

THE ENGINEERING EQUIPMENT AND MATERIALS USERS ASSOCIATION

LIQUID RING VACUUM PUMPS AND COMPRESSORS

PUBLICATION N° 151

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ENGINEERING EQUIPMENT AND MATERIALS USERS' ASSOCIATION

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THE ENGINEERING EQUIPMENT AND MATERIALS USERS ASSOCIATION

Liquid ring vacuum pumps and compressors

EEMUA PUBLICATION No 151 : 1987

Comparison between EEMUA Publication 151 and API Standard 681

AMENDMENT DATED MAY 2002

Overall comment

The vast majority of the requirements of EEMUA 151 are also required in API 681, in many cases using identical wording. Specific EEMUA requirements not required by API or only "when specified" are listed below.

Specific requirements of EEMUA 151 not in API 681 (listed in order of the relevant EEMUA paragraph)

2.2.8 EEMUA requires hold-down bolt holes to be spot-faced - API does only when specified.

2.4.2 EEMUA requires ancillary connections to be flanged or machined and studded, except when otherwise agreed or on cast iron casings. API permits threaded connections and for flammable or toxic services, requires seal welding. Seal welding is generally not considered acceptable.

2.6.1 EEMUA requires the rotor to be stiff enough to avoid contact at 1.5 times max differential pressure. API just specifies max differential pressure.

2.6.10 EEMUA requires rotors to be numbered - API does not.

2.7.1.9 EEMUA requires the seal plate gasket to be confined. API only requires this when specified.

2.8.2.1/2 EEMUA requires rotating parts and complete rotors to be dynamically balanced. API leaves it to the vendor to decide what is necessary.

2.9.6 API permits the use of lip-seals on bearing housings, except when specified - EEMUA does not.

2.9.8 EEMUA discusses oil cooling and specifies max temperatures - API does not.

2.9.13 EEMUA requires replacement of bearings without disturbing machine or driver - API does not.

2.10.1 API specifies grease lubrication - EEMUA permits oil or grease.

2.10.5 EEMUA imposes requirements on oil flingers and rings - API does not.

2.11.3.7 EEMUA invites the purchaser to require to review the ring-liquid separator design - API does not.

2.11.4.5 EEMUA requires air coolers to be in accordance with API 661 - API does not.

2.11.7.1 EEMUA requires ring liquid pumps to comply with API 610 - API permits ANSI pumps.

- 2.11.9 EEMUA requires the ring-liquid system to be protected by relief valves in accordance with API 520 and 526. API makes no mention.
- 2.12.2.5 EEMUA requires nodular iron castings to be in accordance with ASTM A395 - API only when specified.
- 2.12.4.5 and 2.12.4.6 EEMUA specifies requirements relating to fabricated casings - API imposes same requirements but only when specified.
- 3.4.5.3 EEMUA requires valving to enable instruments to be removed with system in operation - API does only when specified
- 3.4.7.1 EEMUA requires vibration instrumentation to comply with API 678. This is incorrect - should be API 670.
- 3.5.1.8 EEMUA imposes requirements for piping systems for flammable or toxic services. API leaves these to be specified by the vendor.
- 3.5.2 EEMUA defines the ring-liquid system as process piping and imposes certain requirements. API leaves the requirements for the ring-liquid system to be specified.
- 3.5.3.3 EEMUA requires instrument and control-air tubing to be stainless steel and specifies minimum tubing thickness - API does not.
- 3.5.4 EEMUA imposes requirements for ancillary piping systems - API makes no reference to such systems.
- 4.3.3.5 EEMUA requires spare rotors to subject to a mechanical running test - API does not.
- 4.3.4.3 API requires the casing gas leak test to be carried out with the seals installed - EEMUA does not.
- 4.3.6.3 EEMUA specifies that the sound-level test be in accordance with EEMUA 140.
- 4.3.6.6 EEMUA specifies a post-test inspection - API does not.
- 4.3.6.7 EEMUA requires inspection of the hub/shaft fit for hydraulically fitted couplings - API does not.
- 5 EEMUA requires the vendor to declare the capacity and power consumption of the machine and specifies acceptance criteria. API no corresponding requirements.
- 6.3.2 EEMUA requires a co-ordination meeting when specified. API makes no reference to a co-ordination meeting.

EEMUA May 02

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SECTION 1 - GENERAL

1.1 Scope

This standard covers the minimum requirements for liquid ring vacuum pumps and compressors for general service. These include basic design, materials and auxiliary equipment.

A liquid ring machine, whether vacuum pump or compressor, is 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. (See Figure 1).

Note : A bullet (o) at the beginning of a paragraph indicates that a decision by the purchaser is required. These decisions should be indicated on the data sheet (see Appendix A); otherwise they should be stated in the quotation request or in the order.

1.2 Alternative Designs

1.2.1 The vendor may offer alternative designs. Equivalent metric dimensions, fasteners and flanges may be substituted as mutually agreed upon by the purchaser and the vendor.

1.2.2 When specified or agreed by the purchaser national standards may be substituted for the codes and standards referenced in this document.

1.3 Conflicting Requirements

In case of conflict between this standard and the enquiry, or order, the information included in the order shall govern.

1.4 Definition of Terms

Terms in this standard are defined as follows:

1.4.1 The Normal Operating Duty defines the conditions under which the machine is required to operate. This is the duty at which the vendor usually certifies that performance is within the tolerances specified.

1.4.2 Normal Speed is the operating speed at which the Normal Operating Duty is achieved.

1.4.3 Maximum Continuous Speed (in revolutions per minute) is the speed at least equal to 105 percent of the highest speed required by any of the specified operating conditions.

1.4.4 Maximum Allowable Speed (in revolutions per minute) is the highest speed at which the manufacturer's design will permit continuous operation.

1.4.5 Minimum Allowable Speed (in revolutions per minute) is the lowest speed at which the manufacturer's design will permit continuous operation.

1.4.6 Maximum Allowable Temperature is the 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 pressure.

1.4.7 Minimum Allowable Temperature is the minimum temperature for which the manufacturer has designed the equipment (or any part to which the term is referred).

1.14.8 Maximum Allowable Working Pressure is the 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 temperature.

1.14.9 Maximum Sealing Pressure is the highest pressure expected at the seals during any specified static or operating condition, and during start-up and shut-down.

1.4.10 Maximum Allowable Differential Pressure is the maximum differential pressure for which the manufacturer has designed the equipment for continuous operation.

1.4.11 Maximum Allowable Vacuum is the maximum vacuum (minimum suction pressure) for which the manufacturer has designed the equipment.

1.4.12 The capacity of a liquid ring machine is the volume flow of gas compressed and delivered referred to the pressure and temperature at the compressor inlet.

1.4.13 The use of the word design in any term (such as design power, design pressure, design temperature or design speed) should be avoided in the purchaser's specifications. This terminology should be used only by the equipment designer and the manufacturer.

1.5 Referenced Publications

1.5.1 The current editions of the standards, codes and specifications listed in Appendix C shall, to the extent specified herein, form a part of this standard. The applicability of changes in standards, codes and specifications that occur after the inquiry shall be mutually agreed upon by the purchaser and the vendor.

1.5.2 The purchaser and the vendor shall mutually determine the measures that must be taken to comply with any national codes, regulations, ordinances, or rules that are applicable to the equipment.

SECTION 2 - BASIC DESIGN

2.1 General

2.1.1 The equipment (including auxiliaries) covered by this standard shall be designed and constructed for a minimum service life of 20 years and at least 3 years of uninterrupted operation. It is recognized that this is a design criterion.

2.1.2. The vendor shall assume responsibility for the engineering coordination of the equipment and all auxiliary systems included in the scope of the order.

- o 2.1.3 The purchaser will specify the equipment's normal operating duty and any alternative duties on the data sheets.
- o 2.1.4 Control of the sound pressure level (SPL) of all equipment furnished shall be a joint effort of the purchaser and the vendor. Unless otherwise specified, the equipment furnished by the vendor shall conform to the requirements of EEMUA publication No. 104 and to the maximum allowable sound pressure level specified by the purchaser.

2.1.5 Unless otherwise specified, cooling water systems (not the ring liquid system) shall be designed for the following conditions:

Velocity over heat exchange surfaces 1.5-2.5 m/s (5-8 ft/s)

Maximum allowable working pressure $\geq$ 5.2 barg ($\geq$ 75 psig)

Test pressure $\geq$ 7.9 barg ($\geq$ 115 psig)

Maximum pressure drop 1 bar (15 psi)

Maximum inlet temperature 32°C (90°F)

Maximum outlet temperature 49°C (120°F)

Maximum temperature rise 17°C (30°F)

Minimum temperature rise 11°C (20°F)

Fouling factor on water side 0.35 m²·°K/kW (0.002 hr.ft²·°F/BTU)

Provision shall be made for complete venting and draining of the system.

NOTE: The vendor shall notify the purchaser if the criteria for minimum temperature rise and velocity over heat exchange surfaces result in a conflicting design. The criterion for velocity over heat exchange surfaces is intended to minimise water-side fouling; the criterion for minimum temperature rise is intended to minimize the use of cooling water. It is accepted that the specified minimum temperature rise may be too restrictive for vacuum pumps handling condensible liquids. The purchaser will approve the final selection.

2.1.6 Equipment shall be designed to operate at the maximum allowable working pressure without damage. All equipment shall be suitable for the maximum differential pressure resulting from the combination of the specified minimum suction pressure and the specified maximum discharge pressure.

2.1.7 The arrangement of the equipment, including piping and auxiliaries, shall be developed jointly by the purchaser and the vendor. The arrangement shall provide adequate clearance areas and safe access for operation and maintenance.

2.1.8 Electrical components and installations shall be suitable for the area classification (class, group, and division) specified by the purchaser on the data sheets.

2.1.9 Oil reservoirs and housings that enclose moving lubricated parts (such as bearings, shaft seals, highly polished parts, instruments, and control elements) shall be designed to minimise contamination by moisture, dust, and other foreign matter during periods of operation or idleness.

2.1.10 All equipment shall be designed to permit rapid and economical maintenance. Major parts such as casing components and bearing housings shall be designed (shouldered or doweled) and manufactured to ensure accurate alignment on reassembly.

- o 2.1.11 Many factors (such as piping loads, alignment at operating conditions, supporting structure, handling during shipment, and handling and assembly at the site) may adversely affect site performance. To minimise the influence of these factors, where specified, the vendor shall review and comment on the purchaser's piping and foundation drawings, and where specified the vendor's representative shall observe a check of the piping performed by parting the flanges. Where specified, the vendor's representative shall check alignment at the operating temperature and, where specified, shall be present during the initial alignment check.
- o 2.1.12 The purchaser will specify whether the installation is indoors (heated or unheated) or outdoors (with or without a roof), as well as the weather and environmental conditions in which the equipment must operate (including maximum and minimum temperatures and unusual humidity or dust problems). The unit and its auxiliaries shall be suitable for operation under these specified conditions. For purchaser's guidance, the vendor shall list in the proposal any special protection that the purchaser is required to supply.

2.1.13 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: It may be necessary to use a different ring liquid to run on air.

2.2 Casings

2.2.1 The thickness of the casing shall be suitable for the maximum allowable vacuum or maximum allowable working pressure. The stress values used in the design of the casing shall not exceed the maximum allowable stress values specified in Section VIII, Division I, of the ASME Code. For cast materials, the factor given in the Code shall be applied. Materials, casting factors, and the quality of any welding shall be equal to that required by Section VIII of the ASME Code. Manufacturer's data report forms and stamping, as specified in the code, are not required.

2.2.2 For pressurised casings, the maximum allowable working pressure of the casing shall be not less than the specified relief valve setting.

2.2.3 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.

2.2.4 Casings and supports shall be designed to have sufficient strength and rigidity to limit any change of shaft alignment at the coupling flange, caused by the worst combination of allowable pressure, torque, and piping forces and moments, to 50 micrometres (0.002 inch). Supports and alignment bolts shall be rigid enough to permit the machine to be moved by the use of its lateral and axial jackscrews.

2.2.5 Tapped holes in vacuum and pressure parts shall be kept to a minimum. To prevent leakage in vacuum and pressure sections of casings, metal at least equivalent to half the nominal diameter of the hole and in addition to the allowance for corrosion, shall be left around and below the bottom of drilled and tapped holes for fasteners.

2.2.6 Studded connections shall be furnished with studs installed. Blind stud holes shall be drilled only deep enough to allow a preferred tap depth of $1\frac{1}{2}$ times the major diameter of the stud; the first $1\frac{1}{2}$ threads at both ends of each stud shall be removed.

2.2.7 Bolting shall be furnished as specified in 2.2.7.1 through 2.2.7.3.

2.2.7.1 The details of threading shall confirm to ANSI B1.1.

2.2.7.2 Studs are preferred to cap screws.

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

2.2.8 Jackscrews and casing alignment dowels shall be provided to facilitate disassembly and reassembly. When Jackscrews are used as a means of parting contacting faces, one of the faces shall be relieved (counterbored or recessed) to prevent a leaking joint or an improper fit caused by marring of the face.

2.2.9 The machined finish of the mounting surface shall be 3.2-6.4 micrometres (125-250 microinches) arithmetic average roughness (Ra). Hold-down or foundation bolt holes shall be drilled perpendicular to the mounting surface or surfaces and spot faced to a diameter three times that of the hole.

2.3 Casing Appurtenances

2.3.1 Casings with double flow inlet or discharge nozzles shall, unless otherwise agreed, be furnished with manifolds to a single terminal point nozzle. The manifolds shall be designed for the same vacuum or maximum allowable working pressure as the casing.

2.4 Casing Connections

- o 2.4.1 Inlet and outlet connections shall be flanged or machined and studded, oriented as specified on the data sheets, and suitable for the maximum allowable working pressure of the casing as defined in 1.4.8.

2.4.2 Other connections shall also be flanged or machined and studded except as otherwise agreed, and shall be not less than $\frac{3}{4}$ inch nominal pipe size.

Threaded connections are not acceptable except in the case of cast iron casings or other cast iron parts and then only where the provision of integral flanges or studded bosses is impractical, or when necessary to facilitate maintenance.

Connections to steel casings, which are not an integral part of the casing, shall be made by welding on a suitable shaped piece of pipe with a flange at its outer end. For sizes above $1\frac{1}{2}$ inch nominal size the attachment shall be a full penetration butt weld as a "set-on" branch. For sizes of $1\frac{1}{2}$ inch nominal size and below "weldolets" or other suitable reinforcement shall be used. The attached pipe shall comply with 2.4.2.3 - 2.4.2.5.

All welded branches of 1 inch nominal size or less shall be reinforced by gusset plates or otherwise adequately supported to avoid a fatigue failure at the point of attachment, particularly where a valve or other mass is supported from the branch.

Where threaded connections are accepted they shall comply with the requirements of 2.4.2.1 through 2.4.2.7.

2.4.2.1 Threaded connections shall be $\frac{1}{2}$ inch, $\frac{3}{4}$ inch, 1 inch or $1\frac{1}{2}$ inch nominal pipe sizes only.

2.4.2.2 A pipe nipple, preferably not more than 6 inches (152 millimetres) long, shall be screwed into the threaded opening.

2.4.2.3 Pipe nipples shall be a minimum of Schedule 160 seamless for sizes 1 inch and smaller and a minimum of Schedule 80 for a size of $1\frac{1}{2}$ inches.

2.4.2.4 The pipe nipple shall be provided with a welding-neck or socket-weld flange at its outer end.

2.4.2.5 The nipple and flange materials shall meet the requirements of 2.4.3.

2.4.2.6 Tapped openings and bosses for pipe threads shall conform to ANSI B16.5.

2.4.2.7 Pipe threads shall be taper threads conforming to ASME B1.20.1.

2.4.3 Connections welded to the casing shall meet the material requirements of the casing, including impact values, rather than the requirements of the connected piping (see 2.12.4.6).

2.4.4 Openings for pipe sizes of $1\frac{1}{2}$, $2\frac{1}{2}$, $3\frac{1}{2}$, 5, 7, and 9 inches shall not be used.

2.4.5 Tapped openings not connected to piping shall be plugged with solid steel plugs furnished in accordance with ANSI B16.11. Plugs that may later require removal shall be of corrosion resistant material. Threads shall be lubricated. Tape shall not be applied to threads of plugs inserted into oil passages. Plastic plugs are not permitted.

2.4.6 Flanges shall conform to ANSI B16.1, B16.5, or B16.42 as applicable, except as specified in 2.4.6.1 through 2.4.6.4.

2.4.6.1 Cast iron flanges shall be flat faced and shall have a minimum thickness of Class 250 per ANSI B16.1 for sizes 8 inches and smaller.

2.4.6.2 Flat-faced flanges with full raised-face thickness are acceptable on cases other than cast iron, only with purchaser agreement.

2.4.6.3 Flanges that are thicker or have a larger outside diameter than that required by ANSI are acceptable.

- o 2.4.6.4 For the purpose of manufacturing mating parts, when connections larger than those covered by ANSI are supplied, the vendor shall supply equipment flange details to the purchaser. When specified, the mating parts shall be furnished by the vendor.

2.4.7 Machined and studded connections shall conform to the facing and drilling requirements of ANSI B16.1, B16.5, or B16.42. Studs and nuts shall be furnished installed. Connections larger than those covered by ANSI shall meet the requirements of 2.4.6.4.

2.4.8 All of the purchaser's connections shall be accessible for disassembly without the machine being moved.

2.4.9 All liquid ring vacuum pumps and compressors shall be provided with a casing vent connection unless they are self-venting by the arrangement of the nozzles.

2.4.10 All liquid ring vacuum pumps and compressors shall be provided with sufficient casing drains to ensure complete drainage.

2.5 External Forces and Moments

2.5.1 The manufacturer shall specify the maximum allowable external forces and moments that the compressor or vacuum pump casing will withstand. These shall be at least equal to 1.85 times the values calculated in accordance with NEMA SM-23. The allowable forces and moments shall be shown on the outline drawing.

2.6 Rotating Elements

2.6.1 Rotating assemblies shall be designed to be stiff enough to prevent contact between the rotor and the casing when subjected to $1\frac{1}{2}$ times the maximum allowable differential pressure. When operating at maximum allowable differential pressure, deflection of the shaft at the seals shall not exceed 0.05 mm (0.002 inch).

2.6.2 The impeller shall be either secured to the shaft by an interference fit capable of transmitting a torque not less than $2\frac{1}{2}$ times that required for any specified duty or it shall be keyed and provided with an arrangement for positive axial location.

2.6.3 Solid rotors are preferred. Hollow rotors will be acceptable only if furnished in compliance with one of the requirements specified in 2.6.3.1 through 2.6.3.3.

2.6.3.1 The resulting void is completely filled with a suitable metal that has a melting point of not less than 260°C (500°F) for machines with cast iron casings and not less than 538°C (1000°F) for cast steel casings.

2.6.3.2 The rotor is self venting.

2.6.3.3 The rotor is provided with a plug to allow complete venting of any accumulated gas before beginning any maintenance activity.

2.6.4 Shafts shall be made of one piece, forged steel or hot rolled bar stock and be of ample size to transmit the maximum torque required under any specified operating conditions and to withstand continuously all stresses resulting from supported weights, thrusts, and starting, including direct-on-line motor starting.

2.6.5 Shafts shall be provided with renewable shaft sleeves, that are removable without machining, in the shaft sealing areas. The sleeves shall be of wear-, corrosion-, and erosion-resistant material. Sleeves shall be ground and polished on their outside surface or finished for the specific seal application. Sleeves shall be positively located on the shaft and shall be not less than 2.5 mm (0.1 inch) thick.

2.6.6 With the purchaser's approval, sleeves may be omitted for small machines provided the proposal so states and the shaft is constructed of a material that has equal finish to that of a sleeve. If sleeves are not furnished, shafts or stub shafts shall include centers to permit refinishing.

2.6.7 For shafts that require sleeve gaskets to pass over threads, the threads shall be at least 1.5 millimetres (1/16 inch) less than the internal diameter of the gasket, and the diameter transition shall be chamfered 15-20 degrees to avoid damage to the gasket.

2.6.8 Shaft sleeves shall be sealed at one end, and the shaft-sleeve assembly shall extend at least 3 millimetres (1/8 inch) beyond the outer face of the seal end plate or the packing gland. Leakage between the shaft and the sleeve thus cannot be confused with leakage through the mechanical seal faces or the stuffing box packing.

2.6.9 Shafts shall be machined and properly finished throughout their length so that there is no more than 25 micrometres (0.001 inch) total indicated run-out. On the shaft sleeve assembled on the shaft, there shall be no more than 50 micrometres (0.002 inch) total indicated run-out.

- o 2.6.10 When specified, each rotating assembly shall be clearly marked with a unique identification number. This number shall be on the end of the shaft.

2.7 Seals

2.7.1 MECHANICAL SHAFT SEALS

2.7.1.1 Mechanical seals shall be furnished unless otherwise specified.

- o 2.7.1.2 Where seal face leakage must be contained double seals, tandem seals, or auxiliary shaft sealing devices may be specified by the purchaser. Venting, flushing or blanketing the space between the primary mechanical seal and the auxiliary sealing device or between mechanical seals shall be accomplished by means of tapped openings of the appropriate size but not less than 1/2 inch nominal pipe size, unless agreed by the purchaser. The arrangement of seal fluid piping shall be approved by the purchaser.

2.7.1.3 This standard does not cover the design of the component parts of mechanical seals, however, the component parts of the seal shall be of design and materials suitable for the specified service conditions. They shall also withstand the maximum vacuum or maximum allowable working pressure, as defined in 1.4.8. In determining the maximum sealing pressure, consideration shall be given to maximum suction pressure, seal fluid pressure, internal clearance changes, and so forth.

2.7.1.4 The mechanical seal shall prevent leakage from or into the vacuum pump or compressor over the entire range of specified operating conditions, during shutdown, start-up, and periods of idleness and shall also be suitable for operation of the machine on air.

2.7.1.5 Seals shall be preferably of the cartridge type with the shaft sleeve installed from outside the stuffing box.

2.7.1.6 Seals shall be removeable without removing the vacuum pump or compressor end housing, inlet or discharge piping or disturbing the driver.

2.7.1.7 Mechanical seal materials shall be approved by the purchaser.

2.7.1.8 The seal end plate component parts shall be satisfactory for at least the maximum design vacuum or maximum allowable working pressure and operating temperature and shall have sufficient rigidity to avoid any distortion that would impair seal operation, including distortion that may occur during tightening of the bolts to set gasketing. Seal end plates shall be provided with bolt holes rather than slots. Provisions shall be made for centering the seal end plate stuffing box bore with either an inside diameter or an outside diameter register fit. A minimum of 3 millimetre (1/8 inch) thick shoulder shall be provided to prevent axial movement of the mechanical seal seat as a result of chamber under or over pressure. Seal end plate bolting shall be based on specified operating temperature and maximum allowable working pressure and shall be in accordance with Section VIII, Division I, of the ASME Code, except that no fewer than four stud bolts shall be used. The nominal diameter of the bolts shall be at least 12.7 millimetre (1/2 inch).

2.7.1.9 The seal end plate and/or stuffing box face mating joint shall incorporate a confined gasket to prevent blowout. The gasket shall be of the controlled compression type (O-ring or spiral-wound gasket, for example) with metal to metal joint contact. However, where space and/or design limitations make this requirement impractical, an alternative seal end plate design shall be submitted to the purchaser for approval.

2.7.1.10 Gland plate connections shall be identified by stamping on the seal end plate the seal fluid inlet and outlet and vent and drain connections. Direction of rotation shall be shown on each gland plate.

- o 2.7.1.11 The vendor shall furnish all mechanical seal piping and appurtenances as specified by the purchaser. The seal piping system, including pipe, tubing, fittings, valves, strainers, orifice, and separators, shall be as specified in 3.5. The seal vendor and the vacuum pump or compressor vendor shall jointly establish the seal chamber circulation rate and shall advise the purchaser of the condition required in the seal chamber to ensure a stable film at the seal faces for proper seal operation. The pressure at the seal faces shall be maintained above atmospheric pressure. In vacuum service, the seal design shall be adequate to seal against atmospheric pressure when the vacuum pump is not operating.
- o 2.7.1.12 A non-sparking throttle bushing, pressed into the seal end plate against an outside shoulder, or other agreed type of secondary sealing device shall be provided for single and double mechanical seals to minimise leakage on complete failure of the seal and to allow control of minor leakage. The purchaser will specify if throttle bushings are required for tandem seals. The diametral clearance at the bushing bore shall not be more than 0.65 millimetre (0.025 inch).

2.7.1.13 Mechanical seals and glands shall not be used during the hydrostatic test but shall be used during all running or performance tests. Mechanical seals shall be installed in the vacuum pump or compressor before shipment and shall be clean and ready for initial service. On machines that require final adjustment in the field, the vendor shall attach a metal tag warning of this requirement.

2.7.2 STUFFING BOXES FOR CONVENTIONAL PACKING

2.7.2.1 Stuffing boxes on all liquid ring vacuum pumps and compressors shall be provided with seal lantern rings for the introduction of a cooling medium directly into the packing. Inlet and outlet connections shall be provided for the seal lantern ring.

2.7.2.2 Ample space shall be provided for replacement of the packing without removing or dismantling any part other than the gland and, if split, the seal cage which should have tapped holes for easy withdrawal.

2.7.2.3 Glands shall be designed so that the bolts cannot slip if the packing becomes loose. Where split glands are used, the halves shall be bolted together. Glands shall be fastened by studs screwed into the casing.

2.8 Dynamics

2.8.1 CRITICAL SPEEDS

2.8.1.1 Critical speeds correspond to resonant frequencies of the rotating assembly/bearing support system. The basic identification of critical speeds is made from the natural frequencies of the system and the forcing phenomena. If the frequency of any harmonic component of a periodic forcing phenomenon is equal to, or approximates, the frequency of any mode of the rotating assembly vibration, a condition of resonance may exist. If resonance exists at a finite speed, that speed is called a critical speed. This specification is concerned with actual critical speeds rather than various calculated values.

2.8.1.2 An exciting frequency may be less than, equal to, or greater than the rotational speed of the rotating assembly. Potential exciting frequencies considered in system design shall include but are not limited to the following sources:

- a. Unbalance in the rotating assembly system.
- b. Internal rubs.
- c. Blade or vane passing frequencies.
- d. Gear-tooth meshing and side bands.
- e. Coupling misalignment.
- f. Loose rotating assembly system components.

2.8.1.3 Resonances of support systems within the vendor's scope of supply shall not occur at the operating speed of a fixed speed machine or at any speed within the operating range of a variable speed machine.

2.8.1.4 The vendor who is specified to have unit responsibility shall determine that the drive-train critical speeds (rotating assembly lateral, system torsional, impeller blade modes, and the like) are compatible with the critical speeds of the machinery being supplied and that the combination will operate safely and reliably at the specified operating speed.

2.8.1.5 Rotating assemblies shall be of a stiff shaft construction with the first critical speed at least 120 per cent of the operating speed.

2.8.1.6 The torsional resonances of the complete train shall be at least 10 per cent above or 10 per cent below any possible excitation frequency at the operating speed of a fixed speed machine or within the operating speed range of a variable speed machine.

- o 2.8.1.7 When specified the equipment vendor shall make a lateral critical speed analysis and determine (a) that the critical speeds of the driver are compatible with the critical speeds of the vacuum pump or compressor and (b) that the combination is suitable for the specified operating speed or speed range.
- o 2.8.1.8 For units including gears, or when specified, the vendor shall perform a torsional analysis of the complete coupled train and shall be responsible for directing the modifications necessary to meet the requirements of 2.8.1.6.

2.8.2 VIBRATION AND BALANCING

2.8.2.1 Major parts of the rotating assembly shall be dynamically balanced. When bare shafts with single keyways are dynamically balanced, the keyway shall be filled with a fully crowned half-key. Shafts with keyways 180 degrees apart but not in the same transverse plane shall also be filled as described above. The initial balance correction to the bare shaft shall be recorded.

2.8.2.2 Each complete rotating assembly shall be dynamically balanced after assembly and before insertion in the casing. On rotors with single keyways, the keyway shall be filled with a fully crowned half-key.

The maximum allowable residual unbalance per plane (journal) shall be calculated as follows :

$$U = 6350 W/N$$

In imperial units, this translates to :

$$U = 4 W/N$$

Where :

U = residual unbalance, in gram-millimetres, (ounce-inches).

W = journal static weight load, in kilograms (pounds).

N = maximum continuous speed, in revolutions per minute.

When spare rotating assemblies are supplied, they shall be dynamically balanced to the same tolerances as the main rotating assembly.

2.8.2.3 After the final balancing of each complete rotating assembly has been completed, the residual unbalance shall be recorded. When specified, the weight of all half-keys used during final balancing of the assembled element shall be recorded

2.8.2.4 The unfiltered vibration for all anti-friction bearing vacuum pumps and compressors, measured in any direction on the bearing housing during the shop test and field operation at rated speed and specified operating pressures, shall not exceed a velocity of 7.6 millimetres per second (0.30 inch per second) peak nor exceed a displacement of 63.5 micrometres (0.0025 inch) peak-to-peak. See also 4.3.3.3.2.

- o 2.8.2.5 When specified by the purchaser, the vendor shall demonstrate that the vacuum pump or compressor can operate at the quoted maximum and minimum pressure ratios without exceeding the limits given in 2.8.2.4.

2.9 Bearings and Bearing Housings

2.9.1 Both radial and thrust bearings shall be the vendor's proven standard antifriction design (ball or roller) unless otherwise specified by the purchaser.

2.9.2 Antifriction bearings shall be selected to give a minimum L10 life of 6 years (50,000 hours) in continuous operation at normal operating duty but not less than 32,000 hours at maximum axial and radial loads and normal speed. (The L10 life is the number of hours which 90 percent of a group of identical bearings will complete or exceed before the first evidence of failure when operating at specified speed and load).

2.9.3 Thrust bearings shall be sized for continuous operation under the most adverse specified operating conditions. Calculations of the thrust loads shall include but shall not be limited to the following factors :

- a. Fouling and variation in clearances up to twice the design internal clearances.
- b. Step thrust from all diameter changes.
- c. Stage differential pressure
- d. Variations in inlet and discharge pressure.
- e. External loads from the driving equipment.

2.9.3.1 Thrust loads for flexible element couplings shall be calculated on the basis of the maximum allowable deflection permitted by the coupling manufacturer.

2.9.4 Thrust bearings shall be arranged to allow axial positioning of the rotor relative to the casing.

- o 2.9.5 Bearing housings for oil-lubricated non-pressure-fed bearings shall be provided with tapped and plugged fill and drain openings at least 1/2 inch National Pipe Thread (NPT) in size. The housings shall be equipped with constant-level sight-feed oilers at least 0.12 litre (4 ounces) in size, with a positive level positioner (not a set screw), transparent containers (not subject to sunlight - or heat induced opacity or deterioration), and protective wire cages. When specified, the oilers shall meet the purchaser's preference. 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.

2.9.6 Housings for oil-lubricated bearings shall be equipped with replaceable labyrinth-type end seals and deflectors where the shaft passes through the housing. The seals and deflectors shall be made of non sparking materials. The design of the seals and deflectors shall effectively retain oil in the housing and prevent entry of foreign material into the housing.

2.9.7 Where the gas/vapour handled or the ring liquid is flammable or toxic, bearing housings, load carrying bearing covers and brackets between the machine casing and the bearing housings shall be steel.

2.9.8 For oil lubricated bearings, sufficient cooling, including an allowance for fouling, shall be provided to maintain the oil temperature below 82°C (180°F) based on the specified operating conditions and ambient temperature. Where water cooling is required, water jackets shall have only external connections between the upper and lower housing jackets and shall have neither gasketed nor threaded connection joints, which may cause water to leak into the oil reservoir. If cooling coils (including fittings) are used, they shall be of non ferrous material and shall have no internal pressure joints or fittings. Coils shall have a thickness of at least 19 Birmingham wire gauge (BWG) [1.07 millimetres (0.042 inch)] and shall be at least 12.7 millimetre (0.5 inch) in diameter.

2.9.9 Antifriction bearings shall be retained on the shaft and fitted into housings in accordance with the requirements of ISO publications; however, the device used to lock ball thrust bearings to the shaft shall be restricted to a nut and lock washer with bent inner tab to ISO 2983 . 1975.

2.9.10 Except for the angular contact type, antifriction bearings shall have a loose internal clearance fit equivalent to ISO Group 3, as defined in ISO 5753 - 1981. Single or double-row bearings shall be of the Conrad type (no filling slots).

- o 2.9.11 Provision for oil mist systems shall be provided as specified by the purchaser.

2.9.12 Provision shall be made for mounting one radial vibration transducer on each bearing housing. The transducer location shall be as specified in API Standard 678.

2.9.13 Bearing housings shall be arranged so that the bearings can be replaced without disturbing the driver of the vacuum pump or compressor.