material Adjustment Factors (Normative)	27
Appendix B Example assessments of applied nozzle loads – ASME B73.1 pumps	30

Appendix C	Example assessments of applied nozzle loads – ASME B73.2 pumps	38
Appendix D	Example assessments of applied nozzle loads – axial split case pumps (single-stage double suction and two-stage single suction)	40
Appendix E	Example assessments of applied nozzle loads – vertical turbine pumps	41
Appendix F	Methods of analysis	43
Appendix G	References	49
Appendix H	Index	51
Figures		
9.6.2.2.2.3	— Example of tight running clearances between stationary and rotating components	5
9.6.2.2.2.4	— Example of nozzle load effect on alignment at coupling	6
9.6.2.3.2.2	— Coordinate system for ASME B73.1 and B73.3 horizontal end suction pumps.	7
9.6.2.3.6.1.1	— Stilt-mounted baseplate	14
9.6.2.4.2.2	— Coordinate system for ASME B73.2 vertical in-line pumps.	15
9.6.2.5.2	— Coordinate system for axial split case pumps	18
9.6.2.6.2a	— Nozzle loads for above pump base (floor) discharge pumps	23
9.6.2.6.2b	— Nozzle loads for below pump base (floor) discharge pumps	24
F.1	— Representation of part of a mesh of a structure with its elements and nodes.	44
F.2	— Example for loads and restraints considered for analysis for an OH2 pump	45
F.3	— Devices that can be used to simulate nozzle loading: a) for moments, b) for forces and moments	47
Tables		
9.6.2.2.1	— Possible problems induced by piping and corresponding mitigations	4
9.6.2.3.4a	— Equation Sets 1 through 5	10
9.6.2.3.4c	— Maximum forces and moments for use with Equation Set 2 to assess applied loads	11
9.6.2.3.4b	— Maximum forces and moments for use with Equation Set 1 to assess applied loads	12
9.6.2.3.4d	— Maximum forces and moments for use with Equation Set 3 to assess applied loads	13
9.6.2.3.4e	— Maximum forces and moments for use with Equation Set 4 to assess applied loads	13
9.6.2.4.4a	— Equation Set 6	16
9.6.2.4.4b	— Maximum forces and moments for use with Equation Set 6 to assess applied loads	17
9.6.2.5.3a	— Equation Set 7	20
9.6.2.5.3b	— Maximum forces and moments for use with Equation Set 7 to assess applied loads based on hold-down bolts	20
9.6.2.5.3c	— Maximum forces and moments for use with Equation Set 7 to assess applied loads based on nozzle stress.	20
A.1	— List of material specifications as used in Table A.2 and A.3.	28
A.2	— ASME B73.1 metallic pump temperature and material adjustment factors to be used on Table 9.6.2.3.4c values for both Class 150 and Class 300 flanges	29
A.3	— ASME B73.2 metallic pump temperature and material adjustment values to be used on Table 9.6.2.4.4b values for both Class 150 and Class 300 flanges	29

Foreword (Not part of Standard)

Purpose and aims of the Hydraulic Institute

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

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

Purpose of Standards and Guidelines

a) Hydraulic Institute Standards and Guidelines are adopted in the public interest and are designed to help eliminate misunderstandings between the manufacturer, the purchaser, and/or the user and to assist the purchaser in selecting and obtaining the proper product for a particular need.

b) Use of Hydraulic Institute Standards and Guidelines is completely voluntary. Existence of Hydraulic Institute Standards does not in any respect preclude a member from manufacturing or selling products not conforming to the standards.

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Quoting from Article XV, Standards, of the By-Laws of the Institute, Section B:

“An Institute Standard defines the product, material, process or procedure with reference to one or more of the following: nomenclature, composition, construction, dimensions, tolerances, safety, operating characteristics, performance, quality, rating, testing and service for which designed.”

Definition of a Hydraulic Institute Guideline

A Hydraulic Institute Guideline is not normative. The guideline is tutorial in nature, to help the reader better understand the subject matter.

Comments from users

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

Revisions

American National Standards of the Hydraulic Institute are subject to constant review, and revisions are undertaken whenever it is found necessary because of new developments and progress in the art. If no revisions are made for five years, the standards are reaffirmed using the ANSI canvass procedure.

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This document does not contain a complete statement of all requirements, analyses, and procedures necessary to ensure safe or appropriate selection, installation, testing, inspection, and operation of any pump or associated products. Each application, service, and selection is unique with process requirements that shall be determined by the owner, operator, or its designated representative.

Units of measurement

Metric units of measurement are used, and corresponding US customary units appear in parentheses. Charts, graphs, and sample calculations are also shown in both metric and US customary units. Because values given in metric units are not exact equivalents to values given in US customary units, it is important that the selected units of measure to be applied be stated in reference to this standard. If no such statement is provided, metric units shall govern.

Consensus

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

Hidrostal	WC Livoti Consulting
4B Engineering & Consulting, LLC	LVVWD- Las Vegas Valley Water District
Patterson Pump Company	Parametrix, Inc.
SULZER	Kemet Inc.
Moving Water Industries (MWI)	Xylem Inc. - Applied Water Systems
Summit Pump, Inc.	Brown and Caldwell
Black & Veatch (B & V)	Stantec
TRWD - Tarrant Regional Water District	ITT Pumps
West Yost Associates	Peerless Pump Company
HRSD - Hampton Roads Sanitation District	

Committee list

Although this standard was processed and approved for submittal to ANSI by the canvass method, a working committee met many times to facilitate its development. At the time it was developed, the committee had the following members:

Chair – Lucian Dobrot, Xylem Inc. - Applied Water Systems
Vice-chair – David Skinner, ITT - Industrial Process

Committee members

	Company
Lloyd Aanonsen	General Rubber Corporation
Paul Boyadjis	Mechanical Solutions, Inc.
Eric Eylat	Flowserve Corporation
Aleksander Roudnev	Weir Minerals North America

9.6.2 Rotodynamic pumps for assessment of applied nozzle loads

9.6.2.1 Introduction

Excessive loads applied to pump nozzles can result in numerous issues that may inhibit safe and reliable operation of the pump. This standard describes the various sources that can cause nozzle loads, the effects these loads can have on a pump, as well as provide manufacturers with suggested techniques and considerations for determining allowable nozzle loads.

Common causes of casing nozzle loads are piping dimensional changes or bend curvature changes due to thermal growth, pressurization strain, Bourdon-tube action, unrestrained discharge lines, installation misalignment, and soft-foot problems.

There are a wide variety of methods to determine how much nozzle load a pump assembly can tolerate in order to function properly. Done properly, manual calculations can provide valid conclusions. More accurate calculations are generally done using the finite element analysis (FEA) method. However, either the manual or computer based methods are only as accurate as the assumptions used and information that is used as input. Lab testing of nozzle loads may be performed to verify actual loads.

9.6.2.1.1 Purpose

This standard induces recommendations for assessment of applied nozzle loads for the the pump types within scope.

9.6.2.1.2 Scope

When specified by the user, pumps within scope that are supplied shall conform to these requirements.

- Horizontal end suction single stage (ANSI/ASME B73.1 *Specification for Horizontal End Suction Centrifugal Pumps for Chemical Process* and B73.3 *Specification for Sealless Horizontal End Suction Metallic Centrifugal Pumps for Chemical Process*).
- Vertical in-line single stage (ANSI/ASME B73.2 *Specification for Vertical In-Line Centrifugal Pumps for Chemical Process*).
- Axially split one and two stage (BB1).
- Vertically suspended pump single casing discharge through column with diffuser and volute (VS1 and VS2).

Many other pump types are not included because of the different designs that are unique to each manufacturer. For pump types outside the scope of this standard, allowable nozzle loads should be established by the pump manufacturer, applied nozzle loads predicted by the purchaser, and differences, if any, negotiated and resolved by the two parties.

For assessment of applied nozzle loads for slurry pumps, see ANSI/HI 12.1-12.6 *Rotodynamic Centrifugal Slurry Pumps for Nomenclature, Definitions, Applications, and Operation*.

9.6.2.2 Relevance of nozzle loading evaluations

Excessive pump nozzle loads sourced in the piping can induce excessive nozzle stress, casing internal misalignment that could lead to rubbing, and driver/pump misalignment that could lead to high vibration and bearing or seal premature failure. Various international standards specify minimum loading that should be supported by the pump's nozzles using certain acceptance criteria. Manufacturers could also quote maximum nozzle loads that they allow at each pump flange. The loads are in the form of direct forces (vertical, axial, or horizontal) at the flange face, and moments (torques) about those axes.

9.6.2.2.1 Piping loads on pumps — practical insights

Not all loading on pump nozzles is mechanical. Sometimes neglected, but potentially substantial, load along the axis of the nozzle occurs when an axially flexible pipe coupling (such as a rubber expansion joints) is used to connect the piping to the nozzle. The same situation occurs if such a joint is placed in the piping network prior to the first piping restraint. In such situations, there is a net axial thrust on the nozzle equal to the pressure of the fluid times the inside area of the coupling.

Flexible pipe coupling is used to prevent residual mechanical pipe strain as well as thermal growth or contraction reaction forces from being imposed on the pump nozzles. A method of preserving this purpose, but avoiding the hydraulic axial load, is to use tie-rods axially across the flanges of the flexible-joint. Such rods, and the flanges they attach to, must be stiff enough to not allow a significant percentage of the hydraulic load from being re-applied to the pump nozzle. The best practice to install tie-rods properly is to align the pump nozzle and pipe flanges at the axial position desired during operation, and then to adjust the tie-rod flange reaction nuts “finger tight” (i.e. not loose but nominally zero torque- provisions need to be made to lock the fasteners). Any significant torque would pull on the pump nozzle, possibly causing stress, distortion, and/or misalignment problems. Conversely, if the tie-rod joint starts loose upon start-up, the hydraulic load will tend to move the pump and the pipe apart from each other. This will place a compressive force on the pump in the nozzle zone. The use of a flexible joints does not eliminate the need to provide a rigid piping support in order to control the loading transmitted to the pump.

A primary objective in any pump installation should be to minimize loads on a pump induced by the piping system design.

The piping near the pump must be carefully evaluated. A system designer should recognize that pump piping loads fall into three categories:

- Residual mechanical pipe strain forces;
- Hydraulic pressure reaction forces;
- Thermal growth or contraction reaction forces.

Solutions for piping loads often do not address all three of these potential load sources. This can be a problem because a piping system designed to reduce or eliminate loads from one or two of these sources may induce excessive loads on the pump from the remaining source.

9.6.2.2.1.1 Mechanical pipe strain forces

Mechanical pipe strain caused by piping misalignment and piping excessive assembly tolerances is the easiest source of piping loads to visualize.

Piping flanges bolted to pumps should be close to the pump flange in their unbolted position so excessive force is not required to pull the flanges into the operating position. In general, the separation of the unbolted pipe flange from the pump flange should be within a small tolerance of the gasket thickness. For small pumps, 0.127 mm (0.005 inches) is a good worst-case limit criterion.

Piping flanges bolted to pumps should also be relatively parallel to the pump flange in their unbolted position. A tolerance of 0.0254 millimeters per millimeter (0.001 inches per inch) of flange outside diameter with a maximum of 0.254 millimeters (0.010 inches) typically ensures that the as-installed piping misalignment will not place undue stress on the pump.

Flexible joints bolted to the pumps will allow for greater piping misalignment. Flexible joints can only operate satisfactorily if the misalignment between the piping flange and the pump flange is below the limits defined by the flexible joint or pump manufacturer.

The effects of the fluid mass are often overlooked. If the piping is not properly supported, piping that is aligned with the pump in the dry state can move and improperly load the pump when the system is filled and prepared for service.

9.6.2.2.1.2 Hydraulic pressure reaction forces

Pressure in a pipe causes expansion of the pipe, even if only a small amount, in all directions. Linear expansion is caused by the pressure acting on the projected area of the pipe corresponding to the inside diameter. If an axially flexible pipe fitting (such as a sleeve type pipe coupling or rubber expansion joint) is used without thrust rods, the axial stiffness "k" of the fitting may be considered to be approximately zero for the range of axial deflection values of interest here. This also results in an effective axial pipe stiffness that approaches zero, situation that should be avoided because:

- The hydraulic pressure force is easily constrained by thrust rods and easily transmitted to the piping that can handle such force;
- The hydraulic pressure reaction loads placed on the pump in such cases are typically relatively high compared with the pump capability;
- Any hydraulic pressure reaction force placed on the pump is transmitted to the support structure and foundation;
- A hydraulic pressure reaction force will load the pump, support structure and foundation each time the pump is started.

For a piping run that is restrained at the pump end only the linear expansion is resisted by the piping as it stretches under the force of hydraulic pressure. All of the expansion is away from the pump with little to no pressure reaction on the pump. Typically, in such an installation, resistance from sliding friction in a pipe support or an orthogonal run of pipe created by an elbow or a manifold resists the axial deflection, and creates a reaction force.

For a piping run restrained at the pump end and the other end, the ability of the restraint opposite the pump is typically far greater than that of the pump. The stretch in the pipe will determine a reaction load on the pump that is also transmitted to the pump support structure, baseplate and foundation.

An axially stiff piping run usually produces lower pump reaction forces, while axially flexible piping (especially using flexible fittings with no thrust rods or weak thrust rods) usually creates higher pump reaction forces to restrain the force produced by pressure. In axially weak piping systems, a relatively strong pump structure produces potentially excessive nozzle loads if the deflection is held to acceptable levels, and a relatively weak pump structure is needed to hold the nozzle load to acceptable levels, however, the deflection is excessive.

9.6.2.2.1.3 Thermal growth or contraction reaction forces

Applications involving hot or cold liquids that are not properly engineered can easily distort and crack pump casings and cause other issues detrimental to pump life. Thermal growth or contraction reaction forces typically involve those forces generated due to thermal expansion or contraction that occurs involving the change in temperature of the piping system from the ambient non-operating condition to the steady state operating temperature.

If the end of the piping run opposite the pump is restrained, a fairly routine piping run and temperature gradient causes an axial deflection that well exceeds the 0.127-mm (0.005-in) or 0.254-mm (0.010-in) criterion used for the hydraulic pressure reaction force analysis. The interaction of the piping with the pump to produce deflection at the pump flange and impose nozzle loads works much the same as in the case of a reaction force due to hydraulic pressure.

Flexible joints bolted to the pumps will allow for greater piping misalignment. Flexible joints can only operate satisfactorily if the misalignment between the piping flange and the pump flange is below the limits defined by the flexible joint or pump manufacturer.

Table 9.6.2.2.1 summarizes the possible problems induced by piping described above and proposed mitigations.

Table 9.6.2.2.1 — Possible problems induced by piping and corresponding mitigations

Piping Load Characteristics	Load Type		M	P	T
			Mechanical pipe forces	Hydraulic pressure reaction forces	Thermal reaction forces
Piping Characteristics	Load Source		Piping not properly aligned; supports inadequate for fluid mass.	Pipe pressure reaction forces not properly restrained	Reaction induced on the pump due to thermal growth or contraction
	R	Rigidly piped (no pipe couplings, expansion joints or other axially flexible fittings)	Piping alignment is needed at the time of installation. Piping supports are needed to avoid loads due to fluid mass	Usually not so vulnerable in average applications but evaluation is needed	Must be addressed by proper analysis and design that may indicate the need for special fittings or designs to avoid problems
Piping Characteristics	F	Flexibly piped (includes couplings, expansion joints or other axially flexible fittings)	Usually not so vulnerable in average applications but evaluation is needed	Can be a problem if flexible fittings are not used properly or are installed improperly	Can be a problem if flexible fittings are not used properly or are installed improperly
Notes: • This summary does not eliminate the need for proper piping system analysis and evaluation; • Higher operating pressures increase vulnerability to hydraulic pressure reaction forces; • Higher temperature gradients increase vulnerability to thermal growth or contraction reaction forces.					

9.6.2.2.2 General nozzle loading effects on pumping equipment

9.6.2.2.2.1 Pump casing stresses

The combined loading applied to the casing could result in high stress areas and lead to its failure. Based on the pump design, failure can occur at various locations (e.g., pump feet, cutwater, nozzles, or welds of fabricated discharge heads). Cyclic loading, induced by vibration or varying operating conditions, may result in fatigue cracking. Depending on the location and magnitude of the induced stresses, cracking may be contained internally, or it may result in a catastrophic failure of the pump casing.

When determining allowable nozzle loads, pump casing stresses due to all internal and external static loading should not exceed specified allowable stress values.

9.6.2.2.2.2 Pump casing/nozzles deformation

High nozzle loads in combination with internal pressure and bolt pre-load can exceed the rated flange pressure causing excessive deflection of pump's flanges (or other gasketed joints) resulting in loss of joint integrity. Excessive deformation may also cause rotational elements to rub inside the pump casing.

9.6.2.2.2.3 Relative movement between stationary and rotating parts

Nozzle loads applied to the pump can cause relative movement between stationary and rotating parts. In critical locations, this relative displacement can lead to issues with safe and reliable operation.

Where internal pump components have tight running clearances, movement of the rotor can lead to contact and rubbing between rotating and stationary components (see Figure 9.6.2.2.2.3). This will result in wear and may result in galling and seizure of the pump. Relative displacement at these locations should be restricted to values below minimum running clearances. Beyond nozzle loads, additional considerations should be made such as manufacturing tolerances and additional relative displacement of the rotor during operation due to axial and radial thrust acting on the impeller(s) (refer to ANSI/HI 14.3 *Rotodynamic Pumps for Design and Application*).

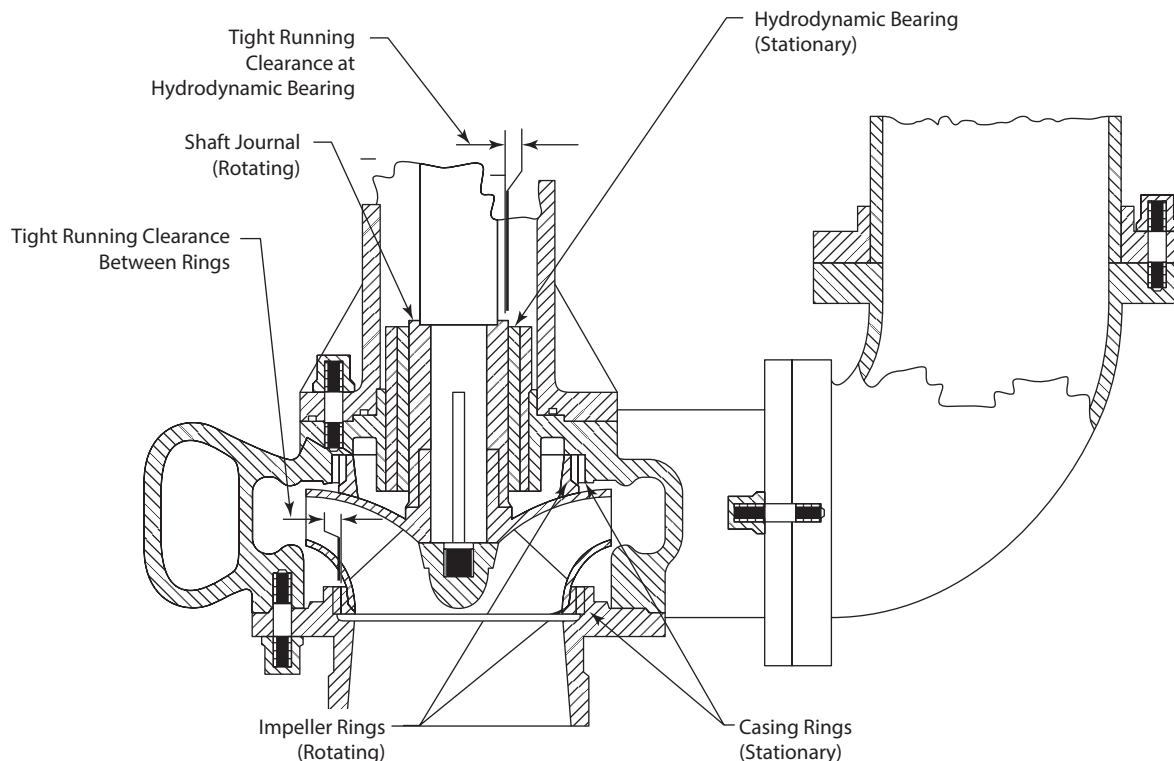


Figure 9.6.2.2.2.3 — Example of tight running clearances between stationary and rotating components

9.6.2.2.2.4 Shaft misalignment at the drive coupling and/or seal face

One of the primary mechanical problems that can result from excessive nozzle loading is pump shaft to driver shaft misalignment (see Figure 9.6.2.2.2.4). Couplings can only operate satisfactorily as long as the misalignment (parallel and angular) between driver and pump shaft-ends is below the limits defined by the coupling or pump manufacturer.

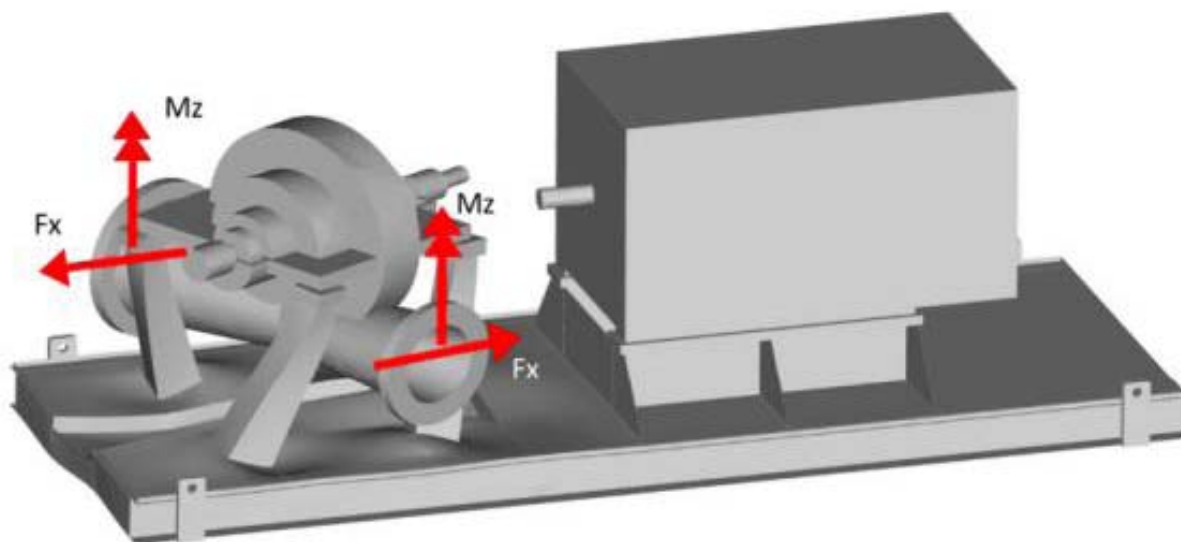


Figure 9.6.2.2.4 — Example of nozzle load effect on alignment at coupling

In the area of the seal chamber, movement of the shaft can cause misalignment of mechanical seal components. Relative displacement between the shaft and seal chamber at this location should be limited to values within the operational tolerances of the mechanical seal.

9.6.2.2.2.5 Pump hold-down bolts

Excessive nozzle loads may overload pump hold down bolts. Such overload may directly lead to bolted joint interface slip and pump/driver misalignment. Also, changes in bolt pre-tension may lead to bolt failure.

9.6.2.2.2.6 Base plate stresses and deflection

Internal stresses within the baseplate should be considered. Combined torsional and bending stresses should be compared to the material yield stresses of the baseplate taking into account the baseplate support conditions. If grout failure is a significant possibility, check baseplate internal stresses in a non-grouted condition.

One of the disruptive effects of forces transmitted to the pump from the connecting piping could be the deflection of the baseplate. Deflection at the baseplate will primarily contribute to misalignment of the shafts. Factors that should be included in the evaluation include the presence/absence of grout, and the structural design of the baseplate itself. Limits on nozzle loads should take into account the implications on baseplate deflection.

9.6.2.2.2.7 Anchor-bolt stresses

Anchor bolts hold the baseplate to the foundation and are used in grouted and un-grouted applications. All the forces and moments generated within and upon the pump and motor, primarily the nozzle loads, are reacted by the anchor bolts/grout/baseplate system. Serious issues begin to arise if the anchor bolts do not hold the baseplate rigidly to the foundation. To eliminate these serious issues nozzle loads in combination with other loads generated by the motor and pump must be within the limits of the anchor bolt design. Standard bolt design practice requires the following criteria:

- Strength (ensure bolt strength is sufficient to handle all loads and moments);
- Separation (ensure bolt preloads min/max along with maximum flange loads do not allow the bolt to become unloaded);
- Fatigue life (ensure cyclical loading is accounted for).

9.6.2.3 Horizontal end suction pumps (ANSI/ASME B73.1 and B73.3)

9.6.2.3.1 Scope

This section covers assessment of applied nozzle loads for the following horizontal end suction pump types:

- Pumps designed and constructed in accordance with ASME B73.1. For metallic pumps, the pump casing and seal chamber or stuffing box must be constructed of a material listed in Table A.1 and subjected to temperatures between -29 and 371 °C (-20 and 700 °F) unless otherwise specified. For thermoplastic and thermoset polymer material pumps, the pump must be constructed of a material with a modulus of elasticity greater than 6.9×10^9 N/m² (1×10^6 psi) at 20 °C (68 °F) and may be subjected to temperatures between -29 and 93 °C (-20 and 200 °F).
- Magnetic drive pumps designed and constructed in accordance with ASME B73.3 with Class 150 and 300 flanges. To be applicable, the pump casing must be constructed of a material listed in Table A.1 and subjected to temperatures between -29 and 260 °C (-20 and 500 °F) unless otherwise specified.

9.6.2.3.2 Nomenclature and definitions

9.6.2.3.2.1 Source

The nomenclature and definitions of pump components shall be in accordance with those promulgated by the HI.

9.6.2.3.2.2 Definitions (refer to Figure 9.6.2.3.2.2)

F_{x_s} = applied force on x_s -axis on suction nozzle, to be assessed using Equation Sets 1-5

F_{y_s} = applied force on y_s -axis on suction nozzle, to be assessed using Equation Sets 1-5

F_{z_s} = applied force on z_s -axis on suction nozzle, to be assessed using Equation Sets 1-5

M_{x_s} = applied moment about x_s -axis on suction nozzle, to be assessed using Equation Sets 1-5

M_{y_s} = applied moment about y_s -axis on suction nozzle, to be assessed using Equation Sets 1-5

M_{z_s} = applied moment about z_s -axis on suction nozzle, to be assessed using Equation Sets 1-5

F_{x_d} = applied force on x_d -axis on discharge nozzle, to be assessed using Equation Sets 1-5

F_{y_d} = applied force on y_d -axis on discharge nozzle, to be assessed using Equation Sets 1-5

F_{z_d} = applied force on z_d -axis on discharge nozzle, to be assessed using Equation Sets 1-5

M_{x_d} = applied moment about x_d -axis on discharge nozzle, to be assessed using Equation Sets 1-5

M_{y_d} = applied moment about y_d -axis on discharge nozzle, to be assessed using Equation Sets 1-5

M_{z_d} = applied moment about z_d -axis on discharge nozzle, to be assessed using Equation Sets 1-5

$F_{x_s \max}$ = maximum value of force on x_s -axis on suction nozzle, to be used with Equation Sets 1-5

$F_{y_s \max}$ = maximum value of force on y_s -axis on suction nozzle, to be used with Equation Sets 1-5

$F_{z_s \max}$ = maximum value of force on z_s -axis on suction nozzle, to be used with Equation Sets 1-5

$M_{x_s \max}$ = maximum value of moment about x_s -axis on suction nozzle, to be used with Equation Sets 1-5

$M_{y_s \max}$ = maximum value of moment about y_s -axis on suction nozzle, to be used with Equation Sets 1-5

$M_{z_s \max}$ = maximum value of moment about z_s -axis on suction nozzle, to be used with Equation Sets 1-5

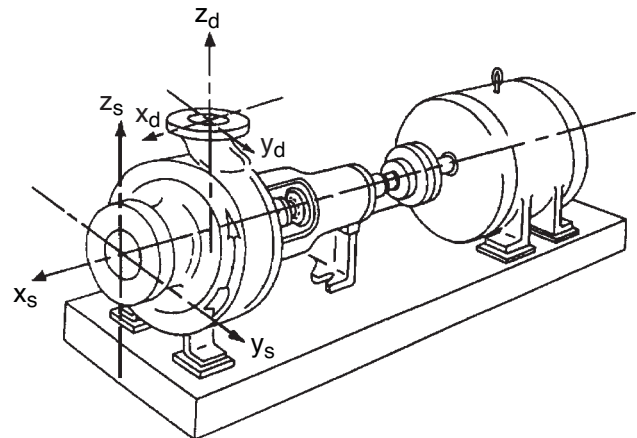


Figure 9.6.2.3.2.2 — Coordinate system for ASME B73.1 and B73.3 horizontal end suction pumps

$F_{x_d \max}$ = maximum value of force on x_d -axis on discharge nozzle, to be used with Equation Sets 1-5

$F_{y_d \max}$ = maximum value of force on y_d -axis on discharge nozzle, to be used with Equation Sets 1-5

$F_{z_d \max}$ = maximum value of force on z_d -axis on discharge nozzle, to be used with Equation Sets 1-5

$M_{x_d \max}$ = maximum value of moment about x_d -axis on discharge nozzle, to be used with Equation Sets 1-5

$M_{y_d \max}$ = maximum value of moment about y_d -axis on discharge nozzle, to be used with Equation Sets 1-5

$M_{z_d \max}$ = maximum value of moment about z_d -axis on discharge nozzle, to be used with Equation Sets 1-5

Group 1 is defined as ASME B73.1 and B73.3 sizes AA and AB; two-/four-pole, 60-cycle speed, and up to 15/7.5 kW (20/10 hp).

Group 2 is defined as ASME B73.1 and B73.3 sizes A05, A10, A20, A30, A50, A40, A60, A70, and A80; two-/four-pole, 60-cycle speed, and up to 97/48 kW (130/65 hp).

Group 3 is defined as ASME B73.1 and B73.3 sizes A90, A100, A110, and A120; four-/six-pole, 60-cycle speed, and up to 164/109 kW (220/146 hp).

9.6.2.3.3 Criteria for loading allowances

9.6.2.3.3.1 Driver/pump coupling alignment

The radial movement of the pump shaft at the pump coupling hub due to nozzle loads shall not exceed 0.125 mm (0.005 in) relative to initial alignment. Axial movement of the pump shaft at the pump coupling hub is not considered in this standard.

9.6.2.3.3.2 Internal pump distortion

No contact between casing and impeller is allowed.

The radial movement of the pump shaft with respect to the seal chamber due to nozzle loads shall not exceed 0.05 mm (0.002 in) relative to initial position.

9.6.2.3.3.3 Pump hold-down bolts

Fasteners used for hold-down bolts should have yield strength greater than or equal to the minimum yield strength of SAE J429 Grade 1 fasteners (2.5×10^8 N/m² or 36,000 psi). The maximum allowable tensile stress in the pump hold-down bolts should be 90% of fastener's material yield strength. The maximum allowable shear stress in the pump hold-down bolts should be 90% of fastener's material shear strength (the shear strength of carbon steel fasteners can be approximated to be 60% of their minimum tensile strengths).

The pump shall be bolted to the baseplate at both the casing feet and rear foot position(s) and sufficiently tightened to prevent slippage of the pump on the baseplate. Required torque values should be calculated based on the required clamp load. It may be necessary to arrange for periodic tightening of the bolts to maintain required torque levels.

9.6.2.3.3.4 Pump mounting

The base for which the loads in Tables 9.6.2.3.4b through 9.6.2.3.4e are established must be a fully grouted metal baseplate with anchor bolts. The base as a minimum must withstand the applied nozzle loads combined with normal operating loads (e.g., driver weight and pump weight).

It is recommended the baseplate be installed and grouted in accordance with ANSI/HI 14.4 *Rotodynamic Pumps for Installation, Operation, and Maintenance*.

9.6.2.3.3.5 Nozzle stress

The maximum stresses developed in the pump nozzles and flanges, constructed of a material listed in Table A.1, by the applied nozzle loads, combined with internal pressure, shall not exceed $1.8 \times 10^8 \text{ N/m}^2$ (26,250 psi) tensile and $9 \times 10^7 \text{ N/m}^2$ (13,125 psi) shear. By applying the temperature and material adjustment factors of Appendix A, applied nozzle loads may be increased for stronger materials and must be decreased for weaker materials.

The allowable suction nozzle stress was based on three-dimensional stress analysis methods. The allowable discharge nozzle stress was based on the method contained in the ASME Boiler and Pressure Vessel Code, 1983 edition, Section III, NC 3653, due to its complex geometry.

9.6.2.3.3.6 Pressure/temperature

Any temperature referenced in Section 9.6.2.3 is the temperature of the pressure-containing components of the pump. In general, this temperature is the same as that of the contained liquid.

Use of a pressure rating as specified in ANSI/ASME B16.5 corresponding to a temperature other than that of the contained liquid is the responsibility of the user, subject to the requirements of the applicable code or regulation.

The effects of high or low temperatures on the connected piping or equipment and on the materials of construction will also have to be considered in the analysis of the applied nozzle loads.

9.6.2.3.4 ANSI/ASME B73.1 pump assessment of applied nozzle loads

9.6.2.3.4.1 Metallic pumps

Loads given in Tables 9.6.2.3.4b through 9.6.2.3.4e are applicable for ASME B73.1 pumps constructed of ASTM A351/A351M - Grade CF8M (Type 316SS) operated between -30 and 38°C (-20 and 100°F) and mounted on a grouted metal baseplate with anchor bolts.

For an individual force or moment, pumps must be capable of satisfactory operation when subjected to loads shown in Table 9.6.2.3.4b (adjusted if applicable) while meeting the criteria of Equation Set 1 (see Table 9.6.2.3.4a).

For a combination of more than one force and/or moment, pumps must be capable of satisfactory operation when subjected to the loads in Tables 9.6.2.3.4c through 9.6.2.3.4e (adjusted if applicable) while meeting the criteria of Equation Sets 2 – 5. When combining loads, the absolute value of any individual load must not exceed the value given in Table 9.6.2.3.4b.

Adjustment of the tabulated maximum forces and moments load values is required if any of the following occur:

- a) Temperature is above 38°C (100°F).
- b) The pump material construction is not ASTM A351/A351M - Grade CF8M.
- c) The base is not a fully grouted metal baseplate with anchor bolts.

Table 9.6.2.3.4a — Equation Sets 1 through 5 (Using the maximum forces and moments of the referenced tables, applied loads shall satisfy the criteria defined by these equations.)

Set	Equation	Reference	Remarks
1	$\left \frac{F_{x_s}}{F_{x_s \max}} \right \leq 1, \left \frac{F_{y_s}}{F_{y_s \max}} \right \leq 1, \left \frac{F_{z_s}}{F_{z_s \max}} \right \leq 1, \left \frac{M_{x_s}}{M_{x_s \max}} \right \leq 1, \left \frac{M_{y_s}}{M_{y_s \max}} \right \leq 1, \left \frac{M_{z_s}}{M_{z_s \max}} \right \leq 1,$ $\left \frac{F_{x_d}}{F_{x_d \max}} \right \leq 1, \left \frac{F_{y_d}}{F_{y_d \max}} \right \leq 1, \left \frac{F_{z_d}}{F_{z_d \max}} \right \leq 1, \left \frac{M_{x_d}}{M_{x_d \max}} \right \leq 1, \left \frac{M_{y_d}}{M_{y_d \max}} \right \leq 1, \left \frac{M_{z_d}}{M_{z_d \max}} \right \leq 1$	Table 9.6.2.1.4b	Individual loading
2	$\left \frac{F_{x_s}}{F_{x_s \max}} \right + \left \frac{F_{y_s}}{F_{y_s \max}} \right + \left \frac{F_{z_s}}{F_{z_s \max}} \right + \left \frac{M_{x_s}}{M_{x_s \max}} \right + \left \frac{M_{y_s}}{M_{y_s \max}} \right + \left \frac{M_{z_s}}{M_{z_s \max}} \right +$ $\left \frac{F_{x_d}}{F_{x_d \max}} \right + \left \frac{F_{y_d}}{F_{y_d \max}} \right + \left \frac{F_{z_d}}{F_{z_d \max}} \right + \left \frac{M_{x_d}}{M_{x_d \max}} \right + \left \frac{M_{y_d}}{M_{y_d \max}} \right + \left \frac{M_{z_d}}{M_{z_d \max}} \right \leq 2$	Table 9.6.2.1.4c	Nozzle stress, hold-down bolt stress, pumps slippage
3	$a = \left \frac{F_{y_s}}{F_{y_s \max}} + \frac{M_{x_s}}{M_{x_s \max}} + \frac{M_{y_s}}{M_{y_s \max}} + \frac{M_{z_s}}{M_{z_s \max}} + \frac{F_{y_d}}{F_{y_d \max}} + \frac{M_{x_d}}{M_{x_d \max}} + \frac{M_{y_d}}{M_{y_d \max}} + \frac{M_{z_d}}{M_{z_d \max}} \right \leq 1$	Table 9.6.2.1.4d	y-axis movement
4	$b = \left \frac{F_{x_s}}{F_{x_s \max}} + \frac{F_{z_s}}{F_{z_s \max}} + \frac{M_{x_s}}{M_{x_s \max}} + \frac{M_{y_s}}{M_{y_s \max}} + \frac{M_{z_s}}{M_{z_s \max}} + \frac{F_{x_d}}{F_{x_d \max}} \right.$ $\left. + \frac{F_{y_d}}{F_{y_d \max}} + \frac{F_{z_d}}{F_{z_d \max}} + \frac{M_{x_d}}{M_{x_d \max}} + \frac{M_{y_d}}{M_{y_d \max}} + \frac{M_{z_d}}{M_{z_d \max}} \right \leq 1$	Table 9.6.2.1.4e	z-axis movement
5	$a^2 + b^2 \leq 1$	Equation Sets 3 and 4	Combined axis movement

Table 9.6.2.3.4b — Maximum forces and moments for use with Equation Set 1 to assess applied loads

ASME B73 Designation	Pump Size	Suction						Discharge					
		Forces, N (lbf)			Moments, N·m (lbf·ft)			Forces, N (lbf)			Moments, N·m (lbf·ft)		
		$F_{x_s \max}$	$F_{y_s \max}$	$F_{z_s \max}$	$M_{x_s \max}$	$M_{y_s \max}$	$M_{z_s \max}$	$F_{x_d \max}$	$F_{y_d \max}$	$F_{z_d \max}$	$M_{x_d \max}$	$M_{y_d \max}$	$M_{z_d \max}$
AA	1.5 × 1 × 6	4671 (1050)	3336 (750)	3336 (750)	976 (720)	230 (170)	230 (170)	3559 (800)	6005 (1350)	13,345 (3000)	556 (410)	556 (410)	556 (410)
AB	3 × 1.5 × 6	4671 (1050)	5516 (1240)	5560 (1250)	1220 (900)	664 (490)	664 (490)	3559 (800)	6005 (1350)	13,345 (3000)	678 (500)	746 (550)	691 (510)
A10	3 × 2 × 6	4671 (1050)	4671 (1050)	4671 (1050)	1220 (900)	298 (220)	298 (220)	3559 (800)	6005 (1350)	13,345 (3000)	678 (500)	1356 (1000)	691 (510)
AA	1.5 × 1 × 8	4671 (1050)	5382 (1210)	5382 (1210)	976 (720)	258 (190)	258 (190)	3559 (800)	6005 (1350)	13,345 (3000)	488 (360)	488 (360)	488 (360)
---	3 × 1.5 × 8 ^a	4671 (1050)	5516 (1240)	4671 (1050)	1220 (900)	664 (490)	664 (490)	3559 (800)	6005 (1350)	13,345 (3000)	597 (440)	597 (440)	597 (440)
A50	3 × 1.5 × 8	12,010 (2700)	6005 (1350)	6672 (1500)	1763 (1300)	502 (370)	502 (370)	6228 (1400)	6005 (1350)	14,457 (3250)	624 (460)	624 (460)	624 (460)
A60	3 × 2 × 8	12,010 (2700)	6005 (1350)	6672 (1500)	1763 (1300)	813 (600)	813 (600)	6228 (1400)	6005 (1350)	14,457 (3250)	895 (660)	895 (660)	895 (660)
A70	4 × 3 × 8	12,010 (2700)	6005 (1350)	6672 (1500)	1763 (1300)	475 (350)	475 (350)	6228 (14000)	6005 (1350)	14,457 (3250)	1627 (1200)	1980 (1460)	936 (690)
A05	2 × 1 × 10	10,409 (2340)	4270 (960)	4270 (960)	1722 (1270)	298 (220)	298 (220)	6228 (1400)	6005 (1350)	14,457 (3250)	895 (660)	895 (660)	895 (660)
A50	3 × 1.5 × 10	12,010 (2700)	6005 (1350)	6672 (1500)	1763 (1300)	569 (420)	569 (420)	6228 (1400)	6005 (1350)	14,457 (3250)	502 (370)	502 (370)	502 (370)
A60	3 × 2 × 10	12,010 (2700)	6005 (1350)	6583 (1480)	1763 (1300)	420 (310)	420 (310)	6228 (1400)	6005 (1350)	14,457 (3250)	759 (560)	759 (560)	759 (560)
A70	4 × 3 × 10	10,231 (2300)	6005 (1350)	6672 (1500)	1763 (1300)	420 (310)	420 (310)	6228 (1400)	6005 (1350)	14,457 (3250)	1627 (1200)	1980 (1460)	936 (690)
A80	6 × 4 × 10	12,010 (2700)	6005 (1350)	6672 (1500)	1763 (1300)	1491 (1100)	1491 (1100)	6228 (1400)	6005 (1350)	14,457 (3250)	1627 (1200)	2034 (1500)	936 (690)
A20	3 × 1.5 × 13	12,010 (2700)	6005 (1350)	6672 (1500)	1763 (1300)	908 (670)	908 (670)	6228 (1400)	6005 (1350)	14,457 (3250)	719 (530)	719 (530)	719 (530)
A30	3 × 2 × 13	8541 (1920)	5471 (1230)	5471 (1230)	1763 (1300)	475 (350)	475 (350)	6228 (1400)	6005 (1350)	14,457 (3250)	1627 (1200)	1722 (1270)	936 (690)
A40	4 × 3 × 13	12,010 (2700)	6005 (1350)	6672 (1500)	1763 (1300)	542 (400)	542 (400)	6228 (1400)	6005 (1350)	14,457 (3250)	1627 (1200)	2034 (1500)	936 (690)
A80	6 × 4 × 13	12,010 (2700)	6005 (1350)	6672 (1500)	1763 (1300)	1763 (1300)	1491 (1100)	6228 (1400)	6005 (1350)	14,457 (3250)	1627 (1200)	2034 (1500)	936 (690)
A90	8 × 6 × 13	15,569 (3500)	14,145 (3180)	8896 (2000)	2034 (1500)	1586 (1170)	1586 (1170)	6672 (1500)	13,345 (3000)	15,569 (3500)	1695 (1250)	3851 (2840)	3851 (2840)
A100	10 × 8 × 13	15,569 (3500)	14,145 (3180)	8896 (2000)	2034 (1500)	2712 (2000)	2150 (2915)	6672 (1500)	13,345 (3000)	15,569 (3500)	1695 (1250)	3851 (2840)	3851 (2840)
A110	8 × 6 × 15	15,569 (3500)	14,145 (3180)	8896 (2000)	2034 (1500)	2007 (1480)	2007 (1480)	6672 (1500)	13,345 (3000)	15,569 (3500)	1695 (1250)	3851 (2840)	3851 (2840)
A120	10 × 8 × 15	15,569 (3500)	14,145 (3180)	8896 (2000)	2034 (1500)	1532 (1130)	1532 (1130)	6672 (1500)	13,345 (3000)	15,569 (3500)	1695 (1250)	3851 (2840)	3851 (2840)

NOTE: Please note that certain sizes do not follow a trend of increased allowable nozzle loads with increased pump size. This is due to interaction of individual pump geometry (i.e., nozzle wall thickness, distance from flange face to nozzle connection with casing, etc.).

^a This is not an ASME size. It is included here as a special Group 1 size that is common among manufacturers.

Table 9.6.2.3.4c — Maximum forces and moments for use with Equation Set 2 to assess applied loads

ASME B73 Designation	Pump Size	Suction						Discharge					
		Forces, N (lbf)			Moments, N•m (lbf•ft)			Forces, N (lbf)			Moments, N•m (lbf•ft)		
		$F_{x_s \max}$	$F_{y_s \max}$	$F_{z_s \max}$	$M_{x_s \max}$	$M_{y_s \max}$	$M_{z_s \max}$	$F_{x_d \max}$	$F_{y_d \max}$	$F_{z_d \max}$	$M_{x_d \max}$	$M_{y_d \max}$	$M_{z_d \max}$
AA	1.5 × 1 × 6	8985 (2020)	3336 (750)	3336 (750)	2481 (1830)	230 (170)	230 (170)	8985 (2020)	6005 (1350)	27,757 (6240)	556 (410)	556 (410)	556 (410)
AB	3 × 1.5 × 6	8985 (2020)	5516 (1240)	9386 (2110)	3105 (2290)	664 (490)	664 (490)	8985 (2020)	6005 (1350)	27,757 (6240)	746 (550)	746 (550)	746 (550)
A10	3 × 2 × 6	8985 (2020)	4671 (1050)	4671 (1050)	3105 (2290)	298 (220)	298 (220)	8985 (2020)	6005 (1350)	27,757 (6240)	1396 (1030)	1396 (1030)	691 (510)
AA	1.5 × 1 × 8	8985 (2020)	5382 (1210)	5382 (1210)	2481 (1830)	258 (190)	258 (190)	8985 (2020)	6005 (1350)	27,757 (6240)	488 (360)	488 (360)	488 (360)
—	3 × 1.5 × 8 ^a	8985 (2020)	5516 (1240)	7295 (1640)	3105 (2290)	664 (490)	664 (490)	8985 (2020)	6005 (1350)	27,757 (6240)	597 (440)	597 (440)	597 (440)
A50	3 × 1.5 × 8	12,010 (2700)	6005 (1350)	8096 (1820)	5057 (3730)	502 (370)	502 (370)	8985 (2020)	6005 (1350)	27,757 (6240)	624 (460)	624 (460)	624 (460)
A60	3 × 2 × 8	12,010 (2700)	6005 (1350)	11,076 (2490)	5057 (3730)	814 (600)	814 (600)	8763 (1970)	6005 (1350)	27,757 (6240)	895 (660)	895 (660)	895 (660)
A70	4 × 3 × 8	12,010 (2700)	6005 (1350)	8185 (1840)	5057 (3730)	475 (350)	475 (350)	8985 (2020)	6005 (1350)	27,757 (6240)	1980 (1460)	1980 (1460)	936 (690)
A05	2 × 1 × 10	10,409 (2340)	4270 (960)	4270 (960)	4936 (3640)	298 (220)	298 (220)	8985 (2020)	6005 (1350)	27,757 (6240)	895 (660)	895 (660)	895 (660)
A50	3 × 1.5 × 10	12,010 (2700)	6005 (1350)	8496 (1910)	5057 (3730)	569 (420)	569 (420)	8630 (1940)	6005 (1350)	27,757 (6240)	502 (370)	502 (370)	502 (370)
A60	3 × 2 × 10	12,010 (2700)	6005 (1350)	6583 (1480)	5057 (3730)	420 (310)	420 (310)	8985 (2020)	6005 (1350)	27,757 (6240)	759 (560)	759 (560)	759 (560)
A70	4 × 3 × 10	10,231 (2300)	6005 (1350)	7295 (1640)	5057 (3730)	420 (310)	420 (310)	8985 (2020)	6005 (1350)	27,757 (6240)	1980 (1460)	1980 (1460)	936 (690)
A80	6 × 4 × 10	12,010 (2700)	6005 (1350)	27,757 (6240)	5057 (3730)	1491 (1100)	1491 (1100)	8985 (2020)	6005 (1350)	27,757 (6240)	4203 (3100)	4203 (3100)	936 (690)
A20	3 × 1.5 × 13	12,010 (2700)	6005 (1350)	13,612 (3060)	5057 (3730)	908 (670)	908 (670)	8985 (2020)	6005 (1350)	27,757 (6240)	719 (530)	719 (530)	719 (530)
A30	3 × 2 × 13	8541 (1920)	5471 (1230)	5471 (1230)	5057 (3730)	475 (350)	475 (350)	8985 (2020)	6005 (1350)	27,757 (6240)	1980 (1460)	1980 (1460)	936 (690)
A40	4 × 3 × 13	12,010 (2700)	6005 (1350)	10,631 (2390)	5057 (3730)	542 (400)	542 (400)	8985 (2020)	6005 (1350)	27,757 (6240)	2346 (1730)	2346 (1730)	936 (690)
A80	6 × 4 × 13	12,010 (2700)	6005 (1350)	27,757 (6240)	5057 (3730)	6752 (4980)	1491 (1100)	8985 (2020)	6005 (1350)	27,757 (6240)	2915 (2150)	2915 (2150)	936 (690)
A90	8 × 6 × 13	28,291 (6360)	14,145 (3180)	22,597 (5080)	12,162 (8970)	1586 (1170)	1586 (1170)	28,291 (6360)	14,145 (3180)	59,873 (13,460)	9192 (6780)	5220 (3850)	3851 (2840)
A100	10 × 8 × 13	28,291 (6360)	14,145 (3180)	59,873 (13,460)	12,162 (8970)	3322 (2450)	2915 (2150)	28,291 (6360)	14,145 (3180)	59,873 (13,460)	12,162 (8970)	9789 (7220)	3851 (2840)
A110	8 × 6 × 15	28,291 (6360)	14,145 (3180)	29,714 (6680)	12,162 (8970)	2007 (1480)	2007 (1480)	28,291 (6360)	14,145 (3180)	59,873 (13,460)	8894 (6560)	5044 (3720)	3851 (2840)
A120	10 × 8 × 15	28,291 (6360)	14,145 (3180)	22,819 (5130)	12,162 (8970)	1532 (1130)	1532 (1130)	28,291 (6360)	14,145 (3180)	59,873 (13,460)	12,162 (8970)	12,284 (9060)	3851 (2840)

^a This is not an ASME size. It is included here as a special Group 1 size that is common among manufacturers.