

# Liquid Ring Compressors and Vacuum Pumps in Petroleum, Chemical, and Gas Industry Services

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## Introduction

Users of this standard should be aware that further or differing requirements may be needed for individual applications. This standard is not intended to inhibit a vendor from offering, or the purchaser from accepting, alternative equipment or engineering solutions for the individual application. This may be particularly appropriate where there is innovative or developing technology. Where an alternative is offered, the vendor should identify any variations from this standard and provide details.

- Annex A contains data sheets which purchasers are encouraged to use.
- Annex B contains guidelines for submittal of contract documents and engineering design data including typical forms which may be used to indicate vendor drawing and data requirements.
- Annex C contains nomenclature for the various equipment components.
- Annex D specifies requirements and gives guidance on materials selection.
- Annex E contains schematic drawings of ring liquid systems.
- Annex F contains system considerations, operating variables, and test performance guidance.
- Annex G contains guidance on packaging.

This standard requires the purchaser to specify certain details and features. A bullet [•] in the margin indicates that either a decision by, or further information from, the purchaser is required. Further information should be shown on the data sheets (see example in Annex A) or stated in the quotation request and purchase order.

In this standard, U.S. customary units are included in brackets for information.



# Liquid Ring Compressors and Vacuum Pumps in Petroleum, Chemical, and Gas Industry Services

## 1 Scope

**1.1** This standard covers the minimum requirements for liquid ring compressor and vacuum pump (LRC/VP) systems for service in the petroleum, chemical, and gas industries. The requirements include basic equipment design, materials, fabrication, inspection, testing, and preparation for shipment.

**1.2** This standard requires the purchaser to specify certain details and features. A bullet [•] in the margin indicates that a decision by, or further information from, the purchaser is required. Further information should be stated in the quotation request and purchase order.

**1.3** The purchaser and the vendor shall mutually determine the measure that shall be taken to comply with governmental codes, regulations, ordinances, or rules that are applicable to the equipment.

## 2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

API Recommended Practice 500, *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division 1 and Division 2*

API Recommended Practice 686, *Machinery Installation, and Installation Design*

API Recommended Practice 691, *Risk-based Machinery Management*

API Standard 520, *Sizing, Selection, and Installation of Pressure-Relieving Devices in Refineries; Part I— Sizing and Selection*

API Standard 520, *Sizing, Selection, and Installation of Pressure- relieving Devices in Refineries; Part II— Installation*

API Standard 526, *Flanged Steel Pressure Relief Valves*

API Standard 541, *Form-wound Squirrel- cage Induction Motors—500 Horsepower and Larger*

API Standard 547, *General-purpose Form- wound Squirrel-cage Induction Motors—250 Horsepower and Larger*

API Standard 614, *Lubrication, Shaft-sealing, and Control-oil Systems and Auxiliaries*

API Standard 670: *Machinery Protection Systems*

API Standard 677, *General-Purpose Gear Units for Petroleum, Chemical and Gas Industry Services*

API Standard 682, *Pumps—Shaft Sealing Systems for Centrifugal and Rotary Pumps*

ABMA Standard 7, <sup>1</sup> *Shaft, Housing Fits for Metric Radial Ball and Roller Bearings (Except Tapered Roller Bearings) Conforming to Basic Boundary Plans*

ABMA 19.1, *Tapered Roller Bearings—Radial Metric Design*

<sup>1</sup> American Bearing Manufacturers Association, 2025 M Street, NW, Suite 800, Washington, DC 20036, [www.abma-dc.org](http://www.abma-dc.org)

ABMA 19.2, *Tapered Roller Bearings—Radial Inch Design*

AGMA 9000, <sup>2</sup> *Flexible Couplings—Potential Unbalance Classification*

AGMA 9002, *Bores and Keyways for Flexible Couplings (Inch Series)*

ASME, <sup>3</sup> *Boiler and Pressure Vessel Code (BPVC), Section V—Non-destructive Examination*

ASMEBPVC, *Section VII—Pressure Vessels—Division 1*

ASME BPVC, *Section IX—Welding and Brazing Qualifications*

ASME B1.1, *Unified Inch Screw Threads (UN and UNR Thread Form)*

ASME B1.20.1, *Pipe Threads, General Purpose (Inch)*

ASME B16.1, *Gray Iron Pipe Flanges and Flanged Fittings (Classes 25, 125 and 250)*

ASME B16.5, *Pipe Flanges and Flanged Fittings NPS 1/2 Through NPS 24 Metric/Inch Standard*

ASME B16.11, *Forged Fittings, Socket Welding and Threaded*

ASME B16.42, *Ductile Iron Pipe Flanges and Flanged Fittings*

ASME B31.3, *Process Piping*

ASTM A388, *Standard Practice for Ultrasonic Examination of Steel Forgings*

ASTM A578/A578M, *Standard Specification for Straight-Beam Ultrasonic Examination of Rolled Steel Plates for Special Applications*

ASTM A609, *Standard Practice for Castings, Carbon, Low-Alloy, and Martensitic Stainless Steel, Ultrasonic Examination Thereof*

AWS D1.1, <sup>4</sup> *Structural Welding Code—Steel*

ANSI B11/B11.19, <sup>5</sup> *Machines—Performance Criteria for Safeguarding*

EN 1092-1, <sup>6</sup> *Flanges and their joints—Circular flanges for pipes, valves, fittings, and accessories, PN designated — Part 1: Steel flanges*

EN 1092-2, *Flanges and their joints—Circular flanges for pipes, valves, fittings, and accessories, PN designated —Part 2: Cast Iron flanges*

HEI 2854, <sup>7</sup> *Performance Standard for Liquid Ring Vacuum Pumps and Compressors*

IEC 60079, <sup>8</sup> *Explosive Atmospheres*

<sup>2</sup> American Gear Manufacturers Association, 500 Montgomery Street, Suite 350, Alexandria, Virginia 22314, [www.agma.org](http://www.agma.org).

<sup>3</sup> ASME International, Three Park Avenue, New York, New York 10016-5990, [www.asme.org](http://www.asme.org).

<sup>4</sup> American Welding Society, 550 NW LeJeune Road, Miami, Florida 33126, [www.aws.org](http://www.aws.org).

<sup>5</sup> B11 Standards Inc. (Formerly AMT), 7901 Westpark Drive, McLean, VA 22102-4269, [www.b11standards.org](http://www.b11standards.org).

<sup>6</sup> European Committee for Standardization, Avenue Marnix 17, B-1000, Brussels, Belgium, [www.cen.eu](http://www.cen.eu).

<sup>7</sup> Heat Exchange Institute, 1300 Sumner Ave., Cleveland, Ohio 44115, [www.heatexchange.org](http://www.heatexchange.org).

<sup>8</sup> International Electro Technical Commission, 3, rue de Varembe, P.O. Box 131, CH-1211, Geneva 20, Switzerland, [www.iec.ch](http://www.iec.ch).

IEEE 841,<sup>9</sup> *Standard for Petroleum and Chemical Industry—Premium Efficiency, Severe-Duty, Totally Enclosed Fan-cooled (TEFC) Squirrel Cage Induction Motors—Up to and Including 370 kw (500 hp)*

ISO 7-1,<sup>10</sup> *Pipe threads where pressure-tight joints are made on the threads — Part 1: Dimensions, tolerances and designation*

ISO 261, *ISO general-purpose metric screw threads — General plan*

ISO 281, *Rolling Bearings — Dynamic load ratings and rating life*

ISO 21940-11, *Mechanical vibration — Rotor balancing — Part 11: Procedures and tolerances for rotors with rigid behaviour*

ISO 3744, *Acoustics — Determination of sound power levels of noise sources using sound pressure — Engineering method in an essentially free field over a reflecting plane*

ISO 5753, (All Parts), *Rolling bearings — Internal Clearance*

ISO 6708, *Pipework components — Definition and selection of DN (nominal size)*

ISO 8501, (All Parts), *Preparation of steel substrates before application of paints and related products—Visual assessment of surface cleanliness*

ISO 8068, *Lubricants, industrial oils, and related products (class L) — Family T (Turbines) — Specification for lubricating oils for turbines*

ISO 9606-1, *Qualification testing of welders — Fusion welding — Part 1: Steels*

ISO 14120, *Safety of Machinery — Guards — General requirement for the design and construction of fixed and movable guards*

MSS SP-55,<sup>11</sup> *Quality Standard for Steel Castings for Valves, Flanges, Fittings and Other Piping Components—Visual Method for Evaluation of Surface Irregularities*

NACE MR 0103,<sup>12</sup> *Petroleum, Petrochemical and Natural Gas Industries — Metallic Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments*

PNEUROP 6612,<sup>13</sup> *Acceptance Specification for Liquid Ring Vacuum Pumps*

SSPC SP 6,<sup>14</sup> *Commercial Blast Cleaning*

<sup>9</sup> Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, New Jersey 08854, [www.ieee.org](http://www.ieee.org).

<sup>10</sup> International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, [www.iso.org](http://www.iso.org).

<sup>11</sup> Manufacturers Standard Society of the Valve and Fittings Industry, Inc., 127 Park Street, NE, Vienna, Virginia 22180-4602, [www.mss-hq.com](http://www.mss-hq.com).

<sup>12</sup> National Association of Corrosion Engineers NACE International, 1440 South Creek Drive, Houston, TX, 77084, [www.nace.org](http://www.nace.org).

<sup>13</sup> European Association of Manufacturers of Compressors, Vacuum Pumps, Pneumatic Tools and Air & Condensate Treatment Equipment, BluePoint Brussels, 80 Bd Reyers, 1030 Brussels, Belgium, [www.pneurop.eu](http://www.pneurop.eu).

<sup>14</sup> The Society for Protective Coatings, 800 Trumbull Drive, Pittsburgh, Pennsylvania 15205, [www.sspc.org](http://www.sspc.org).

## 3 Terms, Definitions, Acronyms, and Abbreviations

### 3.1 Terms and Definitions

For the purposes of this document, the following terms, definitions, acronyms, and abbreviations apply.

#### 3.1.1

##### **anchor bolt**

Bolt used to attach the baseplate to the support structure (concrete foundation or steel structure).

#### 3.1.2

##### **baseplate**

Component on which the drive train and liquid ring compressor or vacuum pump (LRC/VP) are bolted, which is then fastened to the support structure using anchor bolts.

#### 3.1.3

##### **capacity**

Flow rate of the process fluid through the machine at operating conditions.

#### 3.1.4

##### **casing**

The composite of all stationary pressure-containing parts of the unit, including all nozzles, seal glands, and other attached parts but excluding the stationary and rotating members of mechanical seals.

#### 3.1.5

##### **certified material test report**

##### **CMTR**

Certified report documenting the actual chemical composition and physical properties, of furnished materials.

#### 3.1.6

##### **certified point**

Point to which the performance tolerances will be applied.

NOTE 1 Performance includes the following factors: capacity, power, efficiency, rotational speed, and rated suction and discharge pressures.

NOTE 2 This is usually the normal operating point and the vendor will normally require that this point is within the preferred selection range.

#### 3.1.7

##### **containment shell**

Pressure containing boundary located within the drive end that separates the inner and outer magnet rings of a magnetic drive LRC/VP.

#### 3.1.8

##### **critical speed**

Shaft rotational speed at which rotor-bearing-support system is in a state of resonance.

#### 3.1.9

##### **design**

Manufacturer's calculated parameter.

NOTE This is a term used by the equipment manufacturer to describe various parameters such as design power, design pressure, design temperature, or design speed. It is not intended for the purchaser to use this term.

**3.1.10****differential pressure**

The discharge pressure of the process fluid minus the suction pressure of the fluid.

**3.1.11****drive train components**

Equipment used in series to drive the LRC/VP (e.g. motor, gear, fluid drive, clutch).

**3.1.12****efficiency**

Ratio of the LRC/VP net capacity corrected to rated conditions versus brake horsepower.

NOTE 1 This ratio would be expressed as CFM/BHP.

NOTE 2 This differs from efficiency calculations for pumps in that those efficiencies are typically calculated by dividing power out by power in.

**3.1.13****fail safe**

System or component which will cause the equipment to revert to a permanently safe condition (shutdown or depressurized, or both) in the event of a component failure or failure of the energy supply to the system.

**3.1.14****gauge board**

Bracket or plate used to support and display gauges, switches, and other instruments.

NOTE A gauge board is open and not enclosed.

**3.1.15****hold-down bolt  
(mounting bolt)**

Bolts used to attach the equipment to its mounting surface.

**3.1.16****informative**

information only; cf. normative (3.1.41)

NOTE An informative reference or Annex provides advisory or explanatory information. It is intended to assist the understanding or use of the document.

**3.1.17****inlet volume flow**

Flow rate expressed in volume flow units at the conditions of pressure, temperature, compressibility, and gas composition, including moisture content, at the LRC/VP suction flange.

**3.1.18****inspection and test plan****ITP**

Single project-specific document used with extended scope for heavy duty LRC/VP in complex packages to consolidate all inspection and test elements, the criteria required to be met, and the roles and responsibilities.

**3.1.19****liquid ring compressor or vacuum pump  
LRC/VP**

A rotary positive-displacement machine in which gas compression is achieved by the action of a radially bladed impeller mounted in an eccentric or elliptical casing which is partially filled with liquid.

**3.1.20****liquid ring compressor**

Liquid ring compressor is generally designated to apply to all applications where the suction pressure is equal to or above site atmospheric conditions.

**3.1.21****liquid ring vacuum pump**

Liquid ring vacuum pump is generally designated to apply to all applications where the suction pressure is less than site atmospheric conditions regardless of discharge pressure.

**3.1.22****liquid ring**

Liquid ring is the boundary layer of fluid that is created by the interaction of impeller with the fluid contained in the end of the equipment. This ring creates the compression chambers as the impeller rotates.

**3.1.23****local**

Position of devices mounted on or near the equipment or console.

**3.1.24****magnetic coupling**

Attraction of the magnets of the -inner magnet ring and outer magnet ring allowing both to rotate synchronously or asynchronously in the case of a torque ring drive.

**3.1.25****magnetic drive liquid ring compressor or vacuum pump**

Type of sealless LRC/VP which utilizes magnets to drive an internal rotating assembly consisting of an impeller, shaft, and inner drive member (torque ring or inner magnet ring) through a thin, corrosion resistant containment shell (see Annex C).

**3.1.26****maximum allowable temperature**

Maximum continuous temperature for which the manufacturer has designed the equipment (or any part to which the term is referred) when handling the specified fluid at the specified maximum operating pressure.

**3.1.27****maximum allowable working pressure****MAWP**

Maximum continuous pressure for which the manufacturer has designed the equipment (or any part to which the term is referred) when handling the specified fluid at the specified maximum allowable temperature.

**3.1.28****maximum continuous speed**

Highest rotational speed (revolutions per minute) at which the machine, as-built and tested, is capable of continuous operation with the specified ring fluid at any of the specified operating conditions.

**3.1.29****maximum differential pressure**

The maximum differential pressure for which the manufacturer has designed the equipment for continuous operation.

**3.1.30****maximum discharge pressure**

Maximum suction pressure plus the maximum differential pressure that the LRC/VP is able to develop when operating at the specified speed, specific gravity, and pumping temperature.

**3.1.31****maximum suction pressure**

Highest suction pressure the LRC/VP will be subject to in service.

**3.1.32****minimum continuous speed**

Lowest rotational speed (revolutions per minute) at which the manufacturer's design will permit continuous operation with the specified fluid at any of the specified operating conditions.

**3.1.33****minimum continuous non-condensable gas flow**

Lowest non-condensable gas flow at which the LRC/VP equipment can operate.

**3.1.34****minimum continuous ring liquid flow**

Lowest ring liquid flow at which the LRC/VP can operate.

**3.1.35****minimum design metal temperature**

Lowest mean metal temperature (through the thickness) expected in service, including operation upsets, auto-refrigeration, and temperature of the surrounding environment, for which the equipment is designed.

**3.1.36****nominal pipe size****NPS**

Value approximately equal to a diameter in inches (e.g. NPS  $\frac{3}{4}$ ).

EXAMPLE NPS  $\frac{3}{4}$ .

NOTE 1 Refer to ASME B 31.3.

NOTE 2 The letters NPS are followed by a value which is related to an approximate diameter of the bore, in inches, for piping up to and including 12 in. diameter. For piping over 12 in. (NPS 12), the NPS value is the nominal OD.

**3.1.37****nominal pressure****PN**

Numerical designation relating to pressure that is a convenient round number for reference purposes (e.g. PN 100).

EXAMPLE PN 100

NOTE The permissible working pressure associated with a PN designation depends upon materials, design and working temperature and has to be selected from the pressure/temperature rating tables in corresponding standards.

**3.1.38****nondestructive examination****NDE**

Inspection of materials, components, or assemblies typically by means of radiography, liquid penetrant, magnetic particle, or ultrasonic testing. Other methods may be used if agreed to by the purchaser and vendor.

**3.1.39****normal operating point**

Point at which usual operation is expected and optimum efficiency is desired. This point is usually the point at which the vendor certifies that performance is within the tolerances stated in this standard.

**3.1.40****normative**

Information that is required; cf. informative (3.1.16)

NOTE A normative reference or Annex enumerates a requirement or mandate of the specification.

**3.1.41****observed inspection****observed test**

Inspection or test where the purchaser is notified of the timing of the inspection or test and the inspection or test is performed as scheduled even if the purchaser or their representative is not present.

**3.1.42****owner**

Final recipient of the equipment who may delegate another agent as the purchaser of the equipment.

**3.1.43****performance test**

Running test conducted to verify flow rate, density, differential pressure, torque, and power consumed at specified conditions.

**3.1.44****positive material identification****PMI**

Any physical evaluation or test of a material to confirm that the material which has been or will be placed into service is consistent with what is specified by the owner/user. These evaluations or tests can provide either qualitative or quantitative information that is sufficient to verify the composition.

**3.1.45****pressure containing part**

Any part that acts as a barrier between process or motive fluid and the atmosphere.

**3.1.46****pressure retaining part**

Any part whose mechanical failure would allow process or motive fluid to escape to the atmosphere.

**3.1.47****purchaser**

Agency that issues the order and specification to the vendor.

NOTE The purchaser can be the owner of the plant in which the equipment is to be installed or the owner's appointed agent.

**3.1.48****radially split**

Refers to casing joints that are transverse to the shaft centerline.

**3.1.49****rated discharge pressure**

The highest pressure required to meet the conditions specified by the purchaser for the intended service.

**3.1.50****rated point**

Maximum purchaser specified capacity.

**3.1.51****rated power**

Power delivered to the equipment input shaft at rated point. It is also called brake power (brake horsepower, brake kilowatts, etc.).

**3.1.52****rated speed****100 % speed**

Highest rotational speed (revolutions per minute) required to meet any of the specified operating conditions.

NOTE Rated speed can be different than the normal operating speed since the normal operating speed is determined by the normal operating point.

**3.1.53****remote**

Control device located away from the equipment or console, typically in a control room.

**3.1.54****ring liquid**

The fluid that is used to form the liquid ring in an LRC/VP.

NOTE This is not to be confused with Seal Flush Liquid.

**3.1.55****seal flush liquid**

The fluid that is used to provide lubrication or buffering to a mechanical seal.

NOTE This is not to be confused with Ring Liquid.

**3.1.56****shutdown**

Condition as determined by the equipment user that requires action to stop the equipment.

**3.1.57****spark resistant material**

material that is not prone to generate impact sparks under conditions of use.

**3.1.58****special tool**

Tool that is not a commercially available catalog item.

**3.1.59****standard volume flow**

Flow rate expressed in volume flow units at standard conditions. See Table 1.

**Table 1—SI and U.S. Standard Conditions**

| SI Standard Conditions                                                    |                                                                                            |
|---------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| ISO 13443 Standard Conditions (Natural gas standard reference conditions) |                                                                                            |
| Flow                                                                      | Cubic meters per hour (m <sup>3</sup> /h)<br>Cubic meters per minute (m <sup>3</sup> /min) |
| Pressure:                                                                 | 101.325 kPa (1.013 bara)                                                                   |
| Temperature:                                                              | 15 °C                                                                                      |
| Relative Humidity:                                                        | Dry                                                                                        |

**Table 1—SI and U.S. Standard Conditions (Continued)**

| SI Standard Conditions   |                                                                                       |
|--------------------------|---------------------------------------------------------------------------------------|
| U.S. Standard Conditions |                                                                                       |
| Flow                     | Standard cubic feet per minute (scfm)<br>Million standard cubic feet per day (mmscfd) |
| Pressure:                | 14.7 psia                                                                             |
| Temperature:             | 60 °F                                                                                 |
| Relative Humidity:       | Dry                                                                                   |

**3.1.60****steady state**

Condition under which specific metering parameters such as flow rate, differential pressure, speed, suction pressure, discharge pressure, and fluid type are not changing by more than  $\pm 10\%$  over a two-minute period.

**3.1.61****suction pressure**

The pressure of the process fluid measured at the LRC/VP suction flange.

**3.1.62****total indicator reading****total indicated run-out****TIR**

Difference between the maximum and minimum readings of a dial indicator or similar device, monitoring a face or cylindrical surface for one complete revolution of the monitored surface.

NOTE For a cylindrical surface, the indicated run-out implies an eccentricity equal to half the reading. For a flat face, the indicated run-out implies an out-of-squareness equal to the reading. If the diameter in question is not perfectly cylindrical or flat, the interpretation of the meaning of TIR is more complex and can represent ovality or surface irregularities.

**3.1.63****trip**

Automated shutdown to ensure personnel safety (safety critical).

**3.1.64****trip speed**

speed at which the independent emergency overspeed device operates to shut down the driver.

**3.1.65****unit responsibility**

Obligation for coordinating the documentation, delivery, and technical aspects of all the equipment and all auxiliary systems included in the scope of the order.

**3.1.66****vendor**

Manufacturer or manufacturer's agent that supplies the equipment.

**3.1.67****witnessed**

a classification of inspection or test where the purchaser is notified of the schedule of the inspection or test and a hold is placed until the purchaser or the purchaser's representative is in attendance or they waive their presence at the inspection or test.

### 3.2 Acronyms and Abbreviations

|        |                                                                          |
|--------|--------------------------------------------------------------------------|
| ASTM   | ASTM International (formerly American Society for Testing and Materials) |
| EN     | European Committee for Standardization                                   |
| ISO    | International Organization for Standardization                           |
| JIS    | Japanese Industrial Standards                                            |
| LRC/VP | liquid ring compressor or vacuum pump                                    |
| MAWP   | maximum allowable working pressure                                       |
| PMI    | positive material identification                                         |
| PWHT   | post-weld heat treatment                                                 |

## 4 General

### 4.1 Unit Responsibility

The vendor who has unit responsibility shall ensure that all sub-vendors comply with the requirements of this standard and all reference documents. These include, as a minimum, such factors as the functionality, power requirements, speed, rotation, general arrangement, couplings, dynamics, noise, lubrication, sealing system, certified material test reports, instrumentation, piping, documentation, conformance to specifications, and testing of components by vendor and any and all sub-vendors.

### 4.2 Nomenclature

A guide to liquid ring compressor and vacuum pump component nomenclature pertaining to different equipment types, flow configurations, and operational characteristics is outlined and listed in Annex C (informative) for reference.

## 5 Requirements

### 5.1 Units of Measure

Purchaser's use of a USC data sheet (see Annex A.1) indicates the USC system of measurements shall be used for all data, drawings, and maintenance dimensions. Purchaser's use of an SI data sheet (see Annex A.2) indicates the SI system of measurements shall be used.

NOTE Dedicated data sheets for SI units and U.S. customary units are provided in Annex A.

### 5.2 Statutory Requirements

The purchaser and the vendor shall determine the measures to be taken to comply with any governmental codes, regulations, ordinances, directives, or rules that are applicable to the equipment, its packaging, and any preservatives used.

### 5.3 Conflicting Requirements

- [•] The purchaser shall specify the hierarchy of documents.

NOTE Typical documents include company and industry specifications, meeting notes, and modifications to these documents.

## 6 Basic Design

### 6.1 General

#### 6.1.1 Equipment Reliability

- [●] **6.1.1.1** Only equipment that is field proven, as defined by the purchaser, is acceptable.

NOTE Purchasers can use their engineering judgment in determining what equipment is field proven. API 691 can provide guidance.

- [●] **6.1.1.2** If specified, the vendor shall provide the documentation to demonstrate that all equipment proposed qualifies as field proven.

**6.1.1.3** In the event no such equipment is available, the vendor shall submit an explanation of how their proposed equipment can be considered field proven.

NOTE A possible explanation can be that all components comprising the assembled machine satisfy the field proven definition.

- [●] **6.1.1.4** The purchaser shall specify the period of uninterrupted continuous operation. Shutting down the equipment to perform required maintenance or inspection during the specified uninterrupted operation period is not acceptable.

NOTE 1 It is realized that there are some services where this objective is easily attainable and others where it is difficult.

NOTE 2 Auxiliary system design and design of the process in which the equipment is installed are very important in meeting this objective.

**6.1.1.5** Vendor shall advise in the proposal any component designed for a finite life.

NOTE It is recognized that these are design criteria.

- [●] **6.1.2** The purchaser shall specify the equipment's certified operating point, and all other required operating points.

- [●] **6.1.3** The purchaser shall specify gas composition(s), including any corrosive agents, and presence of any liquids.

**6.1.3.1** The LRC/VP vendor shall use the specified values of flow, the gas composition, and the gas conditions to calculate relative molecular mass, ratio of specific heats ( $C_p/C_v$ ) and compressibility factor ( $Z$ ).

**6.1.3.2** The LRC/VP vendor shall provide the calculated values with the proposal and use them to calculate performance data.

- [●] **6.1.4** The purchaser shall furnish properties of the fluid used for the ring liquid including, but not limited to, the following:

- temperature/vapor pressure curve
- temperature/viscosity curve,
- specific heat, and
- specific gravity.

The purchaser shall also furnish information on any gas entrainment or solids present including particle size, percent, and distribution.

NOTE Properties of the fluid being used for the ring liquid are critical.

**6.1.5** Equipment shall be designed for flammable and hazardous applications.

**6.1.6** If non-flammable or non-hazardous service has been specified, the vendor may propose an alternative design.

**6.1.7** The equipment shall be capable of operating within the entire performance map at all specified operating conditions, as well as accommodating other conditions, such as trip and startup.

[•] **6.1.8** Control of the sound pressure level of all equipment furnished shall be a joint effort of the purchaser and the vendor having unit responsibility.

**6.1.8.1** The equipment furnished by the vendor shall conform to the maximum allowable sound pressure level specified.

**6.1.8.2** The vendor shall provide expected values for maximum sound pressure level per octave band for the equipment.

**6.1.9** Cooling water system or systems shall be designed on the water side for the conditions shown in Table 2.

**Table 2—Conditions for Cooling Water System Design Parameters**

|                                             |                                  |                          |
|---------------------------------------------|----------------------------------|--------------------------|
| Water Velocity overheat exchange surfaces   | 5 ft/s to 8 ft/s                 | ≥1.5 m/s to 2.5 m/s      |
| Maximum allowable working pressure (MAWP)   | ≥100 psig                        | ≥700 kPag (7 barg)       |
| Test pressure (≥1.5 MAWP)                   | ≥150 psig                        | ≥1050 kPag (10.5 barg)   |
| Maximum pressure drop                       | 15 psi                           | 100 kPa (1 bar)          |
| Maximum inlet temperature                   | 90 °F                            | 30 °C                    |
| Maximum outlet temperature                  | 120 °F                           | 50 °C                    |
| Maximum temperature rise                    | 30 °F                            | 20 °C                    |
| Minimum temperature rise                    | 20 °F                            | 10 °C                    |
| Water side fouling factor                   | 0.002 hr-ft <sup>2</sup> -°F/Btu | 0.35 m <sup>2</sup> K/kW |
| Corrosion allowance for carbon steel shells | 1/8 in.                          | 3 mm                     |

**6.1.9.1** The vendor shall notify the purchaser if the criteria for minimum temperature rise and velocity overheat exchange surfaces result in a conflict. If such a conflict exists, the purchaser shall approve the final selection.

NOTE The criterion for velocity overheat exchange surfaces is intended to minimize water-side fouling; the criterion for minimum temperature rise is intended to minimize the use of cooling water.

**6.1.9.2** Provision shall be made for complete venting and draining of the system or systems.

**6.1.10** Equipment shall be designed to operate simultaneously at the relief valve setting and trip speed without damage regardless of driver power.

**6.1.11** LRC/VPs shall be capable of operating at least up to the maximum continuous speed. The maximum continuous speed shall be:

a) equal to the speed corresponding to the synchronous speed at frequency for electrical motor

- b) at least 105 % of rated speed for adjustable speed LRC/VPs.

**6.1.12** The equipment's trip speed shall not be less than the following percentages of maximum continuous speed:

- a) adjustable speed motor—105 %,
- b) constant speed motor—102 %.

**6.1.13** Housings that enclose moving lubricated parts such as bearings, shaft seals, highly polished parts, instruments, and control elements shall be designed to minimize contamination by moisture, dust, and other foreign matter during periods of operation and idleness.

**6.1.14** All equipment shall be designed to permit rapid maintenance. Major parts such as casing components and bearing housings shall be designed and manufactured to ensure accurate alignment on reassembly.

NOTE This can be accomplished by the use of shouldering, cylindrical dowels, or keys.

**6.1.15** The equipment (machine, driver, and auxiliary equipment) shall perform on the test stand(s) and on their permanent foundation within the specified acceptance criteria. After installation, the performance of the combined units shall be the joint responsibility of the purchaser and the vendor who has unit responsibility.

- [●] **6.1.16** If specified, the vendor shall review and comment on the purchaser's piping and foundation drawings.

NOTE Many factors can adversely affect site performance. These factors include such items as piping loads, alignment at operating conditions, supporting structure, handling during shipment, and handling and assembly at the site.

- [●] **6.1.17** If specified, the vendor's representative shall witness:

- a) A check of the piping alignment performed by unfastening the major flanged connections of the equipment.
- b) The initial shaft alignment check at ambient conditions.
- c) Shaft alignment at operating temperature. i.e. hot alignment check.

NOTE Refer to API RP 686 for basic guidelines for conducting alignments, shaft hot and cold alignment.

- [●] **6.1.18** The equipment, including all auxiliaries, shall be suitable for operation under the environmental conditions specified. These conditions shall include whether the installation is indoors (heated or unheated) or outdoors (with or without a roof), maximum and minimum temperatures, unusual humidity, and dusty or corrosive conditions.

- [●] **6.1.19** The equipment, including all auxiliaries, shall be suitable for operation using the site and utility conditions specified.

**6.1.20** All equipment shall be additionally suitable for running on air during commissioning. The vendor shall provide air performance curves, operating guidelines, and any additional features required.

NOTE Field run on air is intended to be a confirmation of mechanical integrity, and not a field performance test.

### **6.1.21 Electrical Classification**

**6.1.21.1** Locations for installed equipment can be classified as hazardous electrical areas or they can be unclassified. An unclassified area is considered non-hazardous; therefore, motors, electrical instrumentation, equipment, components, and electrical installations for unclassified areas are not governed by hazardous area electrical codes.

- [•] **6.1.21.2** If an installation location is classified as hazardous, motors, electrical instrumentation, equipment, components, and electrical installations shall be suitable for the hazardous electrical area classification designation as specified.
- [•] **6.1.21.3** All applicable electrical codes shall be specified. Local electrical codes that apply shall be provided by the purchaser upon request.

### **6.1.22 Bolting and Threads**

**6.1.22.1** Bolting shall be furnished with threads conforming to ASME B1.1 or ISO 261.

**6.1.22.2** Fasteners (excluding washers and set-screws) shall have the material grade and manufacturer's identification symbols applied to the exposed end of studs  $\frac{3}{8}$  in. (10 mm) in diameter and larger and to the heads of bolts  $\frac{1}{4}$  in. (6 mm) in diameter and larger.

NOTE A set screw is a headless screw with an internal hexagonal opening in one end.

**6.1.22.3** If the available area is inadequate, the grade symbol shall be marked on the exposed end of studs and the manufacturer's identification symbol marked on the other end.

**6.1.22.4** Adequate clearance shall be provided at all bolting locations to permit the use of socket or box wrenches.

**6.1.22.5** Internal socket-type, slotted-nut, or spanner-type bolting shall not be used unless approved by the purchaser.

NOTE For limited space locations, integrally flanged fastener can be required.

**6.1.23** Spare and replacement parts for the machine and all furnished auxiliaries shall meet all the criteria of this standard.

## **6.2 Pressure Casings**

**6.2.1** The pressure casing shall be designed to:

- a) Operate without leakage or internal contact between rotating and stationary components while subject simultaneously to the MAWP (and corresponding temperature) and the worst case combination of maximum allowable nozzle loads applied to all nozzles.
- b) Withstand the hydrostatic test.

**6.2.1.1** The tensile stress used in the design of the pressure casing for any material shall not exceed 0.25 times the minimum ultimate tensile strength or 0.67 times the minimum yield strength for that material, whichever is lower, across the full range of specified operating temperatures.

NOTE In general deflection is the determining consideration in the design of casings. Ultimate tensile or yield strength is seldom the limiting factor.

**6.2.1.2** For cast materials, the allowable tensile stress shall be multiplied by the appropriate casting factor as shown in Table 3.

**Table 3—Material Casting Factors**

| Type of NDE                                   | Casting Factor |
|-----------------------------------------------|----------------|
| Visual, magnetic particle or liquid penetrant | 0.8            |
| Spot radiography                              | 0.9            |
| Ultrasonic                                    | 0.9            |
| Full radiography                              | 1.0            |

**6.2.1.3** The manufacturer shall state the source of the material properties from those listed in Table D.2 (i.e. ASTM, UNS, ISO, EN, JIS), as well as the casting factors applied, in the proposal.

**6.2.1.4** National material standards other than those listed in Annex D, Table D.2, may be used with purchaser approval.

**6.2.1.5** Design criteria for application of ceramics/composite containment shells shall be agreed between the vendor and purchaser.

**6.2.1.6** Pressure-containing components may be designed with the aid of finite element analysis provided that the value of the stress intensity reflects a requirement to perform a hydrotest at 150 % of MAWP.

**6.2.1.7** Rotating equipment pressure casings are outside of the scope of ASME BPVC. ASME BPVC manufacturing data report forms, third party inspections, and stamping are not required.

**6.2.2** A corrosion allowance of at least  $\frac{1}{8}$  in. (3 mm) shall be added to the casing thickness used in 6.2.1.1 or 6.2.1.6.

**6.2.2.1** This corrosion allowance shall also be added to all auxiliary connections exposed to the same fluid as the pressure containing casing.

**6.2.2.2** The vendor may propose alternative corrosion allowances for consideration if materials of construction with superior corrosion resistance are employed without affecting functionality, safety, and reliability.

**6.2.3** The maximum allowable working pressure of the casing shall be at least equal to the specified relief valve set pressure. If a relief valve set pressure is not specified, the maximum allowable working pressure shall be at least 125 % of the maximum discharge pressure as defined in 3.1.30.

**6.2.4** Where more than one compression stage is incorporated within a single casing, the whole of that casing shall be designed for the maximum allowable working pressure of the higher pressure stage.

**6.2.5** Casings and supports shall be designed to have sufficient strength and rigidity to limit any change in the relative position of the shaft ends at the coupling flange, caused by the worst combination of allowable pressure, torque, and piping forces and moments, to 0.002 in. (50  $\mu$ m).

**6.2.6** Threaded holes in vacuum and pressure parts shall only be provided if approved by the purchaser.

**6.2.6.1** To prevent leakage in pressure sections of casings, metal equal to at least  $\frac{1}{2}$  in. (12 mm), in addition to the corrosion allowance, shall be left around and below the bottom of drilled and threaded holes.

**6.2.6.2** The depth of the threaded holes shall be at least 1.5 times the diameter of the stud, plug, etc.

**6.2.7** Studs shall be supplied on the bolted end covers of radially split casings. Studs shall be used instead of cap screws on all other joints except where hexagonal head cap screws are essential for assembly purposes and have been approved by the purchaser.

**6.2.8** Jackscrews, guide rods, cylindrical casing-alignment dowels or other appropriate devices, or a combination thereof, shall be provided to facilitate disassembly and reassembly.

**6.2.8.1** Guide rods shall be of sufficient length to prevent damage to the internals or casing studs by the casing during disassembly and reassembly.

**6.2.8.2** If jackscrews are used as a means of parting contacting faces, one of the faces shall be relieved (counter bored or recessed) to prevent a leaking joint or an improper fit caused by marring of the face.

**6.2.9** Mounting surfaces on the LRC/VP shall meet the following criteria:

- a) They shall be machined to a finish of 250  $\mu\text{in}$  (6.3  $\mu\text{m}$ ) *Ra* (arithmetic average roughness) or better.
- b) The upper machined or spot-faced surface shall be parallel to the mounting surface.
- c) Hold-down bolt holes shall be drilled perpendicular to the mounting surface or surfaces.

**6.2.9.1** Holes shall be spot faced to a diameter suitable for a washer positioned eccentrically around the bolt.

**6.2.9.2** Holes shall not be slotted.

### **6.3 Casing Connections**

**6.3.1** Casings with double flow suction or discharge connections shall be furnished with manifolds to a single terminal point connection. The manifolds shall be designed for the same vacuum and maximum allowable working pressure as the casing.

**6.3.2** All connections shall be flanged or machined and studded, except where threaded connections are permitted by 6.3.7.

**6.3.2.1** All connections shall be suitable for the maximum allowable working pressure of the casing as defined in 3.1.27.

**6.3.2.2** Flanged connections may be integral with the casing (or cylinder) or, for casings (cylinders) of weldable material, may be formed by a socket-welded or butt-welded pipe nipple or transition piece, and shall terminate with a welding-neck or socket-weld flange.

**6.3.3** All openings or nozzles for piping connections on pressure casings shall be NPS  $\frac{3}{4}$  (DN 20) or larger. DN connections shall be in accordance with ISO 6708.

**6.3.4** Sizes NPS 1- $\frac{1}{4}$ , 2- $\frac{1}{2}$ , 3- $\frac{1}{2}$ , 5, 7, and 9 (DN 32, DN 65, DN 90, DN 125, DN 175 and DN 225) shall not be used.

**6.3.5** Welded auxiliary connections, size NPS 1- $\frac{1}{2}$  (DN 40) and smaller, shall be reinforced by using forged welding inserts or gussets.

**6.3.6** If gussets are provided, the piping shall be gusseted in two orthogonal planes to increase the rigidity of the piped connection in accordance with the following criteria:

- a) Gussets shall be of a material compatible with the pressure casing and the piping and shall be made of either flat bar with a minimum cross section of 1 in. by  $\frac{1}{8}$  in. (25 mm by 3 mm) or round bar with a minimum diameter of  $\frac{3}{8}$  in. (9 mm).
- b) Gusset design shall be as shown in Figure 1.
- c) Gussets shall be located at or near the connection end of the piping and fitted to the closest convenient location on the casing to provide maximum rigidity. The long width of gussets made with bar shall be perpendicular to the casing.

the pipe and shall be located to avoid interference with the flange bolting or any maintenance areas on the LRC/VP.

- d) Gusset welding shall meet the fabrication requirements (see 6.10.3), including post-weld heat treatment (PWHT) when required, and the inspection requirements of this International Standard.
- e) Gussets may also be bolted to the casing if drilling and tapping is done prior to hydrotest.
- f) Proposals to use clamped or bolted gusset designs shall be submitted to the purchaser for approval.

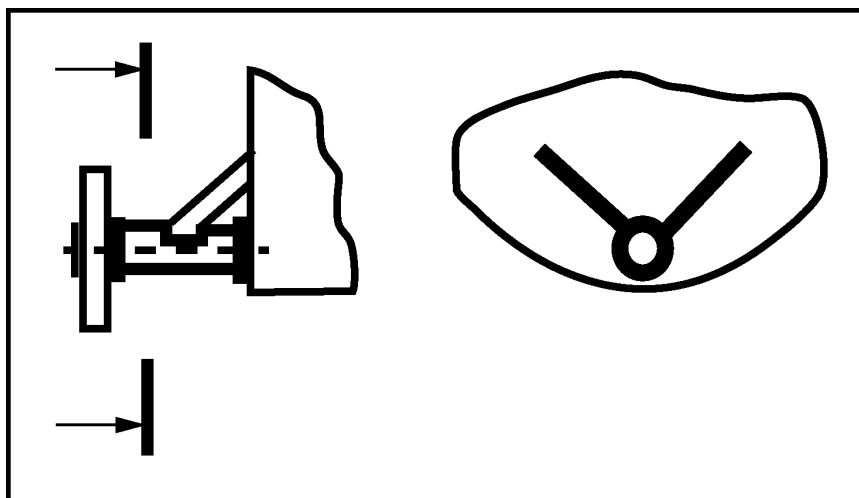


**Figure 1—Typical Gusset Design**

**NOTE** Typically, these connections are required to support heavy valves which can cause fatigue failure if the connections are not properly reinforced.

**6.3.7** For connections other than main process connections, if flanged or machined and studded openings are impractical, threaded connections for pipe sizes not exceeding NPS 1- $\frac{1}{2}$  (DN 40) may be used with purchaser's approval as follows:

- a) On non-weldable materials, such as cast iron;
- b) Where essential for maintenance (disassembly and assembly).

**6.3.8** The first segment of piping screwed or welded to the casing should not be more than 6 in. (150 mm) long and shall be a minimum of Schedule 160 seamless for sizes NPS 1 (DN 25) and smaller and a minimum of Schedule 80 for NPS 1  $\frac{1}{2}$  (DN 40).

**6.3.9** Nipple and flange materials welded to the casing shall meet the requirements of 6.3.10.

- [•] **6.3.10** Threaded openings for tapered pipe threads shall conform to ASME B 1.20.1 or ISO 7-1 or as specified. If ISO 7-1 has been specified, tapered internal and external threads shall be specified. Bosses for pipe threads shall conform to ASME B16.5.

**6.3.11** Threaded connections shall not be seal welded.

**6.3.12** Connections welded to the casing shall meet the material requirements of the casing including impact values and temperature pressure rating, rather than the requirements of the connected piping (see 6.10.3.5).

**6.3.13** All welding of connections shall be completed before the casing is hydrostatically tested per 8.3.2.

**6.3.14** Threaded openings not required to be connected to piping shall be plugged with solid, round-head steel plugs in accordance with ASME B16.11.

**6.3.14.1** As a minimum, these plugs shall meet the material requirements of the pressure casing.

**6.3.14.2** Plugs that may later require removal shall be of a corrosion-resistant material. Plastic plugs are not permitted.

**6.3.15** A process compatible thread sealant/lubricant of proper temperature specification shall be used on all threaded connections. Thread tape shall not be used.

**6.3.16** Casings shall be provided with sufficient drains to ensure complete drainage.

**6.3.17** A vent connection shall be provided if the LRC/VP is not functionally self-venting by the arrangement of the suction and discharge nozzles.

## **6.4 Flanges**

**6.4.1** The CLASS system applies, and all flanges shall conform to ASME B16.1, B16.5, B16.42 as applicable.

- [•] **6.4.2** If the PN system is specified, all flanges shall conform to EN 1092-1 or EN 1092-2 as applicable, except as specified in 6.4.3 through 6.4.12.

NOTE EN 1092-1 flanges are PN 6, 10, 16, 25, 40, 63, 100, 160, 250, 320, and 400.

**6.4.3** Steel flanges shall conform to the dimensional requirements of ASME B16.5 or EN 1092-1 as applicable.

**6.4.4** Cast, Ductile and Malleable iron flanges shall be flat faced and conform to the dimensional requirements of ASME B16.1, B16.42 or EN 1092-2 as applicable.

**6.4.4.1** Class 125 flanges shall have a minimum thickness equal to class 250 for sizes NPS 8 and smaller.

**6.4.4.2** PN16 flanges shall have a minimum thickness equal to PN25 for sizes DN 200 and smaller.

- [•] **6.4.5** The dimensional requirements of flanges in materials other than those covered in 6.4.3 through 6.4.4 shall conform to the dimensional requirements of the flanges specified in 6.4.1 or 6.4.2.

**6.4.6** Pressure and temperature ratings shall be considered for materials not covered by referenced flange standards.

**6.4.7** Flat face flanges with full raised face thickness are acceptable on casings of all materials.

**6.4.8** Flanges in all materials that are thicker or have a larger outside diameter than required by applicable ASME or EN are acceptable.

**6.4.8.1** Non-standard (oversized) flanges shall be completely dimensioned on the arrangement drawing.

**6.4.8.2** If oversized flanges require studs or bolts of non-standard length, this requirement shall be identified on the arrangement drawing.

**6.4.9** Flanges shall be full-faced or spot-faced on the back and shall be designed for through bolting.

NOTE It can be impracticable to spot face smaller equipment due to space constraints and accessibility.

- [•] **6.4.10** Machined and studded connections shall conform to the facing and drilling requirements of ASME B16.1, B16.5, B16.42 or EN 1092-1, EN 1092-2 as specified.

**6.4.11** Studs and nuts shall be provided installed, and the first 1.5 threads at both ends of each stud shall be removed.

**6.4.12** Machined and studded connections and flanges not in accordance with ASME B16.1, B16.5, B16.42 or EN 1092-1, EN 1092-2 require purchaser's approval.

**6.4.13** The vendor shall supply mating flanges, studs, and nuts for all nonstandard connections.

**6.4.14** To minimize nozzle loading, and facilitate installation of piping, machine flanges shall be parallel to the plane of the flange as shown on the general arrangement drawing to within  $0.5^\circ$ .

**6.4.15** Studs or bolt holes shall straddle centerlines parallel to the main axes of the flange.

**6.4.16** All of the purchaser's connections shall be accessible for disassembly without requiring the machine, or any major part of the machine, to be moved.

## 6.5 External Forces and Moments

**6.5.1** LRC/VP and their baseplates shall be designed for satisfactory performance if subjected to the forces and moments in Table 4 applied simultaneously to both suction and discharge nozzles in the worst case combination for the LRC/VP in question. Two effects of nozzle loads shall be considered: distortion of the casing (6.2.1) and misalignment of the LRC/VP and motor shafts.

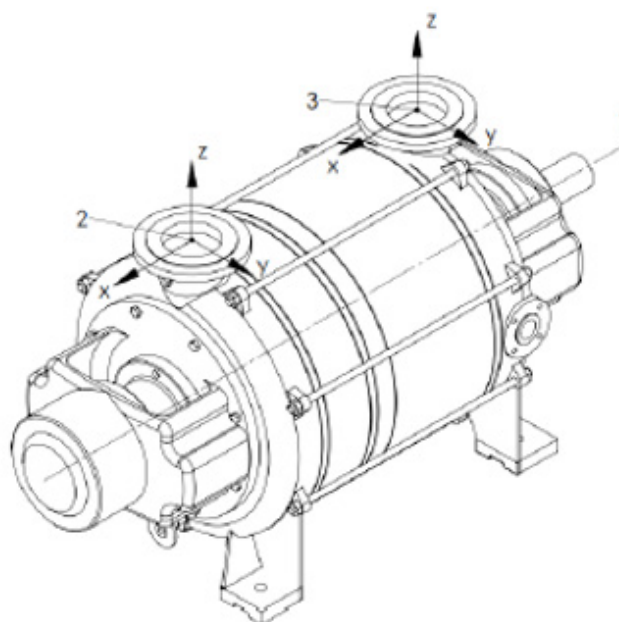
**Table 4—Nozzle Loadings**

| USC Units<br>Nominal Size of Flange<br>(NPS) | Forces Each Nozzle<br>$F_x$ , $F_y$ and $F_z$<br>(lbf) | Moments Each Nozzle<br>$M_x$ , $M_y$ and $M_z$<br>(ft·lbf) |
|----------------------------------------------|--------------------------------------------------------|------------------------------------------------------------|
| ≤2                                           | 150                                                    | 250                                                        |
| 3                                            | 225                                                    | 375                                                        |
| 4                                            | 300                                                    | 600                                                        |
| 6                                            | 450                                                    | 750                                                        |
| 8                                            | 600                                                    | 1000                                                       |
| 10                                           | 750                                                    | 1250                                                       |
| 12                                           | 900                                                    | 1500                                                       |
| 14                                           | 1050                                                   | 1750                                                       |
| 16                                           | 1200                                                   | 2000                                                       |
| 20                                           | 1500                                                   | 2500                                                       |
| 24                                           | 1800                                                   | 3000                                                       |
| SI Units<br>Nominal Size of Flange<br>(DN)   | Forces Each Nozzle<br>$F_x$ , $F_y$ and $F_z$<br>(N)   | Moments Each Nozzle<br>$M_x$ , $M_y$ and $M_z$<br>(N·m)    |
| ≤50                                          | 650                                                    | 350                                                        |
| 80                                           | 1040                                                   | 560                                                        |
| 100                                          | 1300                                                   | 700                                                        |
| 150                                          | 1950                                                   | 1050                                                       |
| 200                                          | 2600                                                   | 1400                                                       |
| 250                                          | 3250                                                   | 1750                                                       |

**Table 4—Nozzle Loadings (Continued)**

| USC Units<br>Nominal Size of Flange<br>(NPS) | Forces Each Nozzle<br>$F_x$ , $F_y$ and $F_z$<br>(lbf) | Moments Each Nozzle<br>$M_x$ , $M_y$ and $M_z$<br>(ft·lbf) |
|----------------------------------------------|--------------------------------------------------------|------------------------------------------------------------|
| 300                                          | 3900                                                   | 2100                                                       |
| 350                                          | 4550                                                   | 2450                                                       |
| 400                                          | 5200                                                   | 2800                                                       |
| 500                                          | 6500                                                   | 3500                                                       |
| 600                                          | 7800                                                   | 4200                                                       |

**6.5.2** The coordinate system(s) shown in Figure 2, Figure 3, and Figure 4 shall be used to apply forces and moments in Table 4.

**Key**

- 1 shaft centerline
- 2 discharge (D)
- 3 suction (S)

**Figure 2—Coordinate System for the Forces and Moments in Table 4, Top Suction/Top Discharge LRC/VP Design**

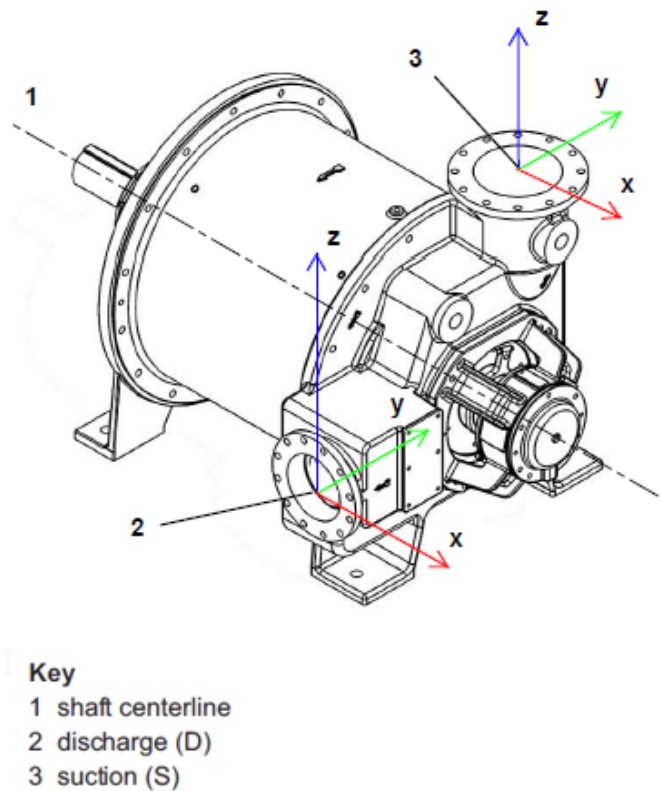


**Figure 3—Coordinate System for the Forces and Moments in Table 4—Top Suction/Side Discharge LRC/VP Design**

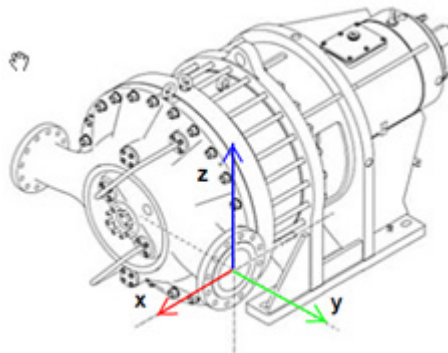


**Figure 4—Coordinate System for the Forces and Moments in Table 4—Side Suction/Side Discharge LRC/VP Design**

## 6.6 Rotating Elements

**6.6.1** Rotating assemblies shall be designed to be stiff enough to prevent contact between the rotor and the casing when operating at the maximum differential pressure.

**6.6.2** Calculated deflection of the shaft at the seals shall not exceed 0.002 in. (50  $\mu\text{m}$ ).

**6.6.3** The impeller shall be either secured to the shaft by an interference fit or keyed and be capable of transmitting a torque not less than 2.5 times that required for any specified duty and provided with an arrangement for positive axial location.

**6.6.4** Solid shaft and single piece impellers are required.

**6.6.5** Impellers and similar major rotating components shall be dynamically balanced to ISO 21940-11, grade G2.5. The mass of the arbour used for balancing shall not exceed the mass of the component being balanced. Shafts are not required to be balanced.

- [•] **6.6.6** If specified, impellers and similar rotating components shall be dynamically balanced to ISO21940-11, grade G1 (equivalent to 6W/n).

**6.6.7** Shafts shall be machined from one-piece heat treated steel.

**6.6.7.1** Shafts with finished diameters 8 in. (200 mm) and larger shall be forged.

**6.6.7.2** Shafts with finished diameters less than 8 in. (200 mm) shall be forged or hot-rolled bar stock purchased to the same quality and heat treatment criteria as shaft forgings.

**6.6.8** If not provided as part of the mechanical seal, renewable shaft sleeves (that are removable without machining) shall be provided in the shaft sealing areas.

NOTE The sleeve is typically a component of the mechanical seal provided with the machine.

**6.6.8.1** Sleeves shall be of wear-, corrosion-, and erosion-resistant material, and shall at a minimum be Stainless Steel.

**6.6.8.2** Sleeves shall be ground and polished on their outside surface or finished for the specific seal application.

**6.6.8.3** Sleeves shall be positively located on the shaft and shall be not less than 0.125 in. (3 mm) thick.

**6.6.8.4** Sleeves shall be sealed at one end and the shaft-sleeve assembly shall extend at least  $\frac{1}{8}$  in. (3 mm) beyond the outer face of the seal end plate.

NOTE Leakage between the shaft and the sleeve thus cannot be confused with leakage through the mechanical seal faces.

**6.6.9** Shafts shall be machined and properly finished throughout their length so that there is no more than 0.001 in. (25  $\mu$ m) total indicated run-out.

**6.6.10** Shaft sleeves shall have no more than 0.002 in. (50  $\mu$ m) total indicated run-out on the outside diameter.

## **6.7 Mechanical Shaft Seals**

**6.7.1** Cartridge mechanical shaft seals shall be furnished.

**6.7.2** Seal selection shall be suitable for specified variations in suction or discharge conditions, or both, during start-up, operation, or shutdown, including possible upset conditions.

- [•] **6.7.3** If specified, shaft seals shall be provided in accordance with API Standard 682.

**6.7.4** For vendor's seals not in accordance with API Standard 682, the following items shall be provided in the proposal:

- a) category;
- b) type;
- c) arrangement and geometry;

- d) material of construction;
- e) reference list.

**NOTE** Space or design parameters for some LRC/VP types, sizes, or applications make the use of API Standard 682 seals impractical.

**6.7.5** The purchaser shall specify the seal requirements using the selection process and the datasheets in API Standard 682 including any required seal flush plans as defined by API Standard 682.

**6.7.6** Seals shall be removable without removing the LRC/VP end housing, suction, or discharge piping, or disturbing the driver.

**6.7.7** A spacer coupling, of sufficient length shall be provided by the vendor to enable removal of the bearing housing.

**6.7.8** Seals, including component parts, shall withstand the maximum vacuum and maximum allowable working pressure.

**6.7.9** Seals shall operate at negligible leakage as required by API Standard 682 at the maximum vacuum and at the maximum allowable working pressure in static and dynamic conditions.

**6.7.10** Single seals shall be equipped with a close-fitting throttle bushing on the atmospheric side of the seal to restrict the rate of leakage. If this is not possible due to space limitations, a suitable means of detecting and controlling the leakage shall be provided.

- [•] **6.7.11** If specified for flammable or toxic fluids, a non-sparking throttle bushing shall be provided to minimize leakage in the event of a complete seal failure. The diametric clearance at the bushing bore shall not be more than 0.025 in. (650 µm).

**6.7.12** The seal chamber (process side) shall be provided with an internal or external vent to permit complete venting of the chamber before start-up.

**6.7.13** If seal flushing and cooling is provided by the pumped fluid, the LRC/VP vendor shall ensure that sufficient flow reaches the primary seal faces to provide for cooling and maintenance of a stable film at the seal faces. Allowance for cooling flow shall be made when determining the LRC/VP capacity to meet delivered flow requirements.

**6.7.14** If an external source of seal flushing is provided by the purchaser, the LRC/VP vendor shall specify the flow, pressure, temperature, and required lubricating properties of the flushing medium. If a restriction orifice is used, it shall not be less than 0.125 in. (3 mm) in diameter.

**6.7.15** If a seal gland is used, seal gland component parts shall be satisfactory for the maximum vacuum and maximum seal-chamber design pressure and pumping temperature. It shall have sufficient rigidity to avoid any distortion that would impair seal operation, including distortion that may occur during tightening of the bolts or nuts.

**6.7.16** Gland plate connections shall be identified by stamping on the seal end plate labels for the seal fluid inlet and outlet and vent and drain connections.

**6.7.17** If required by seal design, direction of rotation shall be shown on each gland plate.

**6.7.18** Seal glands and seal chambers shall have provision for only those connections required by the seal flush plan. If other tapped connections are present but not used, they shall be plugged and labeled in accordance with API Standard 682.

**6.7.19** The mating joint between the seal gland and the seal chamber face shall incorporate a confined gasket to prevent blowout.

**6.7.19.1** The gasket shall be of the controlled compression type with metal to metal gland to seal-chamber contact.

**6.7.19.2** If space or design parameters make this requirement impractical, an alternative seal gland design shall be submitted to the purchaser for approval.

**6.7.20** In vacuum service, the seal design shall be suitable to seal against atmospheric pressure when the LRC/VP is not operating.

## **6.8 Dynamics**

### **6.8.1 Critical Speeds**

**6.8.1.1** Rotating assemblies shall be designed such that their first dry critical speed is at least 120 % of the maximum continuous or trip speed (whichever is greater).

**6.8.1.2** In the design of rotor-bearing systems, consideration shall be given to all potential sources of periodic forcing phenomena (excitation) which shall include, but are not limited to, the following sources:

- a) unbalance in the rotor system;
- b) internal rubs;
- c) blade, vane, and port passing frequencies;
- d) gear-tooth meshing and side bands;
- e) coupling misalignment;
- f) loose rotor-system components;
- g) ball and race frequencies of rolling element bearings;
- h) hydraulic effects.

**NOTE 1** The frequency of a potential source of excitation -can be less than, equal to, or greater than the rotational speed of the rotor.

**NOTE 2** If the frequency of a periodic forcing phenomenon (excitation) applied to a rotor-bearing support system coincides with a natural frequency of that system, the system will be in a state of resonance. A rotor-bearing support system in resonance can have the magnitude of its normal vibration amplified. The magnitude of amplification and, in the case of critical speeds, the rate of change of the phase-angle with respect to speed, is related to the amount of damping in the system.

**6.8.1.3** Resonance of support systems within the vendor's scope of supply shall not occur within  $\pm 20$  % of the operating speed of a fixed speed machine, or from 20 % below to 20 % above the operating range of an adjustable speed machine.

**NOTE** Resonances of structural support systems (base, frame, and bearing housings) can adversely affect rotor vibration amplitude.

**6.8.1.4** The vendor who has the unit responsibility for the complete drive train shall inform the purchaser of the existence of any undesirable running speeds in the range from zero to trip speed.

**NOTE 1** Examples of undesirable speeds are those caused by the rotor lateral critical speeds with amplification factors greater than 2.5, train torsionals, and blading modes.

NOTE 2 Normally LRC/VP machines have a rigid shaft and operate below the first lateral critical speed.

**6.8.1.4.1** Undesirable speeds shall be illustrated using a Campbell diagram.

**6.8.1.4.2** The Campbell Diagram shall be submitted to the purchaser for review and included in the Instruction Manual (see Annex B).

[•] **6.8.1.5** If specified, the equipment vendor shall perform a lateral critical speed analysis to determine the critical speeds of the driver and LRC/VP and to assure amplitudes of vibration at any speed from zero to trip speed are within the limits specified in 6.8.2.

**6.8.1.6** Excitation of torsional natural frequencies may come from many sources which may or may not be a function of running speed and should be considered in the analysis. These sources may include but are not limited to the following:

- a) gear characteristics such as unbalance, pitch line runout, and cumulative pitch error;
- b) cyclic process impulses;
- c) torsional transients such as start-up of synchronous electric motors and generator phase-to-phase or phase-to-ground faults;
- d) torsional excitation resulting from electric motors, reciprocating engines, and rotary type positive displacement machines;
- e) control loop resonance from hydraulic, electronic governors, and adjustable frequency drives;
- f) one and two times line frequency;
- g) running speed or speeds;
- h) harmonic frequencies from adjustable frequency drives.

**6.8.1.7** The torsional natural frequencies of the complete train shall be at least 10 % above or 10 % below any applicable excitation frequency within the specified operating speed range (from minimum to maximum continuous speed).

**6.8.1.8** When torsional resonances are calculated to fall within the margin specified in 6.8.1.7.

- a) The purchaser and vendor shall agree that all efforts to remove the critical from within the limiting frequency range have been exhausted.
- b) A stress analysis shall be performed to demonstrate that the resonances have no adverse effect on the complete train.
- c) The acceptance criteria for this analysis shall be agreed upon by the purchaser and the vendor.

[•] **6.8.1.9** If specified, the vendor shall perform a torsional vibration analysis of the complete coupled train and shall be responsible for directing the modifications necessary to meet the requirements of 6.8.1.6 through 6.8.1.8.

## **6.8.2 Vibration**

**6.8.2.1** The overall vibration limits for LRC/VP shall be  $V_u < 5.1$  mm/s RMS (0.20 in./s RMS), where  $V_u$  is the unfiltered velocity and RMS is the root mean square, as measured on the bearing housing. The limits shall apply to steady state vibration at any speed and any pressure within the operating range on test or in the field.

NOTE See 8.3.3 for vibration requirements related to the Mechanical Running Test.

**6.8.2.2** During the performance test, overall vibration measurements over a range specified in 8.3.3.7.2.1 and a Fast Fourier Transform (FFT) spectrum shall be made at each test point except shutoff.

**6.8.2.3** The vibration measurements shall be taken on the bearing housing(s) or equivalent location(s). Indicative positions are shown in Figure 5.

NOTE Field measurements for noise and vibration can differ from test stand measurements.

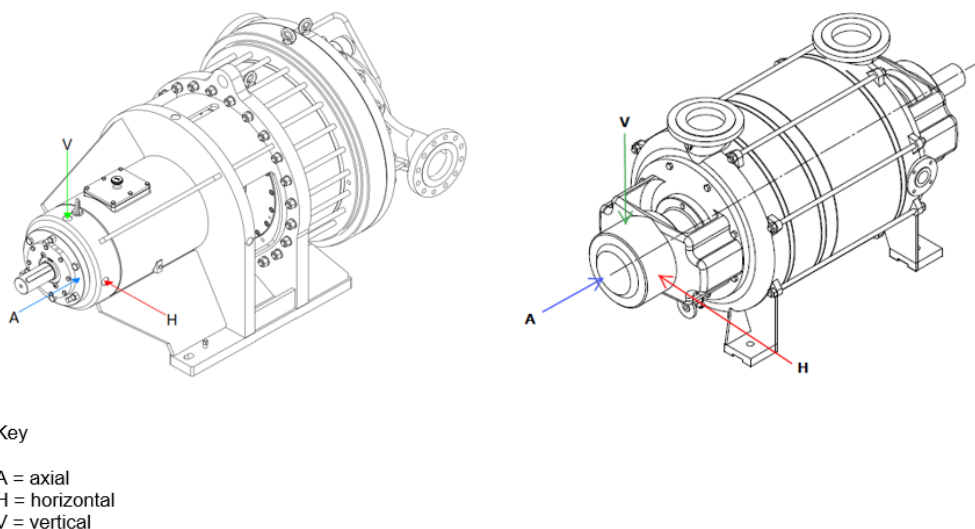


**Figure 5—Indicative Locations for Taking Vibration on Overhung and Between Bearing LRC/VP**

- [•] **6.8.2.4** If specified by the purchaser, the vendor shall demonstrate that the LRC/VP can operate at the quoted maximum and minimum pressure ratios and capacity without exceeding the limits specified in 6.8.2.1.

NOTE Field performance can deviate significantly from test stand performance due to gas gravities, gas condensabilities, etc.

## 6.9 Bearings, Bearing Housings, and Lubrication

### 6.9.1 Bearings

**6.9.1.1** Each shaft shall be supported by two radial bearings.

**6.9.1.2** Each shaft shall have one double acting axial (thrust) bearing, which may be combined with one of the radial bearings.

**6.9.1.3** Rolling element bearing's basic rating life,  $L_{10h}$ , shall be at least 50,000 hours with continuous operation at rated conditions, and at least 32,000 hours at maximum radial and axial loads and rated speed.

**6.9.1.4** The basic rating,  $L_{10h}$  life, shall be calculated in accordance with ISO 281 first edition.

NOTE 1 The basic rating life,  $L_{10h}$ , is the number of hours, at the operating conditions, that 90 percent of a group of identical bearings, will complete or exceed before the evidence of failure.

NOTE 2 ISO 281:1990 defines basic rating life  $L_{10}$  in units of millions of revolutions. Industry practice is to convert this to hours and refer to it as  $L_{10h}$ ,

where

$L_{10h}$  is (1,000,000/60N)  $L_{10}$ ;  
 N is Revolutions per minute.

**6.9.1.5** Thrust bearings shall be sized for continuous operation through the full operating range including the most adverse specified operating conditions.

**6.9.1.6** Calculation of the thrust load shall include but shall not be limited to the following factors within the liquid ring stability range pressures:

- a) fouling and variation in seal clearances at design and at twice the design internal clearances;
- b) step thrust from all diameter changes;
- c) stage reaction and stage maximum differential pressure;
- d) variations in pressure at all inlet and outlet nozzles;
- e) external loads from the driving equipment.

**6.9.1.7** Thrust forces from metallic flexible element couplings shall be calculated on the basis of the maximum allowable deflection permitted by the coupling manufacturer.

**6.9.1.8** Thrust bearings shall be arranged to allow axial positioning of each rotor relative to the casing and setting of the bearings' clearance or preload.

**6.9.1.9** Rolling element bearings shall be located, retained, and mounted in accordance with the following:

- a) Bearings shall be located on the shaft using shoulders, collars, or other positive locating devices; snap rings and spring-type washers are not acceptable.
- b) The device used to lock thrust bearings to shafts shall be restricted to a nut with a tab type lock washer.

**6.9.1.9.1** For inner race rotation, radial ball and roller bearings shall be retained on the shaft with an interference fit and fitted into the housing with a diametrical clearance, both in accordance with the recommendations of ABMA Standard 7.

**6.9.1.9.1.1** Tapered roller bearing fits shall be in accordance with ABMA 19.1 (SI units) and ABMA 19.2 (USC units).

**6.9.1.9.1.2** Interference fits and clearances shall consider the complete range of tolerances and operating conditions for each component.

NOTE 1 ABMA Standard 7 lists figures and tables which describes the various class fits between the shaft and inner race as well as the various fits and clearances between the outer race and bearing housing.

NOTE 2 The actual fits and clearances used in a design depend on many factors such as load, bearing size and type, material properties and other design and performance requirements.

NOTE 3 Bearing and shaft material with different coefficients of thermal expansion or parts with the same coefficient of thermal expansion operating at different temperatures could either increase or decrease the interference fit.

**6.9.1.9.2** Bearings shall be mounted directly on the shaft Bearing carriers (sleeves) may be acceptable with purchaser's approval.

**6.9.1.10** Single row deep-groove ball bearings shall have a radial internal clearance in accordance with ISO 5753: Group 3 [larger than "N" (Normal) internal clearance].

NOTE 1 For the purpose of this provision, ABMA 20 Group 3 is equivalent to ISO 5753 Group 3.

NOTE 2 The internal clearance of a bearing under operating conditions (effective clearance) is usually smaller than the same bearing's initial clearance before being installed and operated. This is due to several factors including bearing shrink fit to the shaft or housing, the difference in temperature between the inner and outer rings, etc.

NOTE 3 Group 3 clearances are also known as C3 clearances.

**6.9.1.11** The selection of the internal clearance Group from ISO 5753 for double row angular contact ball bearings, cylindrical roller bearings, double row self-aligning roller bearings, double row self-aligning ball bearings, and spherical roller bearings shall be determined for the individual application and advised.

NOTE 1 For the purpose of this provision, ABMA 20 Groups are equivalent to ISO 5753-Groups.

NOTE 2 These clearances apply to non-preloaded bearings and of a design such that they can take purely radial load.

NOTE 3 Single row tapered roller bearings and single row angular contact ball bearing mounted back-to-back or face-to-face clearance are not covered in ISO 5753 and ABMA 20 since clearances for these bearings are set during assembly in the machine.

**6.9.1.12** Double row or single row angular contact ball bearings and two single row ball bearings mounted back-to-back, face-to-face, or tandem shall be provided with machined cages. Non-metallic cages shall not be used.

## **6.9.2 Bearing Housings**

**6.9.2.1** The bearing housing shall be equipped with replaceable labyrinth-type end seals and deflectors where the shaft passes through the housing.

**6.9.2.1.1** Lip-type seals shall not be used.

**6.9.2.1.2** The seals and deflectors shall be made of spark resistant materials.

**6.9.2.1.3** The design of the seals and deflectors shall effectively retain lubricant in the housing and prevent entry of foreign material into the housing. This shall be achieved without the requirement for external service such as an air purge or grease.

**6.9.2.2** Bearing housings for grease lubricated bearings shall be provided with stainless steel pressure type grease fittings for filling while operating and a visible discharge port for observing the displaced grease.

**6.9.2.3** For equipment handling flammable or hazardous fluids, bearing housings, load-carrying bearing housing covers and brackets between the machine's casing and the bearing housings shall be steel.

[•] **6.9.2.4** If specified, bearing housings for oil-lubricated non-pressure-fed bearings shall be provided. Bearing housings shall meet the requirements of 6.9.2.4.1 through 6.9.2.4.8 below.

**6.9.2.4.1** The housing shall be tapped and plugged with fill and drain openings at least ½-14 NPT (DN 15) in size.

**6.9.2.4.2** The housings shall be equipped with constant-level sight-feed oilers at least 4 fluid oz (120 ml) in size, with a positive level positioner (not an external screw), heat-resistant glass containers (not subject to sunlight- or heat-induced opacity or deterioration), and protective wire cages.

**6.9.2.4.3** Means shall be provided such as a bulls-eye or an overfill plug, for detecting overfilling of the housings.

**6.9.2.4.4** A permanent indication of the proper oil level shall be accurately located and clearly marked on the outside of the bearing housing with permanent metal tags, marks inscribed in the castings, or another durable means.

**6.9.2.4.5** A “vented to atmosphere” constant level oiler shall be supplied, and the bearing housing shall be vented to atmosphere.

[●] **6.9.2.4.6** If specified, a specific oiler shall be provided.

[●] **6.9.2.4.7** If specified, a “vented to bearing housing” constant level oiler shall be provided.

[●] **6.9.2.4.8** If specified, an oil sump collection container shall be provided.

**6.9.2.4.8.1** This container shall be transparent and shall be located on the bottom of the oil sump to collect bearing housing contaminants such as water.

**6.9.2.4.8.2** It shall be fitted with a spring loaded drain petcock.

**6.9.2.4.8.3** The collector materials of construction shall be suitable for the lubricant used.

[●] **6.9.2.5** If oil mist is specified, the requirements of 6.9.2.5.1 through 6.9.2.5.6 shall apply.

**6.9.2.5.1** For pure oil mist lubrication, bearings and bearing housings shall meet the requirements of a) through e) below.

- a) A threaded 6 mm ( $\frac{1}{4}$  NPT) oil mist inlet connection shall be provided on the housing or end cover for each of the spaces between the rolling element bearing or bearing set and the bearing housing end seal;
- b) Oil mist fitting connections shall be located so that oil mist will flow through rolling element bearings;
- c) Oil rings or flingers and constant level oilers shall not be provided, and a mark indicating the oil level is not required;
- d) Drain-back and any other (feed) oil passages in the bearing housing shall be plugged to prevent the oil mist from bypassing the bearing(s);
- e) Water cooling systems shall not be provided.

NOTE Reclassifiers and oil-mist fittings are normally installed in the field.

**6.9.2.5.2** For purge oil-mist lubrication, bearings and bearing housings shall meet the following requirements:

- a) A threaded NPS  $\frac{1}{4}$  or  $\frac{1}{2}$  (6 mm or 12 mm) oil-mist connection shall be located in the top half of the bearing housing to act also as a vent-and-fill connection.
- b) Constant-level oilers shall be provided, and a mark indicating the oil level is required on the bearing housing. Bearing lubrication is by a conventional oil bath, flinger, or oil ring system.
- c) Constant-level sight feed oilers shall be equipped with overflow control to allow excess coalesced oil from the mist system to drain from the bearing housing so that oil level in the sump is maintained at proper level. The oil shall be contained to prevent it from draining onto the baseplate.
- d) Constant-level sight feed oilers shall be piped so that they operate at the internal pressure of the bearing housing, do not vent excess mist at the bearing housing, or allow oil to drip to the baseplate.

**6.9.2.5.3** For both pure and purge mist applications, a drain connection shall be located on the bottom of the bearing housing to provide complete oil drainage (see 6.9.2.4).

**6.9.2.5.4** Shielded or sealed bearings shall not be used in conjunction with either pure or purge oil-mist systems.

**6.9.2.5.5** The oil-mist supply, re-classifier and drain fittings shall be provided by the purchaser.

**6.9.2.5.6** Directional re-classifiers, if required, shall be provided by the machine manufacturer.

**6.9.2.6** Bearing housings shall have a threaded connection(s) for permanently mounting vibration transducers in accordance with API Standard 670. If metric fasteners are supplied, the threads shall be M8 × 1, 25.

**6.9.2.7** A flat surface at least 1 in. (25 mm) in diameter shall be supplied for the location of magnetic-based vibration measuring equipment.

### **6.9.3 Lubrication**

**6.9.3.1** Bearings and bearing housings shall be arranged for grease lubrication.

**6.9.3.2** Any points that require grease lubrication during operation and which cannot be easily and safely accessed during operation shall be provided with individual austenitic stainless steel extension lines terminating at one common location.

[•] **6.9.3.3** If specified, bearings and bearing housings shall be designed for oil lubrication using a mineral oil in accordance with ISO 8068.

[•] **6.9.3.4** If specified, provisions shall be made for either pure oil or purge oil-mist lubrication (see 6.9.2.5 for requirements).

### **6.10 Materials**

#### **6.10.1 General**

**6.10.1.1** Materials of construction shall be selected for the operating and site environmental conditions specified (see 6.10.1.8).

NOTE Key materials concerns are mechanical properties and corrosion resistance.

**6.10.1.2** Pressure retaining parts of machines shall be steel as a minimum.

**6.10.1.3** The material specification of all major components shall be clearly stated in the vendor's proposal.

**6.10.1.4** LRC/VP parts having strength or pressure-integrity requirements are designated as "full compliance" materials in Table D.1 and shall meet all the requirements of the agreed specifications. For any other part (e.g. if corrosion resistance is the primary concern), it is necessary to comply only with the specified chemical composition.

**6.10.1.5** Materials shall be identified by reference to applicable international standards, including the material grade (refer to Annex D).

- a) Where international standards are not available, internationally recognized national standards may be used.
- b) If no such designation is available, the vendor's material specification, giving physical properties, chemical composition, and test requirements, shall be included in the proposal.

**6.10.1.6** The vendor shall identify the optional tests and inspection procedures that are necessary to ensure that materials are satisfactory for the service. Such tests and inspections shall be listed in the proposal.

**6.10.1.7** Minor parts such as nuts, springs, washers, gaskets, and keys shall have corrosion resistance at least equal to that of specified parts in the same environment.

[•] **6.10.1.8** The purchaser shall specify any agents (including trace quantities) present in the motive and process fluids and in the site environment, including constituents that can cause corrosion.

**6.10.1.9** If austenitic stainless steel parts exposed to conditions that can promote inter-granular corrosion are to be fabricated, hard faced, overlaid, or repaired by welding, they shall be made of low-carbon or stabilized grades.

NOTE Overlays or hard surfaces that contain more than 0.10 % carbon can sensitize both low-carbon and stabilized grades of austenitic stainless steel unless a buffer layer that is not sensitive to inter-granular corrosion is applied.

**6.10.1.10** Where mating parts such as studs and nuts of austenitic stainless steel or materials with similar galling tendencies are used, they shall be lubricated with an anti-seizure compound suitable for the process temperatures and compatible with the material(s) and specified process fluid(s).

NOTE The required torque values to achieve the necessary bolt preload will vary considerably depending if anti-seizure compounds are used on the threads.

**6.10.1.11** If the purchaser has specified the presence of hydrogen sulfide in any fluid, materials exposed to that fluid shall be selected and processed in accordance with the requirements of NACE Standard MR 0103.

**6.10.1.12** For process gas conditions known to cause Sulfide Stress Cracking as identified by NACE MR0103, ferrous materials not covered by NACE MR 0103 shall not have a yield strength exceeding 90,000 psi (620 N/mm<sup>2</sup>) nor a hardness exceeding Rockwell C22.

**6.10.1.13** Components that are fabricated by welding shall be post-weld heat treated, if required, so that both the welds and the heat-affected zones meet the tensile strength, and ductility, requirements and when required, hardness and impact requirements.

**6.10.1.14** The vendor shall select materials to avoid conditions that may result in electrolytic corrosion. Where such conditions cannot be avoided, the purchaser and the vendor shall agree on the material selection and any other precautions necessary.

NOTE When dissimilar materials with significantly different electrical potentials are placed in contact in the presence of an electrolytic solution, galvanic couples that can result in serious corrosion of the less noble material can be created. The *NACE Corrosion Engineer's Reference Guide* [1] is one resource for selection of suitable materials in these situations.

**6.10.1.15** Materials, casting factors, and the quality of any welding shall be equal to those required by Section VIII, Division 1, of the ASME BPVC. The manufacturer's data report forms, as specified in the code, are not required.

NOTE For impact requirements, refer to 6.10.4.

**6.10.1.16** Only fully killed, normalized steels made to fine-grain practice are acceptable. Steel made to a coarse austenitic grain size practice (such as ASTM A515) shall not be used.

NOTE Low-carbon steels can be notch sensitive and susceptible to brittle fracture at ambient or lower temperatures.

[●] **6.10.1.17** If specified, copper or copper alloys shall not be used for parts of machines or auxiliaries in contact with process fluids. Nickel-copper alloy (UNS N04400), bearing babbitt, and precipitation-hardened stainless steels are excluded from this requirement.

NOTE Certain corrosive fluids in contact with copper alloys have been known to form explosive compounds.

**6.10.1.18 Positive Material Identification (PMI)**

**6.10.1.18.1** PMI testing shall be in accordance with 6.10.1.18.2 through 6.10.1.18.8.

[●] **6.10.1.18.2** If specified, the following alloy steel items shall be subject to PMI testing:

- a) The pressure casing of rotating equipment
- b) Shafts

- c) Impellers
- d) Blading and shrouds
- e) Tie bolts
- f) Shaft sleeves
- g) Alloy claddings and weld overlays
- h) Pressure casing joint bolting (studs and nuts)
- i) Auxiliary equipment (as specified)

[•] **6.10.1.18.3** In addition to the components outlined in 6.10.1.18.1 other materials, welds, fabrications, and piping shall be PMI tested as specified.

**6.10.1.18.4** If PMI testing has been specified for a fabrication, the components comprising the fabrication, including welds, shall be checked after the fabrication is complete except as permitted in 6.10.1.18.5. Testing may be performed prior to any heat treatment.

**6.10.1.18.5** Unique (non-stock) components such as impellers and shafts may be tested after manufacturing and prior to rotor assembly.

**6.10.1.18.6** If PMI is specified, techniques providing quantitative results shall be used.

NOTE 1 PMI test methods are intended to identify alloy materials and are not intended to establish the exact conformance of a material to an alloy specification.

NOTE 2 Additional information on PMI testing can be found in API RP 578 <sup>[1]</sup>.

**6.10.1.18.7** Certified material test reports, visual stamps or markings shall not be considered as substitutes for PMI testing, or vice versa.

**6.10.1.18.8** PMI results shall be within the material specification limits, allowing for the measurement uncertainty (inaccuracy) of the PMI device as specified by the device manufacturer.

## **6.10.2 Castings**

**6.10.2.1** Castings shall be free from porosity, hot tears, shrink holes, blow holes, cracks, scale, blisters, and similar injurious defects.

**6.10.2.2** Surfaces of castings shall be cleaned by sandblasting, shot-blasting, chemical cleaning, or other standard methods. Mold-parting fins and the remains of gates and risers shall be chipped, filed, or ground flush.

**6.10.2.3** The use of chaplets in pressure castings shall be held to a minimum. Chaplets shall be clean and corrosion free (plating of chaplets is permitted) and of a composition compatible with the casting.

**6.10.2.4** Pressure-containing ferrous castings shall not be repaired except as specified in items a) through c):

- a) Weldable grades of steel castings shall be repaired by welding, using a qualified welding procedure based on the requirements of Section VIII, Division 1, and Section IX of the ASME BPVC or other internationally recognized standard as approved by the purchaser.
- b) After major weld repairs and before hydrotest, the complete repaired casting shall be given a post-weld heat treatment to ensure stress relief and continuity of mechanical properties of both weld and parent metal and dimensional stability during subsequent machining operations.

- c) All repairs that are not covered by the agreed material specification shall be subject to the purchaser's approval.

**6.10.2.5** Fully enclosed cored voids, which become fully enclosed by methods such as plugging, welding, or assembly, shall not be used.

### **6.10.3 Welding**

**6.10.3.1** Welding of piping, pressure-containing parts, rotating parts and other highly stressed parts, weld repairs and any dissimilar-metal welds shall be performed and inspected by operators and procedures qualified in accordance with Section VIII, Division I, and Section IX of the ASME BPVC or another purchaser approved standard such as ISO 9606-1 and ISO 15607 for welding procedures and welder qualification.

**6.10.3.2** Other welding, such as welding on baseplates, non-pressure ducting, lagging, and control panels, shall be performed by welders qualified in accordance with AWS D1.1 or Section IX of the ASME BPVC or ISO 10721-2 or other purchaser approved welding standard.

**6.10.3.3** The vendor shall be responsible for the review of all repairs and repair welds to ensure that they are properly heat treated and nondestructively examined for soundness and compliance with the applicable qualified procedures (see 6.10.3.1).

- a) Repair welds shall be nondestructively tested by the same method used to detect the original flaw; however, the minimum level of inspection after the repair shall be by the magnetic particle method in accordance with 8.2.2.4 for magnetic material and by the liquid penetrant method in accordance with 8.2.2.5 for nonmagnetic material.
- b) Procedures for major repairs shall be subject to review by the purchaser before any repair is made.

**6.10.3.4** Pressure-containing casings made from wrought materials or combinations of wrought and cast materials shall conform to the conditions specified in 6.10.3.4.1 through 6.10.3.4.5.

**6.10.3.4.1** Before welding, plate edges shall be examined by the magnetic particle method or liquid penetrant examination to confirm the absence of laminations.

**6.10.3.4.2** Accessible surfaces of welds shall be inspected by magnetic particle or liquid penetrant examination after back chipping or gouging and again after post-weld heat treatment. The quality control of welds that will be inaccessible on completion of the fabrication shall be agreed prior to fabrication.

**6.10.3.4.3** Pressure-containing welds, including welds of the case to horizontal and vertical joint flanges, shall be full-penetration welds.

**6.10.3.4.4** Casings fabricated from materials that, according to Section VIII, Division I, of the ASME BPVC or other internationally recognized standard as approved by the purchaser require post-weld heat treatment, shall be heat treated regardless of thickness.

- [•] **6.10.3.4.5** If specified, in addition to the requirements of 6.10.3.1, specific welds shall be subjected to 100 % radiography, magnetic particle inspection, or liquid penetrant inspection.

**6.10.3.5** Connections welded to pressure casings shall be installed as specified in 6.10.3.5.1 through 6.10.3.5.4.

- [•] **6.10.3.5.1** If specified, proposed connection designs shall be submitted for approval before fabrication. The drawings shall show weld designs, size, materials, and pre and post-weld heat treatments.

**6.10.3.5.2** All welds shall be heat treated in accordance with Section VIII, Division 1, Sections UW-10 and UW-40, of the ASME BPVC.

**6.10.3.5.3** Post-weld heat treatment, if required, shall be performed after all welds, including piping welds, have been completed.

**6.10.3.5.4** Auxiliary piping welded to alloy steel casings shall be of a material with the same nominal properties or shall be of low carbon austenitic stainless steel. Other materials compatible with the casing material and intended service may be used with the purchaser's approval.

NOTE Low carbon austenitic stainless steel is identified by the letter L after the numerical designation such as 304L or 316L.

#### **6.10.4 Low Temperature**

- [•] **6.10.4.1** The purchaser shall specify the minimum design metal temperature and concurrent pressure used to establish impact test and other material requirements.

NOTE Normally, this will be the lower of the minimum surrounding ambient temperature or minimum fluid pumping temperature; however, the purchaser can specify a minimum design metal temperature based on properties of the pumped fluid such as auto-refrigeration at reduced pressures.

**6.10.4.2** To avoid brittle failures, materials and construction for low temperature service shall be suitable for the minimum design metal temperature.

**6.10.4.2.1** The purchaser and the vendor shall agree upon the minimum design metal temperature and any special precautions necessary with regard to conditions that may occur during operation, maintenance, transportation, erection, commissioning, and testing.

**6.10.4.2.2** Care shall be taken in the selection of fabrication methods, welding procedures, and materials for vendor furnished steel pressure retaining parts that can be subject to temperatures below the ductile-brittle transition temperature.

**6.10.4.2.3** The published design-allowable stresses for materials manufactured in accordance with the ASME BPVC and ANSI standards or other internationally recognized standard as approved by the purchaser are based on minimum tensile properties. Some standards do not differentiate between rimmed, semi killed, fully killed, hot-rolled, and normalized material, nor do they take into account whether materials were produced under fine- or course-grain practices all of which can affect material ductility. The vendor shall exercise caution in the selection of materials intended for services between  $-20^{\circ}\text{F}$  ( $-30^{\circ}\text{C}$ ) and  $100^{\circ}\text{F}$  ( $40^{\circ}\text{C}$ ).

**6.10.4.3** All carbon and low alloy steel pressure containing components including nozzles, flanges, and weldments shall be impact tested in accordance with the requirements of Section VIII, Division 1, Sections UCS-65 through 68, of the ASME BPVC or purchaser's approved equivalent standard.

NOTE In general, ferritic steels (such as carbon steel and low alloy steel containing chrome and moly) and martensitic steels (such as 12 % chrome) can have ductile-to-brittle transition temperatures as high as  $40^{\circ}\text{C}$  ( $100^{\circ}\text{F}$ ). The ductile-to-brittle transition temperature is affected by such items as steel manufacturing process heat treatment and minor changes in alloy content.

**6.10.4.3.1** High-alloy steels shall be tested in accordance with Section VIII, Division I, Section UHA-51, of the ASME BPVC or purchaser's approved equivalent standard.

- [•] **6.10.4.3.2** For materials and thicknesses not covered by Section VIII, Division I of the ASME BPVC or equivalent standards, the purchaser shall specify requirements.

**6.10.4.3.3** Impact testing of a material may not be required depending on the minimum design metal temperature, thermal, mechanical, and cyclic loading, and the governing thickness. Refer to requirements of Section VIII, Division I, Section UG-20F of the ASME BPVC.

**6.10.4.4** Governing thickness used to determine impact testing requirements shall be the greater of the following:

- a) The nominal thickness of the largest butt welded joint.
- b) The largest nominal section for pressure containment, excluding:
  - 1. Structural support sections such as feet or lugs.
  - 2. Sections with increased thickness required for rigidity to mitigate shaft deflection.
  - 3. Structural sections required for attachment or inclusion of mechanical features such as jackets or seal chambers.
- c) One fourth of the normal flange thickness.

**6.10.4.5** The results of the impact testing shall meet the minimum impact energy requirements of Section VIII, Division I, Section UG-84, of the ASME BPVC or equivalent standard.

## **6.11 Sealless Design**

### **6.11.1 General**

**6.11.1.1** LRC/VPs supplied with sealless drives, and all furnished auxiliaries shall, as a minimum, meet all the criteria of this section.

NOTE API 685 contains clauses that could be applied to API 681 sealless LRC/VP.

**6.11.1.2** The pump design shall ensure that the temperature and pressure in the sealless drive prevent vaporization at all operating conditions. while providing continuous flow for cooling and bearing lubrication.

**6.11.1.3** LRC/VPs with sealless drives shall be designed to prevent damage from reverse rotation on starting check-outs. The LRC/VP shall be supplied with the means to detect backward rotation.

NOTE One Rotation indicators are available that verify direction of rotation.

- [•] **6.11.1.4** If vacuum conditions at the LRC/VP suction are specified, the containment shell or stator liner, as applicable, shall be designed for the resulting external pressure.

### **6.11.2 Secondary Control/Containment**

- [•] **6.11.2.1** Purchaser shall specify if one of the following control/containment options per API Standard 685 for the LRC/VP shall apply:
  - a) Secondary control design;
  - b) Secondary control with primary leakage monitoring device (secondary control system);
  - c) Secondary containment design;
  - d) Secondary containment with primary leakage monitoring device (secondary containment system).
- [•] **6.11.2.2** If applicable, the hazard-based selection procedure in API Standard 685 2<sup>nd</sup> Edition, Annex B shall be applied to select the required Control/Containment option.
- [•] **6.11.2.3** If secondary control system is specified, it shall comply with the requirements of API Standard 685.