INTERNATIONAL STANDARD

ISO 14661

First edition
2000-06-15

Thermal turbines for industrial applications (steam turbines, gas expansion turbines) — General requirements

Turbines thermiques pour applications industrielles (turbines à vapeur, turbines à dilatation de gaz) — Prescriptions générales

Reference number
ISO 14661:2000(E)

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Printed in Switzerland

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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.

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.

International Standard ISO 14661 was prepared by Technical Committee ISO/TC 208, *Thermal turbines for industrial application (steam turbines, gas expansion turbines)*.

Annex B is a normative part of this International Standard. Annexes A and C are for information only.

Introduction

This International Standard is a basic standard. Therefore the users of this International Standard should be aware that additional or differing requirements may be needed to meet the needs for the particular service intended.

It is intended to add later, by means of an amendment, an annex containing data sheets appropriate to the text at hand.

Thermal turbines for industrial applications (steam turbines, gas expansion turbines) — General requirements

1 Scope

This International Standard specifies general requirements intended to facilitate the procurement and supply of steam turbines and gas expansion turbines primarily for industrial applications.

This International Standard should serve as a basis for any application although, for special applications, supplementary specifications may also be required, for example for general and special purpose industrial steam turbines used in the petroleum and natural gas industries.

This International Standard is applicable to axial- and radial-flow industrial-type turbines (steam turbines and gas expansion turbines). It specifies the basic requirements for single-stage and multi-stage impulse or reaction turbines, which are not spared or are in critical service. In addition, this International Standard also specifies some requirements for driven machines, gear units, lubrication and sealing systems, controls, instrumentation and auxiliary units for turbine plants.

Exceptions to the requirements laid down in this International Standard may be agreed between the purchaser and supplier.

NOTE 1 Which standard is to be applied in the individual case is the decision of the purchaser. For instance, the purchaser of a generator-driving turbine connected to the public network will generally be responsible for complying with the technical requirements of the public network regardless which standard is specified. If the purchaser of a generator-driving turbine is also the operator of the public network or if he/she is the supplier of an independent power producer (IPP), he/she usually specifies the application of IEC 60045-1.

NOTE 2 Further standards on industrial steam turbines for the Petroleum and Natural Gas Industries are ISO 10436 and ISO 10437. Information on other relevant International Standards is given in the bibliography.

NOTE 3 A bullet ● at the edge of the text indicates that either a decision is required or further information is to be provided by the purchaser. This information should be indicated on the data sheets (see "Introduction") otherwise it should be stated in the quotation request or in the tender.

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

ISO 263, *ISO inch screw threads — General plan and selection for screws, bolts and nuts — Diameter range 0.06 to 6 in.*

ISO 1122-1, *Glossary of gear terms — Part 1: Geometrical definitions.*

ISO 1127, *Stainless steel tubes — Dimensions, tolerances, and conventional masses per unit length.*

ISO 1925, *Mechanical vibration — Balancing —Vocabulary.*

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

ISO 1940-2, *Mechanical vibration — Balance quality requirements of rigid rotors — Part 2: Balance errors.*

ISO 2041, *Vibration and shock — Vocabulary.*

ISO 3304, *Plain end seamless precision steel tubes —Technical conditions for delivery.*

ISO 4200, *Plain end steel tubes, welded and seamless — General tables of dimensions and masses per unit length.*

ISO 4572, *Hydraulic fluid power — Filters — Multi-pass method for evaluating filtration performance.*

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

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

ISO 7268, *Pipe components — Definition of nominal pressure.*

ISO 7919-1, *Mechanical vibration on non-reciprocating machines — Measurements on rotating shafts and evaluation criteria — Part 1: General guidelines.*

ISO 7919-2, *Mechanical vibration on non-reciprocating machines — Measurements on rotating shafts and evaluation criteria — Part 2: Guidelines for large land-based steam turbine generator sets.*

ISO 7919-3, *Mechanical vibration on non-reciprocating machines —- Measurements on rotating shafts and evaluation criteria — Part 3: Coupled industrial machines.*

ISO 8068, *Petroleum products and lubricants — Petroleum lubricating oils for turbines (categories ISO-L-TSA and ISO-L-TGA) — Specifications.*

ISO 9084, *Calculation of load capacity of spur and helical gears — Application to high speed gears and gears of similar requirements.*

ISO 10816-1, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 1: General guidelines*

ISO 10816-2, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 2: Large land-based steam turbine sets in excess of 50 MW.*

ISO 10816-3, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15 000 r/min when measured in situ.*

ISO 11342, *Mechanical vibration — Methods and criteria for the mechanical balancing of flexible rotors.*

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 60045-1, *Steam turbines — Part 1: Specifications.*

IEC 60079 (all parts), *Electrical apparatus for explosive gas atmospheres.*

IEC 60079-10 , *Electrical apparatus for explosive gas atmospheres — Classification of hazardous areas.*

IEC 60584 (all parts), *Thermocouples.*

IEC 60751, *Industrial platinum resistance thermometer sensors.*

IEC 61515, *Mineral insulated thermocouple cables and thermocouples.*

3 Terms and definitions

For the purposes of this International Standard, the terms and definitions given in ISO 1122-1 (for geometrical definitions), ISO 1925 (for balancing definitions), ISO 2041 (for vibration and shock definitions) and the following apply.

NOTE Use of the word "design" with respect to any steam conditions, power output, speed, etc. should be avoided in contract documents. This terminology should only be applied by the equipment designer and the manufacturer to the values used in design calculations such as the design pressure for pressure vessel.

3.1 Turbines

3.1.1
steam turbine
thermal power unit with rotating components in which the enthalpy drop of steam is converted into mechanical energy in one or several stages

3.1.2
industrial-type steam turbine
steam turbine which is used for industrial purposes.

NOTE In addition to mechanical energy it is typical that, by the use of the turbine, steam can be exported for various production fields. This steam can be extracted from the turbine anywhere during or at the end of expansion.

3.1.3
extraction turbine
turbine in which some of the steam is extracted part-away through the expansion in order to provide process steam

NOTE If the turbine includes means for controlling the pressure of the extracted steam, it is called a controlled (or automatic) extraction turbine.

3.1.4
mixed pressure turbine
turbine where the working fluid enters the turbine at two or more pressures through separate inlet openings

3.1.5
gas expansion turbine
thermal power unit with rotating components, in which the enthalpy drop of a gaseous medium is converted into mechanical energy in one or several stages

NOTE The gas expansion turbine differs from the gas turbine in that it has neither its own associated compression nor combustion system.

3.2 Power output, heat rate and steam rate

3.2.1
rated power output
P_r
maximum power output at the turbine coupling or at the generator terminals, as specified by the purchaser, including the relevant conditions

NOTE The governing valves will not necessarily be fully open.

3.2.2
maximum power output

P_{max}

maximum available power output at the turbine coupling or at the generator terminals, as stated by the manufacturer, including the relevant conditions

3.2.3
heat rate

φ

ratio of the absorbed heat between the motive fluid inlet(s) and outlet(s) to the power output at the coupling or at the generator terminals, considering the specified operating conditions:

$$\varphi = \frac{Q_s - Q_r}{P}$$

where Q_s and Q_r are the heat supplied and the heat returned

NOTE 1 The dimensions are kilojoules per kilowatt second [kJ/(kW·s)] or the equivalent in a coherent unit system to obtain a dimensionless ratio.

NOTE 2 The relationship between the heat rate and the thermal efficiency η_t is

$$\varphi = \frac{1}{\eta_t}$$

3.2.4
steam rate

s

ratio of the steam mass flow rate, q_m, at the inlet of the turbine to the power output at the coupling or at the generator terminals, considering the specified operating conditions:

$$s = \frac{q_m}{P}$$

NOTE 1 The dimensions are kilogram per kilowatt second [kg/(kW·s)] or kilogram per kilowatt hour [kg/(kW·h)] or the equivalent in a coherent unit system.

NOTE 2 The relationship between the steam rate and the thermodynamic efficiency η_{td} and the isentropic drop Δh_s is

$$s = \frac{1}{\eta_{td} \cdot \Delta h_s}$$

where η_{td} is the value of the power output divided by the isentropic power capacity.

NOTE 3 For mixed pressure and for extraction steam turbines it is necessary to declare in addition to the numerical value of the steam rate the associated specific conditions for induction and for extraction steam. These are:

a) for mixed pressure turbines: induction steam

— mass flow,

— pressure,

— temperature;

b) for extraction turbines: extraction steam

— mass flow.

3.3 Connection points

3.3.1
inlet connections
inlet connecting point of the stop valve or casing connecting points for intake and additional induction steam stop valves

3.3.2
outlet connections
outlet connecting point of casing for controlled or uncontrolled extractions or exhaust

3.4 Steam or gas conditions

3.4.1
steam or gas conditions
conditions which define the thermodynamic state of steam or gas, normally (static) pressure and temperature or dryness fraction (or quality)

NOTE Steam or gas pressure should always be quoted in absolute units, not as gauge pressure.

3.4.2
initial steam or gas conditions
steam or gas conditions at the inlet to the stop valves

3.4.3
maximum operating steam or gas conditions
highest steam or gas conditions at which the turbine is required to operate continuously

NOTE The steam conditions should not exceed those permitted by IEC 60045-1.

3.4.4
maximum steam or gas conditions
most severe steam or gas conditions at which the turbine is required to operate continuously

NOTE If the pressure and/or temperature are limited by protecting devices (set values) to protect any component of the turbine's steam or gas system, these set values define the maximum steam or gas condition.

3.4.5
minimum operating steam or gas conditions
least severe steam or gas conditions at which the turbine is required to operate continuously

3.4.6
induction steam conditions
conditions of any additional steam entering the turbine at any pressure lower than the initial pressure

3.4.7
extraction steam conditions
conditions at the extraction connections of the turbine, of steam extracted for feed-heating or process purposes

3.4.8
exhaust conditions
steam or gas conditions at the exhaust connection from the turbine

3.5 Wetness

3.5.1
gas wetness
ratio of the actual mass of vapour and steam droplets contained in a defined gas volume and the total mass of the defined volume

3.5.2
steam wetness
ratio of the actual mass of water in a defined steam volume and the total mass of the defined volume (steam/water mixture)

3.6 Mass flow

3.6.1
steam or gas flow
steam or gas mass flow which the turbine, including the turbine shaft-driven auxiliary equipment, requires to produce the specified power output at the coupling or generator terminals for the different operating points under the specified conditions

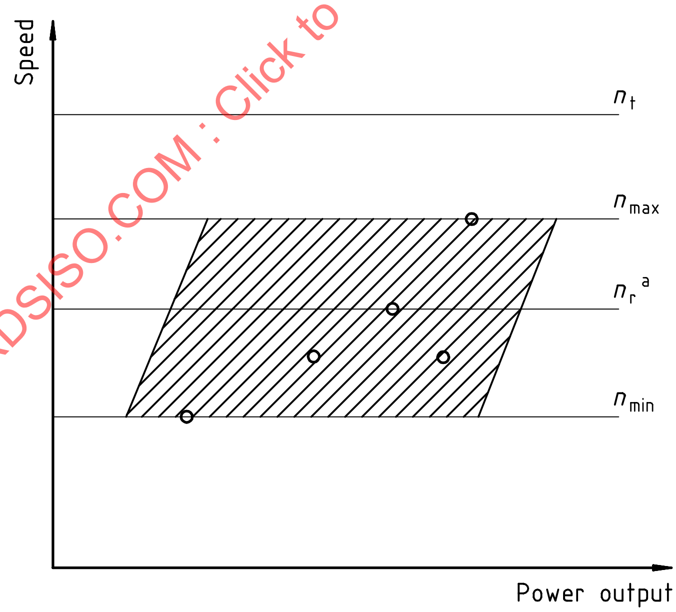
NOTE The requirements for auxiliary steam and power should be agreed upon between the purchaser and the supplier.

3.6.2
extraction or bleed mass flow
steam or gas mass flow extracted from the turbine at a pressure below the inlet pressure but above the outlet pressure

3.6.3
exhaust steam or exhaust gas mass flow
steam or gas mass flow which passes through the casing into the back pressure system or the condensing plant

3.6.4
induction mass flow
steam or gas mass flow induced to the turbine at a pressure below the inlet pressure

3.7 Speeds (see Figure 1)



o = specified operating points

//// = specified operating range for turbines with variable operating speed

a For generator drives, all operating points are situated on this line.

Figure 1 — Definitions of speeds

3.7.1
rated speed
n_r
speed at the rated operating point

3.7.2
minimum continuous operating speed
n_{min}
minimum speed in the specified speed range

NOTE For generator drives this is equal to the rated speed n_r, taking into account a certain variation in network frequency.

3.7.3
maximum continuous operating speed
n_{max}
maximum speed in the specified operating speed range

3.7.4
trip speed
n_t
speed at which the turbine is tripped automatically by the independent overspeed device

NOTE Further details on speeds are given in 10.2 and annex A. Terms concerning speed governing are given in annex B.

3.8 Operating points

3.8.1
normal operating point
point at which usual operation is expected and where optimal efficiency is desired

3.8.2
guarantee point(s)
normal operating point and/or other specified operating points at which guarantee values must be met

3.8.3
rated point
operating point at which the maximum power is produced at the corresponding speed

3.9 Miscellaneous

3.9.1
purchaser
company or corporation which places the order with the supplier

3.9.2
supplier
company or corporation which accepted the order of the purchaser

3.9.3
witnessed inspection or test
inspection or test carried out with the purchaser or his/her representative in attendance

NOTE In this case a hold is applied to the production schedule to ensure that the purchaser can attend.

3.9.4
observed inspection or test
inspection or test carried out after the purchaser has been informed of the timing

NOTE In this case the inspection or test is performed as scheduled and if the purchaser or his/her representative is not present, the supplier may proceed to the next step.

3.9.5
special tools
tools which cannot be found in the catalogues of tooling suppliers

4 Symbols and abbreviations

A Amplitude

F Amplification factor

L_{v} Vibration limit

MSR Maximum speed rise

P Power output

P_{m} Maximum power output at which zero extraction or induction is permitted

P_{max} Maximum available power output

P_{r} Rated power output

Q_{s} Heat supplied

Q_{r} Heat returned

S Separation margin

SV Speed variation

U Input unbalance for rotor response analysis

U_{max} Maximum allowable residual unbalance

W Journal static weight load

h Enthalpy

Δh_{s} Isentropic enthalpy drop

n Speed

n_{c} Rotor critical speed

n_{m} Speed at maximum power output with zero extraction or induction

n_{max} Maximum continuous operating speed

n_{min} Minimum continuous operating speed

n_{r} Rated speed

n_{s} Set point of speed

n_{t} Trip speed

Δn Difference in speeds

q_{m} Mass flow rate of steam

s Steam rate

δ Steady-state speed regulation

δ_{i} Incremental steady-state speed regulation

η_t Thermal efficiency

η_{td} Thermodynamic efficiency

φ Heat rate

5 Enquiry and tender

5.1 General

5.1.1 Because of the long delivery time for turbines, the last but one sentence in the introductory phrase to clause 2 is to read as follows: If not otherwise agreed, the edition of the normative document valid at the moment of order placement, shall apply.

5.1.2 The data sheets for industrial turbines are part of the inquiry or of the order. If there is any contradiction of this International Standard in the inquiry, then the statements in the inquiry take precedent. With an order, the information of the order overrules that given in this International Standard.

Documents which are part of the inquiry, the quotation or the order shall not be passed to a third party, except if this is necessary for setting up the quotation or for the execution of the order.

Documents which have been submitted to the purchaser and which are approved by him shall be incorporated in the order information.The approval does not release the supplier and the purchaser from their contractual obligations.

The responsibility for the coordination of the turbine and the driven machine shall be clarified before the contract is agreed.

5.2 Enquiry

The purchaser shall complete the data sheets for industrial turbines as far as is possible. In the data sheets all statements shall be made which are necessary for the supplier to make a tender. Where the standard requires the purchaser to make a decision, he should make an unequivocal statement.

The purchaser shall state any exceptions and deviations from this International Standard, which are to be considered by the supplier.

● In this enquiry the purchaser shall specify all spare parts, which he/she requires to be taken into account within the tender. The supplier may amend this list with his/her own proposals.

The purchaser shall provide the supplier with all information concerning legislative authority regulations which shall be valid for the turbine and its appurtenances, e.g. noise emission, air pollution, water pollution, fire protection, etc.

The purchaser and the supplier shall agree on any exceptions and deviations from this International Standard.

5.3 Tender

The supplier shall complete the data sheets for industrial turbines and include them as part of the tender documentation. He shall provide additional information where necessary to describe the scope of supply.

In addition, the supplier shall provide the following minimum level of documentation with the tender:

a) arrangement or outline drawings;

b) schematic drawings for the operating fluid systems, control and lubrication oil systems, and overall control systems;

c) a definition of the supply limits and limits of responsibility for coordination;

d) terminal point lists or diagrams;

e) exceptions to this International Standard;

f) exceptions and additions to the enquiry requirements based on the supplier's recommendations and application experience;

g) delivery schedule.

For budget quotations, the extent of documentation shall be mutually agreed by the purchaser and supplier.

5.4 Warranty

The type, extent and duration of the warranty are constituents of the commercial contract.

5.5 Safety requirements

Information on International Standards dealing with aspects of safety is given in the Bibliography.

5.6 Alternative designs

The supplier may offer alternative designs. Any deviations from this International Standard or from the specified design shall be clearly stated in the proposal. It is for the purchaser to decide whether to accept the alternative designs or not.

6 Turbines

6.1 General

6.1.1 Design features

The turbines and their auxiliary equipment shall be designed for continuous running in all specified operating points for the duration specified in the inquiry by the purchaser. Starting, run down and all specified instantaneous overloads shall be taken into account.

Any operating conditions deviating from the rated conditions shall be agreed upon by the purchaser and the supplier.

The direction of rotation of the turbine shall be agreed between the turbine supplier and the supplier of the driven machine.

The purchaser and supplier shall agree as precisely as possible upon the arrangement of the machines and the auxiliary equipment before the order is placed.

Lifting eye bolts, jacking screws and guide pins or similar devices shall be provided to facilitate assembly and dismantling. Where jacking screws are provided, sealing faces shall not be damaged.

Control systems, bearing houses, shaft sealings and oil supply systems shall be designed in such a way that under operation as well as at standstill only the minimum possible amount of humidity, dust and foreign substances should be able to ingress the turbine.

The turbines and auxiliaries shall be suitable for the environmental conditions and the climatic conditions specified by the purchaser in the data sheets.

Facilities for draining the casings and piping systems shall be provided.

All parts which may be damaged or which may fail because of low ambient temperatures shall be protected in a suitable manner.

If necessary, heating devices shall be provided for the lube fluid and the control fluid systems.

If reverse rotation is possible, the circumstances under which this may occur shall be clarified and preventive measures shall be agreed upon by the purchaser and the supplier.

6.1.2 Materials

Information on International Standards for materials is given in the Bibliography.

6.1.3 Welding

All weldings on pressure-containing casings and pipes shall be performed according to the following:

— materials shall be suitable for welding and the filler material shall be compatible with the basic material;

— welding procedures shall be selected according to the character of the material, the thickness of the piece and the stress of the welding seam;

— if not otherwise specified, all weldings take place under the responsibility of the supplier and according to his welding procedures;

— welds shall be performed by qualified welders using qualified procedures; the qualification authority shall be agreed between the purchaser and the supplier before the contract is signed;

— the inspection authority for the welds shall also be agreed between the purchaser and the supplier.

For information on International Standards on welding, see the Bibliography.

6.1.4 Hot surfaces

Components which can reach surface temperatures of more than 340 K (67 °C) under normal operating conditions shall be protected to prevent injuries to operating personnel. The method of protection should be designed in such a manner to prevent contact with the hot surfaces.

Because of the risk of fire, oil pipes shall not be insulated, even when the surface temperature is higher than 340 K.

Only insulation materials free of asbestos are permitted.

6.1.5 Protection against corrosion during longtime shutdowns

The purchaser is recommended to protect the turbine against corrosion during longtime shutdowns in accordance with the supplier's instructions. Details shall be given in the operating instructions.

6.1.6 Area classification

● Electrical components and installations shall be suitable for the area classification specified by the purchaser. Classification of hazardous areas shall be in accordance with IEC 60079-10.

6.1.7 Arrangement of the turbine plant

The final arrangement of the turbine plant with all its appurtenances shall be developed jointly by the purchaser and the supplier.

6.1.8 Legal requirements

The purchaser and the supplier shall mutually determine the measures that shall be taken to comply with any federal, state or local codes, regulations, ordinances or rules that are applicable to the equipment.

6.2 Casings

6.2.1 General design

The design of the casing and its pipe connections shall take into account the most severe conditions of pressure and temperature which are to be expected to occur simultaneously based on the specified steam conditions. For strength calculations and pressure tests, the casing may be subdivided.

In addition to the calculated minimum thickness of the casing, allowance shall be made for corrosion if the casing is not of a corrosion-resistant material.

The casing design pressure shall take into account the maximum pressure specified by the purchaser relevant to each external connection. The purchaser shall take into account the relief valve setting.

6.2.2 Materials

If not otherwise agreed upon between the purchaser and supplier, the supplier shall select the material for the turbine casings under the following considerations.

a) Casings for steam turbines exposed to gauge pressures above 2,5 MPa (25 bar) or temperatures above 625 K (352 °C) shall be made of steel.

b) Casings for steam turbines exposed to conditions lower than the above values but more than 0,5 MPa (5 bar) or 535 K (262 °C) may be made of nodular cast iron as a minimum or of welded steel.

c) Casings for steam turbines exposed to conditions lower than 0,5 MPa (5 bar) or 535 K (262 °C) may be made of lamellar graphite cast iron, nodular cast iron or of steel. At temperatures below 280 K (7 °C) cast iron may not be used.

d) For gas expansion turbines, the purchaser and the supplier shall, because of the special conditions, agree upon the materials to be used.

Structural welding used to join parts of the casing together shall be covered by a qualified procedure and post-weld heat treatment. Information on International Standards on welding is given in the Bibliography.

Unless otherwise specified, all tests and inspections shall be carried out in accordance with the supplier's own standards. This information may be requested by the purchaser as part of the tender documentation. Information on International Standards on testing materials is given in the Bibliography.

6.3 External forces and moments

The supplier specifies the thermal movements and allowable forces and moments for the terminal points. This information may be requested by the purchaser as part of the tender documentation.

The external forces and moments shall allow safe operation of the turbine at each specified operating conditions including standstill. The arrangement of the piping and calculations to consider the displacement of the pipe connections and the allowable forces and moments are within the responsibility of the pipework designer and pipework supplier. It is their responsibility not to exceed the allowable values.

The result of the pipework calculations including their basis shall be submitted to the turbine supplier for comments. This does not reduce the above-mentioned responsibility of the pipework designer and supplier.

6.4 Bolted joints

Metric threads shall comply with ISO 261, inch threads to ISO 263. Bolting joints with tensile shaft may have threads with enlarged clearances.

Manufacturer-specific tapered threads may be used to reduce the thread load.

For casing joints, through bolts and stud bolts should be used. Where threaded holes have to be used, these shall not extend into pressurized areas; the remaining wall thickness shall be sufficient to contain the pressure.

The materials of the casing bolts shall be selected considering the design temperature of the casing. The supplier shall design the casing flange and its bolts with respect to:

— the allowable stress of the flange;

— the allowable stress of the bolts;

— the possible temperature differences between the flange and bolts;

— freedom from leakages at all specified operating points;

— an installation which is as simple as possible.

6.5 Turbine casing openings for pipe connections

6.5.1 For general design, see 6.2.1. However, the following general requirements shall apply, unless otherwise specified.

6.5.2 External connection openings, pipes, fittings, flanges, etc. shall be at least of size DN 15 (DN is the nominal diameter as defined in ISO 6708). Openings used for signal lines may be less than DN 15.

6.5.3 The connections on the casing shall be flanged or welded where possible. If stud bolts are used, they shall be provided by the supplier together with the nuts.

For sizes DN 15 to DN 40, stub pipes welded to the casing and terminating in welded-on flanges are permitted. The welding shall be covered by qualified procedures and post-weld heat treatment.

For threaded connections and screwed pipe couplings, see 6.5.6.

6.5.4 For poisonous, corrosive or inflammable gases, the number of threaded connections shall be kept to a minimum.

6.5.5 Flanges shall be as specified in ISO 7005-1 and they shall be designed for at least PN 10 (PN is the nominal pressure as defined in ISO 7268). For PN 64 and above they shall be of type B (raised face) or type J (ring joint). Flanges up to PN 40 may be of type A (flat face).

There may be exceptions where the use of special flanges is unavoidable, for example for the outlet of condensing turbines.

6.5.6 The use of threaded connections and terminations in screwed pipe couplings shall be kept to a minimum.

Threaded holes to which no piping is connected shall be at least plugged with heavy-duty steel plugs.

6.5.7 If terminal flanges are non-standard, they shall be provided with mating flanges by the turbine supplier. All flanges for the connection of auxiliary lines furnished by the turbine supplier may be made according to the supplier's code of practice.

6.5.8 It shall be possible to disassemble the connections without the machine being moved.

6.6 Turbine rotor

6.6.1 The rotor shall be designed for safe momentary operation under maximum operation temperature at a speed which represents the normal overshoot above the trip speed and shall be at least 10 % above the trip speed. If the rotor is of built-up construction, the disc shall remain secure at the speed selected for the design.

6.6.2 If the construction uses separate discs which can be removed during maintenance, the discs shall be independently dynamically balanced prior to assembly.

6.6.3 Each rotor shall be clearly marked with an unique identification number. The number shall be visible, preferably on a shaft end or the integrated coupling flange, when the uncoupled rotor is enclosed by the casing.

6.6.4 Special care and attention shall be paid to the treatment of sensing areas for radial and axial displacement probes. If not otherwise specified, the sensing areas for radial-vibration probes shall be treated in such a way that the combined total electrical and mechanical runout does not exceed 10 µm.

6.6.5 To prevent the build-up of potential voltage, the magnetism of the rotating element shall not exceed 10×10^{-4} tesla (10 gauss).

6.6.6 If there is a significant risk of circulating currents (e.g. condensing turbines), the rotor shall be fitted with at least one grounding brush. This grounding brush may be installed either on the turbine shaft or on the rotor of the driven machine, provided that the total train is electrically conductive throughout. If there are two or more brushes on a shaft or train which is electrically conductive throughout, they shall be on the same end of the shaft or train to prevent the generation of a circulating current. Worn brushes shall be easy to replace.

6.7 Casing internals

Casing internals shall be designed for operation under the most unfavourable specified conditions with consideration of possible simultaneous effects. The supplier shall take into account transient periods, thermal expansion, creep distortion, water erosion in saturated steam, etc.

6.8 Inner seals

The inner seals between stationary and rotating parts shall be non-contact seals (labyrinth seals). The seal elements may be fitted to the stationary and/or the rotating parts. It shall be possible to replace the seal elements during a routine major overhaul of the machine.

6.9 Balance piston and balance line

In single-flow turbines, especially of reaction type, a balance piston and balance line may be necessary to keep the axial load on the thrust bearing within allowable limits. The balance piston may be designed either as a straight or as a stepped piston.

In double-flow turbines where the flow is led through single stages or groups of stages in opposite axial directions, a balance piston may be omitted or an intermediate seal between two turbine stages may assume the role of the balance piston.

The balance piston shall be provided with a labyrinth seal as specified in 6.8.

6.10 Outer shaft seals

The function of the outer shaft seals is to minimize or to prevent steam or gas emission between the shaft and the casing. In the case of gas-expansion turbines, the outer shaft seal shall prevent the escape to atmosphere of toxic, inflammable or explosive gases.

Essentially there are four types of seals in use:

— labyrinth seals;

— seals with mechanical contact;

— floating ring seals;

— non-contact face seals.

Shaft seals for steam operating against a pressure less than atmospheric pressure shall be designed for admission of sealing steam to seal against air ingress. The admission of sealing steam shall be controlled throughout the load range. A single terminal point shall be provided for connection to the purchaser's auxiliary steam system to provide the sealing steam during starting. The sealing steam for normal operation shall preferably come from a positive pressure section of the steam turbine. (See 8.5.)

For steam turbines, the need for a gland steam condenser or a similar system shall be agreed between the supplier and purchaser, based on the agreed rate of steam leakage.

The gland seal system shall be designed to deal with any leakage which may occur under any expected service condition.

6.11 Bearing and bearing housings

Bearing housings may be integral with the turbine casing or may be separately attached using a system to ensure correct alignment with the casing during service and maintenance.

The type of hydrodynamic radial bearing shall be selected by the supplier, taking into account the requirements of 6.12.

Thrust bearings shall be of the hydrodynamic type, and shall have thrust load capacity in both directions. They shall be steel-backed, with babbitted multiple segments, and arranged for continuous pressurized lubrication to each side.

Thrust bearings shall be sized for continuous operation under the most adverse specified operating conditions and shall be able to accommodate, in both directions, the forces transmitted from the shafts of the driven machines via the coupling as well as the forces evoked by the turbine itself.

When using a toothed coupling, a coefficient of friction of at least 0,15 related to the coupling pitch radius shall be applied for calculating the axial thrust to be transmitted.

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

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

Unless otherwise specified, integral thrust collars shall be furnished. They shall be provided with at least 3 mm of additional stock on the total thickness to enable refinishing if the collar is damaged. When replaceable collars are furnished, they shall be shrunk on and positively locked to the shaft to prevent fretting.

The bearing housings shall prevent the oil from foaming, as far as is possible, and shall be arranged with adequate gravity drainage to ensure that the oil level remains below the shaft and outer oil seals. Outer oil seals shall be replaceable.

Bearings and end seals shall be replaceable without having to remove the upper casing of a horizontally split turbine or the cover of a vertically split turbine.

Provision shall be made for fitting two non-contacting vibration probes spaced at an angle of 90° ± 10° adjacent to each bearing. Unless otherwise agreed between the purchaser and supplier, provision shall be made for at least one axial position probe within the thrust bearing housing and a probe for phase angle reference.

When specified, provisions for the mounting of accelerometers or seismic probes on the bearing houses shall be made.

6.12 Dynamics

6.12.1 General

For terms and definitions, see ISO 2041.

Vibrations affect availability and safety, and can cause serious damage to equipment and structures. For measurement of vibration and its interpretation, see the two series of International Standards:

a) ISO 7919-1, ISO 7919-2 and ISO 7919-3 when the vibration measurements are made on the rotating shafts;

b) ISO 10816-1, ISO 10816-2 and ISO 10816-3 when the vibration measurements are made on non-rotating parts.

ISO 10816-1 and ISO 7919-1 are the basic documents which describe the general requirements for evaluating vibration of various machine types.

ISO 10816-2 and ISO 7919-2 present the special features required for measuring vibrations on large land-based steam turbine sets in excess of 50 MW when measured *in situ*.

ISO 10816-3 and ISO 7919-3 present the special features required for measuring vibrations on coupled industrial machines with nominal power above 15 KW and nominal speeds of between 120 r/min and 15000 r/min when measured *in situ*.

For definitions and explanations concerning dynamics, see annex A.

Vibration measurement are taken on shafts, bearing housings, or casings. The most significant locations for vibration measurement shall be selected regarding the design details, including mass, stiffness and accessibility of the parts. The supplier shall define the locations of the vibration measurements most suitable for the equipment.

Appropriate levels of vibration for the intended service shall be indicated by the supplier in terms of acceptable commissioning and alarm levels, and levels where the turbine train shall be shut down immediately. Those levels should be based upon the above listed International Standards or the limits given in 6.12.2.

The supplier who is specified to have unit responsibility shall determine that the drive-train critical speeds (rotor lateral, system torsional, blading modes, and the like) are compatible with the critical speeds of the driven equipment and that the combination is suitable for the specified operating speed range, including any starting speed detent (hold-point) requirements of the train.

A list of all undesirable speeds, from zero to trip, shall be submitted to the purchaser for review and shall be included in the instruction manual for guidance.

6.12.2 Vibration

If a shop test is specified, the following is valid. For a machine assembled with a balanced rotor and operating at its maximum continuous speed or any other speed within the specified operating range, the peak-to-peak amplitude of unfiltered vibration 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:

$$A = 25{,}4 \times \sqrt{\frac{12\,000}{n_{\max}}} \qquad (1)$$

where

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

n_{max} is the maximum continuous operating speed, in revolutions per minute.

At any speed greater than the maximum continuous speed, up to and including the trip speed of the driver, the vibration shall not exceed 150 % of the permissable value of A given by equation (1).

If the supplier can demonstrate that electrical or mechanical runout is present, a maximum of 25 % of the test level calculated from equation (1) or 8 µm, whichever is greater, may be vectorially subtracted from the vibration signal measured during the factory test.

6.12.3 Balancing

For terms and definitions, see ISO 1925.

For more precise details on possible balancing methods and criteria, see the following International Standards:

— ISO 1940 is concerned with the unbalance quality of rotating rigid bodies;

— ISO 11342 classifies flexible rotors in accordance with their balancing requirements and establishes methods of assessment of residual unbalance.

Major parts of the rotating element, such as the shaft, balancing drum and disks, shall be dynamically balanced. When a bare shaft with a single keyway is dynamically balanced, the keyways shall be filled with a fully crowned half-key. The initial balance correction to the bare shaft shall be recorded. A shaft with keyways 180° apart but not in the same transverse plane shall also be filled as described above.

For low-speed balancing, the rotating element shall be multiplane dynamically balanced during assembly. This shall be accomplished after the addition of no more than two major components. Balancing correction shall be applied only to the elements added. Minor correction of other components may be required during the final trim balancing of the completely assembled element. On rotors with single keyways, the keyway shall be filled with a fully crowned half-key. The maximum allowable residual unbalance per plane (journal) shall be calculated using equation (2):

$$U_{max} = 650 \times \frac{W}{n_{max}} \qquad \left(U_{max} \approx \frac{6\,350}{9{,}81} \times \frac{W}{n_{max}} \right) \tag{2}$$

where

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

W is the journal static weight load, in newtons;

n_{max} is the maximum continuous operating speed, in revolutions per minute.

When spare rotors are supplied, they shall be dynamically balanced to the same tolerances as the main rotor.

After the final low-speed balancing of each assembled rotating element has been completed, a residual unbalance check shall be performed.

If high-speed balancing (balancing in a high-speed balancing machine at the operating speed) is performed, the acceptance criteria for this balancing shall be mutually agreed upon by the purchaser and supplier.

Electrical and mechanical runout shall be determined and recorded.

6.13 Baseframe (baseplate) and soleplates

6.13.1 General

6.13.1.1 The provision of a baseframe shall be by agreement between the supplier and purchaser. When specified, the supplier shall provide any sub-soleplates and anchor bolts required for embedment in the foundation.

Attachment components of baseframes, sub-soleplates and soleplates (screws, anchor bolts, keys, etc.) shall be designed for forces and moments in accordance with those coming from any mounted machinery and equipment.

6.13.1.2 Where pedestals or stools are mounted on the baseframe, the surfaces used for alignment shall be machined. Where a means of adjustment for alignment is necessary, this may be by screwed jacks or adjusting plates with jacking screws. Provision for horizontal adjustment using suitable screws or jacks shall also be made when the equipment has a supported mass of more than 500 kg.

6.13.1.3 The turbine support system shall be designed to limit the change in alignment due to the worst combination of pressure, torque and pipe loads to a value agreed by the purchaser.

6.13.1.4 Adequate working clearance shall be provided at the bolting locations to allow the use of sockets and to allow movement of the equipment using the horizontal and vertical jackscrews.

6.13.1.5 Where soleplates are provided, they shall be larger than the individual mounting pad area for each mating pad.

6.13.2 Baseframe (baseplate)

6.13.2.1 Where a baseframe is to be provided, the design shall be agreed between the supplier and the purchaser. In relation to the general dimension of the set, there may be a common baseframe for the turbine and the driven machine, or two individual baseframes.

Some options for consideration are: the extent of the baseplate; the type of support required; baseplates including oil tanks; provision for aligning and connecting separate baseplates on site.

6.13.2.2 The baseframe shall be provided with at least four lifting lugs and it shall be possible to lift it without any permanent distortion or damage to either the baseframe or the baseframe-mounted equipment.

6.13.2.3 Levelling pads shall be provided that are accessible for field levelling after the installation of the baseframe with all the equipment mounted. When the bottom of the baseframe is open, provision shall be made to vent compartments during grouting.

6.13.2.4 Nonskid decking shall cover all walk and work areas on top of the baseframe.

6.13.2.5 Unless otherwise specified, baseframes shall be fabricated from welded steel plates or rolled steel bars (beams).

6.14 Nameplates and rotation arrows

The turbine shall be supplied with a nameplate made of corrosion-resistant material. As a minimum, the following information shall be given on this plate:

— manufacturer's name;

— serial number/order number;

— model number (type);

— year of manufacture;

— maximum or rated power output in kilowatts (as defined in 3.2.1 and 3.2.2);

— maximum continuous or rated operating speed in reciprocal minutes (as defined in 3.7.1 and 3.7.3);

— maximum permissible operating inlet and induction steam or gas conditions (as defined in 3.4), inlet pressure in pascals or megapascals, inlet temperature in degrees Celsius; pressures shall be designated as absolute or gauge;

— maximum/minimum exhaust and extraction pressure in pascals or megapascals (analogous definition in 3.4); pressures shall be designated as absolute or gauge;

Rotation arrows shall be integrally cast into the bearing housing of the turbine or be firmly attached stainless-steel plates, located for easy visibility.

7 Driven machines, gear units and couplings

7.1 Driven machines

● To ensure the correct design of the turbine unit, the purchaser shall indicate the type of machine to be driven and which requirements the latter, and consequently the turbine, has to fulfil. Of special importance are, for example, the direction of rotation, non-permissible continuous operating speed ranges and, for compressors and pumps, the characteristics of the load throughout the total range of the rotating speed.

Rotation arrows shall be integrally cast into the casing or bearing housing of the driven machine or shall be firmly attached stainless-steel plates, located for easy visibility.

For generator drives, the torques which result from all electrical faults or mal-synchronization shall be considered.

7.2 Gear units

7.2.1 General

For terms and definitions, see ISO 1122-1.

If not otherwise specified, the following requirements shall apply for gear units, which are usually within the scope of supply of the turbine supplier.

They are applicable to single or multiple reduction parallel shaft gear units and to epicyclic gears, as well as to multi-shaft gears.

The principles of 6.1 shall (as far as possible) apply to gear units.

The gear unit shall be capable of withstanding all external loads (thrust, lube oil piping, etc.) while it is operating within the specified operating range.

Each gear and each pinion shall be supported by two bearings. All gears shall comply with the requirements of 7.2.2 to 7.2.5.

7.2.2 Rating

Gearing shall be rated to transmit the maximum torque, within the specified operating range.

The gear unit shall be suitable for the trip speed.

Gears shall be single-helical or double-helical type. The choice of tooth geometry is the responsibility of the gear supplier.

Tooth design shall be carried out according to ISO 9084. Because the evaluation of scuffing load capacity is not taken into consideration in ISO 9084, this shall be determined according to ISO/TR 13989-1 or ISO/TR 13989-2.

7.2.3 Casing

Gear casings shall be either cast or fabricated and shall be designed and constructed to maintain shaft alignment under all conditions (such as torque, temperature, internal and allowable external forces and moments) within the whole operating range specified.

The design shall be such that no resonance occurs between the vibratory excitation and the natural frequencies of the casing or of parts of it.

The gear casing shall preferably be split axially.

To avoid unacceptable heating caused by windage, large side and circumferential clearances between gears, pinions and casing shall be provided.

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

Casings shall be designed to permit rapid drainage of lube oil to minimize oil foaming and to allow adequate gravity drainage to ensure that the oil level remains below the gearwheel. Outer seals shall be replaceable.

When specified or required by the supplier, provision shall be made for fitting two non-contacting vibration probes separated by an angle of 90° ± 10° adjacent to the bearings.

When specified, provision shall be made for mounting accelerometers or velocity probes on the casing.

7.2.4 Bearings

The type of radial bearing shall be selected by the gear supplier, taking into account the requirements of 6.11 and 6.12.

7.2.5 Dynamics

See 6.12.

7.3 Couplings

7.3.1 General

The make, type and mounting arrangement of the couplings shall be agreed between the purchaser and the supplier(s) of the driven machine and the turbine.

7.3.2 Coupling selection

Couplings shall be capable of transmitting, in continuous operation, the maximum torque resulting at any of the specified operating points, multiplied by the corresponding application factor, taken from ISO 9084.

For electrical faults or mal-synchronization, see 7.1.

If an electric motor is part of the train, the characteristics of this motor shall be taken into consideration.

7.3.3 Coupling and mounting arrangement

The coupling shall be arranged so that both coupling halves are accessible without having to dismantle the driven machines, gear units and turbine casings.

The turbine should be capable of being tested with the coupling to the driven machine disengaged.

7.3.4 Fitting of the couplings

Coupling halves which are not integral with the shaft shall be fitted to the latter by means of a cylindrical or taper shrink fit, with or without keys. Hydraulically or temperature-fitted taper couplings are acceptable.

7.3.5 Balancing

Coupling hubs and sleeves which are not integral with the shaft shall be balanced statically and/or dynamically before assembly (see 6.12.3).

Coupling bolts shall be selected according to mass and shall be marked to identify their position in the flange, to avoid a change in the balanced condition after reassembly.

7.3.6 Coupling guard

Coupling guards shall be arranged so that the coupling can be easily inspected. The coupling guard design shall conform to the relevant safety specifications.

7.3.7 Scope of supply

Unless otherwise agreed, the non-integral halves of couplings and guards between the turbine and the driven machine shall be supplied by the supplier of the driven machine. Couplings and guards between tandem drivers or tandem driven machines shall be supplied by the supplier of the tandem machines.

Unless otherwise specified, the turbine half of the coupling shall be mounted by the turbine supplier.

If both halves of a coupling are of the integral type, the turbine supplier shall supply the spacer and any tools necessary for fitting.

Information on shaft, keyway dimensions (if any), and shaft end movements due to end play and thermal effects shall be furnished to the supplier supplying the coupling.

If shop verification is specified, idling adapters shall be furnished by the supplier of the coupling to the turbine supplier together with the half-coupling. The half-coupling and the idling adapter in place shall cause a moment equal to that of the contract half-coupling plus one-half of the coupling spacer. When all testing is finished, the idling adapters shall be furnished to the purchaser of the equipment as part of the special tools.

7.4 Rotor turning device

If specified or considered necessary by the supplier, the turbine shall be equipped with a rotor-turning device to avoid harmful distortion of the rotor during cooling-down periods.

The bearings shall be provided with oil while the rotor is turning and interlocks shall be provided to inhibit turning if lubrication oil is not available. However, if a stroking turning device is used, if not otherwise specified, the supplier shall decide if lubrication at the bearings is necessary.

Turning devices shall be arranged to automatically disengage as the turbine is started. The device shall be protected where necessary from reverse rotation of the turbine line where this can occur (see 6.1.1). If the rotor-turning device fails to act in the normal direction of rotation, it shall be possible to turn the rotor manually.

Motorized turning devices shall be sized for the peak torque required to overcome the breakaway torque in addition to the normal operation and friction torque (see also 9.4.5).

8 Auxiliary equipment

8.1 Piping

The auxiliary piping includes all pipes for

— lubricating oil,

— control oil,

— sealing and leakage fluids,

— drainage,

— signal lines, and

— instrument and control air.

The supplier and purchaser shall agree who shall provide the pipework connecting the turbine and auxiliary equipment within his scope of supply. The supply of pipework connecting with other plant components and packages shall be subject to a separate agreement.

The piping shall be properly supported and secured to prevent damage from vibration and to minimize possible danger from shipment and maintenance. It shall be designed to allow safe access for routine maintenance, preferably running close to the contour of the machine. Pipework containing oil shall be segregated from pipework and parts of the machine which are hot in order to minimize the risk of oil-soaked insulation and possible fire.

The sizes of pipes, valves and fittings shall be not smaller than DN 15, except those used for signal lines. The minimum rating shall be PN 10.

The nominal sizes of piping shall be as specified in ISO 6708.

Piping shall be of seamless steel pipe in accordance with ISO 4200 series 1 or ISO 1127 series 1 in outside diameter and thickness range E, unless otherwise agreed between the supplier and purchaser. Subject to agreement, precision steel pipes as specified in ISO 3304 or for larger sized pipings pipes with longitudinal weld may also be used.

Information on International Standards for the delivery conditions of steel tubes is given in the Bibliography.

Threaded connections shall be kept to a minimum but may generally be used in signal lines. Flanges shall be in accordance with ISO 7005-1. The welding of pipes shall be performed in accordance with a recognized code applying appropriate procedures and qualifications for the duty (see B.3 in annex B). In general, butt-welded fittings are preferred and socket-welded fittings are not permitted downstream of oil filters. For butt welds in stainless-steel pipe, tungsten inert gas root welds shall be used with filler passes by this method or by the shielded metal arc process.

Welding of piping shall be performed by operators who are qualified in accordance with the appropriate recognized code using procedures also in accordance with the appropriate code (see Bibliography).

Gaskets and packings for flanges, valves and other components shall not contain asbestos.

8.2 Inlet strainer and water separator

A replaceable corrosion-resistant and robust inlet strainer shall be incorporated ahead of the seat of the emergency stop valve. For plant commissioning, the provision of an additional fine inlet strainer may be agreed upon. The strainers shall be easily replaceable without having to dismantle the pipework.

If steam at the turbine casing inlet is saturated or only lightly superheated, a water separator may be considered. The water separator shall continuously drain the live steam line via a condensate trap. The purchaser and the turbine supplier shall agree in whose scope of supply the separator is included.

8.3 Electrical systems

The characteristics of electrical power supplies for motors, heaters and instrumentation shall be specified by the purchaser.

● Electrical equipment located on the unit or on any separate panel shall be suitable for the hazard classification specified according to IEC 60079-10. For details concerning electrical apparatus for explosive gas atmospheres, see the relevant part of IEC 60079. Electrical starting and supervisory controls may be either a.c. or d.c.

Power and control wiring within the confines of the baseplate and the oil supply unit shall be resistant to oil, to the temperature to which it is exposed, to moisture and to abrasion. Stranded conductors shall be used within the confines of the baseplate and in other areas subject to vibration. Where rubber or elastomer insulation is used, a Neoprene (or equivalent) high-temperature thermoplastic sheath shall be provided for insulation protection.

To facilitate maintenance, liberal clearances shall be provided for all energized parts (such as terminal blocks and relays). The clearances required for 600 V service shall be, as far as possible, provided for lower voltages.

Electrical materials including insulation shall be corrosion-resistant and non-hygroscopic insofar as possible. When specified for tropical location, materials shall be protected from fungus attack and unprotected surfaces shall be coated.

Control, instrumentation and power wiring (including thermocouple leads) within the limits of the baseplate shall be installed in heavy-duty conduits or cable trays and boxes, properly bracketed to minimize vibration, and isolated or shielded to prevent interference between voltage levels. In general conduits may terminate (and in the case of temperature element heads, shall terminate) with a flexible metallic conduit long enough to permit access to the unit for maintenance without removal of the conduit. For zone 2 locations, flexible metallic conduits shall have a liquidtight thermosetting or thermoplastic outer jacket.

8.4 Condensing plant

If included in the scope of supply, the purchaser and supplier shall agree on the specifications applicable to the design, manufacture and testing of the condensing plant.

8.5 Gland steam or gas system

Where a condenser is to be provided, the supplier shall offer a construction which is suitable for the purchaser's site conditions and system of operation. The supplier shall provide or specifiy any equipment necessary for the system to operate correctly, for example a steam ejector, a vacuum pump or fan.

8.6 Materials for auxiliary equipment

Information on International Standards for materials is given in the Bibliography.

8.7 Drainage system of steam turbines

Steam turbines shall be protected against condensate accumulations inside the turbine and the pipework. Inlet and outlet lines shall not be drained through the turbine.

Special consideration is needed for the drainage of exhaust ducts for condensing turbines with upward exhaust to ensure that condensate can be collected without entering the turbine blading for return to the hotwell.

All piping and casing sections which may contain water shall be provided with amply sized draining connections, which allow the resulting condensate to be discharged without water accumulation occurring. The following may apply.

a) Sections with absolute operating pressures exceeding 1 bar (0,1 MPa) and operating temperatures of not less than 50 °C above saturation temperature: drain pipe with shut-off valve.

b) Sections with absolute operating pressures exceeding 1 bar (0,1 MPa) and operating temperatures of less than 50 °C above saturation temperature: drain pipe with shut-off valve and bypass with condensate trap.

c) Sections with absolute operating pressures close to 1 bar (0,1 MPa) as for example external shaft seals: open drain pipe with water seal (trap) or a permanent orifice.

d) Sections with absolute operating pressures of less than 1 bar (0,1 Mpa): drain pipe with shut-off valve or condensate trap. This drain may also be provided with a shut-off valve and a bypassed condensate trap or with a permanent orifice. Discharge of the drain is into the condenser.

e) Orificed drains which cascade the drain flow from a high-pressure zone to a lower-pressure zone.

8.8 Protection against water flow entering the turbine

The steam piping design shall be such that no water back-flow will enter the casing.

9 Lubricating and control oil systems

9.1 General

Unless otherwise agreed, the turbine supplier shall supply the oil system of the turbine and the accessories.

The lubricating oil system of the turbine may be common to that of the driven equipment, if agreed between the purchaser and supplier. If the oil system is furnished by others, the turbine supplier shall transmit to these all requirements concerning the oil supply of his scope of supply.

Unless otherwise agreed, the turbine supplier shall furnish one single-feed connection for each pressure level and one drain connection for all oil to be returned to the tank.

9.2 Oil types

The oil used shall conform to ISO 8068. For plants with gears additional requirements may be unavoidable. The type of oil to be selected from ISO 8068 shall be agreed between the purchaser and the suppliers of the turbine, couplings, gear unit and driven machine. Strong efforts shall be made to achieve uniformity in the oil quality for the total turboset.

The specified types of oil, the filling quantity, and any recommendations for inspection intervals and maintenance shall be included in the instruction manual. Unless otherwise specified, the oil shall be supplied by the purchaser.

NOTE On agreement between purchaser and supplier, non-flammable non-toxic fluid may be used for the control system.

9.3 Oil reservoirs

9.3.1 Types of oil reservoirs

The oil tank may be separate or built-in or mounted in the turbine base frame, the bearing housing or gear unit casing.

9.3.2 General design criteria

The oil reservoir shall be vented and shall be arranged to prevent contamination from the enviroment. The following shall be raised at 20 mm approximately:

— top-surface openings, with gaskets,

— flanged connections, with gaskets,

— pads for mounting equipment.

Bolt holes shall not extend into the inside of the reservoir.

Oil return connections shall be arranged as far from the pump suction as is possible to allow settling of sediments, releasing of air, and mixing within the reservoir.

All atmospheric oil-return connections shall be located above the maximum operating level. All pressurized oil-return connections shall be separate and shall discharge oil via internal piping below the pump suction-loss level. Reservoirs shall be designed to avoid static areas and to allow access for cleaning. The reservoir shall be supplied in a clean condition with an adequate means of preservation for the duration of transport and installation. Unless otherwise specified, the oil tank is fabricated of carbon steel and without internal painting.

9.3.3 Additional design criteria for separate tanks

To ensure drainage during cleaning, a suitable slope of the bottom should be arranged for the drain connection with a flanged valve of at least DN 50 in size. Pump suction connections shall be located as near as possible to the high end of the sloped tank bottom.

9.3.4 Criteria for sizing

For separate oil tanks the retention time shall be at least 6 min. The free surface of the oil in such a tank shall be a minimum of 0,1 m^2 for each cubic metre per hour (60 cm^2 for each litre per minute) of normal flow.

For oil reservoirs integrated in the baseframe, recommended values are 5 min retention time and a free surface of at a minimum 0,2 m^2 for each cubic metre per hour of normal flow. If the oil reservoir is integrated in the bearing housing, or the gear unit casing, or the control oil and the lubricating oil systems are separated, the supplier may select a shorter retention time.

Lower figures for the retention time shall be agreed by the purchaser.

The rundown capacity shall allow for any additional volume specified by the purchaser. In lube and seal oil systems, the capacity between the minimum and the maximum operating level shall be at least 50 mm.

Depending on the application, a sufficient separation shall be provided between the minimum operating level and the suction loss level.

NOTE The separation margin depends on the period of undisturbed operation which is required when the plant is operating at the minimum operating level and a leakage happens, so that no return flow occurs.

9.3.5 Heating

If heating facilities are specified they shall heat the oil in the tank from the lowest specified ambient temperature to the necessary minimum temperature for start-up within 12 h. The type, size and design of the heating facilities shall be agreed between the purchaser and supplier. The oil may be heated either by steam, hot water or electricity. The surface temperature of the heating facilities on the oil side shall not exceed 120 °C. Electric heaters shall be installed in such a way that they can be removed during operation. If specified, the oil tank shall be so designed that trace heating and thermal insulation can be provided. When using heat transfer oil, a suitable expansion tank with a vent shall be provided. Provisions should be made to cut off the heating medium supply in the event of overheating of the oil or the heating device.

9.4 Oil system pumps and their drivers

9.4.1 General

If the oil is supplied via a combined lubricating and control oil system, the lubricating and control oil flow may, unless otherwise specified, be raised to control oil pressure by a common pump or to the required control oil and lubricating oil pressures by two separate pumps.

Measures shall be provided to prevent the oil from flowing backwards through a standby or emergency pump.

Oil pumps may be installed with the shaft horizontal or vertical.

Each motor driven pump shall have its own motor except for jacking oil pumps. Pumps with separate drivers shall be provided as complete combined units, suitable for mounting on support pads and constructed to withstand the pipework loading.

9.4.2 Types of pumps and other oil sources for the turbine

See Table 1.

Table 1 — Types of pumps and other oil sources for the turbine

Type	If main oil pump is	
	shaft driven	motor (turbine) driven
Stand-by oil pump (substitute for main oil pump)	Stand-by oil pump cannot normally prevent the turbine from being stopped when the shaft driven main oil pump has a failure	In the hydraulic sense the stand-by oil pump is fully inter-changeable with the main oil pump, because the latter is not mechanically connected to the turbine shaft. Stand-by pump usually same configuration as main oil pump.
Auxiliary oil pump [a] (no substitute for main oil pump)	Auxiliary oil pump is necessary for start-up, run-down and cooling down	Auxiliary oil pump is not necessary, because the main oil pump operates independently from turbine speed.
Emergency oil pump (uninterruptable secure power supply, less powerful than auxiliary oil pump)	Emergency oil pump is only suitable for run-down and cooling down	Emergency oil pump is only suitable for run-down and cooling down
Overhead tank Accumulator [b] Ring lubrication	Overhead tank, accumulator and ring lubrication are only suitable for run-down	Overhead tank, accumulator and ring lubrication are only suitable for run-down
If one of the above-mentioned pumps is multiple, these pumps shall be numbered, e.g. first stand-by pump, second stand-by pump, etc.		

[a] The auxiliary oil pump may be substituted by a second stand-by oil pump. It may also be used as an emergency oil pump on a.c. prior to the specific emergency oil pump on d.c. which acts as ultimate relief.

[b] An accumulator may be provided to maintain the system pressure above trip setting during acceleration or transient oil flow.

9.4.3 Main oil pump

Depending on the type of turbine construction, the mode of operation and the type of pump, the main oil pump can be driven

— by the main turbine or gear shafts, or

— by a separate driver (turbine or motor).

A combination of pumps with drivers as above may be used to fulfil this duty.

9.4.4 Stand-by oil pump, auxiliary oil pump and emergency oil supply

The following equipment is recommended:

a) for turbines with shaft-driven main oil pump:

— auxiliary oil pump for start-up, run-down and cooling down,

— emergency oil pump for run-down and cooling down or overhead tank or accumulator or ring lubrication for run-down;

b) for turbines with motor (turbine) driven main oil pump:

— stand-by oil pump from the same type as the main oil pump,

— emergency oil pump for run-down and cooling down or overhead tank or accumulator or ring lubrication for run-down.

The energy sources for the main oil pump and the stand-by oil pump should preferably be independent.

Emergency oil pumps should have an independent, uninterruptable, secure power supply.

9.4.5 Jacking oil pump

An additional jacking oil pump may be required to reduce the bearing friction for heavy turbine rotors and/or rotors of the driven machine when equipped with rotor turning device (see 7.4).

The protection shall be as specified in 9.4.6, and the jacking oil system shall be self-contained to prevent pressurization of the other oil systems.

9.4.6 Pump selection

Pumps may be designed as positive-displacement pumps or as centrifugal pumps. The pump capacities of the lubricating and control oil systems shall be rated for 110 % of normal oil consumption at maximum system pressure in the case of positive-displacement pumps, and 100 % of normal oil consumption at the required system pressure in the case of centrifugal pumps, when the system is in good condition. Transient oil consumption may be covered by accumulators or pump capacity margin.

If not otherwise specified, positive-displacement pumps shall be capable of operating at the specified pump relief valve setting (including accumulation) when the temperature of the pumped oil is at its minimum. The minimum temperature may be the minimum ambiant temperature or the starting temperature of the oil (the oil is warmed up before starting), as agreed between the purchaser and supplier.

Centrifugal pumps shall have a continuous rise in head pressure of at least 5 % from their normal operating point to shutoff. They shall deliver stable flow when the temperature of the pumped oil is 25 °C for an oil of a viscosity grade VG 46, or 15 °C for an oil of a viscosity grade of 32 as a minimum.

Where turbine-driven oil pumps are provided, arrangements shall be made to eliminate risks under abnormal conditions such as overspeed, loss of suction, etc. The turbine-driven oil pump output shall be achieved at the minimum inlet conditions and maximum exhaust pressure.

Turbines arranged vertically on the oil reservoir shall be provided with a reliable shaft seal, which safely prevents the entry of condensate into the oil during operation and at standstill.

Stand-by oil pumps shall be furnished with an automatic starting device to maintain the oil pressure and to ensure safe operation in the event of a failure of the main oil pump, or if the oil pressure drops for any other reason.

The purchaser and supplier shall agree about the scope of supply for electrical equipment required for the automatic starting system.

Stand-by pumps shall be arranged to start without any detrimental interruption of the oil supply. Provision shall be provided for checking the operation of stand-by pumps while the turbine is in operation. The automatic starting system shall have a manual reset and a means of isolation for maintenance.

Pump casings may be of cast iron, steel or aluminium alloy. However, cast iron shall not be used where ambient temperatures are below 7 °C. This limitation is not valid for submersible pumps.

9.4.7 Oil system protection

Relief valves shall be provided for positive-displacement pump-systems.

Relief valve settings shall be determined considering possible failure of the equipment and components and allowance for not more than 10 % overpressure. They shall protect the oil system components and piping. The relief valves shall have a pressure increase proportional to flow after the valves begin to open. The relief valves shall be adjustable and shall operate smoothly, free from shock and vibration. The minimum safety valve opening pressure shall be 10 % higher than the highest required operating pressure. Relief valves shall not be used for continuous pressure regulation. The excess oil shall be drained back into the oil tank.

For high-pressure applications, special considerations may have to be taken.

If positive-displacement pumps are used, pressure-regulating devices shall be provided which ensure a nearly constant pressure in the individual oil systems. They shall have an adequate response time and shall operate smoothly, free from shock and vibration, and shall be so arranged that they can be adjusted during operation. The excess oil shall be drained back into the oil tank. Unless otherwise specified, all pressure-regulating valves shall be sized to maintain the allowed pressure with all pumps working and at the operating temperature for an oil of a viscosity grade of VG 32 or VG 46, as specified. If flow rates vary very much, consideration should be given to the use of two or more control valves in parallel.

If shaft- or turbine-driven centrifugal pumps are used, the oil system shall be rated for the increased pressure at trip speed and zero delivery.

9.4.8 Pump suction and discharge arrangements

Except for shaft-driven pumps, each pump shall be installed with flooded suctions to ensure self-priming. Shaft-driven pumps shall have adequate provisions for priming. Suction lines for all pumps shall be vented to allow air release and shall have provisions for priming during starting.

Designs for suction piping, suction block valves, if any, pump casings, and all other components (particularly those for booster pump arrangements) shall be designed to eliminate any risk from overpressure caused by leaking discharge check valves.

Where agreed between the purchaser and supplier, suction and discharge isolation valves shall be provided to enable the maintenance of stand-by pump units. In this case strong efforts shall be made to prevent misguided actions which may lead to interruption of the oil supply. For positive-displacement pumps, relief valves shall be provided between the pump discharge and its isolation valve.

For each system requiring booster pumps, the supply of low-pressure oil shall be sufficient for simultaneous operation of all high-pressure booster pumps. The supplier shall provide either an auxiliary suction connection to the booster pumps or a switch to alarm or to trip the booster pumps on low pressure.

9.5 Oil filters

Filters shall be provided for lubricating oil supplies, but are not recommended for emergency supplies. On agreement between the purchaser and supplier, the lube oil filter may be omitted. Filters shall have a normal filtration rate $\beta_{25} = 75$ in accordance with ISO 4572 and shall be sized so that with a clean filter the normal operating pressure drop[1)] under steady conditions does not exceed 0,35 bar ($0{,}35 \times 10^5$ Pa). The filter shall withstand a minimum of 5 bar (5×10^5 Pa) pressure drop. The filter unit test pressure shall be at least 1,5 times the maximum operating pressure.

Filters shall be installed downstream of the oil cooler.

Filters for control oil systems are the subject of individual requirements depending on the pressure level.

Unless otherwise specified, the supplier shall provide a duplex oil filter with replaceable elements. Duplex oil filters shall be provided with changeover valves arranged so that the oil supply to the turbine cannot be restricted during changeover. Balance and venting arrangements shall be provided for the filter bowls.

Filter casings, covers and changeover valves may be of cast iron or steel. However, cast iron shall not be used where ambient temperatures are below 7 °C.

9.6 Oil coolers

9.6.1 General

The following requirements refer to oil coolers using water or water-based mixtures as coolant medium. In the case of air-cooled oil coolers, the purchaser and supplier shall come to special agreements.

Oil coolers shall be sized to dissipate the maximum heat load from the oil system such that the oil temperature limits are not exceeded.

● The purchaser shall specify all relevant parameters associated with the cooling water supply system which shall include normal, maximum and minimum design data for the following:

— coolant pressure;

— allowable pressure drop;

— coolant temperature;

— allowable temperature rise;

— coolant analysis/quality.

The cooler shall be designed to withstand the maximum possible pressure and temperature on both oil and water sides, acting either together or independently, without damage. Where not otherwise specified, the cooler shall be designed to accept a pressure of 7 bar (7×10^5 Pa) on the water side. The test pressures for oil and water sides shall be at least 1,5 times the maximum operating pressure.

When the cooler is clean, the pressure losses on the oil and cooling water sides shall not exceed 1 bar (1×10^5 Pa). The working pressure on the water side should (where practical) be less than the working pressure on the oil side to minimize the risk of leakage of water into the oil.

An adequate additional allowance with respect to fouling shall be applied in the design of the cooler depending upon such factors as the type of cooler, the quality of the water and the maintenance intervals. Materials of construction for the cooler shall be compatible with both the oil and the cooling medium and shall not significantly deteriorate during the specified lifetime of the turbine.

[1)] The normal operating pressure drop occurs at the normal operating temperature and the normal flow, where the normal flow is the total amount of oil required by equipment components. It does not include transient flow for controls or oil bypassed directly back to the reservoir. For normal operating temperatures of the oil, see operating instructions.

● For installations with wide variations of water temperature, the purchaser may specify thermostatic control of the oil temperature. A thermostatic valve with a manual override shall be provided to bypass the cooler on the oil side.

Facilities shall be provided by the supplier to facilitate draining and venting of the coolers on the oil side and, where appropriate, on the water side.

Facilities shall be provided by either the supplier or the purchaser, as appropriate, to protect the cooler from overpressure on both the oil and water sides.

When specified by the purchaser, two full-duty oil coolers shall be provided with changeover valves arranged so that the oil supply to the turbine cannot be interrupted during changeover.

Unless otherwise specified, changeover valves may be of grey cast iron. Valve plugs or balls shall be made of corrosion-resistant material, preferably stainless steel.

A smaller pressure balance valve shall be provided where necessary to equalize the pressure in the coolers prior to changeover. This pressure balance line also allows filling of the standby cooler prior to changeover.

Where the water is sufficiently clean, plate-type coolers may be used. This applies particularly to closed cooling water systems or specially treated water or clean sea water.

Where doubt exists about the cleanliness of the cooling water, shell and tube type coolers should be selected.

Sufficient space shall be available to permit maintenance of the cooler heat transfer surfaces without removal of the cooler bodies and, if two full-duty coolers are supplied, without interfering with turbine performance.

If specified by the purchaser, the cooler shall be suitable for use with a heating medium, such as steam or a mixture of steam and water. The pressure and the temperature of the heating medium shall be agreed between the purchaser and supplier (see 9.3.5).

9.6.2 Plate-type oil coolers

Materials for the cooler plates shall be stainless steel or titanium unless other materials are specified by the purchaser, or other materials are required due to the nature of the cooling water. Plates shall be removable from the cooler frame. The distance between plates shall be not less than 2,5 mm.

Plate configuration shall preferably be designed to permit any leakage from either side of the cooler to escape to atmosphere to avoid the risk of contamination of the oil system.

The coolers should preferably be fitted with screens to minimize the hazards associated with a spray leakage of oil or water.

Gasket materials shall be compatible with the fluids on both sides of the cooler. Where practical, gaskets shall be of the removable type. If removable, gaskets shall be designed to have a lifetime equal to or greater than that of the plant.

Unless otherwise agreed, the design shall make allowance for the following fouling resistances on the water side:

— demineralized closed circuit: 0,001 m^2 K/kW;

— clean sea water (open ocean): 0,03 m^2 K/kW;

— cooling tower treated water, coastal sea water, river: 0,05 m^2 K/kW.

9.6.3 Tube and shell coolers

Unless otherwise agreed, the design shall make allowance for the following fouling resistances on the water side:

— closed circuit (treated water): 0,09 m^2 K/kW;

— normal cooling water and clean sea water: 0,17 m^2 K/kW;

— brackish, dirty water: 0,35 m^2 K/kW.

If not otherwise agreed between the purchaser and supplier, the cooling water velocity in the tubes shall be at rated conditions not less than 1 m/s and not more than the following:

— for soft brass and copper-nickel alloy 90/10: 1,8 m/s;

— for carbon steel: 2 m/s;

— for inhibited brass: 2,3 m/s;

— for stainless steel: 2,5 m/s;

— for copper-nickel alloy 70/30: 3 m/s;

— for titanium: 3,5 m/s.

Each cooler shall consist of a shell, water box(es) and an extractable bundle of tubes.

Unless otherwise specified or dictated by the specified cooling water properties, the following materials are recommended:

a) shell, cover and chambers: carbon steel;

b) tube sheets: copper-zinc alloy or carbon steel with anticorrosive coating;

c) tubes: preferably copper-zinc alloy;

d) in special cases:

  — copper-nickel alloy,

  — stainless steel,

  — titanium,

  — carbon steel.

Information on International Standards for copper alloys and for steel are given in the Bibliography.

Unless otherwise specified, the cooling water tubes shall have the following dimensions.

— outer diameter, minimum: 12 mm;

— wall thickness, minimum: 1 mm for copper-zinc and copper-nickel,
0,5 mm for stainless steel and titanium tubes,
1,6 mm for carbon steel.

9.7 Accumulators

Accumulators shall be provided if needed to allow the control system to function within the specification. Accumulators may be required for the lubrication oil system to maintain the system pressure above trip setting during stand-by pump acceleration.

If specified, any special equipment required for charging accumulators shall be provided by the supplier.

Accumulators shall be isolated (for example, by a non-return valve) from the stand-by oil pump start controls to eliminate delay in the actuation of the starting signal.

9.8 Oil pipework

Besides the requirements given in 8.1, the following shall apply to the oil piping.

Where possible, pipework shall be welded with the minimum of flanges and fittings needed for installation and maintenance. Pipework and flanges are permitted in carbon steel unless otherwise specified by the purchaser. The number of threaded connections shall be kept to a minimum.

Oil drains shall be sized to run no more than half full at normal oil temperature and shall be arranged to assure good drainage considering the possibility of foaming conditions. As a guidance, the flow velocity may be 0,5 m/s and the slope may be 15 mm/m or greater.

10 Governing system and protecting systems

10.1 General

● The purchaser shall provide any specific conditions to be observed when designing the governing system. This shall include the relevant data on the driven machine and its operating characteristics.

The governing system of a mechanical drive or a generator in single operation controls the turbine speed. In addition, the governing system may under certain circumstances control other variables such as, for example, inlet pressure, induction pressure, extraction pressure, backpressure. The governing system of a generator drive turbine in parallel operation with the public electricity network controls the generator load or any other of the above-mentioned control variables.

If not otherwise specified, the turbine governing system shall be capable of controlling the speed within the normal operating speed range only. In this case the operator shall be able to control the turbine from standstill to the minimum speed where the governor becomes operative. The protection system shall be active during this period.

This control may be manual, if not otherwise specified.

For turbines driving a generator, the turbine governing system shall be capable of controlling the following:

— the speeds at all loads between no-load and full load inclusive, in a stable manner when the generator is island operated;

— the power input to the interconnected system, in a stable manner when the generator is operating in parallel with other generators.

The governor and its system shall be arranged so that failure of any component will not prevent the turbine from being safely shut down.

NOTE The maximum continuous operating speed n_{max} is, if not otherwise specified, 1,05 times the rated speed n_r for mechanical drives. For generator drives n_{max} is equal to the rated speed n_r, taking into account a certain variation of network frequency.

10.2 Speed governing system classification

Depending on the application, the speed governing system shall comply with one of the classes specified in Table 2. For explanations, see annex B.

Table 2 — Speed governing system classification

	Class 1	Class 2	Class 3	Class 4
Characteristic	PI	P	P	P
Steady-state speed regulation	0 to 0,5 %	4 % to 6 %	6 % to 8 %	8 % to 10 %
Speed variation	⩽ ± 0,25 %	⩽ ± 0,25 %	⩽ ± 0,50 %	⩽ ± 0,75 %
Maximum speed increase	up to 1 % below trip speed			
Total dead band (reversal span)	⩽ 2 %	⩽ 2 %	⩽ 4 %	⩽ 4 %

● The purchaser shall specify the suitable class of speed governing system, depending on the field of application.

10.3 Speed adjustment

Manual adjustment of the speed shall be possible.

Unless otherwise specified, the speed of a generator drive turbine operating at zero load shall be adjustable within at least the range of 5 % below rated speed to 5 % above the rated speed. For testing the overspeed trip system, the speed range shall exceed, by release, 5 % above the trip speed.

Unless otherwise specified, an increase in the control signal shall increase the turbine speed.

● The specified speed range shall correspond to the full range of control signal.

In the event of a failure of the signal or the set-point adjuster, manual adjustment shall still be possible with mechanical governors.

10.4 Electrical speed sensors for electric speed governing systems

If an electronic speed governing system is used, it shall include at least two speed sensors dedicated to speed control. The speed governor shall discriminate the signals from the speed-sensing elements by high signal selection. If more than two speed sensors are applied, the speed governor may use as actual value the middle (not average!) value measured. The failure of one speed-sensing element shall initiate only an alarm. The failure of two elements shall initiate a trip.

A multitoothed surface for speed sensing shall be provided integral with, or positively attached to, or locked to, the turbine shaft. This surface may be shared by the speed governor, overspeed shutdown system and tachometer. The speed sensors shall not be shared with the overspeed shut-down system.

10.5 Protection systems

10.5.1 General

The protection systems shall be designed on a fail-safe principle, such that loss of control fluid pressure shall cause immediate closure of the stop valves and the governing valves.

Removal of the condition that has initiated the operation of the trip system shall not cause the trip device to reset automatically, nor the steam valves to re-open. The trip system shall be arranged so that it can be reset only by the operator. Until the trip system has been reset, it shall be impossible to re-open any of the steam valves.

10.5.2 Overspeed trip system

10.5.2.1 General

Each turbine shall be provided with at least one protection device (mechanical and/or electronic) to prevent the turbine and the driven machine from overspeed. This device shall operate independently of the speed governor and shut off the flow of the working fluid to the turbine by means of one or more stop valve(s) when trip speed is reached.

Likewise it shall immediately trip-close the power-assisted non-return valves (only if these are fitted) in the cold reheat steam lines and in the extraction steam lines, where necessary to prevent the turbine being accelerated by backflowing steam.

The overspeed trip system shall be capable of being reset without stopping the turbine. If provision has been made for functional testing of the overspeed trip-actuating system at operating speed, the turbine shall remain protected from exceeding the trip speed.

In the case of an emergency stop, both the stop valve(s) and the governing valves shall close simultaneously. It shall be possible to operate the trip device at the maximum permissible steam or gas inlet pressure.

Means shall be provided whereby the stop valve(s) may be checked without interrupting operation of the turbine. If there is only a single stop valve it may be checked by partial stroke. The supplier shall state the extent of any output restriction involved.

NOTE The normal setting of the trip speed is 1,10 times the maximum continuous operating speed n_{max}, unless otherwise agreed between the purchaser and supplier. That means:

— for compressor drives $n_t = 1,15 \times n_r$ (if $n_{max} = 1,05 \times n_r$ and not otherwise specified);
— for generator drives $n_t = 1,10 \times n_r$.

10.5.2.2 Electronic overspeed circuit

If no other overspeed system is installed, at least two separate electrical overspeed circuits consisting of speed sensors and logic devices shall be provided. The minimum criteria shall include the following:

a) an overspeed condition sensed by either circuit shall initiate a shutdown;

b) failure of a speed sensor or logic device in either circuit shall initiate an alarm only (de-energized);

c) failure of both circuits shall initiate a shutdown;

d) items a), b) and c) require manual reset;

e) all settings incorporated in the overspeed circuits shall be field changeable and shall be protected through controlled access;

f) each overspeed circuit shall accept inputs from a frequency generator for verifying the trip speed setting: a controlled access lockout shall be provided for on-line testing;

g) each overspeed circuit shall provide an output for speed readout with indicator;

h) the overspeed system speed sensors shall not be shared with any other system;

i) peak hold feature with controlled access reset shall be provided to indicate the maximum speed obtained during a trip condition.

When specified, an overspeed shutdown system based on two-out-of-three voting logic shall be furnished.

Unless otherwise specified, magnetic pickups shall be supplied for speed sensing.

A multitoothed surface for speed sensing shall be provided integral with, or positively attached to, or locked to, the turbine shaft. This surface may be shared by the speed governor, overspeed shutdown system and tachometer.

The number of teeth on a toothed wheel will vary depending on the speed of the turbine and the diameter of the wheel. Special attention should be made during initial startup of the unit at the factory mechanical running test, and again during commissioning, to check the number of teeth on the wheel, to assure that the governor, overspeed shutdown system and tachometers are calibrated for the correct number of teeth for the input from the toothed wheel.

10.5.3 Overpressure protecting systems

The turbine shall be protected against excessive exhaust pressures by one of the following means:

— a safety valve[2)] for maximum flow; the safety valve shall be supplied by the supplier of the exhaust piping;

— a pressure switch acting on the trip system and a pressure limiter acting on the governing valves and a safety valve[2)] for at least 10 % of the maximum flow;

— an interlock logic acting on the isolating valve and a pressure limiter acting on the governing valves and a safety valve[2)] for at least 10 % of the maximum flow;

— two independent operating pressure switches acting on the stop valves and the governor valves.

All those devices shall be installed ahead of the isolating or non-return valve.

NOTE Details of International Standards on safety devices for protection against excessive pressure are given in the Bibliography.

10.5.4 Axial displacement trip device

The turbine may be furnished with a protecting device (mechanical or electronic) which shuts off the flow of the working fluid to the turbine in the event of excessive axial displacement of the rotor.

10.5.5 Low lubricating oil pressure trip

If the lubricating oil pressure decreases to a non-permitted value, the stand-by oil pump or auxiliary pump shall start automatically. If, in spite of this, the lubricating oil pressure remains too low, the turbine trip shall be induced. At the same time the emergency oil pump shall start automatically. (See 9.4.2 and 9.4.4.)

10.5.6 Rotor vibration trip system

Turbine trip is recommended on high vibration.

Records of any vibration and initiated alarm are recommended.

10.5.7 Manual trip system

The turbine shall be furnished with at least one manual trip local to the turbine.

● Further manual trip locations shall be furnished as specified by the purchaser.

[2)] For vacuum systems: blow-off valve or lifting disk (bursting disk).

10.5.8 Further trip system

● Further trip systems shall be furnished as specified by the purchaser or as mutually agreed between the purchaser and supplier (e.g. abnormal temperature rise at the condensing exhaust casing).

10.6 Instrumentation

10.6.1 General

If not otherwise specified, the requirements given in 10.6.2 to 10.6.10 shall apply.

10.6.2 Speed indicators

An easily readable local speed indicator shall be provided by the turbine supplier. If specified, a second speed indicator shall be furnished by the turbine supplier for a remote indication. The minimum indicating range shall be from 0 % to 125 % of the maximum continuous operating speed.

If specified, the speed shall be continuously recorded.

10.6.3 Pressure gauges

Mechanically operated pressure gauges shall be of the bourdon tube type. The internal mechanism shall be fabricated of stainless steel. The dials shall have a diameter of at least 100 mm. Black printing on a white background is standard for gauges. Gauge ranges shall be selected so that the normal operating pressure is about half to three quarters of the full-scale value. In no case, however, shall the maximum reading on the dial be less than the applicable relief valve setting plus 10 %. Each pressure gauge shall be provided with a device designed to relieve excess case pressure. All pressure gauges in the steam system downstream of the trip valve of a condensing turbine shall be capable of tolerating the vacuum existing within this system before the turbine is started.

Each pressure gauge shall be fitted with a block and bleed valve to facilitate removal and/or calibration.

10.6.4 Temperature gauges

Temperature gauges shall be of the stick (rod) or the dial type.

Rod type temperature gauges are liquid-filled. The liquid should be alcohol. The casing may be of brass or steel. The graduation marks and numbers shall be black.

Dial temperature gauges shall be bimetallic or gas filled. They shall have a diameter of at least 100 mm. Black printing on a white background is standard for gauges. The internal mechanism shall be fabricated of stainless steel.

If a fluid is measured, then the sensing elements of temperature gauges shall project into the flowing fluid.

10.6.5 Thermocouples and resistance temperature detectors

10.6.5.1 General

Electrical temperature sensors shall be thermocouples or resistance temperature detectors, as specified.

Where practical, the design and location of thermocouples and resistance temperature detectors, except bearing temperature sensors, shall permit replacement while the unit is in operation. The lead wires shall be installed as continuous leads between the sensor and the terminal box.

Conduit runs from the head of the sensor or from the cable gland of the bearing temperature sensor to the terminal box shall be provided.

10.6.5.2 Thermocouples

Thermocouples and their respective cables shall conform to IEC 61515 and IEC 60584.

10.6.5.3 Resistance temperature detectors

Resistance temperature detectors shall be of the type Pt 100/B/3 in accordance with IEC 60751. Within the terminal box, the three-lead wiring may be converted into a four-lead wiring. The wires shall be shielded.

10.6.6 Thermowells

Temperature gauges or sensors that are located in pressurized or flooded lines or that are in contact with a flammable or toxic medium shall be furnished with solid-bar thermowells, made of the same or the same type of material as its mating part.

10.6.7 Radial shaft vibration measuring devices

The frequency range of the measuring device shall be at least 10 times the rotational frequency.

The fastening thread of the probe shall be M10 × 1 according to ISO 261 and the probe extension cables shall be coaxial.

The oscillator-demodulator shall be designed to operate with the probe tip of the specified diameter and the extension cable. The oscillator-demodulator output shall be 8 mV/µm with a supply voltage agreed between the purchaser and supplier, and shall be calibrated for the oscillator-demodulator, probe, extension cable and specific target material.

10.6.8 Axial position measuring devices

For the axial position measuring device the same is valid as for the radial shaft vibration measuring device. The axial position measuring range shall be suitable for the thrust position clearance of the turbine.

10.6.9 Extent of instrumentation

● The extent of instrumentation shall be as specified by the purchaser.

It is the responsibility of the turbine supplier to add instruments which are necessary for a safe operation of the turbine plant. For guidance on the extent of instrumentation, see the proposal in Table 3.

10.6.10 Instrument arrangement

The instruments may be arranged as follows:

— at the measuring point;

— on an instrument rack at or near the measuring point;

— or in an instrument panel or console;

— in a central control room.

● In order that the instruments be correctly located, the purchaser shall state how the turbine is to be operated. All instruments and functions shall be identified by labels.

Table 3 — Proposed extent of instrumentation

	Indicator [a]	Alarm [a]	Shutdown [a]
Quantities to be measured in the working fluid system			
Pressure near the fluid inlet	X	—	—
Temperature near the fluid inlet	X	(H), (L)	(H), (L)
Pressure ahead of the nozzles	(X)	—	—
Pressure downstream of the control stages	X	(H)	—
Extraction pressure in extraction turbines	X	(H), (L)	(H), (L)
Extraction temperature in extraction turbines	(X)	—	—
Exhaust pressure	X	(H), (L)	(H), (L)
Exhaust temperature	(X)	(H)	(H)
Quantities to be measured in the lubricating and control oil system			
Oil level in main oil tank	X	(H), (L)	(H), (L)
Oil temperature in main oil tank	(X)	—	—
Oil temperature at oil cooler inlet	X	—	—
Oil temperature at oil cooler outlet	X	(H), (L)	—
Lubricating oil pressure ahead of the oil cooler	(X)	—	—
Differential pressure at the oil filter	X	(H)	—
Lubricating oil pressure in the supply line	X	L	L
Control oil pressure	X	(L)	—
Temperature of each turbine bearing	X	(H)	(H)
Temperature of each gear unit bearing	X	(H)	(H)
Shaft position and vibration			
Axial position	(X)	(H)	(H)
Vibration of shaft	(X)	(H)	(H)
Miscellaneous			
Speed	X	—	H
Casing temperature, top/bottom	(X)	(H)	—
Casing temperature, internal/external	(X)	(H)	—
Sealing fluid pressure	(X)	—	—

a The letter H indicates that an alarm and/or shutdown will be initiated when the upper limit value is exceeded.

The letter L indicates that an alarm and/or shutdown will be initiated when the value falls below the lower limit.

The letter X shows if an indicator will be provided. An indicator is understood as a measuring device which shows the current value of the parameter.

Instrumentation shall be provided when the letter H, L or X (letter without brackets) appears in the table.

Instrumentation may be provided when the letter (H), (L) or (X) (letter in brackets) appears in the table.

11 Special tools

When special tools are required to maintain the turbine unit, they shall be included in the quotation and furnished as part of the initial supply of the machine.

12 Inspection and testing

12.1 General

After advance notification of the supplier by the purchaser, the purchaser's representative shall have entry to all supplier and subsupplier plants where manufacturing, testing or inspection of the equipment is in progress. The purchaser shall instruct his subcontractors to grant the purchaser's representative access to their plants.

- In the tender the supplier shall inform the purchaser of the tests he intends to carry out.

- Any additional tests shall be specified by the purchaser before the contract is signed.

- In addition, the purchaser shall specify the extent of his participation in the inspection and testing and the amount of advance notification required.

The supplier shall notify his subsuppliers of the purchaser's inspection and testing requirements. The supplier shall provide notice to the purchaser before conducting any inspection or test that the purchaser has specified to be witnessed or observed.

The purchaser or his representative shall confirm attendance as early as possible before that date. A contractual agreement shall be made on how to proceed if the purchaser or his representative cannot participate in the tests on the date fixed by the supplier. If no such agreement has been made or if the purchaser fails to confirm that he will be present on the fixed date, or if neither the purchaser nor his representative appears on the set date, the test shall be conducted as scheduled in his absence. The supplier shall give immediate notice of any postponements.

When shop inspection and testing have been specified by the purchaser, the purchaser and supplier shall meet to coordinate manufacturing hold points and the inspector's visit.

The supplier shall submit test certificates as specified in the contractual requirements for all the contractually agreed tests.

The purchaser or his representative shall sign all the certificates issued by the supplier for the tests witnessed by the purchaser or his representative.

The purchaser or his representative shall have access to the supplier's quality-control programme for review.

Pressure-containing parts shall not be painted until the specified inspection is completed. For fabricated constructions made from plates, painting is permitted except in welded areas.

12.2 Inspection

12.2.1 General

If not otherwise specified, the supplier shall keep the following data available for at least 10 years for examination by the purchaser or his representative upon request:

— necessary certification of materials, such as mill test reports;

— purchase order and specifications for all items on bill of materials;

— test data to verify that the requirements of the specification have been met;

— results of quality-control tests and inspections;

— final-assembly, maintenance and running clearances.

12.2.2 Material inspection of components

Table 4 shows a proposal for the material inspection of components.

Table 4 — Proposals for the material inspections of components

<table>
<tr><th colspan="2">Component</th><th>Mechanical properties</th><th>Chemical analysis</th><th>Ultrasonic test</th><th>Local X-ray test</th><th>Test for surface cracks</th></tr>
<tr><td rowspan="4">Forged or rolled components</td><td>Wheel discs
Shaft
Balance pistons</td><td>Yes</td><td rowspan="2">Product check analysis or cast analysis [a]</td><td>Yes</td><td>If specified</td><td rowspan="2">Yes</td></tr>
<tr><td>Guide blade carriers
Steel casings</td><td>Yes</td><td colspan="2">If specified</td></tr>
<tr><td>Rotor blades
Guide blades</td><td colspan="2">Random checks [b]</td><td>If specified [c]</td><td>Not applicable</td><td>If specified [c]</td></tr>
<tr><td>Rotor bushes</td><td colspan="3">If specified [c]</td><td>Not applicable</td><td>If specified</td></tr>
<tr><td>Welded components</td><td>Wheel discs
Steel casings
Guide blade carriers</td><td>Yes</td><td>Yes</td><td colspan="2">If specified [c]</td><td>Yes, in welded areas</td></tr>
<tr><td rowspan="4">Castings</td><td>Wheel discs
Steel casings
Steel blade carriers</td><td rowspan="2">Yes</td><td rowspan="2">Product check analysis or cast analysis [a]</td><td>Yes</td><td>If specified [c]</td><td>Yes</td></tr>
<tr><td>Nodular cast iron casings
Nodular cast iron guide blade carriers</td><td colspan="3">If specified [c]</td></tr>
<tr><td>Lamellar cast iron casings
Lamellar cast iron guide blade carriers</td><td colspan="5">If specified [c]</td></tr>
<tr><td>Rotor blades</td><td colspan="2">Random checks</td><td>If specified [c]</td><td>Not applicable</td><td>If specified [c]</td></tr>
<tr><td colspan="7">[a] Of each component, if from several casts.
[b] Of starting material.
[c] Details of testing shall be agreed between the purchaser and supplier.</td></tr>
</table>

12.2.3 Methods of material inspection and deciding criteria

The purchaser and supplier shall agree upon which standards shall apply to the performance of radiographic, ultrasonic, magnetic particle or liquid penetrant inspection and to the acceptance criteria. The acceptance criteria value is the supplier's liability, if not otherwise specified.

NOTE Information on International Standards for testing materials is given in the Bibliography.

12.3 Testing

12.3.1 Hydrostatic test

All parts subjected in normal service to a pressure above atmospheric shall be tested hydraulically so that the pressure loads shall be at least 50 % in excess of the maximum operating pressure that could occur at any operating point as defined in 3.8, but not less than 0,15 MPa (1,5 bar) effective. The hydraulic test may be omitted where, in service, leakage would not be to atmosphere. The hydraulic test may also be omitted by agreement when the supplier can, by other means, satisfy the purchaser of the integrity and suitability of the component.

The hydrostatic test shall be considered satisfactory when neither leaks nor seepage through the casing are observed for a minimum of 30 min.

Seepage past internal closures required for testing of segmented cases and operation of a test pump to maintain pressure are acceptable.

Where hydrostatic testing is not feasible, for example welded exhaust casings of condensing turbines, 100 % inspection of welded joints is required.

12.3.2 Speed governor test

The speed governor is usually tested separately from the turbine. It shall be tested for smooth operation over the operating speed range. The change in signal output as answer to the signal input shall be tested.

12.3.3 Mechanical running test at the the manufacturer's premises.

12.3.3.1 General

If specified, the turbine shall be subjected to a mechanical test run in the no-load condition at the manufacturer's premises.

The conditions of the working fluid shall be as close to design as practicable. Due to no-load operation for extended periods of time during the test, the inlet conditions may need to be reduced to prevent overheating of the unit.

Oil pressures and viscosities shall be within the range of operating values recommended in the supplier's operating instructions for the specific unit being tested.

Filters shall have a normal filtration rate β_{25} = 75 according to ISO 4572.

The contract shaft seals and bearings shall be used in the machine for the mechanical running test.

All purchased vibration probes, cables, oscillator-demodulators and accelerometers or velocity sensors shall be in use during the test. If vibration probes, accelerometers or velocity sensors are not furnished by the equipment supplier or if they are not compatible with shop readout facilities, then shop sensors and readouts may be used.

Shop test facilities shall include instrumentation with the capability of continuously monitoring and plotting revolutions per minute, rotor displacement and phase angle. Presentation of vibration displacement shall also be by oscilloscope and, if specified by spectrum with FFT (Fourier function transmitter).

12.3.3.2 Mechanical running test procedure

See 3.7 and Figure 1 for speed definitions.

The equipment shall be operated at speed increments of approximately 10 % from zero to the maximum continuous operating speed, avoiding any critical speeds until bearings, lube-oil temperatures and shaft vibrations have stabilized. After that, the speed shall be increased to approximately 2 % below the trip speed, where the turbine shall be run for a minimum of 15 min.

Overspeed trip devices shall be checked and adjusted until three consecutive nontrending trip values within 1 % of the nominal trip setting are attained.

If not otherwise specified, the turbine shall be run continuously at the maximum continuous operating speed for 1 h.

During the mechanical running test, the mechanical operation of all equipment being tested and the operation of the test instrumentation shall be satisfactory.

All joints, connections and seals shall be checked for tightness. Any leaks shall be corrected.

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

The turbine shall be tested for smooth performance over the operating speed ranges. No-load stability and response to the control signal shall be checked. The sensitivity and linearity of relationship between speed and control signal, and for adjustable governors, response speed range shall be checked.

If the contract speed governor is not available on the mechanical running test, then the test stand governor may be used.

With regard to the measurement of lateral shaft vibrations, the comparison between the measured values and the limit value obtained by calculating using equation (1) (in 6.12.2) serve as the basis for acceptance or rejection of the machine.

After the mechanical running test is completed, the main bearings of the turbine shall be removed, inspected and reassembled.

● Further tests and examinations associated with the mechanical running test may be specified by the purchaser.

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 test shall not be accepted, and the final shop tests shall be run after these replacements or corrections are made.

● When a spare rotor, spare guide blade carrier or spare radial bearings are included in the supply, the purchaser shall specify whether these spares shall be placed into the turbine casing for inspection purposes and whether a mechanical test run shall be conducted.

12.3.4 Optional tests and inspections

● Any other tests and inspections shall be specified by the purchaser.

They shall be developed jointly and shall be mutually agreed upon by the purchaser and supplier.

13 Preparation for shipment and storage

13.1 General

Equipment shall be suitably prepared for the type of shipment specified. The parts shall be properly secured to protect them from damage by transportation shocks, distortions and by corrosion. A clearly visible corrosion-resistant warning label shall be affixed to the turbine indicating which transport safety devices must be removed prior to commissioning.

The preparation shall make the equipment suitable for the method and duration of storage specified by the purchaser. No disassembly shall be required before operation, except for inspection of bearings and seals.

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

13.2 Special aspects of preparation

Exterior surfaces that are subject to corrosion, except for machined surfaces, shall be given at least one coat of the manufacturer's standard paint. Exterior machined surfaces that are subject to corrosion shall be coated with a suitable rust preventive.

The interior of the equipment shall be clean and free from scale, welding spatter, and foreign objects. The method of using preservatives or rust preventatives shall be mutually agreed upon by the purchaser and supplier.

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

Openings shall be provided with closures (e.g. blind flange, cap, plug).

Lifting points and the centre of gravity shall be clearly identified on the equipment package.

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

14 Foundations

The turbine supplier shall provide the foundation designer with the relevant information (static and dynamic loads, outline drawings, seating details, forces and moments, permissible foundation deflections, thermal expansions, etc.) at the interface between his own design responsibilty and that of the purchaser or the foundation designer, to enable design and construction of the total support system to proceed.

If parts of the foundation are designed or supplied by the turbine supplier, he shall ensure that the deflections, natural frequencies of vibration, and other properties of parts of the foundation designed or supplied by him will have no adverse effect on the operation of the plant over the specified operating range.

Unless agreed otherwise, the purchaser shall provide a suitable foundation in the above sense, on which the turbine supplier shall be given the opportunity to comment at the design stage.

Sufficient space and necessary cut outs in the foundations and building structure shall be provided for installation of the equipment. Suitable openings shall be provided in the building to admit the equipment. The purchaser shall provide sufficient space round the equipment for servicing, including space for removing the rotors and setting the upper halves of the turbine casings (lay down area).

Where auxiliary equipment connected to the turbine (e.g. moisture separators and reheaters) is mounted on a separate foundation supplied by others, the turbine supplier shall specify the permissible movement relative to the turbine foundation, if he is responsible for the design of the connecting pipes between this auxiliary equipment and the turbine.

Further information on foundations is given in annex C.

15 Erection and commission on site

15.1 Preparation on site

If the supplier is responsible for erection, he shall be informed well in advance of the starting date for erection. The supplier has the right to inspect the foundations and the facilities required for erection purposes before the parts arrive or erection commences. This does not relieve the purchaser of the responsibility of providing a foundation of the required quality.

The prerequisites for proper erection, such as the provision of facilities and services on site, shall be agreed between the purchaser and supplier.

The purchaser shall ensure that the supply piping for the working fluid is clean. The degree of cleanliness shall be demonstrated by means of a baffle plate made of soft metal. Details shall be agreed between the purchaser and supplier.

● Before signing the contract, the purchaser shall inform the supplier of rules and regulations applicable to the working conditions on site.

15.2 Erection on site

The type, scope and responsibility may be defined in a separate erection contract.

15.3 Site acceptance test

Details of site acceptance test shall be subject to a special agreement between the purchaser and supplier. For thermal acceptance tests on steam turbines according to this International Standard, the application of IEC 60953-2 is recommended.

15.4 Personnel training

It is recommended that the purchaser's personnel who will operate the plant be present for training during erection, commissioning and trial run. Details of the training shall be agreed between the purchaser and supplier if training is required.

16 Contract documents

16.1 Drawings

The drawings furnished shall contain sufficient information so that with the drawings and manuals specified in 16.5, the purchaser can properly install, operate, and maintain the ordered equipment.

Drawings shall be clearly legible, shall be identifiable and shall be in accordance with the appropriate International Standards.

16.2 Technical data

Any comments on the drawings or revisions of specifications that necessitate a change in the data submitted to the purchaser shall be noted by the supplier.

16.3 Progress report

If specified, the suppliers shall submit progress reports to the purchaser at the intervals and extent specified by the purchaser.

Planned and actual dates and the percentage completed shall be indicated for each milestone in the schedule.

16.4 Recommended spare parts

The supplier shall submit a complete list of spare parts. The list shall include spare parts for all equipment and accessories supplied, with cross-sectional or assembly drawings for identification and part numbers.

It shall be the joint effort of the purchaser and the supplier to ensure that the spare parts can be manufactured or purchased in parallel to the built-in parts.

16.5 Data information for installation, operation and maintenance

16.5.1 General

The supplier shall provide sufficient written instructions, including a cross-referenced list of drawings, which enable the purchaser to correctly install (if installation by the purchaser is specified without supervision by the supplier), operate, and maintain the equipment ordered.

16.5.2 Installation instructions

If installation by the purchaser is specified, all special information required for proper installation that is not on the drawings shall be compiled in a chapter or in a manual, both separate from the operating and maintenance instructions. The installation instructions shall contain information such as special alignment or grouting procedures utility specifications (including quantities), and all installation design data.

16.5.3 Operating and maintenance information

As a minimum the operating and maintenance information shall describe the following:

a) startup;

b) normal shutdown;

c) emergency shutdown;

d) operating limits or other operating restrictions and a list of undesirable speeds;

e) grease and lube-oil recommendations and specifications;

f) routine operational procedures, including recommended inspection schedules and procedures;

g) performance data;

h) as-built data, including:

- as-built dimensions or data,
- hydrostatic test logs,
- any other logs and certificates as specified by the purchaser;

i) drawings and data, including:

- dimensional outline drawing and list of external connections,
- cross-sectional drawing,
- lube-oil schematics and list of external connections,
- electrical and instrumentation schematics and list of external connections,
- governor-, control- and trip-system drawings and data,
- any other drawings and data as specified by the purchaser and agreed by the supplier.

If applicable, the information shall include special instructions for operation at specified extreme environmental conditions.

Annex A
(informative)

Explanations concerning dynamics

A.1 Critical speeds

A.1.1 When the frequency of a periodic forcing phenomenon (exciting frequency) applied to a rotor-bearing-support system corresponds to a natural frequency of that system, the system may be in a state of resonance.

A.1.2 A rotor-bearing-support system in resonance will have its normal vibration displacement amplified. The magnitude of amplification and the rate of phase-angle change are related to the amount of damping in the system and the mode shape taken by the rotor.

NOTE The mode shapes are commonly referred to as the first rigid (translatory or bouncing) mode, the second rigid (conical or rocking) mode, and the (first, second, third, ... n^{th}) bending mode.

A.1.3 When the rotor amplification factor (see Figure A.1), as measured at the vibration probe, is greater than or equal to 2,5, that shaft rotational frequency at which the maximum amplitude occurs is called a critical speed. For the purposes of this International Standard, a critically damped system is one in which the amplification factor is less than 2,5.

A.1.4 Critical speeds shall be determined analytically by means of a damped unbalanced rotor response analysis. If specified, they shall be confirmed by test-stand data.

A.1.5 Separation margins shall be in accordance to supplier standards. If specified, the requirements of A.2.5.1 and A.2.5.2 shall apply.

A.1.6 An exciting frequency may be less than, equal to, or greater than the rotational speed of the rotor. Depending on the application, the potential exciting frequencies considered in the systems design may include the following non-exhaustive list of sources:

— unbalance in the rotor system;

— oil film instabilities (oil whirl);

— internal rub;

— blade, vane, nozzle and diffuser passing frequencies;

— gear tooth meshing and side bands;

— coupling misalignment;

— loose rotor system components;

— hysteretic and friction whirl;

— boundary layer flow separation;

— acoustic and aerodynamic cross-coupling forces;

— asynchronous whirl.

A.1.7 Resonances of structural support systems within the supplier's scope of supply that affect the rotor vibration amplitude shall not occur within the specified operating speed range or the specified separation margins (see A.2.5), unless the resonances are critically damped.

A.2 Lateral analysis

A.2.1 If specified, the supplier shall provide a damped unbalanced response analysis for each machine to assure acceptable amplitudes of vibration at any speed from zero to trip.

A typical logic diagram of the lateral analysis is shown in Figure A.3.

A.2.2 The damped unbalanced response analysis shall include but shall not be limited to the following considerations:

a) support (base, frame and bearing-housing) stiffness, mass and damping characteristics, including effects of rotational speed variation;

b) bearing lubricant-film stiffness and damping changes due to speed, load, preload, oil temperatures, accumulated assembly tolerances, and maximum to minimum clearances;

c) rotational speed, including the various starting-speed detents, operating speed and load ranges (including agreed-upon test conditions if different from those specified), trip speed, and coast-down conditions;

d) rotor masses, including the mass moment of coupling halves, stiffness and damping effects (e.g. accumulated fit tolerances, and frame and casing effects);

e) asymmetrical loading (e.g. partial arc admission, gear forces, side streams, and eccentric clearances).

A.2.3 When specified, the effects of other equipment in the train shall be included in the damped unbalanced response analysis (that is, a train lateral analysis shall be performed). For example, a train lateral analysis should be specified for trains with a rigid coupling.

A.2.4 As a minimum, the damped unbalanced response analysis shall include the following.

A.2.4.1 A plot and identification of the mode shape at each resonant speed (critically damped or not) from zero to trip, as well as the next mode ocurring above the trip speed.

A.2.4.2 Frequency, phase and response amplitude data (Bode plots) at the vibration probe locations through the range of each critical speed, using the arrangement of unbalance shown in Figure A.2 for the particular mode. This unbalance shall be sufficient to raise the displacement of the rotor at the probe locations to the vibration limit defined by equation (A.1):

$$L_{\mathrm{v}} = 25{,}4 \times \sqrt{\frac{12\,000}{n}} \quad \text{(A.1)}$$

where

L_{v} is the vibration limit (amplitude of unfiltered vibration), in micrometres peak to peak;

n is the operating speed nearest the critical of concern, in revolutions per minute.

This unbalance shall be not less than two times the unbalance defined by equation (A.2.):

$$U = 650 \times \frac{W}{n} \qquad \left(U \approx \frac{6\,350}{9{,}81} \times \frac{W}{n} \right) \quad \text{(A.2)}$$

where

U is the input unbalance from the rotor dynamic response analysis, in gram millimetres,

W is the journal static weight load, in newtons,

n is the operating speed nearest the critical of concern, in revolutions per minute.

The unbalance weight or weights shall be placed at the locations that have been analytically determined to affect the particular mode most adversely (e.g. at mid-span for translatory modes, or near both ends and 180° out of phase for conical modes). For bending modes with maximum deflections at the ends of the shaft, the amount of unbalance shall be based on the overhung mass rather than the static bearing loading (see Figure A.2).

A.2.4.3 Modal diagrams for each response in A.2.4.2, indicating the phase and major-axis amplitude at each coupling engagement plane, the centrelines of the bearings, the locations of the vibration probes, and the typical position of each seal area throughout the machine or vibration modes at critical speeds. The minimum design diametral running clearance of the seals shall also be indicated.

A.2.4.4 When specified, a stiffness map of the undamped rotor response from which the damped unbalanced response analysis specified in A.2.4.3 was derived. This plot shall show natural frequency versus support system stiffness, with support system stiffness curves superimposed.

A.2.5 The damped unbalanced response analysis shall indicate that the machine in the unbalanced condition described in A.2.4.2 will meet the supplier standards or if specified the acceptance criteria given in A.2.5.1 and A.2.5.2 (see Figure A.1).

A.2.5.1 Acceptance criteria for separation margins (S_c) are as follows.

a) If the amplification factor (F_c) is less than 2,5, the response is considered critically damped and no separation margin is required.

b) If the amplification factor is between 2,5 and 3,55, a separation margin of 15 % above the maximum continuous speed and 5 % below the minimum operating speed is required.

c) If the amplification factor is greater than 3,55, and the critical response peak below the minimum operating speed, the required separation margin (a percentage of minimum operating speed) is equal to the following (for definitions of symbols, see Figure A.1):

$$S_c = 100 - \left(84 + \frac{6}{F_c - 3}\right) \tag{A.3}$$

d) If the amplification factor is greater than 3,55 and the critical response peak is above the trip speed, the required separation margin (a percentage of maximum continuous speed) is equal to the following (for definitions of symbols, see Figure A.1):

$$S_c = \left(126 - \frac{6}{F_c - 3}\right) - 100 \tag{A.4}$$

A.2.5.2 The calculated unbalanced peak-to-peak rotor amplitudes (see A.2.4.2) at any speed from zero to trip shall not exceed 75 % of the minimum design diametral running clearances throughout the machine (with the exception of floating-ring seal locations and abradable seals).

A.2.6 If, after the purchaser and the supplier have agreed that all practical design efforts have been exhausted, the analysis indicates that the separation margins still cannot be met or that a critical response peak falls within the operating speed range, acceptable amplitudes shall be mutually agreed upon by the purchaser and supplier, subject to the requirements of A.2.5.2.

A.3 Torsional analysis

A.3.1 Excitations of torsional resonances may come from many sources, which should be considered in the analysis. These sources may include, but are not limited to, the following:

a) gear problems such as unbalance and pitch line runout;

b) startup conditions such as speed detents (under inertial impedances) and other torsional oscillations;

c) torsional transients such as startups of synchronous electric motors;

d) excitation by electrical machines;

e) hydraulic governors and electronic feedback and control-loop resonances from variable-frequency motors;

f) electrical faults of electrical machines and/or mains.

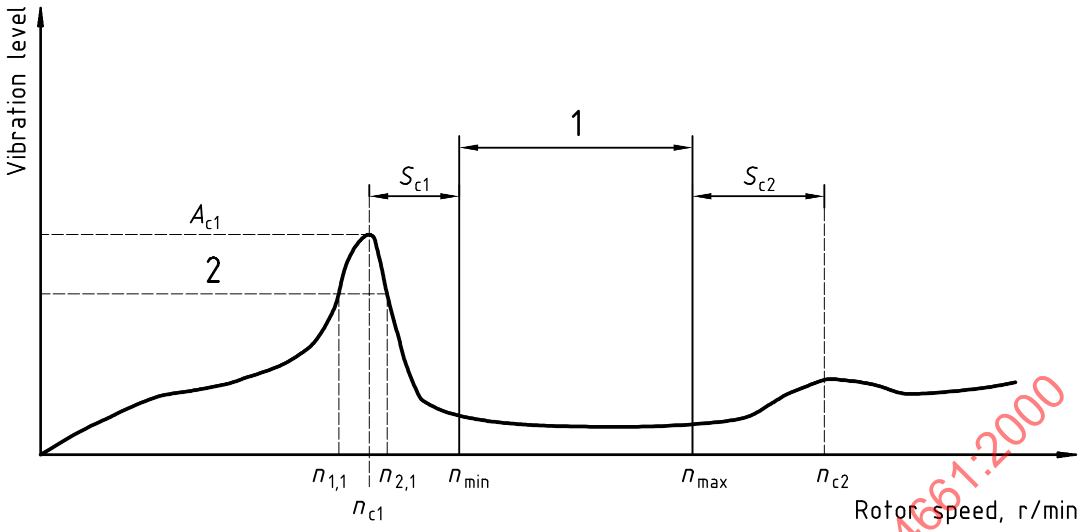
For a typical logic diagram showing torsional analysis, see Figure A.4.

A.3.2 Unless otherwise specified, for motor-driven units, generator drives and trains including gears, the supplier having train responsibility shall perform a torsional vibration analysis of the complete coupled train and shall be responsible for directing the modifications necessary to meet the requirements given in A.3.3 to A.3.5.

A.3.3 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 speed).

A.3.4 Torsional excitations at two or more times running speed, as well as torsional excitations that are not a function of operating speeds or that are non-synchronous in nature, shall be considered in the torsional analysis when applicable. Identification of these frequencies shall be the mutual responsibility of the purchaser and the supplier.

A.3.5 When torsional resonances are calculated to fall within the margin specified above (and the purchaser and supplier have agreed that all efforts to remove the critical from within the limiting frequency range have been exhausted), a stress analysis shall be performed to demonstrate that such resonances will have no adverse effect on the complete train. The acceptance criteria for this analysis shall be mutually aggreed upon by the purchaser and the supplier.



Key

1 Operating speed range

2 0,707 peak

n_{cn} is the n^{th} critical speed of the rotor

$n_{1,n}$ is the initial (lesser) speed at 0,707 × peak amplitude (critical) of the n^{th} critical speed

$n_{2,n}$ is the final (greater) speed at 0,707 × peak amplitude (critical) of the n^{th} critical speed

$n_{2,n} - n_{1,n}$ is the peak width at the half-power point of the n^{th} critical speed

F_{cn} is the amplification factor at the n^{th} critical speed

$$F_{cn} = \frac{n_{cn}}{n_{2,n} - n_{1,n}}$$

S_{cn} is the separation margin of the n^{th} critical speed

A_{cn} is the amplitude at the n^{th} critical speed

NOTE The shape of the curve is for illustration only and does not necessarily represent any actual rotor response plot.

Figure A.1 — Rotor response plot

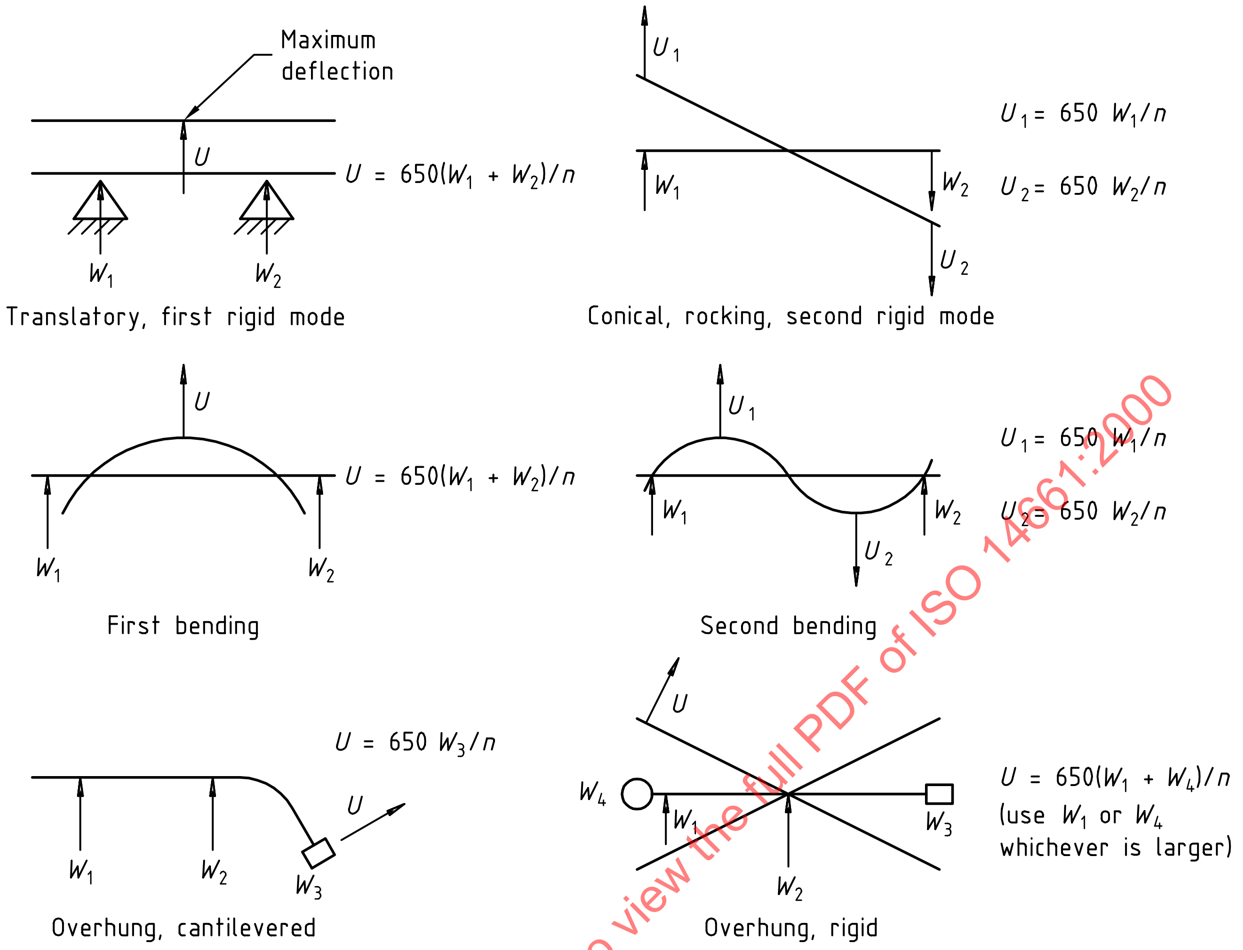


Figure A.2 — Typical mode shapes

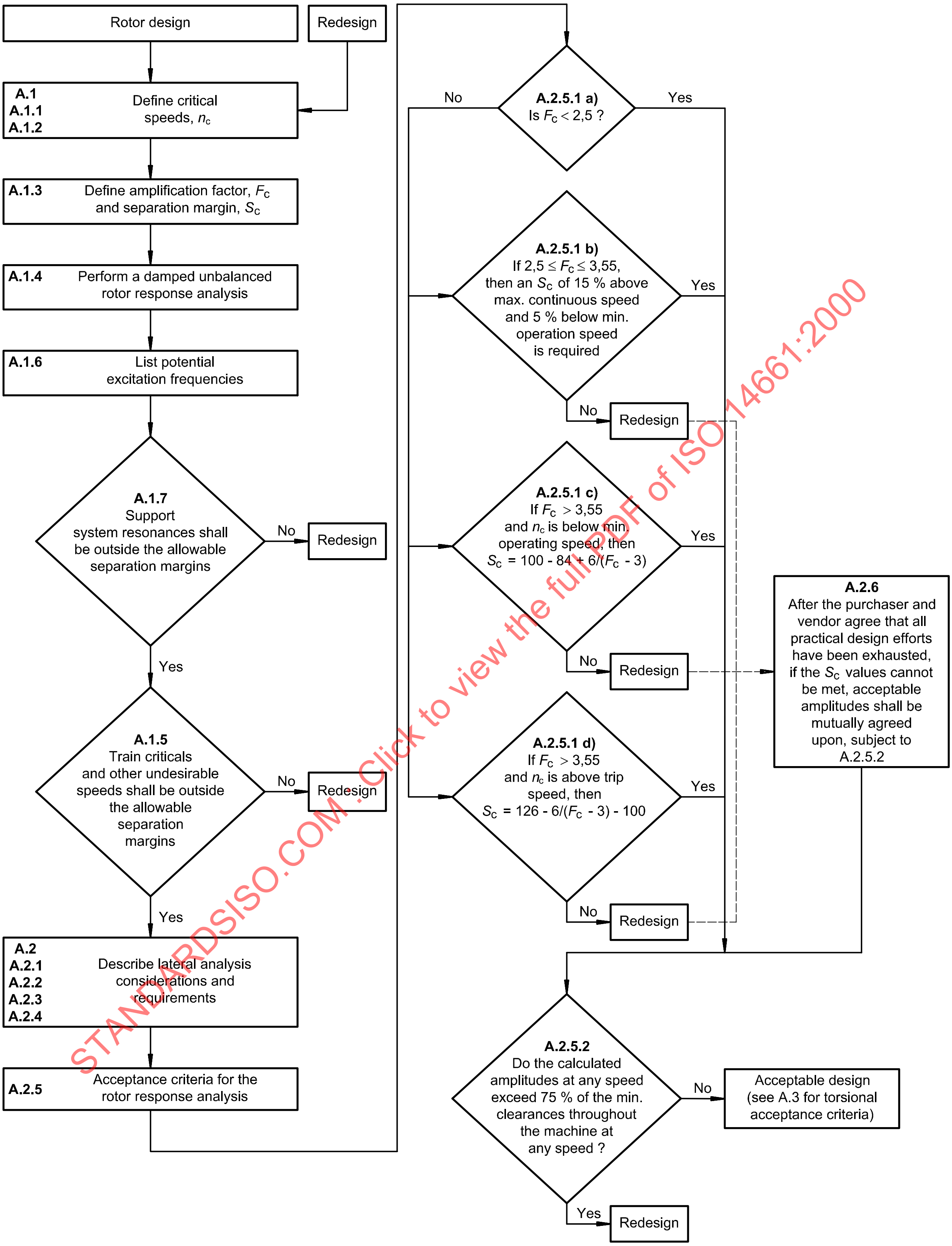


Figure A.3 — Rotor dynamics logic diagram (lateral analysis)

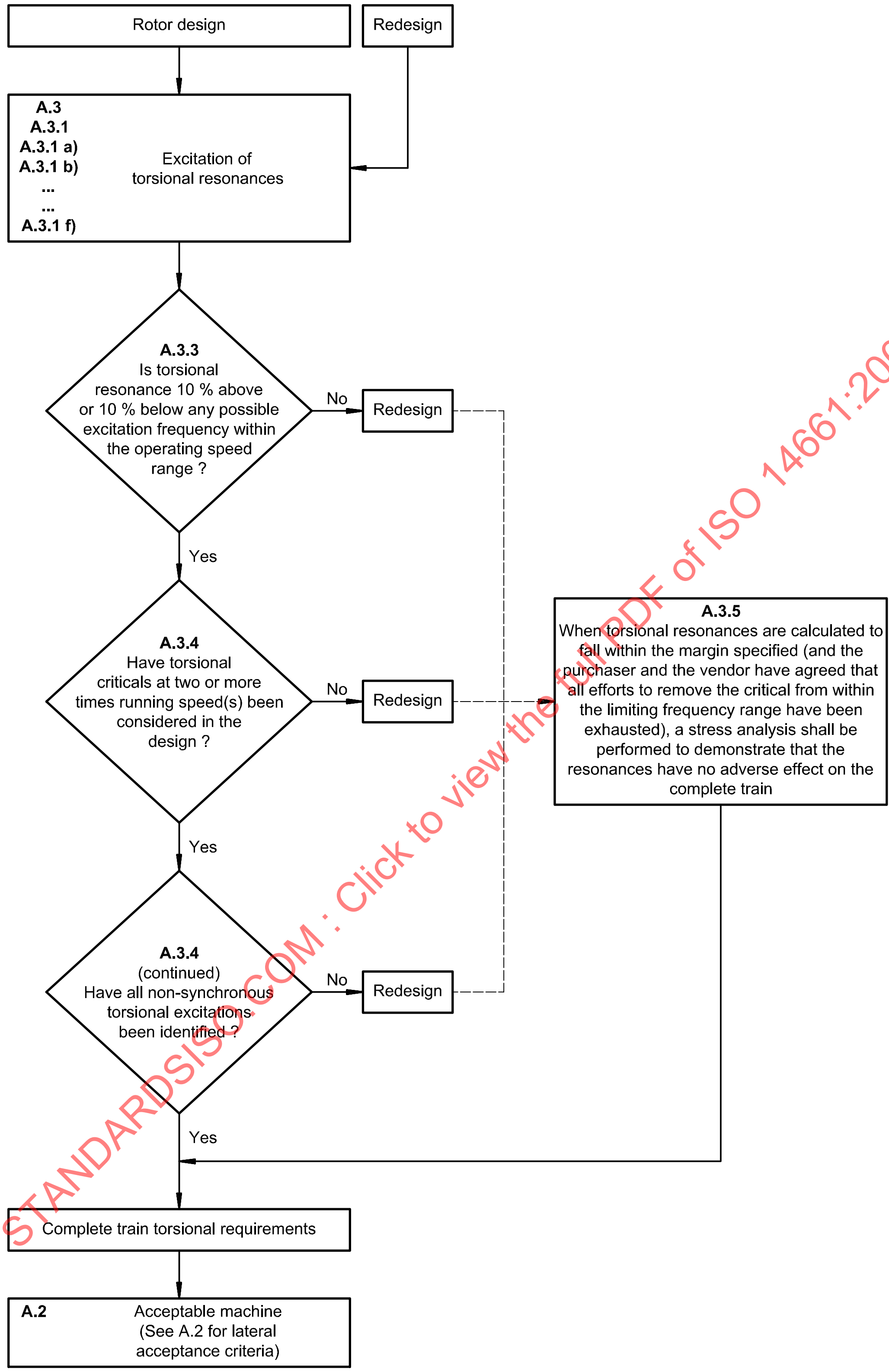


Figure A.4 — Rotor dynamics logic diagram (torsional analysis)

Annex B
(normative)

Explanations of terms concerning the governing system

B.1 Introduction

This annex explains the terms used in 10.2.

B.2 Characteristic (see Figure B.1)

B.2.1 P-characteristic

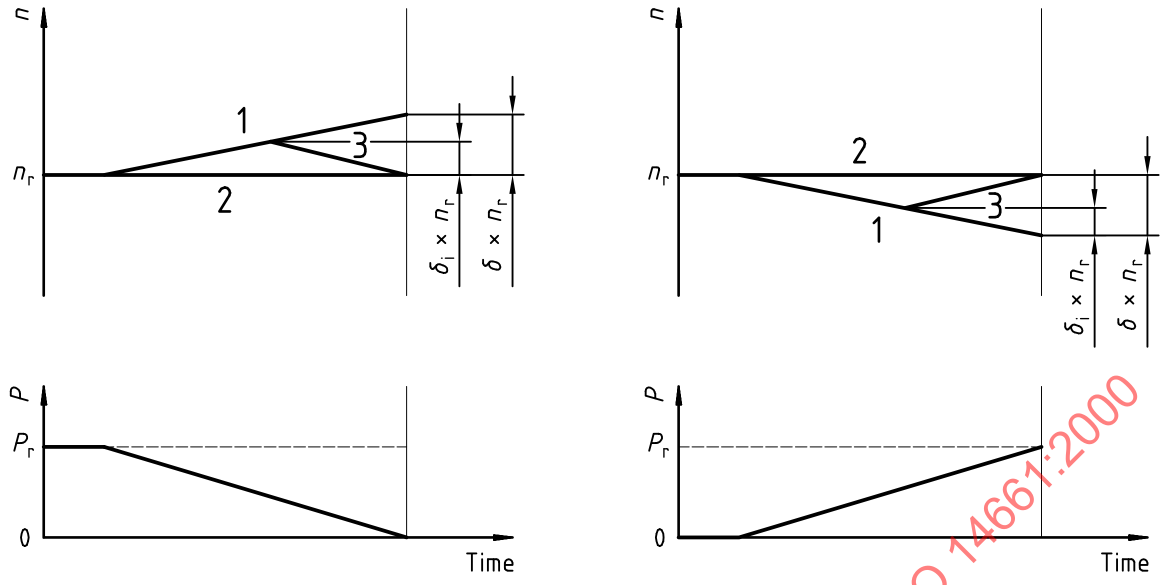
This means that the governing system has a proportional transfer behaviour.

The governor acts in a way that there is a proportional correlation between the actual speed and its reference value, resulting in a sustained deviation δ at steady state.

B.2.2 PI-characteristic

This means that the governing system has a proportional plus integral transfer behaviour.

The governor acts in a way that the actual speed is reset to its reference value, resulting in a sustained deviation δ close to zero at steady state.



δ is the steady-state speed regulation

δ_i is the incremental steady-state speed regulation

n_r is the rated speed

P is the power output

P_r is the rated power output

Key

1 Speed governor with P-characteristic ($\delta > 0$)

2 Speed governor with PI-characteristic ($\delta = 0$)

3 Speed governor with P-characteristic as slave controller and a frequency controller as master controller, resulting in an overall behaviour $\delta = 0$, but with an incremental steady-state speed regulation $\delta_i > 0$. This run of line 3 is only valid for rapid changes of the power output. The slower the change in power output, the more δ_i approaches the value 0 and the more line 3 approaches line 2.

Figure B.1 — Schematic sketch of the behaviour of the turbine speed depending on the characteristic of the governor system (On the left at decreasing load and on the right at increasing load)

B.3 Steady-state speed regulation (speed droop)

B.3.1 Steady-state speed regulation for a turbine without controlled extraction (see Figure B.2)

Speed regulation, expressed as a percentage of the rated speed n_r, is the change in sustained speed when the power output of the turbine is gradually changed from rated power output P_r to zero power output under the following steady-state conditions.

a) When the steam conditions (inlet pressure, inlet temperature, exhaust pressure) are set at rated values and held constant.

b) When any external control device is rendered inoperative and blocked in the open position so as to offer no restriction to the free flow of steam to the governor-controlled valves

$$\delta = \frac{n_A - n_B}{n_r} \times 100\ \%$$

where

n_A is the speed at zero power output;

n_B is the speed at rated power output on the characteristic for the same setting as the speed changer.

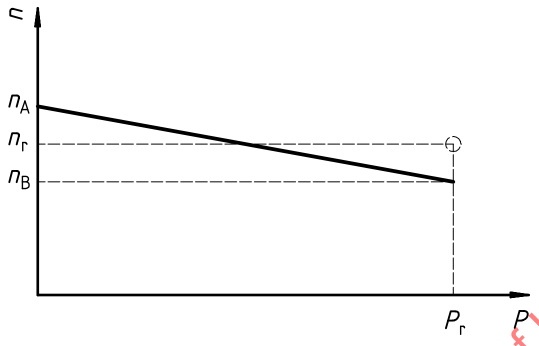


Figure B.2 — Behaviour of the turbine speed depending on the turbine power for a turbine with a speed governor with P-characteristic (turbine without controlled extraction)

In practice it is usual to adjust the speed changer to give rated speed n_r with rated power output P_r, i.e. concerning Figure B.2, the characteristic $n = f(P)$ is shifted upward.

Then the following is valid

$$n_B \equiv n_r$$

and

$$\delta = \frac{n_A - n_r}{n_r} \times 100\ \%$$

B.3.2 Steady-state speed regulation for a turbine with controlled extraction and for a mixed pressure turbine (see Figure B.3)

Speed regulation, expressed as a percentage of the rated speed n_r at rated power output P_r, is the change in sustained speed when the power output of the turbine is gradually changed from maximum power output P_m, at zero extraction or induction to zero power output under the following steady-state conditions.

a) When the steam conditions (inlet pressure, inlet temperature, exhaust pressure) are set at rated values and held constant.

b) When the extraction or induction pressure control system is inoperative and blocked in the position of zero extraction or induction. Additionally any further external control device is rendered inoperative and blocked in the open position so as to offer no restriction to the free flow of steam to the governor-controlled valves.

Therefore

$$\delta = \frac{n_A - n_m}{n_r} \times \frac{P_r}{P_m} \times 100\ \%$$

where

n_m is the speed at maximum power output with zero extraction or induction;

P_m is the maximum power output at which zero extraction or induction is permitted.

In practice it is usual to adjust the speed changer to give rated speed n_r with maximum power output P_m at which zero extraction or induction is permitted.

Then the following is valid:

$$n_m \equiv n_r$$

and

$$\delta = \frac{n_A - n_r}{n_r} \times \frac{P_r}{P_m} \times 100\ \%$$

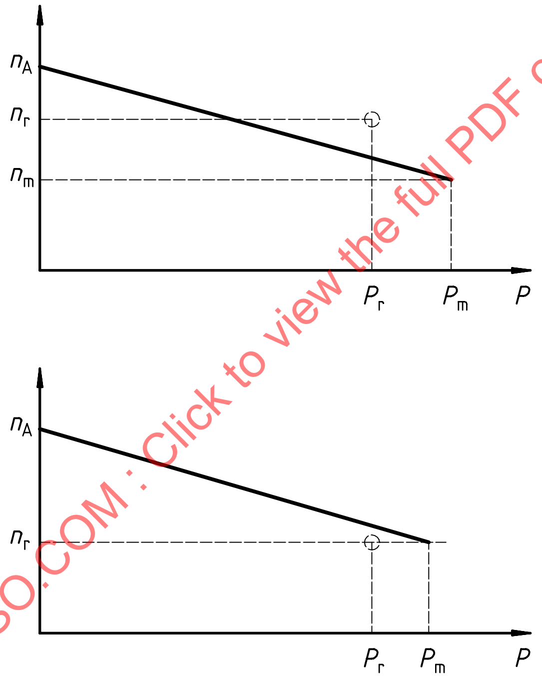


Figure B.3 — Behaviour of the turbine speed depending on the turbine power for a turbine with a speed governor with P-characteristic (turbine with controlled extraction)

B.4 Speed variation (SV) (see Figure B.4)

Speed variation, expressed as a percentage of rated speed n_r, is the total magnitude of speed change or fluctuations Δn from the set point of speed n_s under the above-mentioned steady-state conditions.

NOTE The speed change is defined as the difference in speed between the governing system in operation and the governing system blocked to be inoperative, with all other conditions constant. Speed variation includes the dead band of the control loop and sustained oscillations.

$$\text{SV} = \pm \frac{\Delta n}{2 \times n_r} \times 100\ \%$$