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Petroleum and natural gas industries — High-speed special-purpose gear units

Industries du pétrole et du gaz naturel — Engrenages à grande vitesse pour applications particulières

Reference number
ISO 13691:2001(E)

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Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.ch
Web www.iso.ch

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 13691 was prepared by Technical Committee ISO/TC 60, *Gears*, Subcommittee SC 2, *Gear capacity calculation*.

ISO 13691 is based on API 613 and is intended to give ratings similar to those found when using API 613.

Annexes A to G of this International Standard are for information only.

Introduction

This International Standard is based on the accumulated knowledge and experience of manufacturers and users of gear units. It has been developed to satisfy the requirements of the petroleum, petrochemical and natural gas industries, but its use is not restricted to these industries.

The purpose of this International Standard is to establish minimum requirements for design and construction so that the equipment is suitable for the purpose for which it is required.

Energy conservation and protection of the environment are matters of concern and are important in all aspects of equipment design, application and operation. The manufacturers and users of equipment should aggressively pursue alternative, innovative approaches which improve energy utilization and/or minimize the environmental impact, without sacrificing safety or reliability. Such approaches should be thoroughly investigated and purchase options should increasingly be based on the estimation of whole-life costs and the environmental consequences rather than acquisition costs alone.

This International Standard requires the purchaser to specify certain details and features.

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

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

Petroleum and natural gas industries — High-speed special-purpose gear units

1 Scope

This International Standard specifies the minimum requirements for enclosed, precision, single and double helical, one- and two-stage speed increasers and reducers of parallel shaft design with pinion speeds of 3000 min^{-1} or greater, or pitch line velocities of 25 m/s or greater, for special purpose applications. Such applications will typically be required to operate continuously for extended periods, without installed spare equipment and are critical to the continued operation of the installation. By agreement this International Standard may be used for other services.

This International Standard also specifies a method of rating gears which meet the following criteria:

a) gear accuracy

— teeth accuracy: accuracy grade 4 or better as given in ISO 1328-1:1995, for both single pitch deviation, f_{pt}, and total cumulative pitch deviation, F_p,

— total helix deviation F_β between the helices of the pinion and wheel: accuracy grade 4 or better as given in ISO 1328-1:1995;

b) range of the transverse contact ratios: $1,2 < \varepsilon_\alpha < 2,0$;

c) overlap ratio $\varepsilon_\beta \geqslant 1,0$;

d) helix angle: $5 \leqslant \beta \leqslant 35°$;

e) working flanks of the pinion or gear: provided with profile modifications to obtain a good conjugate tooth load distribution along the path of contact;

f) working flanks of pinion or gear: modified as necessary to compensate for both torsional and bending deflections and, when necessary for gears with pitch line velocities in excess of 100 m/s, also for thermal distortions;

g) gear lubrication: straight mineral oil, viscosity grade VG-32 or VG-46 (see ISO 3448);

h) material of the gear teeth: quality MQ or better, in accordance with ISO 6336-5:1996.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

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

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

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

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

ISO 965-1, *ISO general-purpose metric screw threads — Tolerances — Part 1: Principles and basic data*

ISO 965-2, *ISO general- purpose metric screw threads — Tolerances — Part 2: Limits of sizes for general purpose external and internal screw threads — Medium quality*

ISO 965-3, *ISO general-purpose metric screw threads — Tolerances — Part 3: Deviations for constructional screw threads*

ISO 1122-1, *Vocabulary of gear terms — Part 1: Definitions related to geometry*

ISO 1328-1:1995, *Cylindrical gears — ISO system of accuracy — Part 1: Definitions and allowable values of deviations relevant to corresponding flanks of gear teeth*

ISO 1940-1:1986, *Mechanical vibration — Balance quality requirements of rigid rotors — Part 1: Determination of permissible residual unbalance*

ISO 2953, *Mechanical vibration — Balancing machines — Description and evaluation*

ISO 3448:1992, *Industrial liquid lubricants — ISO viscosity classification*

ISO 6336-3, *Calculation of load capacity of spur and helical gears — Part 3: Calculation of tooth bending strength*

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

ISO 6743-6, *Lubricants, industrial oils and related products (class L) — Classification — Part 6: Family C (Gears)*

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

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

ISO 8501-1:1988, *Preparation of steel substrates before application of paints and related products — Visual assessment of surface cleanliness — Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings*

ISO 8579-1, *Acceptance code for gear units — Part 1: Test code for airborne sound*

ISO 8821, *Mechanical vibration — Balancing — Shaft and fitment key convention*

ISO 9084:2000, *Calculation of load capacity of spur and helical gears — Application to high speed gears and gears of similar requirement*

ISO/TR 10064-4, *Cylindrical gears — Code of inspection practice — Part 4: Recommendations relative to surface texture and tooth contact pattern checking*

ISO 10438-1, *Petroleum and natural gas industries — Lubrication, shaft-sealing and control-oil systems and auxiliaries — Part 1: General requirements*

ISO 10438-2, *Petroleum and natural gas industries — Lubrication, shaft-sealing and control-oil systems and auxiliaries — Part 2: Special-purpose oil systems*

ISO 10438-3, *Petroleum and natural gas industries — Lubrication, shaft-sealing and control-oil systems and auxiliaries — Part 3: General-purpose oil systems*

ISO 10441, *Petroleum and natural gas industries — Flexible couplings for mechanical power transmission — Special purpose applications*

ISO/TR 13593, *Enclosed gear drives for industrial applications*

ISO/TR 13989-1, *Calculation of scuffing load capacity of cylindrical, bevel and hypoid gears — Part 1: Flash temperature method*

ISO/TR 13989-2, *Calculation of scuffing load capacity of cylindrical, bevel and hypoid gears — Part 2: Integral temperature method*

IEC 60079-0, *Electrical apparatus for explosive gas atmospheres — Part 0: General requirements*

API 670, *Vibration, axial position and bearing-temperature monitoring systems*

ASME B16.11, *Forged fittings, Socket-Welding and Threaded*

ASME, *Boiler and pressure vessel code — Section V*

ASME, *Boiler and pressure vessel code — Section VIII, Division 1*

ASME Y 14.2 M, *Line conventions and lettering*

ASTM A956, *Standard test method for Leeb hardness testing of steel products*

ASTM E94, *Standard guide for radiographic examination*

ASTM E125, *Standard reference photographs for magnetic particle indications on ferrous castings*

ASTM E709, *Standard guide for magnetic particle examination*

3 Terms and definitions

For the purposes of this International Standard, the terms and definitions given in ISO 1122-1 and the following apply.

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

3.1
axially [horizontally] split casing joint
casing joint parallel to the shaft centreline

3.2
critical speed
shaft rotational speed at which the rotor-bearing-support system is in a state of resonance with any exciting frequency associated with that speed

3.3
wheel
lower speed gear element in mesh

3.4
pinion
higher speed gear element in mesh

3.5
gear rated power
maximum power specified by the purchaser on the data sheet and stamped on the nameplate

cf. 5.2.1.

3.6
normal transmitted power
power at which usual operation is expected and optimum efficiency is desired

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

3.7
mechanical rating
gear rated power (3.5) multiplied by the specified **gear selection factor** (3.17).

3.8
hunting tooth combination
⟨mating gears⟩ combination existing when a tooth on the pinion does not repeat contact with a tooth on the gear until it has contacted all the other gear teeth

3.9
maximum allowable speed
highest rotational speed at which the manufacturer's design will permit continuous operation

3.10
maximum continuous speed
⟨variable-speed unit⟩ rotational speed at least equal to 105 % of the rated speed

3.11
maximum continuous speed
⟨constant-speed unit⟩ rotational speed equal to the rated speed

3.12
minimum allowable speed
lowest rotational speed at which the manufacturer's design will permit continuous operation

3.13
rated input speed
specified (or nominal) rated speed of the driver, as designated by the purchaser

3.14
rated output speed
specified (or nominal) rated speed of the driven equipment, as designated by the purchaser.

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

3.15
contact stress number
σ_H
contact stress calculated based on the Hertzian contact pressure

3.16
bending stress number
σ_F
bending stress calculated from the resistance to fatigue cracking at the tooth root fillet

3.17
gear selection factor
K_{SL}
factor applied to the calculated contact stress number and the calculated bending stress number, depending on the characteristics of the driver and the driven equipment, to account for potential overload, shock load and/or continuous oscillatory torque characteristics

3.18
trip speed
rotational speed at which the independent emergency overspeed device operates to shut down a prime mover

NOTE 1 For fixed-frequency alternating current motor drives, the trip speed is taken to be the speed corresponding to the synchronous speed of the motor at the highest supply frequency.

NOTE 2 For steam turbines and reciprocating engines, the trip speed is at least 110 % of the maximum continuous speed. For gas turbines, the trip speed is at least 105 % of the maximum continuous speed.

3.19
special-purpose application
application for which the equipment is designed for uninterrupted, continuous operation in critical service and for which there is usually no spare equipment

3.20
total indicated runout
total indicator reading
TIR
runout of a diameter or face determined by measurement with a dial indicator

NOTE The indicator reading implies an out-of-squareness equal to the reading or an eccentricity equal to half the reading.

3.21
Gauss level
magnetic field level of a component measured with a “Hall effect” probe with no interference from adjacent magnetic parts or structures

3.22
unit responsibility
responsibility for coordinating the technical aspects of the equipment and all auxiliary systems included in the scope of the order

NOTE Responsibility for such factors as the power requirements, speed, rotation, general arrangement, couplings, dynamics, noise, lubrication, sealing system, material test reports, instrumentation, piping, and testing of components is included.

3.23
purchaser
individual or organization that issues the order and specification to the vendor

NOTE The purchaser may be the owner of the plant in which the equipment is to be installed, or the owner´s agent (often the vendor of the equipment to be driven by the gear).

3.24
vendor
organization that supplies the equipment

NOTE The vendor may be the manufacturer of the equipment or the manufacturer´s agent and is normally responsible for service support.

4 Symbols and abbreviated terms

See Table 1.

Table 1

Symbol	Meaning or term	Unit
a	centre distance	mm
b	facewidth	mm
b_B	facewidth of one helix on a double helical gear	mm
B	total facewidth of a double helical gear including the gap width	mm
$d_{1,2}$	reference diameter of pinion, wheel	mm
$D_{1,2}$	shaft diameter at coupling of pinion, wheel	mm
f_{pt}	single pitch deviation	µm
F_p	total cumulative pitch deviation	µm
F_t	(nominal) transverse tangential force at reference cylinder	N
F_R	external force (coupling)	N
F_β	total helix deviation	µm
HBW	Brinell hardness	—
HRC	Rockwell hardness number (C scale)	—
K_v	dynamic factor	—
$K_{F\beta}$	face load factor (root stress)	—
$K_{H\beta}$	face load factor (contact stress)	—
K_{SL}	selection factor	—
m_n	normal module	mm
$n_{1,2}$	rotational speed of pinion, of wheel, nominal	min^{-1}
P	gear rated power	kW
Ra	arithmetic average roughness value	µm
u	gear ratio $z_2/z_1 \geqslant 1$	—
v	pitch line velocity at reference cylinder	m/s
Y_F	form factor	—
Y_S	stress correction factor	—
Y_β	helix angle factor (root stress)	—
z_1, z_2	number of teeth of pinion, of wheel	—
Z_E	elasticity factor	$\sqrt{N/mm^2}$
Z_H	zone factor	—
Z_β	helix angle factor (contact stress)	—
Z_ε	contact ratio factor (contact stress)	—
α_n	normal pressure angle	°
α_t	transverse pressure angle	°
α_{wt}	pressure angle at the pitch cylinder	°
β	helix angle at the reference cylinder	°
β_b	base helix angle	°

Table 1 *(continued)*

Symbol	Meaning or term	Unit
ε_α	transverse contact ratio	—
ε_β	overlap ratio	—
σ_F	calculated bending stress number	N/mm^2
σ_{FAD}	allowable design bending stress number	N/mm^2
σ_H	calculated contact stress number	N/mm^2
σ_{HAD}	allowable design contact stress number	N/mm^2

5 Basic design

5.1 General

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

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

● **5.1.3** Control of the sound pressure level (SPL) of all equipment furnished shall be a joint effort of the purchaser and the vendor. Unless otherwise specified, the equipment furnished by the vendor shall conform to the requirements of ISO 8579-1 and to the maximum allowable sound pressure level specified by the purchaser.

5.1.4 Equipment shall be designed to run safely to the trip speed setting. Unless otherwise agreed, rotors for turbine driven gear units shall be designed to operate safely at momentary speeds up to 130 %of the rated speed.

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

● **5.1.6** Electrical components and installations shall be suitable for the area classification (class, group and division) specified and shall comply with the requirements of IEC 60079-0 and with any local codes specified and furnished by the purchaser.

5.1.7 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.

5.1.8 The gear shall perform on the test stand and on its permanent foundation within the specified acceptance criteria. After installation, the performance of the combined units shall be the joint responsibility of the purchaser and the vendor who has unit responsibility.

● **5.1.9** Many factors (such as piping loads, alignment at operating conditions, supporting structure, handling during shipment, and handling and assembly at the site) may adversely affect site performance. To minimize the influence of these factors, the vendor shall review and comment on the purchaser’s baseplate and foundation drawings. In addition, the vendor’s representative may be requested to check alignment at the operating temperature and may be requested to be present during the initial alignment check and the tooth contact check.

● **5.1.10** The purchaser shall specify whether the installation is indoors (heated or unheated) or outdoors (with or without a roof) as well as the weather and environmental conditions in which the equipment must operate (including maximum and minimum temperatures, unusual humidity and dusty or corrosive conditions).

5.1.11 Unless otherwise agreed, gear units shall not require a running-in period at reduced speed and load in the field.

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

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

5.1.13 All equipment shall be designed to permit rapid and economical maintenance. Major parts such as casing components and bearing housings shall be designed (shouldered or cylindrical dowelled) and manufactured to ensure accurate alignment on reassembly. Where practical, components should be dowelled, keyed or shouldered asymmetrically to prevent incorrect assembly.

5.1.14 Spare parts for the machine and all furnished auxiliaries shall meet all the criteria of this International Standard.

● **5.1.15** The purchaser shall specify the appropriate shaft assembly designation selected from the combinations listed in Table 2 and illustrated in Figure 1. The purchaser may alternatively circle one or more of the assembly designations on a copy of Figure 1 and submit the copy with the quotation request. If the shaft arrangement has not been finalized at the time of the quotation request, the purchaser shall designate all of the combinations under consideration.

Table 2 — Shaft assembly combinations

High-speed shaft	Low-speed shaft
L	R
R	L
L	L
R	R
R	LR
L	LR
LR	L
LR	R
LR	LR

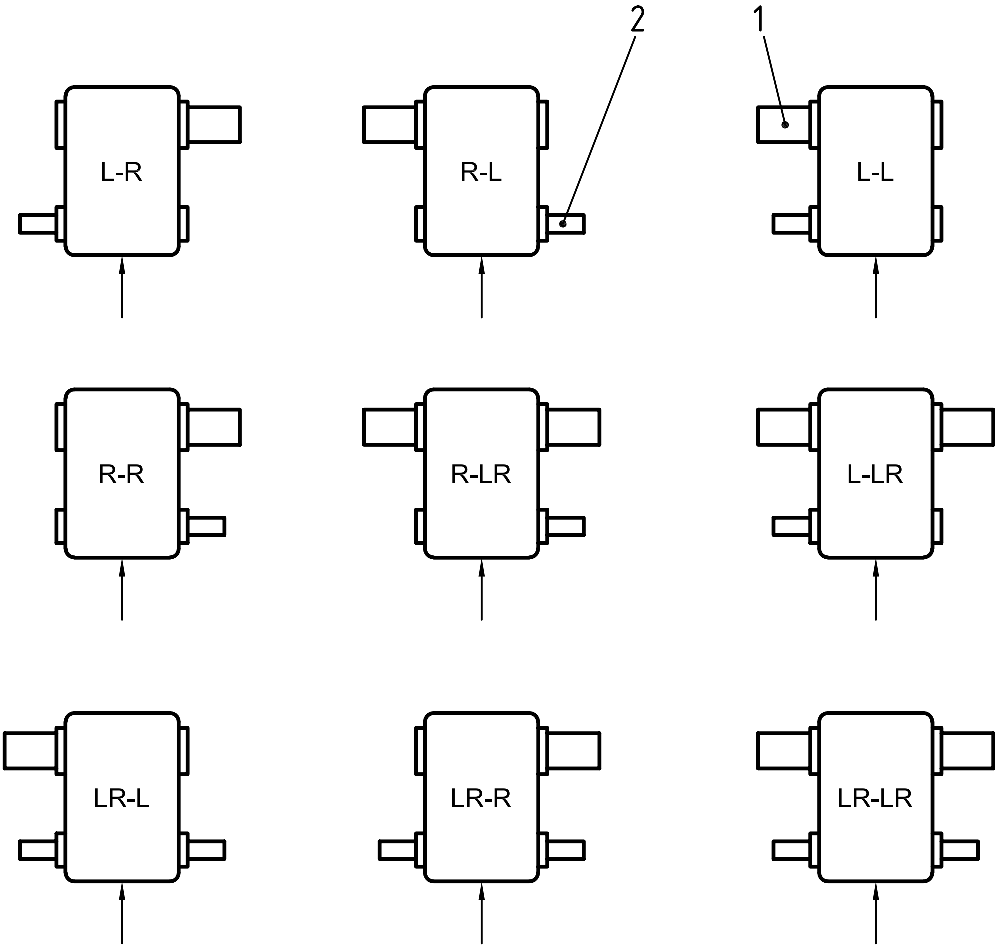
NOTE L = left; R = right. The letters refer to the number and direction of shaft extensions (see Figure 1).

5.1.16 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 shaft.

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

● **5.1.16.2** 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 1) and submit a copy of the figure with the quotation request.

● **5.1.16.3** In finalizing the data for purchase, the purchaser shall prepare a sketch that shows the direction of rotation of each item in the train.



Key

1 Low-speed shaft
2 High-speed shaft

NOTE 1 L = left; R = right

NOTE 2 Arrows indicate the line of sight used to determine the direction of the shaft extensions. (The figure depicts plan views.)

NOTE 3 The letter(s) before the hyphen refer to the number and direction of high-speed shaft extensions; the letter(s) after the hyphen refer to the number and direction of low speed shaft extensions.

NOTE 4 The material for this figure was extracted from AGMA 6010-F97 with permission of the publisher.

Figure 1 — Shaft assembly designations (for parallel-shaft, single- and double-helical one- and two-stage speed increasers and reducers)

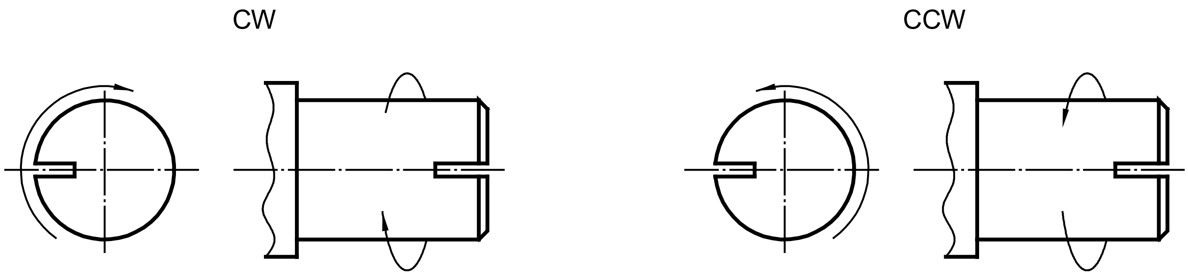


Figure 2 — Shaft rotation designations

5.2 Gear rating

5.2.1 General

The rating method to be used for gears which are not within the limits in clause 1 a) to h) shall be subject to agreement between purchaser and vendor.

It is recognized that special cases will exist in which it may be desirable or even mandatory to deviate from the rating rules specified in 5.2.1 through 5.2.9. The vendor shall describe and justify such deviations in the proposal.

5.2.2 Gear rated power, P

● The required gear rated power P shall be specified by the purchaser. All modes of normal and abnormal operation should be considered. Modes of operation should include the number of starts per unit of time, reduced load, reversed load (if possible), reduced speed, overload and overspeed conditions. For electric motor drives, the gear rated power will be the motor manufacturer's name plate rating multiplied by the motor service factor.

For gear units located next to a single-ended driver, the required gear rated power should be the maximum installed power capability of the driver.

For gear units located between two items of driven equipment, or where the drive is taken from both ends of the driver, the required rated power of the gear should be not less than item 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 pro-rated between the driven equipment, based on normal power demands.

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

5.2.3 Rating criteria

For each gear mesh of the unit, the stress numbers shall be calculated with regard to

— surface durability (pitting),

— tooth-bending strength.

The calculated stress numbers shall not exceed the allowable design stress numbers as shown in Table 3.

In addition, scuffing resistance should be considered.

The rating factors used assume that the working flanks of pinion and gear have been modified as necessary to compensate for both torsional and bending deflections and, when necessary for gears with pitch line velocities in excess of 100 m/s, also for thermal distortions.

Table 3 — Allowable design stress numbers σ_{HAD}, σ_{FAD} — Maximum (L/d) ratios of pinion

Material	Tooth hardness	Allowable design stress number of contact σ_{HAD} N/mm²	Allowable design stress number of bending σ_{FAD} N/mm²	Maximum L/d ratio of pinion: double helical	Maximum L/d ratio of pinion: single helical
Through-hardened steels	302 HBW	525	250	2,2	1,6
	321 HBW	542	256	2,2	1,6
	341 HBW	560	263	2,2	1,6
	363 HBW	580	270	2,2	1,6
Carburized and case-hardened steels	58 HRC	760	350	2,0	1,6
Nitrided steels	58 HRC	660	270	2,2	1,6

NOTE 1 HBW = Brinell hardness number, HRC = Rockwell “C” hardness number.

NOTE 2 $L = b$ (for single-helical gear); $L = B$ (for double-helical gear); d = pinion operating pitch diameter, in millimetres.

NOTE 3 For gears which are subject to full load reversal in each load cycle, the values of σ_{FAD} shall be multiplied by a factor 0,7.

5.2.4 Surface durability

The surface stress of the gear teeth is based on the Hertzian contact pressure theory. The following equation has been derived from the method in ISO 9084, see annex G.

$$\sigma_H = 426\sqrt{\frac{F_t}{d_1 b}\cdot\frac{u+1}{u}}\sqrt{K_{SL}} \quad (1)$$

(for a double-helical gear, $b = 2b_B$)

The value of the factor K_{SL} in the above equation shall be determined in accordance with 5.2.8. The symbols are defined in clause 4.

The relation between the calculated contact stress number σ_H and the allowable design contact stress number σ_{HAD} is:

$$\sigma_H \leqslant \sigma_{HAD} \quad (2)$$

(see Table 3).

5.2.5 Tooth-bending strength

The bending strength of a gear is a measure of the resistance to fatigue cracking at the tooth root fillet. The calculated bending stress number σ_F shall be determined separately for the pinion and the gear. For an explanation of the factors used, see annex G. The following equation has been derived from the method in ISO 9084, see annex G.

$$\sigma_F = K_{SL}\cdot 1{,}55\cdot Y_F\cdot Y_S\cdot Y_\beta\cdot\frac{F_t}{m_n b} \quad (3)$$

The values of the factors in the above equation shall be determined in accordance with 5.2.8 and 5.2.9. For double-helical gears, $b = 2b_B$.

The relation between calculated bending stress number σ_F and the allowable design bending stress number σ_{FAD} is:

$$\sigma_F \leqslant \sigma_{FAD} \quad (4)$$

(see Table 3).

5.2.6 Allowable design stress numbers σ_{HAD}, σ_{FAD}

5.2.6.1 General

Table 3 presents allowable design contact stress numbers σ_{HAD} (for surface durability) and allowable design bending stress numbers σ_{FAD} (for bending strength) and also maximum length-to-diameter (L/d) ratios of pinion for several materials in current use (see 7.2.2.6.3).

The L/d values shown in Table 3 apply to helical gears when designed to transmit the rated power.

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

For through-hardened steel, the following formulae may be used to determine the allowable design stress numbers for hardness values intermediate between the tabulated values:

$$\sigma_{HAD} = 253 + 0{,}9\text{HBW} \quad (5)$$

$$\sigma_{FAD} = 149 + 0{,}33\text{HBW} \quad (6)$$

5.2.6.2 Hardness combinations

Some common hardness combinations of the pinion and gear are given in Table 4. These values are listed for reference and are not intended to indicate the only combinations of hardness that are satisfactory.

Table 4 — Some commonly used hardness combinations for the pinion and gear

Minimum gear hardness	Minimum pinion hardness
302 HBW	341 HBW
321 HBW	341 HBW
341 HBW	363 HBW
363 HBW	58 HRC [a]
58 HRC [a]	58 HRC [a]
58 HRC [b]	58 HRC [a]
58 HRC [b]	58 HRC [b]

[a] Carburized and case-hardened steels.

[b] Gas-nitrided steels.

5.2.7 Scuffing

Scuffing is a form of gear tooth surface damage due to the absence or breakdown of a lubricant film between the contacting tooth flanks of mating gears.

The risk of scuffing damage varies with the properties of the gear material, the lubricant used, the surface roughness of the tooth flanks, the sliding velocities and the load.

Two established methods for calculating scuffing resistance are:

a) the flash temperature method,

b) the integral temperature method.

Both methods are described in ISO/TR 13989-1 and ISO/TR 13989-2.

The vendor may use an alternative method to evaluate scuffing resistance but, when required, shall provide evidence to support the method used.

5.2.8 Common influence factors

5.2.8.1 Nominal tangential load F_t

The nominal tangential load, F_t, is determined in the transverse plane at the reference cylinder based on the gear rated power.

$$F_t = \frac{1\,000 P}{v} = \frac{19\,098 \times 1\,000 P}{d_{1,2} \times n_{1,2}} \qquad (7)$$

5.2.8.2 Pitch line velocity, v

The pitch line velocity, v, is determined at the reference cylinder.

$$v = \frac{d_{1,2} \times n_{1,2}}{19\,098} \qquad (8)$$

5.2.8.3 Selection factor, K_{SL}

The selection factor, K_{SL}, is intended to allow for incremental gear loads from external sources. These incremental loads may result from the characteristics of the driving and driven machines, possible torsional amplification effects in the coupled train, and the probability, in the industry for which this standard is intended, that the operating conditions of the driving or driven machines may change.

Where the characteristics of the whole machine train and the application are precisely known, the magnitude of these effects can be calculated and an appropriate value for K_{SL} determined. By agreement, this calculated value may be used.

Unless otherwise agreed, the values given in Table 5 shall be used.

Table 5 — Selection factors, K_{SL}

Driven equipment	Driver type			
	Synchronous motors and variable frequency motors	Induction motors	Gas or steam turbines	Internal combustion engines (multi-cylinder)
	Selection factors K_{SL}			
Centrifugal blowers	1,6	1,4	1,6	1,7
Compressors				
Centrifugal	1,6	1,4	1,6	1,7
Axial	1,6	1,4	1,6	1,7
Rotary lobe (radial, axial, screw, etc.)	1,8	1,7	1,7	2,0
Reciprocating	2,1	2,0	2,0	2,3
Contactors	1,8	1,7	1,7	2,0
Extruders	1,8	1,7	1,7	—
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
Generators and exciters				
Base load and continuous	1,1	1,1	1,1	1,3
Peak-duty cycle	1,3	1,3	1,3	1,7
Pumps				
Centrifugal (all services, 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, high speed (over 3 600 r/min)	—	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

5.2.9 Tooth bending strength factors

5.2.9.1 Form factor, Y_F

The form factor is the factor by means of which the influence of tooth form on nominal bending stress is taken into account. It is based on the application of load at the outer limit of single-pair tooth contact.

The form factor Y_F shall be determined in accordance with ISO 9084, which is method B from ISO 6336-3:1996, and shall be determined separately for pinion and wheel.

5.2.9.2 Stress correction factor, Y_S

The stress correction factor is used to convert the nominal bending stress to local tooth root stress.

The stress correction factor, Y_S, shall be determined in accordance with ISO 9084 and shall be determined separately for pinion and wheel.

5.2.9.3 Helix angle factor, Y_β

The helix angle factor converts the tooth root stress of the virtual spur gear to that of the corresponding helical gear.

$$Y_\beta = 1 - \frac{\beta}{120°} \qquad (9)$$

5.3 Gear elements

5.3.1 General

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

a) grinding;

b) shaving;

c) honing;

d) precision hobbing.

All gear teeth finished by shaving or honing shall have been generated by hobbing. Shaving cutters and rotary hones shall have a hunting tooth combination with the workpiece. The accuracy of the gear teeth and the modifications on profile and helix shall be consistent with the method of rating the gear [see clause 1 a)]. This shall be demonstrated on purchaser request.

5.3.1.2 The unplated tooth surface on loaded faces of completed gears shall have a finish of Ra 0,8 µm or smoother, measured at the pitch line in accordance with ISO/TR 10064-4.

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

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

5.3.1.5 Hunting tooth combinations are required. To achieve this requirement, it may be necessary to adjust the exact gear ratio. If such adjustment is not acceptable, the purchaser and the vendor shall agree a solution.

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

5.3.2 Quality assurance

● **5.3.2.1** With each gear or pinion mounted on the hobbing, shaving or grinding machine, prior to the final finishing operation, the journal runouts of each principal rotating element shall be charted using a surface-contact-type electronic indicator or a purchaser-approved equivalent. For gears with pitch line velocities up to 60 m/s, the total runout shall not exceed 12 µm; for gears with greater pitch line velocities, the total runout shall not exceed 8 µm. In the case of a vertical hobber or grinder where one journal is inaccessible for a continuous indicator check, the runout shall be recorded on the exposed journal at each end of the journal surface. The records of the journal runouts shall be maintained by the vendor for a period of not less than 20 years, and shall be available to the purchaser on request.

- **5.3.2.2** The accuracy of the mating shall be demonstrated. Unless otherwise agreed, this shall be by the use of profile, lead and pitch deviation records and/or tooth contact checks. The mating gears shall be considered as a matched set and shall be checked for contact on a contact checking stand and in the job casing at the vendor's shop. A thin coating of colour transfer material (such as Prussian blue) shall be applied at three locations 120° apart to four or more teeth of the dry degreased gear. (Layout dye shall not be used for the contact check on the checking stand.) With the gear elements held firmly on the correct centre distance and with the shaft centrelines parallel within 40 µm per meter with a total misalignment of not more than 25 µm, the coated teeth shall be rotated through the mesh with a moderate drag torque applied in a direction that will cause the teeth to contact on the normally loaded faces. The colour transfer shall show evidence of contact distributed across each helix as prescribed by the vendor. Before the contact tests, the vendor shall make available to the purchaser a contact drawing or vendor engineering specification that defines the acceptable contact. Gear sets with unmodified leads generally show about 80 % contact over the face width. The drawing or specification, the measurement records and results of the checking-stand and/or job-casing contacts shall be preserved for at least 20 years and shall be available to the purchaser on request.

- When specified by the purchaser, the results of the contact check shall be preserved by lifting the contrasting colours with adhesive tape from a tooth and applying the tape to a notated sheet of white paper.

The methods of carrying out these checks and the acceptance criteria shall be agreed between purchaser and vendor and shall be consistent with the assumption made in the rating calculations.

NOTE When used to support the gear elements during contact checking, runout of shaft centres or rollers may require mechanical compensation to demonstrate the contact pattern.

5.3.2.3 The vendor shall demonstrate the axial stability of each meshing pair of double helical gears by either

a) measuring the unfiltered peak-to-peak shaft axial vibration, which shall not exceed 50 µm during testing, or

b) using indicators to make a slow rotation check. The preferred method for this slow rotation check is to hold one member (usually the gear) firmly in a fixed axial position, and indicate the axial movement of the other member (usually the pinion) as the parts are rotated through at least one full revolution of the gear while applying a drag torque in a direction that will force the normally loaded tooth faces into contact. The axial motion of the pinion relative to the gear shall not exceed 40 µm.

NOTE Under no-load or light-load conditions on the test stand, double-helical pinions may exhibit random axial movement greater than 50 µm.

5.3.3 Fabrication

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

5.3.3.2 For pitch line velocities at maximum continuous speed above 150 m/s, gears shall be integrally forged with their shafts. For pitch line velocities of 150 m/s and less, gears may be integrally forged with, or separate from their shafts. Separate gears shall be forgings or shall be of fabricated construction using forged steel rims and shall be assembled on their shafts with an interference fit. The pitch line velocities for each form of construction listed in Table 6 shall not be exceeded without the purchaser's specific approval.

NOTE Forgings with high volume concentrations of material may suffer from non-homogeneities such as shrinkage cavities, segregations and non-metallic inclusions. Residual stresses caused by heat treatment can intensify these discontinuities, resulting in potential crack initiation sites. In some cases, the problem can be alleviated by using hollow shaft designs.

Large integrally forged gears shall be subject to additional non-destructive testing. Possible methods are described in SEP 1923 and ÖNORM M 3002.

Table 6 — Pitch line velocities

Gear manufacturing method	Pitch line velocity at maximum continuous speed m/s
Shrunk-on forged rims	60
Welded with forged rims	125
Shrunk-on forged gears	150

5.3.4 Shafts

5.3.4.1 Shafts shall be sized to transmit the gear rated power within the stress limits of ISO/TR 13593. Shaft end configuration should be in accordance with ISO 10441 or as specified by the purchaser or as agreed to by the purchaser and vendor. Shafts shall be made of one-piece, heat-treated forged or hot-rolled steel; shall be accurately machined throughout their entire length; and shall be suitably finished at their bearing surfaces.

5.3.4.2 The rotor shaft sensing areas to be observed by radial-vibration probes shall be concentric with the bearing journals. All shaft sensing areas (both radial vibration and axial position) shall be free from stencil and scribe marks or any other surface discontinuity, such as an oil hole or a keyway. These areas shall not be metallized, sleeved or plated. The final surface finish shall be to a maximum Ra of 1,0 µm , preferably obtained by honing or burnishing. These areas shall be properly demagnetised or otherwise treated so that the combined total electrical and mechanical runout does not exceed 25 % of the maximum allowed peak-to-peak vibration amplitude or the following value, whichever is greater:

a) for areas to be observed by radial-vibration probes, 6,0 µm;

b) for areas to be observed by axial-position probes, 12,0 µm.

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

● **5.3.4.3** When specified, the vendor shall make the provisions specified in 5.3.4.3.1 to measure torsional oscillations.

5.3.4.3.1 When specified, one threaded opening of DN 25 with a plug shall be provided in the upper half of the casing for each gear element to permit mounting of detectors for use with a frequency-modulating torsional analyser. The tapped openings shall be oriented in a plane that is transverse (orthogonal) to the centreline axis of both the gear shaft and the pinion shaft. The openings shall also be positioned so that detectors screwed into them will sense the passing of the teeth.

Alternatively, another method may be agreed between the purchaser and the vendor.

● **5.3.4.4** The shaft end configuration for the coupling mounting (integrally flanged, cylindrical, tapered, etc.) shall be as specified by the purchaser and in accordance with the requirements of 6.2 or as agreed with the purchaser.

5.3.4.5 All major gear elements shall be clearly marked with a unique identification number. This number shall be on the end of the shaft opposite the coupling or in an accessible area that is not prone to maintenance damage.

5.3.4.6 To prevent build-up of potential voltages in the shaft, residual magnetism (free air gauss levels) of the rotating elements shall not exceed 5 Gs.

5.4 Casings

5.4.1 Design parameters

5.4.1.1 Gear casings shall be either cast or fabricated, and shall be designed and constructed to maintain correct gear meshing and rotor alignment and prevent any other injurious distortion caused by temperature, torque, and allowable external forces and moments, under all load conditions.

5.4.1.2 Provision shall be made to permit dowelling or keying the casing to the soleplate or baseplate at two points as close as possible to the vertical plane of the pinion's centreline (to minimize misalignment of the high-speed pinion with connected equipment). Casings not dowelled or keyed by the vendor shall be provided with dowel starter holes. The angle and location of the starter holes shall be such as to provide reasonable access in the field.

5.4.1.3 The machined finish of the mounting surface shall have a surface roughness Ra of arithmetic average 3,2 µm to 6,4 µm. Hold-down or foundation bolt holes shall be drilled perpendicular to the mounting surface or surfaces, and spot-faced to a diameter two times that of the hole.

5.4.1.4 The gear casing feet shall be provided with vertical jackscrews.

5.4.1.5 Bearing housing bores shall be machined to a sufficient degree of accuracy so that a gear set that contacts correctly on true centres on a rotor checking stand also contacts correctly in its own casing.

5.4.1.6 To the maximum extent practicable, casings shall be designed with internal oil passages to minimize external piping. All internal piping shall if possible be welded and shall if possible use flanges for all connections. Threaded connections shall only be used where essential for maintenance purposes.

5.4.1.7 Where internal space does not permit the use of pipe, seamless steel tubing or stainless steel tubing conforming to appropriate standards may be furnished. In either case, stainless steel fittings shall be used. Tubing thicknesses shall meet the requirements of Table 7. The make and model of fittings shall be subject to the purchaser's approval.

Table 7 — Minimum tubing wall thickness

Dimensions in millimetres

Nominal tubing size	Minimum wall thickness
12,7	1,65
19,05	2,40
25,4	2,75

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

5.4.1.9 Internal piping and oil passages shall be cleaned to remove all foreign material prior to any running test.

5.4.1.10 Casings shall be designed to permit rapid drainage of lubricating oil and to minimize oil foaming, which could lead to excessive temperature rise of the oil. For gears with pitch line velocities of more than 125 m/s, consideration shall be given to special designs such as the following:

a) a false bottom in the gear unit;

b) a sump depth at least 610 mm below the bottom of the gear.;

c) meshing direction;

d) an oil drain line to the reservoir that is independent from all other oil system drains;

e) a second full-size drain connection;

f) larger side and circumferential clearances between gears and pinions and the casing;

g) windage baffles;

h) vertical oil drain through the bottom of the gear case.

5.4.1.11 A filter-breather shall be provided. The filter-breather shall be constructed of austenitic stainless steel with austenitic stainless steel or copper-nickel alloy (for example, Monel) internals, designed and located to prevent the discharge of entrained oil to the atmosphere, pressure build-up in the casing, entrance of water during violent rainstorms, and entrance of dirt entrained in the air. The filter-breather connection shall be at least DN 40 and its construction shall permit easy disassembly for inspection and cleaning.

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

5.4.1.12 A removable, gasketed inspection cover(s) shall be provided in the gear casing to permit direct visual inspection of the full-face width of the pinion and gear. The inspection opening(s) shall be at least one-half the width of the gear face.

5.4.1.13 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.

5.4.2 Joints

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

5.4.3 Bolting

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

5.4.3.2 The details of threading shall conform to ISO 261, ISO 262, ISO 724 and ISO 965.

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

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

5.4.4 Assembly and disassembly

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

5.4.4.2 Jackscrews, guide rods and casing alignment dowels shall be provided to facilitate disassembly and reassembly. When jackscrews are used as a means of parting contacting faces, one of the faces shall be relieved (counterbored or recessed) to prevent a leaking joint or improper fit caused by marring. Guide rods shall be of sufficient length to prevent damage to the internals or casing studs by the casing during disassembly and reassembly. Lifting lugs or eyebolts shall be provided for lifting only the top half of the casing. Methods of lifting the assembled gear shall be specified by the vendor.

5.5 Casing connections

5.5.1 A single lubricating-oil supply connection is preferred.

5.5.2 A single lubricating-oil drain connection from the gear casing is preferred. The minimum drain pipe size shall be based on the total inlet flowrate to the gear casing, as shown in Table 8. The drain connection and drain pipe shall be sized and installed to maintain an oil drain velocity of not more than 0,40 m/s, based on a drain line running no more than half full.

Table 8 — Drain pipe sizes

Inlet flowrate l/min	**Minimum drain size** mm
26	75
56	100
170	150
380	200
585	250
830	300
1 000	350

● **5.5.3** When specified, casings shall be provided with an inlet purge connection of at least DN 15 located to assure a sweep of purge gas across the casing to the filter-breather.

5.5.4 Openings for sizes DN 32, DN 65, DN 90, DN 125, DN 175 and DN 225 shall not be used.

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

5.5.6 Oil inlet and drain connections shall be flanged or machined and studded, oriented as specified, and not less than DN 20. Where flanged or machined and studded openings are impractical, threaded openings in sizes DN 20 through DN 40 are permissible. These threaded openings shall be installed as specified in 5.5.6.1 through 5.5.6.4 below.

5.5.6.1 A pipe nipple, preferably not more than 150 mm long, shall be screwed into the threaded opening.

5.5.6.2 Pipe nipples shall be a minimum of Schedule 160 seamless for DN 25 and smaller and a minimum of Schedule 80 for DN 40.

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

5.5.6.4 The threaded connection shall not be seal-welded.

5.5.7 Flanges shall conform to ISO 7005-1 or ISO 7005-2 as applicable, except as specified in 5.5.7.1 through 5.5.7.2 below.

5.5.7.1 Cast iron flanges shall be flat-faced and shall have a minimum thickness of Class 250 in accordance with ISO 7005-2 for DN 200 and smaller.

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

5.5.7.3 Flanges that are thicker or have a larger outside diameter than that required by ISO 7005-1 or ISO 7005-2 are acceptable.

• **5.5.7.4** Connections other than those covered by ISO 7005-1 or ISO 7005-2 require the purchaser's approval. When specified, mating parts shall be furnished by the vendor.

5.5.8 Machined and studded connections shall conform to the facing and drilling requirements of ISO 7005-1 or ISO 7005-2. Studs and nuts shall be furnished installed.

5.5.9 Threaded connections shall not be more than DN 40. Tapped openings and bosses for pipe threads shall conform to ISO 7-1. Pipe threads shall be taper threads conforming to ISO 7-1.

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

5.6 Dynamics

5.6.1 Critical speeds

5.6.1.1 When the frequency of a periodic forcing phenomenon (exciting frequency) applied to a rotor-bearing support system coincides with a natural frequency of that system, the system may be in a state of resonance. A shaft rotational speed at which the rotor-bearing-support system is in a state of resonance with any exciting frequency associated with that speed, is called a "critical speed".

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

a) unbalance in the rotor system;

b) oil film frequencies;

c) internal rub frequencies;

d) gear-meshing and side-band frequencies, as well as other frequencies produced by inaccuracies in the generation of the gear teeth;

e) coupling misalignment frequencies;

f) loose rotor-system component frequencies;

g) asynchronous whirl frequencies;

h) synchronous electric motor start-up or start-up transient torsional resonances;

i) torque fluctuations resulting from the harmonic frequencies in variable frequency electrical drive systems;

j) operating speeds of other gear elements in the unit.

5.6.1.3 Slow roll, start-up and shutdown of rotating equipment shall not cause any damage as critical speeds are passed.

5.6.1.4 Three lateral critical speed modes are generally of concern with gear units: the cylindrical (translational or bouncing) mode, the conical (pivoted or rocking) mode, and the first bending mode. The frequency at which these modes occur varies as a function of the transmitted load, primarily due to the resulting change in stiffness of the bearing-oil film (see annex B). The gear rotors shall meet the requirements given in 5.6.1.4.1 through 5.6.1.4.3 below.

5.6.1.4.1 When operating at the maximum torque, the three defined critical speeds of each rotor shall not be less than 20 %above the maximum continuous speed of that rotor.

5.6.1.4.2 When the operating torque is in the range of 50 % to 100 % of the maximum torque, the separation margin above the maximum continuous speed of each rotor shall be a minimum 10 % to 20 % in linear proportion to the transmitted torque.

5.6.1.4.3 When specified that operating conditions at no load (at less than 50 %of the maximum torque) or less than 70 % of the maximum continuous speed are anticipated, the vendor shall submit a damped unbalanced response analysis in addition to the undamped analysis. Unloaded operation shall be considered for proper performance.

NOTE Gear units are normally required to withstand periods of unloaded operation.

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

a) the bearing oil film, bearing structure and gear-casing-support structure stiffnesses;

b) the coupling mass to be supported by each gearbox shaft (the mass of the coupling hubs plus half the mass of the coupling spacers). The coupling mass shall be applied at the proper centre of gravity relative to the shaft end. The mass and the centre of gravity shall be specified by the purchaser of the coupling.

● **5.6.1.6** The vendor shall submit a report containing a graphic display of undamped critical speeds versus support stiffness or percentage of torque load. The graphic display shall show all applicable conditions specified in 5.6.1.4 and no-load test conditions (approximately 10 % of the rated torque) at the maximum continuous speed. With the purchaser's approval, the vendor may submit, or when specified, the vendor shall submit a plot of damped unbalanced rotor response for the conditions above, in addition to maps of the undamped critical speeds.

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

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

5.6.1.9 The separation margins specified in 5.6.1.4 and 5.6.1.8 are intended to prevent any critical response envelope from overlapping the range of operating speeds.

5.6.2 Balance

5.6.2.1 All gear elements shall be multiplane dynamically balanced after final assembly of the rotor. Rotors with single keys for couplings shall be balanced using the half-key convention of ISO 8821. The maximum residual unbalance shall be calculated from the following:

$$U_{\text{max}} = \frac{6\,350}{N} \cdot W \tag{10}$$

where

U_{max} is the amount of residual unbalance, in gram millimetres;

W is the journal static load, in kilograms;

N is the maximum continuous speed, in revolutions per minute.

5.6.2.2 After the final balancing of the assembled rotating element has been completed, the calibration of the rotor balancing machine shall be verified in accordance with ISO 2953. With the purchaser's approval, documentation of a calibration check performed less than one month before the balancing of the rotor may be submitted in lieu of the calibration check performed after the balancing of the rotor.

● **5.6.2.3** When specified, after the final balancing of the assembled rotating element has been completed, the sensitivity of the rotor-balancing-machine system shall be confirmed and reported in accordance with ISO 2953.

● **5.6.2.4** When specified, after the final balancing of each assembled rotating element has been completed, a residual unbalance check shall be performed in accordance with ISO 1940-1. The mass of all half-keys used during the final balancing of the assembled rotor shall be recorded.

5.6.3 Vibration

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

$$A = 25{,}4\sqrt{\frac{12\ 000}{N}} \qquad (11)$$

where

A is the amplitude of unfiltered vibration, in micrometres true peak-to-peak;

N is the maximum continuous speed, in revolutions per minute.

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

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

5.6.3.3 Accurate records of electrical and mechanical runouts, for the full 360° at each probe location, shall be included in the report of mechanical tests.

5.6.3.4 If the vendor can demonstrate that electrical or mechanical runout is present, this may be vectorially subtracted from the vibration signal measured during the factory test, up to a maximum of 25 % of the test level, calculated from equation (11) in 5.6.3.1, or 6,4 µm, whichever is greater.

5.6.3.5 When accelerometers to measure casing vibration have been specified, they shall be used during the mechanical running test. The overall vibration levels during the mechanical running test shall not exceed the values shown in Table 9.

Table 9 — Casing vibration levels

Measurement conditions	**Frequency range** [a]	
	10 Hz to 2,5 kHz	2,5 kHz to 10 kHz
	Vibration levels	
	Velocity (rms) [b]	**Acceleration** (peak)
Unfiltered	4,0 mm/s	$4g_n$ [c]
Filtered component [d]	2,5 mm/s	—

[a] The above vibration levels are for horizontal offset gears units only. The allowable vibration levels for vertical offset gears are twice those shown in the table.

[b] g_n = gravitational acceleration = 9,81 m/s^2.

[c] The specified vibration levels apply to vibration within the specified frequency ranges.

[d] Filtered component means any vibration peak within the frequency range.

5.7 Bearings and bearing housings

5.7.1 General

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

5.7.1.2 Bearings shall be designed to prevent incorrect installation.

5.7.1.3 Unless otherwise specified, thrust bearings and radial bearings shall be fitted with bearing-metal temperature sensors installed in accordance with ISO 10438 (all parts) and API 670.

5.7.2 Radial bearings

5.7.2.1 Hydrodynamic radial bearings shall be split for ease of assembly, precision bored, and of the sleeve or pad type, with steel-backed babbitted replaceable liners, pads or shells. These bearings shall be equipped with antirotation pins and shall be positively secured in the axial direction. The bearing design shall suppress hydrodynamic instabilities and provide sufficient damping to limit rotor vibration to the maximum specified amplitudes (see 5.6.3) while the equipment is operating loaded or unloaded at specified operating speeds, including operation at any critical frequency. The bearing design shall not require removal of the coupling hub to permit replacement of the bearing liners, pads or shells. To facilitate adjustment of the gear mesh, one of the bearings may be adjustable.

5.7.2.2 The bearing specific loading shall not exceed the value shown in Table 10. The minimum oil film thickness shall not be less than the value shown in Table 10.

Table 10 — Normal design limits for hydrodynamic bearings

Type of bearing	**Load on specific projected area** N/mm^2	**Minimum oil film thickness** mm
Radial bearing — cylindrical profile or tilting pad	3,8	0,025
Thrust bearing — tilting pad	3,0	0,015

5.7.3 Thrust bearings

5.7.3.1 Unless otherwise approved by the purchaser, thrust bearings shall be provided on the low-speed shaft for all double-helical gears. Thrust bearings shall be provided on each shaft for all single-helical gears or, by agreement, the axial forces of the gear teeth may be compensated by thrust cones on the pinion, and one thrust bearing on the low or high speed shaft shall be provided. When gears are supplied without thrust bearings, limited-end float or diaphragm-type couplings shall be used to maintain positive axial positioning of the connected rotors. (See Figure C.1, panels A to F, for typical system arrangements in which thrust bearings may be eliminated from double-helical gears.)

All gears without thrust bearings shall be supplied with locating collars on the low speed shaft to prevent contact of the rotating elements with the gear casing. Axial float shall not be less than 12,0 µm.

5.7.3.2 Hydrodynamic thrust bearings shall be of the steel-backed, babbitted multiple-segment type, designed for equal thrust capacity in both directions and arranged for continuous pressurized lubrication to each side. Both sides shall be of the tilting-pad type, incorporating a self-levelling feature which assures that each segment carries an equal share of the thrust load with minor variation in segment thickness. Integral thrust collars are preferred. When replaceable collars are furnished (for assembly and maintenance purposes) they shall be positively locked to the shaft to prevent fretting. When integral thrust collars are furnished, they shall be provided with at least 3,2 mm of additional stock to enable refinishing if the collar is damaged. Both faces of the collar shall have a surface finish of not more than Ra 0,4 µm, and the axial total indicated runout of either face shall not exceed 12,7 µm after the collar is mounted.

5.7.3.3 Thrust bearings shall be sized for continuous operation under all specified conditions, including all external forces transmitted by the couplings. Thrust bearings shall be selected at no more than 50 % of the bearing's ultimate load capability (based on test data) for the specific application, taking into account speed, lubricant and lubricant temperature. The projected unit load shall not be greater, nor the minimum oil film thickness be less, than the values given in Table 9. The sizing basis shall be reviewed with and approved by the purchaser. The external axial force transmitted by the coupling shall be considered as being numerically additive to any internal thrust forces. If the thrust forces from two or more connected rotors or meshing gear rotors are carried by one thrust bearing, these thrust forces shall be considered as being numerically additive. The minimum external force transmitted by a flexible coupling shall be as specified in 5.7.3.3.1 through 5.7.3.3.3.

5.7.3.3.1 For couplings located so that the external force is produced by a single-ended drive motor with sleeve bearings, the external force shall be considered equal to the maximum magnetic centreing force of the motor. If the maximum magnetic centreing force is not specified, a force of 1,5 Newtons per kilowatt of motor rated power shall be used.

5.7.3.3.2 For gear-type couplings (located other than as described in 5.7.3.3.1), the external force shall be calculated from the following formula:

$$F_{\mathrm{R}} = \frac{250 \times 9\,549 \times P}{n_{1,2} \times D_{1,2}} \qquad (12)$$

NOTE Shaft diameter $D_{1,2}$ is an approximation of the coupling pitch radius.

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

5.7.4 Bearing housings

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

5.7.4.2 Bearing housings shall be equipped with replaceable labyrinth-type seals and deflectors where the shaft passes through the housing; lip-type seals shall not be used. The seals and deflectors shall be made of nonsparking materials. The design of the seals and deflectors shall effectively retain oil in the housing and prevent entry from foreign material into the housing. Shaft oil seals shall be easily accessible for removal and re-installation without removing couplings.

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

5.8 Lubrication

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

5.8.2 The gear unit and lubrication system shall be designed to limit the temperature of the casing drain oil to 80°C, with an inlet oil temperature of 50°C to ensure high mechanical efficiency and dimensional stability and to limit the maximum temperature of the tooth metal. Where oil inlet temperatures exceed 50°C, special consideration shall be given to bearing design, oil flows and allowable temperature rise. Oil outlets from thrust bearings shall be tangential in the control ring, or in the thrust bearing cartridge if oil control rings are not used.

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

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

5.8.5 Unless otherwise specified, pressurized oil systems shall conform to the requirements of ISO 10438-1, ISO 10438-2 and ISO 10438-3.

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

The usual lubricant employed in a common oil system is a hydrocarbon oil that corresponds to viscosity grade VG 32 or VG 46 of ISO 3448:1992. The lubricant should pass the minimum requirement of load stage 6 of ISO 14635. EP oil is normally not required. The lubricant shall meet the requirements listed in ISO 6743-6.

5.9 Materials

5.9.1 General

5.9.1.1 Materials of construction shall be the manufacturer's standard for the specified operating conditions, except as required by the data sheets or this standard (see 6.5 for requirements for auxiliary piping materials). The metallurgy of all major components shall be clearly stated in the vendors proposal.

5.9.1.2 All materials shall be identified by reference to appropriate international standards. Where no suitable International Standard exists, reference shall be made to internationally recognized national or industry standards. Where no appropriate standard exists, the vendor shall provide full details of the material, including chemical composition, heat treatment and mechanical properties. Some coarse grain steels (e.g. ASTM A515) may be notch-sensitive and prone to brittle fracture. The use of such steels is prohibited.

5.9.1.3 The vendor shall specify the tests and inspection procedures to ensure that materials are satisfactory for the service. Such test and inspections shall be listed in the proposal by reference to ASTM standards or other appropriate recognized standards. The purchaser may consider specifying additional tests and inspections, especially for materials used in critical components.

5.9.1.4 Materials used for wheel and pinion teeth shall be forged or hot-rolled alloy steel of high quality, selected to meet the criteria for surface durability and tooth bending strength outlined in 5.2. In selecting the material, the vendor shall consider whether the wheel and pinion are to be through-hardened, carburized or nitrided. The material quality of gear teeth shall conform to material quality grade MQ or better of ISO 6336-5:1996. The material and manufacturing method will be submitted by the purchaser.

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

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

5.9.2 Welding of rotating elements

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

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

5.9.2.3 The vendor shall be responsible for the review of all repairs and repair welds to ensure that they are properly heat-treated and nondestructively examined for soundness and compliance with the applicable qualified procedures.

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

5.9.3 Heat treatment

5.9.3.1 Heat treatment shall be carried out after rough machining, to achieve the required mechanical properties in accordance with ISO 6336-5.

5.9.3.2 After through-hardened gear materials have been rough-machined to the approximate final contour of the blank and heat-treated, the tooth area shall be checked for proper hardness. For surface-hardened parts, final tooth hardness shall be verified by a suitable nondestructive method such as ASTM A956.

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

5.9.4 Low temperature

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

5.10 Nameplates and rotation arrows

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

c) vendor's name;

d) size and type of the gear unit;

e) gear ratio;

f) serial number;

g) gear rated power;

h) rated input speed, in revolutions per minute;

i) rated output speed, in revolutions per minute;

j) gear selection factor as defined in this International Standard;

k) purchaser's item number;

l) number of gear teeth;

m) number of pinion teeth.

6 Accessories

6.1 General

● The purchaser specifies the accessories to be supplied by the vendor.

6.2 Couplings and guards

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

6.2.2 Couplings shall conform to ISO 10441. The make, type and mounting arrangement of the coupling shall be agreed by the purchaser and the vendors of the driving and driven equipment.

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

6.2.4 The purchaser of the coupling shall supply an idling adapter, as required for the mechanical running tests [see 7.3.2.1 f)].

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

6.2.5 The power rating of the coupling-to-shaft juncture shall be as defined in ISO 10441.

6.2.6 The coupling mounting shall conform to ISO 10441.

6.3 Mounting plates

6.3.1 General

● **6.3.1.1** When specified, the gear shall be furnished with soleplates or a baseplate. In 6.3.1.2. through 6.3.1.12, the term mounting plate refers to both baseplates and soleplates.

6.3.1.2 The upper and lower surfaces of mounting plates shall be machined parallel. Their surface roughness shall be *Ra* 5,0 µm arithmetic average or better**.**

6.3.1.3 The mounting plates shall be equipped with vertical levelling screws.

6.3.1.4 When the equipment supported weighs more than 500 kg, the mounting plates shall be furnished with horizontal jackscrews the same size as or larger than the vertical jackscrews in the gear casing. The lugs holding these jackscrews shall be attached to the mounting plates so that they do not interfere with the installation or removal of the shims.

6.3.1.5 Machinery supports shall be designed to limit a change of alignment caused by the worst combination of pressure, torque and allowable piping stress to 50 µm at either coupling.

- **6.3.1.6** When epoxy grout is specified on the data sheets, the vendor shall commercial sandblast, in accordance with Grade Sa 2 of ISO 8501-1:1988, all the grouting surfaces of the mounting plates and shall precoat these surfaces with an inorganic zinc silicate. The inorganic zinc silicate shall be compatible with epoxy grout. The vendor shall submit to the purchaser instructions for field preparation of the inorganic zinc silicate.

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

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

6.3.1.8 Mounting plates shall not be drilled for equipment to be mounted by others. Mounting plates that are to be grouted shall have 50-mm-radiused outside corners (in the plan view).

6.3.1.9 Mounting plates shall extend at least 25 mm beyond the outer three sides of equipment feet.

6.3.1.10 The vendor of the mounting plates shall furnish austenitic stainless steel shim packs with a total thickness of at least 3,0 mm between the equipment feet and the mounting plates. All shim packs shall straddle the hold-down bolts.

6.3.1.11 Anchor bolts shall be furnished by the purchaser.

6.3.1.12 When the vendor supplies the mounting plate, fasteners for attaching the equipment to the mounting plate (hold down bolts) and all jackscrews, shall be supplied by the vendor.

6.3.2 Baseplate

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

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

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

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

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

6.3.2.6 The bottom of the baseplate between structural members shall be open. When the baseplate is installed on a concrete foundation, it shall be provided with at least one grout hole having a clear area of at least 0,01 m^2 and no dimension less than 75 mm in each bulkhead section. These holes shall be located to permit grouting under all load-carrying structural members. Where practical, the holes shall be accessible for grouting with the equipment installed. The holes shall have 13-mm raised-lip edges, and if located in an area where liquids could impinge on the exposed grout, metallic covers with a minimum thickness of 1,5 mm shall be provided. Vent holes at least 13 mm in size shall be provided at the highest point in each bulkhead section of the baseplate.

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

6.3.2.8 Unless otherwise specified, non-skid decking covering all walk and work areas shall be provided on the top of the baseplate.

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

6.3.3 Soleplates and sub-soleplates

6.3.3.1 When soleplates are specified, they shall meet requirements in 6.3.3.1.1 and 6.3.3.1.2 below in addition to those of 6.3.2.

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

6.3.3.1.2 Soleplates shall be steel plates that are thick enough to transmit the expected loads from the equipment feet to the foundation, but in no case shall the plates be less than 38 mm thick.

6.3.3.2 When subplates are specified, they shall be steel plates at least 25 mm thick. The finish of the sub-soleplate mating surfaces shall match that of the sub-soleplates.

6.4 Controls and instrumentation

6.4.1 General

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

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

6.4.1.3 All controls and instrumentation shall be suitable for the area classification specified and shall comply with the standards specified and with any local codes and regulations.

6.4.2 Vibration and axial position detectors

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

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

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

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

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

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

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

● **6.4.2.5** When specified, a key phaser shall be provided on one or both shafts in accordance with API 670.

6.5 Piping and appurtenances

Unless otherwise specified, lubricating-oil piping and appurtenances shall conform to the requirements of ISO 10438-1.

6.6 Special tools

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

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

7 Inspection, testing and preparation for shipment

7.1 General

7.1.1 The purchaser's participation in inspection and testing is as follows.

● a) The purchaser shall specify the extent of his participation in the inspection and testing and the amount of advance notification he requires.

b) When shop inspection and testing have been specified by the purchaser, the purchaser and the vendor shall meet to coordinate manufacturing hold points, witnessed or observed tests and inspectors' visits.

   1) Witnessed tests are those carried out with the purchaser or his representative in attendance, after a hold is applied to the production schedule. For mechanical running or performance tests, this requires written notification of a successful preliminary test.

   2) Observed tests are those carried out after the purchaser is notified of the timing of the inspection or test; however, the inspection or test is performed as scheduled, and if the purchaser or his representative is not present, the vendor shall proceed to the next step. (The purchaser should expect to be in the factory longer than for a witnessed test.)

   ● 3) When specified, the purchaser's representative, the vendor's representative, or both shall indicate compliance in accordance with the inspector's checklist in annex F by initialling, dating and submitting the completed checklist to the purchaser before shipment.

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

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

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

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

7.1.5 The purchaser's representative shall have access to the vendor's quality programme for review.

7.2 Inspection

7.2.1 General

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

a) necessary certification of materials, such as mill test reports;

b) purchase specification for all items on bills of materials;

c) test data to verify that the requirements of the specification are being met;

d) results of documented tests and inspections, including fully identified records of all heat treatment and radiography;

● e) when specified, final-assembly maintenance and running clearances.

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

a) parts that shall be subjected to surface and/or subsurface examination;

b) the type of inspection required, such as magnetic particle, dye penetrant, radiographic and ultrasonic examination.

7.2.2 Material inspection

7.2.2.1 General

● When radiographic, ultrasonic, magnetic particle or liquid penetrant inspection of welds or materials is required or specified, except for rotating elements, the criteria in 7.2.2.2 through 7.2.2.5 shall apply unless other criteria are specified by the purchaser. Cast iron may be inspected in accordance with 7.2.2.4 and 7.2.2.5. Welds, cast steel, and wrought material may be inspected in accordance with 7.2.2.2 through 7.2.2.5. For rotating elements see 7.2.2.6.

7.2.2.2 Radiography (see 7.2.2.1)

7.2.2.2.1 Radiography shall be in accordance with ASTM E94.

7.2.2.2.2 The acceptance standard used for welding fabrications shall be Section VIII, Division 1, UW-52, of the ASME Boiler and Pressure Vessel Code. The acceptance standard used for castings shall be Section VIII, Division 1, Annex 7, of the ASME Code.

7.2.2.3 Ultrasonic inspection (see 7.2.2.1)

7.2.2.3.1 Ultrasonic inspection shall be in accordance with Section V, Articles 5 and 23, of the ASME Boiler and Pressure Vessel Code.

7.2.2.3.2 The acceptance standard used for welded fabrications shall be Section VIII, Division 1, Annex 12, of the ASME Boiler and Pressure Vessel Code. The acceptance standard used for castings shall be Section VIII, Division 1, Annex 7, of the ASME Code.

7.2.2.4 Magnetic particle inspection (see 7.2.2.1)

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

7.2.2.4.2 The acceptance standard used for welded fabrications shall be Section VIII, Division 1, Annexes 6 and 25 of the ASME Boiler and Pressure Vessel Code. The acceptability of defects in castings shall be based on a comparison with the photographs in ASTM E125. For each type of defect, the degree of severity shall not exceed the limits specified in Table 11.

Regardless of the generalized limits in 7.2.2, it shall be the vendor's responsibility to review the design limits of the equipment in the event that more stringent requirements are necessary. Defects that exceed the limits imposed in 7.2.2 shall be removed to meet the quality standards cited, as determined by the inspection method specified.

Table 11 — Maximum severity of defects in castings

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

7.2.2.5 Liquid penetrant inspection (see 7.2.2.1)

7.2.2.5.1 Liquid penetrant inspection shall be in accordance with Section V, Article 6, of the ASME Boiler and Pressure Vessel Code.

7.2.2.5.2 The acceptance standard used for welded fabrications shall be Section VIII, Division 1, Annexes 8 and 24, of the ASME Boiler and Pressure Vessel Code. The acceptance standard used for castings shall be Section VIII, Division 1, Annex 7, of the ASME Code.

7.2.2.6 Rotating elements

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

a) chemical and physical data from specimens made and heat-treated with the parts;

b) records of all heat treatment and resulting hardnesses;

c) radiographs and records of ultrasonic inspections, if radiography and ultrasonic inspection are performed;

d) for surface-hardened gears, hardnesses and case depths determined on coupons treated with the workpiece;

e) for through-hardened gears, hardnesses determined in at least three dispersed locations in the tooth blank area.

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

7.2.2.6.3 The material of gears and pinions shall be subject, as a minimum, to the quality control and inspection requirements of ISO 6336-5 appropriate to material quality grade MQ.

7.2.2.7 Additional inspection

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

7.2.3 Mechanical inspection

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

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

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

7.3 Testing

7.3.1 General

7.3.1.1 Gears shall be tested in accordance with 7.3.2. Other tests that may be specified by the purchaser are described in 7.3.3.

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

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

7.3.2 Mechanical running tests

7.3.2.1 Before the mechanical test is performed, the following requirements shall be met.

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

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

c) Test-stand oil filtration shall be 10 µm or better. Oil system components downstream of the filters shall meet the cleanliness requirements of ISO 10438-1, ISO 10438-2 and ISO 10438-3 before any test is started.

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

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

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

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

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

7.3.2.2 During the mechanical running tests the following requirements shall be met.

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

1) inlet oil temperature and pressure;

2) oil flow;

3) outlet oil (drain) temperature;

4) shaft vibration, frequency, and amplitude, both filtered (synchronous) and unfiltered (raw);

5) bearing temperatures;

6) casing vibration (refer to Table 9).

b) The vibration characteristics determined by the use of the instrumentation specified in 7.3.2.1 g) and 7.3.2.1 h) shall serve as the basis for acceptance or rejection of the machine (see 5.6.3).

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

d) The gear shall be operated at maximum continuous speed until the bearing temperatures and the lubricating-oil temperatures have stabilized.

e) The gear shall be operated at 110 % of maximum continuous speed for a minimum of 15 min.

f) The gear shall be operated at maximum continuous speed for 4 h.

NOTE The sequence of steps listed in 7.3.2.2 e) and 7.3.2.2 f) is optional.

g) The mechanical operation of all equipment being tested and the operation of the test instrumentation shall be satisfactory. The measured unfiltered vibration shall not exceed the limits of 5.6.3 and shall be recorded throughout the operating speed range (see 5.3.2.3).

h) For shaft vibration, measure with non-contacting transducers while the gear is operating at maximum continuous speed, a sweep shall be made for vibration amplitudes at frequencies other than synchronous. As a minimum, the sweep shall cover a frequency range from 0,25 times the synchronous speed of the low-speed gear to 4 times the synchronous speed of the high-speed gear, but not less than 1 500 Hz. If the amplitude of any discrete, nonsynchronous vibration exceeds 20 % of the allowable vibration as defined in 5.6.3.1, the purchaser and the vendor shall mutually agree on requirements for any additional testing and on the gear's suitability for shipment.

i) For casing vibration, measured with casing mounted acceleration transducers, while the gear is operating at maximum continuous speed, a sweep shall be made at a frequency range of from 10 Hz up to and including 10 kHz. The values of velocity and acceleration shall not exceed the allowable levels defined in 5.6.3.5 and shown in Table 9.

j) The mechanical running tests shall verify that no harmful resonant condition exists within the operating speed range.

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

● l) Lubricating-oil inlet pressures and temperatures shall be varied through the range permitted in the operating manual. This shall be done during the 4-h test.

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

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

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

7.3.2.3 After the mechanical running test is completed, the following requirements shall be met.

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

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

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

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

• 7.3.3 Optional tests

7.3.3.1 General

When specified, the shop tests described in 7.3.3.2 through 7.3.3.6 shall be performed.

7.3.3.2 Full-speed/full- or partial-load test

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

When partial or full-load tests are specified, the vendor's test stand lubrication system shall include an automatic low lube-oil pressure shutdown system. See note in 7.3.3.3.

7.3.3.3 Full-torque/slow-roll test

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

EXAMPLE At 10 000 r/min, 14,9 MW is equivalent to 14,2 kN·m of torque. At 50 r/min, torque at this speed is equivalent to 75,0 kW.

Vibration and temperature limits, as outlined in this International Standard, shall not apply.

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

NOTE The full torque/slow roll test is designed to demonstrate only tooth contact and load-carrying capability. However, the observed contact pattern may be affected because field conditions are not duplicated on the test stand. For gears where a significant portion of the lead modification is due to thermal distortion, a full torque/slow roll test may not produce a test pattern representative of field contact operating pattern. Bearing damage is possible because slow running speeds do not allow the bearings to develop a full hydrodynamic oil film.

7.3.3.4 Full-torque/static test

One shaft of the gear shall be locked. The full torque, as calculated in 7.3.3.3, shall then be applied to the other shaft by mechanical or hydraulic means. This procedure shall be repeated at several mesh points of gear set. The number of load applications shall be negotiated before the time of order. (See note in 7.3.3.3.)

7.3.3.5 Back-to-back locked-torque test

Two identical gear units shall be coupled together, input shaft to input shaft and output shaft to output shaft. The full torque, as calculated in 7.3.3.3, shall then be introduced by removing the spacer and turning one shaft against its mate while the other shafts remain coupled. This torque shall be maintained in the system by mechanical or hydraulic means (for example, coupling halves keyed on shafts, torque introduced, and then coupling halves bolted together). The units shall then be run at their rated input and output speeds. The duration of the run shall be negotiated before the time of order.

7.3.3.6 Sound-level test

The sound-level test shall be performed in accordance with ISO 8579-1.

7.4 Preparation for shipment

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

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

7.4.3 The equipment shall be prepared for shipment after all testing and inspection has been completed and the equipment has been approved by the purchaser. The preparation shall include that specified in 7.4.3 a) through 7.4.3 j).

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

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

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

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

e) Flanged openings shall be provided with metal closures at least 5,0 mm thick, with rubber gaskets, and at least four full-diameter bolts. For studded openings, all nuts needed for the intended service shall be used to secure closures.

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

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

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

i) When spare gear elements are purchased, the rotors shall be suitably prepared for unheated indoor storage for a period of at least three years. The rotors shall be treated with a rust preventive and shall be housed in a vapour-barrier envelope with a slow-release vapour-phase inhibitor. The rotors shall be suitably crated for domestic or export shipment, as specified. Lead sheeting, at least 3,0 mm thick, or a purchaser-approved equivalent shall be used between the rotors and the cradle at the support areas. The rotors shall not be supported at journals.

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

8 Vendor's data

8.1 General

8.1.1 The information to be furnished by the vendor is specified in 8.2 and 8.3. The vendor shall complete and forward the Vendor Drawing and Data Requirements (VDDR) form (see annex D) to the address(es) noted on the inquiry or order. This form shall detail the schedule for transmission of drawings, curves and data as agreed to at the time of the proposal or order as well as the number and type of copies required by the purchaser.

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

a) purchaser's/user's corporate name;

b) job/project;

c) equipment item number and service name;

d) inquiry or purchase order number;

e) any other identification specified in the inquiry or purchase order;

f) vendor's identifying proposal number, shop order number, serial number or other reference required to completely identify return correspondence.

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

a) purchase order, scope of supply, vendor's internal order details and subvendor item;

b) data sheets;

c) applicable specifications and previously agreed-upon exceptions;

d) schedules for transmittal of data, production and testing;

e) quality assurance programme, procedures and acceptance criteria;

f) inspection, expediting and testing;

g) schematics and Bill of Materials (B/M) of auxiliary systems;

h) physical orientation of equipment, shaft rotation, piping and auxiliary systems;

i) coupling selection;

j) thrust and radial bearing sizing and estimated loadings;

k) rotor dynamic analysis;

l) audit of subsuppliers;

m) other technical items.

8.2 Proposals

8.2.1 General

The vendor shall forward the original and the specified number of copies of the proposal to the addressee stated on the inquiry documents. This proposal shall contain the data specified in 8.2.2 through 8.2.4 as well as a specific statement that the system and all its components are in strict accordance with this standard. If the gear and components are not in strict accordance, the vendor shall include a list that details and explains each deviation. The vendor shall provide details to enable the purchaser to evaluate any proposed alternative designs. All correspondence shall be clearly identified in accordance with 8.1.2.

8.2.2 Drawings

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

a) a general arrangement or outline drawing for each gear unit showing overall dimensions, maintenance clearance dimensions, overall masses, erection masses and maximum maintenance masses (indicate for each piece). The direction of rotation, and the size and location of major purchaser connections shall be indicated;

b) cross-sectional drawings showing the details of the proposed equipment;

c) sketches that show methods of lifting the assembled gear. [This information may be included on the drawings specified in item a) above.]

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

8.2.3 Technical data

The following data shall be included in the proposal:

a) the purchaser's data sheets, with completed vendor's information entered thereon and with literature to fully describe details of the offering;

b) the purchaser's noise data sheet when provided, or if not provided, the vendor's alternative form;

c) the Vendor Drawing and Data Requirements form (see annex D), indicating the schedule according to which the vendor agrees to transmit all the data specified as part of the contract;

d) a schedule for shipment of the equipment, in weeks after receipt of the order;

e) a list of major wearing components, showing interchangeability with the purchaser's other units;

f) a list of recommended start-up spares, including any items that the vendor's experience indicates are likely to be required;

g) a list of special tools furnished for maintenance. The vendor shall identify any metric items included in the offering;

h) a statement of any special protection required for start-up, operation and periods of idleness under the site conditions specified on the data sheets. The list shall show the protection to be furnished by the purchaser, as well as that included in the vendor's scope of supply;

i) a complete tabulation of the utility requirements, including the quantity of lubricating oil required and the supply pressure, the heat load to be removed by the oil at the nameplate power rating. (Approximate data shall be defined and identified as such.);

j) a description of the tests and inspection procedures for materials, as required by 5.9.1.3;

k) a description of any special requirements as outlined in 5.9.1.2;

l) a list of similar machines installed and operating under conditions analogous to those specified in the proposal;

m) any start-up, shutdown or operating restrictions required to protect the integrity of the equipment.

8.2.4 Options

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

8.3 Contract data

8.3.1 General

8.3.1.1 The contract information to be furnished by the vendor is specified in Annex D. Each drawing, Bill of Material (B/M), or data sheet shall have a title block in the lower right hand corner with the date of certification, reference to all identification data specified in 8.1.2, the revision number and date, and the title.

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

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

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

8.3.2 Drawings

The drawings furnished shall contain sufficient information so that when combined with the manuals specified in 8.3.6, the purchaser can properly install, operate and maintain the ordered equipment. Drawings shall be clearly legible, be identified in accordance with 8.3.1.1 and in accordance with ASME Y 14.2M. As a minimum, each drawing shall include the details listed for that drawing in annex D.

8.3.3 Technical data

Data shall be submitted in accordance with annexes A and D, and identified in accordance with 8.3.1.1.

8.3.4 Progress reports

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

8.3.5 Recommended spares

The vendor shall submit a complete list of spare parts, including those shown in the original proposal. The list shall include spare parts for all equipment and accessories supplied, with cross-sectional or assembly-type drawings for identification, part numbers and delivery times. Part numbers shall identify each part for interchangeability. Standard purchased items shall be identified by the data specified in 8.1.2.

8.3.6 Installation, operation, maintenance and data manuals

8.3.6.1 General

The vendor shall provide sufficient written instructions and a cross-referenced list of all drawings to enable the purchaser to correctly install, operate and maintain all the equipment ordered. This information shall be compiled in a manual or manuals with a cover sheet containing all reference-identifying data specified in 8.1.2, an index sheet containing section titles, and a complete list of referenced and enclosed drawings by title and drawing number. The manual shall be prepared for the specified installation; a typical manual is not acceptable.

8.3.6.2 Installation manual

Any special information required for proper installation design that is not on the drawings shall be compiled in a manual that is separate from the operation and maintenance instructions. This manual shall be forwarded at a time that is mutually agreed upon in the order, but not later than final issue of prints. The manual shall contain information such as special alignment and grouting procedures, utility specifications (including quantities), and all other installation design data, including drawings and data specified in 8.2.2 and 8.2.3. The manual shall also include sketches that show the location of the centre of gravity and rigging provisions to permit the removal of the top half of the casing, rotors and subassemblies that weigh more than 136 kg.

8.3.6.3 Manual for operation, maintenance and technical data

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

Annex A
(informative)

Special-purpose gear unit data sheets

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

SPECIAL PURPOSE GEAR UNITS DATA SHEET (ISO 13691) SI UNITS	JOB NO. ____ ITEM NO. ____ PURCHASE ORDER NO. ____ SPECIFICATION NO. ____ REVISION NO. ____ DATE ____ PAGE 1 OF 4 BY

1	APPLICABLE TO: ○ PROPOSAL ○ PURCHASE ○ AS BUILT	
2	FOR ____	MANUFACTURER ____
3	SITE ____	MODEL NO. ____
4	UNIT ____	SERIAL NO. ____
5	SERVICE ____	DRIVER TYPE ____
6	NO. REQUIRED	DRIVEN EQUIPMENT
7	**NOTE:** NUMBERS WITHIN ( ) REFER TO APPLICABLE PARAGRAPHS OF ISO 13691	
8	○ INFORMATION TO BE COMPLETED BY PURCHASER	□ INFORMATION TO BE COMPLETED BY MANUFACTURER
9	○ **RATING REQUIREMENTS**	□ **BASIC GEAR DATA**
10	DRIVEN EQUIP POWER NORMAL ____ kW MAX ____ kW	
11	DRIVER POWER RATED ____ kW MAX ____ kW	MECHANICAL RATING (3) ____ kW @ ____ min^{-1}
12	GEAR RATED POWER (5.2.2) ____ kW	FULL LOAD POWER LOSS ____ kW
13	TORQUE @ MAX CONT. SPEED ____ N·m	MECHANICAL EFFICIENCY ____ %
14	MAX TORQUE (5.2.2) ____ N·m @ ____ min^{-1}	PITCH LINE VELOCITY ____ m/s
15	RATED SPEED, (3):	TANGENTIAL LOAD (5.2.8.1) ____ N
16	INPUT ____ min^{-1} ○ SPECIFIED ○ NOMINAL	CONTACT STRESS NUMBER (5.2.6)
17	OUTPUT ____ min^{-1} ○ SPECIFIED ○ NOMINAL	CALCULATED ____ N/mm^2 ALLOWABLE (5.2.6) ____ N/mm^2
18	ALLOW VAR IN GEAR RATIO (3) (+) (-) ____ %	
19	MAX CONTINUOUS SPEED (3) ____ min^{-1}	BENDING STRESS NUMBER (5.2.6)
20	TRIP SPEED (3) ____ min^{-1}	PINION GEAR
21	SELECTION FACTOR (5.2.5.3) ____	CALCULATED ____ N/mm^2 ____ N/mm^2
22	TOOTH HARDNESS (5.2.6) ____	ALLOWABLE (5.2.6) ____ N/mm^2 ____ N/mm^2
23	SHAFT ASSEMBLY DESIGNATION (5.1.16) ____	ANTICIPATED SPL (5.1.3) ____ dBA @ ____ m
24	HS SHAFT ROT FAC'G CPL'G (5.1.16) ○ CW ○ CCW	JOURNAL STATIC WEIGHT LOADS (5.6.2.1):
25	LS SHAFT ROT FAC'G CPL'G (5.1.16) ○ CW ○ CCW	PINION ____ kg GEAR ____ kg
26	HS SHAFT END: ○ CYLN. ○ TAPER ○ 1- KEY ○ 2-KEYS	WR² REFERRED TO LS SHAFT ____ $kg\ m^2$
27	○ HYDR'LC TAPER ○ INTEGRAL FLANGE	BREAKAWAY TORQUE N·m @ LS SHAFT
28	LS SHAFT END: ○ CYLN. ○ TAPER ○ 1- KEY ○ 2-KEYS	□ **CONSTRUCTION FEATURES**
29	○ HYDR'LC TAPER ○ INTEGRAL FLANGE	TYPE OF GEAR □ REDUCER □ INCREASER
30	EXTERNAL LOADS (5.1.12) ____ N	□ SINGLE STAGE □ DOUBLE STAGE
31	OTHER OPERATING CONDITIONS (5.2.6) (5.6.1.4)	□ SINGLE HELICAL □ DOUBLE HELICAL
32		□ ____
33	○ **INSTALLATION DATA**	**TEETH**
34	○ INDOOR ○ HEATED ○ UNDER ROOF	NUMBER OF TEETH PINION ____ GEAR ____
35	○ OUT DOOR ○ UNHEATED ○ PARTIAL SIDES	GEAR RATIO ____ CENTRE DIST ____ mm
36	○ GRADE ○ MEZZANINE ○ ____	PITCH DIA, mm PINION ____ GEAR ____
37	○ WINTERIZATION REQ'D ○ TROPICALIZATION REQ'D	FINISH *Ra*
38	ELECTRICAL AREA (5.1.6) CLASS ____ GRP ____ DIV ____	PINION ____ µm GEAR ____ µm
39	MAX ALLOW SPL (5.1.3) ____ dBA @ ____ m	HELIX ANGLE ____ DEGREES
40	ELEVATION ____ m BAROMETER ____ kPa abs	NORMAL PRESSURE ANGLE ____ DEGREES
41	RANGE OF AMBIENT TEMPERATURES:	FACE WIDTH, *b* ____ mm PINION *L/d* ____
42	DRY BULB WET BULB	NORMAL MODULE ____ mm BACKLASH ____ mm
43	NORMAL ____ °C ____ °C	TOOTH PLATING (5.3.1.3) □ RECOM'D □ NOT RECOM'D
44	MAXIMUM ____ °C ____ °C	**MANUFACTURING METHODS**
45	MINIMUM ____ °C ____ °C	TEETH GENERATED BY THE ____ PROCESS
46	UNUSUAL CONDITIONS ○ DUST ○ FUMES ○	TEETH FINISHED BY THE ____ PROCESS
47	NOTES: ____	TEETH HARDENING METHOD ____
48	____	GEAR TO SHAFT (5.3.3.2) □ INTEGRAL □ SHRUNK-ON
49		RIM ATTACHMENT (5.3.3.2)
50	**ADDITIONAL REMARKS:**	

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No.					
1	○ **ADDITIONAL REQUIREMENTS**		☐ **RADIAL BEARINGS**		
2	**MOUNTING PLATES (6.3)**			PINION	GEAR
3	○ GEAR FURNISHED WITH (6.3.1):		TYPE		
4	○ BASEPLATE ○ SOLEPLATE (S) ○ SUBPLATE (S)		DIAMETER, mm		
5	○ MOUNTING PLATE(S) FURNISHED BY (6.3.1.1)		LENGTH, mm		
6	○ EQUIPMENT ON BASEPLATE (6.3.2.1)		JOURNAL VELOCITY, m/s		
7			LOADING, N/mm^2		
8	○ BASEPLATE WITH LEVELLING PADS (6.3.2.3)		CLEARANCE (min-max), mm		
9	○ BASEPLATE SUITABLE FOR COLUMN MOUNTING (6.3.2.4)		SPAN, mm		
10	○ GROUT TYPE (6.3.1.6)	EPOXY	☐ **THRUST BEARING(S)**		
11	○ PAINTING [7.4.3 a)]		LOCATION		
12	**MISCELLANEOUS**		MANUFACTURER		
13	○ UNDAMPED CRITICAL ANALYSIS REPORT (5.6.1.6):		TYPE		
14	○ WITH DAMPED ROTOR RESPONSE ANALYSIS REPORT (5.6.1.6)		SIZE		
15	TORSIONAL ANALYSIS BY (5.6.1.8): ○ VENDOR ○ OTHER		AREA, mm²		
16	○ SPARE SET OF GEAR ROTORS (7.3.2.4)		LOADING, N/mm^2		
17	○ GEAR CASE FURNISHED WITH INLET PURGE CONNECTION (5.5.3)		RATING, N/mm^2		
18	○ ORIENTATION OF OIL INLET AND DRAIN CONNECTIONS		INT. THRUST LOAD, N (+) (-)		
19			EXT. THRUST LOAD, N (+) (-)		
20			☐ **COUPLING(S)**		
21			MANUFACTURER		
22			MODEL		
23			CPLG. RATING, kW/100 min^{-1}		
24	○ **VIBRATION DETECTORS (6.4.2)**		CPLG. GEAR PITCH DIA., mm		
25	**RADIAL (6.4.2.1)**		CPLG. PRESS. ANGLE, DEG.		
26	○ MANUFACTURER		CYLINDRICAL / 1-KEY	☐	☐
27	○ NO. AT EACH SHAFT BEARING	TOTAL NO.	CYLINDRICAL / 2-KEYS	☐	☐
28	○ OSCILLATOR-DEMODULATORS SUPPLIED BY		TAPERED / 1-KEY	☐	☐
29	○ MANUFACTURER		TAPERED / 2-KEYS	☐	☐
30	**AXIAL (6.4.2.1)**		TAPERED / KEYLESS	☐	☐
31	○ MANUFACTURER	NO. REQUIRED	☐ **MATERIALS**		
32	○ LOCATION		GEAR CASING	OIL SEALS	
33	○ OSCILLATOR-DEMODULATORS SUPPLIED BY		RADIAL BEARINGS		
34	○ MANUFACTURER		THRUST BEARING (S)		
35	**ACCELEROMETER (6.4.2.1)**		HS SHAFT	LS SHAFT	
36	○ MANUFACTURER	NO. REQUIRED	PINION (S)	HARDNESS	
37	○ LOCATION		GEAR RIM (S)	HARDNESS	
38	**KEY PHASER (6.4.2.5)**		LOW TEMP. OPERATION (5.9.4)		
39	○ MANUFACTURER	NO. REQUIRED	☐ **PIPING CONNECTIONS**		
40	○ LOCATION			NO.	SIZE / TYPE
41			SERVICE		
42			LUBE OIL INLET		
43			LUBE OIL OUTLET		
44			CASING DRAIN		
45			VENT		
46			CASING PURGE		
47					
48					
49	**REMARKS:**				
50					

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○ INSTRUMENTS

○ MERCURY THERMOMETERS (6.4.1.1) ______
○ BEARING METAL TEMP. SENSORS (5.7.1.3)

± CONTRACT DATA

○ VENDOR'S REP AT SITE (5.1.9)
○ TEST DATA PRIOR TO SHIPMENT ______
○ PROGRESS REPORTS (8.3.4) ______

○ SHIPMENT (7.4.1)

	CONTRACT UNIT	SPARES
EXPORT BOXING [7.4.3 i)]	○	○
DOMESTIC BOXING	○	○
OUT STORAGE OVER 6 MONTHS	○	○

○ COUPLINGS AND GUARDS

	HIGH SPEED	LOW SPEED
COUPLING FURNISHED BY		
COUPLING TYPE		
COUPLING LUBRICATION		
MOUNT COUPLING HALVES (6.2.1)		
TAPER		
LIMITED END FLOAT		
CPLG. GUARD FURNISHED BY		

○ LUBRICATION REQUIREMENTS

○ OIL SYSTEM FURNISHED BY (5.8.3)
○ OIL VISC.: mm^2/s @ 40°C

○ INSPECTIONS AND TESTS (7.1)

	REQ'D	WIT-NESS	OB-SERVED	TEST LOG
SHOP INSPECTION [7.1.1 b)]	○	○	○	
CLEANLINESS INSPECTION (7.2.3.2)	○	○	○	
HARDNESS VERIFICATION INSPECTION (7.2.3.3)	○	○	○	○
DISMANTLE-REASSEMBLY INSPECTION [7.3.2.3 a)]	○	○	○	
CONTACT CHECK (5.3.2.2)	○	○	○	○
CONTACT CHECK TAPE LIFT (5.3.2.2)	○	○	○	○
JOURNAL RUNOUT CHECK (5.3.2.1)	○	○	○	○
AXIAL STABILITY CHECK (5.3.2.3)	○	○	○	○
ROTOR BALANCING MACHINE SENSITIVITY CHECK (5.6.2.3)	○	○	○	○
RESIDUAL UNBALANCE CHECK (5.6.2.4)	○	○	○	○
MECHANICAL RUN TEST (7.3.2)	○	○	○	○
MECHANICAL RUN TEST (SPARE ROTORS) (7.3.2.4)	○	○	○	○

□ LUBRICATION REQUIREMENTS

MIN. STARTUP OIL TEMPERATURE		°C
UNIT OIL FLOW (TOTAL)		l/min
UNIT OIL PRESSURE		bar
OIL FLOW, MESH		l/min
OIL FLOW, HS BEARINGS		l/min
OIL FLOW, LS BEARINGS		l/min
OIL FLOW, THRUST BEARING (S)		l/min

ADDITIONAL REQUIREMENTS

FILTER BREATHER LOCATION (5.4.1.11)

□ GEAR DATA

POWER LOSS EACH HS BEARING		kW
POWER LOSS EACH LS BEARING		kW
POWER LOSS EACH THRUST BEARING		kW

	PINION	GEAR
TIP DIAMETER, mm		
ROOT DIAMETER, mm		
CENTRE GROOVE DIAMETER, mm		
OVERLAP RATIO		
TRANSVERSE CONTACT RATIO		
PATH OF CONTACT, mm		

NOTES

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INSPECTIONS AND TESTS (Con't)

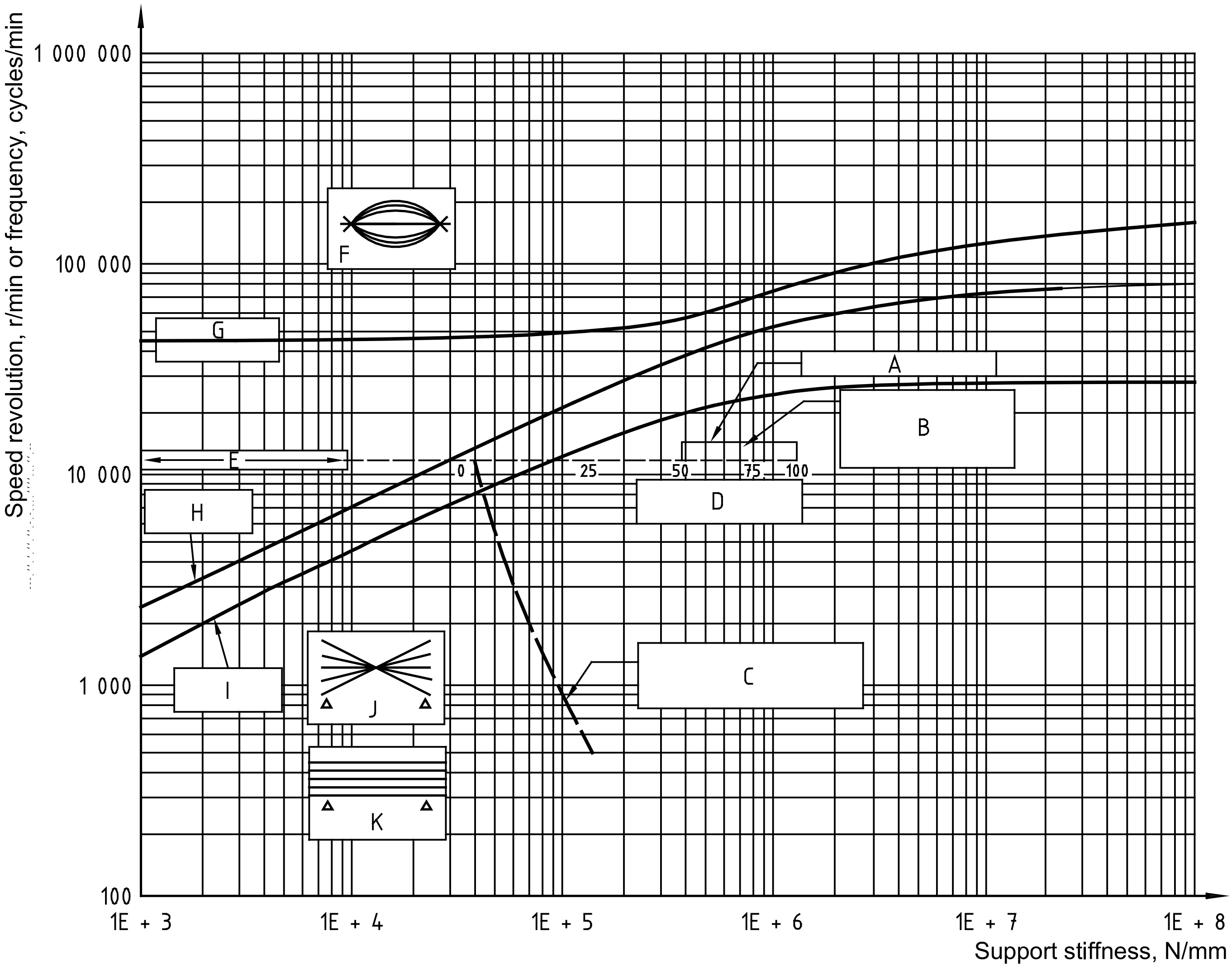
	REQ'D	WIT- NESS	OB- SERVED	TEST LOG
ADD'L MECHANICAL TESTS [7.3.2.2 o)]	○	○	○	○
PART OR FULL LOAD AND FULL SPEED TEST (7.3.3.2)	○	○	○	○
FULL TORQUE, SLOW ROLL TEST (7.3.3.3)	○	○	○	○
FULL TORQUE STATIC TEST (7.3.3.4)	○	○	○	○
BACK-TO-BACK LOCKED TORQUE TEST (7.3.3.5)	○	○	○	○
SOUND LEVEL TEST (7.3.3.6)	○	○	○	○
ADDITIONAL GEAR TOOTH TEST (7.2.2.7)	○	○	○	○
USE SHOP LUBE SYSTEM	○	○	○	
USE JOB LUBE SYSTEM	○	○	○	
USE SHOP VIBRATION PROBES, ETC.	○	○	○	
USE JOB VIBRATION PROBES, ETC.	○	○	○	
OTHER (7.2.1.2)	○	○	○	
FINAL ASSEMBLY, MAINTENANCE & RUNNING CLEARANCE [7.2.1.1 e)]	○	○	○	○
OIL SYSTEM CLEANLINESS [7.3.2.1 c)]	○	○	○	
OIL SYSTEM-CASING JOINT TIGHTNESS [7.3.2.1 d)]	○	○	○	
WARNING AND PROTECTION DEVICES [7.3.2.1 e)]	○	○	○	

NOTES

NOTES

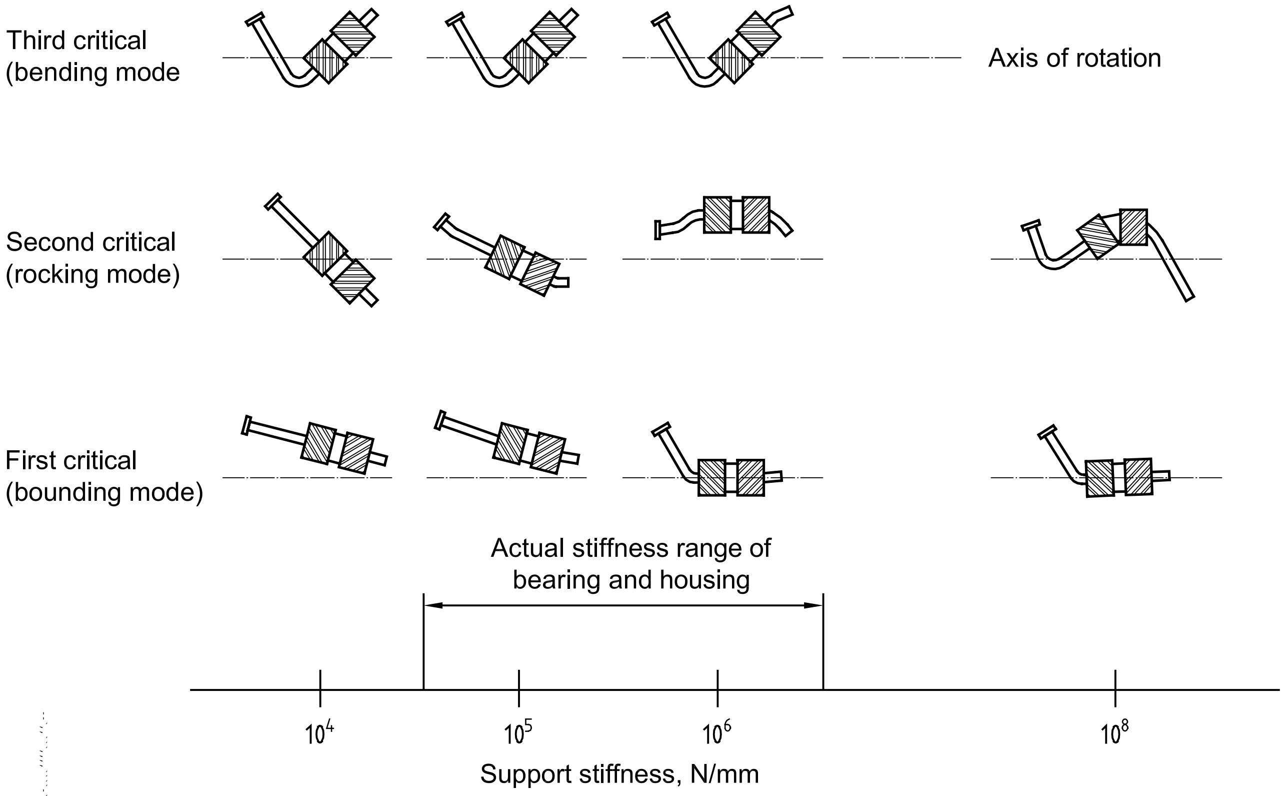
Annex B
(informative)

Lateral critical speed map and mode shapes for typical rotor



A 120 % maximum continuous speed
B Dynamic stiffness of shaft supports at maximum continuous speed for percentage maximum torque shown
C Estimated dynamic stiffness of shaft supports for start-up under no load and low acceleration
D % maximum torque at maximum continuous speed
E Maximum continuous speed
F First bending mode
G Third critical (first bending mode)
H Second critical (rocking mode)
I First critical (bouncing mode)
J Conical pivotal-rocking
K Cylindrical translational-bouncing

Figure B.1 — Lateral critical speed map for a typical rotor



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

Figure B.2 — Shapes versus support stiffness for a typical rotor

Annex C
(informative)

Couplings for high-speed gear units

C.1 General

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

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

C.2 Coupling types

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

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

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

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

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

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

a) the driving force on the coupling teeth;

b) the speed of rotation;

c) the condition of the coupling tooth surfaces;

d) the hardness of the coupling tooth surfaces;

e) the degree of misalignment between the connected shafts;

f) the smoothness of operation of the connected machines;

g) the lubrication of the coupling teeth.

Experiments have been performed to try to determine the force exhibited by these couplings, but these attempts have been succesful only in proving how widely variable the force is. Machinery designers currently assume a coefficient of friction of 0,25, although they know that under adverse maintenance conditions this value may reach 0,3 or more. With a tendency toward overdesign in the name of reliability, the sizing of thrust bearings becomes a problem that may result in an inefficient gear unit. A definite hazard of this approach lies in the possibility of overloading the teeth of a double-helical gear in the event of coupling hang-up caused by sludging or excessive wear.

C.3 Diaphragm couplings

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

C.4 Limited-end-float couplings

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

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

C.5 Flexible-shaft couplings

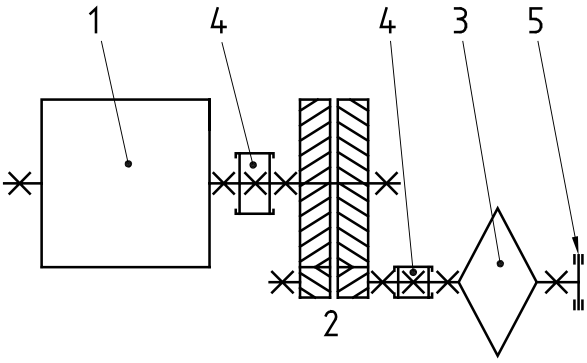
As machinery trains increase in size and power, the use of flexible-shaft couplings between the high-speed gear and one or both of the connected machines is gaining in popularity. The flexible shafts are usually arranged to pass through hollow pinions or gear shafts, thereby greatly shortening the overall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

C.6 Rigid-flange couplings

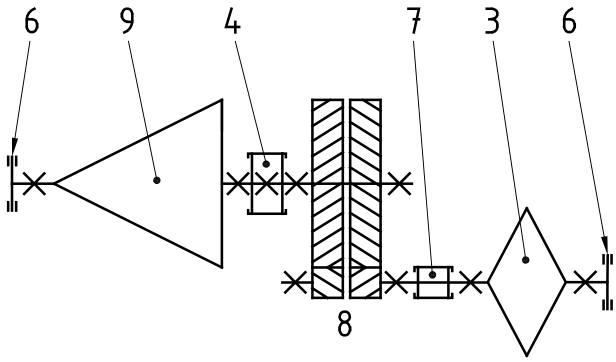
The only place where a rigid-flange connection between a gear unit and a coupled machine is permitted is where the coupled machine has only one radial bearing, as is the case with a single-bearing motor or generator (Figure C.1, Panel F). Such a coupling arrangement is practical only for relatively low-speed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

C.7 Torsionally flexible couplings

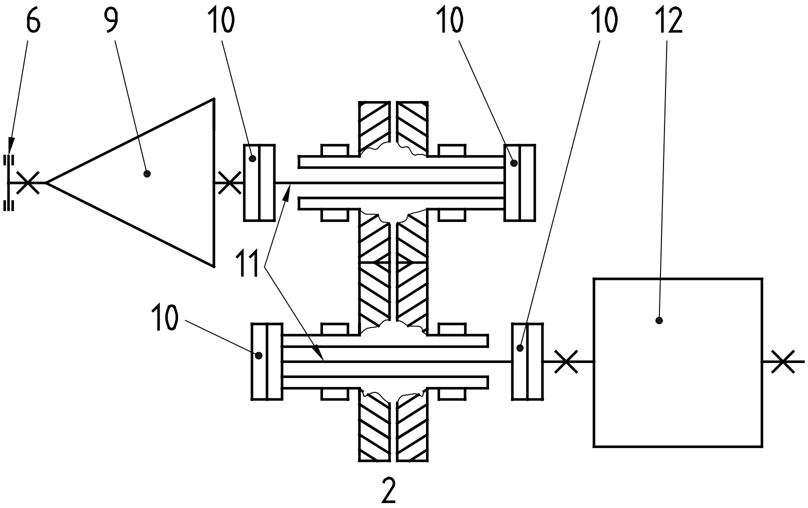
Analysis of the rotor dynamics of a complex multi-mass system sometimes indicates the need to use torsionally flexible couplings between the connected rotors to obtain the desired torsional tuning of the system. Several choices are available to the designer, each with characteristics that shall be considered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



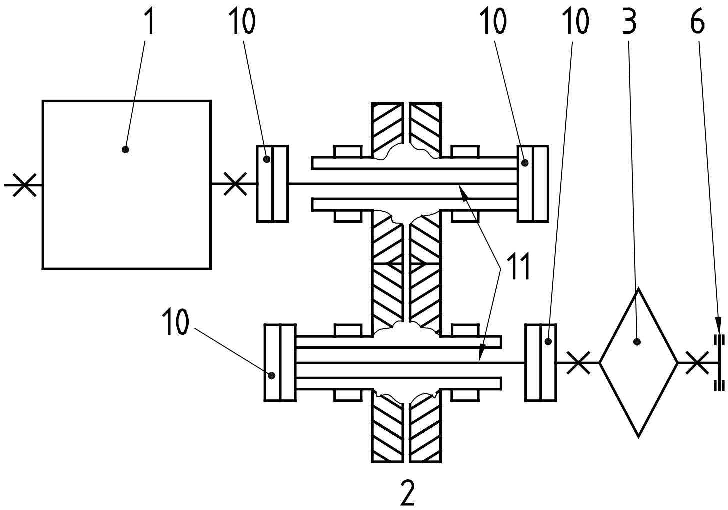
a) Panel A



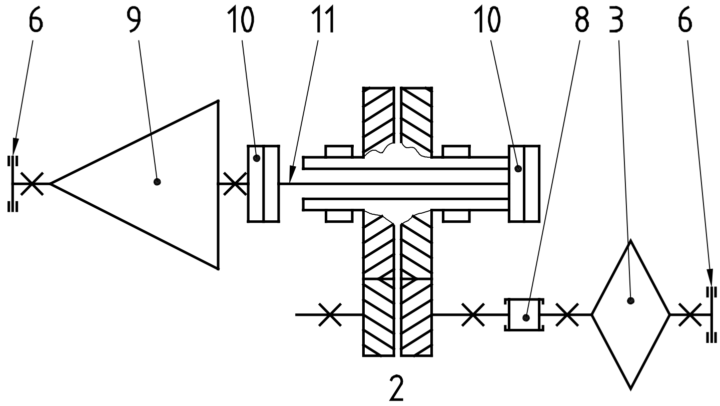
b) Panel B



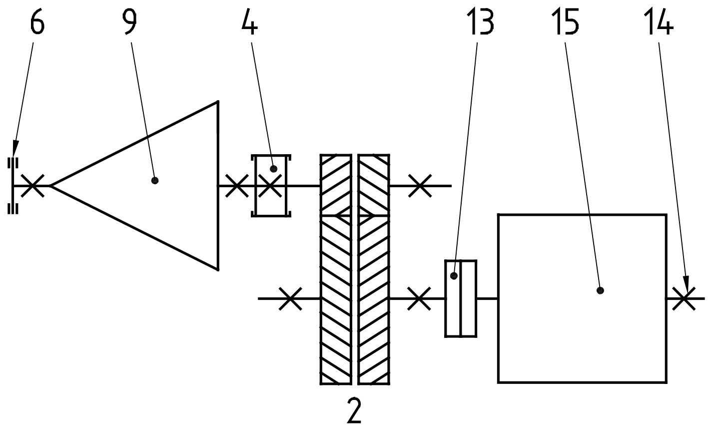
c) Panel C



d) Panel D



e) Panel E



f) Panel F

Key

1 Motor (no thrust bearing)
2 Gear (no thrust bearing)
3 Compressor
4 Limited-end-float coupling
5 Only one active thrust bearing in system
6 Thrust bearing
7 Flexible coupling with normal float
8 Gear
9 Turbine
10 Rigid coupling
11 Flexible shafts
12 Generator (no thrust bearing)
13 Rigid-flange coupling
14 Movable pedestal bearing
15 Single-bearing generator (no thrust bearing)

Figure C.1 —Couplings for high-speed gear units

Annex D
(informative)

Vendor requirements regarding drawings and data

D.1 General

This annex gives an example of a data sheet detailing the requirements of the vendor for drawing and data. It also provides the different elements which should be taken into account in the description of the required items.

SPECIAL PURPOSE GEAR UNITS
VENDOR DATA DRAWING AND DATA REQUIREMENTS

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

Proposal [a] Purchaser shall furnish _____ copies of data for all items indicated by an X.
Review [b] Vendor shall furnish _____ copies and _____ transparencies of drawings and data indicated.
Final [c] Vendor shall furnish _____ copies and _____ transparencies of drawings and data indicated.
Vendor shall furnish _____ operating and maintenance manuals.

DISTRIBUTION RECORD

Final - Received from vendor
Final - Due from vendor [c]
Review - Returned to vendor
Review - Received from vendor
Review - Due from vendor [c]

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

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

Where necessary to meet the scheduled shipping date, the vendor shall proceed with manufacture upon receipt of the order and without awaiting the purchaser's approval of drawings.

The vendor shall send all drawings and data to the following:

____

All drawings and data shall show project, purchase order, and item numbers as well as plant location and unit. One set of the drawings and instructions necessary for field installation, in addition to the copies specified above, shall be forwarded with shipment.

See the descriptions of required items that follow.

All of the information indicated on the distribution schedule shall be received before final payment is made.

Nomenclature:

S - number of weeks before shipment.

F - number of weeks after firm order.

D - number of weeks after receipt of approved drawings.

Vendor ____

Date ____________________ Vendor reference ________________________

Signature ____

(Signature acknowledges receipt of all instructions)

D.2 Factors to take into account in the description of required items

1 Certified dimensional outline drawing and list of connections, including the following:

a) the size, rating and location of all customer connections;

b) approximate overall and handling masses;

c) overall dimensions, and maintenance and dismantling clearances;

d) shaft centreline height;

e) dimensions of baseplates (if furnished) complete with diameters, number and locations of bolt holes and the thicknesses of sections through which the bolts must pass;

f) grouting details;

g) forces and moments for suction and discharge nozzles;

h) centre of gravity and lifting points;

i) shaft end separation and alignment data;

j) direction of rotation;

k) winterization, tropicalization and/or noise attenuation details, when required.

2 Cross-sectional drawings and part numbers.

3 Rotor assembly drawings and part numbers.

4 Thrust-bearing assembly drawing and part numbers.

5 Journal-bearing assembly drawings and bills of materials.

6 Coupling assembly drawing and bill of materials.

7 Lubricating oil schematic and bill of materials, including the following:

a) oil flows, temperatures and pressures at each point of use;

b) control, alarm and trip settings (pressure and recommended temperatures);

c) total heat loads;

d) utility requirements, including electricity, water and air;

e) pipe, valve and orifice sizes;

f) instrumentation, safety devices, control schemes and wiring diagrams.

8 Lubricating oil arrangement drawing and list of connections.

9 Lubricating oil component drawings and data, including the following:

a) pumps and drivers;

b) coolers, filters and reservoir;

c) instrumentation;

d) spare parts lists and recommendations.

10 Electrical and instrumentation schematics and bills of materials, including the following:

a) vibration alarm and shutdown limits;

b) bearing temperature alarm and shutdown limits;

c) lubricating oil temperature alarm and shutdown limits;

d) driver.

11 Electrical and instrumentation arrangement drawing and list of connections.

12 Tooth contact drawing and specifications.

13 Tooth contact check records.

14 Record of deviations from manufacturing process control system.

15 Mass elastic data.

16 Lateral critical speed analysis report.

17 Torsional analysis report.

18 Input and output shaft position diagram.

19 Weld procedures.

20 Hydrostatic test logs (oil system).

21 Mechanical running test logs.

22 Rotor balancing logs.

23 Rotor mechanical and electrical runout.

24 As-built data sheets.

25 As-built dimensions or data.

26 Installation manual.

27 Operating, maintenance and technical manual.

Section 1 — Installation:

a) storage;
b) foundation;
c) grouting;
d) setting equipment, rigging procedures, component weights and lifting diagram;
e) alignment;
f) piping recommendations;
g) composite outline drawing for pump/driver train, including anchor bolt locations;
h) dismantling clearances.

Section 2 — Operation:

a) start-up including tests and checks before start-up;
b) routine operational procedures;
c) lubricating oil recommendations.

Section 3 — Disassembly and assembly:

a) rotor and pump casing;
b) journal bearings;
c) thrust bearings (including clearance and preload on antifriction bearings);
d) seals;
e) thrust collars, if applicable;
f) allowable wear of running clearances;
g) fits and clearances for rebuilding;
h) routine maintenance procedures and intervals.

Section 4 — Vibration data:

a) vibration analysis data;
b) lateral critical speed analysis;
c) torsional critical speed analysis.

Section 5 — As-built data:

a) as-built data sheets;
b) as-built clearances;
c) noise data sheets;
d) performance data.

Section 6 — Drawing and data requirements:

a) certified dimensional outline drawing and list of connections;
b) cross-sectional drawing and bill of materials;
c) shaft seal drawing and bill of materials;
d) lubricating oil arrangement drawing and list of connections;
e) lubricating oil component drawings and data, and bill of materials;
f) electrical and instrumentation schematics, wiring diagrams, and bills of materials;
g) electrical and instrumentation arrangement drawing and list of connections;
h) coupling assembly drawing and bill of materials.

28 Spare parts recommendation and price list.

29 Progress reports and delivery schedule.

30 Preservation, packaging and shipping procedures.

31 List of special tools furnished for maintenance.

32 Nondestructive test procedures and acceptance criteria.

Annex E
(informative)

Gear tooth inspection

E.1 General

E.1.1 ISO/TR 10064-1 describes gear-measuring methods and is a general summary of the different procedures used. Many of these procedures may not be applicable, due to availability of manufacturing methods and measuring equipment.

E.1.2 Gears in accordance with ISO 13691 may have large diameters and wide facewidths and by necesssity are manufactured in matched sets with the tolerances in terms of mismatch between the contacting tooth flanks.

E.1.3 The measuring methods described in this annex cannot be used to replace tooth contact checking procedures traditionally used to verify the gear tooth fit in the job casing in the vendor's shop as described in 5.3.2.2 and the recommission contact checking after field installation and alignment.

E.2 Double-helical gears

E.2.1 The measurement methods described in ISO/TR 10064-1 apply to single-helical or spur gears.

E.2.2 Double-helical gears are two single-helical gears on the same rotor. These gears require data for both the right-hand and left-hand helixes.

E.2.3 When performing tooth contact inspections, it is necessary that the pinion be allowed to move axially to obtain true tooth contact patterns.

E.2.4 Apex runout measurements are required in accordance with 5.3.2.3 for double-helical gears.

E.3 Modified leads (helix angle)

E.3.1 Many high speed, high power, wide-facewidth gear sets are manufactured with a modified lead to account for torsional and bending deflection and thermal distortions. When properly applied, these modified leads considerably improve load distribution across the facewidth.

E.3.2 When modified leads are used, face contact patterns will be different under no-load and load conditions.

Annex F
(informative)

Inspector´s checklist

See Table F.1

Table F.1

Item	Inspection agency	Inspector's initials	Date	Extent W/O/*	Reference in this International Standard
1 Basic design					
a) special tools shipped with gear, such as bearing mandrel	C			*	6.6.1, 6.6.2
b) shaft assembly in accordance with approved data sheets	V			*	5.1.15
c) shaft rotation arrows in accordance with approved general arrangement drawings and data sheets	C			*	5.1.16.1, 5.1.16.2
2 Casings					
a) dowelling provisions	C			*	5.4.1.2
b) internal piping	C			*	5.4.1.6
c) piping and tubing	V			*	5.4.1.7
d) support of internal piping	C			*	5.4.1.8
e) cleanliness of internal piping	C			*	5.4.1.9
f) lubricating oil drainage	C & V			*	5.4.1.10
g) filter breather	C			*	5.4.1.11
h) inspection covers	C			*	5.4.1.12
i) interior coatings	V			*	5.4.1.13
j) sealing of horizontal joint	C			*	5.4.2
k) all dowelling of parts	C			*	
3 Bolting					
a) through bolting	V			*	5.4.3.1
b) studded connections	V			*	5.4.3.3
c) bolting clearance	C			*	5.4.3.4
4 Assembly and disassembly					
a) oil piping	V & C			*	5.4.4.1
b) lifting lugs, jackscrews, and relieved surfaces	C			*	5.4.4.2

Table F.1 *(continued)*

Item	Inspection agency	Inspector's initials	Date	Extent W/O/*	Reference in this International Standard
5 Casing connections					
a) single lubricating oil supply	V			*	5.5.1
b) single lubricating oil drain and its size	V			*	5.5.2
c) inlet purge connection	C			*	5.5.3
d) unacceptable pipe sizes	V			*	5.5.4
e) accessibility of customer connections	C			*	5.5.5
f) drain and oil connection size and location per latest approved general assembly drawing	C			*	5.5.6
g) installation of threaded connections	C			*	5.5.6.1
h) flanges in accordance with ISO 7005-1 or 7005-2	C			*	5.5.7
i) studs installed	V & C			*	5.5.8
j) threaded connections	C			*	5.5.9
k) tapped openings not connected to piping	C			*	5.5.10
6 Gear elements					
a) gear tooth surface finish	V & C			W	5.3.1.2
b) plating of teeth per data sheets	V			*	5.3.1.3
c) overhung design	V			*	5.3.1.6
7 Critical speeds and balancing					
a) critical speeds	V			*	5.6.1.4
b) rotor balancing	C			W	5.6.2.1
c) rotor balance machine calibration	C			*	5.6.2.3
d) coupling balance	V			W	ISO 10441
e) mechanical and electrical runout (in vee blocks)	C			W	5.6.3.2 to 5.6.3.4
f) Gauss levels	C			W	5.3.4.6
8 Bearings					
a) pins anti-rotation and axially secured	V			*	5.7.1.2, 5.7.2.1
b) bearing fitted with RTDs	V & C			*	5.7.1.3 [a]
c) bearing white metal (journal and thrust)	C			W	5.7.2.1, 5.7.3.2 [a, b]
d) integral thrust collar stock	V			*	5.7.3.2
e) thrust collar finish and runout	C			W	5.7.3.2
9 Vibration and position detectors					
a) Installed in accordance with API 670	V & C			*	6.4.2.1

Table F.1 *(continued)*

Item	Inspection agency	Inspector's initials	Date	Extent W/O/*	Reference in this International Standard
10 Materials					
a) review vendor in-house quality control checks on materials and manufacturing methods concerning gears, pinions, bearings	C			*	5.3.2
b) review manufacturers in-house quality control rejects with written explanation of reject pieces disposition	C			*	
c) no repairs to be made without customer approval	V & C			W	5.9.2.1
11 Nameplate versus data sheets	C			*	
a) provide nameplate rubbing	C			*	5.10
12 Mounting plates					
a) vertical jackscrews	C			*	6.3.1.3
b) horizontal jackscrews	C			*	6.3.1.4
c) preparation of mounting plates for epoxy	V & C			O	6.3.1.6
d) mounting bolts	C			*	6.3.1.12
e) gear dowel holes	C			*	5.4.1.2
f) foundation bolt hole location versus item, i.e. annex F	C			*	VDDR, item 1 e) [c]
13 Controls and instrumentation					
a) instrumentation supplied against approved data sheets	C			*	6.4, annex A
14 Piping and appurtances					
a) site flow glasses	C			*	6.5
15 Inspection					
a) mill test reports [d] for all gear element components	C & V			*	7.2.1.1 a)
b) UT of all gear element components after rough machinery	C & V			W	
c) record of all heat treatment and resulting hardnesses	C & V			*	7.2.2.6.1 b)
d) records of all radiographs and UT inspection	C & V			W	7.2.2.6.1 c)
e) hardness versus case depth of teeth	C & V			W	5.2.5, 7.2.2.6.1 d)
f) hardness of through-hardened gears	C & V			W	5.2.5, 7.2.2.6.1 e)
g) stress relieve of casing	V			*	5.9.3.3
h) hardness of welds and heat affected zones on gear elements	V & C			*	7.2.2.3
i) UT or MP inspection of all welds on rotating elements	V & C			W	7.2.2.6.1
j) MP of gear and pinion teeth	V & C			W	7.2.2.6.3

Table F.1 *(continued)*

Item	Inspection agency	Inspector's initials	Date	Extent W/O/*	Reference in this International Standard
k) purchase specifications[e]	V			*	7.2.1.1 b)
l) running data [e]	V			*	7.2.1.1 e)
m) results of quality control checks					5.3.2, 7.2.1.1 d)
i. Journal runout check prior to finishing teeth	V & C			O	5.3.2.1
ii. Tooth profile, helix deviation pitch error, and cumulative pitch error	V & C			W	
iii. Check stand contact	V & C			W	5.3.2.2
iv. Contact check in job casing	V & C			W	5.3.2.2
v. Axial stability	V & C				5.3.2.3
n) setting of thrust bearing	V & C			W	
o) cleanliness of equipment including lubricating oil system prior to running any tests: cleanliness per ISO 10438 (all parts)				O	7.3.2.1 c), 7.3.2.1 d), 7.3.2.1 e)
p) final assembly clearances (journal bearing, thrust bearing, etc.)				W	Annex D, VDDR, item 25
16 Special tools					
a) separately packaged and labelled with item number				*	6.6.2
b) each tool tagged for intended use				*	6.6.2
17 Testing					
a) mechanical running test	C			W	7.3.2
b) 25 %, 50 %, 75 % and 100 % full torque slow roll tests, optional tests	C			W	7.3.3
c) check alignment prior to any running tests	C			W	
d) check position of lubricating oil sprays	C			W	5.8.1
18 Preparation for shipment					
a) painting	C			*	7.4.3 a)
b) rust preventative	C			*	7.4.3 b)
c) interior of gear preserved	C			*	7.4.3 c)
d) metal closures	C			*	7.4.3 e)
e) car sealing of metal closures prior to shipment	C			*	
f) threaded opening	C			*	7.4.3 f)
g) lifting points clearly marked	C			*	7.4.3 g)
h) exposed shafts and couplings wrapped with waterproof mouldable wound cloth or VPI inhibitor paper and seams sealed with oil-proof adhesive tape	C			*	7.4.3 j)

Table F.1 *(continued)*

Item	Inspection agency	Inspector's initials	Date	Extent W/O/*	Reference in this International Standard
i) identification of items	C			*	7.4.3 h)
j) installation instructions	C			*	8.3.6
k) bill of lading for each packaged box against box contents	C			*	

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

[a] RTDs installed in accordance with API 670.

[b] Bearing white metal shall be liquid-penetrant checked.

[c] Location and size of bolt holes shall be checked against foundation drawing and gear manufacturer's drawings.

[d] Chemical and mechanical properties, hardness, and impact results should be reviewed prior to machining of gear elements.

[e] Include in instruction book.

Annex G
(informative)

Relationship of tooth rating factors between ISO 13691, ISO 9084 and API 613

G.1 Purpose

The purpose of this annex is to show the relationship between the method for rating gear sets found in ISO 9084 to those used in this International Standard, which is based on API 613 and is intended to give ratings similar to those found when using API 613.

G.2 Design assumptions

The rating method and factors below assume:

a) steel pinion and steel wheel;

b) single pitch deviation, f_{pt}, and cumulative pitch deviation, F_p, is Q4 or better;

c) helix deviation match, F_β, is Q4 or better;

d) proper profile modification;

e) proper control of lead mismatch;

f) helical gears with $\varepsilon_\beta > 1$;

g) helical gears with $1,2 \leqslant \varepsilon_\alpha \leqslant 2,0$;

h) helical gears with $5° \leqslant \beta \leqslant 35°$.

G.3 Symbols and units

See Table G.1.

Table G.1

Symbol	Meaning	Unit
Q	accuracy grade in accordance with ISO 1328-1	—
ε_β	face overlap ratio	—
ε_α	transverse contact ratio	—
β	helix angle	°
F_t	tangential load	N
P	transmitted power	kW
d_1	pinion reference pitch diameter	mm

Table G.1 *(continued)*

Symbol	Meaning	Unit
n_1	pinion speed	min^{-1}
K_{SL}	selection factor (ISO 13691)	—
K_A	application factor (ISO 9084)	—
SF	service factor (API 613)	—
σ_H	calculated contact stress number	N/mm^2
Z_H	zone factor	—
Z_E	elasticity factor	$\sqrt{\text{N/mm}^2}$
Z_ε	contact ratio factor	—
Z_β	helix angle factor	—
K_v	dynamic factor	—
$K_{H\beta}$	face load factor for contact stress	—
b	face width	mm
u	gear ratio	—
β_b	base helix angle	°
α_{wt}	operating transverse pressure angle	°
α_t	transverse pressure angle	°
σ_F	calculated bending stress number	N/mm^2
m_n	normal module	mm
Y_F	form factor	—
Y_S	stress correction factor	—
Y_β	helix angle factor	—
$K_{F\beta}$	face load factor for tooth root stress	—

G.4 Nominal tangential load, F_t

The nominal tangential load, F_t determined in the transverse plane at the reference cylinder is used in the stress calculations and is calculated by:

$$F_t = \frac{19\,098 \times 1\,000 P}{d_1 \times n_1} \qquad \text{(G.1)}$$

G.5 Selection factor, K_{SL}

The application factor, K_A, in ISO 9084 has been renamed selection factor, K_{SL}, in ISO 13691. For like combinations of prime mover and driven equipment the selection factor, K_{SL}, is the same numerical value and serves the same purpose as the service factor, SF, found in API 613.

G.6 Rating formulas

G.6.1 Contact stress for pinion/gear, σ_H

The rating method for contact stress found in this International Standard is a simplification of the method found in ISO 9084 wherein some of the rating factors are set. To maintain consistency with accepted practice, the 'application factor' K_A as found in ISO 9084 has been changed to a 'selection factor' K_{SL}. With this change the basic rating equation for contact stress found in ISO 9084 is:

$$\sigma_H = Z_H Z_E Z_\varepsilon Z_\beta \sqrt{\frac{K_{SL} K_v K_{H\beta} F_t}{d_1 b} \frac{u+1}{u}} \quad \text{(G.2)}$$

Three factors associated with the geometry of the gear teeth, 'zone factor', Z_H, 'contact ratio factor', Z_ε, and 'helix angle factor', Z_β are calculated as shown below:

$$Z_H = \sqrt{\frac{2 \cos \beta_b \cdot \cos \alpha_{wt}}{\cos^2 \alpha_t \cdot \sin \alpha_{wt}}} \quad \text{(G.3)}$$

$$Z_\varepsilon = \sqrt{\frac{1}{\varepsilon_\alpha}} \quad \text{(G.4)}$$

$$Z_\beta = \sqrt{\cos \beta} \quad \text{(G.5)}$$

The product of the 'zone factor', 'contact ratio factor' and 'helix angle factor' varies closely around a value of 1,8 or $Z_H\ Z_\varepsilon\ Z_\beta \cong 1{,}8$. Therefore, a value of 1,8 is used and:

$$Z_H Z_\varepsilon Z_\beta = 1{,}8 \quad \text{(G.6)}$$

For a steel pinion and wheel, the value for the elasticity factor is 189,8 and:

$$Z_E = 189{,}8 \quad \text{(G.7)}$$

The internal dynamic factor K_v allows for the dynamic effects resulting from the geometrical deviations in the gear teeth. For high-speed gears with a gear accuracy grade Q5 or better according to ISO 1328-1, a value of 1,15 shall be assumed and:

$$K_v = 1{,}15 \quad \text{(G.8)}$$

The face load factor $K_{H\beta}$ takes into account the influence of the non-uniform distribution of load across the gear face width. As explained in the body of the standard proper control of the influences which effect this factor are required. Therefore, a value of 1,35 is selected for the face load factor and:

$$K_{H\beta} = 1{,}35 \quad \text{(G.9)}$$

Inserting these values into the equation for contact stress results in:

$$\sigma_H = 1{,}8\ (189{,}9) \cdot \sqrt{\frac{K_{SL} \cdot 1{,}15 \cdot 1{,}35 \cdot F_t}{d_1 \cdot b} \cdot \frac{u+1}{u}} \quad \text{(G.10)}$$

or

$$\sigma_H = 426 \cdot \sqrt{\frac{F_t}{d_1 \cdot b} \cdot \frac{u+1}{u}} \sqrt{K_{SL}} \quad \text{(G.11)}$$

G.6.2 Calculated bending stress number, σ_F

The rating method for the calculated bending stress number root stress found in this International Standard is a simplification of the method found in ISO 9084 wherein some of the rating factors are set. To maintain consistency with accepted practice the 'application factor' K_A as found in ISO 9084 has been changed to a 'selection factor' K_{SL}. With this change the basic rating equation for tooth root stress found in ISO 9084 is:

$$\sigma_F = \frac{F_t}{m_n \cdot b} \cdot Y_F \cdot Y_S \cdot Y_\beta \cdot K_{SL} \cdot K_v \cdot F_{F\beta} \quad \text{(G.12)}$$

The internal dynamic factor K_v allows for the dynamic effects resulting from the geometrical deviations in the gear teeth. For high speed gears with a gear accuracy grade Q5 or better according to ISO 1328-1, a value of 1,15 shall be assumed and:

$$K_v = 1{,}15 \quad \text{(G.13)}$$

The face load factor $K_{F\beta}$ takes into account the influence of the non-uniform distribution of load across the gear face width. As explained in the body of the standard proper control of the influences which effect this factor are required. Therefore, a value of 1,35 is selected for the face load, so:

$$K_{F\beta} = 1{,}35 \quad \text{(G.14)}$$

Inserting these values into the equation for bending stress results in:

$$\sigma_F = \frac{F_t}{m_n \cdot b} \cdot Y_F \cdot Y_S \cdot Y_\beta \cdot K_{SL} \cdot 1{,}15 \cdot 1{,}35 \quad \text{(G.15)}$$

or:

$$\sigma_F = K_{SL} \cdot 1{,}55 \cdot Y_F \cdot Y_S \cdot Y_\beta \frac{F_t}{m_n \cdot b} \quad \text{(G.16)}$$

The factors Y_F Y_S Y_β are as calculated in accordance with ISO 9084. These factors taken together are analogous to the Geometry Factor 'J' as found in AGMA and API standards.

G.6.3 Allowable design stress numbers, σ_{HAD} and σ_{FAD}

The allowable design contact stress numbers σ_{HAD} (for surface durability) and allowable design bending stress number σ_{FAD} (for bending strength) are established by applying the principle that the successful and satisfactory gear design experience when using API 613 be fully maintained. The values for the allowable design contact stress numbers, σ_{HAD} and allowable design bending stress number, σ_{FAD} have been selected such that gears designed in accordance with API 613 and this International Standard should have equal safety margins relative to torque capacity when applying numerically equal values to the service factor, SF, in API 613 and the selection factor, K_{SL}, in this International Standard.

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