Special Purpose Gear Units For Petroleum, Chemical, And Gas Industry Services

API STANDARD 613
FOURTH EDITION, JUNE 1995

American Petroleum Institute
1220 L Street, Northwest
Washington, D.C. 20005

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Manufacturing, Distribution and Marketing Department

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FOREWORD

This standard is based on the accumulated knowledge and experience of petroleum refiners and gear manufacturers. The objective of this publication is to provide a purchase specification to facilitate the manufacture and procurement of special purpose gear units for use in petroleum, chemical, and gas industry services.

The primary purpose of API standards for mechanical equipment is to establish minimum mechanical requirements. Energy conservation is of concern and has become increasingly important in all aspects of equipment design, application, and operation. Thus, innovative energy-conserving approaches should be aggressively pursued by the manufacturer and the user during these steps. Alternative approaches that may result in improved energy utilization should be thoroughly investigated and brought forth. This is especially true of new equipment proposals, since the evaluation of purchase options will be based increasingly on total life costs as opposed to acquisition cost alone. Equipment manufacturers, in particular, are encouraged to suggest alternatives to those specified when such approaches achieve improved energy effectiveness and reduced total life costs without sacrifice of safety or reliability.

This standard requires the purchaser to specify certain details and features. Although it is recognized that the purchaser may desire to modify, delete, or amplify sections of this standard, it is strongly recommended that such modifications, deletions, and amplifications be made by supplementing this standard, rather than by rewriting or incorporating sections thereof into another complete standard.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to ensure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any federal, state, or municipal regulation with which this publication may conflict.

Suggested revisions are invited and should be submitted to the director of the Manufacturing, Distribution and Marketing Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

IMPORTANT INFORMATION CONCERNING USE OF ASBESTOS OR ALTERNATIVE MATERIALS

Asbestos is specified or referenced for certain components of the equipment described in some API standards. It has been of extreme usefulness in minimizing fire hazards associated with petroleum processing. It has also been a universal sealing material, compatible with most refining fluid services.

Certain serious adverse health effects are associated with asbestos, among them the serious and often fatal diseases of lung cancer, asbestosis, and mesothelioma (a cancer of the chest and abdominal linings). The degree of exposure to asbestos varies with the product and the work practices involved.

Consult the most recent edition of the Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, Occupational Safety and Health Standard for Asbestos, Tremolite, Anthophyllite, and Actinolite, 29 *Code of Federal Regulations* Section 1910.1001; the U.S. Environmental Protection Agency, National Emission Standard for Asbestos, 40 *Code of Federal Regulations* Sections 61.140 through 61.156; and the U.S. Environmental Protection Agency (EPA) rule on labeling requirements and phased banning of asbestos products, published at 54 *Federal Register* 29460 (July 12, 1989).

There are currently in use and under development a number of substitute materials to replace asbestos in certain applications. Manufacturers and users are encouraged to develop and use effective substitute materials that can meet the specifications for, and operating requirements of, the equipment to which they would apply.

SAFETY AND HEALTH INFORMATION WITH RESPECT TO PARTICULAR PRODUCTS OR MATERIALS CAN BE OBTAINED FROM THE EMPLOYER, THE MANUFACTURER OR SUPPLIER OF THAT PRODUCT OR MATERIAL, OR THE MATERIAL SAFETY DATA SHEET.

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Special Purpose Gear Units for Petroleum, Chemical, and Gas Industry Services

SECTION 1—GENERAL

1.1 Scope

1.1.1 This standard covers the minimum requirements for special-purpose, enclosed, precision single- and double-helical one- and two-stage speed increasers and reducers of parallel-shaft design for refinery services. This standard is primarily intended for gears that are in continuous service without installed spare equipment. Gear sets furnished to this standard shall be considered matched sets.

Note: The purchase of a spare set of gear rotors or a complete gear unit does not mean that the equipment is spared.

This standard includes related lubricating systems, controls, instrumentation, and other auxiliary equipment. This standard is not intended to apply to gears in general-purpose service, which are covered by API Standard 677; to gears integral with other equipment; or to gears other than helical.

Note: A bullet (●) at the beginning of a paragraph indicates that either a decision is required or further information is to be provided by the purchaser. This information should be indicated on the data sheets (see Appendix A); otherwise it should be stated in the quotation request or in the order.

1.1.2 The following gear-driven applications may be covered by this standard:

a. Speed increasers, including those for centrifugal compressors, axial compressors, blowers, rotary positive displacement compressors, contactors, separators, and centrifugal pumps.
b. Speed reducers, including those for reciprocating compressors, rotary positive displacement compressors, contactors, centrifugal pumps, extruders, generators, and fans.

1.2 Alternative Designs

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.

1.3 Conflicting Requirements

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

1.4 Definition of Terms

Terms used in this standard are defined in 1.4.1 through 1.4.21.

1.4.1 *Axially (horizontally) split* refers to casing joints that are parallel to the shaft centerline.

1.4.2 *Critical speed* is defined in 2.6.1.

1.4.3 *Gear* refers to the lowest speed rotor.

1.4.4 *Pinion* refers to the highest speed rotor.

1.4.5 *Gear rated power* is the maximum power specified by the purchaser on the data sheet and stamped on the nameplate (see 2.2.1).

1.4.6 *Normal transmitted power* is the power at which usual operation is expected and optimum efficiency is desired. The normal transmitted power may be equal to or less than the gear rated power.

1.4.7 *Mechanical rating* is the gear rated power (1.4.5) multiplied by the specified gear service factor (1.4.16).

1.4.8 A *hunting tooth combination* exists for mating gears when a tooth on the pinion does not repeat contact with a tooth on the gear until it has contacted all the other gear teeth.

1.4.9 *Maximum allowable speed* (in revolutions per minute) is the highest speed at which the manufacturer's design will permit continuous operation.

1.4.10 *Maximum continuous speed* (in revolutions per minute) is the speed at least equal to 105 percent of the rated pinion speed for variable-speed units and is the rated pinion speed for constant-speed units.

1.4.11 *Minimum allowable speed* (in revolutions per minute) is the lowest speed at which the manufacturer's design will permit continuous operation.

1.4.12 The *rated input speed* of the gear unit (in revolutions per minute) is the specified (or nominal) rated speed of its driver, as designated by the purchaser on the data sheets.

1.4.13 The *rated output speed* of the gear unit (in revolutions per minute) is the specified (or nominal) rated speed of its driven equipment, as designated by the purchaser on the data sheets.

Note: In selecting the number of teeth for the pinion and gear, it is often impracticable for the vendor to match exactly both the rated input and the rated output speed designated on the data sheets. The purchaser will therefore indicate which of the two is specified (that is, must be exactly adhered to by the vendor) and which is nominal (that is, permits some variation). An *S* will be used to indicate the specified speed, and an *N* will be used to indicate the nominal speed. The purchaser will also indicate on the data sheets the allowable percentage of variation in the designated gear ratio.

1.4.14 The *tooth pitting index* (*K*) is defined in 2.2.3.

1.4.15 The *bending stress number* (*S*) is defined in 2.2.4.2.

1.4.16 The *gear service factor* (*SF*) is the factor that is applied to the tooth pitting index and the bending stress number, depending on the characteristics of the driver and the driven equipment, to account for differences in potential overload, shock load, and/or continuous oscillatory torque characteristics.

1.4.17 *Trip speed* (revolutions per minute) is the speed at which the independent emergency overspeed device operates to shut down a prime mover. (For steam turbines and reciprocating engines, the trip speed will be at least 110 percent of the maximum continuous speed. For gas turbines, the trip speed will be at least 105 percent of the maximum continuous speed.)

1.4.18 The use of the word *design* in any term (such as design horsepower, 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.

1.4.19 A *special purpose application* is an application for which the equipment is designed for uninterrupted, continuous operation in critical service and for which there is usually no spare equipment.

1.4.20 *Total indicated runout* (TIR), also known as total indicator reading, is the runout of a diameter or face determined by measurement with a dial indicator. The indicator reading implies an out-of-squareness equal to the reading or an eccentricity equal to half the reading.

1.4.21 *Gauss Levels* refers to the magnetic field level of a component measured with a "Hall effect" probe with no interference from adjacent magnetic parts or structures.

1.4.22 *Unit responsibility* refers to the responsibility for coordinating the technical aspects of the equipment and all auxiliary systems included in the scope of the order. Responsibility for such factors as the power requirements, speed, rotation, general arrangement, couplings, dynamics, noise, lubrication, sealing system, material test reports, instrumentation, piping, and testing of components shall be reviewed.

1.5 Referenced Publications

The editions of the following standards, codes, and specifications that are in effect at the time of publication of this standard 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.

AGMA[1]

- 295 *Specification for Measurement of Sound on High Speed Helical Gear Units*
- 908 *Information Sheet—Geometry Factors for Determining the Strength of Spur, Helical, Herringbone, and Bevel Gear Teeth*
- 2000 *Gear Classification and Inspection Handbook for Unassembled Spur and Helical Gears*
- 2001 *Fundamental Rating Factors and Calculation Methods for Involute, Spur, and Helical Gear Teeth*
- 6010 *Practice for Enclosed Speed Reducer or Increasers Using Spur, Helical, Herringbone and Spiral Bevel Gears*
- 6011 *Practice for High Speed Helical and Herringbone Gear Units*

API

- RP 500 *Classification of Locations for Electrical Installation in Petroleum Facilities*
- RP 550 *Manual on Installation of Refinery Instruments and Control Systems (out of print)*
- Std 614 *Lubrication, Shaft-Sealing, and Control Oil Systems for Special-Purpose Applications*
- Std 615 *Sound Control of Mechanical Equipment for Refinery Services (out of print)*
- Std 670 *Vibration, Axial-Position and Bearing-Temperature Monitoring Systems*
- Std 671 *Special-Purpose Couplings for Refinery Service*
- Std 677 *General-Purpose Gear Units for Refinery Service*

ASME[2]

- B1.1 *Unified Inch Screw Threads (UN and UNR Thread Form)*
- B1.20.1 *Pipe Threads, General Purpose, Inch*
- B16.1 *Cast Iron Pipe Flanges and Flanged Fittings,* Class 25, 125, 250, and 800
- B16.5 *Pipe Flanges and Flange Fittings, Steel Nickel Alloy and Other Special Alloys*
- B16.11 *Forged Steel Fittings, Socket-Welding and Threaded*
- B16.42 *Ductile Iron Pipe Flanges and Flanged Fittings,* Class 150 and 300
- *Boiler and Pressure Vessel Code,* Section V, "Non-Destructive Examination;" Section VIII, "Pressure Vessels;" and Section IX, "Welding and Brazing Qualifications"
- Y14.2M *Line Conventions and Lettering*

ASTM[3]

- A 6 *General Requirements for Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use*
- A 27 *Carbon Steel Castings for General Application*
- A 36 *Structural Steel*
- A 48 *Gray Iron Castings*
- A 192 *Seamless Carbon Steel Boiler Tubes for High-Pressure Service*

[1]American Gear Manufacturers Association, 1500 King Street, Suite 201, Alexandria, Virginia 22314.

[2]American Society of Mechanical Engineers, 345 East 47th Street, New York, New York 10017.

[3]American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.

A 269 *Seamless and Welded Austenitic Stainless Steel Tubing for General Service*
A 275 *Method for Magnetic Particle Examination of Steel Forgings*
A 283 *Low and Intermediate Tensile Strength Carbon Steel Plates, Shapes, and Bars*
A 284 *Low and Intermediate Tensile Strength Carbon-Silicon Steel Plates for Machine Parts and General Construction*
A 285 *Low- and Intermediate-Tensile Strength Carbon Steel Pressure Vessel Plates*
A 312 *Seamless and Welded Austenitic Stainless Steel Pipe*
A 388 *Recommended Practice for Ultrasonic Examination of Heavy Steel Forgings*
A 515 *Carbon Steel Pressure Vessel Plates for Intermediate- and Higher-Temperature Service*
A 516 *Carbon Steel Pressure Vessel Plates for Moderate- and Lower-Temperature Service*
A 575 *Merchant Quality Carbon Steel Bars, MGrades*
A 576 *Special Quality Hot-Wrought Carbon Steel Bars*
E94 *Guide for Radiographic Testing*
E125 *Reference Photographs for Magnetic Particle Indications on Ferrous Castings*
E142 *Method for Controlling Quality of Radiographic Testing*
E709 *Practice for Magnetic Particle Examination*
DS 56B *Metals and Alloys in the Unified Numbering System*

ISO[4]
3448 *Standard Industrial Liquid Lubricants— ISO Viscosity Classification*

NFPA[5]
70 *National Electrical Code*

OSHA[6]
Occupational Safety and Health Standards (29 Code of Federal Regulation Part 1910)

SSPC[7]
SP-6 *Commercial Blast Cleaning*

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

[4]International Organization for Standardization. ISO publications are available from the American National Standards Institute, 11 West 42nd Street, New York, New York 10036.
[5]National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02269.
[6]Occupational Safety and Health Administration, U.S. Department of Labor, 200 Constitution Avenue, N.W. Washington, D.C. 20210.
[7]Steel Structures Painting Council, 4400 5th Avenue, Pittsburgh, Pennsylvania 15213-2683

SECTION 2—BASIC DESIGN

2.1 General

2.1.1 Gear units purchased according to this standard shall conform to AGMA 6011 and to related AGMA standards referenced therein, except as modified or supplemented by this standard.

2.1.2 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.

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

● **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 API Standard 615 and to the maximum allowable sound pressure level specified by the purchaser.

2.1.5 Equipment shall be designed to run safely to the trip speed setting. Rotors for turbine-driven gear units shall be designed to operate safely at momentary speeds up to 130 percent of the rated speed.

2.1.6 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.

● **2.1.7** Electrical components and installations shall be suitable for the area classification (class group and division) specified by the requirements of NFPA 70, Articles 500 and 502, and by local codes specified and furnished by the purchaser.

2.1.8 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 minimize contamination by moisture, dust, and other foreign matter during periods of operation and idleness.

2.1.9 The gear shall perform on the test stand and on its 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.

● **2.1.10** 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 minimize the influence of these factors, the vendor shall review and comment on the purchaser's baseplate and foundation drawings. In addition, the vendor's representative may be requested to check alignment at the operating temperature and may be requested to be present during the initial alignment check and the tooth contact check.

● **2.1.11** 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, unusual humidity, and dusty or corrosive conditions).

2.1.12 Gear units shall not require a break-in period at reduced speed and load in the field.

Note: It is recognized that under certain conditions a break-in period may be requested. If a break-in period is required, the vendor shall specify in the proposal the required load, speed, and duration of the period. The vendor shall also specify in the proposal any additional field inspection and commissioning required during the break-in period.

● **2.1.13** The gearing shall be designed to withstand all internal and external loads inherent to geared, rotating machinery systems. The gearing shall be capable of withstanding the specified external loads (thrust, lube-oil piping, and so forth) transmitted across the gear mesh while the unit is operating at the gear rated power specified by the purchaser.

2.1.14 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 cylindrically doweled) and manufactured to ensure accurate alignment on reassembly. Where practical, components should be doweled, keyed, or shouldered asymmetrically to prevent incorrect assembly.

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

● **2.1.16** The purchaser will specify the appropriate shaft assembly designation selected from the combinations listed in Table 1 and illustrated in Figure 1. The purchaser may alternatively circle one or more of the assembly designations on a copy of Figure 1 and submit the copy with the quotation request. If the shaft arrangement has not been finalized at the time of the quotation request, the purchaser will designate all of the combinations under consideration.

2.1.17 The rotational direction of high-speed and low-speed shafts is either clockwise (CW) or counterclockwise (CCW) as viewed from the coupling ends of the respective shafts.

Table 1—Shaft Assembly Combinations

High-Speed Shaft	Low-Speed Shaft
L	R
R	L
L	L
R	R
R	LR
L	LR
LR	L
LR	R
LR	LR

Note: L = left; R = right. The letters refer to the number and direction of shaft extensions (see Figure 1). The material for this table was extracted from AGMA 6010 with permission of the publisher.

2.1.17.1 On the data sheets and in drawings and tables, the shaft rotational direction shall be designated by the abbreviations CW or CCW as indicated by the circular arrows in Figure 2.

2.1.17.2 The purchaser will specify the rotational direction of both the high-speed and the low-speed shaft. When either or both shafts have an extension at each end, the purchaser may alternatively indicate the rotational directions on the appropriate assembly designation (see Figure 1) and submit a copy of the figure with the quotation request.

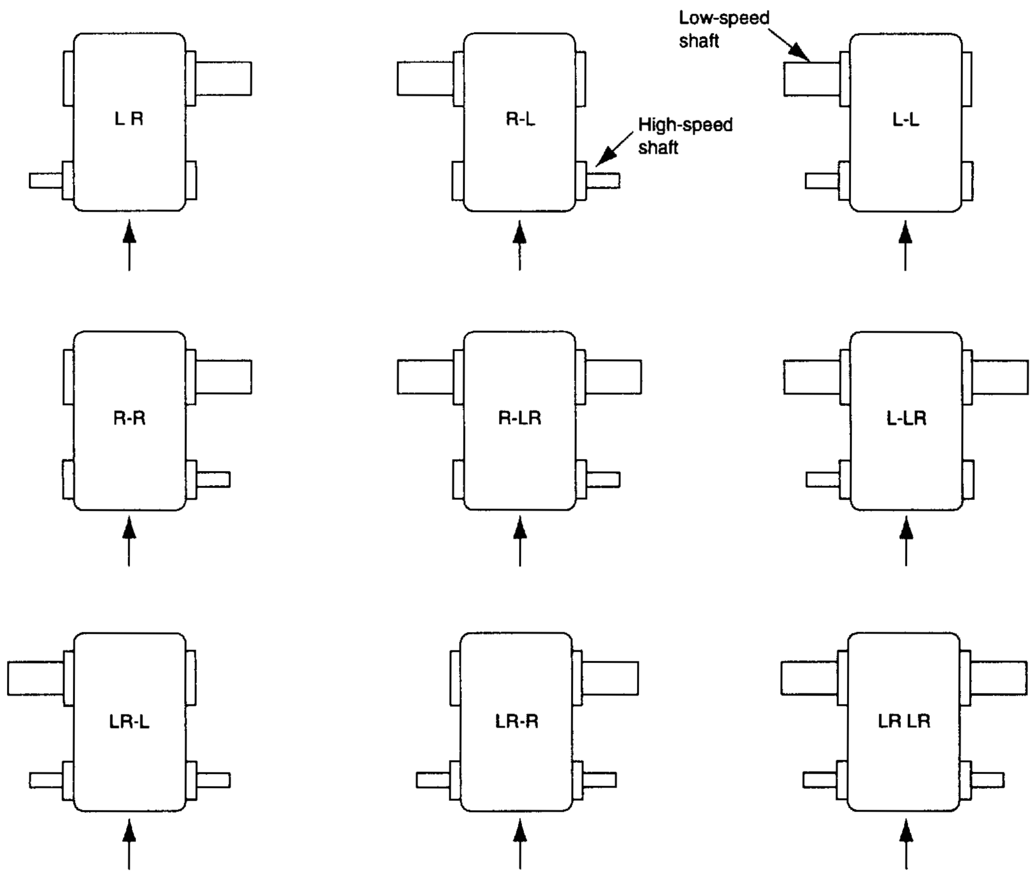
2.1.17.3 In finalizing the data for purchase, the purchaser will prepare a sketch that shows the direction of rotation of each item in the train.

2.2 Rating

● 2.2.1 GEAR RATED POWER

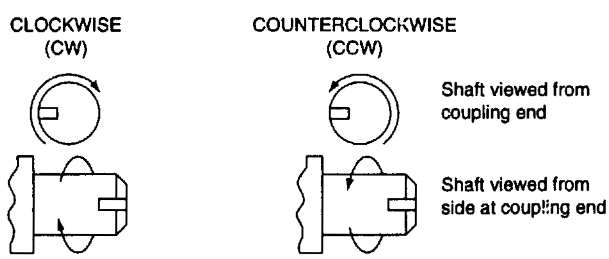
The gear rated power of the unit will normally be specified by the purchaser. For gear units located next to the driver, the gear rated power will be the maximum installed power of the driver. For electric motor drivers, the gear rated power will be the motor nameplate rating multiplied by the motor service factor. All modes of normal and abnormal operation shall be examined. Modes of operation may include the number of starts per unit of time, reduced load, removal, reversed load, reduced speed, and overload and overspeed conditions. For gear units between two items of driven equipment, the power rating of such gears should normally be not less than Item a or b, whichever is greater:

a. 110 percent of the maximum power required by the equipment driven by the gear.
b. The maximum power of the driver prorated between the driven equipment, based on normal power demands. If the maximum transmitted torque occurs at an operating speed other than the maximum continuous speed, this torque and



Notes:
1. L = left; R= right.
2. Arrows indicate the line of sight used to determine the direction of the shaft extensions. (The figure depicts plan views.)
3. The letter or letters before the hyphen refer to the number and direction of high-speed shaft extensions; the letter or letters after the hyphen refer to the number and direction of low-speed shaft extensions.
4. The material for this figure was extracted from AGMA 6011 with permission of the publisher.

Figure 1—Shaft Assembly Designations (for Parallel-Shaft, Single- and Double-Helical One- and Two-Stage Speed Increasers and Reducers)



Note: The material for this figure was extracted from AGMA 6010 with permission of the publisher.

Figure 2—Shaft Rotation Designations

its corresponding speed will be specified by the purchaser and shall be the basis for sizing the gear.

2.2.2 GEAR SERVICE FACTOR

● **2.2.2.1** The minimum gear service factor (SF) will be specified by the purchaser on the data sheets. In no case should the service factor be less than that required for the service by Table 2.

2.2.2.2 In addition to specifying the service factor, the purchaser may specify the hardnesses of the pinion and gear to establish power and frame sizes. The purchaser should consider the following factors when determining these hardnesses:

Table 2—Minimum Gear Service Factors

Driven Equipment	Prime Mover: Motor	Turbine	Internal Combustion Engine
Centrifugal blowers	1.4	1.6	1.7
Compressors			
Centrifugal	1.4	1.6	1.7
Axial	1.4	1.6	1.7
Rotary lobe (radial, axial, screw, and so forth)	1.7	1.7	2.0
Reciprocating	2.0	2.0	2.3
Contactors	1.7	1.7	2.0
Extruders	1.7	1.7	—
Fans			
Centrifugal	1.4	1.6	1.7
Forced draft	1.4	1.6	1.7
Induced draft	1.7	2.0	2.2
Generators and exciters			
Base load and continuous	1.1	1.1	1.3
Peak-duty cycle	1.3	1.3	1.7
Pumps			
Centrifugal (all services, except as listed below)	1.3	1.5	1.7
Centrifugal, boiler feed	1.7	2.0	—
Centrifugal, hot oil	1.7	2.0	—
Centrifugal, high speed (over 3600 rpm)	1.7	2.0	—
Centrifugal, water supply	1.5	1.7	2.0
Rotary, axial flow (all types)	1.5	1.5	1.8
Rotary, gear	1.5	1.5	1.8
Reciprocating	2.0	2.0	2.3

Note: rpm = revolutions per minute.

a. The ductility of the gear teeth.
b. Noise.
c. Future upgrading.
d. Conventional versus special machine finish requirements.

2.2.3 TOOTH PITTING INDEX

2.2.3.1 Gear units shall be sized on the basis of a tooth pitting index called a *K factor*. This method includes factors to account for such considerations as the radii of curvature of the contacting tooth surfaces, extended life, high reliability, dynamic load effects, maldistribution of tooth loading across the face, and the strength of the materials in terms of pitting resistance. This simplified system for sizing the gear unit is consistent with AGMA 2001, with conservative assumptions for each variable in the more complex basic equations contained in that document.

2.2.3.2 The *K* factor is defined as follows:

$$K = \left[W_t / dF_w\right]\left[(R+1)/R\right] \quad (1)$$

In SI units:

$$W_t = \left[(1.91 \times 10_7)P_g\right] / N_p d \quad (2)$$

In U.S. customary units, W_t can be expressed as follows:

$$W_t = (126{,}000 P_s) / N_p d$$

Where:

K = tooth pitting index in megapascals (pounds per square inch).
Wt = transmitted tangential load at the operating pitch diameter, in newtons (pounds).
Fw = net face width, in millimeters (inches).
d = pinion pitch diameter, in millimeters (inches).
R = number of teeth in the gear divided by number of teeth in the pinion.
Pg = gear rated power, in kilowatts (horsepower).
Np = pinion speed, in revolutions per minute.

2.2.3.3 The allowable *K* factor at the gear rated power will vary with the materials selected for the gear teeth, the tooth hardening processes used, and the service factor. The allowable *K* factor is calculated as follows:

$$K_a = I_m / (SF) \quad (3)$$

Where:

Ka = allowable *K* factor.
Im = material index number (from Table 3 and Figure 3).
SF = minimum gear service factor (from Table 2).

● **2.2.3.4** Table 3 presents material index numbers and maximum length-to-diameter *(L/d)* ratios for several combinations of materials in current use. Index numbers for other materials' hardnesses can be determined by referring to Figure 3. It should be noted that the minimum hardness is specified. The normal heat-treating practice requires a tolerance range of about 40-50 Brinell numbers. A gear on the high side of its range and a pinion on the low side of its range may, therefore, have the same or overlapping hardness. Such a combination is perfectly satisfactory.

2.2.3.5 The *L/d* values shown in Table 3 apply to helical gears with unmodified leads when designed to transmit the rated power. Generally, higher *L/d* ratios can be allowed when the total lead mismatch caused by deflection (combined bending and torsional) across a helix is less than 0.038 millimeter (0.0015 inch) on through hardened gears and 0.025 millimeter (0.0010 inch) on case hardened gears. The determination of deflection is to be based on the rated power.

2.2.3.6 When a higher *L/d* ratio than tabulated in Table 3 is proposed, the gear vendor shall submit justification in the proposal for using the higher *L/d* ratio. Purchaser's approval is required when *L/d* ratios exceed those in Table 3. When operating conditions other than the gear rated power are specified by the purchaser, such as the normal transmitted power, the gear vendor shall consider in the analysis the length of time and load range at which the gear unit will operate at each condition so that the correct lead modification can be determined. When modified leads are to be furnished, purchaser

Table 3—Material Index Numbers and Maximum *L/d* Ratios

		Material Index Number, I_m		Maximum Pinion *L/d* Ratio	
Minimum Gear Hardness	Minimum Pinion Hardness	Pounds per Square Inch	Megapascals	Double Helical	Single Helical
223 BHN	262 BHN	130	0.896	2.4	1.7
262 BHN	302 BHN	160	1.103	2.3	1.6
302 BHN	341 BHN	200	1.379	2.2	1.5
352 BHN	50 RC[a]	260	1.793	2.0	1.45
50 RC[a]	50 RC[a]	300	2.068	1.9	1.4
55 RC[b]	55 RC[b]	410	2.827	1.7	1.35
58 RC[b]	58 RC[b]	440	3.034	1.6	1.3

Note: *L* = net face width plus gap, in millimeters (inches); *d* = pinion pitch diameter, in millimeters (inches); BHN = Brinell hardness number; RC = Rockwell hardness (C scale).
[a]Nitrided.
[b]Carburized.

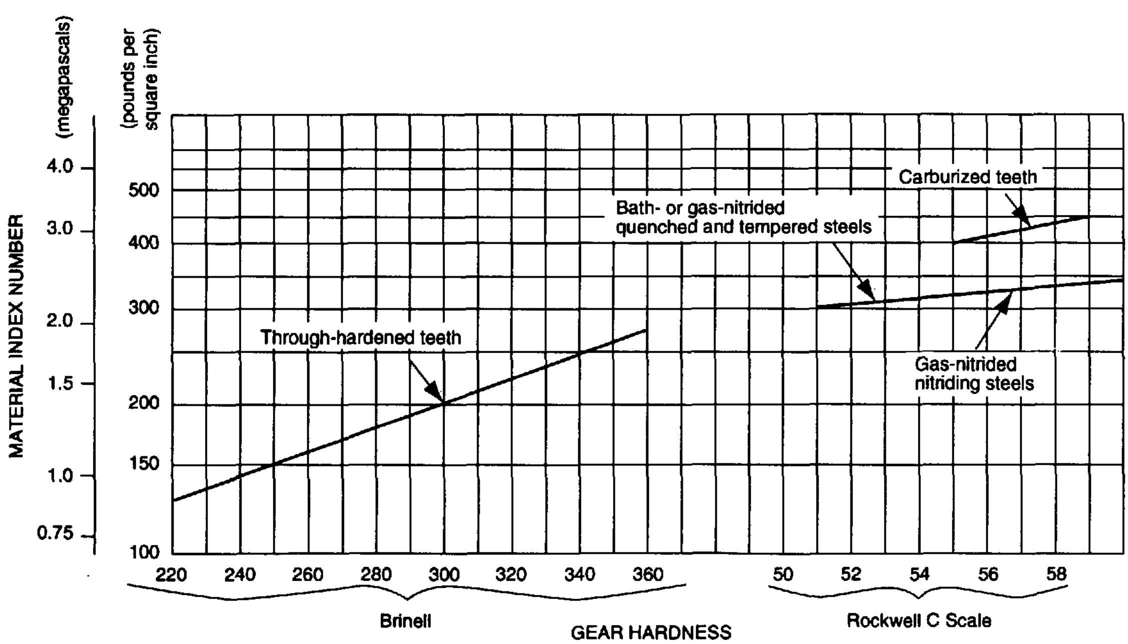


Figure 3—Material Index Numbers

and vendor shall agree on the tooth contact patterns obtained in the checking stand, housing, and test stand.

The analysis of gear tooth-load distribution versus lead modification is not within the scope of this standard.

2.2.4 TOOTH SIZE AND GEOMETRY

2.2.4.1 The size and geometry of the gear teeth shall be selected so that the bending stress number as calculated using Equation 1 does not exceed the values in Figure 4. This method includes factors similar to those used to determine the allowable *K* factor. This simplified system for sizing gear teeth is consistent with AGMA 2001.

2.2.4.2 The vendor shall calculate the bending stress number for both the pinion and the gear. Where idlers are used, the calculated stress shall be limited to 70 percent of the value given in Figure 4. The bending stress number is calculated as follows:

In SI units:

$$S=\left[W_t/(m_n F_w)\right](SF)\left[(1.8\cos\gamma)/J\right] \quad (4)$$

In U.S. customary units:

$$S=\left[(W_t P_{nd})/F_w\right](SF)\left[(1.8\cos\gamma)/J\right]$$

Where:

S = bending stress number.
Pnd = normal diametral pitch, in 1/inches.
γ = helix angle.
J = geometry factor (from AGMA 908).
mn = module number, in millimeters.

2.2.5 DEVIATIONS

It is recognized that special cases will exist in which it may be desirable to deviate from the rating rules specified in 2.2.1 through 2.2.4. The vendor shall describe and justify such deviations in the proposal.

2.3 Casings

2.3.1 DESIGN PARAMETERS

2.3.1.1 Gear casings shall be either cast or fabricated and shall be designed and constructed to maintain rotor alignment under all load conditions.

2.3.1.2 Provision shall be made to permit doweling or keying the casing to the soleplate or baseplate at two points as close as possible to the vertical plane of the pinion's centerline (to minimize misalignment of the high-speed pinion with connected equipment). Casings not doweled or keyed by the vendor shall be provided with dowel starter holes. Drilling interferences in the field installation shall be considered in determining the location and angle (that is, 90 degrees versus 60 degrees) of the starter holes.

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

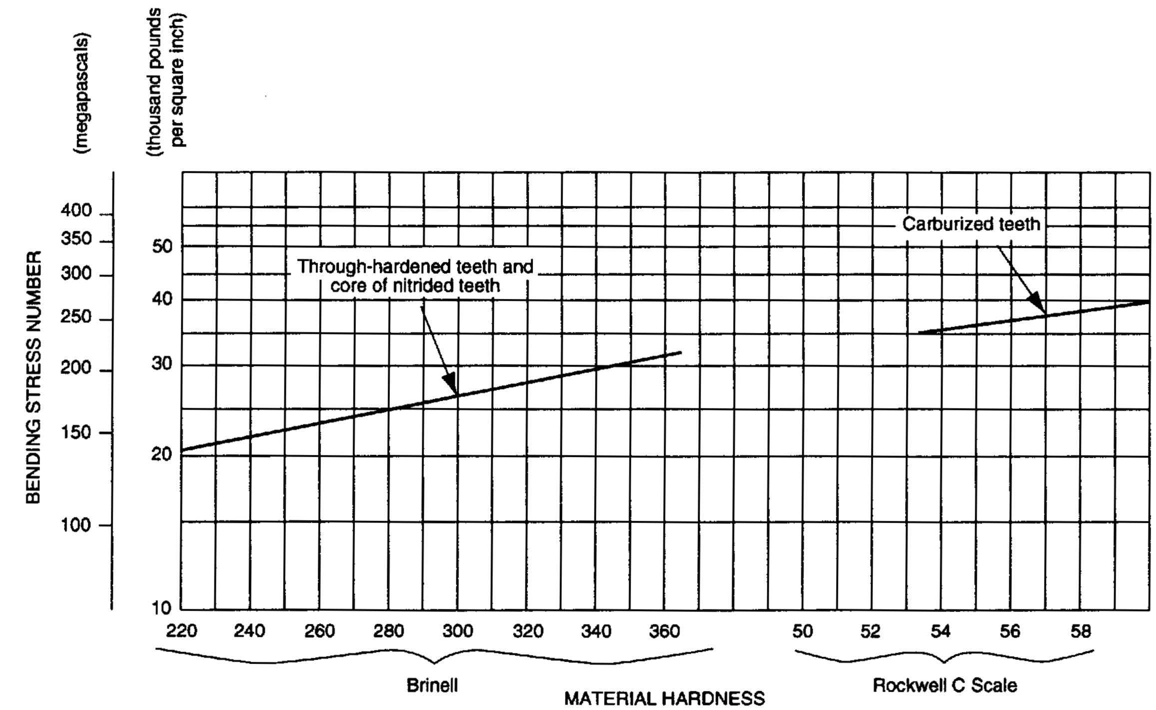


Figure 4—Bending Stress Numbers

2.3.1.4 The equipment feet shall be provided with vertical jackscrews and shall be drilled with pilot holes that are accessible for use in final doweling.

2.3.1.5 Bores shall be machined to a sufficient degree of accuracy so that a gear set that contacts correctly on true centers on a rotor checking stand will also contact correctly in its own casing.

2.3.1.6 Casings shall be designed to prevent injurious distortion caused by temperature, torque, and allowable external forces and moments.

2.3.1.7 To the maximum extent practicable, casings shall be designed with internal oil passages to minimize external piping. All internal piping should preferably be welded and should preferably use flanges for all connections. Any threaded piping shall be a minimum of Schedule 80 and shall be seal welded at flanges (see 2.4.6.4).

2.3.1.8 Where internal space does not permit the use of ½, ¾-, or 1-inch ASTM A 312 pipe, seamless steel tubing conforming to ASTM A 192 may be furnished with stainless steel fittings, or stainless steel tubing conforming to ASTM A 269 may be furnished with steel fittings. Tubing thicknesses shall meet the requirements of Table 4. The make and model of fittings shall be subject to the purchaser's approval.

2.3.1.9 The design of internal piping shall achieve proper support and protection to prevent damage from vibration or from shipment, operation, and maintenance. Cantilevered piping shall include reinforcing gussets in two planes at all pipe-to-flange connections.

2.3.1.10 Internal piping and oil passages shall be cleaned to remove all foreign material.

2.3.1.11 Casings shall be designed to permit rapid drainage of lube oil and to minimize oil foaming, which could lead to excessive heat rise of the oil. For gears with pitch line velocities of more than 125 meters per second (25,000 feet per minute), consideration shall be given to special designs such as the following:

a. A false bottom in the gear unit.
b. A sump depth at least 610 millimeters (2 feet) below the bottom of the gear.
c. Meshing direction.
d. An oil drain line to the reservoir that is independent from all other oil system drains.
e. A second full-size drain connection.
f. Larger side and circumferential clearances between gears and pinions and the casing.
g. Windage baffles.

2.3.1.12 A filter-breather shall be provided. The filter-breather shall be constructed of Series 300 stainless steel with Series 300 stainless steel or copper-nickel alloy (for example, Monel) internals, designed and located to prevent: entrainment or discharge of oil to the atmosphere, pressure buildup in the casing, entrance of water during violent rainstorms, and entrance of dirt entrained in the air. The filter-breather shall be at least NPS 1½, and its construction shall permit easy disassembly for inspection and cleaning.

Note: The location generally recommended by gear manufacturers for the filter-breather is on the drain pipe immediately adjacent to the casing, with no breather on the casing itself.

2.3.1.13 A removable, gasketed inspection cover or covers shall be provided in the gear casing to permit direct visual inspection of the full-face width of the pinion and gear. The inspection opening or openings shall be at least one-half the width of the gear face.

2.3.1.14 Permanent coatings or paint shall not be applied to the interior of the casing unless the purchaser approves in advance the material and method of application.

2.3.2 JOINTS

Axially split casings shall use a metal-to-metal joint (with a suitable joint compound) that is tightly maintained by suitable bolting. Gaskets (including string type) shall not be used on the axial joint.

2.3.3 BOLTING

2.3.3.1 Case bolting should preferably be of the through-bolt type. Where this is impractical, studs shall be used unless assembly or disassembly prevents their use. Cap screws are acceptable in such instances.

2.3.3.2 The details of threading shall conform to ASME B1.1.

2.3.3.3 Studded connections shall be furnished with studs installed. Blind stud holes should be drilled only deep enough to allow a preferred tap depth of 1½ times the major diameter of the stud; the first 1½ threads at both ends of each stud shall be removed.

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

2.3.4 ASSEMBLY AND DISASSEMBLY

2.3.4.1 It shall be possible to lift the upper half of the casing without disturbing the piping of the main oil supply to the lower half of the casing.

2.3.4.2 Jackscrews, guide rods, and casing alignment dowels shall be provided to facilitate disassembly and re-

Table 4—Minimum Tubing Wall Thickness

Nominal Tubing Size		Minimum Wall Thickness	
Millimeters	Inches	Millimeters	Inches
12.7	½	1.65	0.065
19.05	¾	2.40	0.095
25.4	1	2.75	0.109

assembly. 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 improper fit caused by marring. Guide rods shall be of sufficient length to prevent damage to the internals or casing studs by the casing during disassembly and reassembly. Lifting lugs or eyebolts shall be provided for lifting only the top half of the casing. Methods of lifting the assembled machine shall be specified by the vendor.

2.4 Casing Connections

2.4.1 A single lube-oil supply connection is preferred.

2.4.2 A single lube-oil drain connection from the gear casing is preferred. The minimum drain pipe size shall be based on the total inlet flow to the gear casing, as shown in Table 5. The drain connection and drain pipe shall be sized and installed to maintain an oil drain velocity of not more than 0.30 meter per second (1.0 foot per second), based on a drain line running no more than half full.

2.4.3 When specified, casings shall be provided with an inlet purge connection at least NPS ½ inch, located to assure a sweep of purge gas across the casing to the filter-breather.

2.4.4 Openings for NPS 1¼, 2½, 3½, 5, 7, and 9 shall not be used.

2.4.5 All of the purchaser's connections on the gear case shall be accessible for disassembly without the gear unit being moved.

2.4.6 Oil inlet and drain connections shall be flanged or machined and studded, oriented as specified, and not less than NPS ¾. Where flanged or machined and studded openings are impractical, threaded openings in sizes NPS ¾ through NPS 1½ are permissible. These threaded openings shall be installed as specified in 2.4.6.1 through 2.4.6.4.

2.4.6.1 A pipe nipple, preferably not more than 150 millimeters (6 inches) long, shall be screwed into the threaded opening.

2.4.6.2 Pipe nipples shall be a minimum of Schedule 160 seamless for NPS 1 and smaller and a minimum of Schedule 80 for NPS 1½.

Table 5—Drain Pipe Sizes

Inlet Flow Rate		Minimum Drain Size	
Liters Per Minute	Gallons Per Minute	Millimeters	Inches[a]
26	7	75	3
56	15	100	4
170	45	150	6
380	100	200	8
585	155	250	10
830	220	300	12
1000	264	350	14

[a]Nominal pipe size.

2.4.6.3 The pipe nipple shall be provided with a welding-neck or slip-on flange.

2.4.6.4 The threaded connection shall be seal welded; however, seal welding is not permitted on cast iron equipment, for instrument connections, or where disassembly is required for maintenance. Seal-welded joints shall be in accordance with ASME B31.3.

2.4.7 Flanges shall conform to ASME B16.1, B16.5, or B16.42 as applicable, except as specified in 2.4.7.1 through 2.4.7.4 as follows:

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

2.4.7.2 Flat-faced flanges with full raised-face thickness are acceptable on cases other than cast iron.

2.4.7.3 Flanges that are thicker or have a larger outside diameter than that required by ASME B16.5 are acceptable.

2.4.7.4 Connections other than those covered by ASME B16.5 require the purchaser's approval. When specified, mating parts shall be furnished by the vendor.

2.4.8 Machined and studded connections shall conform to the facing and drilling requirements of ASME B16.1, B16.5, or B16.42. Studs and nuts shall be furnished installed.

2.4.9 Threaded connections shall not be more than NPS 1½. Tapped openings and bosses for pipe threads shall conform to ASME B16.5. Pipe threads shall be taper threads conforming to ASME B1.20.1

2.4.10 Tapped openings not connected to piping shall be plugged with solid plugs furnished in accordance with ASME 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.

2.5 Gear Elements

2.5.1 GENERAL

2.5.1.1 All gear teeth shall be finish cut or finish ground on the assembled gear and shaft. One or more of the following processes shall be used in finishing the gear teeth:

a. Grinding.
b. Shaving.
c. Honing.
d. Precision hobbing.

All gear teeth finished by shaving or honing shall have been generated by hobbing. Shaving cutters and rotary hones shall have a hunting tooth combination with the workpiece.

2.5.1.2 When mutually agreed upon by the purchaser and the vendor, lapping may be used as a surface finishing process only, not to establish a profile. Sets finished by lapping together shall have a hunting tooth combination.

2.5.1.3 The unplated tooth surface on loaded faces of completed gears shall have a finish, as measured along the pitch line, of 0.8 micrometers (32 microinches) R_a or better.

2.5.1.4 Teeth may be silver or copper plated to provide added protection from scoring during initial operation. The desirability of such plating shall be mutually determined by the purchaser and the vendor.

Note: Oils with extreme pressure (EP) additives may remove the plating.

2.5.1.5 The design of single-helical gears shall be such that the effects of the moments on the gear elements, resulting from axial tooth reaction at the gear mesh, will not impair the expected performance of the gear unit.

2.5.1.6 Hunting tooth combinations are required. To achieve this requirement, it may be necessary for the purchaser to adjust the exact gear ratio. If *such adjustment* is impractical, the purchaser and the vendor shall negotiate a solution.

Note: A hunting tooth combination is required because the intent is for every tooth on a pinion to mesh with as many teeth as possible on the mating gear before the same teeth mesh again or repeat.

2.5.1.7 Each gear and each pinion shall be supported on two bearings. Overhung designs are not acceptable.

2.5.2 QUALITY ASSURANCE

● **2.5.2.1** Before the gear teeth are finish-cut, shaved, or ground on a hobbing, shaving, or grinding machine, the journal runouts of each principal rotating element shall be charted using a surface-contact-type electronic indicator or a purchaser-approved equivalent. For gears with pitch line velocities up to 60 meters per second (12,000 feet per minute), the total runout shall not exceed 12.7 micrometers (0.0005 inch); for gears with greater pitch line velocities, the total runout shall not exceed 7.6 micrometers (0.0003 inch). In the case of a vertical hobber or grinder where one journal is inaccessible for a continuous indicator check, the runout shall be recorded on the exposed journal at each end of the journal surface. The records of the journal runouts shall be maintained by the vendor for a period of not less than 20 years and shall be available to the purchaser on request.

Note: For pitch line velocities above 150 meters per second (30,000 feet per minute) it may be advisable to produce lead, involute (tooth profile), and tooth spacing records.

● **2.5.2.2** Each pair of mating gears shall be considered as a matched set and shall be checked for contact on a contact checking stand and in the job casing at the vendor's shop. A thin coating of color transfer material (such as Prussian blue) shall be applied at three locations 120 degrees apart to four or more teeth of the dry degreased gear. (Layout dye shall not be used for the contact check on the checking stand.) With the gear elements held firmly on the correct center distance and with the shaft centerlines parallel within 41.5 micrometers per meter (0.0005 inch per foot) with a total misalignment of not more than 25.4 micrometers (0.001 inch), the coated teeth shall be rotated through the mesh with a moderate drag torque applied in a direction that will cause the teeth to contact on the normally loaded faces. The color transfer shall show evidence of contact distributed across each helix as prescribed by the vendor. Before the contact tests, the vendor shall make available to the purchaser a contact drawing or vendor engineering specification that defines the acceptable contact. Unmodified leads generally show about 80-percent contact across the tooth length. The drawing or specification and the results of the checking-stand and job-casing contact checks shall be preserved for at least 20 years and shall be available to the purchaser on request. (When specified by the purchaser, the results of the contact check shall be preserved by lifting the contrasting colors from a tooth by applying and peeling off a strip of clear, adhesive tape and then applying the tape to a notated sheet of white paper.)

Note: When used to support the gear elements during contact checking, runout of shaft centers or rollers may require mechanical compensation to demonstrate the true contact pattern.

2.5.2.3 The vendor shall demonstrate the axial stability of each meshing pair of double-helical gears by either (a) measuring the unfiltered peak-to-peak shaft axial vibration, which shall not exceed 50 micrometers (2.0 mils) during testing, or (b) using indicators to make a slow rotation check. The preferred method for this slow rotation check is to hold one member (usually the gear) firmly in a fixed axial position, and indicate the axial movement of the other member (usually the pinion) as the parts are rotated through at least one full revolution of the gear while applying a drag torque in a direction that will force the normally loaded tooth faces into contact. The axial motion of the pinion relative to the gear shall not exceed 38 micrometers (0.0015 inch).

Note: Under no-load or light-load conditions on the test stand, double-helical pinions may exhibit random axial movement greater than 50 micrometers (2.0 mils).

2.5.3 FABRICATION

2.5.3.1 Unless otherwise specifically approved by the purchaser, pinions shall be integrally forged with their shafts.

2.5.3.2 For pitch line velocities above 150 meters per second (30,000 feet per minute), gears shall be integrally forged with their shafts. For pitch line velocities of 150 meters per second (30,000 feet per minute) and less, gears may be integrally forged with, or separate from their shafts. Separate gears shall be forgings or shall be of fabricated construction using forged steel rims and shall be assembled on their shafts with an interference fit. The pitch line velocities listed in Table 6 shall not be exceeded without the purchaser's specific approval.

Table 6—Pitch Line Velocities

Gear Manufacturing Method	Maximum Pitch Line Velocity Meters Per Second	Feet Per Minute
Shrunk-on forged Rims	60	12,000
Welded with forged Rims	127	25,000
Shrunk-on forged Gears	152	30,000

2.5.4 SHAFTS

2.5.4.1 Shafts shall be sized to transmit the gear-rated power within the stress limits of AGMA 6010. Shafts shall be made of one-piece, heat-treated forged or hot-rolled steel; shall be accurately machined throughout their entire length; and shall be suitably finished at their bearing surfaces.

2.5.4.2 The rotor shaft sensing areas to be observed by radial-vibration probes shall be concentric with the bearing journals. All shaft sensing areas (both radial vibration and axial position) shall be free from stencil and scribe marks or any other surface discontinuity, such as an oil hole or a keyway. These areas shall not be metallized, sleeved, or plated. The final surface finish shall be to a maximum of 1.0 micrometer (32 microinches) R_a, preferably obtained by honing or burnishing. These areas shall be properly demagnetized to the levels specified in API Standard 670, or otherwise treated so that the combined total electrical and mechanical runout does not exceed 25 percent of the maximum allowed peak-to-peak vibration amplitude or the following value, whichever is greater:

a. For areas to be observed by radial-vibration probes, 5.0 micrometers (0.25 mil).

b. For areas to be observed by axial-position probes, 10.0 micrometers (0.5 mil).

Note: Steels used in manufacturing gears are prone to develop higher levels of electrical runout which is difficult to reduce using conventional means such as degaussing, burnishing, and electro peening. When it has become evident that further attempts to lower the electrical runout will be unproductive, other reduction methods may be implemented with purchaser's approval.

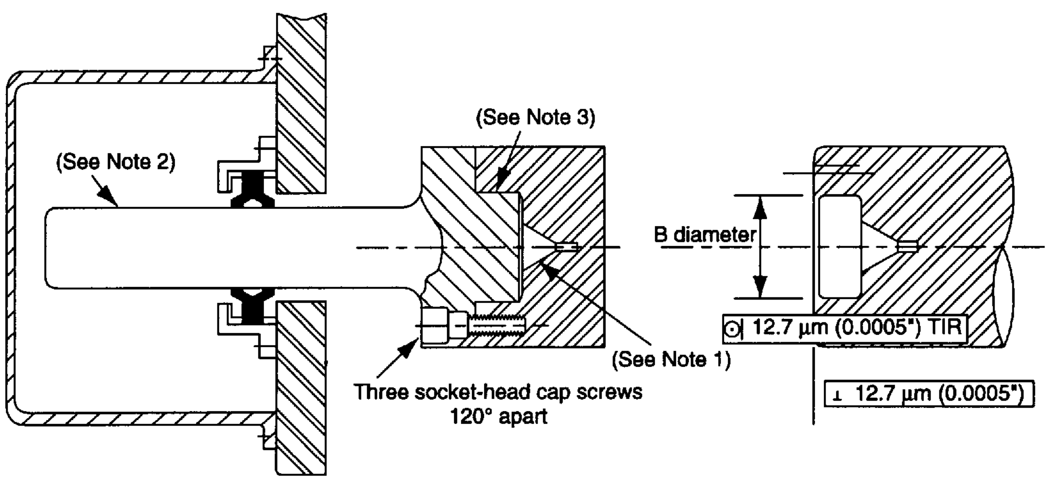
● **2.5.4.3** When specified, the vendor shall make one of the provisions specified in 2.5.4.3.1 through 2.5.4.3.3 to measure torsional response.

2.5.4.3.1 As mutually agreed upon by the purchaser and the vendor, the shaft end and stub shaft shall have a counterbore and bolting arrangement similar to that shown in Figure 5. The shaft end and mating stub faces shall be perpendicular to the shaft centerline within 12.7 micrometers (0.0005 inch) total indicated runout. The counterbore and mating stubs shall be concentric with and parallel to the shaft centerline within 12.7 micrometers (0.0005 inch).

2.5.4.3.2 One NPS 1-inch tapped opening with a plug shall be provided in the upper half of the casing for each gear element to permit mounting of detectors for use with a frequency-modulating torsional analyzer. The tapped openings shall be oriented in a plane that is transverse (orthogonal) to the centerline axis of both the gear shaft and the pinion shaft. The openings shall also be positioned so that detectors screwed into them will sense the passing of the teeth.

2.5.4.3.3 The purchaser and the vendor shall mutually agree upon any other method.

2.5.4.4 The shaft end configuration for the coupling mounting shall conform to the requirements of 3.2.



Notes:
1. It is very important that the centering hole for the gear (pinion) shaft be permanent in the counter bore.
2. The stub shaft extension is to be machined true with the journals.
3. The tolerance for the B diameter is to be from 0.0 to 25.4 micrometers (0.000 to 0.001 inch) tight.

Figure 5—Typical Torsiograph Modification

2.5.4.5 Each rotor shall be clearly marked with a unique identification number. This number shall be on the end of the shaft opposite the coupling or in an accessible area that is not prone to maintenance damage.

2.5.4.6 Shaft ends shall conform to API Standard 671.

2.5.4.7 To prevent buildup of potential voltages in the shaft, residual magnetism (Free Air Gauss Levels) of the rotations element shall not exceed 5 Gauss (.0005 Tesla).

2.6 Dynamics

2.6.1 CRITICAL SPEEDS

2.6.1.1 Critical speeds correspond to resonant frequencies of the rotor-bearing support system. The basic identification of critical speeds is made from the natural frequencies of the system and of the forcing phenomena. If the frequency of any harmonic component of a periodic forcing phenomenon is equal to or approximates the natural frequency of any mode of rotor vibration, a condition of resonance may exist; if resonance exists at any rotational speed, the speed at which the peak response occurs is called a critical speed. This specification is concerned both with actual critical speeds confirmed by operational data and with calculated values for critical speeds that are above operating speeds.

2.6.1.2 A forcing phenomenon or exciting frequency may be less than, equal to, or greater than the synchronous frequency of the rotor. Potential forcing frequencies may include but are not limited to the following:

a. Unbalance in the rotor system.
b. Oil film frequencies.
c. Internal rub frequencies.
d. Gear-meshing and side-band frequencies, as well as other frequencies produced by inaccuracies in the generation of the gear teeth.
e. Coupling misalignment frequencies.
f. Loose rotor-system component frequencies.
g. Asynchronous whirl frequencies.
h. Synchronous electric motor startup or startup transient torsional resonances.

2.6.1.3 Slow roll, startup, and shutdown of rotating equipment shall not cause any damage as critical speeds are passed.

2.6.1.4 Three lateral critical speed modes are generally of concern with gear units: the cylindrical (translational or bouncing) mode, the conical (pivoted or rocking) mode, and the first bending mode. The speed or frequency at which these modes occur varies with the degree of transmitted load, primarily as a result of the change in the stiffness of the bearing-oil film (see Appendix B) For any rotor, these three critical speeds shall not be less than 20 percent above the maximum continuous speed of the rotor; for meshing rotors, these three critical speeds shall not be within 10 percent of the operating speed for from 50 to 100 percent of the maximum torque at the maximum continuous speed. Operating conditions at no load and at less than 50 percent of the maximum torque or less than 70 percent of the maximum continuous speed will be specified by the purchaser on the data sheets. When these conditions are specified, the vendor shall submit a damped unbalanced response analysis in addition to the undamped analysis. Unloaded operation shall be considered for proper performance. Gear units will normally be required to withstand periods of unloaded operation.

2.6.1.5 The vendor shall perform lateral critical speed analyses of all rotors. The analyses shall include the following:

a. The bearing-oil film, bearing structure, and gear-casing-support structure stiffnesses.
b. The coupling weight to be supported by each gearbox shaft (the weight of the coupling hubs plus ½ the weight of the coupling spacers). The coupling weight shall be applied at the proper center of gravity relative to the shaft end. The weight and the center of gravity will be specified by the purchaser of the coupling.

● **2.6.1.6** The vendor shall submit a report containing a graphic display of undamped critical speeds versus support stiffness or percentage of torque load. The graphic display shall show all applicable conditions specified in 2.6.1.4 and no-load test conditions (approximately 10 percent of the rated torque) at the maximum continuous speed. With the purchaser's approval, the vendor may submit, or when specified, the vendor shall submit a plot of damped unbalanced rotor response for the conditions above in addition to maps of the undamped critical speeds.

2.6.1.7 Resonant vibration of the gear or the bearing housing shall not occur within the specified range of operating speeds or the specified separation margins.

● **2.6.1.8** The torsional resonances of the complete machinery train shall be at least 10 percent below any operating speed or at least 10 percent above the trip speed. The purchaser will assign responsibility for the torsional analysis and the torsional compatibility of the train.

2.6.1.9 The separation margins specified in 2.6.1.4 and 2.6.1.8 are intended to prevent the critical response envelope from overlapping the range of operating speeds.

2.6.2 BALANCE

2.6.2.1 All gear elements shall be multiplane dynamically balanced after final assembly of the rotor. Rotors with single keys for couplings shall be balanced with their keyway fitted with a fully crowned half-key so that the shaft keyway is filled for its entire length. The maximum allowable unbalanced force at any journal at maximum continuous speed shall not exceed 10 percent of the static loading of that journal.

2.6.2.2 After the final balancing of the assembled rotating element has been completed, the calibration of the rotor balancing machine shall be verified in accordance with the balancing-machine manufacturer's procedure. With the purchaser's approval, documentation of a calibration check performed less than 1 month before the balancing of the rotor may be submitted in lieu of the calibration check performed after the balancing of the rotor.

● **2.6.2.3** When specified, after the final balancing of the assembled rotating element has been completed, the sensitivity of the rotor-balancing-machine system shall be performed and reported as specified in Appendix G.

2.6.2.3.1 The vendor shall supply to the purchaser the journal static loading, in kilograms (pounds).

2.6.2.3.2 The maximum allowable residual unbalance shall be calculated from the following equation:

In SI units:

$$U_{max} = 6350W/N$$

In U.S. customary units:

$$U_{max} = 4W/N$$

Where:

U_{max} = amount of residual rotor unbalance, in gram-millimeters (ounce-inches).
W = journal static loading, in kilograms (pounds).
N = maximum continuous speed, in revolutions per minute.

● **2.6.2.3.3** When specified, after the final balancing of each assembled rotating element has been completed, a residual unbalance check shall be performed and recorded in accordance with the residual unbalance work sheet (see Appendix G). The weight of all half-keys used during the final balancing of the assembled rotor shall be recorded.

2.6.3 VIBRATION

2.6.3.1 Shaft Vibration

During the shop test of the assembled gear operating at its maximum continuous speed or at any other speed within the specified range of operating speeds, the double amplitude of vibration for each shaft in any plane measured on the shaft adjacent and relative to each radial bearing shall not exceed the following value or 50 micrometers (2.0 mils), whichever is less:

In SI units:

$$A = 25.4\sqrt{\frac{12{,}000}{N}} \quad (6)$$

In U.S. customary units:

$$A = \sqrt{\frac{12{,}000}{N}}$$

Where:

A = amplitude of unfiltered vibration, in micrometers (mils) true peak to peak.
N = maximum continuous speed, in revolutions per minute.

At any speed greater than the maximum continuous speed, up to and including the trip speed of the driver, the vibration shall not exceed 150 percent of the maximum value recorded at the maximum continuous speed.

2.6.3.2 Electrical and mechanical runout shall be determined and recorded by rolling the rotor in V blocks at the journal centerline while measuring runout with a noncontacting vibration probe and a dial indicator at the centerline of the probe location and one probe-tip diameter to either side. *The vibration probe and dial indicator shall be perpendicular to the same face of the V block.*

2.6.3.3 Accurate records of electrical and mechanical runout, for the full 360 degrees at each probe location, shall be included in the mechanical test report.

2.6.3.4 If the vendor can demonstrate that electrical or mechanical runout is present, a maximum of 25 percent of the test level calculated from Equation 6 or 6.4 micrometers (0.25 mils) whichever is greater, may be vectorially subtracted from the vibration signal measured during the factory test.

2.6.3.5 Casing Vibration

When accelerometers have been specified, they shall be used during testing. The overall vibration levels during testing shall not exceed the values shown in Table 7.

2.7 Bearings and Bearing Housings

2.7.1 GENERAL

2.7.1.1 Radial and thrust bearings shall be of the hydrodynamic fluid film type.

2.7.1.2 Bearings shall be designed to prevent installing backwards and/or upside down.

2.7.1.3 Unless otherwise specified, thrust bearings and radial bearings shall be fitted with bearing-metal temperature sensors and installed as specified in API Standard 670.

Table 7—Casing Vibration Levels

	Velocity	Acceleration
Frequency Range	10 Hz - 2.5 kHz	2.5 kHz - 10 kHz
Unfiltered (Peak)	4.07 mm/sec (0.15 in./sec)	4 G's
Filtered (Peak)	2.5 mm/sec (0.10 in./sec)	

Note:
1. The above vibration levels are for horizontal offset gears units only. The allowable vibration levels for vertical offset gears are twice those shown in the table.
2. Hz = hertz; kHz = kilohertz; in./sec = inches per second; mm/sec = millimeters per second; G's = m/sec^2 (ft/sec^2)

2.7.2 RADIAL BEARINGS

2.7.2.1 Hydrodynamic radial bearings shall be split for ease of assembly, precision bored, and of the sleeve or pad type, with steel-backed babbitted replaceable liners, pads, or shells. These bearings shall be equipped with antirotation pins and shall be positively secured in the axial direction. The bearing design shall suppress hydrodynamic instabilities and provide sufficient damping over the entire range of allowable bearing clearances to limit rotor vibration to the maximum specified amplitudes (see 2.6.3) while the equipment is operating loaded or unloaded at specified operating speeds, including operation at any critical frequency. The liners, pads, or shells shall be in horizontally split housings and shall be replaceable without the removal of the top half of the casing of an axially split machine or the head of a radially split unit and without the removal of the coupling hub.

2.7.2.2 The bearing loading shall not exceed 34.5 bar (500 pounds per square inch) on a projected-area basis; however, for any specified operating condition, the load capacity of the bearing shall also be limited by a minimum film thickness of 25 micrometers (0.001 inch).

2.7.3 THRUST BEARINGS

2.7.3.1 Unless otherwise approved by the purchaser, thrust bearings shall be provided on the low-speed shaft for all double-helical gears. Thrust bearings shall be provided on each shaft for all single-helical gears. When gears are supplied without thrust bearings, limited-end float or diaphragm-type couplings shall be used to maintain positive axial positioning of the connected rotors. (See Figure C-1, panels A-F, Appendix C, for typical system arrangements in which thrust bearings may be eliminated from double-helical gears.) All gears without thrust bearings shall be supplied with locating collars on the low-speed shaft to prevent contact of the rotating elements with the gear casing. Axial float shall not be less than 12.7 millimeters (0.5 inch).

2.7.3.2 Hydrodynamic thrust bearings shall be of the steel-backed, babbitted multiple-segment type, designed for equal thrust capacity in both directions and arranged for continuous pressurized lubrication to each side. Both sides shall be of the tilting-pad type, incorporating a self-leveling feature which assures that each segment carries an equal share of the thrust load with minor variation in segment thickness. Integral thrust collars are preferred. When replaceable collars are furnished (for assembly and maintenance purposes) they shall be positively locked to the shaft to prevent fretting. When integral thrust collars are furnished, they shall be provided with at least 3.2 millimeters (⅛ inch) of additional stock to enable refinishing if the collar is damaged. Both faces of the collar shall have a surface finish of not more than 0.4 micrometer (16 microinches) R_a, and the axial total indicated runout of either face shall not exceed 12.7 micrometers (0.0005 inch) after the collar is mounted.

2.7.3.3 Thrust bearings shall be sized for continuous operation under all specified conditions, including all external forces transmitted by the couplings. Thrust bearings shall be selected at no more than 50 percent of the bearing's ultimate load capability (based on test data) for the specific application taking into account speed, lubricant, and lubricant temperature. (See Appendix D for bearing selections based on loading, speed, and thrust-shoe area.) The sizing basis shall be reviewed with and approved by the purchaser. The external axial force transmitted by the coupling shall be considered as being numerically additive to any internal thrust forces. If the thrust forces from two or more connected rotors or meshing gear rotors are carried by one thrust bearing, these thrust forces shall be considered as being numerically additive. The minimum external force transmitted by a flexible coupling shall be as specified in 2.7.3.3.1 through 2.7.3.3.3.

2.7.3.3.1 For couplings located so that the external force is produced by a single-ended drive motor with sleeve bearings, the external force shall be considered equal to the maximum magnetic centering force of the motor. If the maximum magnetic centering force is not specified, a force of 250 pounds per 1000 motor rated horsepower (1.5 newtons per kilowatt) shall be used.

2.7.3.3.2 For gear-type couplings (located other than as described in 2.7.3.3.1), the external force shall be calculated from the following formula:

In SI units:

$$F_R = \frac{(0.25)(9,549)P_R}{(N_R D)} \qquad (7)$$

In U.S. customary units:

$$F_R = \frac{(0.25)(63,000)P_R}{(N_R D)}$$

Where:

F_R = external force, in kilonewtons.(pounds).
P_R = rated power, in kilowatts (horsepower).
N_R = rated speed, in revolutions per minute.
D = shaft diameter at the coupling, in millimeters (inches).

Note: Shaft diameter is an approximation of the coupling pitch radius.

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

2.7.4 BEARING HOUSINGS

2.7.4.1 In this standard, the term bearing housing refers to all bearing enclosures, including the gear casing. Bearing housings for hydrodynamic bearings designed for pressure lubrication shall be arranged to minimize foaming. The drain system shall be adequate to maintain the oil and foam level below shaft end seals. Gaskets shall not be used on housing end covers where the gasket thickness would affect the end play or clearance of the thrust bearing.

2.7.4.2 Bearing housings shall be equipped with replaceable labyrinth-type end seals and deflectors where the shaft passes through the housing; lip-type seals shall not be used. The seals and deflectors shall be made of nonsparking materials. The design of the seals and deflectors shall effectively retain oil in the housing and prevent entry of foreign material into the housing.

2.7.4.3 Provision shall be made for mounting two radial vibration probes in each bearing housing and two axial position probes at the thrust end of each gear unit. The probe installation shall be as specified in API Standard 670.

2.8 Lubrication

2.8.1 The gear unit shall be pressure lubricated. Spray nozzles for the teeth shall be provided.

2.8.2 The gear unit and lubrication system shall be designed to limit the temperature of the casing drain oil to 77°C (170°F), with an inlet oil temperature of 49°C (120°F) to ensure high mechanical efficiency and dimensional stability and to limit the maximum temperature of the tooth metal. Where oil inlet temperatures exceed 49°C (120°F), special consideration shall be given to bearing design, oil flows, and allowable temperature rise. Oil outlets from thrust bearings shall be tangential in the control ring or in the thrust bearing cartridge if oil control rings are not used.

● **2.8.3** The oil system shall be furnished by either the purchaser or the vendor, as specified.

2.8.4 Unless otherwise specified, gears shall be arranged for hydrocarbon oil lubrication.

2.8.5 Unless otherwise specified, pressurized oil systems shall conform to the requirements of API Standard 614.

2.8.6 Where oil is supplied from a common system to two or more machines (such as a compressor, a gear, and a motor), the oil's characteristics will be specified on the data sheets by the purchaser on the basis of mutual agreement with all vendors supplying equipment served by the common oil system.

Note: The usual lubricant employed in a common oil system is a hydrocarbon oil that corresponds to ISO Grade 32, as specified in ISO 3448.

2.9 Materials

2.9.1 GENERAL

2.9.1.1 Materials of construction shall be the manufacturer's standard for the specified operating conditions, except as required by the data sheets or this standard (see 3.5 for requirements for auxiliary piping materials). The metallurgy of all major components shall be clearly stated in the vendors proposal.

2.9.1.2 Materials shall be identified in the proposal with their applicable ASTM, AISI, ASME, or SAE15 numbers, including the material grade (see Appendix E). When no such designation is available, the vendor's material specification, giving physical properties, chemical composition, and test requirements, shall be included in the proposal.

2.9.1.3 ASTM A 515 steel can be notch sensitive and prone to brittle fracture at ambient temperatures. The use of ASTM A 515 steel is, therefore, prohibited.

2.9.1.4 The vendor shall specify the ASTM tests and inspection procedures to ensure that materials are satisfactory for the service. Such tests and inspections shall be listed in the proposal. The purchaser may consider specifying additional tests and inspections, especially for materials used in critical components.

2.9.1.5 Gear and pinion materials shall be selected to meet the criteria for tooth pitting index and strength outlined in 2.2. In selecting the material, the vendor shall consider whether the gear and pinion are to be through hardened, case hardened, forged, or welded. The material and manufacturing method will be approved by the purchaser.

2.9.1.6 Castings shall be sound and free from shrink holes, blow holes, cracks, scale, blisters, and other similar injurious defects. Surfaces of castings shall be cleaned by sandblasting, shotblasting, pickling, or any other standard method. Mold-parting fins and remains of gates and risers shall be chipped, filed, or ground flush.

2.9.1.7 Fully enclosed cored voids, including voids closed by plugging, are prohibited.

2.9.2 WELDING OF ROTATING ELEMENTS

2.9.2.1 All welds shall be made by operators qualified on the materials being welded. The qualifying procedure shall be mutually agreed upon by the purchaser and the vendor. The procedures given in Section IX of the ASME Code are suggested as a guide.

2.9.2.2 All welds shall be continuous full-penetration welds. All welds shall be double welded, except when only one side is accessible; in such instances a backup ring, a consumable insert, or an inert gas shield weld with an internal gas purge backup shall be used.

2.9.2.3 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.

2.9.2.4 Repair welding in the area of the gear teeth is prohibited.

2.9.3 HEAT TREATMENT

2.9.3.1 After the gear materials have been rough machined to the approximate final contour of the blank and heat treated, the tooth area shall be checked for proper hardness.

2.9.3.2 Casings, whether of cast or fabricated construction, shall be stress relieved before final machining and after any welding, including repairs.

● 2.9.4 LOW TEMPERATURE

For operating temperatures below –29°C (–20°F) and when specified for low ambient temperatures, steels shall have at the lowest specified temperature an impact strength sufficient to qualify under the minimum Charpy V-notch impact energy requirements of Section VIII, Division 1, UG-84, of the ASME Code. For materials and thicknesses not covered by the code, the purchaser will specify the requirements on the data sheets.

2.10 Nameplates and Rotation Arrows

Nameplates and rotation arrows shall be of Series 300 stainless steel or of nickel-copper alloy (Monel or its equivalent) attached by pins of similar material and located for easy visibility. As a minimum, the following data shall be clearly stamped on the nameplate:

a. The vendor's name.
b. The size and type of the gear unit.
c. The gear ratio.
d. The serial number.
e. The gear rated power.
f. The rated input speed in revolutions per minute.
g. The rated output speed in revolutions per minute.
h. The gear service factor as defined in this standard.
i. The purchaser's item number.
j. The number of gear teeth.
k. The number of pinion teeth.

The purchaser will specify whether U.S. customary or SI units are to be shown.

SECTION 3—ACCESSORIES

● 3.1 General

The purchaser will specify the accessories to be supplied by the vendor.

3.2 Couplings and Guards

● **3.2.1** Flexible couplings and guards between drivers, gears, and driven equipment shall be supplied by the manufacturer of the driven equipment, unless otherwise specified. If specified, half-couplings shall be mounted by the vendor.

3.2.2 Couplings and guards shall conform to API Standard 671. The make, type, and mounting arrangement of the coupling shall be agreed upon by the purchaser and the vendors of the drivers, gears, and driven equipment.

3.2.3 Information on shafts, keyway dimensions (if any), and shaft end movements due to end play and thermal effects shall be furnished by the vendor to the purchaser.

3.2.4 The power rating of the coupling-to-shaft juncture shall be as defined in API Standard 671.

3.2.5 The purchaser of the coupling will supply an idling adapter, as required for the mechanical running tests (see 4.3.2.1.6).

3.2.6 The coupling mounting shall conform to API Standard 671.

Note: Appendix C provides a guide to the selection of coupling types and the location of thrust bearings in equipment trains that employ high-speed gears.

3.3 Mounting Plates

3.3.1 GENERAL

● **3.3.1.1** When specified, the gear shall be furnished with soleplates or a baseplate.

3.3.1.2 In 3.3.1.2.1 through 3.3.1.2.11, the term mounting plate refers to both baseplates and soleplates.

3.3.1.2.1 The mounting plates shall have machined surfaces. The maximum surface finish shall be 5.0 micrometers (125 microinches) R_a.

3.3.1.2.2 The mounting plates shall be equipped with vertical jackscrews.

3.3.1.2.3 When the equipment supported weighs more than 453 kilograms (1000 pounds), the mounting plates shall be furnished with horizontal jackscrews the same size as or larger than the vertical jackscrews. The lugs holding these jackscrews shall be attached to the mounting plates so that they do not interfere with the installation or removal of the shims.

3.3.1.2.4 Machinery supports shall be designed to limit a change of alignment caused by the worst combination of pressure, torque, and allowable piping stress to 50 micrometers (0.002 inch) at the coupling flange.

● **3.3.1.2.5** When epoxy grout is specified on the data sheets, the vendor shall commercial sandblast, in accordance with SSPC SP6, all the grouting surfaces of the mounting plates and shall precoat these surfaces with a catalyzed epoxy primer. The epoxy primer shall be compatible with epoxy grout. The vendor shall submit to the purchaser instructions for field preparation of the epoxy primer.

Note: Epoxy primers have a limited life after application. The grout manufacturer should be consulted to ensure proper field preparation of the mounting plate for satisfactory bonding of the grout.

3.3.1.2.6 Anchor bolts shall not be used to fasten machinery to the mounting plates.

3.3.1.2.7 Mounting plates shall not be drilled for equipment to be mounted by others. Mounting plates intended for installation on concrete shall be supplied with leveling screws. Mounting plates that are to be grouted shall have 50-millimeter-radiused (2-inch-radiused) outside corners (in the plan view).

3.3.1.2.8 Mounting plates shall extend at least 25 millimeters (1 inch) beyond the outer three sides of equipment feet.

3.3.1.2.9 The vendor of the mounting plates shall furnish stainless steel shim packs with a total thickness of at least 3.2 millimeters (⅛ inch) between the equipment feet and the mounting plates. All shim packs shall straddle the hold-down bolts.

3.3.1.2.10 Anchor bolts will be furnished by the purchaser.

3.3.1.2.11 Fasteners for attaching the gear to the mounting plates where furnished by the vendor shall be supplied by the vendor.

3.3.2 BASEPLATE

3.3.2.1 When a baseplate is specified, the data sheets will indicate the major equipment to be mounted on it. A baseplate shall be a single fabricated steel unit, unless the purchaser and the vendor mutually agree that it may be fabricated in multiple sections. Multiple-section baseplates shall have machined and doweled mating surfaces to ensure accurate field reassembly.

3.3.2.2 Unless otherwise specified, the baseplate shall extend under the drive-train components so that any leakage from these components is contained within the baseplate.

3.3.2.3 When specified, the baseplate shall be provided with leveling pads or targets protected with removable covers. The pads or targets shall be accessible for field leveling after installation, with the equipment mounted and the baseplate on the foundation.

3.3.2.4 When specified, the baseplate shall be suitable for column mounting (that is, of sufficient rigidity to be supported at specified points) without continuous grouting under structural members. The baseplate design shall be mutually agreed upon by the purchaser and the vendor.

3.3.2.5 The baseplate shall be provided with lifting lugs for a four-point lift. Lifting the baseplate complete with all equipment mounted shall not permanently distort or otherwise damage the baseplate or the machinery mounted on it.

3.3.2.6 The bottom of the baseplate between structural members shall be open. When the baseplate is installed on a concrete foundation, it shall be provided with at least one grout hole having a clear area of at least 0.01 square meter (19 square inches) and no dimension less than 75 millimeters (3 inches) in each bulkhead section. These holes shall be located to permit grouting under all load-carrying structural members. Where practical, the holes shall be accessible for grouting with the equipment installed. The holes shall have 13-millimeter (½ inch) raised-lip edges, and if located in an area where liquids could impinge on the exposed grout, metallic covers with a minimum thickness of 16 gauge shall be provided. Vent holes at least 13 millimeters (½ inch) in size shall be provided at the highest point in each bulkhead section of the baseplate.

● **3.3.2.7** The mounting pads on the bottom of the baseplate shall be in one plane to permit use of a single-level foundation. When specified, subsoleplates shall be provided by the vendor.

3.3.2.8 Unless otherwise specified, nonskid decking covering all walk and work areas shall be provided on the top of the baseplate.

3.3.2.9 The baseplate mounting pads shall be machined flat and parallel after the baseplate is fabricated.

3.3.3 SOLEPLATES AND SUBPLATES

3.3.3.1 When soleplates are specified, they shall meet the requirements of 3.3.3.1.1 and 3.3.3.1.2 in addition to those of 3.3.2.

3.3.3.1.1 Adequate working clearance shall be provided at the bolting locations to allow the use of socket or box wrenches and to allow the equipment to be moved using the horizontal and vertical jackscrews.

3.3.3.1.2 Soleplates shall be steel plates that are thick enough to transmit the expected loads from the equipment feet to the foundation, but in no case shall the plates be less than 38 millimeters (1½ inches) thick.

3.3.3.2 When subplates are specified, they shall be steel plates at least 25 millimeters (1 inch) thick. The finish of the subplates' mating surfaces shall match that of the soleplates.

3.4 Controls and Instrumentation

3.4.1 GENERAL

3.4.1.1 Instrumentation and installation shall conform to any detailed specifications in the purchaser's inquiry or order or both. When no detailed specifications are furnished, instrumentation and installation shall conform to the requirements of API Standards 614 and 670.

3.4.1.2 Unless otherwise specified, instrumentation shall be suitable for outdoor installation.

3.4.1.3 Where applicable, instrumentation shall conform to API Recommended Practice 550 and area classification, based on API Recommended Practice 500.

3.4.2 VIBRATION AND POSITION DETECTORS

3.4.2.1 Unless otherwise specified, radial shaft vibration probes, accelerometers, and axial position probes shall be installed and calibrated in accordance with API Standard 670.

Note: The number of axial probes should consider the type of gear (double or single helical) and thrust bearing location.

3.4.2.2 Accelerometers shall be located horizontally, on the input and output bearing housings below the split line unless otherwise specified.

Note: Other locations should consider maintenance requirements (cable routing, cover removal, etc.).

3.4.2.3 Radial shaft vibration probes shall be located in the X-Y positions on the input and output shaft bearings with provision for X-Y probes, including shaft burnishing of the target areas on all other radial bearings unless otherwise specified.

3.4.2.4 Axial position probes shall be located at the blind end of the input and output shafts unless otherwise specified.

Note: Gear shafts without thrust bearings may have axial floats that require axial position probes with extended linear range.

● **3.4.2.5** When specified, radial shaft vibration and axial position monitors shall be supplied and calibrated in accordance with API Standard 670.

● **3.4.2.6** When specified, casing vibration monitors shall be supplied, installed, and calibrated in accordance with API Standard 670.

3.5 Piping and Appurtenances

Unless otherwise specified, lube-oil piping and appurtenances shall conform to the requirements of API Standard 614.

3.6 Special Tools

3.6.1 When special tools and fixtures are required to disassemble, assemble, or maintain the unit, they shall be included in the quotation and furnished as part of the initial supply of the machine. For multiple-unit installations, the requirements for quantities of special tools and fixtures shall be mutually agreed upon by the purchaser and the vendor. These or similar special tools shall be used during shop assembly and post-test disassembly of the equipment.

3.6.2 When special tools are provided, they shall be packaged in a separate, rugged metal box and shall be marked "special tools for (provide tag/item number)." Each tool shall be stamped or tagged to indicate its intended use.

SECTION 4—INSPECTION, TESTING, AND PREPARATION FOR SHIPMENT

4.1 General

● **4.1.1** The purchaser will specify the extent of his participation in the inspection and testing and the amount of advance notification he requires.

4.1.1.1 When shop inspection and testing have been specified by the purchaser, the purchaser and the vendor shall meet to coordinate manufacturing hold points and inspectors' visits.

4.1.1.2 *Witnessed* means that a hold shall be applied to the production schedule and that the inspection or test shall be carried out with the purchaser or his representative in attendance. For mechanical running or performance tests, this requires written notification of a successful preliminary test.

4.1.1.3 *Observed* means that the purchaser shall be notified of the timing of the inspection or test; however, the inspection or test is performed as scheduled, and if the purchaser or his representative is not present, the vendor shall proceed to the next step. (The purchaser should expect to be in the factory longer than for a witnessed test.)

● **4.1.1.4** When specified, the purchaser's representative, the vendor's representative, or both shall indicate compliance in accordance with the inspector's checklist in Appendix I by initialing, dating, and submitting the completed checklist to the purchaser before shipment.

4.1.1.5 After advance notification of the vendor by the purchaser, the purchaser's representative shall have entry to all vendor and subvendor plants where manufacturing, testing, or inspection of the equipment is in progress.

4.1.2 The vendor shall notify subvendors of the purchaser's inspection and testing requirements.

4.1.3 The vendor shall provide sufficient advance notice to the purchaser before conducting any inspection or test that the purchaser desires to be witnessed or observed.

4.1.4 Equipment for the specified inspection and tests shall be provided by the vendor.

4.1.5 The purchaser's representative shall have access to the vendor's quality program for review.

4.2 Inspection

4.2.1 GENERAL

4.2.1.1 The vendor shall keep the following data available for at least 20 years for examination or reproduction by the purchaser or his representative upon request:

a. Necessary certification of materials, such as mill test reports.
b. Purchase specifications for all items on bills of materials.
c. Test data to verify that the requirements of the specification are being met.
d. Results of documented tests and inspections, including fully identified records of all heat treatment and radiography.
● e. When specified, final-assembly maintenance and running clearances.

● **4.2.1.2** The purchaser may specify the following:

a. Parts that shall be subjected to surface and subsurface examination.
b. The type of inspection required, such as magnetic particle, dye penetrant, radiographic, and ultrasonic examination.

4.2.2 MATERIAL INSPECTION

● 4.2.2.1 General

When radiographic, ultrasonic, magnetic particle, or liquid penetrant inspection of welds or materials is required or specified, the criteria in 4.2.2.2 through 4.2.2.5 shall apply unless other criteria are specified by the purchaser. Cast iron may be inspected in accordance with 4.2.2.4 and 4.2.2.5. Welds, cast steel, and wrought material may be inspected in accordance with 4.2.2.2 through 4.2.2.5.

4.2.2.2 Radiography (See 4.2.2.1)

4.2.2.2.1 Radiography shall be in accordance with ASTM E94 and ASTM E142.

4.2.2.2.2 The acceptance standard used for welding fabrications shall be Section VIII, Division 1, UW-52, of the ASME Code. The acceptance standard used for castings shall be Section VIII, Division 1, Appendix 7, of the ASME Code.

4.2.2.3 Ultrasonic Inspection (See 4.2.2.1)

4.2.2.3.1 Ultrasonic inspection shall be in accordance with Section V, Articles 5 and 23, of the ASME Code.

4.2.2.3.2 The acceptance standard used for welded fabrications shall be Section VIII, Division 1, Appendix 12, of the ASME Code. The acceptance standard used for castings shall be Section VIII, Division 1, Appendix 7, of the ASME Code.

4.2.2.4 Magnetic Particle Inspection (See 2.11.4.2 and 4.2.2.1)

4.2.2.4.1 Both wet and dry methods of magnetic particle inspection shall be in accordance with ASTM E709.

4.2.2.4.2 The acceptance standard used for welded fabrications shall be Section VIII, Division 1, Appendixes 6 and 25, of the ASME Code. The acceptability of defects in castings shall be based on a comparison with the photographs in ASTM E125. For each type of defect, the degree of severity shall not exceed the limits specified in Table 8.

4.2.2.5 Liquid Penetrant Inspection (4.2.2.1)

4.2.2.5.1 Liquid penetrant inspection shall be in accordance with Section V, Article 6, of the ASME Code.

4.2.2.5.2 The acceptance standard used for welded fabrications shall be Section VIII, Division 1, Appendixes 8 and 24, of the ASME Code. The acceptance standard used for castings shall be Section VIII, Division 1, Appendix 7, of the ASME Code.

4.2.2.6 Rotating Elements

4.2.2.6.1 Certified information on the major rotating elements shall be kept available for 20 years from the date of shipment and shall be obtainable by the purchaser upon request. All records of work, whether performed in the normal course of manufacture or as part of a repair procedure, shall be fully identified. This information shall include the following:

a. Chemical and physical data from specimens made and heat treated with the parts.
b. Records of all heat treatment and resulting hardnesses.
c. Radiographs and records of ultrasonic inspections, if radiography and ultrasonic inspection are performed.
d. For surface-hardened gears, hardnesses and case depths determined on coupons treated with the workpiece.
e. For through-hardened gears, hardnesses determined in at least three dispersed locations in the tooth blank area.

Table 8—Maximum Severity of Defects in Castings

Type	Defect	Severity Level
I	Linear discontinuities	1
II	Shrinkage	2
III	Inclusions	2
IV	Chills and chaplets	1
V	Porosity	1
VI	Welds	1

Note: Regardless of the generalized limits in 4.2.2, it shall be the vendor's responsibility to review the design limits of the equipment in the event that more stringent requirements are necessary. Defects that exceed the limits imposed in 4.2.2 shall be removed to meet the quality standards cited, as determined by the inspection method specified.

4.2.2.6.2 All welds in rotating elements, including those attaching gears to shafts, shall receive 100 percent inspection. Accessible surfaces of welds shall be inspected after back chipping or gouging and again after stress relieving. Magnetic particle or ultrasonic inspection is preferred. Other methods, such as dye penetrant and radiography, are acceptable only as mutually agreed upon by the purchaser and the vendor.

4.2.2.6.3 All gear and pinion teeth shall be subjected to 100 percent magnetic particle inspection in accordance with ASTM A 275. Cracks are not acceptable. Linear indications that result from nonmetallic inclusions in the tooth flanks or roots that are larger than 1.5 millimeters (0.06 inch) shall be reported to the purchaser for disposition. Linear indications are defined as those having a length equal to or greater than three times the width. Acceptance or rejection shall be decided on a case-by-case basis and shall be mutually agreed upon by the purchaser and the vendor.

4.2.2.7 Forgings and hot-rolled steel shafts.

4.2.2.7.1 Forgings and hot-rolled steel shafts shall be free from cracks, seams, laps, shrinkage, and other similar injurious defects.

4.2.2.7.2 After rough machining, forgings and bar stock for major rotating elements shall be subjected to 100 percent ultrasonic inspection in accordance with ASTM A 388. Acceptance criteria shall be mutually agreed upon by the purchaser and the vendor.

4.2.2.8 Additional Inspection

Additional Gear tooth inspections may be required when mutually agreed upon by the purchaser and the vendor. These may include (but are not limited to) inspections of tooth spacing, pitch line runout, profile, and lead.

4.2.3 MECHANICAL INSPECTION

4.2.3.1 During assembly of the system and before testing, each component (including cast-in passages of these components) and all piping and appurtenances shall be cleaned by pickling or by another appropriate method to remove foreign materials, corrosion products, and mill scale.

● **4.2.3.2** When specified, the purchaser may inspect for cleanliness the equipment and all piping and appurtenances furnished by or through the vendor before piping is finally assembled.

● **4.2.3.3** When specified, the hardness of parts, welds, and heat-affected zones shall be verified as being within the allowable values by testing of the parts, welds, or zones. The method, extent, documentation, and witnessing of the testing shall be mutually agreed upon by the purchaser and the vendor.

4.3 Testing

4.3.1 GENERAL

4.3.1.1 Gears shall be tested in accordance with 4.3.2. Other tests that may be specified by the purchaser are described in 4.3.3.

4.3.1.2 At least 6 weeks before the first scheduled running test, the vendor shall submit to the purchaser, for his review and comment, detailed procedures for all running tests, including acceptance criteria for all monitored parameters.

4.3.1.3 The vendor shall notify the purchaser not less than 5 working days before the date the equipment will be ready for testing. If the testing is rescheduled, the vendor shall notify the purchaser not less than 5 working days before the new test date.

4.3.2 MECHANICAL RUNNING TESTS

4.3.2.1 Before the mechanical test is performed, the requirements of 4.3.2.1.1 through 4.3.2.1.8 shall be met.

4.3.2.1.1 The contract bearings shall be used in the machine for the mechanical running tests.

4.3.2.1.2 All oil pressures, viscosities, and temperatures shall be at the operating values recommended in the manufacturer's operating instructions for the specific unit being tested. The overall oil flow rate to the gears shall be recorded.

4.3.2.1.3 Test-stand oil filtration shall be 10 microns or better. Oil system components downstream of the filters shall meet the cleanliness requirements of API Standard 614 before any test is started.

4.3.2.1.4 The joints and connections in the casing and the oil system shall be checked for tightness, and any leaks shall be corrected.

4.3.2.1.5 All warning, protective, and control devices used during the test shall be checked, and adjustments shall be made as required.

4.3.2.1.6 The mechanical running tests shall be conducted with half-couplings and idling adapters in place, resulting in a moment equal to that of the contract half-coupling plus one-half that of the coupling spacer. When all testing is completed, the idling adapters' solo plates shall be furnished to the purchaser as part of the special tools.

4.3.2.1.7 All purchased vibration probes, cables, oscillator demodulators and accelerometers shall be in use during the test. When vibration transducers are not furnished by the vendor or if the purchased units are not compatible with shop readout facilities, then shop transducers and readouts that meet the accuracy requirements of API Standard 670 shall be used.

4.3.2.1.8 Shop test facilities shall include instrumentation with the capability of continuously monitoring and plotting revolutions per minute, peak-to-peak displacement, and phase angle (x-y-y′). Presentation of vibration displacement and phase marker shall also be by oscilloscope.

4.3.2.2 During the mechanical running tests the requirements of 4.3.2.2.1 through 4.3.2.2.12 shall be met.

4.3.2.2.1 The vendor shall keep a detailed log of the final tests, making entries every 15 minutes for the first hour and every 30 minutes for the duration of the tests. Each entry shall include the following information:

a. Inlet oil temperature and pressure.
b. Oil flow.
c. Outlet oil (drain) temperature.
d. Shaft vibration, frequency, and amplitude, both filtered (synchronous) and unfiltered (raw).
e. Bearing temperatures.
f. Casing vibration (refer to Table 7).

4.3.2.2.2 The vibration characteristics determined by the use of the instrumentation specified in 4.3.2.1.7 and 4.3.2.1.8 shall serve as the basis for acceptance or rejection of the machine (see 2.6.3).

4.3.2.2.3 When seismic test values are specified, vibration data (minimum and maximum values) shall be recorded and located (clock angle) in a radial plane transverse to each bearing centerline (if possible), using shop instrumentation during the tests.

4.3.2.2.4 The gear shall be operated at maximum continuous speed until the bearing temperatures and the lube-oil temperatures have stabilized.

4.3.2.2.5 The gear shall be operated at 110 percent of maximum continuous speed for a minimum of 15 minutes.

4.3.2.2.6 The gear shall be operated at maximum continuous speed for 4 hours.

Note: The sequence of steps listed in paragraphs 4.3.2.2.5 and 4.3.2.2.6 is optional.

4.3.2.2.7 The mechanical operation of all equipment being tested and the operation of the test instrumentation shall be satisfactory. The measured unfiltered vibration shall not exceed the limits of 2.6.3 and shall be recorded throughout the operating speed range (see 2.5.2.3).

4.3.2.2.8 For shaft vibration, measure with non-contacting transducers while the gear is operating at maximum continuous speed, a sweep shall be made for vibration amplitudes at frequencies other than synchronous. As a minimum, the sweep shall cover a frequency range from 0.25 times the synchronous speed of the low-speed gear to 4 times the synchronous speed of the high-speed gear, but not less than 1500 hertz. If the amplitude of any discrete, nonsynchronous vibration exceeds 20 percent of the allowable vibration as defined in 2.6.3.1, the purchaser and the vendor shall mutually agree on requirements for any additional testing and on the gear's suitability for shipment.

4.3.2.2.9 For casing vibration, measured with casing mounted acceleration transducers, while the gear is operating at maximum continuous speed, a sweep shall be made at a frequency range of from 10 kHz up to, and including 10 kHz. The values of velocity and acceleration shall not exceed the allowable levels defined in 2.6.3.5 and shown on Table 7.

4.3.2.2.10 The mechanical running tests shall verify that lateral critical speeds conform to the requirements of 2.6.1.

● **4.3.2.2.11** Plots showing synchronous vibration amplitude and phase angle versus speed for deceleration hall be made before and after the 4-hour run. Plots shall be made of both the filtered (one per revolution) and the unfiltered vibration levels, when specified, these data shall also be furnished in polar form. The speed range covered by these plots shall be 400 rpm to the specified driver trip speed.

● **4.3.2.2.12** Lube-oil inlet pressures and temperatures shall be varied through the range permitted in the operating manual. This shall be done during the 4-hour test.

● **4.3.2.2.13** When specified, tape recordings shall be made of all real-time vibration data.

● **4.3.2.2.14** When specified, the tape recordings of real-time vibration data shall be provided to the purchaser.

● **4.3.2.2.15** Testing at any additional speeds, the duration of testing at each speed, and the data to be recorded will be specified by the purchaser at the time of purchase.

4.3.2.3 After the mechanical running test is completed, the requirements of 4.3.2.3.1 through 4.3.2.3.3 shall be met.

4.3.2.3.1 The top half of the casing shall be removed and the tooth mesh shall be inspected for proper contact and for surface damage resulting from the tests.

4.3.2.3.2 Hydrodynamic bearings shall be removed, inspected, and reassembled after the mechanical running tests are completed.

4.3.2.3.3 If replacement or modification of bearings or seals, or dismantling of the case to replace or modify other parts is required to correct mechanical or performance deficiencies, the initial tests will not be acceptable, and the final shop tests shall be run after these replacements or corrections are made.

4.3.2.4 When spare gear elements are ordered to permit concurrent manufacture, each spare element shall also be given mechanical running tests in accordance with the requirements of this standard.

4.3.3 OPTIONAL TESTS

When specified, the shop tests described in 4.3.3.1 through 4.3.3.5 shall be performed.

4.3.3.1 Full-Speed/Full- or Part-Load Test

The gear unit shall be tested to transmit its partial or full rated power, as agreed upon by the purchaser and the vendor, at its rated input speed. The load shall be applied by a mechanical or a hydraulic method (dynamometers, prony brakes, and so forth) until the bearing and lube-oil temperatures have stabilized. Details of the test, including vibration limits, shall be negotiated before the order. Where shop dynamometers have a sufficient torque rating but an insufficient speed rating, shop stepdown gears shall be used in lieu of testing at a reduced speed.

4.3.3.1.1 When partial or full-load tests are specified, the vendor's test stand lubrication system shall include an automatic low lube-oil shutdown system.

4.3.3.2 Full-Torque/Slow-Roll Test

The unit's full torque shall be calculated at the gear rated power and the rated input or output speed. The full torque shall then be applied to its respective shaft by mechanical or hydraulic means at a speed convenient for the vendor's test-stand equipment.

Example: At 10,000 revolutions per minute, 14.9 megawatts (20,000 horsepower) is equivalent to 14.2 kilonewton-meters (126,050 inch-pounds) of torque. At 50 revolutions per minute, torque at this speed is equivalent to 75.0 kilowatts (100 horsepower).

The duration of the test shall be negotiated before the time of order.

Note: The full-torque/slow-roll test is designed to demonstrate only tooth contact and load-carrying capability. Vibration and temperature limitations, as outlined elsewhere in this standard, should not be applied.

4.3.3.3 Full-Torque/Static Test

One shaft of the gear shall be locked. The full torque, as calculated in 4.3.3.2, shall then be applied to the other shaft by mechanical or hydraulic means. This procedure shall be repeated at several mesh points of gear set. The number of load applications shall be negotiated before the time of order.

4.3.3.4 Back-to-Back Locked-Torque Test

Two identical gear units shall be coupled together, input shaft to input shaft and output shaft to output shaft. The full torque, as calculated in 4.3.3.2, shall then be introduced by removing the spacer and turning one shaft against its mate while the other shafts remain coupled. This torque shall be maintained in the system by mechanical or hydraulic means (for example, coupling halves keyed on shafts, torque introduced, and then coupling halves bolted together). The units shall then be run at their rated input and output speeds. The duration of the run shall be negotiated before the time of order.

4.3.3.5 Sound-Level Test

The sound-level test shall be performed in accordance with API Standard 615. When approved by the purchaser, required shop testing shall meet the speed and load requirements of AGMA 295.

4.4 Preparation for Shipment

4.4.1 Equipment shall be suitably prepared for the type of shipment specified. The preparation shall make the equipment suitable for 6 months of outdoor storage from the time of shipment, with no disassembly required before operation. If storage for a longer period is contemplated, the purchaser will consult with the vendor regarding the recommended procedures to be followed.

4.4.2 The vendor shall provide the purchaser with the instructions necessary to preserve the integrity of the storage preparation after the equipment arrives at job site and before startup.

4.4.3 The equipment shall be prepared for shipment after all testing and inspection has been completed and the equipment has been approved by the purchaser. The preparation shall include that specified in 4.4.3.1 through 4.4.3.10.

4.4.3.1 Exterior surfaces, except for machined surfaces, shall be given at least one coat of the manufacturer's standard paint. The paint shall not contain lead or chromates.

4.4.3.2 Exterior machined surfaces shall be coated with a suitable rust preventive.

4.4.3.3 The interior of the gear unit shall be clean; free from scale, welding spatter, and foreign objects; and sprayed or flushed with a suitable rust preventive that can be removed with solvent. The rust preventive shall be applied through all openings while the gear unit is slow-rolled.

4.4.3.4 Internal steel areas of bearing housings and carbon steel oil systems' auxiliary equipment (such as reservoirs, vessels, and piping) shall be coated with a suitable oil-soluble rust preventive.

4.4.3.5 Flanged openings shall be provided with metal closures at least 4.8 millimeters (3/16 inch) thick, with rubber gaskets, and at least four full-diameter bolts. For studded openings, all nuts needed for the intended service shall be used to secure closures.

4.4.3.6 Threaded openings shall be provided with steel caps or round-head steel plugs in accordance with ANSI B16.11. The caps or plugs shall be of material equal to or better than that of the pressure casing. In no case shall non-metallic (such as plastic) caps or plugs be used.

4.4.3.7 Lifting points and the center of gravity shall be clearly identified on the equipment package. The vendor shall provide the recommended lifting arrangement.

4.4.3.8 The equipment shall be identified with item and serial numbers. Material shipped separately shall be identified with securely affixed, corrosion resistant metal tags indicating the item and serial number of the equipment for which the material is intended. In addition, crated equipment shall be shipped with duplicate packing lists, one inside and one on the outside of the shipping container.

4.4.3.9 When spare gear elements are purchased, the rotors shall be suitably prepared for unheated indoor storage for a period of at least 3 years. The rotors shall be treated with a rust preventive and shall be housed in a vaporbarrier envelope with a slow-release vapor-phase inhibitor. The rotors shall be suitably crated for domestic or export shipment, as specified. Lead sheeting, at least 3.2 millimeters (⅛ inch) thick, or a purchaser-approved equivalent shall be used between the rotors and the cradle at the support areas. The rotors shall not be supported at journals.

4.4.3.10 Exposed shafts and shaft couplings shall be wrapped with waterproof, moldable waxed cloth or vapor-phase-inhibitor paper. The seams shall be sealed with oil-proof adhesive tape.

4.4.4 Components (both individual pieces and packaged sets) shipped with mounted preassembled piping, tubing, or wiring shall comply with the requirements of the Occupational Safety and Health Administration and shall carry outside securely affixed, large, red all-weather tags stating the following in bold letters:

THIS SYSTEM HAS BEEN PREASSEMBLED AND TESTED FOR OPERABILITY AND SAFETY, COMPLIES WITH ALL REQUIREMENTS OF OSHA (OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION), AND SHALL NOT BE DISTURBED BY UNAUTHORIZED PERSONNEL.

SECTION 5—VENDOR'S DATA

5.1 General

5.1.1 The information to be furnished by the vendor is specified in 5.2 and 5.3. The vendor shall complete and forward the Vendor Drawing and Data Requirements (VDDR) form (see Appendix F) to the addresses(es) noted on the inquiry or order. This form shall detail the schedule for transmission of drawings, curves, and data as agreed to at the time of the proposal or order as well as the number and type of copies required by the purchaser.

5.1.2 The data shall be identified on the transmittal (cover) letters and in the title blocks or title pages with the following information:

a. The purchaser's/user's corporate name.
b. The job/project.
c. The equipment item number and service name.
d. The inquiry or purchase order number.
e. Any other identification specified in the inquiry or purchase order.
f. The vendor's identifying proposal number, shop order number, serial number, or other reference required to completely identify return correspondence.

5.1.3 A coordination meeting shall be held, preferably at the vendor's plant, within 4-6 weeks after purchase commitment. Unless otherwise specified, the vendor shall prepare and distribute an agenda prior to this meeting which, as a minimum, will include the review of the following items:

a. The purchase order, scope of supply, vendor's internal order details, and subvendor items.
b. The data sheets.
c. Applicable specifications and previously agreed-upon exceptions.
d. Schedules for transmittal of data, production, and testing.
e. Quality assurance program, procedures, and acceptance criteria.
f. Inspection, expediting, and testing.
g. Schematics and Bill of Materials (B/Ms) of auxiliary systems.
h. The physical orientation of equipment, shaft rotation, piping, and auxiliary systems.
i. Coupling selection.
j. Thrust and radial bearing sizing and estimated loadings.
k. Rotor dynamic analysis.
l. Audit of subsuppliers.
m. Other technical items.

5.2 Proposals

5.2.1 GENERAL

The vendor shall forward the original and the specified number of copies of the proposal to the addressee stated on the inquiry documents. This proposal shall contain the data specified in 5.2.2 through 5.2.4. as well as a specific statement that the system and all its components are in strict accordance with this standard. If the gear and components are not in strict accordance, the vendor shall include a list that details and explains each deviation. The vendor shall provide details to enable the purchaser to evaluate any proposed alternative designs. All correspondence shall be clearly identified in accordance with 5.1.2.

5.2.2 DRAWINGS

5.2.2.1 The drawings indicated on the Vendor Drawing and Data Requirements form (see Appendix F) shall be included in the proposal. As a minimum, the following data shall be furnished:

a. A general arrangement or outline drawing for each gear unit showing overall dimensions, maintenance clearance dimensions, overall weights, erection weights, and maximum maintenance weights (indicate for each piece). The direction of rotation,and the size and location of major purchaser connections shall be indicated.
b. Cross-sectional drawings showing the details of the proposed equipment.
c. Sketches that show methods of lifting the assembled gear. (This information may be included on the drawings specified in preceding Item a.)

5.2.2.2 If typical drawings, schematics, and bills of materials are used, they shall be marked up to show the correct weight and dimension data and to reflect the actual equipment and scope proposed.

5.2.3 TECHNICAL DATA

The following data shall be included in the proposal:

a. The purchaser's data sheets, with completed vendor's information entered thereon and with literature to fully describe details of the offering.
b. The purchaser's noise data sheet or the form from the appendix of API Standard 615.
c. The Vendor Drawing and Data Requirements form (see Appendix F), indicating the schedule according to which the vendor agrees to transmit all the data specified as part of the contract.
d. A schedule for shipment of the equipment, in weeks after receipt of the order.
e. A list of major wearing components, showing interchangeability with the purchaser's other units.
f. A list of recommended start-up spares, including any items that the vendor's experience indicates are likely to be required.
g. A list of special tools furnished for maintenance. The vendor shall identify any metric items included in the offering.
h. A statement of any special protection required for start-up, operation, and periods of idleness under the site conditions specified on the data sheets. The list shall show the protection to be furnished by the purchaser, as well as that included in the vendors scope of supply.
i. A complete tabulation of the utility requirements, including the quantity of lube oil required and the supply pressure, the heat load to be removed by the oil, and the nameplate power rating. (Approximate data shall be defined and identified as such.)
j. A description of the tests and inspection procedures for materials, as required by 2.9.1.4.
k. A description of any special requirements as outlined in 2.9.1.2.
l. A list of similar machines installed and operating under conditions analogous to those specified in the proposal.
m. Any start-up, shutdown, or operating restrictions required to protect the integrity of the equipment.

● 5.2.4 OPTIONS

When specified, the vendor shall furnish a list of the procedures for any special or optional tests that have been specified by the purchaser or proposed by the vendor.

5.3 Contract Data

5.3.1 GENERAL

5.3.1.1 The contract information to be furnished by the vendor is specified in Appendix F. Each drawing, Bill of Materials (B/Ms), or data sheet shall have a title block in the lower right hand corner with the date of certification, reference to all identification data specified in 5.1.2, the revision number and date, and the title.

5.3.1.2 The purchaser will promptly review the vendor's data when he receives them; however, this review shall not constitute permission to deviate from any requirements in the order unless specifically agreed upon in writing. After the data have been reviewed, the vendor shall furnish certified copies in the quantity specified.

5.3.1.3 A complete list of all vendor data shall be included with the first issue of major drawings. This list shall contain titles, drawing numbers, and a schedule for transmission of all data the vendor will furnish (see Appendix F).

5.3.1.4 Inquiry documents shall be revised to reflect any subsequent changes. These changes will result in the purchaser's issue of completed, corrected data sheets as part of the order specifications.

5.3.2 DRAWINGS

The drawings furnished shall contain sufficient information so that when combined with the manuals specified in 5.3.6, the purchaser can properly install, operate, and maintain the ordered equipment. Drawings shall be clearly legible, be identified per 5.3.1.1, and be in accordance with ASME Y14.2M. As a minimum, each drawing shall include the details listed for that drawing in Appendix F.

5.3.3 TECHNICAL DATA

Data shall be submitted in accordance with Appendix F, and identified in accordance with 5.3.1.1.

5.3.4 PROGRESS REPORTS

The vendor shall submit progress reports to the purchaser at the interval specified on the Vendor Drawing and Data Requirement form (see Appendix F).

5.3.5 RECOMMENDED SPARES

The vendor shall submit a complete list of spare parts, including those shown in the original proposal. The list shall include spare parts for all equipment and accessories supplied, with cross-sectional or assembly-type drawings for identification, part numbers, and delivery times. Part numbers shall identify each part for interchangeability. Standard purchased items shall be identified by the original manufacturer's numbers. The vendor shall forward the list to the purchaser promptly after receipt of the reviewed drawings and in time to permit order and delivery of the parts before field start-up. The transmittal letter shall be identified by the data specified in 5.1.2.

5.3.6 INSTALLATION, OPERATION, MAINTENANCE AND DATA MANUALS.

5.3.6.1 General

The vendor shall provide sufficient written instructions and cross-referenced list of all drawings to enable the purchaser to correctly install, operate, and maintain all the equipment ordered. This information shall be compiled in a manual or manuals with a cover sheet containing all reference-identifying data specified in 5.1.2, an index sheet containing section titles, and a complete list of referenced and enclosed drawings by title and drawing number. The manual shall be prepared for the specified installation; a typical manual is not acceptable.

5.3.6.2 Installation Manual

Any special information required for proper installation design that is not on the drawings shall be compiled in a manual that is separate from the operation and maintenance instructions. This manual shall be forwarded at a time that is mutually agreed upon in the order, but not later than final issue of prints. The manual shall contain information such as special alignment and grouting procedures, utility specifications (including quantities), and all other installation design data, including drawings and data specified in 5.2.2 and 5.2.3. The manual shall also include sketches that show the location of the center of gravity and rigging provisions to permit the removal of the top half of the casing, rotors, and subassemblies that weigh more than 136 kilograms (300 pounds).

5.3.6.3 Operation, Maintenance, and Technical Manual

The manual containing operating, maintenance, and technical data shall be forwarded no more than 2 weeks after all of the specified tests have been successfully completed. This manual shall contain a section that provides special instructions for operation at specified extreme environmental conditions, such as temperatures. As a minimum the manual shall include all of the data listed in Appendix F.

APPENDIX A—SPECIAL PURPOSE GEAR UNIT DATA SHEETS

The data sheets presented in this appendix are for use by the gear purchaser and the gear manufacturer to communicate the drive system requirements and the manufacturing specifications of a gear drive to interested parties.

SPECIAL PURPOSE GEAR UNITS
API 613 FOURTH EDITION
DATA SHEET
SI UNITS

Job No. ______ Item No. ______
P.O. No. ______ Date ______
Requisition No. ______
Inquiry No. ______
Revision ______ Date ______ By ______

Applicable To: ○ Proposal ○ Purchase ○ As Built

For ______ Manufacturer ______
Site ______ Model No. ______
Unit ______ Serial No. ______
Service ______ Driver Type ______
No. Required ______ Driven Equipment ______

NOTE: Numbers Within ( ) Refer To Applicable API Standard 613 Paragraphs

○ **Information To Be Completed By Purchaser** ☐ **Information To Be Completed By Manufacturer**

○ RATING REQUIREMENTS

Driven Equip. Power Normal ______ Max ______
Driver Power Rated ______ Max ______
Gear Rated Power (2.2.1) ______
Torque @ Max Cont Speed ______ kg·m
Max Torque (2.2.1) ______ kg·m @ ______ RPM
Rated Speed, RPM (1.4):
Input ______ ○ Specified ○ Nominal
Output ______ ○ Specified ○ Nominal
Allow Var In Gear Ratio (1.4) (+) (-) ______ %
Max Continuous Speed (1.4) ______ RPM
Trip Speed (1.4) ______ RPM
Gear Service Factor (2.2.2.1) ______ (Min)
Pinion Hardness (2.2.2.2) ______
Shaft Assembly Designation (2.1.17.2) ______
HS Shaft Rot Fac'g Cpl'g (2.1.17.2) ○ CW ○ CCW
LS Shaft Rot Fac'g Cpl'g (2.1.17.2) ○ CW ○ CCW
HS Shaft End: ○ Cylindrical ○ Taper ○ 1-Key ○ 2-Keys
○ Hydraulic Taper ○ Integral Flange
LS Shaft End: ○ Cylindrical ○ Taper ○ 1-Key ○ 2-Keys
○ Hydraulic Taper ○ Integral Flange
External Loads (2.1.13) ______
Other Operating Conditions (2.2.3.4) (2.6.1.4) ______

○ INSTALLATION DATA

○ Indoor ○ Heated ○ Under Roof
○ Outdoor ○ Unheated ○ Partial Sides
○ Grade ○ Mezzanine ○ ______
○ Winterization Req'd ○ Tropicalization Req'd
Electrical Area (2.1.7) Class ______ Grp ______ Div ______
Max Allow SPL (2.1.4) ______ dBA @ ______ m
Elevation ______ m Barometer ______ kPa abs
Range Of Ambient Temperatures:

	Dry Bulb	Wet Bulb
Normal	______ C	______ C
Maximum	______ C	______ C
Minimum	______ C	______ C

Unusual Conditions ○ Dust ○ Fumes ○ ______

NOTES: ______

☐ BASIC GEAR DATA

Mechanical Rating (1.4) ______ kw@ ______ RPM
Full Load Power Loss ______ kw
Mechanical Efficiency ______ %
Pitch Line Velocity ______ m/sec
Tooth Pitting Index, "K" (2.2.3):
Actual ______ Allowable ______
Tangential Load, "W_t" (2.2.3.2) ______ kg
Bending Stress Number, "S_t" (2.2.4.2):

	Pinion	Gear
Actual	______	______
Allowable	______	______

Material Index Number (Fig 2, Table 3) ______
Anticipated SPL (2.1.4) ______ dBA @ ______ m
Journal Static Weight Loads (2.6.2.1):
Pinion ______ kg Gear ______ kg
WR² Referred To LS Shaft ______ kg·mm²
Breakaway Torque ______ N·m @ LS Shaft

☐ CONSTRUCTION FEATURES

TYPE OF GEAR ☐ Reducer ☐ Increaser
☐ Single Stage ☐ Double Stage
☐ Single Helical ☐ Double Helical
☐ Epicyclic ☐ ______

TEETH
Number of Teeth Pinion ______ Gear ______
Gear Ratio ______ Center Dist ______ mm
Pitch Dia, mm Pinion ______ Gear ______
Finish ______ RA AGMA Geometry Factor "J":
Pinion ______ Gear ______
Helix Angle ______ Degrees
Normal Pressure Angle ______ Degrees
Net Face Width, "Fw" ______ mm Pinion L/D ______
Normal Diametral Pitch ______ Backlash ______ mm
Tooth Plating (2.5.1.4) ☐ Recom'd ☐ Not Recom'd

MANUFACTURING METHODS
Teeth Generated By The ______ Process
Teeth Finished By The ______ Process
Teeth Hardening Method ______
Gear To Shaft (2.5.3.2) ☐ Integral ☐ Shrunk-on
Rim Attachment (2.5.3.2) ______

SPECIAL PURPOSE GEAR UNITS
API 613 FOURTH EDITION
DATA SHEET
SI UNITS

Job No. ______ Item No.
Date ______ By ______
Revision No. ______ By ______

○ ADDITIONAL REQUIREMENTS

MOUNTING PLATES (3.3.1)

○ Gear Furnished With (3.3.3.1):
○ Baseplate ○ Soleplate(s) ○ Subplate(s)
○ Mounting Plate(s) Furnished By (3.3.1.1) ______
○ Equipment On Baseplate (3.3.2.1) ______
______
○ Baseplate With Leveling Pads (3.3.2.3)
○ Baseplate Suitable For Column Mounting (3.3.2.4)
○ Grout Type (3.3.1.2.5): ○ Epoxy ○ ______
● **PAINTING** (4.4.3.1) ○ ______

MISCELLANEOUS

● Undamped Critical Analysis Report (2.6.1.6):
○ With Damped Rotor Response Analysis Report (2.6.1.6)
Torsional Analysis By (2.6.1.8) ○ Gear Vendor ○ Other
○ Spare Set Of Gear Rotors (4.3.2.4)
○ Gear Case Furnished With Inlet Purge Connection (2.4.3)
○ Orientation Of Oil Inlet And Drain Connections ______

● VIBRATION DETECTORS (3.4.2)

RADIAL (3.4.2.1)

○ Manufacturer ______
○ No. At Each Shaft Bearing ______ Total No. ______
○ Oscillator-Demodulators Supplied By ______
○ Manufacturer ______
○ Monitor Supplied By (3.4.2.5) ______
○ Location ______ Enclosure ______
○ Manufacturer ______
○ Alarm ______ ○ Shutdown ______
○ Shutdown Time Delay ______ Seconds

AXIAL (3.4.2.1)

○ Manufacturer ______ No. Required ______
○ Location ______
○ Oscillator-Demodulators Supplied By ______
○ Manufacturer ______
○ Monitor Supplied By (3.4.2.5) ______
○ Location ______ Enclosure ______
○ Manufacturer ______
○ Alarm ______ ○ Shutdown ______
○ Shutdown: Time Delay ______ Seconds ______

ACCELEROMETER (3.4.3.1)

Manufacturer ______ No. Required ______
Location ______
Monitor Supplied By (3.4.2.5) ______

☐ RADIAL BEARINGS

	Pinion	Gear
Type		
Diameter, mm		
Length, mm		
Journal Velocity, m/sec		
Loading, kPa		
Clearance (min-max), mm		
Span, mm		

☐ THRUST BEARING(S)

Location		
Manufacturer		
Type		
Size		
Area, mm²		
Loading, kPa		
Rating, kPa		
Int.Thrust Load, N (+)(-)		
Ext.Thrust Load, N (+)(-)		

☐ COUPLING(S)

Manufacturer		
Model		
Cplg.Rating, kw/100 RPM		
Cplg. Gear Pitch Dia.,mm		
Cplg.Press.Angle, Deg.		
Cylindrical / 1-Key	☐	☐
Cylindrical / 2-Keys	☐	☐
Tapered / 1-Key	☐	☐
Tapered / 2-Keys	☐	☐
Tapered / Keyless	☐	☐

☐ MATERIALS

Gear Casing ______ Oil Seals ______
Radial Bearings ______
Thrust Bearing(s) ______
HS Shaft ______ LS Shaft ______
Pinion(s) ______ Hardness ______
Gear Rim(s) ______ Hardness ______
Low Temp.Operation (2.9.4) ______

☐ PIPING CONNECTIONS

	No.	Size	Type
Service			
Lube Oil Inlet			
Lube Oil Outlet			
Casing Drain			
Vent			
Casing Purge			

NOTES: ______

SPECIAL PURPOSE GEAR UNITS
API 613 FOURTH EDITION
DATA SHEET
SI UNITS

Job No. ______ Item No.
Date ______ By ______
Revision No. ______ By ______

○ INSTRUMENTS

○ Mercury Thermometers (3.4.1.1) ______
○ Bearing Metal Temp. Sensors (2.7.1.3) ______

○ CONTRACT DATA

○ Vendor's Rep At Site (2.1.10)
○ Test Data Prior To Shipment ______
○ Progress Reports (5.3.4) ______

______
______
______
______

○ SHIPMENT (4.4.1)

	Contract Unit	Spares
Export Boxing (4.4.3.9)	○	○
Domestic Boxing	○	○
Outdoor Storage Over 6 mos.	○	○

○ COUPLINGS AND GUARDS.

	High Speed	Low Speed
Coupling Furnished By		
Coupling Type		
Coupling Lubrication		
Mount Coupling Halves (3.2.1)		
Taper		
Limited End Float		
Cplg. Guard Furnished By		

○ LUBRICATION REQUIREMENTS

○ Oil System Furnished By (2.8.3) ______
○ Oil Visc.: ____ cP@ 40 C ____ cP@100 C (2.8.6)

○ INSPECTIONS AND TESTS (4.1)

	Req'd	Wit-ness	Ob-served	Test Log
Shop Inspection (4.1.1.1)	○	○	○	
Cleanliness Inspection (4.2.3.2)	○	○	○	
Hardness Verification Inspection (4.2.3.3)	○	○	○	○
Dismantle-Reassembly Inspection (4.3.2.3.1)	○	○	○	
Contact Check (2.5.2.2)	○	○	○	○
Contact Check Tape Lift (2.5.2.2)	○	○	○	○
Journal Runout Check (2.5.2.1)	○	○	○	○
Axial Stability Check (2.5.2.3)	○	○	○	○
Rotor Balancing Machine Sensitivity Check (2.6.2.3)	○	○	○	○
Residual Unbalance Check (2.6.2.3.3)	○	○	○	○
Mechanical Run Test (4.3.2)	○	○	○	○
Mechanical Run Test (Spare Rotors) (4.3.2.4)	○	○	○	○

☐ LUBRICATION REQUIREMENTS

Min. Startup Oil Temperature	______	C
Unit Oil Flow (Total)	______	m^3/hr
Unit Oil Pressure	______	kPa
Oil Flow, Mesh	______	m^3/hr
Oil Flow, HS Bearings	______	m^3/hr
Oil Flow, LS Bearings	______	m^3/hr
Oil Flow, Thrust Bearing(s)	______	m^3/hr

ADDITIONAL REQUIREMENTS

Filter Breather Location (2.3.1.10) ______

☐ GEAR DATA

Power Loss Each HS Bearing ______
Power Loss Each LS Bearing ______
Power Loss Each Thrust Bearing ______

	Pinion	Gear
Outside Diameter, mm		
Root Diameter, mm		
Center Groove Diameter, mm		
Durability Power		
Strength Power		
Face Overlap Ratio		
Transverse Contact Ratio		
Length Line of Action, mm		

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Job No. ____________ Item No.
Date ____________ By ____________
Revision No. ____________ By ____________

○ INSPECTIONS AND TESTS (Con't.)

	Req'd.	Wit-ness	Ob-serve	Test Log
Add'l. Mechanical Tests(4.3.2.2.15)	○	○	○	○
Part or Full Load And Full Speed Test (4.3.3.1)	○	○	○	○
Full Torque, Slow Roll Test (4.3.3.2)	○	○	○	○
Full Torque Static Test (4.3.3.3)	○	○	○	○
Back-To-Back Locked Torque Test (4.3.3.4)	○	○	○	○
Sound Level Test (4.3.3.5)	○	○	○	○
Additional Gear Tooth Test (4.2.2.8)	○	○	○	○
Use Shop Lube System	○	○	○	
Use Job Lube System	○	○	○	
Use Shop Vibration Probes, Etc.	○	○	○	
Use Job Vibration Probes, Etc.	○	○	○	
Other (4.2.1.2)	○	○	○	
Final Assembly, Maintenance & Running Clearance (4.2.1.1.e)	○	○	○	○
Oil System Cleanliness (4.3.2.1.3)	○	○	○	
Oil System-Casing Joint Tightness (4.3.2.1.4)	○	○	○	
Warning And Protection Devices (4.3.2.1.5)	○	○	○	

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Job No. ________ Item No. ________
P.O. No. ________ Date ________
Requisition No. ________
Inquiry No. ________
Revision ____ Date ________ By ________

1	Applicable To: ○ Proposal ○ Purchase ○ As Built	
2	For ________	Manufacturer ________
3	Site ________	Model No. ________
4	Unit ________	Serial No. ________
5	Service ________	Driver Type ________
6	No. Required ________	Driven Equipment ________
7	NOTE: Numbers Within ( ) Refer To Applicable API Standard 613 Paragraphs	
8	○ Information To Be Completed By Purchaser	☐ Information To Be Completed By Manufacturer
9	○ RATING REQUIREMENTS	☐ BASIC GEAR DATA
10	Driven Equip Power Normal ________ Max ________	
11	Driver Power Rated ________ Max ________	Mechanical Rating (1.4) ________ HP@ ________ RPM
12	Gear Rated Power (2.2.1) ________	Full Load Power Loss ________ HP
13	Torque @ Max Cont. Speed ________ Lb Ft	Mechanical Efficiency ________ %
14	Max Torque (2.2.1) ________ Lb Ft @ ________ RPM	Pitch Line Velocity ________ FPM
15	Rated Speed, RPM (1.4):	Tooth Pitting Index, "K" (2.2.3):
16	Input ________ ○ Specified ○ Nominal	Actual ________ Allowable ________
17	Output ________ ○ Specified ○ Nominal	Tangential Load, "W_t" (2.2.3.2) ________ Lb
18	Allow Var In Gear Ratio (1.4) (+) (-) ________ %	Bending Stress Number, "S_t" (2.2.4.2):
19	Max Continuous Speed (1.4) ________ RPM	Pinion Gear
20	Trip Speed (1.4) ________ RPM	Actual ________ ________
21	Gear Service Factor (2.2.2.1) ________ (Min)	Allowable ________ ________
22	Pinion Hardness (2.2.2.2) ________	Material Index Number (Fig 2, Table 3) ________
23	Shaft Assembly Designation (2.1.17.2) ________	Anticipated SPL (2.1.4) ________ dBA @ ________ Ft
24	HS Shaft Rot Fac'g Cpl'g (2.1.17.2) ○ CW ○ CCW	Journal Static Weight Loads (2.6.2.1):
25	LS Shaft Rot Fac'g Cpl'g (2.1.17.2) ○ CW ○ CCW	Pinion ________ Lb Gear ________ Lb
26	HS Shaft End: ○ Cylindrical ○ Taper ○ 1-Key ○ 2-Keys	WR^2 Referred To LS Shaft ________ Lb Ft^2
27	○ Hydraulic Taper ○ Integral Flange	Breakaway Torque ________ Lb Ft @ LS Shaft
28	LS Shaft End: ○ Cylindrical ○ Taper ○ 1-Key ○ 2-Keys	☐ CONSTRUCTION FEATURES
29	○ Hydraulic Taper ○ Integral Flange	
30	External Loads (2.1.13) ________	**TYPE OF GEAR** ☐ Reducer ☐ Increaser
31	Other Operating Conditions (2.2.3.4) (2.6.1.4) ________	☐ Single Stage ☐ Double Stage
32		☐ Single Helical ☐ Double Helical
33	○ INSTALLATION DATA	☐ Epicyclic ☐ ________
34	○ Indoor ○ Heated ○ Under Roof	**TEETH**
35	○ Outdoor ○ Unheated ○ Partial Sides	Number of Teeth Pinion ________ Gear ________
36	○ Grade ○ Mezzanine ○ ________	Gear Ratio ________ Center Dist ________ In
37	○ Winterization Req'd ○ Tropicalization Req'd	Pitch Dia, In Pinion ________ Gear ________
38	Electrical Area (2.1.7) Class ____ Grp ____ Div ____	Finish ____ RA AGMA Geometry Factor "J":
39	Max Allow SPL (2.1.4) ________ dBA @ ________ Ft	Pinion ________ Gear ________
40	Elevation ________ Ft Barometer ________ PSIA	Helix Angle ________ Degrees
41	Range Of Ambient Temperatures:	Normal Pressure Angle ________ Degrees
42	Dry Bulb Wet Bulb	Net Face Width, "Fw" ________ In Pinion L/D ________
43	Normal ________ F ________ F	Normal Diametral Pitch ________ Backlash ________ In
44	Maximum ________ F ________ F	Tooth Plating (2.5.1.4) ☐ Recom'd ☐ Not Recom'd
45	Minimum ________ F ________ F	**MANUFACTURING METHODS**
46	Unusual Conditions ○ Dust ○ Fumes ○ ________	Teeth Generated By The ________ Process
47	NOTES: ________	Teeth Finished By The ________ Process
48		Teeth Hardening Method ________
49		Gear To Shaft (2.5.3.2) ☐ Integral ☐ Shrunk-on
50		Rim Attachment (2.5.3.2) ________

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Job No. ________ Item No.
Date ________ By ________
Revision No. ________ By ________

○ ADDITIONAL REQUIREMENTS

MOUNTING PLATES (3.3.1)
○Gear Furnished With (3.3.3.1):
○ Baseplate ○ Soleplate(s) ○ Subplate(s)
○Mounting Plate(s) Furnished By(3.3.1.1) ________
○Equipment On Baseplate (3.3.2.1) ________
○Baseplate With Leveling Pads (3.3.2.3)
○Baseplate Suitable For Column Mounting (3.3.2.4)
○Grout Type (3.3.1.2.5) ○Epoxy ○ ________
●**PAINTING** (4.4.3.1) ○ ________
MISCELLANEOUS
●Undamped Critical Analysis Report (2.6.1.6):
○With Damped Rotor Response Analysis Report (2.6.1.6)
○Torsional Analysis By (2.6.1.8): ○ Gear Vendor ○Other
Spare Set Of Gear Rotors (4.3.2.4)
○Gear Case Furnished With Inlet Purge Connection (2.4.3)
○ Orientation Of Oil Inlet And Drain Connections ________

● VIBRATION DETECTORS (3.4.2)

RADIAL (3.4.2.1)
○ Manufacturer ________
○ No. At Each Shaft Bearing ____ Total No. ____
○ Oscillator-Demodulators Supplied By ________
○Manufacturer ________
○ Monitor Supplied By (3.4.2.5) ________
○ Location ________ Enclosure ________
○ Manufacturer ________
○ Alarm ________ ○Shutdown ________
○Shutdown Time Delay ____ Seconds
AXIAL (3.4.2.1)
○Manufacturer ________ No. Required ____
○Location ________
○Oscillator-Demodulators Supplied By ________
○Manufacturer ________
○Monitor Supplied By (3.4.2.5) ________
○ Location ________ Enclosure ________
○ Manufacturer ________
○Alarm ________ ○Shutdown ________
○Shutdown: Time Delay ____ Seconds ____
ACCELEROMETER (3.4.3.1)
Manufacturer ________ No. Required ____
Location ________
Monitor Supplied By (3.4.2.5) ________

☐ RADIAL BEARINGS

	Pinion	Gear
Type		
Diameter, In		
Length, In		
Journal Velocity, FPS		
Loading, PSI		
Clearance (min-max), In		
Span, In		

☐ THRUST BEARING(S)

Location		
Manufacturer		
Type		
Size		
Area, In^2		
Loading, PSI		
Rating, PSI		
Int. Thrust Load, Lb (+)(-)		
Ext. Thrust Load, Lb (+)(-)		

☐ COUPLING(S)

Manufacturer		
Model		
Cplg. Rating, HP/100 RPM		
Cplg. Gear Pitch Dia., In		
Cplg. Press. Angle, Deg.		
Cylindrical / 1-Key	☐	☐
Cylindrical / 2-Keys	☐	☐
Tapered / 1-Key	☐	☐
Tapered / 2-Keys	☐	☐
Tapered / Keyless	☐	☐

☐ MATERIALS

Gear Casing ________ Oil Seals ________
Radial Bearings ________
Thrust Bearing(s) ________
HS Shaft ________ LS Shaft ________
Pinion(s) ________ Hardness ________
Gear Rim(s) ________ Hardness ________
Low Temp. Operation (2.9.4) ________

☐ PIPING CONNECTIONS

Service	No.	Size	Type
Lube Oil Inlet			
Lube Oil Outlet			
Casing Drain			
Vent			
Casing Purge			

NOTES: ________

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Job No. ____________ Item No.
Date ____________ By ____________
Revision No. ____________ By ____________

○ INSTRUMENTS

○ Mercury Thermometers (3.4.1.1) ____________
○ Bearing Metal Temp. Sensors (2.7.1.3) ____________

○ CONTRACT DATA

○ Vendor's Rep At Site (2.1.10)
○ Test Data Prior To Shipment ____________
○ Progress Reports (5.3.4) ____________

○ SHIPMENT (4.4.1)

	Contract Unit	Spares
Export Boxing (4.4.3.9)	○	○
Domestic Boxing	○	○
Outdoor Storage Over 6 mos.	○	○

○ COUPLINGS AND GUARDS.

	High Speed	Low Speed
Coupling Furnished By		
Coupling Type		
Coupling Lubrication		
Mount Coupling Halves (3.2.1)		
Taper		
Limited End Float		
Cplg. Guard Furnished By		

○ LUBRICATION REQUIREMENTS

○ Oil System Furnished By (2.8.3) ____________
○ Oil Visc.: ____SSU@100 F____SSU@210 F (2.8.6)

○ INSPECTIONS AND TESTS (4.1)

	Req'd	Wit-ness	Ob-served	Test Log
Shop Inspection (4.1.1.1)	○	○	○	
Cleanliness Inspection (4.2.3.2)	○	○	○	
Hardness Verification Inspection (4.2.3.3)	○	○	○	○
Dismantle-Reassembly Inspection (4.3.2.3.1)	○	○	○	
Contact Check (2.5.2.2)	○	○	○	○
Contact Check Tape Lift (2.5.2.2)	○	○	○	○
Journal Runout Check (2.5.2.1)	○	○	○	○
Axial Stability Check (2.5.2.3)	○	○	○	○
Rotor Balancing Machine Sensitivity Check (2.6.2.3)	○	○	○	○
Residual Unbalance Check (2.6.2.3.3)	○	○	○	○
Mechanical Run Test (4.3.2)	○	○	○	○
Mechanical Run Test (Spare Rotors) (4.3.2.4)	○	○	○	○

□ LUBRICATION REQUIREMENTS

Min. Startup Oil Temperature ____________ F
Unit Oil Flow (Total) ____________ GPM(US)
Unit Oil Pressure ____________ PSI
Oil Flow, Mesh ____________ GPM(US)
Oil Flow, HS Bearings ____________ GPM(US)
Oil Flow, LS Bearings ____________ GPM(US)
Oil Flow, Thrust Bearing(s) ____________ GPM(US)

ADDITIONAL REQUIREMENTS

Filter Breather Location (2.3.1.10) ____________

□ GEAR DATA

Power Loss Each HS Bearing ____________
Power Loss Each LS Bearing ____________
Power Loss Each Thrust Bearing ____________

	Pinion	Gear
Outside Diameter, In		
Root Diameter, In		
Center Groove Diameter, In		
Durability Power		
Strength Power		
Face Overlap Ratio		
Transverse Contact Ratio		
Length Line of Action, In		

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Job No. ________ Item No.
Date ________ By ________
Revision No. ________ By ________

○ INSPECTIONS AND TESTS (Con't.)

	Req'd.	Wit-ness	Ob-serve	Test Log
Add'l. Mechanical Tests (4.3.2.2.15)	○	○	○	○
Part or Full Load And Full Speed Test (4.3.3.1)	○	○	○	○
Full Torque, Slow Roll Test (4.3.3.2)	○	○	○	○
Full Torque Static Test (4.3.3.3)	○	○	○	○
Back-To-Back Locked Torque Test (4.3.3.4)	○	○	○	○
Sound Level Test (4.3.3.5)	○	○	○	○
Additional Gear Tooth Test (4.2.2.8)	○	○	○	○
Use Shop Lube System	○	○	○	
Use Job Lube System	○	○	○	
Use Shop Vibration Probes, Etc.	○	○	○	
Use Job Vibration Probes, Etc.	○	○	○	
Other (4.2.1.2)	○	○	○	
Final Assembly, Maintenance & Running Clearance (4.2.1.1.e)	○	○	○	○
Oil System Cleanliness (4.3.2.1.3)	○	○	○	
Oil System-Casing Joint Tightness (4.3.2.1.4)	○	○	○	
Warning And Protection Devices (4.3.2.1.5)	○	○	○	

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APPENDIX B—LATERAL CRITICAL SPEED MAP AND MODE SHAPES FOR TYPICAL ROTOR

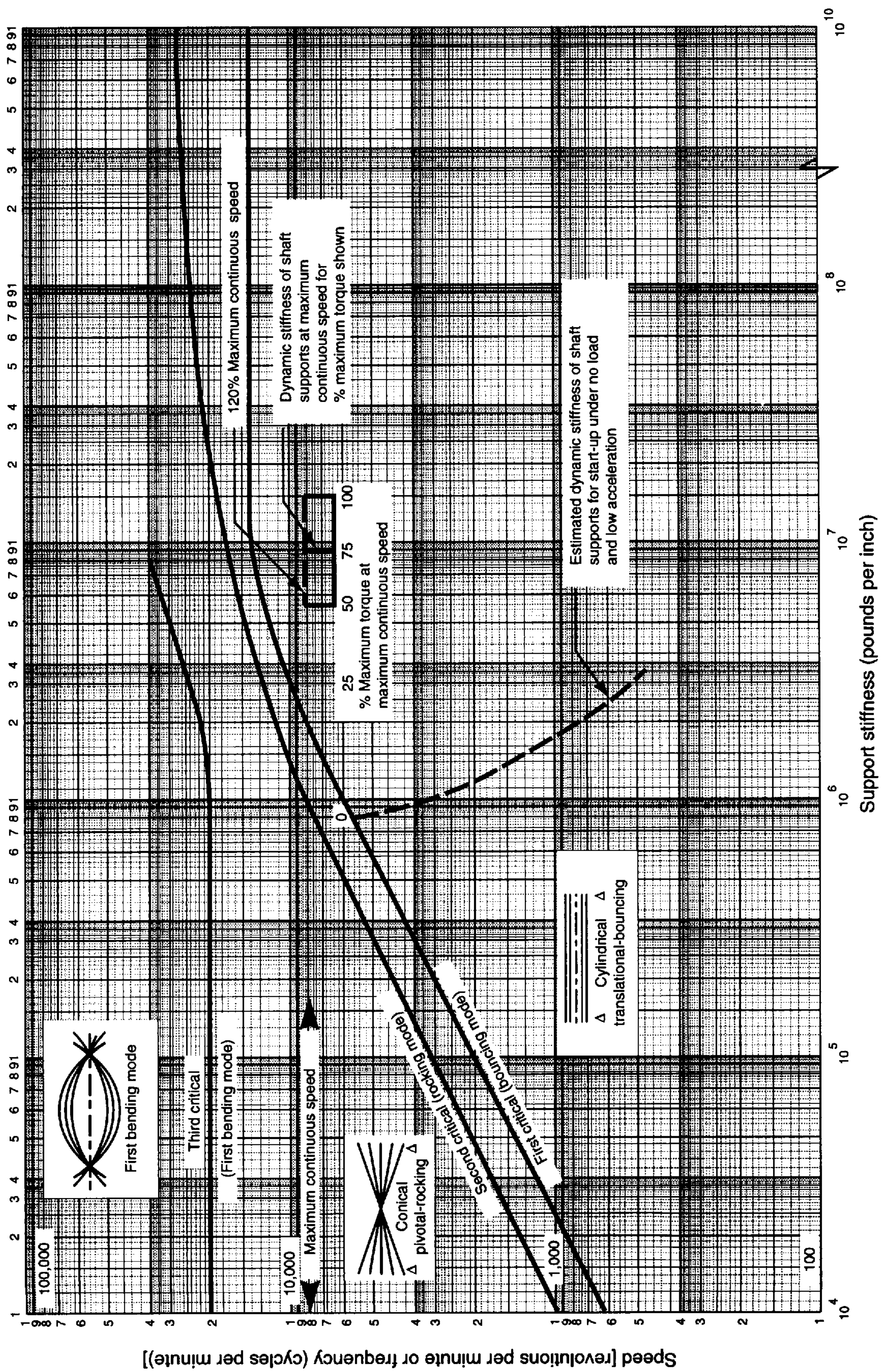
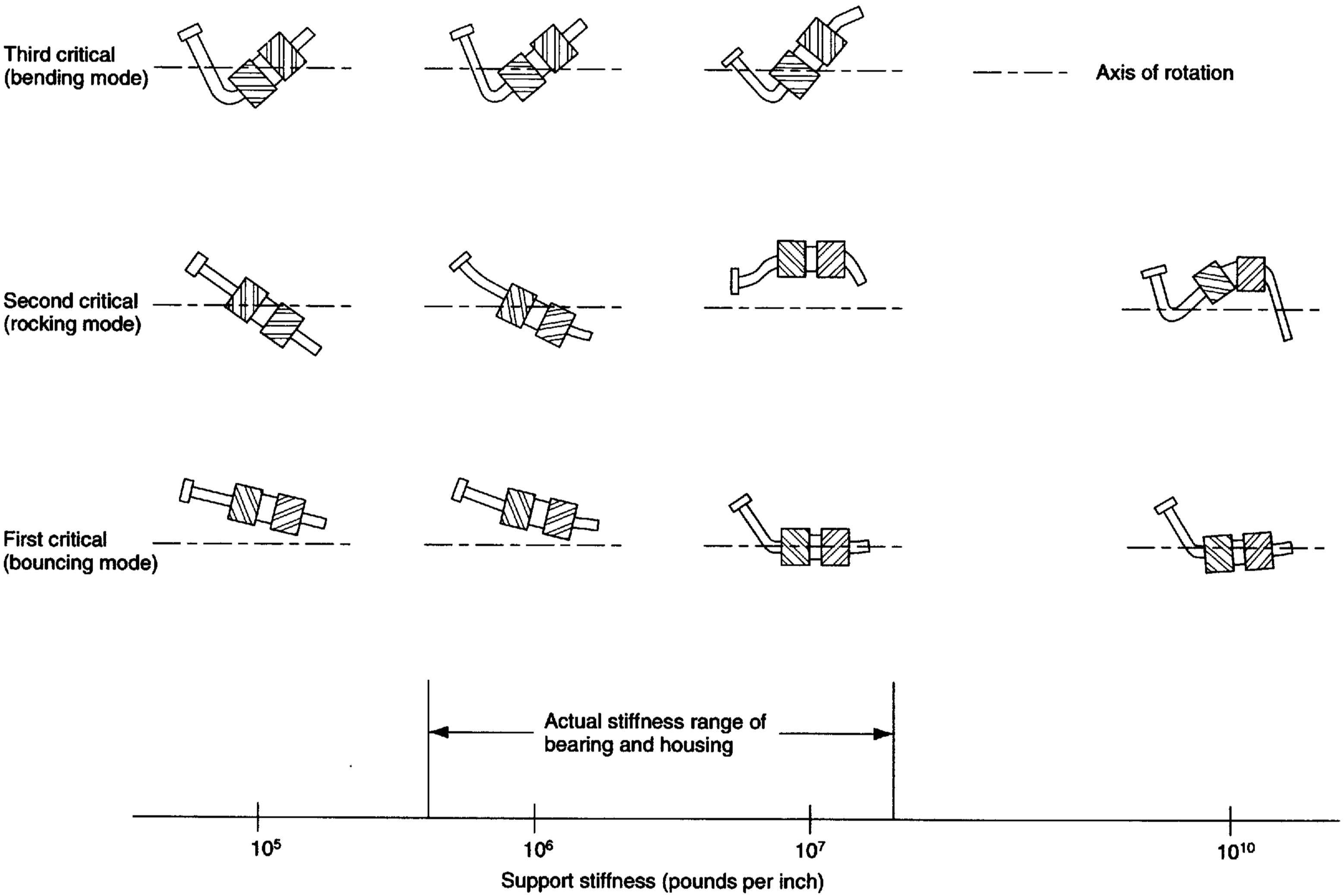


Figure B-1—Lateral Critical Speed Map for a Typical Rotor



Note: The mode shapes in this figure are normalized, which exaggerates the deflections of the rotor. The actual maximum deflection may be so small that it is insignificant. These mode shapes apply only to operation directly on a critical speed. Mode shapes will vary with the geometry of the rotor.

Figure B-2—Mode Shapes Versus Support Stiffness for a Typical Rotor

APPENDIX C—COUPLINGS FOR HIGH-SPEED GEAR UNITS

C.1 General

C.1.1 Appendix C is intended to provide a guide to the selection of coupling types and the location of thrust bearings in equipment trains that employ high-speed gears. This appendix is not intended to supersede this standard or the information contained in the data sheets.

C.1.2 High-speed gear units must be connected to driving and driven machines by means of couplings that will not impose harmful forces on the rotating elements of the gear unit. This is necessary to maintain uniform distribution of the tooth loading across the face of the gears throughout varying thermal and load conditions. Excessive moment forces exerted across a coupling will cause the pinion or gear to cock n its bearings, resulting in a shift in the tooth loading toward one end of the gear teeth. Excessive axial force transmitted across a coupling will cause one helix of a double-helical gear to be more heavily loaded than the other if the arrangement of machinery is such that the axial force is transmitted across the gear-tooth mesh to reach an opposing thrust bearing.

C.2 Coupling Types

C.2.1 Many different types of couplings have been developed over the years, and many variations within a particular generic type of coupling have evolved. The coupling types listed in C.2.2 through C.2.5 are not intended to be all inclusive, but are intended to include the most popular types used in conjunction with high-speed gear units.

C.2.2 Generic types (popular designations) of couplings include gear-tooth- or gear-type, grid-type, flexible-disk, and diaphragm couplings.

C.2.3 Rubber-bushed couplings (which are not recommended for high-speed applications) include the rubber-in-shear, flexible-shaft (quill), and rigid-flange (solid) types.

C.2.4 Any of the couplings listed in C.2.2 and C.2.3 may be arranged to have a limited end float, that is, to limit the axial freedom of one connected shaft with respect to the other.

C.2.5 Of the couplings listed in C.2.2 and C.2.3, those considered to be torsionally flexible, or soft, are the grid-type, rubber-in-shear, and flexible-shaft couplings.

C.2.6 Several of the coupling types listed in C.2.2 and C.2.3 have the potential for transmitting high axial forces as thermal or lead changes cause connected shafts to grow toward each other or to try to separate. Only in the gear-tooth and grid types is the axial force indeterminant, since in these the slip force is directly related to the coefficient of friction that the coupling is exhibiting at the moment. This coefficient of friction depends on many variables, including the following:

a. The driving force ont he coupling teeth.
b. The speed of rotation.
c. The condition of the coupling tooth surfaces.
d. The hardness of the coupling tooth surfaces.
e. The degree of misalignment between the connected shafts.
f. The smoothness of operation of the connected machines.
g. The lubrication of the coupling teeth.

Experiments have been performed to try to determine the force exhibited by these couplings, but these attempts have been successful only in proving how widely variable the force is. Machinery designers currently assume a coefficient of friction of 0.25, although they know that under adverse maintenance conditions this value may reach 0.3 or more. With a tendency toward overdesign in the name of reliability, the sizing of thrust bearings becomes a problem that may result in an inefficient gear unit. A definite hazard of this approach lies in the possibility of overloading the teeth of a double-helical gear in the event of coupling hang-up caused by sludging or excessive wear.

C.3 Diaphragm Coupings

Flexible-disk- and diaphragm-type couplings have a distinct advantage with regard to axial force problems, since the force required to displace one half of a coupling with respect to the other half is quite predictable. Once the machine is properly installed and correct axial settings are obtained, the maximum axial force that may be transmitted across a gear mesh or carried by opposing thrust bearings is known. Thrust bearings can be selected for optimum conditions. The axial forces to be transmitted across the gear mesh can readily be included with other factors in the sizing of the gear unit.

C.4 Limited-End-Float Couplings

C.4.1 The use of limited-end-float couplings makes it possible to retain the known advantages of gear-type couplings while eliminating or reducing the potential problem of excessive thrust. In a machinery train in which only one unit (such as a compressor) requires a thrust bearing to maintain the internal axial clearances between the stator and the rotor, having one limited-end-float coupling between the compressor and the gear and having a second limited-end-float coupling between the gear and the motor eliminate the need for thrust bearings on either the gear or the motor. This arrangement minimizes the load on the compressor thrust bearing, since the most it will feel from the connected machinery will be equal to the motor centering force (see Figure C-1, Panel A).

C.4.2 In a machinery train that involves a steam- or gas-turbine prime mover, a double-helical gear, and a compressor, both the turbine and the compressor require thrust bearings. In this case, the use of a single limited-end-float coupling, can eliminate the thrust bearing form the gear. Selecting the coupling that has the higher calculated thrust-transmitting potential (usually the low-speed coupling) as a limited-end-float coupling, plus eliminating the thrust bearing from the gear can drastically reduce the thrust on the machine connected to that gear shaft. Selecting smaller thrust bearings with improved machine efficiency is possible (see Figure C-1, Panel B).

C.5 Flexible-Shaft Couplings

As machinery trains increase in size and power, the use of flexible-shaft couplings between the high-speed gear and one or both of the connected machines is gaining in popularity. The flexible shafts are usually arranged to pass through hollow pinions or gear shafts, thereby greatly shortening the overall length of the machine, compared with one using more conventional couplings. For turbine-driven generators (Figure C-1, Panel C) or motor-driven compressors (Figure C-1, Panel D), both connections may use a quill arrangement (a flexible shaft through a hollow shaft). For turbine-driven geared compressors (Figure C-1, Panel E), one connection must incorporate axial freedom to accommodate thermal expansion. In this case, an arrangement in which the quill is fixed at one end and flexibly coupled with axial float at the other end should be considered.

C.6 Rigid-Flange Couplings

The only place where a rigid-flange connection between a gear unit and a coupled machine is permitted is where the coupled machine has only one radial bearing, as is the case with a single-bearing motor or generator (Figure C-1, Panel F). Such a coupling arrangement is practical only for relatively low speed units and where the connected shafts can be installed and maintained in excellent alignment with proper elevation and offset of the single bearing pedestal.

C.7 Torsionally Flexible Couplings

Analysis of the rotor dynamics of a complex multi-mass system sometimes indicated the need to use torsionally flexible couplings between the connected rotors to obtain the desired torsional tuning of the system. Several choices are available to the designer, each with characteristics that must be considered with the entire system in mind; for example, the linearity of the spring rate is different for each of the three types (grid-type, rubber-in-shear, and flexible-shaft) of torsionally flexible couplings in popular use. The ability to accommodate angular and offset misalignment, as well as end-float characteristics, also varies. Selecting the right coupling for the job must be guided by experience in the design and application of high-speed machinery systems.

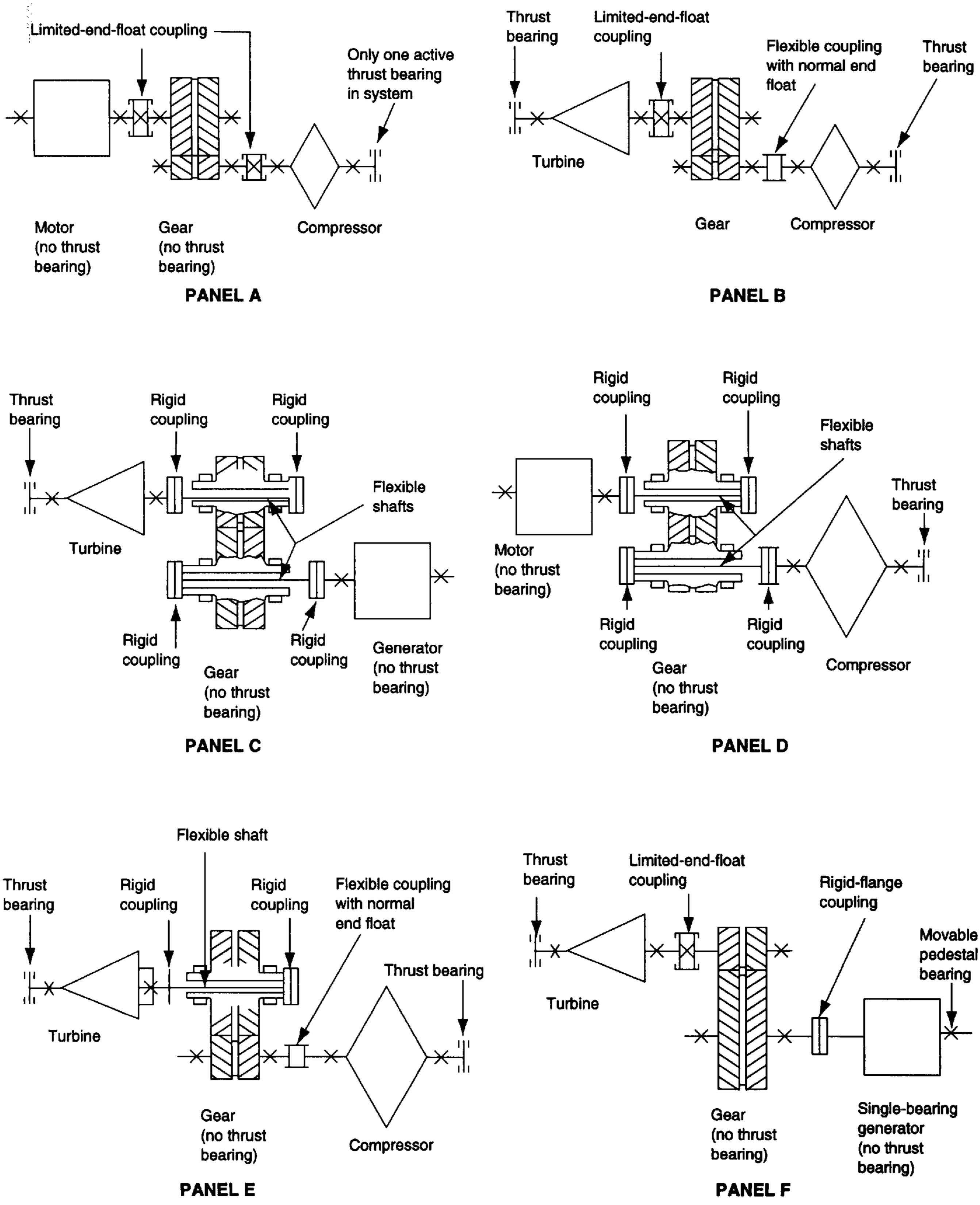
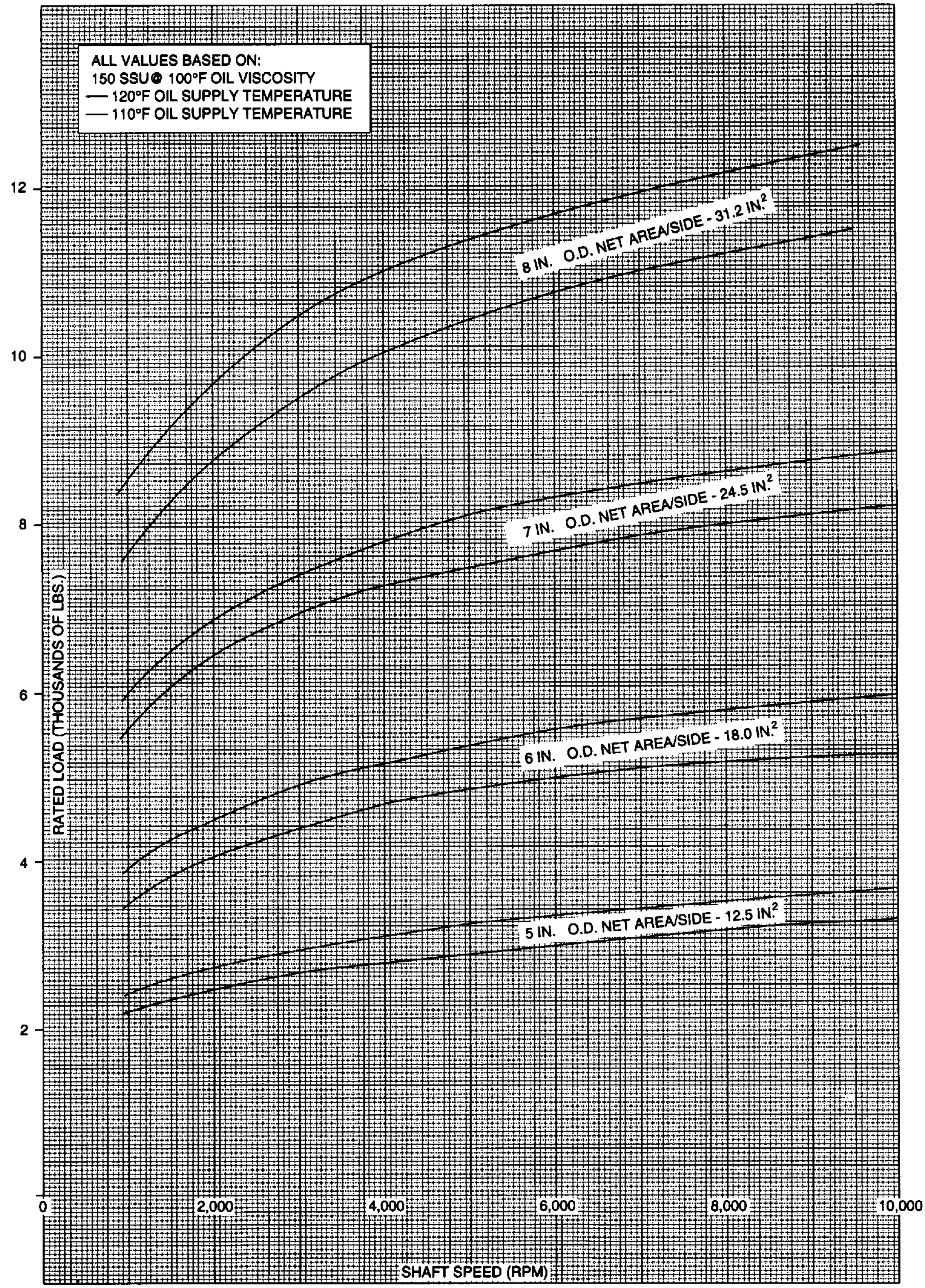


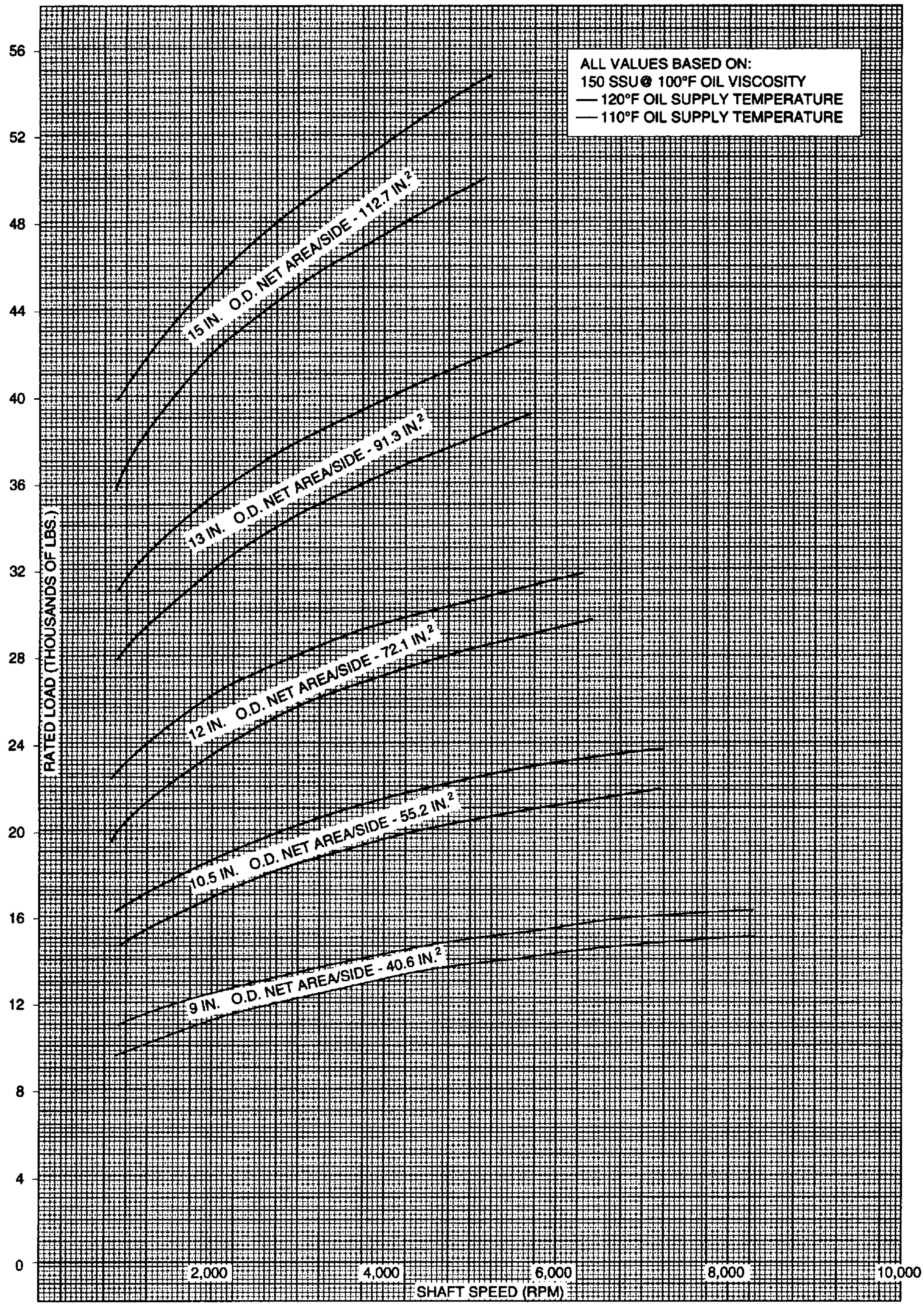
Figure C-1—Couplings for High-Speed Gear Units

APPENDIX D—RATED LOAD CURVES FOR THRUST BEARINGS WITH STANDARD 6 X 6 SHOES



Note: OD = outside diameter. All values are based on an oil viscosity of 32 square millimeter per second at 38°C (150 Saybolt universal seconds at 100°F).

Figure D-1—Rated Load Curves for Thrust Bearings With Standard 6 x 6 Shoes: Outside Diameters From 5 Inches to 8 Inches



Note: OD = outside diameter. All values are based on an oil viscosity of 32 square millimeter per second at 38°C (150 Saybolt universal seconds at 100°F).

Figure D-2—Rated Load Curves for Thrust Bearings With Standard 6 x 6 Shoes: Outside Diameters From 9 Inches to 15 Inches

APPENDIX E—MATERIAL SPECIFICATIONS FOR SPECIAL PURPOSE GEAR UNITS

Table E-1—Material Specifications for Special Purpose Gear Units

Part	Material[a]	Form
Casing		
Cast	ASTM A 27, Grade 65-35	Cast
	ASTM A 48, Class 30[b]	Cast
Fabricated	ASTM A 575, A 576	Hot-rolled bars
	ASTM A 131	Plate
	ASTM A 283	Plate
	ASTM A 284, Grade B	Plate
	ASTM A 285	Plate
	ASTM A 516	Plate
	ASTM A 6	Plate or shapes
	ASTM A 36	Plate or shapes
	AISI 1010	Plate or shapes
	AISI 1020	Plate or shapes
Gear		
Forged	AISI 4140	Nitrided or through hardened
	AISI 4340	Nitrided or through hardened
	AISI E4140H	Through hardened
	AISI E4145H	Through hardened
	AISI E4340[c]	Through hardened
	AISI 2317	Carburized
	AISI 3310	Carburized
	AISI 4320	Carburized
	AISI 4620	Carburized
	AISI 8620	Carburized
	AISI 9310	Carburized
Fabricated		
Web	ASTM A 283, Grade B	Plate
	ASTM A 285, Grades B and C	Plate
	ASTM A 36	Plate or shapes
Hub	AISI 1020	Forged or hot rolled
	AISI 4140	Forged or hot rolled
	AISI 4340	Forged or hot rolled
Rim	AISI 1045	Through hardened
	AISI 4130	Through hardened
	AISI 4135	Through hardened
	AISI E4140H	Through hardened
	AISI E4145H	Through hardened
	AISI 4140	Nitrided or through hardened
	AISI 4340	Nitrided or through hardened
	AISI 2317	Carburized
	AISI 3310	Carburized
	AISI 4320	Carburized
	AISI 4620	Carburized
	AISI 8620	Carburized
	AISI 9310	Carburized
Forged Pinion	AISI 4140	Nitrided or through hardened
	AISI 4340	Nitrided or through hardened
	AISI E4145H	Through hardened
	AISI E4340H[d]	Through hardened
	AISI 2317	Carburized
	AISI 3310	Carburized
	AISI 4320	Carburized
	AISI 4620	Carburized
	AISI 8620	Carburized
	AISI 9310	Carburized
Shaft	AISI 1030	Forged or hot rolled
	AISI 1045	Forged or hot rolled
	AISI 4140	Forged or hot rolled
	AISI 4145H	Forged or hot rolled
	AISI 4340	Forged or hot rolled

[a]Descriptions of AISI designations can be found in ASTM DS 56B.
[b]Minimum.
[c]Vacuum degas on critical applications.
[d]Generally vacuum degas.

APPENDIX F—VENDOR DRAWING AND DATA REQUIREMENTS

SPECIAL PURPOSE GEAR UNITS VENDOR DRAWING AND DATA REQUIREMENTS

JOB NO. ______ ITEM NO. ______
PURCHASE ORDER NO. ______ DATE ______
REQUISITION NO. ______ DATE ______
INQUIRY NO. ______ DATE ______
PAGE 1 OF 2 BY ______
FOR ______ REVISION ______
SITE ______ UNIT ______
SERVICE ______ NO. REQUIRED ______

Proposal[a] Bidder shall furnish ______ copies of data for all items indicated by an X.

Review[b] Vendor shall furnish ______ copies and ______ transparencies of drawings and data indicated.

Final[c] Vendor shall furnish ______ copies and ______ transparencies of drawings and data indicated.
Vendor shall furnish ______ operating and maintenance manuals.

DISTRIBUTION RECORD

Final—Receive from vendor
Final—Due from vendor[c]
Review—Returned to vendor
Review—Received from vendor
Review—Due from vendor[c]

Proposal	Review	Final	DESCRIPTION	Review—Due from vendor	Review—Received from vendor	Review—Returned to vendor	Final—Due from vendor	Final—Receive from vendor
			1. Certified dimensional outline drawing and list of connections.					
			2. Cross-sectional drawings and part numbers.[d]					
			3. Rotor assembly drawings and part numbers.[d]					
			4. Thrust-bearing assembly drawing and part numbers.[d]					
			5. Journal-bearing assembly drawings and bills of materials.					
			6. Coupling assembly drawing and bill of materials.[d,e]					
			7. Lube-oil schematic and bill of materials.					
			8. Lube-oil arrangement drawing and list of connections.[e]					
			9. Lube-oil component drawings and data.[d]					
			10. Electrical and instrumentation schematics and bills of materials.					
			11. Electrical and instrumentation arrangement drawing and list of connections.					
			12. Tooth-contact drawing and specifications.[d]					
			13. Tooth-contact check records.					
			14. Record of deviations from manufacturing process control system.[f]					
			15. Mass elastic data.					
			16. Lateral critical speed analysis report.[f]					
			17. Torsional analysis report.[f]					
			18. Input and output shaft position diagram.					
			19. Weld procedures.[f]					
			20. Hydrostatic test logs (oil system).					
			21. Mechanical running test logs.[f]					
			22. Rotor balancing logs.					
			23. Rotor mechanical and electrical runout.[f]					
			24. As-built data sheets.					
			25. As-built dimensions or data.[d]					
			26. Installation manual.					
			27. Operating, maintenance, and technical manual.					
			28. Spare parts recommendation and price list.					
			29. Progress reports and delivery schedule.					

[a]Proposal drawings and data do not have to be certified or as built.
[b]Purchaser will indicate in this column the desired time frame for submission of materials, using the nomenclature given at the end of the form.
[c]Bidder shall complete this column to reflect his actual distribution schedule and shall include this form with his proposal.
[d]These items are normally provided only in instruction manuals.
[e]If furnished by the vendor.
[f]If specified.

SPECIAL PURPOSE GEAR UNITS VENDOR DRAWING AND DATA REQUIREMENTS

JOB NO. ______ ITEM NO. ______
PAGE 2 OF 2 BY ______
DATE ______ REVISION ______

Proposal[a] Bidder shall furnish ______ copies of data for all items indicated by an X.

Review[b] Vendor shall furnish ______ copies and ______ transparencies of drawings and data indicated.

Final[c] Vendor shall furnish ______ copies and ______ transparencies of drawings and data indicated.
Vendor shall furnish ______ operating and maintenance manuals.

DISTRIBUTION RECORD

Final—Receive from vendor
Final—Due from vendor[c]
Review—Returned to vendor
Review—Received from vendor
Review—Due from vendor[c]

Proposal	Review	Final	DESCRIPTION	Review—Due from vendor	Review—Received from vendor	Review—Returned to vendor	Final—Due from vendor	Final—Receive from vendor
			30. Preservation, packaging, and shipping procedures.					
			31. List of special tools furnished for maintenance.					
			32. Material safety data sheets (OSHA Form 20).					
			33. Nondestructive test procedures and acceptance criteria.					

[a]Proposal drawings and data do not have to be certified or as built.
[b]Purchaser will indicate in this column the desired time frame for submission of materials, using the nomenclature given at the end of the form.
[c]Bidder shall complete this column to reflect his actual distribution schedule and shall include this form with his proposal.
[d]These items are normally provided only in instruction manuals.
[e]If furnished by the vendor.
[f]If specified.

Notes:

1. Where necessary to meet the scheduled shipping date, the vendor shall proceed with manufacture upon receipt of the order and without awaiting the purchaser's approval of drawings.
2. The vendor shall send all drawings and data to the following:

   ____

3. All drawings and data shall show project, purchase order, and item numbers as well as plant location and unit. One set of the drawings and instructions necessary for field installation, in addition to the copies specified above, shall be forwarded with shipment.
4. See the descriptions of required items that follow.
5. All of the information indicated on the distribution schedule shall be received before final payment is made.

Nomenclature:

S—number of weeks before shipment.
F—number of weeks after firm order.
D—number of weeks after receipt of approved drawings.

Vendor ______________________________

Date ______________ Vendor Reference ______________

Signature ______________________________

(Signature acknowledges receipt of all instructions)

DESCRIPTION

1. Certified dimensional outline drawing and list of connections including the following:
   a. The size, rating, and location of all customer connections.
   b. Approximate overall and handling weights.
   c. Overall dimensions, and maintenance and dismantling clearances.
   d. Shaft centerline height.
   e. Dimensions of baseplates (if furnished) complete with diameters, number, and locations of bolt holes and the thicknesses of sections through which the bolts must pass.
   f. Grouting details.
   g. Forces and moments for suction and discharge nozzles.
   h. Center of gravity and lifting points.
   i. Shaft end separation and alignment data.
   j. Direction of rotation.
   k. Winterization, tropicalization, and/or noise attenuation details, when required.
2. Cross-sectional drawings and part numbers.
3. Rotor assembly drawings and part numbers.
4. Thrust-bearing assembly drawing and part numbers.
5. Journal-bearing assembly drawings and bills of materials.
6. Coupling assembly drawing and bill of materials.
7. Lube oil schematic and bill of materials including the following:
   a. Oil flows, temperatures, and pressures at each use point.
   b. Control, alarm, and trip settings (pressure and recommended temperatures).
   c. Total heat loads.
   d. Utility requirements, including electrical, water, and air.
   e. Pipe, valve, and orifice sizes.
   f. Instrumentation, safety devices, control schemes, and wiring diagrams.
8. Lube oil arrangement drawing and list of connections.
9. Lube oil component drawings and data including the following:
   a. Pumps and drivers.
   b. Coolers, filters, and reservoir.
   c. Instrumentation.
   d. Spare parts lists and recommendations.
10. Electrical and instrumentation schematics and bills of materials including the following:
    a. Vibration alarm and shutdown limits.
    b. Bearing temperature alarm and shutdown limits.
    c. Lube oil temperature alarm and shutdown limits.
    d. Driver.
11. Electrical and instrumentation arrangement drawing and list of connections.
12. Tooth-contact drawing and specifications.
13. Tooth-contact check records.
14. Record of deviations from manufacturing process control system.

15. Mass elastic data.
16. Lateral critical speed analysis report.
17. Torsional analysis report.
18. Input and output shaft position diagram.
19. Weld procedures.
20. Hydrostatic test logs (oil system).
21. Mechanical running test logs.
22. Rotor balancing logs.
23. Rotor mechanical and electrical runout.
24. As-built data sheets.
25. As-built dimensions or data.
26. Installation manual.
27. Operating, maintenance and technical manual.
28. Spare parts recommendation and price list.
29. Progress reports and delivery schedule.

Section 1—Installation:

a. Storage.
b. Foundation.
c. Grouting.
d. Setting equipment, rigging procedures, component weights, and lifting diagram.
e. Alignment.
f. Piping recommendations.
g. Composite outline drawing for pump/driver train, including anchor bolt locations.
h. Dismantling clearances.

Section 2—Operation:

a. Start-up including tests and checks before start-up.
b. Routine operational procedures.
c. Lube oil recommendations.

Section 3—Disassembly and assembly:

a. Rotor in pump casing.
b. Journal bearings.
c. Thrust bearings (including clearance and preload on antifriction bearings).
d. Seals.
e. Thrust collars, if applicable.
f. Allowable wear of running clearances.
g. Fits and clearances for rebuilding.
h. Routine maintenance procedures and intervals.

Section 4— Performance curves including differential head, efficiency, water NPSHR, and brake horsepower versus capacity for all operating conditions specified on the data sheets.

Section 5—Vibration data:
- a. Vibration analysis data.
- b. Lateral critical speed analysis.
- c. Torsional critical speed analysis.

Section 6—As-built data:
- a. As-built data sheets.
- b. As-built clearances.
- c. Rotor balance data for multistage pumps.
- d. Noise data sheets.
- e. Performance data.

Section 7—Drawing and data requirements:
- a. Certified dimensional outline drawing and list of connections.
- b. Cross-sectional drawing and bill of materials.
- c. Shaft seal drawing and bill of materials.
- d. Lube oil arrangement drawing and list of connections.
- e. Lube oil component drawings and data, and bill of materials.
- f. Electrical and instrumentation schematics, wiring diagrams, and bills of materials.
- g. Electrical and instrumentation arrangement drawing and list of connections.
- h. Coupling assembly drawing and bill of materials.
- i. Primary and auxiliary seal schematic and bill of materials.
- j. Primary and auxiliary seal piping, instrumentation, arrangement, and list of connections.
- k. Cooling or heating schematic and bill of materials.
- l. Cooling or heating piping, instrumentation arrangement, and list of connections.

30. Preservation, packaging, and shipping procedures.

31. List of special tools furnished for maintenance.

32. Material safety data sheets (OSHA Form 20).

33. Nondestructive test procedures and acceptance criteria.

APPENDIX G—PROCEDURE FOR DETERMINATION OF RESIDUAL UNBALANCE

APPENDIX G—PROCEDURE FOR DETERMINATION OF RESIDUAL UNBALANCE

G.1 Scope

This appendix describes the procedure to be used to determine residual unbalance in machine rotors. Although some balancing machines may be set up to read out the exact amount of unbalance, the calibration can be in error. The only sure method of determining residual unbalance is to test the rotor with a known amount of unbalance.

G.2 Definition

Residual unbalance refers to the amount of unbalance remaining in a rotor after balancing. Unless otherwise specified, residual unbalance shall be expressed in oz-in. or g•mm.

G.3 Maximum Allowable Residual Unbalance

G.3.1 The maximum allowable residual unbalance per plane shall be determined from Table 5.2.2 of this standard.

G.3.2 If the actual static weight load on each journal is not known, assume that the total rotor weight is equally supported by the bearings. For example, a two-bearing rotor weighing 2700 kg (6000 lbs) would be assumed to impose a static weight load of 1350 kg (3000 lbs) on each journal.

G.4 Residual Unbalance Check

G.4.1 GENERAL

G.4.1.1 When the balancing-machine readings indicate that the rotor has been balanced to within the specified tolerance, a residual unbalance check shall be performed before the rotor is removed from the balancing machine.

G.4.1.2 To check the residual unbalance, a known trial weight is attached to the rotor sequentially in six (or twelve, if specified by the purchaser) equally spaced radial positions, each at the same radius. The check is run in each correction plane, and the readings in each plane are plotted on a graph using the procedure specified in G.4.2.

G.4.2 PROCEDURE

G.4.2.1 Select a trial weight and radius that will be equivalent to between one and two times the maximum allowable residual unbalance [that is, if U_{max} is 1440 g•mm (2 oz-in.), the trial weight should cause 1440–2880 g•mm (2–4 oz-in.) of unbalance].

G.4.2.2 Starting at the last known heavy spot in each correction plane, mark off the specified number of radial positions (six or twelve) in equal (60 or 30 degree) increments around the rotor. Add the trial weight to the last known heavy spot in one plane. If the rotor has been balanced very precisely and the final heavy spot cannot be determined, add the trial weight to any one of the marked radial positions.

G.4.2.3 To verify that an appropriate trial weight has been selected, operate the balancing machine and note the units of unbalance indicated on the meter. If the meter pegs, a smaller trial weight should be used. If little or no meter reading results, a larger trial weight should be used. Little or no meter reading generally indicates that the rotor was not balanced correctly, the balancing machine is not sensitive enough, or a balancing machine fault exists (i.e., a faulty pickup). Whatever the error, it must be corrected before proceeding with the residual check.

G.4.2.4 Locate the weight at each of the equally spaced positions in turn, and record the amount of unbalance indicated on the meter for each position. Repeat the initial position as a check. All verification shall be performed using only one sensitivity range on the balance machine.

G.4.2.5 Plot the readings on the residual unbalance work sheet and calculate the amount of residual unbalance (see Figure G-1). The maximum meter reading occurs when the trial weight is added at the rotor's heavy spot; the minimum reading occurs when the trial weight is opposite the heavy spot. Thus, the plotted readings should form an approximate circle (see Figure G-2). An average of the maximum and minimum meter readings represents the effect of the trial weight. The distance of the circle's center from the origin of the polar plot represents the residual unbalance in that plane.

G.4.2.6 Repeat the steps described in G.4.2.1 through G.4.2.5 for each balance plane. If the specified maximum allowable residual unbalance has been exceeded in any balance plane, the rotor shall be balanced more precisely and checked again. If a correction is made in any balance plane, the residual unbalance check shall be repeated in all planes.

G.4.2.7 For stack component balanced rotors, a residual unbalance check shall be performed after the addition and balancing of the first rotor component, and at the completion of balancing of the entire rotor, as a minimum (see note).

Note: This ensures that time is not wasted and rotor components are not subjected to unnecessary material removal in attempting to balance a multiple component rotor with a faulty balancing machine.

Equipment (Rotor) No.: ____________

Purchase Order No.: ____________

Correction Plane (inlet, drive end, etc.–use sketch): ____________

Balancing Speed: ____________ rpm

N—Maximum Allowable Rotor Speed: ____________ rpm

W—Weight of Journal (closest to this correction plane): ____________ kg (lbs)

U_{max}—Maximum Allowable Residual Unbalance =
6350 *W/N* (4 *W/N*)
6350 × ______ kg/______ rpm; 4 × ______lbs/______rpm ____________ g•mm (oz-in.)

Trial unbalance (2 × U_{max}) ____________ g•mm (oz-in.)

R—Radius (at which weight will be placed): ____________ mm (in.)

Trial Unbalance Weight = Trial Unbalance/*R*

_____g•mm/_____mm/_____oz-in./______in. ____________ g (oz.)

Conversion Information: 1 ounce = 28.350 grams

Position	Trial Weight Angular Location	Balancing Machine Amplitude Readout
1		
2		
3		
4		
5		
6		
7		

Rotor Sketch

Test Date—Graphic Analysis

Step 1: Plot data on the polar chart (Figure G-1 Continued). Scale the chart so the largest and smallest amplitude will fit conveniently.

Step 2: With a compass, draw the best fit circle through the six points and mark the center of this circle.

Step 3: Measure the diameter of the circle in units of scale chosen in Step 1 and record. ____________ unit

Step 4: Record the trial unbalance from above. ____________ g•mm (oz-in.)

Step 5: Double the trial unbalance in Step 4 (may use twice the actual residual unbalance). ____________ g•mm (oz-in.)

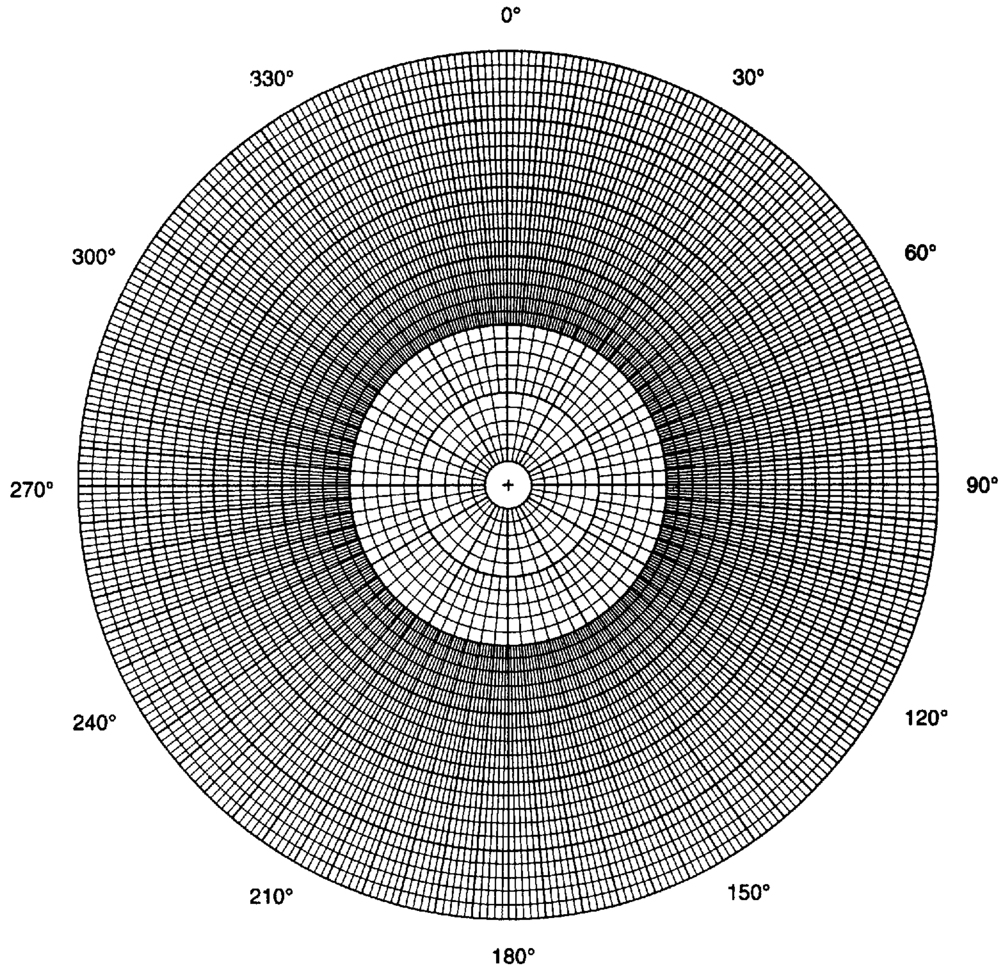
Step 6: Divide the answer in Step 5 by the answer in Step 3. ____________ Scale Factor

You now have a correlation between the units on the polar chart and the g•in. of actual balance.

Notes:

1. The trial weight angular location should be referenced to a keyway or some other permanent marking on the rotor.
2. The balancing machine amplitude readout for position "7" should be the same as position "1," indicating repeatability. Slight variations may result from imprecise positioning of the trial weight.

Figure G-1—Residual Unbalance Work Sheet



The circle you have drawn must contain the origin of the polar chart. If it doesn't, the residual unbalance of the rotor exceeds the applied test unbalance.

NOTE: Several possibilities for the drawn circle, not including the origin of the polar chart, include: operator error during balancing, a faulty balancing machine pickup or cable, or the balancing machine is not sensitive enough.

If the circle does contain the origin of the polar chart, the distance between origin of the chart and the center of your circle is the actual residual unbalance present on the rotor correction plane. Measure the distance in units of scale you choose in Step 1 and multiply this number by the scale factor determined in Step 6. Distance in units of scale between origin and center of the circle times scale factor equals actual residual unbalance.

Record actual residual unbalance____________________(g•mm)(oz-in.)

Record allowable residual unbalance (from Figure G-1) _______(g•mm)(oz-in.)

Correction plane__________ for Rotor No. ________ (has/has not) passed.

By____________________ Date____________________

Figure G-1—Residual Unbalance Work Sheet (Continued)

Equipment (Rotor) No.: *C–101*

Purchase Order No.: ______

Correction Plane (inlet, drive end, etc.–use sketch): *A*

Balancing Speed: *800* rpm

N—Maximum Allowable Rotor Speed: *10,000* rpm

W—Weight of Journal (closet to this correction plane): *908* ~~kg~~ (lbs)

U_{max}—Maximum Allowable Residual Unbalance =
6350 *W/N* (4 *W/N*)
~~6350 × ______ kg/ ______ rpm~~; 4 × *908* lbs/ *10,000* rpm — *0.36* ~~g•mm~~ (oz-in.)

Trial unbalance (2 × U_{max}) — *0.72* ~~g•mm~~ (oz-in.)

R—Radius (at which weight will be placed): *6.875* ~~mm~~ (in.)

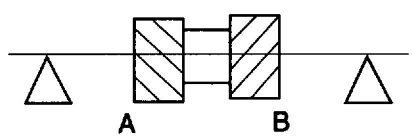
Trial Unbalance Weight = Trial Unbalance/*R*
~~______ g•mm/ ______ mm~~/ *0.72* oz-in./ *6.875* in. — *0.10* ~~g~~ (oz.)

Conversion Information: 1 ounce = 28.350 grams

Test Data

Position	Trial Weight Angular Location	Balancing Machine Amplitude Readout
1	*0*	*14.0*
2	*60*	*12.0*
3	*120*	*14.0*
4	*180*	*23.5*
5	*240*	*23.0*
6	*300*	*15.5*
7	*0*	*13.5*

Rotor Sketch



C-101

Test Date—Graphic Analysis

Step 1: Plot data on the polar chart (Figure G-2 Continued). Scale the chart so the largest and smallest amplitude will fit conveniently.

Step 2: With a compass, draw the best fit circle through the six points and mark the center of this circle.

Step 3: Measure the diameter of the circle in units of scale chosen in Step 1 and record. — *35* units

Step 4: Record the trial unbalance from above. — *0.72* ~~g•mm~~ (oz-in.)

Step 5: Double the trial unbalance in Step 4 (may use twice the actual residual unbalance). — *1.44* ~~g•mm~~ (oz-in.)

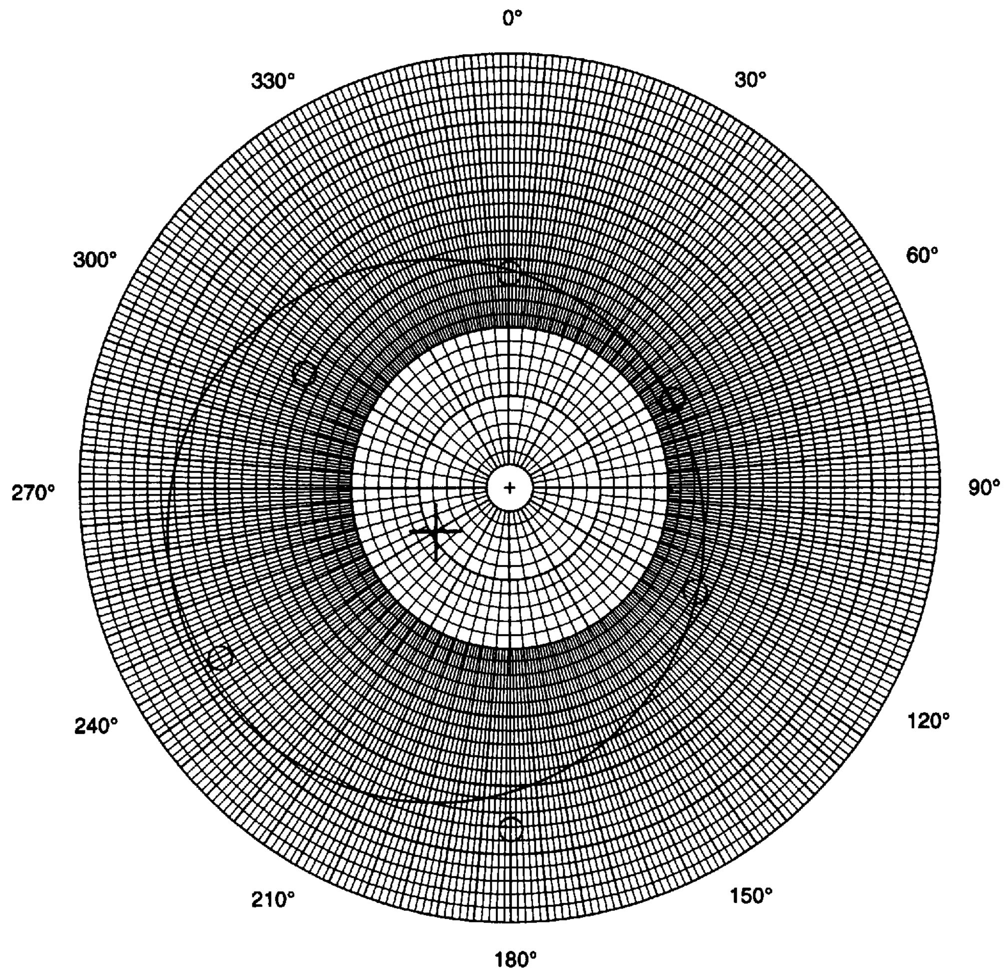
Step 6: Divide the answer in Step 5 by the answer in Step 3. — *0.041* Scale Factor

You now have a correlation between the units on the polar chart and the g•in. of actual balance.

Notes:

1. The trial weight angular location should be referenced to a keyway or some other permanent marking on the rotor.
2. The balancing machine amplitude readout for position "7" should be the same as position "1" indicating repeatability. Slight variations may result from imprecise positioning of the trial weight.

Figure G-2—Sample Calculations for Residual Unbalance



The circle you have drawn must contain the origin of the polar chart. If it doesn't, the residual unbalance of the rotor exceeds the applied test unbalance.

NOTE: Several possibilities for the drawn circle, not including the origin of the polar chart, include: operator error during balancing, a faulty balancing machine pickup or cable, or the balancing machine is not sensitive enough.

If the circle does contain the origin of the polar chart, the distance between origin of the chart and the center of your circle is the actual residual unbalance present on the rotor correction plane. Measure the distance in units of scale you choose in Step 1 and multiply this number by the scale factor determined in Step 6. Distance in units of scale between origin and center of the circle times scale factor equals actual residual unbalance.

Record actual residual unbalance *6.5 (0.041) = 0.27* (~~g-mm~~)(oz-in.)

Record allowable residual unbalance (from Figure G-2) *0.36* (~~g-mm~~)(oz-in.)

Correction plane *A* for Rotor No. *C-101* (has/~~has not~~) passed.

By *John Inspector* Date *11-31-94*

Figure G-2—Sample Calculations for Residual Unbalance (Continued)

APPENDIX H—GEAR TOOTH INSPECTION

H.1 General

H.1.1 AGMA Standard 2000, *Gear Classification and Inspection Handbook for Unassembled Spur and Helical Gears,* describes gear measuring methods and is a general summary of the different procedures used. Many of these procedures may not be applicable due to manufacturing methods and measuring equipment available.

H.1.2 Gears meeting API Standard 613 generally have large diameters and wide face widths and by necessity are manufactured in matched sets with the tolerances in terms of mis-match between the contacting tooth surfaces.

H.1.3 The measuring methods described in this appendix cannot be used to replace tooth contact checking procedures traditionally used to verify the gear tooth fit in the job casing in the vendor's shop as described in 2.5.2.2 and the recommission contact checking after field installation and alignment.

H.2 Double Helical Gears

The measuring methods described in AGMA Standard 2000 are for single helical or spur gears.

H.2.1 Double helical gears are two single helical gears on the same rotor. These gears will require data for both the right-hand and left-hand helixes.

H.2.2 When performing tooth contact inspections, it is necessary that the pinion be allowed to move axially to obtain true tooth contact patterns.

H.2.3 Apex runout measurements are required in accordance with 2.5.2.3 for double helical gears.

H.3 Modified Leads (Helix Angle)

H.3.1 Some high speed, high horsepower, wide face width gear sets are manufactured with a modified lead to account for torsional twist, bending deflection, and thermal effects. When properly applied, these modified leads can improve load distribution across the face width.

H.3.2 When modified leads are used, face contact patterns will be different under no-load and load conditions. The purchaser of gear drive must communicate to the vendor the actual loads to be transmitted, which are very seldom equal to the data sheet value of the maximum power of the driver.

APPENDIX I—INSPECTOR'S CHECKLIST

INSPECTOR'S CHECKLIST

Item	Inspection Agency	Inspector's Initials	Date	Extent W/O/*	API Std 613 Reference
1. Basic Design					
a. Special tools shipped with gear, such as bearing mandrel	C			*	3.6.1 3.6.2
b. Shaft assembly in accordance with approved data sheets	V			*	2.1.16
c. Shaft rotation arrows in accordance with approved general arrangement drawings and data sheets	C			*	2.1.17.1 2.1.17.2
2. Casings					
a. Doweling provisions	C			*	2.3.1.2
b. Internal piping	C			*	2.3.1.7
c. Piping and tubing	V			*	2.3.1.8
d. Support of internal piping	C			*	2.3.1.9
e. Cleanliness of internal piping	C			*	2.3.1.10
f. Lube oil drainage	C & V			*	2.3.1.11
g. Filter breather	C			*	2.3.1.12
h. Inspection covers	C			*	2.3.1.13
i. Interior coatings	V			*	2.3.1.14
j. Sealing of horizontal joint	C			*	2.3.2
k. All doweling of parts	C			*	
3. Bolting					
a. Thru bolting	V			*	2.3.3.1
b. Studded connections	V			*	2.3.3.3
c. Bolting clearance	C			*	2.3.3.4
4. Assembly and Disassembly					
a. Oil piping	V & C			*	2.3.4.1
b. Lifting lugs, jackscrews, and relieved surfaces	C			*	2.3.4.2
5. Casing Connections					
a. Single lube oil supply	V			*	2.4.1
b. Single lube oil drain and its size	V			*	2.4.2
c. Inlet purge connection	C			*	2.4.3
d. Unacceptable pipe sizes	V			*	2.4.4
e. Accessibility of customer connections	C			*	2.4.5
f. Drain and oil connection size and location per latest approved general assembly drawing	C			*	2.4.6
g. Installation of threaded					
connections	C			*	2.4.6.1
h. Flanges in accordance with ASME B16.1, B16.5, or B16.42	C			*	2.4.7
i. Studs installed	V & C			*	2.4.8

Note: W = witnessed; O = observed; * = designated inspection agency is to confirm that the requirement is satisfied; V = vendor; C = contractor; VDDR = vendor drawing and data requirements; UT = ultrasonic inspection; MP = wet magnetic particle inspection.

INSPECTOR'S CHECKLIST—Continued

Item	Inspection Agency	Inspector's Initials	Date	Extent W/O/*	API Std 613 Reference
j. Threaded connections	C			*	2.4.9
k. Tapped openings not connected to piping	C			*	2.4.10
6. Gear Elements					
a. Gear tooth surface finish	V & C			W	2.5.1.3
b. Plating of teeth per data sheets	V			*	2.5.1.4
c. Overhung design	V			*	2.5.1.7
7. Critical Speeds and Balancing					
a. Critical speeds	V			*	2.6.1.4
b. Rotor balancing	C			W	2.6.2.1
c. Rotor balance machine calibration	C			*	2.6.2.3
d. Coupling balance	V			W	API Std 671
e. Mechanical and electrical runout (in vee blocks)	C			W	2.6.3.2–2.6.3.4
f. Gauss levels	C			W	2.5.4.3 API Std 670
8. Bearings					
a. Anti-rotation pins and axially secured	V			*	2.7.1.2 2.7.2.1
b. Bearing fitted with RTDs	V & C			*	2.7.1.3 [a]
c. Bearing white metal (journal and thrust)	C			W	2.7.2.1 2.7.3.2 or [b]
d. Integral thrust collar stock	V			*	2.7.3.2
e. Thrust collar finish and runout	C			W	2.7.3.2
9. Vibration and Position Detectors					
a. Installed in accordance with API Std 670	V & C			*	3.4.2.1
10. Materials					
a. Review vendor in-house quality control checks on materials and manufacturing methods concerning gears, pinions, bearings	C			*	2.5.2
b. Review manufacturers in-house quality control rejects with written explanation of rejects pieces disposition	C			*	
c. No repairs to be made without customer approval	V & C			W	2.9.2.1
11. Nameplate versus Data Sheets	C			*	
a. Provide nameplate rubbing	C			*	2.10
12. Mounting Plates					

Note: W = witnessed; O = observed; * = designated inspection agency is to confirm that the requirement is satisfied; V = vendor; C = contractor; VDDR = vendor drawing and data requirements; UT = ultrasonic inspection; MP = wet magnetic particle inspection.

[a] RTDs installed per API Standard 670.
[b] Bearing white metal shall be liquid penetrant checked.

INSPECTOR'S CHECKLIST—Continued

Item	Inspection Agency	Inspector's Initials	Date	Extent W/O/*	API Std 613 Reference
a. Vertical jackscrews	C			*	3.3.1.2.2
b. Horizontal jackscrews	C			*	3.3.1.2.3
c. Preparation of mounting plates for epoxy grout	V & C			O	3.3.1.2.5
d. Mounting bolts	C			*	3.3.1.2.11
e. Gear dowel holes	C			*	2.3.1.2
f. Foundation bolt hole location versus item l.e Appendix F	C			*	VDDR, Item 1.e.[c]
13. Controls and Instrumentation					
a. Instrumentation supplied against approved data sheets	C			*	3.4, Appendix A
14. Piping and Appurtenances					
a. Site flow glasses	C			*	3.5
15. Inspection					
a. Mill test reports[d] for all gear element components	C & V			*	4.2.1.1.a
b. UT of all gear element components after rough machinery	C & V			W	4.2.2.7.2
c. Record of all heat treatment and resulting hardnesses	C & V			*	4.2.2.6.1.b
d. Records of all radiographs and UT inspections	C & V			W	4.2.2.6.1.c
e. Hardness versus case depth of teeth	C & V			W	2.2.3.4 4.2.2.6.1.d
f. Hardness of thru hardened gears	C & V			W	2.2.3.4 4.2.2.6.1.e
g. Stress relieve of casing	V			*	2.9.3.2
h. Hardness of welds and heat effected zones on gear elements	V & C			*	4.2.2.3
i. UT or MP inspection of all welds on rotating elements	V & C			W	4.2.2.6.1
j. MP of gear and pinion teeth	V & C			W	4.2.2.6.3
k. Purchase specifications[e]	V			*	4.2.1.1.b
l. Running data[f]	V			*	4.2.1.1.e
m. Results of quality control checks					2.5.2 & 4.2.1.1.d
1. Journal runout check prior to finishing teeth	V & C			O	2.5.2.1
2. Tooth profile, helix deviation pitch error, and cumulative pitch error	V & C			W	Note in 2.5.2.1
3. Check stand contact	V & C			W	2.5.2.2
4. Contact check in job casing	V & C			W	2.5.2.2
5. Axial stability	V & C			2.5.2.3	
n. Setting of thrust bearing	V & C			W	
o. Cleanliness of equipment including lube oil system prior to running any tests: cleanliness per API Std 614				O	4.3.2.1.4 4.3.2.1.5 4.3.2.1.6

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[c] Location and size of bolt holes shall be checked against foundation drawing and gear manufacturer's drawings.
[d] Chemical and mechanical properties, hardness, and impact results should be reviewed prior to machining of gear elements.
[e, f] Include in instruction book.

IINSPECTOR'S CHECKLIST—Continued

Item	Inspection Agency	Inspector's Initials	Date	Extent W/O/*	API Std 613 Reference
p. Final assembly clearances (journal bearing, thrust bearing, etc.)				W	Appendix F VDDR, Item 25
16. Special Tools					
a. Separately packaged and labeled with item number				*	3.6.2
b. Each tool tagged for intended use				*	3.6.2
17. Testing					
a. Mechanical running test	C			W	4.3.2
b. 25, 50, 75, and 100 percent full torque slow roll tests, optional tests	C			W	4.3.3
c. Check alignment prior to any running tests	C			W	
d. Check position of lube oil sprays	C			W	2.8.1
18. Preparation for Shipment					
a. Painting	C			*	4.4.3.1
b. Rust preventative	C			*	4.4.3.2
c. Interior of gear preserved	C			*	4.4.3.3
d. Metal closures	C			*	4.4.3.5
e. Car sealing of metal closure prior to shipment	C			*	
f. Threaded opening	C			*	4.4.3.6
g. Lifting points clearly marked	C			*	4.4.3.7
h. Exposed shafts and couplings wrapped with waterproof moldable wound cloth or VPI inhibitor paper and seams sealed with oil proof adhesive tape	C			*	4.4.3.10
i. Identification of items	C			*	4.4.3.8
j. Installation instructions	C			*	5.3.6
k. Bill of lading for each packaged box against box contents	C			*	

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