

General-purpose, Extruder, and Epicyclic Gear Units for Petroleum, Chemical, and Gas Industry Services

API STANDARD 677
FOURTH EDITION, SEPTEMBER 2021



Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed. The use of API publications is voluntary. In some cases, third parties or authorities having jurisdiction may choose to incorporate API standards by reference and may mandate compliance.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

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 authorities having jurisdiction with which this publication may conflict.

Users of this standard should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

API is not undertaking to meet the duties of employers, manufacturers, or vendors to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions, nor undertaking their obligations under local, state, or federal laws. Information concerning safety and health risks and proper precautions with respect to particular materials and conditions should be obtained from the employer, the manufacturer or vendor of that material, or the safety data sheet.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be utilized. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

All rights reserved. No part of this work may be reproduced, translated, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the publisher, API Publishing Services, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001.

Copyright © 2021 American Petroleum Institute

Foreword

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

The verbal forms used to express the provisions in this document are as follows.

Shall: As used in a standard, “shall” denotes a minimum requirement in order to conform to the standard.

Should: As used in a standard, “should” denotes a recommendation or that which is advised but not required in order to conform to the standard.

May: As used in a standard, “may” denotes a course of action permissible within the limits of a standard.

Can: As used in a standard, “can” denotes a statement of possibility or capability.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this publication or comments and questions concerning the procedures under which this publication was developed should be directed in writing to the Director of Standards, American Petroleum Institute, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. Status of the publication can be ascertained from the API Standards Department, telephone (202) 682-8000. A catalog of API publications and materials is published annually by API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001.

Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001, standards@api.org.

Contents

1	Scope.....	1
2	Normative References	1
3	Terms, Definitions, Acronyms, and Abbreviations	5
3.1	Terms and Definitions	5
3.2	Acronyms and Abbreviations	15
4	General	15
4.1	Unit Responsibility.....	15
4.2	Unit Conversion	15
4.3	Standards and Codes	15
5	Requirements	15
5.1	Units of Measure	15
5.2	Statutory Requirements	16
5.3	Hierarchy of Requirements	16
6	Basic Design.....	16
6.1	General	16
6.2	Shaft Assembly Designation	18
6.3	Shaft Rotation.....	20
6.4	Rating	21
6.5	Casings	29
6.6	Casing Connections	32
6.7	Gear Elements	35
6.8	Dynamics	40
6.9	Bearings and Bearing Housings	51
6.10	Lubrication.....	56
6.11	Materials.....	58
6.12	Nameplates and Rotation Arrows	62
7	Accessories	63
7.2	Couplings and Guards.....	63
7.3	Belt Drives	64
7.4	Mounting Plates, Soleplates, Subsoleplates, and Baseplates	64
7.5	Controls and Instrumentation.....	67
7.6	Piping and Appurtenances.....	68
7.7	Special Tools	70
8	Inspection, Testing, and Preparation for Shipment	70
8.1	General	70
8.2	Inspection	71
8.3	Testing.....	76
8.4	Preparation for Shipment	79
9	Low-speed/High-torque Applications, Extruder Gears	82
9.1	General	82
9.2	Basic Design.....	83
9.3	Materials.....	84
9.4	Controls and Instrumentation.....	84
9.5	Inspection	85
9.6	Testing.....	87
9.7	Preparation for Shipment	89
10	Epicyclic Gear Units	89
10.1	Scope.....	89
10.2	General	89
10.3	Definition of Terms	90

10.4	Configurations and Shaft Arrangements.....	91
10.5	Rating	93
10.6	Casings	102
10.7	Casing Connections	103
10.8	Gear Elements	103
10.9	Balancing	105
10.10	Bearings	106
10.11	Lubrication.....	106
10.12	Materials.....	107
10.13	Nameplates and Rotation Arrows	107
10.14	Controls and Instrumentation.....	107
10.15	Testing.....	108
11	Vendor's Data	108
Annex A	(informative) Data Sheets	109
Annex B	(normative) Lubrication Systems.....	124
Annex C	(normative) Material Specifications for General-purpose, Extruder, and Epicyclic Gear Units	129
Annex D	(informative) Proposal and Contract Documents and Engineering Design Data.....	134
Annex E	(normative) Vendor Drawing and Data Requirements	140
Annex F	(normative) Procedure for the Verification of Residual Unbalance.....	147
Annex G	(informative) Inspector's Checklist.....	153
Annex H	(informative) Nomenclature for General-purpose, Extruder, and Epicyclic Gears	157
Annex I	(informative) Tooth Configuration—Applicable to Epicyclic Gear Applications	161
Annex J	(informative) Installation and Commissioning	163
Bibliography		176
Figures		
1	Apex	6
2	Lead.....	9
3	Shaft Assembly Designations	19
4	Shaft Rotation Designations	20
5	Gear Mesh	20
6	Material Index Number, Through Hardened	25
7	Material Index Number, Carburized	25
8	Allowable Bending Stress Number, Through Hardened	27
9	Allowable Bending Stress Number, Carburized Steel	28
10	Undamped Lateral Critical Speed Map	41
11	Unbalance Placement.....	44
12	Rotor Response Plot	46
13	Plot of Applicable Speed Range of Vibration Limit.....	47
14	Star Gearing Configuration	91
15	Planetary Gearing Configurations	91
16	Compound Gearing Configuration	92
17	Solar Gearing Configurations	92
18	Single Stage Epicyclic Rotor Pitch Diameters	94
19	Compound Epicyclic Rotor Pitch Diameters	95
20	Face Width-to-Diameter Ratio (b/d_{ws}) Limits.....	99
B.1	Typical Circulating Lube Oil System for Gear Units	125
B.2	Schematic Symbols for a Pressurized Lube Oil System	126
B.3	Typical Pressurized Lube Oil System for Hydrodynamic Bearings in Gear Units.....	127
F.1	Residual Unbalance Worksheet	150

F.2	Sample Residual Unbalance Worksheet for Left Plane (Metric)	151
F.3	Sample Residual Unbalance Worksheet for Right Plane (USC)	152
H.1	Parallel Shaft Gearbox	157
H.2	Co-rotating Twin Screw Extruder	158
H.3	Epicyclic Gearbox—Planetary Configuration	159
H.4	Epicyclic Gearbox—Star Configuration	160

Tables

1	Corresponding DN and NPS Pipe Sizes	8
2	Pipe Sizes and Number of Threads per Inch (ASME B.1.20.1 Table 2)	11
3	Driver Trip Speeds	18
4	Shaft Assembly Combinations	19
5	Minimum Gear Tooth Service Factors	22
6	Allowable Material Index Numbers, I_m	24
7	Allowable Bending Stress Number, S_{all}	27
8	Overhung Load Factors Applied to Parallel Shaft Gears	29
9	Minimum Tubing Wall Thickness	31
10	Drain Pipe Sizes	33
11	Bearing Cap Vibration Limits	50
12	Maximum $d_m N$ Numbers for Rolling Element Bearings	51
13	Cage Types	52
14	Minimum Requirements for Piping System Components	69
15	ASME Materials Inspection Standards	72
16	Maximum Severity of Defects in Castings	73
17	Mesh Load Factor, K_y	96
18	Material Index Number, I_m	97
19	Allowable Bending Stress Number, S_a	100
20	Guideline for Maximum Ratio for Simple Star and Planetary Epicyclics with Different Numbers of Planets	105
B.1	Lube Oil System Schematic	128
C.1	Gear Unit Housings	130
C.2	Shafts, Pinions, and Gear Wheels	131
C.3	Fabricated Gears	133
F.1	Trial Weight Multiplier vs N_{mc}	148
I.1	Differentiating Characteristics of Spur, Single Helical, and Double Helical Gearing	162
J.1	Storage Preservative Types	166

Introduction

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

A bullet (•) at the beginning of a section or subsection indicates that either a decision is required or the purchaser is required to provide further information. It is necessary that this information be indicated on data sheets or stated in the enquiry or purchase order (see examples in Annex A).

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 standard.

For effective use of this standard and ease of reference to the text, the use of the data sheets in Annex A is recommended.

General-purpose, Extruder, and Epicyclic Gear Units for Petroleum, Chemical, and Gas Industry Services

1 Scope

This standard covers the minimum requirements for general-purpose, enclosed single and multistage gear units incorporating parallel shaft spur, and helical gears for use in the petroleum, chemical, and gas industry services. General-purpose and extruder gears manufactured according to this standard are limited to pitch line velocities that do not exceed 60 m/s (12,000 ft/min).

The requirements for parallel shaft helical gears applied to extruder services are included in Section 9 of this standard.

The requirements for epicyclic gears driving equipment, such as electrical generators, centrifugal compressors, and pumps, are included in Section 10 of this standard.

This standard does not apply to gears in special-purpose service, which are covered in API 613, to gears integral with other equipment, or gears with noninvolute tooth forms.

NOTE General-purpose gears are applied in equipment trains that are usually spared, or are in noncritical service. Typical applications for which this standard is intended are cooling tower water pump systems, forced and induced draft fan systems, and other general-purpose equipment trains.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Specification 5L, *Line Pipe*

API Standard 670, *Machinery Protection Systems*

API Standard 671, *Special-purpose Couplings for Petroleum, Chemical, and Gas Industry Services*

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

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

API Manual of Petroleum Measurement Standards (MPMS) Chapter 15, *Guidelines for the Use of Petroleum Industry-specific International System (SI) Units*

AGMA 925-A03 ¹, *Effect of Lubrication on Gear Surface Distress*

ANSI ²/API Standard 614, *Lubrication, Shaft-sealing and Oil-control Systems and Auxiliaries*, Fifth Edition, April 2008

ANSI/ABMA Standard 7 ³, *Shaft and Housing Fits for Metric Radial Ball and Roller Bearings (Except Tapered Roller Bearings) Conforming to Basic Boundary Plan*

¹ American Gear Manufacturers Association, 1001 N. Fairfax Street, Suite 500, Alexandria, Virginia 22314, www.agma.org.

² American National Standards Institute, 1899 L. Street, NW, 11th Floor, Washington, DC 20036, www.ansi.org.

³ American Bearing Manufacturers Association, 1001 N. Fairfax Street, Suite 500, Alexandria, Virginia 22314, www.americanbearings.org.

ANSI/ABMA Standard 9 (R2008), *Load Ratings and Fatigue Life for Ball Bearings*

ANSI/ABMA Standard 11 (R2008), *Load Ratings and Fatigue Life for Roller Bearings*

ANSI/ABMA Standard 19.1, *Tapered Roller Bearings—Radial Metric Design*

ANSI/ABMA Standard 19.2, *Tapered Roller Bearings—Radial Inch Design*

ANSI/ABMA Standard 20, *Radial Bearings of Ball, Cylindrical Roller and Spherical Roller Types—Metric Design*

ANSI/AGMA 908, *Geometry Factors for Determining the Pitting Resistance and Bending Strength of Spur, Helical and Herringbone Gear Teeth*

ANSI/AGMA 2001-D04, *Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth*

ANSI/AGMA 2101-D04, *Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth (Metric Edition)*

ANSI/AGMA 6001-E08, *Design and Selection of Components for Enclosed Gear Drives*

ANSI/AGMA 6011-I03, *Specification for High Speed Helical Gear Units*

ANSI/AGMA 6013-B16, *Standard for Industrial Enclosed Gear Drives*

ANSI/AGMA 6025-D98, *Sound for Enclosed Helical, Herringbone, and Spiral Bevel Gear Drives*

ANSI/AGMA 9002-B04, *Bores and Keyways for Flexible Couplings (Inch Series)*

ANSI/ASME B1.1 ⁴, *Unified Inch Screw Threads (UN, UNR, and UNJ Thread Forms)*

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

ANSI/ASME B16.1, *Gray Iron Pipe Flanges and Flanged Fittings: Classes 25, 125, and 250*

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

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

ANSI/ASME B16.42, *Ductile Iron Pipe Flanges and Flanged Fittings: Classes 150 and 300*

ANSI/ASME B31.3, *Process Piping*

ASME *Boiler and Pressure Vessel Code, Section V: Nondestructive Examination*

ASME *Boiler and Pressure Vessel Code, Section VIII, Division 1: Rules for Construction of Pressure Vessels*

ASME *Boiler and Pressure Vessel Code, Section IX: Welding and Brazing Qualifications*

ASME B1.13M, *Metric Screw Threads: M Profile*

ASME B16.47, *Large Diameter Steel Flanges: NPS 26 Through NPS 60 Metric/Inch Standard*

ASME B17.1, *Keys and Keyseats*

ASME PTC 36, *Measurement of Industrial Noise*

ASTM A105/A105M ⁵, *Standard Specification for Carbon Steel Forgings for Piping Applications*

ASTM A106/A106M, *Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service*

⁴ American Society of Mechanical Engineers, Two Park Avenue, New York, New York 10016, www.asme.org.

⁵ ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

ASTM A181/A181M, *Standard Specification for Carbon Steel Forgings, for General-Purpose Piping*

ASTM A192/A192M, *Standard Specification for Seamless Carbon Steel Boiler Tubes for High-Pressure Service*

ASTM A193/A193M, *Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications*

ASTM A194/A194M, *Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both*

ASTM A247, *Standard Test Method for Evaluating the Microstructure of Graphite in Iron Castings*

ASTM A307, *Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rod 60 000 PSI Tensile Strength*

ASTM A312, *Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes*

ASTM A320/A320M-05, *Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for Low-Temperature Service*

ASTM A388/A388M, *Standard Practice for Ultrasonic Examination of Steel Forgings*

ASTM A524, *Standard Specification for Seamless Carbon Steel Pipe for Atmospheric and Lower Temperatures*

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

ASTM A269/A269M, *Standard Specification for Seamless and Welded Austenitic Stainless Steel Tubing for General Service*

ASTM A275/A275M, *Standard Practice for Magnetic Particle Examination of Steel Forgings*

ASTM A312/A312M, *Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes*

ASTM A609/A609M, *Standard Practice for Castings, Carbon, Low-Alloy, and Martensitic Stainless Steel, Ultrasonic Examination Thereof*

ASTM E94/E94M, *Standard Guide for Radiographic Examination Using Industrial Radiographic Film*

ASTM E125-63, *Standard Reference Photographs for Magnetic Particle Indications on Ferrous Castings*

ASTM E165/E165M, *Standard Practice for Liquid Penetrant Testing for General Industry*

ASTM E709, *Standard Guide for Magnetic Particle Testing*

ASTM E1417/E1417M, *Standard Practice for Liquid Penetrant Testing*

ASTM F104, *Standard Classification System for Nonmetallic Gasket Materials*

EN 1092-1 ⁶, *Flanges and Their Joints—Circular Flanges for Pipes, Valves, Fittings and Accessories, PN Designated—Part 1: Steel Flanges*

EN 1092-2, *Flanges and Their Joints—Circular Flanges for Pipes, Valves, Fittings and Accessories, PN Designated—Part 2: Cast Iron Flanges*

EN 1561, *Founding—Grey Cast Irons*

⁶ European Committee for Standardization (CEN), Management Centre, Rue de la Science 23, B - 1040 Brussels, Belgium, <https://www.cen.eu>.

EN 1563, *Founding—Spheroidal Graphite Cast Irons*

EN 10083 (all parts), *Steels for Quenching and Tempering*

EN 10084, *Case Hardening Steels*

EN 10085, *Nitriding Steel—Technical Delivery Conditions*

IEC 60079 (all parts) ⁷, *Explosive Atmospheres*

IEC 60529, *Degrees of Protection Provided by Enclosures*

ISO 7-1 ⁸, *Pipe threads where pressure-tight joints are made on the threads*

ISO 15, *Rolling bearings—Radial bearings—Boundary dimensions, general plan*

ISO 76, *Rolling bearings—Static load ratings*

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

ISO 262, *ISO general-purpose metric screw threads—Selected sizes for screws, bolts and nuts*

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

ISO/R 286, *ISO system of limits and fits—Part 1: General, tolerances and deviations*

ISO 355, *Rolling bearings—Tapered roller bearings—Boundary dimensions and series designations*

ISO 492, *Rolling bearings—Radial bearings—Dimensional and geometrical tolerances*

ISO 582, *Rolling bearings—Chamfer dimensions—Maximum values*

ISO 724, *ISO general-purpose metric screw threads—Basic dimensions*

ISO/R 775, *Cylindrical and 1/10 conical shaft ends*

ISO 965 (all parts), *ISO general purpose metric screw threads—Tolerances*

ISO 1328-1, *Cylindrical gears—ISO system of flank tolerance classification—Part 1: Definitions and allowable values of deviations relevant to flanks of gear teeth*

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

ISO 3290, *Rolling bearings—Balls—Part 1: Steel balls*

ISO 3448, *Industrial liquid lubricants—ISO viscosity classification*

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

ISO 3746, *Acoustics—Determination of sound power levels and sound energy levels of noise sources using sound pressure—Survey method using an enveloping measurement surface over a reflecting plane*

ISO 4386-1, *Plain bearings—Metallic multilayer plain bearings—Part 1: Non-destructive ultrasonic testing of bond thickness greater than or equal to 0,5 mm*

ISO 4386-3, *Plain bearings—Metallic multilayer plain bearings—Part 3: Non-destructive penetrant testing*

⁷ International Electrotechnical Commission, 3 rue de Varembé, CH-1211 Geneva 20, Switzerland, www.iec.ch.

⁸ International Organization for Standardization, ISO Central Secretariat, Chemin de Blandonnet 8, CP 401 – 1214 Vernier, Geneva, Switzerland, www.iso.org.

ISO 5753-1, *Rolling bearings—Internal clearance—Part 1: Radial internal clearance for radial bearings*

ISO 6336-5, *Calculation of load capacity of spur and helical gears—Part 5: Strength and quality of materials*

ISO/TS 6336-21, *Calculation of load capacity of spur and helical gears—Part 21: Calculation of scuffing load capacity (also applicable to bevel and hypoid gears)—Integral temperature method*

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

ISO 7005-1, *Metallic flanges—Part 1: Steel flanges*

ISO 7005-2, *Metallic flanges—Part 2: Cast iron flanges*

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

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

ISO 14635-1, *Gears—FZG test procedures—Part 1: FZG test method A/8, 3/90 for relative scuffing load-carrying capacity of oils*

ISO 14732, *Welding personnel—Qualification testing of welding operators and weld setters for mechanized and automatic welding of metallic materials*

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

ISO 21940-12, *Mechanical vibration—Rotor balancing—Part 12: Procedures and tolerances for rotors with flexible behavior*

MSS SP-44 ⁹, *Steel Pipeline Flanges*

MSS SP-55, *Quality Standard for Steel Castings for Valves, Flanges, Fittings, and Other Piping Components: Visual Method for Evaluation of Surface Irregularities*

NEMA SM 23 (R2002) ¹⁰, *Steam Turbines for Mechanical Drive Service*

NEMA 250, *Standard for Enclosures for Electrical Equipment (1000 Volts Maximum)*

NFPA 70:2008 ¹¹, *National Electrical Code*, Articles 500, 501, 502, and 504

SSPC SP 6 ¹², *Commercial Blast Cleaning*

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

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

3.1.1

apex

The plane defined by the point at which the left and right inclinations (helices) of a double helical gear meet.

⁹ Manufacturers Standardization Society, 127 Park St. NE, Vienna, Virginia 22180, <http://msshq.org>.

¹⁰ National Electrical Manufacturers Association, 1300 17th Street N 900, Arlington, Virginia 22209, www.nema.org.

¹¹ National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169, www.nfpa.org.

¹² The Society for Protective Coatings, 800 Trumbull Drive, Pittsburgh, Pennsylvania 15205, www.sspc.org.

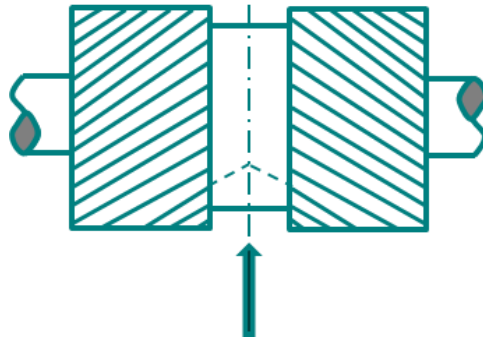


Figure 1—Apex

3.1.2

apex runout

A slight deviation in the plane of the apex created during the manufacturing process.

NOTE The deviation only exhibits itself when the gear and the pinion helices are meshed together. A measurement is taken axially on the pinion through one revolution of the gear. The measured runout is commonly referred to as apex runout or wander. This causes a shuttling of the pinion axially with respect to the gear during operation. This shuttling is evident as an axial vibration.

3.1.3

axial float

Free movement of a shaft parallel to its axis of rotation, normally limited by either thrust bearing clearance or gear mesh clearance or a combination of the two.

3.1.4

axially split joint

Joint split with the principal face parallel to the shaft centerline.

3.1.5

backlash

The amount by which the width of a tooth space exceeds the thickness of the engaging tooth on the operating pitch diameters in the transverse plane.

NOTE Backlash between mating pairs of gear teeth is measured in the transverse plane with a dial indicator at the operating pitch diameter with gears installed in job casing or on checking stands at the operating center distance.

3.1.6

bending stress number

Corresponds to the likelihood of fatigue cracking at the tooth root fillet, which, if excessive, can lead to failure of the gear teeth.

3.1.7

Brinell hardness

Hardness is a characteristic of a material, not a fundamental physical property. It is defined as the resistance to indentation, and it is determined by measuring the permanent depth of the indentation.

NOTE 1 The Brinell method applies a predetermined test load to a carbide ball of fixed diameter that is held for a predetermined time period and then removed. The resulting impression is measured with a specially designed Brinell microscope or optical system across at least 2 diameters—usually at right angles to each other and these results are averaged.

NOTE 2 The Brinell hardness test method, as used to determine Brinell hardness, is defined in ASTM E10. Most commonly it is used to test materials that have a structure that is too coarse or that have a surface that is too rough to be tested using another test method, e.g. castings and forgings. Brinell testing often use a very high test load (3000 kg) and a 10 mm diameter indenter so that the resulting indentation averages out most surface and subsurface inconsistencies.

3.1.8

case depth

Thickness of the hardened layer on a specimen.

NOTE 1 Case hardening improves both the wear resistance and the fatigue strength of parts under dynamic and/or thermal stresses.

NOTE 2 Hardened steel parts are typically used in rotating applications where high wear resistance and strength is required.

NOTE 3 The characteristics of case hardening are primarily determined by surface hardness, the effective hardness depth and the depth profile of the residual stress.

NOTE 4 Gears and engine parts are examples where hardening is used.

NOTE 5 Effective case depth is the depth up to a further point for which a specified level of hardness is maintained.

NOTE 6 Total case depth is the depth to a point where there is no difference in the chemical or physical properties.

3.1.9

critical speed

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

3.1.10

design

Manufacturer's calculated parameter.

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

3.1.11

diamètre nominal (nominal diameter)

DN

Alphanumeric designation of size for components of a pipework system as shown in Table 1.

EXAMPLE DN20.

NOTE 1 Adapted from ISO 6708:1995.

NOTE 2 The letters DN are followed by a dimensionless whole number that is indirectly related to the physical size, in millimeters, of the bore or outside diameter of the end connection.

NOTE 3 The number following the letters DN does not represent a measurable value.

NOTE 4 In those standards that use the DN designation system, any relationship between DN and component dimensions should be given, e.g. DN/OD or DN/ID [ISO 6708:1995 (E)].

Table 1—Corresponding DN and NPS Pipe Sizes

Diameter Nominal (DN) mm	Nominal Pipe Size (NPS) in.	Diameter Nominal (DN) mm	Nominal Pipe Size (NPS) in.
6	$\frac{1}{8}$	450	18
8	$\frac{1}{4}$	500	20
10	$\frac{3}{8}$	550	22
15	$\frac{1}{2}$	600	24
20	$\frac{3}{4}$	650	26
25	1	700	28
32	1 $\frac{1}{4}$	750	30
40	1 $\frac{1}{2}$	800	32
50	2	900	36
65	2 $\frac{1}{2}$	1000	40
80	3	1100	42
100	4	1200	48
150	6	1400	54
200	8	1500	60
250	10	1600	64
300	12	1800	72
350	14	2000	80
400	16	2200	88
NOTE 1 Up to and including NPS 12-in. diameter piping, the “inside diameter” is the nominal dimension of the pipe. Above NPS 12 in. pipe, the O.D. is the nominal dimension of the pipe.			
NOTE 2 The thickness of the pipe is determined by specifying the pipe schedule.			

3.1.12**gear**

Refers to either the pinion or gear wheel.

3.1.13**gear service factor****SF**

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.

3.1.14**gear unit**

Complete power transmission assembly including the housing, gears, and bearings.

3.1.15**gear unit rated power**

Maximum power specified by the purchaser on the data sheet and stamped on the nameplate.

3.1.16**gear wheel (bull gear)**

Lowest speed rotor.

3.1.17**general purpose**

Application that is usually spared and in noncritical service.

3.1.18**Hall effect probe**

A transducer that varies its output voltage in response to a magnetic field.

NOTE Hall effect sensors are used for proximity switching, positioning, speed detection, and current sensing applications.

3.1.19**hunting tooth combination**

Exists for mating gears when a tooth on the pinion does not repeat contact with a tooth on the gear wheel until it has contacted all the other gear wheel teeth.

3.1.20**informative**

For information only an informative reference or annex provides advisory or explanatory information. It is intended to assist the understanding or use of the document.

3.1.21**installer**

The person or organization responsible for the initial and subsequent gearbox installation on its baseplate, skid, or soleplate. Also responsible for installation decisions, inspection requirements, and so forth. This representative may be an employee of the owner, a third-party contractor, equipment packager, vendor, or OEM as delegated by the owner.

3.1.22**Lead**

The axial advance of a helix gear tooth during one complete turn (360°), that is, the Lead is the axial travel (length along the axle) for one single complete helical revolution about the pitch diameter of the gear.

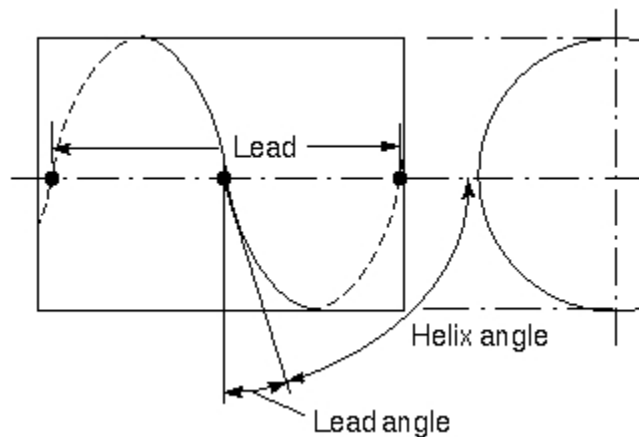


Figure 2—Lead

3.1.23**lead modification**

Calculated machined deviation of the pinion and/or the gear wheel tooth flank from the theoretical tooth form intended to improve uniformity of the load distribution across the face width of the mating rotors when the gears are operating at normal load.

3.1.24**maximum continuous speed**

Highest rotational speed (revolutions per minute) at which the machine, as built and tested, is capable of continuous operation.

3.1.25**nominal pipe size****NPS**

Dimensionless value approximately equal to the diameter in inches [see diamètre nominal or nominal diameter (DN) (3.1.11)].

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

NOTE 1 Adapted from ASME B31.3:2006, Paragraph 300.2.

NOTE 2 The letters NPS are followed by a dimensionless number that is related to the physical size, in inches of the bore or outside diameter of the pipe.

NOTE 3 The number following the letters NPS does not represent a measurable value.

NOTE 4 NPS is a designation of pipe size only. The pipe end can be threaded or prepared for a welded fitting.

NOTE 5 Up to and including 12 in. diameter piping, the bore is the nominal dimension of the pipe, above 12 in. pipe, the O.D. is the nominal dimension of the pipe.

NOTE 6 The thickness of the pipe is determined by specifying the pipe schedule.

3.1.26**nominal pressures****PN**

Numerical designation relating to pressure that is a convenient round number for reference purposes.

3.1.27**normal transmitted power**

Power at which usual operation is expected and optimum efficiency is desired.

NOTE The normal transmitted power can be equal to or less than the gear unit rated power.

3.1.28**normative**

This is a requirement.

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

3.1.29**NPT**

Thread form designation for pipe threads.

EXAMPLE NPT $\frac{3}{4}$ – 14.

NOTE 1 It is comprised of a number representing nominal pipe size followed by the number of threads per inch and the letters NPT representing the thread series.

NOTE 2 Pipe size and number of threads per inch can be found in ASME B.1.20.1:2006, Table 2, a section of which has been reproduced for reference below in Table 2.

Table 2—Pipe Sizes and Number of Threads per Inch (ASME B.1.20.1 Table 2)

Nominal Pipe Size (NPS)	Outside Diameter (O.D.) of Pipe (D)	Threads/in. (n)
$\frac{1}{16}$	0.3125	27
$\frac{1}{8}$	0.405	27
$\frac{1}{4}$	0.540	18
$\frac{3}{8}$	0.675	18
$\frac{1}{2}$	0.840	14
$\frac{3}{4}$	1.050	14
1	1.315	11.5
1 $\frac{1}{4}$	1.660	11.5
1 $\frac{1}{2}$	1.900	11.5
2	2.375	11.5
2 $\frac{1}{2}$	2.875	8
3	3.500	8
3 $\frac{1}{2}$	4.000	8
4	4.500	8
5	5.563	8
6	6.625	8
8	8.625	8
10	10.750	8
12	12.750	8
14 O.D.	14.000	8
16 O.D.	16.000	8
18 O.D.	18.000	8
20 O.D.	20.000	8
24 O.D.	24.000	8

3.1.30 observed

Inspection or test where the purchaser or the purchaser's representative is notified of the timing of the event with adequate lead time to observe the activity; however, the activity will be performed by the vendor as scheduled in the absence of the purchaser or the purchaser's representative.

3.1.31 oil mist lubrication

Lubrication systems that employ oil mist produced by atomization in a central unit and transported to the bearing housing, or housings, by compressed air.

3.1.32 owner

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

3.1.33 pinion

Highest speed rotor.

3.1.34**pitch line velocity**

Linear velocity of a point on the gear at the radius of the pitch circle.

3.1.35**preliminary alignment**

The aligning of two adjacent machinery shafts to ensure that final alignment can be achieved without being bolt bound. This is accomplished before grouting and the measurement of piping strain on the machinery.

3.1.36**purchaser**

Agency that issues the order and specification to the vendor.

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

3.1.37**purge oil mist lubrication**

Lubrication systems in which the mist purges the bearing housing.

NOTE There is an oil level in the bearing housing when using purge oil mist lubrication and the bearing is lubricated by a conventional oil-bath, oil disc, or ring-oil lubrication system (i.e. wet sump).

3.1.38**rated input speed**

Specified (or nominal) rated speed of the gear unit driver (in revolutions per minute), as designated by the purchaser.

3.1.39**rated output speed**

Specified (or nominal) rated speed of the gear unit driven equipment (in revolutions per minute), as designated by the purchaser.

3.1.40**Rockwell testing, scale**

Rockwell hardness test method, as defined in ASTM E18, is the most commonly used hardness test method.

NOTE 1 The Rockwell test is generally easier to perform and is more accurate than other types of hardness testing methods.

NOTE 2 The Rockwell test method is used on all metals, except in condition where the test metal structure or surface conditions would introduce too much variations, where the indentations would be too large for the application, or where the sample size or sample shape prohibits its use.

NOTE 3 The Rockwell method measures the permanent depth of indentation produced by a force/load on an indenter. First, a preliminary test force (commonly referred to as preload or minor load) is applied to a sample using a diamond or ball indenter. This preload breaks through the surface to reduce the effects of surface finish. After holding the preliminary test force for a specified dwell time, the baseline depth of indentation is measured.

NOTE 4 After the preload, an additional load, call the major load, is added to reach the total required test load. This force is held for a predetermined amount of time (dwell time) to allow for elastic recovery. This major load is then released, returning to the preliminary load. After holding the preliminary test force for a specified dwell time, the final depth of indentation is measured. The Rockwell hardness value is derived from the difference in the baseline and final depth measurements. This distance is converted to a hardness number. The preliminary test force is removed and the indenter is removed from the test specimen.

3.1.41**rolling element bearings**

An assembly of mechanical components that utilizes rolling contacts between the rolling elements and race rings to support load while permitting constrained motion of one race ring relative to the other race ring.

3.1.42**roughness value****Ra**

Arithmetical average of the absolute value of the profile height deviations recorded within the evaluation length and measured from the mean line.

NOTE 1 Adapted from ASME B46.1:2009, Paragraph 1.4.1.1.

NOTE 2 It is the average variation in height of the entire surface, within the sampling length, from the mean line.

3.1.43**service life**

The duration of time that a system or component can be utilized at site-rated conditions, power and duty cycle, and while following the vendor-specified operation and maintenance requirements.

3.1.44**scuffing**

Form of gear tooth surface damage that refers to welding and tearing of the tooth surface by the flank of the mating gear.

NOTE Scuffing occurs when the oil film thickness is small enough to allow the flanks of the gear teeth to contact and slide against each other.

3.1.45**scuffing risk**

Inversely proportional to the oil film ability in preventing metal to metal contact of the gear set teeth in the mesh during operation.

3.1.46**shutdown**

Condition as determined by the equipment user that requires action to stop the equipment to ensure plant personnel safety and/or protect equipment.

3.1.47**shutdown (HH) set point**

Preset value of a measured parameter at which automatic or manual shutdown of the system or equipment is required.

3.1.48**special tool**

Tool that is not a commercially available catalog item.

3.1.49**structure stiffness and damping**

Refers to the bearing housing to ground equivalent complex stiffness.

3.1.50**thermal capacity**

Horsepower a unit will transmit continuously for 3 hours or more without exceeding an operating sump temperature rise of 45 °C (80 °F) above ambient.

**3.1.51
tooth contact**

Interface between gear teeth that transmits the torque from one gear to another gear.

**3.1.52
tooth pitting index**

K

Contact stress number.

NOTE The tooth pitting index is used to determine a load rating at which progressive pitting of the teeth does not occur during their design life.

**3.1.53
total indicator reading
total indicated runout
TIR**

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

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

**3.1.54
trip**

Automated shutdown to ensure personnel safety (safety critical).

**3.1.55
trip speed**

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

NOTE For electric motor drivers, it is the speed corresponding to the synchronous speed of the motor at maximum supply frequency at the motor terminals.

**3.1.56
ultimate load rating (hydrodynamic thrust bearing)**

Load that will produce the minimum acceptable oil film thickness without inducing failure during continuous service, or the load that will not exceed the creep initiation or yield strength of the babbitt or bearing material.

**3.1.57
unit responsibility**

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

NOTE The technical aspects to be considered include, but are not limited to, such factors as the power requirements, speed, direction of rotation, general arrangement, couplings, dynamics, lubrication, sealing system, material test reports, instrumentation, piping, conformance to specifications, and testing of components.

**3.1.58
vendor**

Manufacturer or manufacturer's agent that supplies the equipment.

**3.1.59
witnessed**

Inspection or test where the purchaser is notified of the timing of the inspection or test and a hold is placed on the inspection or test until the purchaser or the purchaser's representative is in attendance.

3.2 Acronyms and Abbreviations

AF	amplification factor
CW	clockwise (rotation)
CCW	counter clockwise (rotation)
DBSE	distance between shaft ends
DN	nominal diameter
I.D.	inside diameter
O.D.	outside diameter
OEM	original equipment manufacturer
PTFE	polytetrafluoroethylene
RTD	resistance temperature detector
SI	International System of units
TFE	tetrafluoroethylene
USC	United States customary units
VDDR	vendor drawing and data requirements

4 General

4.1 Unit Responsibility

The gear vendor shall assume unit responsibility and shall assure that all subvendors comply with the requirements of this standard and all reference documents. The technical aspects to be considered by the vendor include, but are not limited to, such factors as the power requirements, speed, rotation, general arrangement, couplings, dynamics, lubrication, sealing system, material test reports, instrumentation, piping, conformance to specifications and testing of components.

NOTE It is recognized that normally another party, usually the driven equipment supplier, assumes the overall technical unit responsibility for the entire train of equipment including the general-purpose gear. The gear supplier, however, has technical responsibility for everything provided as part of his scope of supply.

4.2 Unit Conversion

For unit conversion, the factors in API *MPMS* Chapter 15 were used to convert from United States customary (USC) to SI (International System) units. The resulting exact SI units were then rounded off.

4.3 Standards and Codes

4.3.1 The editions of the standards, codes, and specifications (see Section 2) that are in effect at the time of publication of this standard shall, to the extent specified herein, form a part of this standard.

4.3.2 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.

5 Requirements

• 5.1 Units of Measure

5.1.1 The purchaser shall specify whether data, drawings, hardware (including fasteners), and equipment supplied to this standard shall use the SI or USC system of measurements.

5.1.2 Use of a USC data sheet (see Annex A) indicates the USC system of measurements to be used.

5.1.3 Use of an SI data sheet (see Annex A) indicates the SI system of measurements to be used.

NOTE Dedicated data sheets for SI units and for USC units are provided in Annex A.

5.2 Statutory Requirements

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

5.2.2 Equipment installed in the European Economic Area shall comply with all applicable European Union Directives.

NOTE The European Economic Area includes the countries of the European Union plus Norway, Iceland, and Liechtenstein.

5.3 Hierarchy of Requirements

5.3.1 In case of conflict between this standard and the inquiry, the inquiry shall govern.

5.3.2 At the time of the order, the purchase order shall govern.

5.3.3 The purchaser shall specify the hierarchy of documents in the purchase order.

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

6 Basic Design

6.1 General

6.1.1 Equipment Reliability

- **6.1.1.1** Only equipment that is field proven is acceptable. The purchaser shall specify the TRL level from API 691 for qualified equipment.

NOTE Purchasers can use their engineering judgment in determining what equipment is field proven.

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

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

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

6.1.2 Gear units purchased according to this standard shall conform to AGMA 6013 or 6011 and to related standards referenced therein, except as modified or supplemented by this standard.

6.1.3 General-purpose and extruder gears manufactured according to this standard shall be limited to pitch line velocities of 60 m/s (12,000 ft/min).

6.1.4 Vendor shall advise in their proposal any component designed for a finite life.

NOTE It is recognized that this is design criteria.

6.1.5 The vendor shall assume unit responsibility for all equipment and all auxiliary systems included in the scope of the order.

- **6.1.6** The purchaser shall specify the equipment's normal transmitted power and corresponding speed (see 6.4.1 for gear rated power). This is the power associated with the normal operating point of the driven equipment.

6.1.7 Fluids that are flammable, hazardous, or toxic shall be identified by the purchaser.

- **6.1.8** The purchaser shall also specify all expected operating conditions in addition to the normal transmitted power and corresponding speed specified in 6.1.6.

6.1.9 The purchaser shall specify the input and output speed and the allowable speed variation for both.

NOTE In selecting the number of teeth for the pinion and gear, it is often impractical for the vendor to match exactly both the rated input and rated output speeds designated.

6.1.10 The purchaser shall specify if equipment will be supplied in accordance with API 691.

6.1.11 If API 691 has been specified, the vendor shall identify all machinery components that have a TRL < 7 per API 691, 4.3.2, Table 1.

6.1.12 Control of the sound pressure level of all equipment furnished shall be a joint effort of the purchaser and the vendor having train responsibility.

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

6.1.12.2 In order to determine compliance, the vendor shall provide both maximum sound pressure and sound power level data per octave band for the equipment. ISO 3740, ISO 3744, and ASME PTC 36 or ISO 3746 may be consulted for guidance.

6.1.13 Cooling water system or systems shall be designed on the water side based on criteria in API 614.

6.1.13.1 The vendor shall notify the purchaser if the criteria for minimum temperature rise and velocity overheat exchange surfaces result in a conflict.

6.1.13.2 If such a conflict exists, the purchaser shall approve the final selection.

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

6.1.14 Equipment shall be designed to run without damage to the trip speed setting indicated in Table 3. Rotors for turbine-driven gear units shall be designed to operate without damage at momentary speeds up to 110 % of the trip speed.

NOTE This is intended to address the scenario of sudden full load rejection and subsequent acceleration above trip speed.

6.1.15 The arrangement of the equipment, including piping and auxiliaries, shall be developed jointly by the purchaser and the vendor.

- **6.1.16** Motors, electrical components, and electrical installations shall be suitable for the area classification (class, group, and division or zone) specified by the purchaser and shall meet the requirements of the applicable sections of IEC 60079-0 (NFPA 70, Articles 500, 501, 502, and 504) as well as any local codes specified and furnished on request by the purchaser (see 5.2).

6.1.17 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.

6.1.18 Major parts, such as casing components and bearing housings, shall be designed and manufactured with the use of shouldering, dowels, or keys to ensure accurate alignment on reassembly.

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

6.1.19 After installation, the combined performance of gear unit (with driver and driven machines) shall be the joint responsibility of the purchaser and the vendor.

Table 3—Driver Trip Speeds

Drive Type	Trip Speed (% of Max Continuous Speed)
Steam turbine	
NEMA Class A ^a	115
NEMA Class B, C, D ^a	110
Gas turbine	105
Variable-speed motor	110
Constant-speed motor	100
Reciprocating engine	110
^a Indicates governor class, as specified in NEMA SM 23.	

6.1.20 The equipment, including all auxiliaries, shall be suitable for operation under the environmental conditions specified by the purchaser.

6.1.21 These conditions shall include whether the installation is indoors (heated or unheated) or outdoors (with or without a roof), maximum and minimum temperatures, unusual humidity, and dusty or corrosive conditions.

6.1.22 Gear units shall not require a break-in period.

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

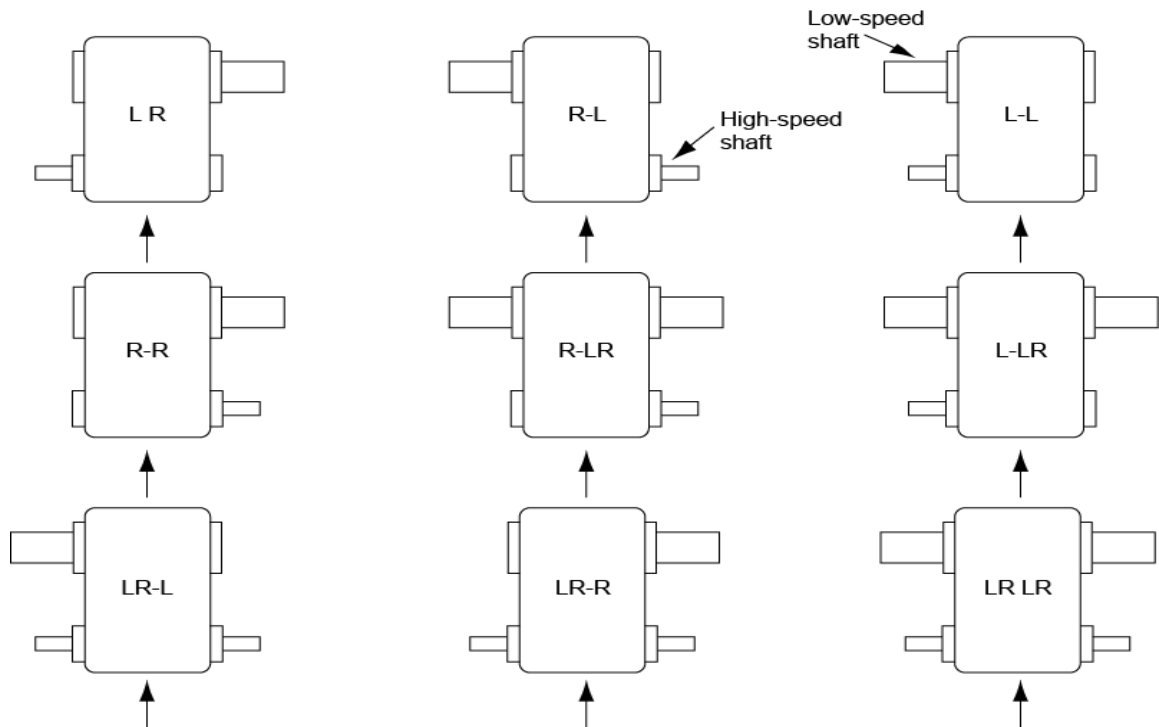
• 6.2 Shaft Assembly Designation

The purchaser shall specify the appropriate shaft assembly designation(s) selected from the combinations listed in Table 4 and illustrated in Figure 3.

Table 4—Shaft Assembly Combinations

Parallel Shaft Assembly Combination (See Figure 3)	
High-speed Shaft	Low-speed Shaft
L	R
R	L
L	L
R	R
R	LR
L	LR
LR	L
LR	R
LR	LR

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 ANSI/AGMA 6113-B16 (6013-B16) with permission from the publisher.

**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.

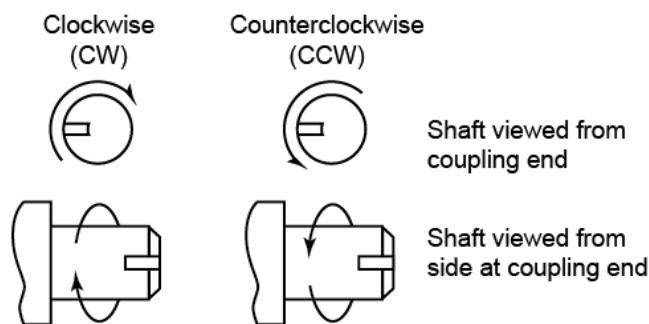
Figure 3—Shaft Assembly Designations

6.3 Shaft Rotation

6.3.1 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.

6.3.2 The shaft rotational direction shall be designated by the abbreviations CW or CCW, as indicated by the circular arrows in Figure 4.

- **6.3.3** The purchaser shall specify the rotational direction of both the high-speed and the low-speed shafts. 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 4) and submit a copy of the figure with the quotation request.
- **6.3.4** The purchaser (vendor with train responsibility) shall advise the direction of rotation for each item in the train.



Note: Reprinted from AGMA 6010 with permission from the publisher.

Figure 4—Shaft Rotation Designations

For increased gear stability, the configuration and shaft rotational direction shall be selected in a way that achieves a downloaded bull gear. In order to achieve this, speed increaser gears shall be oriented with an up mesh rotation and speed reduction gears shall be oriented with a down mesh rotation (see Figure 5).

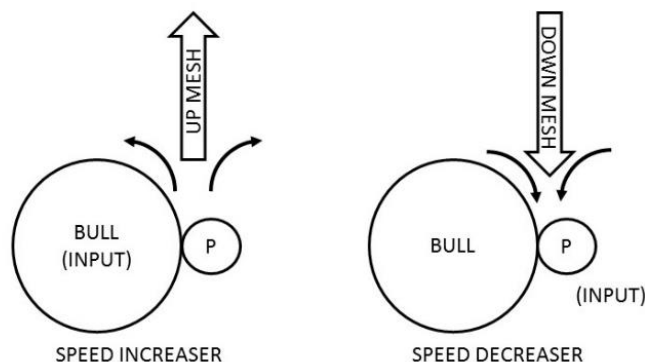


Figure 5—Gear Mesh

6.4 Rating

6.4.1 Gear Rated Power

- **6.4.1.1** The gear rated power of the unit shall be specified by the purchaser.

6.4.1.1.1 For gear units connected directly to the driver, the minimum gear unit rated power shall be the maximum installed power of the driver.

6.4.1.1.2 For electric motor drivers, the gear rated power shall be the motor nameplate rating multiplied by the motor service factor.

6.4.1.1.3 All modes of normal and transient operation shall be examined. Modes of operation include the number of starts per unit of time, reduced load, removal, reversed load, reduced speed, and overload and overspeed conditions.

6.4.1.1.4 If the maximum transmitted torque occurs at an operating speed other than the maximum continuous speed, this torque and its corresponding speed will be specified by the purchaser and shall be the basis for sizing the gear.

6.4.1.1.5 For gear units between two items of driven equipment, the power rating of such gears shall be not less than items a) or b) below, whichever is greater.

- a) 110 % 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.

NOTE 1 The gear unit rated power is normally the maximum installed power of the driver. In some cases, a higher rated power is specified in order to plan for future upgrades.

NOTE 2 In other applications, the maximum installed power of the driver can be significantly greater than the normal transmitted power, resulting in oversizing of the gear. If the purchaser can demonstrate that the maximum installed power of the driver will never be transmitted through the gear, the specified gear unit rated power can be smaller than the maximum installed power of the driver.

6.4.1.2 Normal Transmitted Power

- **6.4.1.2.1** For optimal gear unit design (rotor dynamics, lead modification), the purchaser shall specify the normal transmitted power and any special operating conditions (such as load reversals), in addition to the gear unit rated power.

6.4.1.2.2 Gear unit rating shall be based on the lowest of the following capacities: tooth pitting resistance, tooth bending strength, or thermal capacity.

6.4.2 Gear Tooth Service Factor

- **6.4.2.1** The minimum gear tooth service factor shall be specified by the purchaser based on the application, as listed in Table 5.

6.4.2.2 The minimum gear tooth service factors apply to the gear unit rated power at rated speeds (gear rated input speed and gear rated output speed).

Table 5—Minimum Gear Tooth Service Factors

Driven Equipment	Prime Mover			
	Motors Sync and Var.	Motors Induction	Turbine Steam and Gas	Reciprocating Engine
Agitators and mixers	1.8	1.7	1.7	2.0
Blowers				
Centrifugal	1.5	1.4	1.6	1.7
Rotary lobe	1.8	1.7	1.7	2.0
Vane	1.5	1.4	1.6	1.7
Compressors				
Rotary lobe (radial, axial, screw, and so forth)	1.8	1.7	1.7	2.0
Reciprocating	2.1	2.0	2.0	2.3
Conveyors				
Uniformly loaded and fed	1.5	1.4	1.6	1.7
Nonuniformly fed	1.8	1.7	1.7	2.0
Shaker or reciprocating	2.1	2.0	2.0	2.3
Crusher (ore or stone)	2.1	2.0	2.0	2.3
Plasticizing equipment				
Single screw extruders	1.6	1.5	—	—
Twin screw extruders				
Co-rotating	1.6	1.5	—	—
Counter-rotating	1.6	1.5	—	—
Twin screw mixers	1.3	1.2	—	—
Melt pumps	1.6	1.5	—	—
Fans				
Centrifugal	1.5	1.4	1.6	1.7
Forced draft	1.5	1.4	1.6	1.7
Induced draft	1.8	1.7	2.0	2.2
Cooling tower	2.0	2.0	2.0	—
Feeders				
General service	1.8	1.7	1.7	2.0
Reciprocating	2.1	2.0	2.0	2.3
Generators	1.3	1.3	1.3	1.7
Pumps				
Centrifugal (all service except as listed below)	1.5	1.3	1.5	1.7
Centrifugal, boiler feed	1.8	1.7	2.0	—
Centrifugal, hot oil	1.8	1.7	2.0	—
Centrifugal, water supply	1.6	1.5	1.7	2.0
Rotary, axial flow (all types)	1.6	1.5	1.5	1.8
Rotary, gear	1.6	1.5	1.5	1.8
Reciprocating	2.1	2.0	2.0	2.3

6.4.3 Minimum Tooth Hardness

The minimum tooth hardness shall be as follows:

- a) for through hardened: 300 HB;
- b) for nitrided: 83.5 HR15N;
- c) for carburized: 55 Rc.

6.4.4 Tooth Pitting Number

6.4.4.1 Gear elements shall be sized on the basis of a tooth pitting number 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, poor distribution of tooth loading across the face, and the strength of the materials in terms of pitting resistance.

NOTE AGMA 2101 is the basis for the calculation methods shown in 6.4.4.2 through 6.4.6.3, with conservative assumptions for each variable and simplified equations.

6.4.4.2 The actual tooth pitting number K factor is defined by Equation (1):

$$K_{\text{act}} = \left(\frac{F_t}{d_1 \times b} \right) \times \left[\frac{(u \times 1)}{u} \right] \quad (1)$$

In SI units, F_t can be expressed as follows:

$$F_t = \frac{\left(\frac{6}{\pi} \right) 10^7 \times P}{n_1 \times d_1} \quad (2a)$$

In USC units, F_t can be expressed as follows:

$$F_t = \frac{\left(\frac{396,000}{\pi} \right) \times P}{n_1 \times d_1} \quad (2b)$$

where

- K_{act} is the tooth pitting number, N/mm² (lb/in.²);
- F_t is the transmitted tangential load at the operating pitch, N (lb);
- b is the net face width, (less gap) mm (in.);
- d_1 is the pinion pitch diameter, mm (in.);
- u is the number of teeth in the gear wheel divided by number of teeth in the pinion;
- P is the gear unit rated power, kilowatts (horsepower);
- n_1 is the pinion speed, rpm.

6.4.4.3 The allowable K factor at the gear unit 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:

$$K_{\text{all}} = I_m / (SF) \quad (3)$$

where

K_{all} is the allowable K factor;

I_m is the material index number (from Table 6 and Figures 6 and 7);

SF is the minimum gear service factor (from Table 5).

6.4.4.4 The actual K factor shall be less than or equal to the allowable K factor:

$$K_{\text{act}} \leq K_{\text{all}} \quad (4)$$

6.4.4.5 Table 6 presents material index numbers for materials in current use. The material hardness is selected by the gear vendor. The material index number is based upon the lowest minimum hardness for the element, pinion, or gear wheel. Do not extrapolate the curve specified in Table 5 beyond the limits shown (for through hardened material and carburized material, see Figures 6 and 7, and NOTE below).

NOTE Normal heat treating practice requires a tolerance range on hardness. The upper end of the hardness range can fall outside the limits shown in Figures 6 and 7.

Table 6—Allowable Material Index Numbers, I_m

Hardening Method	Hardness	Allowable Material Index Number, I_m	
		N/mm ²	lb/in. ²
Through hardened	300–363 HB	$76.1 \times 10^{-6} \text{ HB}^{1.717}$	$0.011 \text{ HB}^{1.717}$
Nitrided alloy steels	46 Rc	2.07	300
Carburized	$55 \leq \text{Rc} < 58$	$0.0033 \text{ Rc}^{1.6777}$	$0.4814 \text{ Rc}^{1.6777}$
	$58 \leq \text{Rc} \leq 64$	3.03	440

NOTE 1 See 3.1.7 and 3.1.40 for definitions of Brinell hardness and Rockwell C hardness scale.

NOTE 2 The hardness limit for nitrided alloy steels is shown in Rockwell C scale; the equivalent Rockwell HR15N scale is 83.5 HR15N. Rc 46 is equivalent to 83.5 HR15N. The Rockwell HR15N scale is known as a “superficial” hardness test scale and uses an indenter of smaller mass than the HRC test scale. It has been traditionally applied to nitrided steels because of the relatively thin case depth that results from the nitriding process, as opposed to the heavier case depth that results from carburizing. Basically, the idea is that an HR15N hardness test should be more accurate for measuring the surface hardness of nitrided steel than an HRC hardness test.

NOTE 3 It is still possible to conduct the actual hardness test using the HR15N scale and test method; then convert the result into HRC.

NOTE 4 In Europe, it is customary to measure nitrided alloy steels with the Vickers hardness scale. The Vickers hardness scale is specified in ISO 6536-5:2016.

6.4.4.6 For nitriding steels in ISO 6336-5, a minimum surface hardness of 650 HV to maximum of 900 HV is required, which corresponds to 88.5 HR15N (minimum) and 92.3 HR15N (maximum).

6.4.4.7 For through hardening steels a minimum 450 HV, corresponding to 83.5 HR15N is required in ISO 6336-5.

NOTE As most of the hardness tests on a gear tooth are done with UCI-method (Ultrasonic Contact Impedance) and not as real Rockwell or Vickers test, use of either HRC or HV as called in ISO 6336-5 is acceptable.

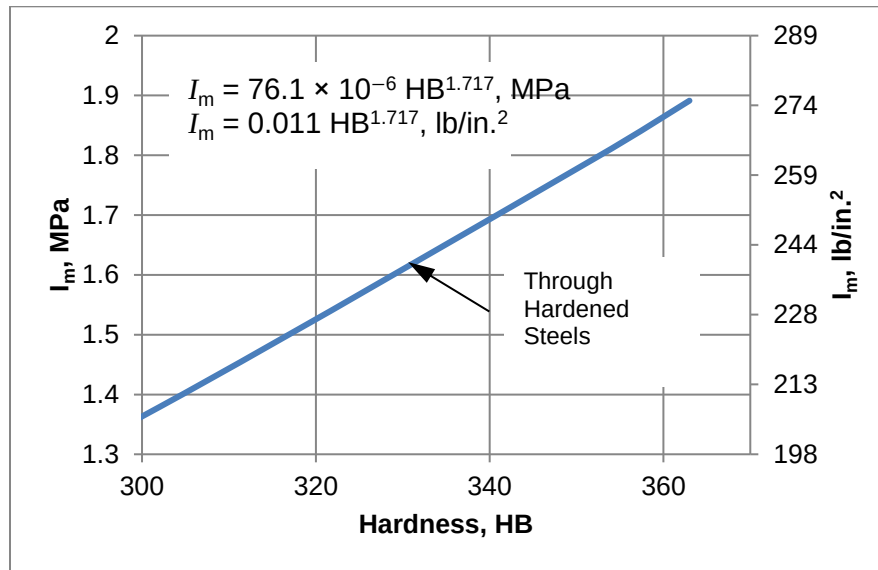


Figure 6—Material Index Number, Through Hardened

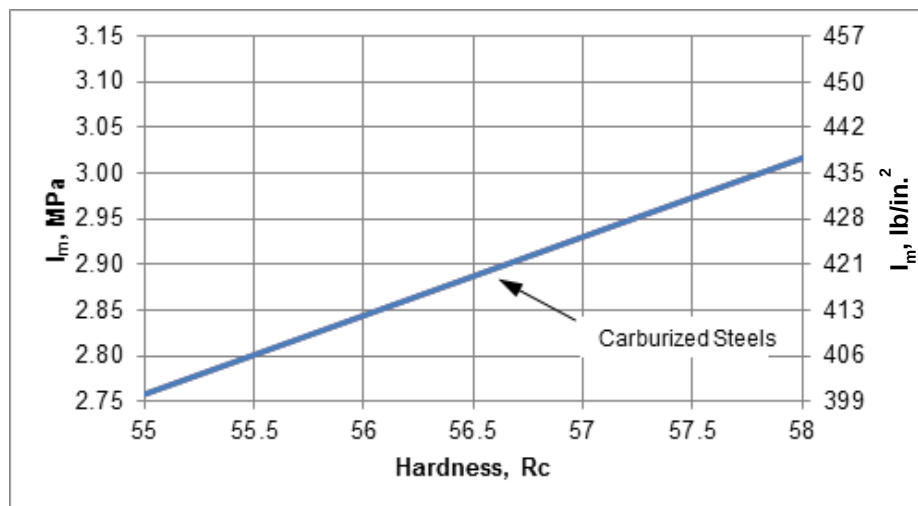


Figure 7—Material Index Number, Carburized

6.4.5 Pinion Length-to-Diameter Ratio

6.4.5.1 The maximum length-to-diameter (L/d_1) ratios for gears shall be 2.2 for double helical and 1.6 for single helical gears. Where:

L = Face width (b) for single helical gears;

L = Full face width (b) including gap width for double helical gears;

b = net active face width (less gap), mm (in.);

d_1 = pinion pitch diameter, mm (in.).

6.4.5.2 Deflection of gears with unmodified leads shall not have a total lead mismatch (combined bending, torsional deflection and thermal distortion) of the rotors across the gear face width greater than 0.018 mm (0.0007 in.). The determination of rotor deformation is to be based on the rated power and rated speed.

6.4.5.3 If a higher L/d_1 ratio than that established in 6.4.5.1 is proposed, the gear unit vendor shall submit justification in the proposal for using the higher L/d_1 ratio.

6.4.5.3.1 Purchaser's approval is required when L/d_1 ratios exceed those of 6.4.5.1.

6.4.5.3.2 When operating conditions other than the gear unit rated power are specified by the purchaser, such as the normal transmitted power, the gear unit 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.

6.4.5.3.3 When modified leads are to be furnished, purchaser and vendor shall agree on the tooth contact patterns obtained in the checking stand, housing, and test stand.

6.4.5.4 If the rotor deformation exceeds the values limited by 6.4.5.2, regardless of the L/d_1 , an analytically determined lead modification shall be applied in order to reduce the total actual mismatch to a magnitude below the limiting values in 6.4.5.2.

6.4.6 Tooth Size and Geometry

6.4.6.1 The size and geometry of the gear teeth shall be selected so that the actual bending stress number, as calculated using Equation (5a) and (5b), does not exceed the allowable values in Table 7 (respectively in Figures 8 and 9).

Where idlers are used, the calculated stress for the idler gears shall not exceed 70 % of the values given in Table 7 (respectively in Figures 8 or 9).

6.4.6.2 The material hardness shall be selected by the gear vendor.

6.4.6.2.1 The allowable bending stress number shall be based on the specified minimum hardness for the element, pinion, or gear wheel.

6.4.6.2.2 After manufacture, if the achieved hardness is below the specified minimum hardness, the allowable bending stress number shall be recalculated based on actual hardness to check if the actual bending stress number is still lower than the allowable bending stress number.

6.4.6.2.3 The curves shown in Figures 8 and 9 shall not be extrapolated beyond the limits shown.

NOTE The minimum specified hardness is used for applying values in Table 7. Normal heat treating practice requires a tolerance range on hardness. The upper end of the hardness range can fall outside the limits shown in Figures 8 and 9.

Table 7—Allowable Bending Stress Number, S_{all}

		Allowable Bending Stress Number, S_{all}	
Hardening method	Hardness	N/mm ²	lb/in. ²
Through hardened	300–363 HB	$S_a = 0.75 \text{ HB}^{0.96}$	$S_a = 108.8 \text{ HB}^{0.96}$
Nitrided alloy steels	83.5 HR15N	190	27,500
Carburized	$\geq 55 \text{ Rc to } < 58 \text{ Rc}$	$S_a = 3.361 \text{ Rc}^{1.0764}$	$S_a = 487.58 \text{ Rc}^{1.0764}$
	$\geq 58 \text{ Rc to } 64 \text{ Rc}$	266	38,500

NOTE 1 See 3.1.7 and 3.1.40 for definitions of Brinell Hardness and Rockwell C hardness scale.

NOTE 2 The hardness limit for nitrided alloy steels is shown in Rockwell C scale; the equivalent Rockwell HR15N scale is 83.5 HR15N. The Rockwell HR15N scale is known as a “superficial” hardness test scale and uses an indenter of smaller mass than the HRC test scale. It has been traditionally applied to nitrided steels because of the relatively thin case depth that results from the nitriding process, as opposed to the heavier case depth that results from carburizing. Basically, the idea is that an HR15N hardness test should be more accurate for measuring the surface hardness of nitrided steel than an HRC hardness test.

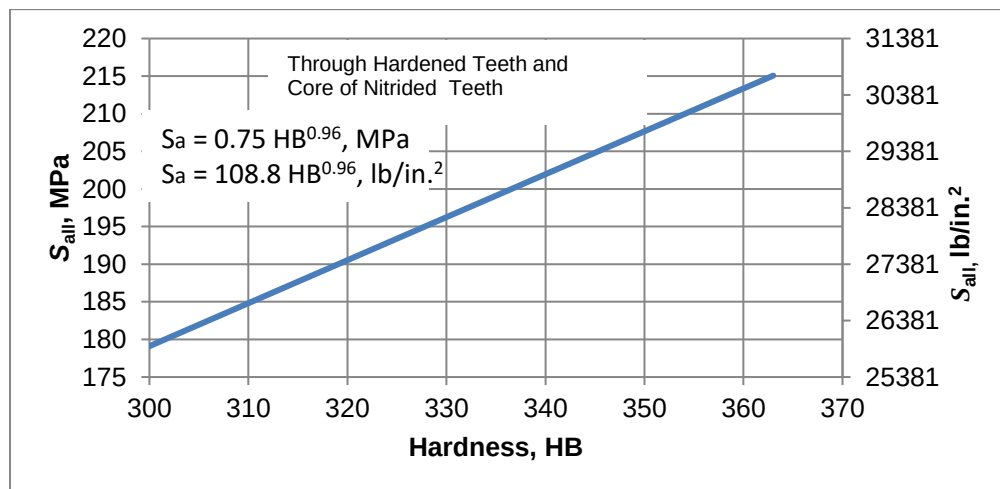
NOTE 3 It is still possible to conduct the actual hardness test using the HR15N scale and test method; then convert the result into HRC.

NOTE 4 In Europe, it is customary to measure nitrided alloy steels with the Vickers hardness scale. The Vickers hardness scale is specified in ISO 6336-5:2016.

6.4.6.2.4 For nitriding steels in ISO 6336-5, a minimum surface hardness of 650 HV to maximum of 900 HV is required, which corresponds to 88.5 HR15N (minimum) and 92.3 HR15N (maximum).

6.4.6.2.5 For through hardening steels a minimum 450 HV, corresponding to 83.5 HR15N is required in ISO 6336-5.

NOTE As most of the hardness tests on a gear tooth are done with UCI-method (Ultrasonic Contact Impedance) and not as real Rockwell or Vickers test, use of either HRC or HV as called in ISO 6336-5 is acceptable.

**Figure 8—Allowable Bending Stress Number, Through Hardened**

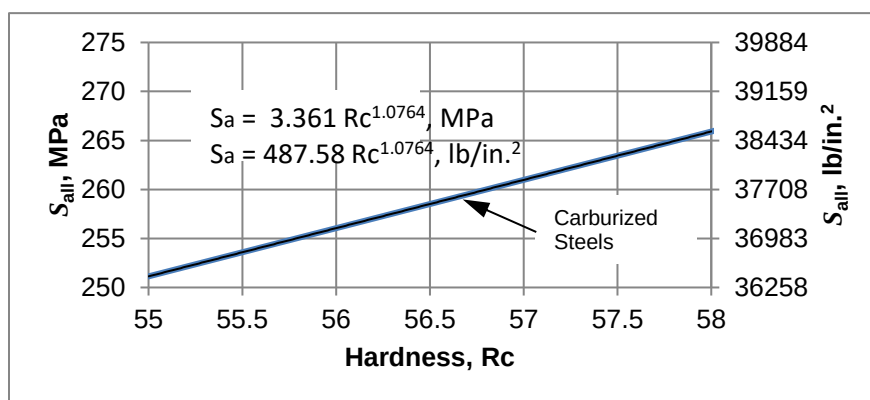


Figure 9—Allowable Bending Stress Number, Carburized Steel

6.4.6.3 The actual bending stress number for helical gears is calculated as follows:

In SI units:

$$S_{\text{act}} = \left(\frac{F_t}{m_n b} \right) SF_{\min} \left(\frac{1.8 \cos \beta}{Y_j} \right) \quad (5a)$$

where

S_{act} is the allowable bending stress number (see Table 7);

m_n is the module number, mm;

β is the helix angle, degrees;

Y_j is the geometry factor (from AGMA 908).

In USC units:

$$S_{\text{act}} = \left(\frac{F_t P_{\text{nd}}}{b} \right) SF_{\min} \left(\frac{1.8 \cos \beta}{Y_j} \right) \quad (5b)$$

where

S_{act} is the allowable bending stress number (see Table 7);

P_{nd} is the normal diametral pitch, 1/in.;

β is the helix angle, degrees;

Y_j is the geometry factor (from AGMA 908);

m_n is the module number, in.

6.4.7 Scuffing

6.4.7.1 The gear shall meet the requirements of AGMA 6011, Annex B.

6.4.7.2 Alternate calculating methods such as ISO/TS 6336-21 can be used based on gear vendor experience. Any such alternate calculating method(s) shall be submitted to purchaser for review and approval.

NOTE 1 Refer to AGMA 925-A03 for tribological information that relates to oil lubrication of gears for power transmission applications and to calculations for specific oil film thickness and instantaneous contact (flash) temperatures for gears.

NOTE 2 If gears are subject to highly loaded conditions and/or high sliding velocities the lubricant film cannot adequately separate the surfaces. These conditions could result in localized damage on the tooth surface. This localized damage to the tooth surface is referred to as “scuffing” (sometimes incorrectly called scoring). Scuffing will exhibit itself as a dull matte or rough finish usually at the extreme end regions of the contact path or near the points of a single pair tooth contact resulting in severe adhesive wear.

NOTE 3 Scuffing is not a fatigue phenomenon and can occur instantaneously. The risk of scuffing damage varies with the material of the gear, the lubricant being used, the viscosity of the lubricant, the temperature of the lubricant, the surface roughness of the tooth flanks, the sliding velocity of the mating gear set under load, and the geometry of the gear teeth.

6.4.7.3 The gear unit shall be designed for use with a load stage 6 oil according to FZG test A/8.3/90, as described in ISO 14635-1.

6.4.7.4 When an alternative oil is requested, the vendor shall provide calculations and an experience list to support a request for an alternate oil selection.

6.4.8 Overhung Loads

6.4.8.1 When an overhung load is mounted on the input or output shaft, the overhung load shall be calculated by multiplying the transmitted force that is tangent to the pitch circle by the applicable factor from Table 8.

6.4.8.2 Shafts, bearings, and bolting shall be sized according to the overhung load. All forces shall be considered to be acting in the most unfavorable direction.

Table 8—Overhung Load Factors Applied to Parallel Shaft Gears

Drive Type	Factor
Cut pinion run with cut gear	1.25

6.5 Casings

6.5.1 Design Parameters

6.5.1.1 Gear casings shall be either cast or fabricated and shall be designed and constructed to maintain rotor alignment under all load conditions when provided with supports and installed in accordance with the vendor’s written instructions.

6.5.1.2 Casing bores shall be machined to such accuracy that spare gear sets purchased with the gearbox or at a later date will have the gear-tooth contact and power rating of the original gear set.

6.5.1.3 A gear set that contacts correctly on true centers on a rotor checking stand shall also contact correctly in its own casing.

6.5.1.4 Twisting the gear case to improve contact is not allowed.

6.5.1.5 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.

6.5.1.6 On units with pitch line velocities above 15 m/s (3000 ft/min), the gearbox casing shall be designed so that the gears do not dip into the oil during operation or upon shutdown.

6.5.2 Mounting

6.5.2.1 Mounting surfaces shall be machined to a finish of 60 μm (250 $\mu\text{in.}$) arithmetic average roughness (Ra) or better.

6.5.2.2 Mounting surfaces shall be in the same horizontal plane within 25 μm (1 mil).

6.5.2.3 Each mounting surface shall be machined within a flatness of 42 μm per linear m (0.5 mil per linear ft) of mounting surface.

6.5.2.4 Different mounting planes shall be parallel to each other within 50 μm (2 mil).

6.5.2.5 The upper machined or spot faced surface shall be parallel to the mounting surface.

6.5.2.6 Hold-down bolts holes shall be drilled perpendicular to the mounting surface or surfaces, machined or spot faced to a diameter three times that of the bolt diameter and to allow for equipment alignment, be 13 mm ($1/2$ in.) larger in diameter than the hold-down bolt.

6.5.2.7 The equipment shall be provided with vertical jackscrews.

6.5.2.8 The equipment shall be drilled with pilot holes at two locations that are accessible for use in final doweling.

6.5.2.8.1 An alternative arrangement utilizing keys and keyways may be provided.

6.5.2.8.2 Dowel hole or keys locations shall be selected to minimize the effects of casing distortion and misalignment with connected equipment.

NOTE For parallel shaft units, these locations are typically as close as possible to the vertical plane of the highest speed pinion centerline.

6.5.3 Piping and Tubing

6.5.3.1 Cast gear casings may not be adaptable to flanged connections; in this case reinforced boss threaded connections shall be provided.

6.5.3.2 Socket weld piping connections are prohibited.

6.5.3.3 Any internal tubing shall be stainless steel tubing in accordance with 7.6.5 and 6.5.3.4 through 6.5.3.7.

6.5.3.4 Where internal space does not permit the use of DN15, DN20, or DN25 ($1/2$, $3/4$, or 1 in.) ASTM A312 pipe, seamless steel tubing conforming to ASTM A192 with stainless steel fittings, or stainless steel tubing conforming to ASTM A269 with stainless steel fittings may be furnished. Tubing thicknesses shall meet the requirements of Table 9.

Table 9—Minimum Tubing Wall Thickness

	Nominal Tubing Size		Minimum Wall Thickness	
	mm	in.	mm	in.
DN15	12.7	1/2	1.65	0.065
DN20	19.05	3/4	2.40	0.095
DN25	25.4	1	2.75	0.109

6.5.3.5 Prior to gear unit assembly, all internal piping and oil passages shall be cleaned to remove all foreign material.

6.5.3.6 The design of internal piping and oil pans shall achieve proper support and protection to prevent damage from vibration or from shipment, operation, and maintenance.

6.5.3.7 Cantilevered piping shall include reinforcing gussets in two planes at all pipe-to-flange connections.

6.5.4 Joints

6.5.4.1 The main split line joints casings shall use a metal-to-metal bolted joint.

6.5.4.2 The joint shall be sealed with a compound that is compatible with the fluids to be handled.

6.5.4.3 Gaskets (including string type) shall not be used.

6.5.5 Bolting

6.5.5.1 Case bolting may be of the through-bolt or studded type.

6.5.5.1.1 Threaded bolt holes shall not penetrate through the wall into the interior of the casing.

6.5.5.1.2 Disassembly shall not require removal of studs.

6.5.5.2 Hexagonal cap screws are acceptable on all other joints where cap screws are essential for assembly purposes and have been approved by the purchaser.

6.5.5.3 Cap screws other than hexagonal cap screws are not permitted.

6.5.5.4 Studded connections shall be furnished with studs installed.

6.5.5.4.1 Blind stud holes should be drilled only deep enough to allow a preferred tap depth of 1 1/2 times the major diameter of the stud.

- **6.5.5.4.2** Machined and studded connections shall conform to the facing and drilling requirements of ASME B16.1, ASME B16.5, ASME B16.42, or ASME B16.47 or EN 1092-1 and EN 1092-2, as specified.

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

6.5.5.5 Bolting shall be furnished as follows.

- a) The details of threading shall conform to ISO 261, ISO 262, ISO 724, ASME B1.1 (ISO 965).
- b) Adequate clearance shall be provided at bolting locations to permit the use of socket or box wrenches.
- c) Internal socket-type, slotted-nut, or spanner-type bolting shall not be used unless specifically approved by the purchaser.

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

6.5.5.6.1 If the available area is inadequate, the grade symbol may be marked on one end and the manufacturer's identification symbol marked on the other end.

6.5.5.6.2 All studs shall be marked on the exposed end.

6.5.5.7 Set screws shall be secured after final tightening.

NOTE A set screw is a headless screw with an internal hex opening on one end.

6.5.6 Assembly and Disassembly

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

6.5.6.2 Lifting lugs or eyebolts shall be provided for lifting the top half of the casing.

6.5.6.3 Lifting lugs or eyebolts not capable of lifting the entire casing shall be clearly and permanently marked on the casing.

6.5.6.3.1 Methods of lifting the assembled machine shall be specified by the vendor.

6.5.6.3.2 If an eyebolt is used, it shall be a shouldered type design.

6.5.6.4 Lifting lugs shall be inspected by nondestructive examination method; such method shall be suitable for the materials of gear casing construction.

6.5.6.5 Casing shall be provided with a relief under the parting line jacking screws.

6.6 Casing Connections

6.6.1 Service and Size Criteria

6.6.1.1 The vendor shall provide a single supply and a single drain connection on the gear casing for purchaser supplied external lube oil systems.

NOTE General-purpose gear casings usually have a self-contained lube oil system.

6.6.1.2 The minimum drain pipe size shall be based on the total inlet flow to the gear casing. For drains with a nominal internal diameter less than or equal to 12 in., minimum drain size shall be according to Table 10.

6.6.1.3 For drains with a nominal internal diameter greater than 305 mm (12 in.), the design velocity shall

not exceed 0.38 m/s (1.25 ft/s) based on the drain line running at no more than half full. The allowable flow may be calculated as:

$$\text{In SI units: } F_{df} = 0.009D^2 \quad (6a)$$

$$\text{In USC units: } F_{df} = 1.53D^2 \quad (6b)$$

where

F_{df} is the allowable flow in drain line with D over 300 mm, l/m (gpm);

D is the internal drain line diameter, mm (in.).

Table 10—Drain Pipe Sizes

Inlet Flow Rate		Minimum Drain Size	
Liters per Minute	Gallons per Minute	Millimeters	Nominal Pipe Size (NPS)
26	7	75	3
56	15	100	4
170	45	150	6
380	100	200	8
585	155	250	10
830	220	300	12

NOTE Sizing and sloping of the drain piping is specified in API 614. If the drain piping is not designed to ensure that it is never more than half full at any point, the gear unit cannot drain properly. Gear units with insufficient drainage can experience overheating, oil leakage, and potential damage.

6.6.1.4 Openings for piping connections shall be DN 20 ($\frac{3}{4}$ NPS) or larger and in accordance with ISO 6708. Sizes DN 32, DN 65, DN 90, DN 125, DN 175, and DN 225, ($1\frac{1}{4}$, $2\frac{1}{2}$, $3\frac{1}{2}$, 5, 7, and 9 NPS) shall not be used.

6.6.2 Lube Oil Connections

- **6.6.2.1** Lube oil inlet and drain connections, oriented as specified, shall be at least DN 20 ($\frac{3}{4}$ in. NPS) and shall be flanged or machined and studded.
- **6.6.2.1.1** Dimensions for these connections shall conform to ASME B16.5 or EN 1092-1, EN 1092-2, as specified.

6.6.2.1.2 The connection face surface shall be machined flat with a nominal surface finish of $R_a = 3.2\text{ }\mu\text{m}$.

6.6.2.1.3 Where flanged or machined and studded openings are impractical, threaded openings in sizes DN 20 (NPS $\frac{3}{4}$) through DN 40 (NPS $1\frac{1}{2}$) are permissible.

6.6.2.1.4 These threaded openings shall be installed as follows.

- a) A pipe nipple, preferably not more than 150 mm (6 in.) long, shall be screwed into the threaded opening.
- b) Pipe nipples shall be a minimum of Schedule 160 seamless for DN 25 (NPS 1) and smaller and a minimum of Schedule 80 for DN 40 (NPS 1 1/2).
- c) The pipe nipple shall be provided with a welding-neck or socket-weld flange.
- d) 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.
- e) Seal-welded joints shall be in accordance with ASME B31.3.
- f) Tapped openings and bosses for pipe threads shall conform to ASME B16.5 (ISO 7-1).
- g) Pipe threads shall be taper threads conforming to ASME B1.20.1.

6.6.2.2 Tapped openings not connected to piping shall be plugged with solid plugs furnished in accordance with ASME B16.11.

6.6.2.2.1 Plugs that may later require removal shall be of corrosion-resistant material.

6.6.2.2.2 Threads shall be lubricated.

6.6.2.2.3 Tape shall not be applied to threads of plugs inserted into oil passages.

6.6.2.2.4 Plastic plugs are not permitted.

6.6.2.3 Flanges shall conform to ISO 7005-1, Series 1, including Annex D and Annex E, or ASME B16.5, as specified, except as specified in 6.6.2.2 through 6.6.2.2.4 and 6.6.2.3.

NOTE 1 ISO 7005-1 (steel flanges) PN 20, 50, 110, 150, 260, 420 are designed to be interchangeable with ASME B16.5 and MSS SP-44 flanges, ISO 7005-1 flanges are not identical to ASME B16.5 and MSS SP-44 but are deemed to comply with the dimensions specified in ASME B16.5 and MSS SP-44.

NOTE 2 ISO PN 2.5, 6 do not have a corresponding ASME class and ASME Class 75, 400, and 800 do not have corresponding ISO PN designation. The use of these PN and Class flange ratings are therefore not recommended.

- **6.6.2.3.1** When ISO 7005-1 has been specified, materials shall be in accordance with Table D-1 (DIN) or Table D-2 (ASTM), as specified.

6.6.2.3.2 The pressure temperature ratings in Annex C shall correspond to the materials specified in ISO 7005-1 Annex E; Table 1-4 covers D-1 materials and Table 5-21 covers D-2 materials.

- **6.6.2.3.3** Gray, malleable, ductile, and cast iron flanges shall be flat faced and conform to the dimensional requirements of ISO 7005-2, ASME B16.1 or ASME B16.42, as specified.

6.6.2.3.4 PN 20 (Class 125) flanges shall have a minimum thickness equal to PN 50 (Class 250) for sizes DN 200 (8 NPS) and smaller.

6.6.2.3.5 Flanges other than those covered in ISO 7005-2 shall conform to the dimensional requirements of the flanges specified in 6.6.2.3.

6.6.2.3.6 Purchaser connections other than those covered by ISO 7005-1, ISO 7005-2, ASME B16.1, or ASME B16.5 require purchaser's approval.

- **6.6.2.3.7** If specified, mating parts shall be furnished by the vendor.
- **6.6.2.3.8** If specified, studs and nuts shall be provided installed.
- 6.6.2.3.9** For studs that bottom out, the first 1 1/2 threads at both ends of each stud shall be removed.
- 6.6.2.3.10** Alternative connections (e.g. SAE, tubing, etc.) are permitted for nonpurchaser connections.
- 6.6.2.3.11** All of the purchaser's connections shall be accessible for disassembly without requiring the machine, or any major part of the machine, to be moved.
- 6.6.2.3.12** The concentricity of the bolt circle and the bore of all casing flanges shall be such that the area of the machined gasket-seating surface is adequate to accommodate a complete standard gasket without protrusion of the gasket into the fluid flow.
- 6.6.2.3.13** 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 gear elements.
- 6.6.2.3.14** The inspection opening, or openings, shall be at least one-half the width of the gear face.

6.7 Gear Elements

6.7.1 General

6.7.1.1 Gear-teeth profiles shall be manufactured by the generating, shaping, or form process.

6.7.1.1.1 Gears and pinions with pitch line velocities below 15 m/s (3000 ft/min) may be finished unassembled with their shafts. Pitch line velocity is calculated using Equations (7a), (7b), and (7c).

In SI units:

$$V = \frac{\pi dn}{(60)(1000)} \text{ mps} \quad (7a)$$

$$V = \frac{\pi dn}{(1000)} \text{ m/min} \quad (7b)$$

d is the pitch diameter, mm.

In USC units:

$$V = \frac{\pi dn}{12} \text{ fpm} \quad (7c)$$

d is the pitch diameter, in.;

n is the rpm.

6.7.1.1.2 Gears and pinions with pitch line velocities at or above 15 m/s (3000 ft/min) shall be finish cut or ground assembled with their respective shafts.

6.7.1.1.3 Shaving and shaping cutters shall have a hunting tooth combination with the work piece.

6.7.1.2 For pitch line velocities up to 15 m/s (3000 ft/min), gear teeth shall be of ISO 1328 Grade 8 accuracy or better.

6.7.1.2.1 For pitch line velocities between 15 and 30 m/s (3000 and 6000 ft/min), gear teeth shall be of ISO 1328 Grade 7 accuracy or better.

6.7.1.2.2 For pitch line velocities between 30 and 45 m/s (6000 and 9000 ft/min), gear teeth shall be of ISO 1328 Grade 6 accuracy or better.

6.7.1.2.3 For pitch line velocities above 45 m/s (9000 ft/min), gear teeth shall be of ISO 1328 Grade 5 accuracy or better.

6.7.1.3 The tooth surface on loaded faces of completed gears shall have a roughness, as measured along the pitch line, of 0.8 μm (32 $\mu\text{in.}$) Ra above a 20 m/s (4000 ft/min) pitch line velocity limit and 1.6 μm (64 $\mu\text{in.}$) Ra at or below a 20 m/s (4000 ft/min) minimum pitch line velocity limit.

NOTE See also ASME B46.1 on measuring methods.

6.7.1.4 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.

- **6.7.1.5** If specified, a hunting tooth combination is required.

NOTE A pair of mating gears have a hunting tooth combination, so that a tooth on the pinion does not repeat contact with a tooth on the gear wheel until it has contacted all of the other gear wheel teeth. This is to ensure even wear on all teeth.

6.7.1.6 If gear manufacturer cannot achieve a hunting tooth combination and acceptable gear ratio variation, the gear manufacturer and the vendor shall negotiate a mutually agreeable solution.

6.7.1.7 Each helical gear and pinion of parallel shaft gear sets shall be supported between two bearings. Overhung designs are acceptable only below 15 m/s (3000 ft/min) pitch line velocity and 225 kilowatts (300 horsepower).

6.7.1.8 Double helical gears continuous to their apex (herringbone gears) are not acceptable.

6.7.1.9 Shrunk-on forged rims may be used if approved by the purchaser.

6.7.2 Gear Wheel to Shaft Attachment

6.7.2.1 If the gear wheel is separate from the shaft (not integral), gear wheel shall be assembled on the shaft with an interference fit and either with or without a key.

6.7.2.1.1 Unkeyed fits with appropriate design interference are permissible with purchaser's approval.

6.7.2.1.2 The fit shall have a minimum interference of 0.001 mm per mm (0.001 in. per in.) of bore diameter.

6.7.2.1.3 The actual interference fit shall be determined by the gear manufacturer to prevent the gear to shaft juncture from becoming loose under any condition of speed, torque, temperature, etc.

6.7.2.1.4 The interference shall be shown on the data sheet and outline drawing.

6.7.2.2 The method of attaching the gear wheel to the shaft (the interference fit) shall maintain concentricity and balance under all specified operating conditions, including overspeed (see 6.1.9).

6.7.2.3 Design of the gear to shaft juncture shall include the following minimum considerations:

- a) operational duty requirements such as all specified operating conditions, overloads, and thrust loads;
- b) centrifugal forces acting on the wheel;
- c) stresses exerted on the gear wheel and shaft due to the interference fit;
- d) thermal dilatation of the gear wheel and the shaft together with temperature differences between gear wheel and shaft (especially in the period after a start-up from cold condition);
- e) surface roughness and loss of interference due to smoothening of the surface roughness in the area of the interference that occurs in the shrinking process;
- f) installation requirements for fitting the wheel onto the shaft and the amount of installation clearance achievable by heating/cooling without adversely affecting the components.

6.7.2.4 The gear to shaft fit design shall preclude axial movement of the gear along the shaft caused by changes in temperature.

6.7.2.5 The hub bore and shaft outside diameter (O.D.) shall be machined to a finish of 32 μm . arithmetic average roughness (Ra) or better in the interference fit contact area.

6.7.2.6 Keys and keyways shall meet the requirements of ASME B17.1.

6.7.3 Shafts

6.7.3.1 Shafts shall be sized to transmit the maximum torque, taking into consideration the gear rated power and any other condition specified by the purchaser/entity having train responsibility (such as minimum speed and starting conditions) within the stress limits of AGMA 6001-E08.

6.7.3.1.1 Shafts shall be made of one-piece, heat-treated forged, or hot-rolled steel.

6.7.3.1.2 Shafts shall be accurately machined throughout their entire length.

6.7.3.1.3 Shafts shall be finished at their bearing surfaces.

- **6.7.3.2** If specified, or when vibration and/or axial-position probes are furnished, the rotor shaft-sensing areas to be observed by radial-vibration probes shall be concentric with the bearing journals.

6.7.3.2.1 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, for a minimum of one probe-tip diameter on each side of the probe.

6.7.3.2.2 For gear units with axial floats that exceed half of a probe tip diameter, the probe sensing area shall be long enough to cover the entire float, plus one probe tip diameter on each side.

6.7.3.2.2.1 These areas shall not be metallized, sleeved, or plated.

NOTE Electrical and mechanical runout checks are not required on shafts supported by rolling element bearings.

6.7.3.3 The final surface finish of sensing areas observed by radial vibration probes shall be a maximum of 0.8 μm (32 $\mu\text{in.}$) Ra, preferably obtained by honing or burnishing.

6.7.3.3.1 For areas observed by radial vibration probes the combined total electrical and mechanical runout shall not exceed the value from Equation (8a, 8b) or 6.35 μm (0.25 mil), whichever is greater.

In SI units:

$$R = \frac{25.4}{4} \sqrt{\frac{12,000}{N}} \quad (8a)$$

In USC units:

$$R = \frac{1}{4} \sqrt{\frac{12,000}{N}} \quad (8b)$$

where

N is the maximum continuous operating speed (rpm);

R is the allowable runout ($\mu\text{m}/\text{mil}$).

6.7.3.3.2 For areas observed by axial vibration position probes, the combined total electrical and mechanical runout shall not exceed 12.7 μm (0.5 mil).

NOTE 1 If all reasonable efforts fail to achieve the limits noted in 6.7.3.3, the vendor and the purchaser can agree on alternate acceptance criteria.

NOTE 2 Diamond burnishing of probe areas has been shown to be effective in reducing electrical runout.

NOTE 3 Manufacturers should avoid the use of magnetic holders or chucks in the probe areas during manufacture or handling, which can cause electrical runout.

NOTE 4 Shaft materials such as 17-4 PH frequently exhibit excessive electrical runout. Some vendors have successfully reduced electrical runout to acceptable levels with treatments such as the application of 1 mm (0.04 in.) radial thickness of metalized aluminum. Only vendors with proven successful experience or test data should be permitted to metalize shafts to reduce electrical runout.

6.7.3.4 To prevent the buildup of potential voltages in the shaft, residual magnetism of the rotating element free air gauss level shall not exceed 3 gauss when measured with a calibrated indicator (see 8.2.2.4).

NOTE 1 The free air gauss level is measured while suspending the rotor from nonconductive straps with no influence from stray magnetic fields.

NOTE 2 A Hall effect probe is preferred.

6.7.3.5 Electrical and mechanical runout shall be determined by rotating the rotor through the full 360 degrees supported in V-blocks at the journal centers while measuring runout with a noncontacting vibration probe and a dial indicator at the centerline of each probe location and one probe-tip diameter to either side.

NOTE The rotor runout determined in V-blocks generally will not be reproduced when the rotor is installed in a machine with hydrodynamic bearings. This is due to pad orientation on tilt pad bearings and effect of lubrication in all journal bearings. The rotor will assume a unique position in the bearings based on the slow roll speed and rotor weight.

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

6.7.4 Shaft Ends

6.7.4.1 Unless otherwise specified, cylindrical keyed shaft end design shall be provided.

NOTE Other options include taper or integral shaft end.

6.7.4.2 If shaft end keyways are specified, or keyed fits are used in the gear assembly, shaft keyways shall have fillet radii conforming to ASME B17.1.

6.7.4.3 The shaft extension type shall be as specified on the data sheets.

6.7.4.3.1 Cylindrical shaft extensions shall conform to the requirements of AGMA 9002-B04.

6.7.4.3.2 Tapered shaft extensions shall conform to the requirements of API 671.

6.7.5 Quality Assurance

6.7.5.1 Gear Contact Check

6.7.5.1.1 Each pair of mating gears for parallel shaft units shall have a contact check in the gear casing at the vendor's shop.

6.7.5.1.2 Those gear sets operating above 20 m/s (4000 ft/min) pitch line velocity shall be checked for contact on a contact checking stand and in the job casing at the vendor's shop.

6.7.5.1.3 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.

6.7.5.1.3.1 With the gear elements held firmly on the correct center distance and with the shaft centerlines parallel within 42 μm per m (0.5 mil/ft) with a total misalignment of not more than 25 μm (1 mil), 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.

6.7.5.1.3.2 The color transfer shall show evidence of contact distributed across the face as prescribed by the vendor.

6.7.5.1.3.3 Prior to the contact tests, the vendor shall make available to the purchaser a contact drawing or vendor engineering specification that defines the expected and acceptable contact.

6.7.5.1.3.4 Unmodified tooth profile leads shall show a minimum contact of 70 % along the axis and 30 % radially.

6.7.5.1.3.5 Contact drawings or specifications and the results of the contact checks shall be delivered with the unit documentation.

6.7.5.1.3.6 The results of the contact check shall be preserved by lifting the colors from a tooth, by applying and peeling off a strip of clear adhesive tape and then sticking the tape to an annotated sheet of paper.

6.7.5.2 The vendor shall have a manufacturing process control system to ensure that the designed quality of gearing is produced.

NOTE The process control system should include manufacturing planning, machine tool maintenance and inspection programs, gear generating, hardening and finishing procedures, cutting tool selection and maintenance procedures, material control procedures, heat treatment control, inspection procedures, and quality assurance programs required to achieve and maintain the required gear quality.

6.7.5.3 Gear elements shall be checked per ISO 1328-1.

- **6.7.5.4** If specified, gear tooth accuracy reports shall be provided.

6.7.5.5 Gear elements shall not be modified on the basis of tooth contact checks made in the gear casing. Gear elements may be modified on the basis of results from gear checking machines or contact pattern while in the checking stand.

6.7.5.6 To verify apex runout, the gear vendor shall demonstrate the axial stability of each meshing pair of double-helical gears operating with pinion speeds above 1800 r/min by either a) measuring the unfiltered peak-to-peak shaft axial vibration, that do not exceed 63 μm (0.0025 in.) during full-speed testing, or b) using indicators to make a slow rotation check.

NOTE The preferred method for this slow rotation check is to hold one member (usually the gear wheel) 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 wheel with a drag torque applied in a direction that will force the normally loaded tooth faces into contact.

6.7.5.7 The total axial motion of the other member (pinion) relative to the fixed member (gear) shall not exceed 38 μm (0.0015 in.) for gear units having a 20 m/s (4000 ft/min) pitch line velocity or greater and 63 μm (0.0025 in.) for gear units having less than a 20 m/s (4000 ft/min) pitch line velocity.

6.8 Dynamics

6.8.1 General

6.8.1.1 For a detailed discussion on rotor dynamics, refer to API PUBL 684.

6.8.1.2 In the design of rotor-bearing systems, consideration shall be given to all potential sources of excitation that shall include, but are not limited to, the following:

- a) unbalance in the rotor system;
- b) fluid destabilizing forces from bearings, seals, and aerodynamics;
- c) internal rubs;
- d) lobe passing frequencies;
- e) gear-tooth meshing and side bands;
- f) coupling misalignment;
- g) loose rotor-system components;
- h) internal friction within the rotor assembly;
- i) synchronous excitation from complimentary geared elements;
- j) control loop dynamics such as those involving active magnetic bearings and variable frequency drives;
- k) electrical line frequency.

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

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

6.8.2 Lateral Analysis

6.8.2.1 Critical speeds and their associated amplification factors (AFs) shall be determined by means of a damped unbalanced rotor response analysis.

6.8.2.2 The location of all critical speeds below the trip speed shall be confirmed on the test stand during the mechanical running test (see 6.8.3.1). The accuracy of the analytical model shall be demonstrated.

- 6.8.2.3** If specified, the gear vendor shall provide an undamped lateral critical speed analysis to identify the first four undamped critical speeds.

NOTE 1 Critical speeds are typically not a problem for gear elements operating at 3700 r/min (1800 r/min for overhung bevel gears) or below.

NOTE 2 Gear wheels that operate between 40 % and 50 % of pinion speed (2:1 to 2.5:1 gear ratio) can excite instability in the pinion bearings. Therefore, if gear ratios between 2:1 and 2.5:1 are required, consideration should be given to performing a pinion stability analysis.

NOTE 3 For the purposes of this standard, casing support structure stiffness does not have to include foundation or other support stiffness effects, since gear manufacturers typically have no control over the support base stiffness. If the supports are not sufficiently stiff, the results of these analyses can be affected.

NOTE 4 Figure 10 shows a typical undamped lateral critical speed map.

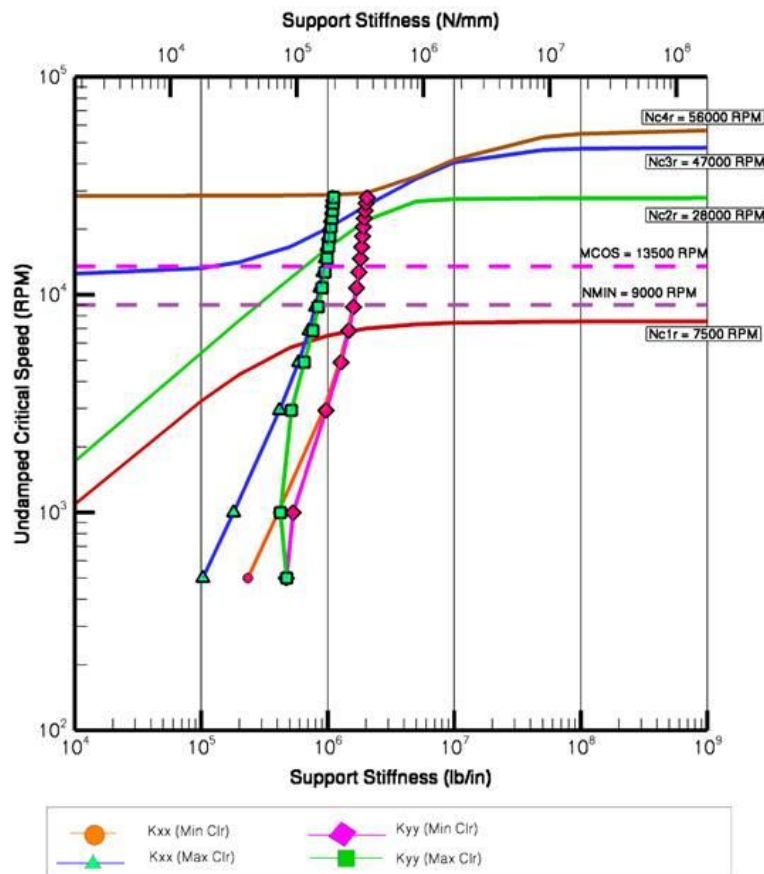


Figure 10—Undamped Lateral Critical Speed Map

6.8.2.4 The rotor dynamic analysis shall include but shall not be limited to the following:

- a) rotor stiffness, mass and polar and transverse moments of inertia, including coupling halves, and rotor stiffness changes due to shrunk on components;
- b) material properties as a function of operating temperature variation along the shaft;
- c) bearing lubricant-film stiffness and damping values including changes due to speed, load, preload, range of oil inlet temperature, maximum to minimum clearances resulting from accumulated assembly tolerances, and the effect of asymmetrical loading that may be caused by gear forces (including the changes over range of maximum to minimum torque), side streams, eccentric clearances, volutes, partial arc admission, etc.;
- d) for tilt-pad bearings, the pad pivot stiffness;
- e) structure stiffness, mass, and damping characteristics, including effects of excitation frequency over the required analysis range; for machines whose dynamic structural stiffness values are less than or equal to 3.5 times the bearing stiffness values in the range from 0 to 150 % of N_{mc} , the structure characteristics shall be incorporated as an adequate dynamic system model, calculated frequency dependent structure stiffness and damping values (impedances), or structure stiffness and damping values (impedances) derived from modal or other testing; the vendor shall state the structure characteristic values used in the analysis and the basis for these values (for example, modal tests of similar rotor structure systems, or calculated structure stiffness values);
- f) rotational speed, including the various starting-speed detents, operating speed and load ranges (including agreed upon test conditions if different from those specified), trip speed, and coast-down conditions;
- g) the influence, over the operating range, of the casing shaft end oil seals, if present; minimum and maximum stiffness will be considered taking into account the tolerance on the component clearance and the oil inlet temperature;
- h) the location and orientation of the radial vibration probes that shall be the same in the analysis as in the machine;
- i) squeeze film damper mass, stiffness and damping values considering the component clearance and centering tolerance, oil inlet temperature range, and operating eccentricity;
- j) for machines equipped with rolling element bearings, the vendor shall state the bearing stiffness and damping values used for the analysis; the basis for these values or the assumptions made in calculating the values shall be presented.

- **6.8.2.5** If specified, the vendor with unit responsibility shall provide a train lateral analysis for machinery trains with flexible couplings.

6.8.2.6 At least three power levels shall be analyzed for the undamped analyses.

6.8.2.7 The analysis shall include bearing-oil film, bearing structure at 10 %, 50 %, and 100 % gear unit rated power, and gear unit casing support structure stiffnesses.

- **6.8.2.8** If specified, a separate damped unbalanced response analysis shall be conducted for each critical speed within the speed range of 0 %–150 % of N_{mc} .

6.8.2.8.1 Unbalance shall analytically be placed at the locations defined in Figure 11.