PIP RECE002
Design of Piping Loads on Rotating Machinery Nozzles
PURPOSE AND USE OF PROCESS INDUSTRY PRACTICES

In an effort to minimize the cost of process industry facilities, this Practice has been prepared from the technical requirements in the existing standards of major industrial users, contractors, or standards organizations. By harmonizing these technical requirements into a single set of Practices, administrative, application, and engineering costs to both the purchaser and the manufacturer should be reduced. While this Practice is expected to incorporate the majority of requirements of most users, individual applications may involve requirements that will be appended to and take precedence over this Practice. Determinations concerning fitness for purpose and particular matters or application of the Practice to particular project or engineering situations should not be made solely on information contained in these materials. The use of trade names from time to time should not be viewed as an expression of preference but rather recognized as normal usage in the trade. Other brands having the same specifications are equally correct and may be substituted for those named. All Practices or guidelines are intended to be consistent with applicable laws and regulations including OSHA requirements. To the extent these Practices or guidelines should conflict with OSHA or other applicable laws or regulations, such laws or regulations must be followed. Consult an appropriate professional before applying or acting on any material contained in or suggested by the Practice.

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1. **Scope**

This Practice provides designers and engineers with requirements to help reduce the Total Cost of Ownership (TCO) of rotating machinery by determining allowable piping loads and piping load applications.

*Comment:* Owner experience has shown that designing machinery piping to the maximum published allowable loads results in low mean time between repair (MTBR) and higher than acceptable maintenance costs.

This Practice limits the application of the entire maximum allowable nozzle load during the equipment installation design, allowing some reserve margin to maximize the possibility of the final installation actually remaining within the allowable loading.

This Practice drives the stated, published and calculated allowable nozzle loads to become more performance based, tied more closely to actual effects on the MTBR and TCO for the machinery in order to:

a. Promote the highest reliability for vital or sensitive machinery and the determination of those allowable loads that will allow the achievement of that reliability

b. Allow spared (essential) machinery to be more heavily loaded, and encourage manufacturers to either furnish allowable load data or be in accordance with a published standard
c. Encourage machinery manufacturers to generate more meaningful reliability-based allowable nozzle load recommendations
d. Encourage standards organizations to look at the basis for their allowable load values/calculation methods and verify the effects on the demonstrated MTBR and Total Cost of Ownership (TCO)

This Practice describes the requirements for calculating allowable piping loads and the application of those loads for rotating machinery including pumps and compressors (centrifugal, reciprocating and rotary screw), steam and gas turbines, and liquid ring compressors. Also, this Practice may be used on fans and blowers after consultation with the manufacturer.

This Practice describes the requirements for allowable nozzle loads for vital or sensitive machinery and for essential (spared) machinery.

This Practice also outlines the requirements for minimizing loads imposed on equipment by the piping systems.

2. **References**

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

### 2.1 Process Industry Practices (PIP)

- PIP PNE00003 - *Process Unit and Offsites Layout Guide*
2.2 Industry Codes and Standards

- American Petroleum Institute (API)
  - API 610 - Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries
  - API 611 - General Purpose Steam Turbines for Petroleum, Chemical, and Gas Industry Services
  - API 612 – Petroleum, Petrochemical and Natural Gas Industries - Steam Turbines – Special Purpose Applications
  - API 617 – Axial and Centrifugal Compressors and Expanders

- Hydraulic Institute (HI)
  - HI (ANSI) 9.6.2 Rotodynamic Pumps for Assessment of Applied Nozzle Loads - B119

3. Definitions

**Allowable Nozzle Load (ANL):** The machinery nozzle loading value that is provided by the manufacturer, a code or standard with which the equipment is stated to be compliant, or calculated by a method specified by a code or standard.

**essential machinery:** A machinery application that typically has an installed spare, such that machinery downtime does not result in unit shutdown or unacceptable production losses.

**Total Cost of Ownership (TCO):** The total cost of a rotating machinery train over its useful life. TCO includes the costs for the engineering design, purchase, installation, start-up, operation, maintenance, and final disposal of the equipment.

**manufacturer:** The party responsible for manufacturing the equipment for which allowable piping loads are being determined.

**Mean Time Between Repair (MTBR):** The most common measure of rotating machinery reliability (utilizing failure frequency data). MTBR is the average operating time between repairs for a machinery train.

**owner:** The party who owns the facility where the piping system will be installed.

**purchaser:** The party who awards the contract to the supplier. The purchaser may be the owner or the owner’s authorized agent.

**sensitive machinery:** A particular type, manufacturer, style or application of machinery that has demonstrated an unacceptable MTBR in response to nozzle loadings (values that could otherwise be considered normal). Machinery is classified in this category only when specifically designated by the owner and/or purchaser.

**supplier:** The party responsible for designing and verifying the installation of piping systems that include attachments to machinery nozzles.

**vital machinery:** A special purpose machinery application that is designed or designated for uninterrupted, continuous operation, with no full capacity installed spare machinery.
4. Requirements

4.1 Calculation of Nozzle Loads

4.1.1 General

4.1.1.1 Piping nozzle loads shall be calculated in accordance with API or ASME methods as applicable.

Comment: Commercial computer programs are available for the performance of piping load calculations.

4.1.1.2 Agreement shall be reached between the manufacturer and the purchaser as to the coordinate system to be used for the calculations.

Comment: Current standards have utilized the ISO standard coordinate designations. Early discussion and agreement between the manufacturer and purchaser will decrease subsequent confusion.

4.1.1.3 Conditions Requiring Calculation

Piping loads for machinery nozzles shall be calculated if any of the following conditions exist:

a. Pipe size DN80 (NPS 3) pipe or larger
b. System temperature in excess of 150°C (300°F)
c. System temperature -100°C (-150°F) and below
d. Vital or sensitive machinery
e. Machinery with a history of nozzle load sensitivity/problems, either for a particular application or for a particular machinery type

4.1.1.4 A static, pulsation and mechanical analysis shall be conducted on piping systems for reciprocation machinery or machinery subject to pulsating flows. (See PIP REIE686/API RP686.)

4.1.1.5 The following shall be considered if calculating piping loads:

a. Weight of the piping system and its contents
b. Weight of insulation
c. Thermal movement of the pipe and machinery due to process fluid temperature changes, including start-up, shutdown, clean-out, and off-design operation, as well as the normal operating temperature cases
d. Movement of the pipe, machinery, and support systems due to thermal distortion from the sun, weather, radiant heating from nearby equipment, and process flow effects
e. Heat tracing
f. Differential settlement of foundations and/or frost heaving
g. Reactions from restraints such as anchors, pins and ties (See Section 4.3.1.5.)
h. Other attached piping that may exert significant loading
i. Adjacent equipment attached to the same header

Comment: Suction and discharge piping systems around machinery should initially be evaluated independent of each other and then together.

4.1.1.6 If applicable or if specified, the following considerations shall also be included in the analysis:

a. Friction forces from piping supports, guides and restrictions
b. Unsteady operation, such as two phase flow or vibration
c. Pulsating flow
d. Wind loading
e. Snow and/or ice loading
f. Maintenance requirements, including the installation and removal of blinds, startup strainers, etc.
g. Steam-out or purging conditions
h. Equipment (such as instruments) supported by the piping

4.1.2 Resolution of Forces and Moments

4.1.2.1 Steam Turbines

The forces and moments shall be resolved at the exhaust flange in accordance with API 611 or API 612 as applicable.

4.1.2.2 Centrifugal Compressors

The forces and moments shall be resolved at the fixed end (API 617). If there is no fixed end nozzle, forces and moments shall be resolved at the largest nozzle.

Comment: The fixed end is usually both the suction end and the largest nozzle.

4.1.2.3 Centrifugal Pumps

Centrifugal pumps shall have the forces and moments resolved at the intersection of the shaft centerline and the casing transverse centerline (API 610), as well as satisfy the individual nozzle limitations. Pump manufacturers shall provide the allowable nozzle loads for their equipment. Industry practice is to use 50% of allowable nozzle loads during the design phase.

4.1.2.4 Other Equipment

Reciprocating compressors, blowers, fans, and vertical centrifugal pumps, forces and moments, etc., shall be calculated per nozzle unless purchased to a standard with a defined convention for their combination.

The combining of forces (resolution) shall be done in accordance with the manufacturer’s recommended methods.
4.2 Allowable Nozzle Loads (ANLs)

4.2.1 General

The concept of ANL carries a degree of conservatism and implies not only the safety of applying this load but also the expectation of design life achievement including the design MTBR. *Hydraulic Institute Standard* 9.6.2 provides the recommended minimum for allowable machinery nozzle loads.

4.2.1.1 It is implied that compliance with these limit values shall not cause harmful distortion or any measurable decrease (>2%) in the MTBR of the machinery train. If the basis for any of the loading values is other than that stated here, that basis shall be specifically stated by the manufacturer at the time such values are furnished.

4.2.1.2 If loading values are available from the manufacturer and the equipment is also in compliance with an industry standard that provides different values, the lower values shall be used as the basis for machinery nozzle loading, unless otherwise approved by both the purchaser and the manufacturer.

*Comment:* In cases where the equipment OEM guarantees that higher nozzle loading than allowed for in industry standards, due to robustness of design or other factors, will not adversely affect the reliability of the installed assets, the user may want to allow an exception. It is recommended that this be done on an exception basis since not all equipment can meet this expectation.

4.2.1.3 Determination of ANLs shall take the following *machinery factors* into consideration:

a. Internal clearances
b. Nozzle stresses
c. Casing strength and rigidity
d. Machinery weight and distribution
e. Rigidity of the machinery base and support system
f. Expected pressure and temperature effects
g. Any other factors that would contribute to a decrease in the MTBR for the machinery train

*Comment:* ANLs are typically not determined by stress in the nozzles but rather by deflections in the casing and bearing/seal systems and/or by reactions at supports that affect internal clearance and/or shaft alignment at transient and operating conditions.

4.2.1.4 Determination of ANLs shall consider materials of construction and special design requirements.

*Comment:* Materials of construction or special design requirements may severely limit ANLs. For example, glass-lined, plastic, fiber reinforced plastic, and silicon iron pumps are susceptible to breakage.

4.2.1.5 The ANL values utilized shall be those furnished by the manufacturer or specified in the standard to which the purchased equipment is compliant,
as adjusted in accordance with Sections 4.2.2 and 4.2.3. If more than one set of ANL values are applicable (unless intended for alternate operating conditions), the values to be utilized shall be designated by the owner.

4.2.2 Vital or Sensitive Machinery

4.2.2.1 For vital or sensitive machinery, piping loads on machinery nozzles shall not have a negative impact on the MTBR of the machinery train.

4.2.2.2 The manufacturer shall be required to include in the proposal (and formally respond to all inquiries stating):
   a. Their ANL recommendations or the code/standard to which the equipment that is proposed/furnished complies
   b. The basis for their ANL values
   c. The impact of full application of their ANLs on the machinery’s MTBR (i.e., MTBR with and without nozzle loads applied)

Comment: This requirement may mean that calculated or published ANLs may have to be further reduced to produce an MTBR that is acceptable.

Comment: It is expected initially that MTBR data will not be universally available. However, owners who seek out manufacturers (or other owners) with such actual data may be able to take advantage of the TCOs minimization for the installed equipment.

4.2.2.3 For vital or sensitive machinery, a maximum of 50% of the industry ANLs shall be used during the piping layout and system design stage due to the difficulty in accurately predicting piping loads and the probability of installation errors.

Comment: This requirement helps assure that the actual loading criteria (Section 4.2.2.7) shall be met, after conditions such as installation inaccuracies occur. This criteria is not intended to relax the need or requirements for accurate field alignment of piping connections.

4.2.2.4 Vital or sensitive machinery that was not purchased as compliant to a published ANL standard, or was purchased from a manufacturer that does not provide ANLs, shall be subject to a limit of 25% of the allowable values calculated in accordance with HI (ANSI) 9.6.2 during the piping layout and system design stage.

4.2.2.5 Actual nozzle alignment shall be field verified and documented in accordance with PIP REIE686/API RP686. See PIP REIE686/API RP686 for recommended tolerances and values on flange alignment.

4.2.2.6 Operating loads as evidenced by their measurable effects shall be verified to be as calculated in accordance with PIP REIE686/API RP686.

4.2.2.7 All flanges shall be aligned in accordance with PIP REIE686/API RP686. Measurement of the actual ANLs shall be required for all cold flange alignments that exceed the limits of PIP REIE686/API RP686.
Comment: This typically involves measurement of the forces required to correct the flange alignment and nozzle make-up.

4.2.2.8 Calculated final loading of machinery nozzles in the installed system (as built) is permitted up to values in Table 1, *Allowable Nozzle Loads*.

Comment: This refers to the piping designer’s allowable limits such as those calculated and applied without a multiplier, i.e., Appendix F in *API 610*.

Comment: Some types of equipment are more sensitive to nozzle loads and may require lower than manufacturer’s allowable loads to achieve satisfactory reliability.

4.2.2.9 See Table 1, *Allowable Nozzle Loads*.

### 4.2.3 Essential (Spared) Machinery

4.2.3.1 For essential machinery, piping loads on machinery nozzles should not have a negative impact on the availability or MTBR of the machinery train.

Comment: This preference may not allow full use of the maximum calculated or published allowable loading in order to produce machinery availability and MTBR acceptable to the owner.

4.2.3.2 The manufacturer shall be requested to provide allowable nozzle load recommendations/data (or state the code/standard to which the allowable nozzle loads comply) for the equipment they furnish, as well as the MTBR expected in a machinery installation utilizing these values.

4.2.3.3 A maximum of 100% of the manufacturer’s allowable nozzle loads or the agreed industry standard may be used during the piping layout and system design stage.

Comment: This loading application refers to the piping designer’s allowables and are calculated and applied without a multiplier, i.e., as in *API 610* Appendix F. This mandates an accurate installation that is in accordance with *PIP REIE686/API RP686* because there is no remaining allowable load to accommodate installation inaccuracies.

4.2.3.4 In the absence of applicable manufacturer’s allowable nozzle load data, or stated compliance to a code/standard, a maximum of 50% of the *HI (ANSI) 9.6.2* values shall be used as the allowable nozzle loads for the design.

4.2.3.5 Actual nozzle loading, as indicated by flange alignment, shall be field verified and documented. See *PIP REIE686/API RP686* for recommended tolerances and values for flange alignment.

4.2.3.6 Operating loads as evidenced by their measurable effects shall be verified to be as calculated.

4.2.3.7 All flanges shall be aligned in accordance with *PIP REIE686/API RP686*. Measurement of the actual applied nozzle loads is required for all cold flange alignments that exceed the limits of *PIP REIE686/API RP686*. 
Comment: This typically involves the measurement of the forces required for correction of the flange alignment and nozzle make-up.

4.2.3.8 Calculated final loading of machinery nozzles in the installed system (as built) is permitted up to values in Table 1, Allowable Nozzle Loads.

Comment: Some types of equipment are more sensitive to nozzle loads and may require lower than manufacturer’s allowable loads to achieve satisfactory reliability.

4.2.3.9 See Table 1, Allowable Nozzle Loads.

4.3 Minimizing Nozzle Loads

4.3.1 Design

4.3.1.1 The initial design of piping layout shall minimize nozzle loads.

4.3.1.2 Design of piping guides, supports, and restraints shall be reviewed to ensure that they conform to assumptions for strength, rigidity, clearance, and friction factors used in the nozzle loading calculations.

4.3.1.3 Unless otherwise specified, anchors and restraints shall not be used within a distance of 10 pipe diameters of the machinery nozzles to facilitate blinding and removal of the machinery for maintenance. Suction piping shall be vertically supported so that temporary suction strainers can be removed without requiring temporary piping supports.

4.3.1.4 Anchors or supports adjacent to machinery shall be adjustable, but shall not require adjustment from ambient to operating temperature.

Comment: Normal thermal movement of machinery flanges shall not be restrained by rigid supports.

Comment: Field adjustment may be needed during construction and maintenance.

4.3.1.5 Anchor deflections, for those anchors/restraints adjacent to the machinery, shall be taken into account on piping systems for vital and sensitive machinery.

4.3.1.6 Piping design shall take liquid load into account in spring supported piping systems.

4.3.1.7 Agreement on the nozzle loading criteria and any noncompliance with this Practice should be formally documented between the owner and supplier. In addition, any agreement by the equipment vendor to deviate from his published allowable nozzle loading shall be formally documented.

Comment: While deviations from this Practice on nozzle loadings are discouraged, it is recognized that achieving these criteria may not always be reasonably possible. In such cases, the owner shall be informed of the reasons for deviation, and formally approve the proposed solution. If the resulting loads exceed any of the manufacturer’s allowable loads, written approval is also required of the calculated loads by the manufacturer.

4.3.1.8 Owner approval is required for use of flexible joints, expansion joints, or hoses to minimize nozzle loads.
4.3.1.9 The use of cold spring to compensate for pipe growth shall not be permitted.

4.3.1.10 Where low friction supports are essential in maintaining acceptable nozzle loading, PTFE or other low friction material shall be used.

4.3.1.11 Where low friction is essential in guides and restraints, PTFE or other low friction material shoes or restraining rods with ball ends shall be used.

### 4.3.2 Field Verification

4.3.2.1 Installation of piping shall conform to the requirements of PIP REIE686/API RP686 and PIP PNE00003.

4.3.2.2 Significant actual cold nozzle loads (conditions in excess of the limits stated in PIP REIE686/API RP686), shall be measured to assure that the loadings are within the allowable values.

4.3.2.3 Field verification by the piping stress analysts shall be conducted to ensure that the piping system is in accordance with PIP REIE686/API RP686, the system design, and the nozzle load limitations. Remaining problems, if any, shall be resolved in accordance with this Practice and as mutually agreed and formally documented by the contractor and the owner.

### Table 1 – Allowable Nozzle Loads

<table>
<thead>
<tr>
<th>Equipment Purchase Standard</th>
<th>Piping System and Layout Design</th>
<th>Actual Installation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MACHINERY TYPE</strong></td>
<td><strong>VITAL OR SENSITIVE</strong></td>
<td><strong>ESSENTIAL (SPARED)</strong></td>
</tr>
<tr>
<td>API</td>
<td>50% API</td>
<td>100% API</td>
</tr>
<tr>
<td>HI (ANSI) 9.6.2</td>
<td>50% HI (ANSI) 9.6.2</td>
<td>100% HI (ANSI) 9.6.2</td>
</tr>
<tr>
<td>Manufacturer’s Allowable Values</td>
<td>50% Manufacturer’s Allowable Values</td>
<td>100% Manufacturer’s Allowable Values</td>
</tr>
<tr>
<td>None</td>
<td>25% HI (ANSI) 9.6.2*</td>
<td>50% HI (ANSI) 9.6.2*</td>
</tr>
<tr>
<td>API</td>
<td>100% API</td>
<td>100% API</td>
</tr>
<tr>
<td>HI (ANSI) 9.6.2</td>
<td>100% HI (ANSI) 9.6.2</td>
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</tr>
<tr>
<td>Manufacturer’s Allowable Values</td>
<td>100% Manufacturer’s Allowable Values</td>
<td>100% Manufacturer’s Allowable Values</td>
</tr>
<tr>
<td>None</td>
<td>50% HI (ANSI) 9.6.2*</td>
<td>100% HI (ANSI) 9.6.2*</td>
</tr>
</tbody>
</table>

*Note: Application of significant nozzle loads to equipment that has no stated allowable value, from the manufacturer, may not be acceptable. All such applications, of equipment nozzle loads, should be specifically approved by the manufacturer. In some of these cases, even the application of the values calculated in accordance with the above table may be excessive.

Note: Design allowable loads for vital or sensitive machinery is reduced to 50% to provide additional tolerance during the construction phase of a project.