NEWBUILDINGS
MACHINERY AND SYSTEMS – MAIN CLASS

Rotating machinery, drivers

JANUARY 2016
FOREWORD

DNV is a global provider of knowledge for managing risk. Today, safe and responsible business conduct is both a license to operate and a competitive advantage. Our core competence is to identify, assess, and advise on risk management. From our leading position in certification, classification, verification, and training, we develop and apply standards and best practices. This helps our customers safely and responsibly improve their business performance. DNV is an independent organisation with dedicated risk professionals in more than 100 countries, with the purpose of safeguarding life, property and the environment.

The Rules lay down technical and procedural requirements related to obtaining and retaining a Class Certificate. It is used as a contractual document and includes both requirements and acceptance criteria.

© Det Norske Veritas AS January 2016

Any comments may be sent by e-mail to rules@dnvgl.com

If any person suffers loss or damage which is proved to have been caused by any negligent act or omission of Det Norske Veritas, then Det Norske Veritas shall pay compensation to such person for his proved direct loss or damage. However, the compensation shall not exceed an amount equal to ten times the fee charged for the service in question, provided that the maximum compensation shall never exceed USD 2 million.

In this provision “Det Norske Veritas” shall mean the Foundation Det Norske Veritas as well as all its subsidiaries, directors, officers, employees, agents and any other acting on behalf of Det Norske Veritas.
CHANGES – CURRENT

General
This document supersedes the January 2009 edition.

Text affected by the main changes in this edition is highlighted in red colour. However, if the changes involve a whole chapter, section or sub-section, normally only the title will be in red colour.

Det Norske Veritas AS, company registration number 945 748 931, has on 27th November 2013 changed its name to DNV GL AS. For further information, see www.dnvgl.com. Any reference in this document to “Det Norske Veritas AS” or “DNV” shall therefore also be a reference to “DNV GL AS”.

Main changes January 2016, entering into force July 2016

• Sec.1 Diesel engines
  — Requirements to type approval, certification of engine components, workshop testing and shipboard testing of diesel engines replaced by a reference to DNV GL rules for classification: Ships Pt.4 Ch.3 Sec.1 in order to reduce the amount of set of rules to consider, both for engine manufacturer and DNV GL.
  — Revised requirements for passing barred speed range. See A601, G401 f) and G405 c).

Editorial corrections
In addition to the above stated main changes, editorial corrections may have been made.
## CONTENTS

<table>
<thead>
<tr>
<th>Sec. 1 Diesel engines</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A. General</td>
<td>7</td>
</tr>
<tr>
<td>A 100 Application</td>
<td>7</td>
</tr>
<tr>
<td>A 200 Dormant</td>
<td>7</td>
</tr>
<tr>
<td>A 300 Dormant</td>
<td>7</td>
</tr>
<tr>
<td>A 400 Dormant</td>
<td>7</td>
</tr>
<tr>
<td>A 500 Documentation of arrangement</td>
<td>7</td>
</tr>
<tr>
<td>A 600 Documentation of vibration</td>
<td>7</td>
</tr>
<tr>
<td>B. Design</td>
<td>9</td>
</tr>
<tr>
<td>B 100 Dormant</td>
<td>9</td>
</tr>
<tr>
<td>C. Testing and inspection</td>
<td>9</td>
</tr>
<tr>
<td>C 100 Dormant</td>
<td>9</td>
</tr>
<tr>
<td>D. Workshop testing</td>
<td>9</td>
</tr>
<tr>
<td>D 100 Dormant</td>
<td>9</td>
</tr>
<tr>
<td>E. Control and monitoring</td>
<td>9</td>
</tr>
<tr>
<td>E 100 Dormant</td>
<td>9</td>
</tr>
<tr>
<td>F. Arrangement</td>
<td>9</td>
</tr>
<tr>
<td>F 100 Alignment and reaction forces</td>
<td>9</td>
</tr>
<tr>
<td>F 200 Rigid mounting</td>
<td>9</td>
</tr>
<tr>
<td>F 300 Resilient mounting</td>
<td>10</td>
</tr>
<tr>
<td>F 400 Exhaust pipes</td>
<td>10</td>
</tr>
<tr>
<td>F 500 Lubrication and fuel pipes</td>
<td>10</td>
</tr>
<tr>
<td>F 600 Crankcase ventilation pipes</td>
<td>10</td>
</tr>
<tr>
<td>G. Vibration</td>
<td>11</td>
</tr>
<tr>
<td>G 100 Symbols and definitions</td>
<td>11</td>
</tr>
<tr>
<td>G 200 Vibration measurements</td>
<td>11</td>
</tr>
<tr>
<td>G 300 Steady state torsional vibration</td>
<td>11</td>
</tr>
<tr>
<td>G 400 Transient torsional vibration</td>
<td>15</td>
</tr>
<tr>
<td>G 500 Axial vibration</td>
<td>16</td>
</tr>
<tr>
<td>G 600 Engine vibration</td>
<td>16</td>
</tr>
<tr>
<td>H. Installation inspections</td>
<td>17</td>
</tr>
<tr>
<td>H 100 Application</td>
<td>17</td>
</tr>
<tr>
<td>H 200 Assembling of engines supplied in sections</td>
<td>17</td>
</tr>
<tr>
<td>H 300 Alignment and foundation</td>
<td>17</td>
</tr>
<tr>
<td>H 400 Resiliently mounted engines</td>
<td>17</td>
</tr>
<tr>
<td>H 500 Fuel, lubrication and cooling systems</td>
<td>18</td>
</tr>
<tr>
<td>I. Shipboard testing</td>
<td>18</td>
</tr>
<tr>
<td>I 100 Application</td>
<td>18</td>
</tr>
<tr>
<td>I 200 Dormant</td>
<td>19</td>
</tr>
<tr>
<td>I 300 Dormant</td>
<td>19</td>
</tr>
<tr>
<td>I 400 Dormant</td>
<td>19</td>
</tr>
<tr>
<td>I 500 Steady state torsional vibration</td>
<td>19</td>
</tr>
<tr>
<td>I 600 Transient torsional vibration</td>
<td>19</td>
</tr>
<tr>
<td>I 700 Engine vibration</td>
<td>19</td>
</tr>
<tr>
<td>Sec. 2 Gas turbines</td>
<td>20</td>
</tr>
<tr>
<td>A. General</td>
<td>20</td>
</tr>
<tr>
<td>A 100 Application</td>
<td>20</td>
</tr>
<tr>
<td>A 200 Definitions</td>
<td>20</td>
</tr>
<tr>
<td>A 300 Certification</td>
<td>20</td>
</tr>
<tr>
<td>A 400 Documentation requirements - manufacturer</td>
<td>23</td>
</tr>
<tr>
<td>A 500 Documentation requirements - builder</td>
<td>24</td>
</tr>
<tr>
<td>B. Design</td>
<td>26</td>
</tr>
<tr>
<td>B 100 General</td>
<td>26</td>
</tr>
<tr>
<td>B 200 Structural components</td>
<td>27</td>
</tr>
<tr>
<td>B 300 Component design requirements</td>
<td>27</td>
</tr>
<tr>
<td>B 400 Engine testing</td>
<td>34</td>
</tr>
<tr>
<td>B 500 General requirements for all engine tests</td>
<td>34</td>
</tr>
<tr>
<td>Section</td>
<td>Title</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>A 200</td>
<td>Documentation</td>
</tr>
<tr>
<td>A 100</td>
<td>Application</td>
</tr>
<tr>
<td>A 200</td>
<td>Documentation</td>
</tr>
<tr>
<td>B 600</td>
<td>Engine test data collection</td>
</tr>
<tr>
<td>B 700</td>
<td>Power measurement</td>
</tr>
<tr>
<td>B 800</td>
<td>Type testing, general</td>
</tr>
<tr>
<td>B 900</td>
<td>Type testing program</td>
</tr>
<tr>
<td>B 1000</td>
<td>Boroscope inspection and tear-down after testing</td>
</tr>
<tr>
<td>C 100</td>
<td>General</td>
</tr>
<tr>
<td>C 200</td>
<td>Certification of parts</td>
</tr>
<tr>
<td>C 300</td>
<td>Production verification</td>
</tr>
<tr>
<td>D 100</td>
<td>Application</td>
</tr>
<tr>
<td>D 200</td>
<td>Certification testing</td>
</tr>
<tr>
<td>D 300</td>
<td>Certification testing of propulsion engines</td>
</tr>
<tr>
<td>D 400</td>
<td>Certification testing of engines for generating sets</td>
</tr>
<tr>
<td>D 500</td>
<td>Boroscope inspection</td>
</tr>
<tr>
<td>E 100</td>
<td>Core engine controls</td>
</tr>
<tr>
<td>E 200</td>
<td>Monitoring and instrumentation system</td>
</tr>
<tr>
<td>E 300</td>
<td>Safety system</td>
</tr>
<tr>
<td>E 400</td>
<td>Auxiliary system controls</td>
</tr>
<tr>
<td>F 100</td>
<td>Alignment and reaction forces</td>
</tr>
<tr>
<td>F 200</td>
<td>Mounting in general</td>
</tr>
<tr>
<td>F 300</td>
<td>Rigid mounting</td>
</tr>
<tr>
<td>F 400</td>
<td>Resilient mounting</td>
</tr>
<tr>
<td>F 500</td>
<td>Inlet and outlet passages</td>
</tr>
<tr>
<td>F 600</td>
<td>Carboc system</td>
</tr>
<tr>
<td>F 700</td>
<td>Gas turbine enclosure</td>
</tr>
<tr>
<td>F 800</td>
<td>Fire safety</td>
</tr>
<tr>
<td>G 100</td>
<td>General</td>
</tr>
<tr>
<td>G 200</td>
<td>Documentation of vibration analysis</td>
</tr>
<tr>
<td>G 300</td>
<td>Engine vibration</td>
</tr>
<tr>
<td>H 100</td>
<td>Application</td>
</tr>
<tr>
<td>H 200</td>
<td>Assembly of gas turbines supplied in modules</td>
</tr>
<tr>
<td>H 300</td>
<td>Alignment and foundation</td>
</tr>
<tr>
<td>H 400</td>
<td>Inlet and outlet passages</td>
</tr>
<tr>
<td>H 500</td>
<td>On-engine ancillaries, including fuel and lubrication systems</td>
</tr>
<tr>
<td>H 600</td>
<td>Fire prevention</td>
</tr>
<tr>
<td>H 700</td>
<td>Control and monitoring</td>
</tr>
<tr>
<td>I 100</td>
<td>General</td>
</tr>
<tr>
<td>I 200</td>
<td>Quay trial</td>
</tr>
<tr>
<td>I 300</td>
<td>Sea trial</td>
</tr>
<tr>
<td>I 400</td>
<td>Boroscope inspection</td>
</tr>
<tr>
<td>Sec. 3</td>
<td>Steam turbines</td>
</tr>
<tr>
<td>A 100</td>
<td>Application</td>
</tr>
<tr>
<td>A 200</td>
<td>Documentation</td>
</tr>
<tr>
<td>B 100</td>
<td>General</td>
</tr>
<tr>
<td>B 200</td>
<td>Component design requirements</td>
</tr>
<tr>
<td>C 100</td>
<td>General</td>
</tr>
<tr>
<td>D 100</td>
<td>General turbine tests</td>
</tr>
<tr>
<td>E 100</td>
<td>General</td>
</tr>
<tr>
<td>E 200</td>
<td>Speed governing</td>
</tr>
<tr>
<td>E 300</td>
<td>Safety functions and devices</td>
</tr>
<tr>
<td>E 400</td>
<td>Monitoring</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------</td>
</tr>
<tr>
<td>F. Arrangement</td>
<td>58</td>
</tr>
<tr>
<td>F 100 General arrangement</td>
<td></td>
</tr>
<tr>
<td>F 200 Arrangement of propulsion machinery</td>
<td>58</td>
</tr>
<tr>
<td>G. Vibrations</td>
<td>58</td>
</tr>
<tr>
<td>G 100 Torsional vibrations</td>
<td></td>
</tr>
<tr>
<td>H. Installation inspections</td>
<td>59</td>
</tr>
<tr>
<td>H 100 General</td>
<td></td>
</tr>
<tr>
<td>I. Shipboard testing</td>
<td>59</td>
</tr>
<tr>
<td>I 100 General</td>
<td></td>
</tr>
<tr>
<td>I 200 Auxiliary turbines</td>
<td>59</td>
</tr>
<tr>
<td>I 300 Propulsion turbines</td>
<td></td>
</tr>
<tr>
<td>CHANGES – HISTORIC</td>
<td>60</td>
</tr>
</tbody>
</table>
SECTION 1 DIESEL ENGINES

A. General

A 100 Application

101 This section covers requirements applicable to diesel, petrol, gas and dual fuel.

102 Unless otherwise stated, DNV GL rules for classification: Ships Pt.4 Ch.3 Sec.1 applies to this section with the following comments:

— Chapters B - Design, C - Testing and inspection, D - Workshop testing and E - Control and monitoring are in their entirety covered by DNV GL rules for classification: Ships.
— Installations intended for running on crude oil or gas, additional requirements are given in Pt.6 Ch.13 and Pt.6 Ch.32 of the DNV rules for Classification of Ships.
— In case of engines intended for vessels approved for unmanned machinery installations (class notation E0), DNV rules for Classification of Ships Pt.6 Ch.3 applies

A 200 Dormant

Paragraph only kept to ensure numbering and references in the document.

A 300 Dormant

Paragraph only kept to ensure correct numbering and references in the document.

A 400 Dormant

Paragraph only kept to ensure correct numbering and references in the document.

A 500 Documentation of arrangement

501 The following plans and particulars shall be in accordance with the engine designer/manufacturer's specifications and be submitted by the yard for approval:

<table>
<thead>
<tr>
<th>Table A1 Documentation of arrangement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
</tr>
<tr>
<td>Documentation of arrangement</td>
</tr>
<tr>
<td>Drawings</td>
</tr>
<tr>
<td>Material specification</td>
</tr>
<tr>
<td>Calculations</td>
</tr>
<tr>
<td>Miscellaneous for approval (A) or information (I)</td>
</tr>
<tr>
<td>Reference to design requirements</td>
</tr>
</tbody>
</table>

a) For propulsion engines, fastening arrangement with bolts, pre-stress, epoxy (including calculations) or metallic chocks (see F200), if applicable.

b) Top stay arrangement, if applicable, including reaction forces (see F205).

c) Resilient mounts under engines shall be type approved. See F300.
   However resilient mounts under a common frame for an engine-generator set are not required for approval. Correspondingly, the engine movement calculations in F300 are not required.

d) For resiliently mounted engines, calculations of the static positions within the elastic mounts shall be submitted. See F303.

A 600 Documentation of vibration

601 The following specified calculations, when applicable, shall be submitted by the yard, or a sub-supplier acting on behalf of the yard, for approval for all plants, except auxiliary plants with less than 500 kW engine rated power.

The calculation shall be accompanied by an analysis, Ch.2 Sec.3 A104 describes the general contents, and the analyses shall compare the result of the calculation with the acceptance levels for all components in the system, and conclude with respect to possible restrictions.

a) Torsional vibration calculations for steady state conditions.

b) Torsional vibration calculations for transient conditions:

   1) Passing through a barred speed range (typical for 2-stroke engine): This applies when it is necessary for the acceptance of the shafting to document a certain vibration and stress level when passing through a barred speed range, see Ch.4 Sec.1 B200. A fatigue calculation shall be submitted upon request.

   2) Starting and stopping operations (typical for plants where the driven inertia is a multiple of the engine inertia): This applies when requested by the Society in order to prove that starting and stopping procedures, involving passage of major critical areas, is not detrimental to any power transmitting parts, see G402.
3) Clutching in: This applies to plants with rapidly engaging clutches. The specified pressure-time characteristics will be considered and if found necessary, transient vibration calculations will be required.

4) Short circuit in PTO generators driven by main reduction gears: This applies to plants with power take off (PTO) driven generators where short circuits can occur. Transient vibration calculations due to short-circuiting will be required if the ratio torsional dynamic stiffness \( (k\text{Nm}/\text{rad}) \) (considering the excitation frequency of 50 Hz or 60 Hz) by rated torque \( (\text{kNm}) \) exceeds 10, i.e. \( K_{\text{dyn}}/T_0 > 10 \) in the PTO branch.

5) Short circuit in propulsion engine driven PTO generators other than in item 4) to be specially considered.

c) Axial vibration calculations. This applies only when requested by the Society.

**Guidance note:**
Requests for axial vibration calculations are normally made when:
- direct coupled plants are running sub-critically on the lowest major torsional order
- engines are rigidly connected to extraordinary heavy masses (e.g. generator) and run in high-speed ranges where no field experience exists.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

d) Engine vibration calculations. This applies to all resiliently mounted engines except to engine-generator sets where the engine and generator are rigidly mounted on a common frame and the frame is resiliently mounted.

602 The calculations shall contain:
- objectives
- description of the method
- plant and system layout
- conditions
- assumptions
- conclusion.

The conclusion shall be based on a comparison between calculated dynamic response and the permissible values for all the sensitive parts in the plant.

603 In all kinds of torsional vibration calculations the variation of essential data such as dynamic characteristics of elastic couplings and dampers shall be considered, see Ch.2 Sec.3 A101. Especially rubber couplings and certain types of vibration dampers have wide tolerances of stiffness and damping. It is normally not required to perform calculations with all combinations of these extreme data, but as a minimum the influence of such wide tolerances shall be qualitatively considered and also addressed in the conclusions. For couplings having stiffness with strong dependency on vibratory torque and/or temperature (as a consequence of power loss) it may be required to carry out either iterative direct calculations or simulation calculation where these dependencies are included.

604 In vibration calculations the source of all essential data shall be listed. For data that cannot be given as constant parameters (see for example 603), the assumed parameter dependency and tolerance range shall be specified.

605 In connection with torsional vibration calculations the following may be requested:
- type of speed governor
- position of speed sensor.

606 Measurements and analysis of camshaft and gear drive vibration may be required if service experience with this or similar engine types indicate excessive vibration. If the type test engine has a considerably lower number of cylinders than the maximum number for that engine type, this test requirement may be postponed to the sea trial testing of the first engine with the high number of cylinders.

**Guidance note:**
It is desirable to minimise the extent of documentation of vibration as given in 600 for the actual plants. This can be achieved by e.g.:

a) System type approval, see Ch.2 Sec.2. For example:
- Engines which use a limited number of elastic couplings, generators, gearboxes, shafting lengths, propellers, water jets etc. may be suitable for system type approval.
- Resiliently mounted engines where standard mounts are used and all connections (including the drive coupling) are made so flexible that they have no influence on the vibration, may be covered by a system type approval.
b) Including the “crankshaft vibration” in the engine’s type approval. For engines where the crankshaft stresses are practically independent of the driven system, i.e. engines that are generally fitted with an elastic coupling, it is advised to have both axial (if necessary) and torsional vibration included in the type approval. Thus, this part of the torsional vibration need not be submitted for the actual applications. Such torsional vibration calculations shall be made with the maximum relevant engine load in the whole actual speed range. Misfiring (no fuel injection) of one cylinder is also to be considered. For this purpose, the worst cylinder shall be selected, see G301 d).

---end---of---guidance---note---

B. Design

B 100 Dormant
Paragraph only kept to ensure correct numbering and references in the document.

C. Testing and inspection

C 100 Dormant
Paragraph only kept to ensure correct numbering and references in the document.

D. Workshop testing

D 100 Dormant
Paragraph only kept to ensure correct numbering and references in the document.

E. Control and monitoring

E 100 Dormant
Paragraph only kept to ensure correct numbering and references in the document.

F. Arrangement

F 100 Alignment and reaction forces

101 Direct coupled engines shall be aligned so that the internal bearing reactions within the engine comply with the engine specification.

102 For engines driving generators with one bearing, the common frame shall have a stiffness that fulfils the requirement in 101 with regard to bearing reactions.

103 For direct coupled propulsion engines the alignment specification (see Ch.4 Sec.1 A402) may be required substantiated by shaft alignment calculations, see Ch.4 Sec.1 F400.

104 For engines with elastic couplings the alignment shall be within the permissible values for the couplings under all relevant driving conditions. This is particularly important for resiliently mounted engines, see 300.

105 For engine plants with elastic coupling, universal joints, spline connections, tooth couplings, etc. the reaction forces under all relevant driving conditions shall be considered. These forces shall be within the limits specified by the engine manufacturer.

F 200 Rigid mounting

201 For mounting on epoxy, the surface pressure shall be within the approved values (surface pressure and thickness) for the applicable epoxy type. The epoxy resin shall be type approved.

202 Metallic chocks shall be at least 20 mm thick. The accuracy of the fit between chocks and bedplate and foundation, respectively, shall be better than 0.1 mm. Shims or combinations of shims and chocks are not acceptable.

203 For crosshead engines the pre-tensioning of the holding down bolts shall be specified with regard to tightening as well as the method. The friction forces shall prevent dynamic movements between bedplate and chocks and epoxy.
Side and end stoppers are normally required. They are regarded as safety devices in case of relative movement between engine and foundation caused by loosened bolts. End stoppers may be waived if fitted bolts or equivalent solutions are used.

The securing of the engine top stays to the hull structure shall be designed to avoid cracks at the fastening points.

### F 300  Resilient mounting

All connections to the engine such as couplings, exhaust pipes, fuel pipes, lubrication oil and cooling water connections shall be designed for the maximum possible engine movements as limited by dual characteristic mounts or stoppers. For determination of dynamic movements, see G600.

The elastic mounts shall be able to support the mass of the engine, the reaction forces due to engine torque, the maximum environmental conditions as list and trim (see Ch.1 of the Rules for Classification of Ships), and the dynamic loads (see G600) without exceeding the approved specification.

The static positions of the engine on the elastic mounts shall be calculated under consideration of the static loads given in 302.

Excessive (static and dynamic) movements shall be prevented either by dual characteristic mounts or by stoppers. Excessive movements are movements beyond those expected and determined in 303 and G600. Under the running conditions considered in G, the stoppers are not to be reached. For dual characteristic mounts the “second level” may be utilised provided that this is foreseen in the dynamic analysis and with regard to the vibration isolation of the engine as well as the engine’s compatibility with the resulting accelerations.

### F 400  Exhaust pipes

Where exhaust pipes are led overboard near the water line, means shall be provided to avoid the possibility of water entering the engine.

Exhaust pipes from several engines are not to be connected, but shall have separate outlets, unless precautions are taken to prevent the return of exhaust gases to a stopped engine.

All hot surfaces shall be properly insulated. There shall be no surface temperature in excess of 220°C, see D208.

### F 500  Lubrication and fuel pipes

Short lengths of flexible pipes and hoses may be used when necessary to admit relative movements between machinery and fixed piping systems. For requirements for such hoses, see Ch.6 Sec.6 D. Flexible Hoses.

Pipes and hoses shall be type approved.

The lubricating oil drain pipes from the engine sump to the system tank shall be submerged at their outlet ends during all operating conditions as defined in Ch.1 of the Rules for Classification of Ships. Drain pipes from different engines shall be laid independently of each other in order to avoid intercommunication between crankcases.

Pipe connections in piping containing flammable liquids shall be adequately screened. The screening shall ensure that leakage from pipe connections does not reach potentially hot surfaces. Any insulated surface, where the temperature may exceed 220°C in the event that insulation is detached or otherwise is degraded, shall be regarded a potentially hot surface.

### F 600  Crankcase ventilation pipes

Crankcase ventilation pipes from different engines shall be laid independently of each other in order to prevent intercommunication between crankcases.

**Guidance note:**

Oil vapour from the ventilation pipes should preferably be led to free air.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---
G. Vibration

G 100 Symbols and definitions

101 The following symbols are used in G:

- \( n_0 \) = r.p.m. at maximum continuous power
- \( n \) = r.p.m. at which vibration are considered
- \( \lambda \) = speed ratio defined as \( n/n_0 \)
- \( T_0 \) = rated torque (at maximum continuous power)
- \( T \) = mean torque at \( n \) r.p.m.
- \( T_v \) = vibratory torque at \( n \) r.p.m.
- \( \tau \) = torsional stress (N/mm\(^2\)) corresponding to \( T \)
- \( \tau_v \) = torsional stress (N/mm\(^2\)) corresponding to \( T_v \).

102 The amplitude of vibratory torque is defined as:

\[ T_v = 0.5 \left( \text{maximum torque} - \text{minimum torque} \right) \text{ during a time interval that covers the period of the lowest order, including possible beat orders.} \]

This definition also applies for non-linear vibration and for synthesised linear vibration where the average torque (which is the average between the maximum torque and the minimum torque) differs significantly from the effective driving torque (mean torque \( T \)). In such cases the mean torque used in various fatigue criteria shall be replaced with the average torque.

103 Misfiring in a cylinder is defined as no fuel injection. The compression - expansion cycle is assumed to be maintained under the same charge air pressure as normal.

104 Transient torsional vibration in this context is operations as:

a) Acceleration or deceleration through a barred speed range.
b) Starting and stopping operations.
c) Clutching in.
d) Short circuit in PTO driven generators.
e) System instability.

The latter condition is in principle a transient condition even if it occurs at constant speed because the excitation increases due to the feedback from the speed governor. However, since this condition is prohibited (see 303 c), it will not be further mentioned.

G 200 Vibration measurements

201 When vibration measurements are required, the type of instrumentation, location of pick ups, signal processing method, and the measurement procedure shall be agreed by the Society.

202 A complete report containing results from unfiltered signals (e.g. shaft stresses) as well as processed signals (e.g. frequency analyses) shall be submitted for approval.

G 300 Steady state torsional vibration

301 Extent of calculations

a) In A600, some ways to minimise the extent of calculations are mentioned. The following apply when none of those options are used.

b) Natural frequency calculations of the complete system are required. These shall include tables of relative displacement amplitudes, relative inertia torques, vector sums and, if used later, also their phase angles.
For branched systems where certain branches may be disengaged, natural frequency calculations are only required for those combinations of disengaged branches which will yield significantly different vibration modes and natural frequencies.

For systems with elements (such as non-linear elastic couplings or dampers) that have wide stiffness range within the relevant operating conditions, natural frequency calculations with at least the maximum and minimum values shall be made.

c) Forced torsional vibration calculations are required for all operating conditions where vibration levels are expected to be higher than 50% of the permissible levels. Driving conditions to be considered are:

— one cylinder misfiring per engine
— for twin engines, both in-phase and anti-phase
— for direct coupled engines the whole speed range with and without misfiring
— for multi-branch systems the expected worst combination of engaged branches.

**Guidance note:**
For 2-stroke engines it is advised also to calculate with one cylinder with open exhaust valve. Cylinder selected as for ordinary misfiring.

d) For calculation in misfiring condition the misfiring cylinder shall be selected as follows:

— for vibration modes and orders with vector sums almost equal zero, any cylinder may be selected
— for vibration modes with significant vector sums (e.g. > 0.1 relative to maximum cylinder amplitude) either - the cylinder which has the opposite phase angle of the vector sum should be selected or - calculating all combinations and presenting the worst.

**Guidance note:**
The choice of misfiring cylinder should preferably be agreed in general for each engine type and firing sequence. The selection may be based on an assumed relative crankshaft deflection from the free end to the flywheel, for example from unity to 0.9.

e) The normal operation, i.e. engines with a certain imbalance between the cylinders, is considered as a combination of the ideal and the misfiring condition as:

\[ T_V = (T_{V\text{misfiring}} - T_{V\text{ideal}}) \frac{z}{24} + T_{V\text{ideal}} \]

However, not less than \( T_{V\text{ideal}} \)

\[ z = \text{number of cylinders in the engine.} \]

For plants with different engines, the vibration response from each engine is considered as described above, and then added. For twin engines, the least favourable phase is considered.

**Guidance note:**
For plants dominated by vibration modes that have insignificant vector sums in the relevant speed range the \( T_{V\text{ideal}} \) may be assumed to be zero.

Note that the above mentioned way of estimating the normal operating condition is not an obligatory calculation.

Other methods may be considered if they are consistent with cylinder balance requirements in the operational phase.

g) If any vibration condition results in high vibration at the governor pick up position of flexibly coupled propulsion engines, evaluation of the torsional vibration system including the speed governor loop should be considered, see 302 f).

### 302 Calculation method

a) The plant can be described as a lumped mass system.

**Guidance note:**
For plants with highly elastic couplings, the branches on the non-excitation sides of such couplings may be described by few lumped inertia.

b) The natural frequency calculations can be performed with matrix methods or Holzer method. For plants with hydrodynamic couplings or torque converters the system may be considered "cut" in the fluid provided there is a significant slip in the coupling.

c) The forced torsional vibration can be calculated by means of linear differential equations, one for each lumped mass. Each mass is described by its inertia, connected by torsional springs to adjacent masses, damping described as absolute (mass) damping and relative (shaft) damping, and excitation applied on mass.
d) The parameters used in vibration calculations shall be representative for the actual speed, mean torque, frequency, temperature, and vibratory torque. The latter implies that if an element is strongly dependent on the level of the vibratory torque and used in a linear vibration calculation, then the whole calculation may have to be made by iteration.

e) Alternatively to the above mentioned conventional forced torsional vibration calculation procedure, simulation by numeric time integration can be used. This is suitable for determination of vibration outside the engine itself, such as in couplings and gear meshes. The dependencies mentioned in d) can be built into the procedure and thereby avoiding iterative calculation. If the natural frequency calculations (of the detailed system) indicate that only a few lower modes are of importance, then the mass elastic system for numeric simulation can be essentially simplified, e.g. the engine with flywheel can be described as one mass, and so on. It is required to verify by natural frequency calculations that the simplified system has approximately the same lower (only the important) frequencies as the detailed system.

f) If the speed governor influence shall be taken into account (see 301 f), it is advised to do this by means of numeric simulation as described above.

g) Engine excitation shall be as realistic as practically possible and shall contain both impulse and phase angle for each harmonic. The following acceptable methods are mentioned in descending preference:

— Measured pressure-crank angle data at relevant running conditions. I.e. for engines typically used in fixed pitch propeller plants, the data should be recorded at several points along the propeller curve. For engines typically used in controllable pitch propeller plants or generator sets, the data should be recorded at several loads at full r.p.m.

— Misfiring (no injection) shall be included. The gas impulses and phase angles shall be analysed at each measured condition. For the forced vibration calculation the necessary excitation data shall be determined by interpolation and extrapolation of the analysed measurements and combined with the calculated excitation due to mass forces.

— Calculation of pressure-crank angle based on engine particulars as maximum pressure, mean indicated pressure, charge air pressure, compression ratio, expansion and compression exponents. From these theoretical pressure diagrams (including misfiring), the gas impulses and phase angles shall be evaluated and combined with the mass impulses. This procedure may be carried out at each single case (r.p.m. and load) or at larger intervals with interpolation to each case.

— Gas impulses with phase angles may be taken from general (not engine particular) sources and combined with mass forces. It should be noted that this procedure is considered as far less accurate than the two first.

h) Propeller excitation can be taken as a percentage of the actual mean torque according to Table G1 unless other values are substantiated by the propeller manufacturer. The values are representative for steady forward operation. During heavy rolling or steering manoeuvres the values will be higher.

<table>
<thead>
<tr>
<th>Number of blades</th>
<th>Blade frequency (%)</th>
<th>Double blade frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>1.5</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>1.5</td>
</tr>
</tbody>
</table>

i) Other excitation sources as water jet impeller pulses, universal joints (second order), etc. may have to be taken into account in special cases.

j) The results of the forced torsional vibration calculations shall be presented as relevant for the various components in the system, see 303. If any result is close to the acceptance limit and there are uncertainties in the calculations, vibration measurements may be required. Exceeding the acceptance limits in normal operation will result in a barred speed range well covering the range where the limits are exceeded. A barred speed range above \( \lambda = 0.8 \) is not permitted. Exceeding the acceptance limits in misfiring condition will result in:

— restricted (e.g. \( < 0.5 \) hours) operation when the vibration level is acceptable for limited time (slow heating of rubber elements)
— restricted driving or load condition (barred speed range or speed reduction etc.)
— rejection when the vibration level may be critical as e.g. speed governor response, heating of rubber elements causing damping and stiffness to alter to further increase the vibration level, hard gear hammer, etc.

303 Acceptance criteria

Speed ranges or operating conditions where the following acceptance criteria are exceeded, shall be barred for continuous operation. Corresponding signboards shall be fitted at all manoeuvring stands and all tachometers marked with red. The tachometers shall be accurate within the tolerance \( \pm 0.01 n_0 \).
The width of a barred speed range shall be determined as follows:

— range where permissible values are exceeded
— extend with tachometer tolerance in both ends
— further extension in case of unstable engine operation at any end of the barred range.

**Guidance note:**
For 2-stroke fixed pitch plants the width of the barred speed range should not be made unnecessarily wide because this can result in a too slow passage with the consequence of higher vibratory stresses and more cycles.

---end---of---guidance---note---

**a) Dampers**
Depending on the type of damper (viscous, rubber, steel spring) the following shall be considered:

— dissipated power (all kinds)
— vibration torque (rubber type and some steel spring types)
— vibration angle (some steel spring types)

The limits specified in the respective type approvals apply.

**b) Crankshafts**
The permissible vibration torque (or shear stresses) and peak torque (only applicable to semi-built shafts) are determined in connection with the engine approval. Other criteria may also apply, such as acceleration at mass for cam drive branch or journal movements in bearings.

**c) Speed governor**
The vibration levels at the sensor location of flexibly coupled propulsion engines are not to exceed the value specified by the engine manufacturer. If no value is specified and approved, tests and measurements shall be made in order to verify that the governor response is insignificant.

**d) Couplings**
Torsional elastic couplings are limited with regard to:

— dissipated power
— vibration torque.

These limits are for continuous operation. Higher values may be accepted for a limited time of operation (see 302 j). This applies when twist amplitudes are monitored.

Other couplings and similar components such as membrane couplings, universal joints, link couplings, elements of composite materials, etc. are limited with regard to the approved vibration torque.

Tooth couplings are limited with regard to cyclic torque reversals. The negative torque is not to exceed 20% of $T_0$ unless especially approved.

**e) Gear transmissions**
The permissible vibration torque in gear transmissions is normally limited as:

1) In the full speed and load range (> 90% of rated speed and load) the vibration torque is not to exceed $(K_A - 1)T_0$ where $K_A$ is the application factor used in the gear transmission approval.

2) The vibration torque is limited to 35% of $T_0$ throughout the entire operation range.

3) Gear hammer (negative torque) is not permitted except in unloaded power take off branches where 10% of $T_0$ (referred to the subject shaft speed) is permitted and for short duration misfiring 15% is permitted. However, higher values may be considered, see Ch.4 Sec.2 B106.

**f) Shafts**
Design requirements with acceptance criteria for shafts are found in Ch.4 Sec.1.

For plants with gear transmissions, the shafts (inside as well as outside the gearbox or thruster) shall be designed for at least the same vibration level as the gearing. Unless significantly higher vibration are expected to occur somewhere in the shafting, documentation of the vibration levels in the shafts is not required.

For direct coupled plants the vibration level ($τ_v$) is not to exceed the values used for the shafting design with regard to continuous operation. Alternatively, the calculated vibration for continuous operation may be used for the shafting design.

**g) Shrink fits including propeller fitting**
Permissible vibration torque in shrink fit connections is only to be considered for direct coupled plants and when the peak torque in a barred speed range exceeds the peak torque at full load. The vibration torque is not to exceed the value used in the approval of the shrink fit connection.
h) Propellers
No specific limitations apply unless especially mentioned in connection with the propeller approval.
i) Generators, pumps, compressors etc.
The vibration level is not to exceed the limit given by the manufacturer.

G 400 Transient torsional vibration

401 Passing through a barred speed range

a) Documentation (note that this is not always required, see A601 b) of the vibration level and number of cycles when passing through a barred speed range may be:
   — direct calculation by means of numeric time integration
   — result of steady state calculations reduced by a factor based on experience from measurements.

b) Direct calculations for fixed pitch plants shall take into account the ship mass and resistance (fully loaded) as well as the foreseen fuel rack position.

c) When steady state vibration results are reduced according to experience, the measurements used to collect this experience shall be made under relevant conditions. This means e.g. full or high ship load, fully submerged propeller, resonance at approximately same λ value, similar engine and turbocharger characteristic, same fuel rack position, etc. All these parameters shall be documented as well as the corresponding steady state vibration calculations.

d) The result of a transient vibration documentation shall contain the peak vibration level and an approximation of the equivalent number of cycles. The acceptance criterion is the peak torque (or stress) and the corresponding equivalent number of cycles that shall be used for the shaft calculations.

e) The equivalent number of cycles is defined as the number that results in the same accumulated partial damage (Miner’s theory) as the real load spectrum. This equivalent number of cycles for passing up and down through the barred speed range shall be multiplied with the expected number of passages during the foreseen lifetime of the ship. A detailed method for evaluating the equivalent number of cycles and expected number of passages is presented in classification guideline DNVGL-CG-0038.

f) Where barred speed range is required, maximum time for passing shall be specified.

402 Starting operations

Note that the following is not always required, see also A601 b.

a) For plants that have a major critical resonance below idling speed and the damping of this critical resonance is dependant on the oil pressure supplying the dampers and couplings, the start up shall be delayed to give the standby oil pump time to fill up this damping element. This shall be included in the operating manual.

b) For plants that have a major critical resonance below idling speed and a low ratio of engine inertia to driven machinery inertia, the transient vibration torque shall be considered. This applies e.g. to diesel generator sets with highly elastic couplings and similar propulsion plants without clutch.

403 Clutching-in

Note that the following is not always required, see also A601 b.

a) The calculation (numeric simulation) of the system shall determine:
   — the peak torque in couplings and gears
   — the first decreasing torque amplitudes
   — the heat developed in the clutch
   — the flash power in the clutch.

b) The plant should be described as a lumped mass system, but may be essentially simplified as described in 302 e). The clutch parameters as the actuation pressure-time characteristics and if necessary also the changing coefficient of friction shall be used in the calculation.

c) The results are not to exceed the permissible peak torques and amplitudes in couplings and gears as well as the permissible heat (J) and flash power (W) in the clutch.

d) Torque measurements during the clutching-in may be required. This applies when calculations indicate peak torques or amplitudes near the approved limits.

404 Short circuit in PTO driven generators

Note that the following is not always required, see also A601 b.

a) A possible short circuit in a generator is not to be detrimental for the power transmitting elements such as couplings and gears.

   The purpose of the calculation shall determine the peak torques and amplitudes that occur before the safety system (circuit breaker) is in action. The duration to be considered is 1 s.
b) The plant can be described as a lumped mass system, but essentially simplified as described in 302 e). If the excitation torque (in the air gap between rotor and stator) is not specified, it can be assumed as:

\[
T = T_0 \left[ 10 e^{-t/0.4} \sin(\Omega t) - 5 e^{-t/0.4} \sin(2\Omega t) \right]
\]

\[\Omega = \text{the net frequency (50 or 60 Hz)}\]
\[t = \text{time in s.}\]

405 Acceptance criteria
In the following, limitations for transient vibration are given.

a) Torsionally elastic couplings
   Transient vibration as determined in 402 and 403 are not to exceed neither \( Tk_{\text{max}1} \) nor \( \Delta T_{k_{\text{max}2}} \).
   Transient vibration as determined in 404 are not to exceed \( Tk_{\text{max}2} \).
   Power loss need not be considered for transient operation.

b) Gear transmissions
   Transient vibration as determined in 402 are not to cause negative torques of more than 25% of \( T_0 \).
   Transient peak torques as determined in 403 are not to exceed \( T_0 \).
   Transient peak torques as determined in 404 are not to exceed the approved \( K_{AP} T_0 \) or 1.5 \( T_0 \).

c) Shafts
   For shafts that are designed on the basis of transient vibration, the torque amplitudes as well as number of equivalent cycles per passage are not to exceed the prerequisites for the shaft design.
   Extended documentation to be submitted for designs where it is likely to expect high cycle fatigue due to passing of barred speed range (see guidance note below).
   Guidance note:
   In this context high cycle fatigue is expected when high transient stress amplitudes are combined with a large number of cycles. Total number of cycles is dependent of cycles for each passing of barred speed range (BSR) and the vessel's operation profile. A large number of cycles are to be understood as above \( 10^5 \) cycles. Extended documentation should normally contain fatigue analysis supported by engine and propeller curves as found relevant. Classification guideline DNVGL-CG-0038 Calculation of shafts in marine applications can be used for fatigue analysis. DNVGL-CG-0038 calculates fatigue capacity based on Wöhler curve (S-N curve) and Miner sum.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

G 500 Axial vibration

501 Extent and method of calculation
Note that the following is not always required, see also A601 e.

a) For engines with elastic coupling, the axial vibration, calculations may be restricted to the engine itself. For direct-coupled engines, the whole plant shall be included.

b) As a minimum, the calculations shall include the natural frequencies and mode shapes of the relevant vibration modes. Coupled torsional and axial vibration may also be required.

c) If the lowest vibration mode (with the node in the thrust bearing) is of significance to the conclusion, the calculations shall be made with various thrust bearing stiffness in order to see the influence of an estimation error.

d) If major critical resonance occurs near or in the operational speed range and no damper is foreseen, forced axial vibration calculations and measurements (see 200) will be required.

502 Acceptance criteria

a) In crankshafts, the stresses due to axial vibration are not to exceed the values used in connection with the engine approval.

b) The amplitudes at the front end of the crankshaft shall be within the engine designer’s specified limit.

G 600 Engine vibration

601 Extent and method of calculation of resiliently mounted engines, see also F300.

a) Resiliently mounted engines shall be calculated with regard to natural frequencies for all six degrees of freedom. The influence of the shaft connections (elastic couplings) and piping shall be accounted for.

b) Calculation of forced responses may be required if excitation frequencies (whole operating speed range) and natural frequencies are closer than 20% for ships, and 30% for HS, LC and NSC, of the excitation frequency.

c) The response due to motions in sea way shall be considered, see Ch.1.
As a simplified approach, the dynamic response may be assumed as an addition of 20% for ships, and 30% for HS, LC and NSC, to the static response due to the various conditions as calculated in F303.

602 Acceptance criteria

a) The acceptance criteria for resilient mount deflections considering the combined static and dynamic responses, and are given in F304.
b) The acceptance criteria for engine connections such as couplings and piping are given in F301. If the gearbox also is resiliently mounted, the combined (relative) movements of engine and gearbox shall be considered for the coupling misalignment

H. Installation inspections

H 100 Application

101 The paragraphs in H apply to installation inspections of diesel engines including the engine fastening, shaft connections and all piping to the engine. The alignment of intermediate shafts and elastic couplings is specified in Ch.4 Sec.1.

102 Unless otherwise stated, a surveyor shall attend the inspections given in H.

H 200 Assembling of engines supplied in sections

201 Crosshead engines

a) The bedplate alignment shall be carried out under stable conditions. All welding in the engine room that may influence the alignment shall be finished. The temperatures shall be stable.
b) The crankshaft deflections shall be checked as per manufacturer’s specifications.
c) If required in the designer's quality specification, the piston, piston rod and crosshead alignment shall be recorded. These records shall be reviewed by the surveyor and compared with the corresponding workshop records. The results shall be within the designer’s tolerances.

202 All engines

Parts that have not been integral with the engine during the workshop testing, e.g. a torsional vibration damper, shall be checked versus approved drawings or type approval.

H 300 Alignment and foundation

301 Alignment of engine

a) The engine shall be aligned in relation to the aligned shafting and gearbox, respectively.
b) The thermal growth shall be considered in the shaft alignment and bedplate alignment procedure.
c) After tightening of the foundation bolts, the crankshaft deflections shall be checked. If any of the results differ from the previous readings by more than 20% of the permissible value, the bedplate (for crosshead engines) shall be re-checked for twist and straightness. The final results shall be within the designer's specification.

302 Rigid fastening of engines

a) For mounting on metallic chocks (see F202), the fitting shall be checked with feeler gauge and shall be better than 0.1 mm unless otherwise approved.
b) For mounting on epoxy resin, it shall be checked that:
   — the resin is type approved
   — the mixing, casting and curing is carried out as per maker’s instructions
   — the cleanliness of tank top and bedplate before casting is as per maker’s instructions
   — the area and height of resin are within approved dimensions
   — the resin is properly cured before bolt tightening.
c) Side and end stoppers and top stays (if applicable) shall be checked according to the arrangement drawing. See also F204 and F205.
d) The tightening of the holding down bolts shall be checked versus approved specification.
**H 400 Resiliently mounted engines**

**401 Resilient mounts**

a) The engine mounts shall be checked as follows:
   - mounts shall be type approved
   - load distribution between mounts of same type (approximately equal deflection)
   - distance to stoppers (or second level if dual characteristic mounts) as approved.

The distance or clearance to the stoppers shall be checked after some sink in of the rubber, e.g. one or two weeks after fully loaded. Some further sink in should also be considered.

**402 Engine connections**

a) The coupling alignment should be checked after the sink in of the rubber mounts. Alternatively, the adjustment may be made under the assumption of a sink in based on experienced values.

b) It shall be checked that all flexible pipes and hoses are:
   - type approved (for fuel and lubrication oil)
   - arranged so that in case of leakage no flammable fluid can get in contact with hot surfaces
   - arranged to allow for the maximum possible engine movements (i.e. reaching the stoppers) without restricting the engine movement. See guidance in Fig.1.

![Recommended arrangements of hoses and pipes](image)

**H 500 Fuel, lubrication and cooling systems**

**501** Every system such as fuel oil, hydraulic oil, lubrication oil and cooling systems that has been opened after the workshop testing or has been connected to other systems on board, shall be flushed in accordance with the manufacturer’s specification.

**502** Drip trays under fuel filters including drainage to tank to be checked.

**503** For piping containing flammable liquids, it shall be checked that pipe connections are adequately screened as required in F503.

---

**I. Shipboard testing**

**I 100 Application**

**101** The paragraphs in I apply to all shipboard testing of diesel engines including vibration that are influenced by the diesel engines.
Unless otherwise stated, DNV GL rules for classification: Ships Pt.4 Ch.3 Sec.1 [9] applies.

I 200 Dormant
Paragraph only kept to ensure numbering and references in the document.

I 300 Dormant
Paragraph only kept to ensure numbering and references in the document.

I 400 Dormant
Paragraph only kept to ensure numbering and references in the document.

I 500 Steady state torsional vibration

501 The engine is to be checked for stable running (steady fuel index) at both upper and lower borders of the barred speed range. Steady fuel index means an oscillation range less than 5% of the effective stroke (idle to full index) (IACS UR M51.4.5).

For controllable pitch propellers, this shall be tested with both zero and full pitch unless otherwise agreed.

502 Reduction gears and power take off gears shall be detected for gear hammer in misfiring condition in ranges specified in connection with the approval. Speed ranges where gear hammer occurs shall be barred for continuous operation. However, in power take off gears light gear hammer in unloaded condition is acceptable, see G303 e). For testing procedures, see 503.

503 Engines with elastic couplings shall be checked for stability of the speed governing system when provoked by misfiring. For selection of misfiring cylinder, see approved torsional vibration calculations.

Unless otherwise stated in the approved torsional vibration calculations, the following apply for each plant on board:

— for a single engine plant, the entire speed range with either full pitch or combination pitch shall be checked. This may be done by a slow sweep or stepwise speed increase
— for two engine plants, the same applies, but the misfiring of the engines shall be combined. This may be done by keeping the selected misfiring for engine one, and first select a cylinder at random for the second engine and afterwards select the adjacent cylinder
— for plants with more than two engines, special considerations apply
— diesel generator sets shall be checked at a minimum of 50% load and with another set operating in parallel.

Speed ranges where gear hammer occurs due to one misfiring cylinder shall be restricted for continuous operation in that operation mode.

Fuel rack oscillations peak to peak (with combined misfiring for twin engines) are not to exceed 10% of the effective stroke (idle to full). Somewhat higher oscillations may be accepted if acceptable torsional vibration can be substantiated by measurements.

I 600 Transient torsional vibration

601 Where a barred speed range (BSR) is required, passages through this BSR, both accelerating and decelerating, are to be demonstrated. The times taken are to be recorded and are to be equal to or below those times stipulated in the approved documentation. This also includes when passing through the BSR in reverse rotational direction, especially during the stopping test. This applies also for manual and automatic passing-through systems. The ship's draft and speed during all these demonstrations is to be recorded. In the case of a controllable pitch propeller, the pitch is also to be recorded (IACS UR M51.4.5).

602 Passing through a barred speed range shall be made in an optimum way. Normally this means as quickly as possible. If a specific procedure is given in the torsional vibration calculations, this shall be verified under the foreseen operational conditions.

603 When a barred speed range is required, signboards describing how to pass through shall be provided at all engine operating stands.

604 After the clutch characteristics (pressure - time) is checked, the clutching-in shall be checked at the minimum respectively the maximum permissible engine speed for clutching-in. The speed governing system shall respond with quickly damped oscillations.

I 700 Engine vibration

701 For resiliently mounted engines the engine movements shall be observed during the misfiring tests of the engine (torsional vibration), especially at full load. The engine is not to reach contact with the stoppers, see F304. None of the engine connections such as exhaust pipe compensators, cooling water bellows, lubrication oil pipes, etc. shall restrict the engine movements.
SECTION 2 GAS TURBINES

A. General

A 100 Application

101 This section applies to gas turbine arrangements serving the functions given by Ch.2 Sec.1 A201. This section provides technical requirements to the turbines and their installation, as well as procedural requirements relating to certification, documentation, testing at the manufacturer and testing on board. The requirements are aimed at manufacturers, builders (yards) and operators.

The rules in this section apply for Ships, High Speed, Light Craft and Naval Surface Craft. For Naval Surface Craft Pt.5 Ch.14 applies in addition to these rules.

102 Sub-sections B to E apply to the gas turbine. Sub-sections F to I apply to the gas turbine arrangement.

103 Requirements to gas turbines used for propulsion apply also to gas turbines driving generators in electric propulsion systems.

A 200 Definitions

201 Gas turbine: An internal combustion engine, consisting of upstream rotating compressors coupled to downstream turbines, and a combustion chamber in-between. The power turbine in multiple shaft configurations is also included.

202 Gas turbine arrangement: A gas turbine together with its enclosure and fixation arrangements, and systems externally to the gas turbine, e.g.:

— fire detection and extinguishing system
— ventilation system
— carbo blasting system
— anti-icing system
— compressor washing system.

203 Maximum continuous output rating: The maximum power level at which the engine has passed the engine type testing specified in B800.

204 Start-stop stress cycle: A mission cycle or an equivalent representation of engine usage. It includes starting the engine, accelerating to maximum rated power, decelerating, and stopping.

205 Time between overhaul (TBO): The period which the engine is expected to run prior to removal for overhaul, assuming normal recommended shipboard maintenance procedures have been followed, air quality specification has been met, limiting pressures, temperatures and power ratings have not been exceded and lubricating (when applicable) and fuel oils specified in the type approval certificate have been used. All essential parts that are normally not carried on board for regular on board maintenance shall have a lifetime exceeding the TBO.

206 OEM: means Original Equipment Manufacturer.

A 300 Certification

301 The gas turbine shall be certified as required by Table A1.

<table>
<thead>
<tr>
<th>Table A1 – Certification requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Object</strong></td>
</tr>
<tr>
<td>Gas turbine</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

302 Normally, gas turbines intended for propulsion, power generation or any major functions such as gas compression, water injection, etc, on DNV classed objects shall be type approved. This applies to engines of existing or modified designs, where documented service experience is available for the specific application, operating profile, and rating.

Novel, or new designs may receive a preliminary (time limited) design approval so as to allow initial operation. It is required that the manufacturer documents 2500 \(^{1}\) hours of in-service experience of one unit, without major \(^{2}\) faults or replacement of components before the type approval certificate will be issued. Exception is made for static non-essential parts and components such as filters and components external to the casing of the engine that can be replaced within 2 hours using typical on board parts. The in-service experience should be relevant for the application that type approval is applied for, with respect to working profile, and rating. It is
also a condition for type approval that the manufacturer has satisfied the following criteria:

a) The engine has been thoroughly tested during the development phase.

b) The engine test program has been designed to cover uncertainties in the design analysis.

1) 500 hours for yachts

2) In case of any dissension between DNV and other parties with respect to the definition of “major faults”, DNV has the final say.

303 Fig. 1 shows the type approval and certification processes for a gas turbine (first engine).

Note that novel or new designs may receive a “Provisional Acceptance of Gas Turbine” so as to allow initial operation. This acceptance is regarded as equivalent with the product certificate with respect to engine safety. The availability is however not yet fully documented. Hence the society only accepts a “Provisional Acceptance of Gas Turbine” for multi-engine installations. It will be a condition for the vessel’s classification certificate that the engines obtain gas turbine product certificates (by operating successfully in 2500 hours) within a defined time period.

It is the responsibility of the gas turbine manufacturer to inform the buyer of the above constraints. The vessel owner shall be informed through the contractual partner. In addition DNV will issue a Memo to Owner.

Engines that can document more than 2500 hours trouble-free operation on similar applications will receive a product certificate directly after the certification test.

Guidance note:

“Similar application” means an application with operation profile (cyclic loading) and environmental operation conditions comparable to (or more demanding than) the intended application(s) relevant for the type approval.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

Fig. 2 presents the certification process for subsequent type approved engines.

It is assumed that the following is in place:

— type approval certificate
— manufacturer survey arrangement (MSA) (see C100).

304 Where the rule requirements defined herein are not explicitly complied with, or documented, the Society will, upon request, evaluate alternative and or equivalent solutions in accordance with Pt. 1 Ch. 1 Sec. 1 B600 of the Rules for Classification of Ships.

Guidance note:

This implies e.g. that during the design assessment credit may be given for extensive relevant operational experience, approval by other recognised bodies such as CAA, FAA, etc.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---
Fig. 1  
Type approval and certification process for the first engine

Fig. 2  
Certification process for subsequent engines
A 400  Documentation requirements - manufacturer

401  The manufacturer is responsible for providing the documentation required by Table A2.

<table>
<thead>
<tr>
<th>Object</th>
<th>Documentation type</th>
<th>Additional description</th>
<th>Info</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas turbine general</td>
<td>C020 – Assembly or arrangement drawing</td>
<td></td>
<td>Fl, TA</td>
</tr>
<tr>
<td></td>
<td>Q010 – Quality manual</td>
<td>See C300.</td>
<td>Fl, TA</td>
</tr>
<tr>
<td></td>
<td>Z071 – Failure mode and effect analysis (FMEA)</td>
<td>See B321.</td>
<td>Fl, TA</td>
</tr>
<tr>
<td></td>
<td>Z100 – Specification</td>
<td>See A402.</td>
<td>AP, TA</td>
</tr>
<tr>
<td></td>
<td>Z100 – Specification Performance</td>
<td>see B320.</td>
<td>Fl, TA</td>
</tr>
<tr>
<td></td>
<td>Z120 – Test procedure at manufacturer</td>
<td></td>
<td>Fl, TA</td>
</tr>
<tr>
<td></td>
<td>Z160 – Operation manual</td>
<td></td>
<td>Fl, TA</td>
</tr>
<tr>
<td></td>
<td>Z180 – Maintenance manual</td>
<td>See B322.</td>
<td>Fl, TA</td>
</tr>
<tr>
<td></td>
<td>Z241 – Measurement report</td>
<td>Vibration measurements see B914 to B916 and D210.</td>
<td>Fl</td>
</tr>
<tr>
<td>Turbine and compressor casings</td>
<td>C030 – Detailed drawing</td>
<td></td>
<td>AP, TA</td>
</tr>
<tr>
<td></td>
<td>C040 – Design analysis</td>
<td>See B302.</td>
<td>AP, TA</td>
</tr>
<tr>
<td>Bearing housings</td>
<td>C020 – Assembly or arrangement drawing</td>
<td>For journal bearings, see B308.</td>
<td>Fl, TA</td>
</tr>
<tr>
<td>Turbine and compressor bladed disks</td>
<td>C030 – Detailed drawing</td>
<td></td>
<td>AP, TA</td>
</tr>
<tr>
<td></td>
<td>C040 – Design analysis</td>
<td>See B301.</td>
<td>AP, TA</td>
</tr>
<tr>
<td>Rotor shaft arrangement</td>
<td>C020 – Assembly or arrangement drawing</td>
<td>Including bearings and shaft.</td>
<td>Fl, TA</td>
</tr>
<tr>
<td></td>
<td>C030 – Detailed drawing</td>
<td>Tie rods, see B309.</td>
<td>AP, TA</td>
</tr>
<tr>
<td></td>
<td>C030 – Detailed drawing</td>
<td>Shaft, see B311.</td>
<td>AP, TA</td>
</tr>
<tr>
<td></td>
<td>C040 – Design analysis</td>
<td>See B309, B310 and B311.</td>
<td>AP, TA</td>
</tr>
<tr>
<td>Turbine seals</td>
<td>C020 – Assembly or arrangement drawing</td>
<td></td>
<td>Fl, TA</td>
</tr>
<tr>
<td>Compressor guide vanes</td>
<td>C020 – Assembly or arrangement drawing</td>
<td>See B303.</td>
<td>Fl, TA</td>
</tr>
<tr>
<td></td>
<td>S040 – Control diagram</td>
<td></td>
<td>Fl, TA</td>
</tr>
<tr>
<td>Bleed valves</td>
<td>C020 – Assembly or arrangement drawing</td>
<td>See B304.</td>
<td>Fl, TA</td>
</tr>
<tr>
<td></td>
<td>S040 – Control diagram</td>
<td></td>
<td>Fl, TA</td>
</tr>
<tr>
<td>Rotor radial bearings</td>
<td>C030 – Detailed drawing</td>
<td>See B305 and B306.</td>
<td>Fl, TA</td>
</tr>
<tr>
<td></td>
<td>C040 – Design analysis</td>
<td></td>
<td>Fl, TA</td>
</tr>
<tr>
<td>Rotor thrust bearings</td>
<td>C030 – Detailed drawing</td>
<td>See B307.</td>
<td>Fl, TA</td>
</tr>
<tr>
<td></td>
<td>C040 – Design analysis</td>
<td></td>
<td>Fl, TA</td>
</tr>
<tr>
<td>Combustion unit</td>
<td>C030 – Detailed drawing</td>
<td>Burner, flame tube and nozzles, see B312, B313 and B314.</td>
<td>AP, TA</td>
</tr>
<tr>
<td></td>
<td>C040 – Design analysis</td>
<td></td>
<td>Fl, TA</td>
</tr>
<tr>
<td>Starting system</td>
<td>C020 – Assembly or arrangement drawing</td>
<td>See B316.</td>
<td>AP, TA</td>
</tr>
<tr>
<td></td>
<td>Z100 – Specification</td>
<td></td>
<td>AP, TA</td>
</tr>
<tr>
<td>Lubrication oil system</td>
<td>S011 – Piping and instrumentation diagram (P&amp;ID)</td>
<td>See B317 and B318.</td>
<td>AP, TA</td>
</tr>
<tr>
<td>Fuel system</td>
<td>S011 – Piping and instrumentation diagram (P&amp;ID)</td>
<td>See B317 and B319.</td>
<td>Fl, TA</td>
</tr>
<tr>
<td></td>
<td>Z100 – Specification</td>
<td>Fuel, see B319.</td>
<td>AP, TA</td>
</tr>
<tr>
<td>Internal air cooling system</td>
<td>C020 – Assembly or arrangement drawing</td>
<td>See B315.</td>
<td>Fl, TA</td>
</tr>
<tr>
<td>Control and monitoring system</td>
<td>I200 – Control and monitoring system documentation</td>
<td>See E101 and E102.</td>
<td>AP, TA</td>
</tr>
<tr>
<td>Safety system</td>
<td>I200 – Control and monitoring system documentation</td>
<td>See E301.</td>
<td>AP, TA</td>
</tr>
</tbody>
</table>
402 Gas turbine specification

The specification shall provide an overview of turbine design and technical capabilities. It shall include key parameters as given in Table A3, and application constraints as given in Table A4.

Table A3 Key parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>IDLE</th>
<th>MCR ISO(^1)</th>
<th>MCR(^2)</th>
<th>PEAK(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time between overhaul (hrs / cycles or equivalent hours)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum continuous ratings (kW)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum air mass flow rate (kg/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature at all main sections of the gas turbine, see Fig. 3 (°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure at all main sections of the gas turbine, see Fig. 3 (bar)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas generator speed(s) (rpm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power turbine speed (rpm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAXIMUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum permissible rate of load increase and load decrease (kW/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum permissible rate of acceleration and deceleration (gas generator and power turbine) (r.p.m./s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) MCR at standard ISO 2314 ambient conditions, see B808

\(^2\) Maximum parameter value for continuous running independent of ambient conditions

\(^3\) If applicable, maximum parameter value for time limited peak or emergency operation for naval surface craft (independent of ambient conditions)

Table A4 Application constraints

<table>
<thead>
<tr>
<th>Subject</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max allowable list and trim</td>
<td>(degrees)</td>
</tr>
<tr>
<td>Max allowable pitch and roll</td>
<td>(degrees/s)</td>
</tr>
<tr>
<td>Max allowable shear force on output shaft</td>
<td>(N)</td>
</tr>
<tr>
<td>Max allowable axial force on output shaft</td>
<td>(N)</td>
</tr>
<tr>
<td>Max allowable bending moment at output shaft</td>
<td>(Nm)</td>
</tr>
<tr>
<td>Max allowable acceleration loads, see B102</td>
<td>(g)</td>
</tr>
<tr>
<td>Fuel type designation</td>
<td></td>
</tr>
<tr>
<td>Max allowable salt content in inlet air</td>
<td>(wppm)</td>
</tr>
</tbody>
</table>

A 500 Documentation requirements - builder

501 The builder is responsible for providing the documentation required by Table A5.

Table A5 – Documentation requirements – builder

<table>
<thead>
<tr>
<th>Object</th>
<th>Documentation type</th>
<th>Additional description</th>
<th>Info</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas turbine arrangement</td>
<td>C040 – Design analysis</td>
<td>Turbine and driven equipment: Lateral, torsional and turbine vibrations, see G.</td>
<td>AP</td>
</tr>
<tr>
<td></td>
<td>Z030 – Arrangement plan</td>
<td>Engine room with enclosure, ventilation system, gas turbine hook-ups and adjacent components.</td>
<td>AP</td>
</tr>
<tr>
<td></td>
<td>Z140 – Test procedure for quay and sea trial</td>
<td></td>
<td>AP</td>
</tr>
<tr>
<td></td>
<td>Z241 – Measurement report</td>
<td>Turbine and system (including ancillaries and piping) vibration levels, see B504, I203 and I302.</td>
<td>AP</td>
</tr>
<tr>
<td>Enclosure</td>
<td>C020 – Assembly or arrangement drawing</td>
<td>Including doors, pumps, valves, starting system and electric panels. Including material specification of enclosure.</td>
<td>AP</td>
</tr>
<tr>
<td>Object</td>
<td>Documentation type</td>
<td>Additional description</td>
<td>Info</td>
</tr>
<tr>
<td>--------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>------</td>
</tr>
</tbody>
</table>
| Fixation arrangement | C020 – Assembly or arrangement drawing | Including:  
  — bolts pre-tension  
  — foundation members stress  
  — supports and struts buckling  
  — foundation system natural frequency (upon request). | AP |
| | C040 – Design analysis | — foundation members stress  
  — supports and struts buckling  
  — foundation system natural frequency (upon request). | FI |
| | C030 – Detailed drawing | Resilient foundation. | AP |
| | C040 – Design analysis | Resilient foundation: Dynamic and static analysis. | FI |
| | C030 – Detailed drawing | Epoxy resin supports. | AP |
| | C040 – Design analysis | Epoxy resin supports: Surface pressure analysis. | FI |
| | C030 – Detailed drawing | Chocks. | AP |
| | C030 – Detailed drawing | Shims. | AP |
| | C030 – Detailed drawing | Cantilevered on reduction gear. | AP |
| Fire detection and extinguishing system | G130 – Cause and effect diagram | Including specification of measures to prevent personnel being exposed to fire extinguishing medium constituting a health hazard. | AP |
| | G200 – Fixed fire extinguishing system documentation | Including:  
  — specification of measures to prevent personnel being exposed to fire extinguishing medium constituting a health hazard  
  — fuel spray shields, applicable for turbines not fitted within an enclosure  
  — pipes, hoses, filters, valves and pumps in relation to potential ignition sources  
  — fire insulation type, method and arrangement  
  — fuel trays and handling of fuel and lubrication oil leaks  
  — fire detectors location and types. | AP |
| Z030 – Arrangement plan | Including ducting, fans, blowers and fire dampers. Including material specification of fire dampers. Upon request, air distribution. | AP |
| Ventilation system | Z030 – Arrangement plan | | |
| Carbo blasting system | Z100 – Specification | | |
| Anti-icing system | Z100 – Specification | Including:  
  — expected maximum mass flow, temperature, and pressure of hot gas, and location of source (when applicable)  
  — resulting power loss to the turbine, at maximum output to anti-icing  
  — heating system (when sources are other than the gas turbine)  
  — method of detecting ice formation at the filters  
  — instrumentation of the detection system. | AP |
| Z100 – Specification | | | |
| Compressor wash system | Z100 – Specification | | AP |
| Coupling | Z100 – Specification | Alignment. | AP |
| Inlet and exhaust ducting | Z030 – Arrangement plan | Including filtration systems, silencer systems and expansion bellows. | AP |
| Z100 – Specification | | | AP |
B. Design

B 100 General

101 For general design principles for machinery, see Pt.4 Ch.1 and Pt.4 Ch.2 Sec.3.

102 The design and construction shall enable the gas turbine to meet the general requirements in Pt.4 Ch.1, with regard to environmental conditions, functional capability and to reliability and availability.

The engine must be capable of withstanding environmentally induced acceleration loads during operations. The manufacturer shall provide a two-dimensional design envelope made up of what may be sustained during normal operation and what may be experienced occasionally (e.g., storm conditions). The engine must not suffer unreasonable distortion (or stress) if these loads are applied repeatedly. See also G300.

Guidance note:
Example of design envelope diagram:

---end---of---guidance---note---

103 The reliability and availability of new designed turbines shall be supported through a design analysis, complemented with results from development testing, as well as full scale testing.

104 Design calculations or test conditions shall be based on the maximum permissible loads, as well as load variations, e.g. frequent idle (or start) - full load – idle (or stop) sequences and permissible rates of engine load increase and decrease.

105 The engine loads to be considered are as follows:

— propulsion engines according to maximum continuous rated power
— other auxiliary purposes according to maximum continuous rated power unless otherwise specified.

If applicable, temporary peak loads shall be considered for naval surface craft.

The engines shall be limited to the specified maximum rating (working envelope approved by the Society) by blocking the controls. Override functions are not permitted without the written consent from the Society. Special considerations apply for naval surface craft.

106 Design approval of gas turbines consists of both design analysis and testing. For some components, a combination of testing and design calculations may be necessary, while either testing or calculations may document other components.

In general instrumented test runs shall support and calibrate analyses of high cycle fatigue, low cycle fatigue and creep. In special cases experience from similar designs might replace such tests.

Components subjected to high cycle fatigue shall be tested at all speeds in the operational speed interval with small separation steps ensuring more than $10^7$ cycles at a possible resonance condition.

For requirement for engine testing, see 400.

107 For components such as turbine disks, the maximum number of thermal cycles (full cycle, from cold start) shall be documented and correlated to the design calculations.

108 Previously approved engines with an upgraded or modified design or up-rated operational parameters can be granted approval with a reduced documentation scope, provided that the engine:

— has been thoroughly tested during the development phase or
— the test program has been extended to cover uncertainties in the design analysis or
the modifications are supported by analyses, and more than 2500 hrs of relevant operation without major faults can be documented.

However, the allowable modifications in such cases are limited as follows:

— 20ºC increase of maximum turbine inlet temperature
— 5% increase of mass flow
— 5% increase of r.p.m.
— minor changes to structural integrity components
— minor changes to operational profile.

The precise design assessment scope needed shall be agreed with the Society on a case by case basis.

109 For new and uprated engines the information from internal development testing, such as thermal paint results, shall be documented and available to be presented upon request from the Society.

110 Gas turbines shall have a TBO in excess of 2500 running hours. This should be substantiated through design and operating experience.

111 Material for pre-tensioned bolts should generally not be exposed to temperatures where creep is significant.

B 200 Structural components

201 See F200.

B 300 Component design requirements

301 Turbine and compressor bladed disks

The documentation of the bladed disk shall as a minimum contain the data required in this item. In addition drawings indicating main dimensions, materials and presence of coating shall be submitted.

Static strength evaluation

The bladed disk static strength documentation shall be based on low cycle fatigue (LCF) and creep. The loads to consider are centrifugal forces, aerodynamic pressure and thermal loads for steady state conditions and worst case transient conditions. Finite element analysis (FEM) or equivalent methods shall be used for the stress calculations. Fatigue diagrams shall be used in demonstrating life for LCF. For documentation of creep life, recognised methods, as e.g. Larson-Miller shall be used. The thermal analysis required for the evaluations should be documented and verified by running tests with thermocouple instrumentation and or thermal paint tests.

The conclusion of the analysis shall take into account the actual material specification (including test specimen scatter), and result in a margin of safety, at critical locations. This will form the basis for acceptance by the Society.

Analyses shall take into consideration geometric stress raisers e.g. blade neck, fir-tree blade, disk interface and typically disk stress raisers.

Blades fitted with interference shall document local pressure, and analyses shall include combined stress.

Thermally loaded areas shall take into consideration local “hot spots”; e.g. areas where boundary layers due to the rotating disk may form insulation against forced cooling air or the blocking of cooling air due to other reasons. In the case of blades with internal cooling passages, calculations shall include analysis at thinnest cross section, and thickest cross-section, and the consequence of loss of cooling medium (FMEA).

Normally only the following blades shall be documented as representative of the different stages as applicable:

— low pressure compressor, first stage and last stage
— high pressure compressor, first stage and last stage
— high pressure turbine, first stage
— low pressure turbine, first stage
— power turbine, first stage and last.

If the gas turbine is a single spool engine, middle compressor stage shall be added.

If rubbing of the blade tips can be expected during operation, the blades shall be designed so as to minimise the mechanical damage.

If the disk is film cooled, calculations shall take into account the effect of cooling failure resulting from both cooling film breakdown and loss of cooling air.

In cases where the disk is connected to the shaft with interference fit, documentation is required to substantiate the disk's capability to transmit the required torque. This documentation shall include the effect of centrifugal forces, the thermal loads, the effect of thermal expansion at the interface and interference tolerances.

Documentation of the strength of the disk is to include analysis to establish the disk blade retention capacity,
with special attention to the blade and root disk connections. The documentation shall also establish the disk blade retention capacity versus speed for all foreseeable overspeeds. The disk burst speed shall be documented, and shall be higher than that achievable while the unit is governed by the control system. Events potentially leading to extreme overspeed shall be shown through documentation to avoid disk rupture through fail-safe unit design. For example, in the event of a shaft or coupling failure, the resultant overspeed should be limited by mechanical braking, such as intermesh.

Dynamic strength evaluation
The bladed disk dynamic strength documentation shall be based on high cycle fatigue (HCF). When evaluating the HCF life of a bladed disc the dynamic loads shall be combined with the static loads in a total strength evaluation.

Blade vibration modes shall be documented. The excitation sources to be considered as a minimum are the following frequencies in the whole operating range: 1st, 2nd and 3rd order of rotating speed and 1st and 2nd order of nozzle passing frequency. The frequencies shall be presented in a Campbell diagram or equivalent for speeds from 0% to 110% full speed.

The blade – disc coupling influence on the blade natural modes shall be considered if applicable. When analysing the blade modes the nodal diameter of interest shall be considered. In case resonance is exited by any source within ±10% of the operating speed range, measurements and tests must document high cycle fatigue margin. See also 106.

In the case of shrouded blades the Campbell diagram shall show the frequencies above and below the lock-up speed of the blade, together with the blade lock-up speed.

302 Turbine and compressor casings
The casing design shall be supported by an analysis, covering the most severe conditions of temperature, transient temperature gradients and pressure during operation. Overall strength shall be documented combining following loads if applicable:

— tension
— bending moment
— shear
— torque.

Also buckling shall be considered if applicable.

The hoop-stress values seen in the design shall not exceed the allowable values as required by international standards such as ASME codes (Section VIII Division 1, the revision is that which coincides with the validity of these rules) or equivalent aerospace standards.

Bolted flange design
Bolt pre-load calculations shall be submitted for information, including thermal effects and fatigue considerations (Goodman diagram).

Containment and rotor failure
All sections of the casing exposed to rotating parts including power turbine casing, shall be capable of containing a projectile such as blades or parts thereof (minimum one blade for axial units, in the case of a radial units 1/3 disk disintegration) should be considered and not lead to fire initiation and failure in the mounting system.

Exceptions to these requirements can be given if the enclosure is designed for complete containment capability from the same rotor failure modes.

Containment calculations or other methods are required to document the containment requirements.

Inspection openings
The design shall have features that permit boroscope inspection or equivalent of the first stage in the compressor and the last stage in the power turbine.

The engine shall accommodate features that permit inspection of the combustors, and the compressor and turbine stages, such as holes for boroscope inspection. Inspection procedures shall be described in the operating instructions.

303 Compressor guide vanes
In the case where variable guide vanes are used, the mechanism of operation shall be documented, together with the maximum and minimum angles. The design of the mechanism shall not allow play to be introduced as a result of normal wear. Any single failure in the actuating control system shall not have detrimental effect on the compressor.

Calibration procedures for the mechanism shall be submitted for information.

A logic diagram for the control of the variable vanes to be submitted for information.
304 **Bleed valves**

The mechanism of operation shall be documented, together with the maximum and minimum openings. In case of variable bleed valves, calibration procedures for the mechanism shall be submitted for information. The variation of compressor mass flow as function of bleed valve opening shall be documented.

Any single failure in the actuating control system shall not have detrimental effect on the compressor.

305 **Rolling bearings**

The documentation shall cover:

— details of bearings, such as major dimensions, materials, grade of precession etc.
— lifetime calculations based on normal loads (forces and gyroscopic moments due to vessel movements, vibration load, mass load, thrust load, misalignment load, pre-loading, etc. as applicable)
— overload capability based on loss of a part, e.g. blade.

The following conditions shall be specified:

— maximum lubrication oil inlet temperature
— maximum lubrication oil outlet temperature
— minimum lubrication oil inlet pressure.

Blade-out loads shall be based on worst case blade loss, in terms of resulting unbalance in the applicable time interval where these forces will act (shutdown, step to idle).

Bearings are generally to be designed with the capability of withstanding forces resulting from any rotor failure modes as described in B302. In case of a shaft coupling separation and consequent overspeed, the bearings shall be capable of withstanding the increased unbalance forces (e.g. due to consequent blade loss). In this case the bearings only need to hold the rotor from complete destruction, bearings could themselves be damaged.

Upon request, this shall be substantiated through design documentation.

Upon request historical failure data for the bearings shall be submitted.

306 **Journal bearings**

The documentation shall cover:

— drawings showing bearing detail, such as bearing type, major dimensions, materials used etc.
— drawings shall be of sufficient details to locate the oil slits and holes
— specification of bearing load capacity, allowable temperature of bearing material, oil inlet temperature and oil inlet pressure
— speed dependent coefficients of stiffness and damping and their influence by design tolerances. Also crosscoupling effects are to be presented.

307 **Rotor thrust bearings**

Documentation shall be provided as given in 305 or 306. Irrespective of bearing type, thrust force calculations shall be submitted. The calculations shall, as a minimum, take into consideration the following items:

— aerodynamic loading and the influence by design tolerances
— allowable thrustload from driven equipment
— if two or more rotor thrust forces shall be carried by one thrust bearing, the thrust force used for calculations shall be the worst case vector sum of thrust forces
— potential unloaded conditions (skidding for rolling bearing elements) must be carefully evaluated (e.g., change of direction for thrust in the speed range). The design should take into consideration the combination of clearances, loads, oil viscosity and operation so as to minimise the risk of this occurring.

308 **Bearing housings for journal bearings**

The structure of the bearing housing and the casing shall be designed such that blade loss or other rotor damage (see 305) will not cause the bearing housing or casing to fracture in the actual time interval when exposed to these abnormal forces.

Bearing housing for pressure lubricated plain bearings shall be adequate to maintain the oil and foam mixture level below the shaft seals at all times.

Temperature rise in the bearings and bearing housing, together with lubrication oil inlet and outlet temperatures, shall be within manufacturer's specifications when operating under the most severe conditions of ambient temperature and load.

Bearings shall be equipped with replaceable labyrinth-type seals and deflectors where the shaft passes through the housing.

309 **Tie rods**

The drawings shall include material properties and heat treatment procedures where applicable.
The analyses shall cover calculation of tie rod strength for all applicable steady state and transient load cases.

### 310 Rotors

Power turbine rotor dynamics, is application dependent. Hence if the application is not standard, power turbine vibration analysis can not be included in the type approval, but must be evaluated on a case-by-case basis.

Documentation shall cover:

- a) Drawings indicating overall dimensions.
- b) Calculations of natural frequencies, including support structures.
- c) Maximum permissible residual unbalance.

Gas generator rotors and rotors of single shaft machines shall be able to operate safely from zero to 110% of turbine trip speed.

For vibration analyses requirements, see G202 and G203. G202 is applicable for all rotors, while G203 only applies for power turbine rotors.

Rotors shall be able to withstand instantaneous coupling shaft failure at full load. Rotor disk or shaft failure or separation as result of the ensuing overspeed is not acceptable. See also 301. Blade loss will be acceptable provided it can be proven that the blade or blades loss can be contained, see 302 for details.

### 311 Shafts

Documentation shall cover:

- a) main dimension, stress raisers and material specification
- b) When relevant, the drawings shall show where proximity probes are located. Surface finish shall be specified. The admissible run-out, electrical, and mechanical shall be documented. The admissible residual magnetism shall be stated.
- c) Shaft strength shall be documented through analyses taking into consideration stress raisers, such as notches, holes, etc., and shall include the effects due to interference fits. The documentation shall conclude with a margin of safety for normal running and abnormal conditions, such as shock-load conditions, where applicable.

### 312 Combustion unit

Documentation shall cover:

- a) main dimensions and material specifications
- b) drawings shall be sufficiently detailed to allow correlation with CFD (computational fluid dynamics) calculations or flow visualisation if needed.
- c) description and designation
- d) cooling method (film cooling, impingement cooling, etc.) calculations showing the combined stress (thermal, pressure, and external loads) at critical locations, taking into consideration stress raisers, shall be calculated. Cyclic thermal loads (including transient conditions) and cooling effects shall be taken into account. The results shall include expected combustor life.
- e) where thermal barriers are used, the locations shall be shown on the drawings. While life calculations shall take the thermal barrier into account, the impact of barrier loss on material temperature and combustor life shall be evaluated
- f) results from CFD calculations, upon request.
- g) results of thermal paint tests
- h) Maximum allowable temperature spread at outlet plane.

**Guidance note:**
The combustion process is assessed in order to evaluate thermal loads and aerodynamic effects on hot section components.

The uniformity of the combustor outlet plane temperature may be characterised in terms of the temperature traverse quality factor as defined below:

$$TTQ = \frac{T_{\max} - T_3}{T_3 - T_2}$$

- $T_{\max}$ = the maximum gas temperature in the outlet plane
- $T_3$ = the mean temperature in the outlet plane
- $T_2$ = the compressor exit temperature.
A typical combustor will have a temperature traverse quality in the order of 20%.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

i) Igniters shall normally not remain in the primary combustion zone during operation.

j) The design of combustor shall be such that the radial and circumferential gas temperature distribution will be acceptable during all normal and transient running conditions, such that the specified life of the components will be maintained. The design shall also ensure that normal wear of the burners (see 313), or variations in fuel and gas flow conditions due to normal wear of other components, will not lead to flame distortion having a negative impact on component life.

k) Provisions shall be made for inspection of the combustor system such that all important sections can easily be inspected, particularly the burner area and combustor outlet (gas collector, NGV's).

l) For requirements for evacuation of unintended accumulated fuel, see F802.

### 313 Burners

Documentation shall cover:

- main dimensions and material specifications.

Drawings shall include flow paths of fuel and air.

The maximum fuel delivery temperatures and pressures, together with the compressor air delivery temperature, shall be specified.

The maximum mass flow rate of the fuel and the expected airflow (fuel air ratio), upon request.

Burner lifetime shall be specified together with the nominal change-out intervals.

Fuel nozzles shall be removable without disassembly of the combustor system.

### 314 Turbine nozzles

Documentation shall cover:

- dimensional drawings and material properties
- pressure loads
- thermal loads
- stress due to expansion limitations
- cooling system*
- coatings.*

* Cooling hole patterns or coating composition are not required. The stages where cooled and coated nozzles are used shall be specified.

Life calculations for high pressure turbine nozzles shall consider the elements listed above and take into account the effects of both loss of coating and cooling (independently).

When brazing or other fixation methods are used to connect vanes to the outer and inner rings, they shall be complete, i.e. brazing shall not be intermittent, unless otherwise substantiated.

### 315 Internal air cooling system

Documentation shall cover:

- maximum and minimum flow rate of air required for cooling
- maximum and minimum temperature of air required for cooling
- maximum and minimum pressure of air required for cooling
- monitoring instrumentation for cooling air supply, if installed.

The design of the cooling air system shall be such that documentation and experience can prove that there will always be a required minimum air flow available at maximum temperature and minimum cooling air pressure. This shall also take normal air cooling system degradation into account, if relevant.

In cases where hot section design assessment indicates that reduction or loss of cooling air will reduce component life to a level jeopardising turbine safety, the Society will require monitoring of the cooling air supply. See Table E1.

### 316 Starting system

Documentation shall cover:

a) Electric starting system:

- starting torque required
- motor power and speed
- starting logic and set points
- disengaging speed.
b) Pneumatic start system:
   — pressure and volume of air required
   — redundancy in technical design and physical arrangement, of the air supply system
   — operation of the air supply valves (set points, relief etc.)
   — safety system in case of pressure build-up
   — starting logic and set points
   — disengaging speed (air turbine starter).

c) Hydraulic start system:
   — hydraulic pressure required for starting
   — safety system in case of pressure build-up
   — redundancy in technical design and physical arrangement of the hydraulic fluid supply system
   — starting logic and set points
   — disengaging speed.

Regarding requirements for starting air capacity, see Pt.4 Ch.6 Sec.5 I in the Rules for Classification of Ships or the Rules for Classification of HS, LC and NSC.

The start system shall have a dedicated logic protective system to ensure that failure to reach ignition speed shall not cause damage to the starting system.

In pressurised systems there shall be provision for safe relief of pressure in the event that the pressure goes above the design limit.

317 Turbine mounted piping

Included in the term piping is fuel piping, lubricating oil piping, hydraulic piping, instrument and control air piping, starting system piping, and other piping determined to be subject to these rules.

Piping shall be designed to withstand all expected vibration and environmental loads, including normal, engine induced, vibration loads.

Piping ancillaries such as pumps, coolers, filters and valves, that are integral parts of gas turbine piping system, does not need separate design approval.

Normally steel is required for piping (including ancillary housings) conveying flammable fluid. Exception can be given for flexible hoses, if Type Approved for the intended use.

Other materials (than steel) might be accepted for housings if it can be documented that a burned-through housing can not supply any flammable fluid to a fire, e.g. by gravity (when fuel supply is tripped). Means must also be provided to drain the housings when tripping the engine. See also F800.

Flexible hoses and pipe couplings shall be type approved, see Pt.4 Ch.6 in the Rules for Classification of Ships or the Rules for Classification of HS, LC and NSC.

318 Lubrication oil system

Documentation shall cover:
   — maximum and minimum pressure and temperature in the system, e.g. before bearings, relief valve setting, etc.
   — type of lubricating oil
   — approved list of lubricants
   — maximum permissible amount by volume of water in the oil
   — oil filtration requirement, according to NAS 1638 or ISO 4406 (or equivalent).

The system shall comply with the following:
   — the system shall include sufficient filtering, heat exchanger capacity, magnetic chip detectors located as necessary, and water separator arrangements (if necessary). Location of these components shall be indicated on the drawings listed above
   — any shutdown of the gas turbine, either due to a normal shutdown, shutdown due to turbine trip, or due to a blackout of the vessel, is not to result in damage to any turbine bearings.
   — in case the lubrication oil system is shared with other machinery components (e.g. gear or generator), the following must be complied with:
      — The system shall be designed to prevent transferring of contaminated oil between the components.
      — The oil specification shall be acceptable for all components in the system.

Normally, gas turbines with rolling element bearings shall have a separate lubrication oil system.

Heat balance calculations for the lubrication oil system shall be submitted upon request. The heat balance shall be considered at seawater cooler inlet temperature of 32°C, an ambient air temperature of 45°C or conditions specified by the specifications for the vessel or project, whichever is more demanding.
319  Fuel system

Documentation shall cover:

— Drawings of the gas turbine fuel system (see guidance note).

**Guidance note:**
Gas turbine fuel system is defined as gas turbine manufacturer’s scope of supply. Normally the border line is set at fuel booster pump inlet.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

Fuel systems shall comply with the following:

— fuel nozzles shall be replaceable without major adjustments for the fuel system
— the system shall be equipped with suitable means for draining the fuel manifold and fuel nozzles after shutdown (normal and emergency) of the engine fuel supply. The drainage must be sufficient to avoid coking of fuel.

**Guidance note:**
The requirements for a separate drainage systems may be waived if the engine design itself can be proven to hinder unwanted fuel accumulation.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

If biocides are needed, the type used shall be accepted by the engine manufacturer.
The manufacturer shall specify the different fuel qualities that the gas turbine is designed for.

When heavy fuels shall be used the manufacturers shall document the turbine’s ability to maintain serviceability at full power, without significant loss of component life. If special maintenance is required to reduce degradation of the turbine, the methods used to clean the turbine shall be submitted to the Society for information.

320  Performance

Documentation of the performance shall include:

a) Compressor characteristics including a documented surge margin for all running conditions and transients. Avoidance of choke to be documented or tested.

b) Overall gas turbine performance curves. These are normally to be based on the overall efficiency ($\eta$) and the quasidimensionless massflow group $m\sqrt{T_0}/p_0$ as function of the pressure ratio $p_{05}/p_{06}$. This shall be presented for various values of the quasidimensionless speed group $N/\sqrt{T_{05}}$, where 5 and 6 denote turbine inlet and outlet conditions (see Fig.3). Equivalent performance curves are also acceptable.

c) Performance characteristics including engine power and speed dependency on ambient temperature.

d) The normal performance or power loss as a function of running time. The turbine in this case is assumed to be running within design specification.

e) The expected recoverable performance of a used engine (after a complete overhaul).

The turbine shall be designed to permit rapid start from cold conditions, without working outside the performance envelope of the either the gas generator or power turbine.

The design shall take into consideration thermal gradients for all modes of operation including trips, and shall permit immediate restart (within control system constraints, e.g. thermal interlock) if operational conditions so require.

---Fig. 3---
Station numbering, basic cycle
321  Failure mode and effect analysis (FMEA)

The FMEA shall identify critical components and systems together with failure modes and consequences. The analysis shall, as a minimum, cover the following as applicable:

— gas path components
— bearings
— seals
— fuel system
— lubricating oil system
— turbine hot section cooling system (e.g. blade and disk cooling)
— turbine cooling and ventilation system (shell and casing)
— control system
— control system power supply
— instrumentation system (e.g. vibration, temperature, pressure)
— mechanical control system (e.g. variable guide vanes)
— anti-icing system*
— heat recovery system (only that portion in the exhaust gas path)*
— inlet air systems (e.g. filtration)*
— heat absorption system (cooling water for the lubrication oil system).*

* To be included in FMEA if defined as part of type approved system, only.

Coupling shaft failure and its consequences shall be identified and documented.

The analysis should be presented in a format that is clear, e.g. tabulated in the form of name components and system, type of expected failures, consequences, expected frequency of failure. See also E301.

322  Maintenance

Maintenance manuals shall cover:

— illustrated list of parts
— assembly and disassembly process with tools and procedures, such as clearances, pre-tightening procedures, torque limits etc.
— time between inspection, overhaul and change out of major components, e.g. blades, disks, nozzles, burners etc.
— methods used to identify the remaining lifetime on the component
— acceptance and rejection criteria of major components, e.g. maximum blade crack length, for acceptance without repair, with repair, and reject.

Overhaul is normally to be accomplished at the engine manufacturer's plant or at an OEM's approved plant. It shall include disassembly, examination, cleaning and repair of the gas turbine engine and accessories.

The turbine manufacturer shall provide a list of their approved overhaul depots for the respective gas turbine types.

B 400  Engine testing

401  The test procedures shall include acceptance criteria, and methods of evaluating parameters, such as, power.

402  General requirements for engine testing are covered in 500, 600 and 700. Type testing requirements are defined in 800 and 900, while requirements for certification testing and shipboard testing are covered in D200, D300 and I100 and I200, respectively.

B 500  General requirements for all engine tests

501  All measurements at the various ratings shall be made at steady operating conditions unless otherwise stated.

502  The following external particulars shall be recorded:

— ambient air temperature
— ambient air pressure
— relative humidity
— fuel designation or specification
— lubricating oil specification.

Lower heating value for liquid fuel normally to be supported by test of fuel actually used.

Lower heating value of gaseous fuel to be supported either by test or by calculations based on gas composition analysis of fuel actually used.

503  During testing the engine shall be checked for leakage of fuel or lubrication oils.
504 During testing all ancillaries and piping shall be visually inspected for vibrations.
505 The safety systems, to the extent they are integrated in the engine design, shall be tested.
506 Subject to pre-test approval by the Society, the precise details of test scope, arrangement and performance may be adjusted for engines with extensive relevant operational experience, or for engines where extensive amounts of relevant test data is already available.

B 600 Engine test data collection

601 The engine and system data given in Table B3 shall be measured and recorded. Subject to pre-test approval by the Society the parameter list may be adjusted to accommodate engine design issues and test facility limitations.

B 700 Power measurement

701 The following methods may be applied (in descending priority).

a) Torque measurements based on absorption dynamometers.

b) Torque determined through twist measurement (encoder) of a stiffness-calibrated shaft.

c) Torque determined through strain gauge measurements might be accepted for onboard testing. The expected errors shall be agreed with the Society.

d) Thermodynamic method may be used when it is not possible to use direct shaft torque measurements. That is, in the case that a gas generator is being tested alone. However, a new test will normally be required based on shaft torque when the power turbine is coupled to the gas generator.

This method can normally not be used alone during a type test for a unit consisting of both gas generator and power turbine, but may (based on proven accuracy) be used during a certification test for the gas generator.

B 800 Type testing, general

801 For definition of engines subject to type approval see A200.

802 Type testing serves the primary purpose of substantiating the engine design documentation. It is furthermore intended to validate that the engine will provide acceptable performance under the worst-case operational conditions of its intended service.

An approved type test is a pre-requisite for the engine to start accumulating the 2500 hours needed in operation for the type certificate to be issued, see A302 and Fig.1.

803 The complete type testing program is subject to approval. The tests shall be witnessed by a surveyor, however, the precise extent shall be agreed in each case.

<table>
<thead>
<tr>
<th>Table B3 Engine and system data acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>Power (thermodynamic)</td>
</tr>
<tr>
<td>Gas generator, and power turbine speed</td>
</tr>
<tr>
<td>Shaft torque at drive end (power turbine output)</td>
</tr>
<tr>
<td>Electrical power at drive end (generator set only)</td>
</tr>
<tr>
<td>Compressor inlet pressure and temperature</td>
</tr>
<tr>
<td>Compressor discharge pressure and temperature</td>
</tr>
<tr>
<td>Turbine inlet temperature</td>
</tr>
<tr>
<td>Gas generator exit pressure and temperature</td>
</tr>
<tr>
<td>Gas generator exit gas temperature spread</td>
</tr>
<tr>
<td>Power turbine exhaust pressure and temperature</td>
</tr>
<tr>
<td>Lubrication oil temperature and pressure</td>
</tr>
<tr>
<td>Fuel temperature and pressure, at the fuel inlet</td>
</tr>
<tr>
<td>Hydraulic fluid pressure</td>
</tr>
<tr>
<td>Coolant temperature and pressure</td>
</tr>
<tr>
<td>Temperature of external surfaces of the engine</td>
</tr>
<tr>
<td>Bearing metal temperatures</td>
</tr>
<tr>
<td>Intake pressure loss</td>
</tr>
</tbody>
</table>
Table B3 Engine and system data acquisition (Continued)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Type test</th>
<th>Certification test</th>
<th>Quay trial</th>
<th>Sea trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exhaust pressure loss</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Vibration levels</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Position of variable stator vanes, or bleed valve opening, as applicable</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1) To be corrected to standard reference conditions (ISO 2314). Note that both raw and corrected parameters shall be recorded.
2) If more spools are involved, their respective speed shall be recorded.
3) These values may be derived values from other measured points.
4) At locations specified by the manufacturer.
5) May be substituted by torque measurement at power turbine output.
6) Measurement not required, calculation acceptable.
7) Lubricating oil temperature measurement after bearing is also acceptable.

804 Type testing is normally valid for only one specific type of engine, and does not cover a range of design variations. The maximum speeds of the spools, firing temperature, turbine inlet temperature, exhaust temperatures, mass flow rate, etc. are fixed for a given type of turbine, and will be specified on the type approval certificate.

805 Type testing shall preferably be made with the type of fuel oil for which the engine is intended, or equivalent. If this is not possible then there shall be prior agreement with Society as to the fuel used for the test, and its consequences to the results of the test. For engines intended for running on heavy fuel oil, the test verification of the engine’s suitability for this may be postponed to the sea trial.

806 If no special turbine application considerations apply (such as e.g. fitness for purpose testing, significant application limitations, or extensive relevant operational experience), the type test program shall be arranged as outlined in 900. If special considerations apply, the test program will be agreed between the Society and the manufacturer on a case by case basis, but will be based on the elements in 900.

807 If a type tested engine that has proven reliability in service, is design approved for an increase of power by less than 5%, and does not require internal (manufacturer) design review, a new type test is normally not necessary. The percentage refers to increases since the last type testing, not to the last approved level. It is assumed that the original design calculation of the engine has taken into consideration the intended increase in power.

808 All test results shall be corrected to standard reference conditions as defined by ISO 2314. The type test shall be performed as close to standard reference conditions as possible in order to minimise correction errors. The method for correction of parameters could be as described by ISO2314, or an accepted manufacturer developed alternative.

The standard reference conditions are (ISO 2314):

- Temperature: 15°C
- Humidity: 60% relative
- Barometric pressure: 1.013 bar (760 mmHg).

809 Control settings of the gas turbine, such as alarm and shutdown shall be agreed upon with the Society. Set points that shall be used in the test that are inappropriate in relation to those used in normal running require written agreement.

810 Variation in control parameters (compressor discharge temperature, turbine inlet temperature, etc.) during data acquisition shall normally not exceed ±1% (or the manufacturer’s specification.). Shaft power shall not vary more than ±3% (or that agreed upon in the contract specification).

811 If during the test, the observed data is obviously inconsistent with expected data or out of specifications of the manufacturer, all possible effort shall be made to rectify the inconsistency during the testing. This shall be done in a mutually agreed upon manner between the manufacturer and the Society. Failure to reach an agreement shall result in a retest. Even if the inconsistency is rectified during the test, a re-test or test extension may be required by the Society.

812 When measured test parameters do not conform with design specification (e.g. high temperature spread), then formal changes in the design specification need to be documented before acceptance shall be given for the test. If not the test shall be considered as failed.

813 Test data shall be recorded only after steady state conditions have been reached by the gas turbine, for the specific test point. Steady state is achieved when all key control parameters of the gas turbine have reached a steady state for that specific test condition. Variation within expected limits under testing conditions are however permitted, see 810.
For gas turbines driving electric generators, the requirements in Ch.2 Sec.4 shall be verified by testing.

B 900 Type testing program

901 It is assumed that:

a) The investigations and measurements required for reliable engine operation have been carried out during internal tests, according to the manufacturer established and documented procedures.

b) As a final validation of a new gas turbine design, the gas turbine shall be tested at the limit of the intended operation, see guidance note.

The length of the validation testing must in each case be determined based on the extent of design changes from parent engine, but 100 hours will normally be considered as minimum. No major faults (as defined by DNV) shall occur during this test.

After the completion of the test, the gas turbine shall be dismantled for inspection. Test procedure and report to be submitted to DNV for information.

Guidance note:
Thermal stress cycles obtained by idle (or start) – full load – idle (or stop) sequences shall be run in a way that results in the most severe thermal stresses, i.e. normally with the maximum load change per time unit that is possible with the foreseen control system, or permitted in the operating manual. The maximum and minimum loads shall be kept for sufficient time to stabilise the temperatures of the relevant parts. The number of thermal stress cycles depends on the intended application of the engine (e.g. fast ferry = many cycles, generator drive = few cycles). In general, testing with many cycles is considered conservative for most applications.

The purpose of this test shall validate the design concept. Changes might be accepted after conducting this test, provided that they are properly qualified by other means.

c) Design assessment acceptance by the Society has been obtained for the engine in question based on documentation requested, and the Society has been informed about the nature and extent of investigations carried out during the pre-production stages.

Type approval of gas turbines involves the following type tests: start test, mechanical running test, and performance test. These tests shall be carried out in the presence of a surveyor, see 803. They may be conducted separately, or be integrated so as to combine items from the three tests into one.

The recorded test results shall be endorsed by the attending surveyor upon completion of the type test.

902 Before and after test, lube oil shall be sampled for testing of contamination of metallic wear particles. The result shall be in accordance with the specification of the manufacturer.

903 Functional tests and collection of operating values including test hours shall be documented. The relevant results shall be presented to attending surveyor during the type test.

904 Component inspections after completion of the test program shall be conducted or witnessed by attending surveyor, see 1000.

905 The engine designer shall compile results in a type test report, which shall be submitted for approval. If deviation from design specifications exists, this shall be agreed upon between the engine designer and the Society.

For emergency operating situation, the following tests may be performed:

— quick start
— override functions
— test run at emergency (or peak) rating (10 minutes).

906 Start test

Seven starts must be made, of which one start must be preceded by at least a two-hour engine shutdown. There must be at least one false engine start, pausing for the manufacturer's specified minimum fuel drainage time, before attempting a normal start. There must be at least three normal restarts with not longer than 15 minutes (unless otherwise stated) since engine emergency shutdown (see 908). All variations of pre-programmed start sequences shall be tested (e.g. quick start if applicable).

907 Starts done in the other type tests can be incorporated in the start test to reach the sum of seven, provided that time interval between consecutive restarts are according 906.

908 Engine emergency shutdown

The following emergency shut-downs shall be tested:

a) Hot shutdown, at full load (as soon as permitted by the manufacturer's instructions). Restart to be achieved before lockout and within 30 minutes.

b) Failure to ignite, resulting in aborted start sequence. This may need to be induced, and should be agreed
upon with the manufacturer prior to the test. Documented occurrences of this type of start may be used as verification of this test.

c) Flame out. This may need to be induced, and should be agreed upon with the manufacturer prior to the test. Documented occurrences of this type of shutdown may be used as verification of this test.

909 Testing of abnormal operation
Testing of operation at the limits of the protection system (set points for step to idle and shutdown) might be required unless documented occurrences can verify acceptable operation. Operation at the power turbine overspeed limit is one such test that is normally required.

910 Mechanical running test
It is not required that the test be conducted at full load condition. See 910 to 916.

911 Lubricating oil pressure and temperature shall be monitored and recorded during the test. The parameters shall be within the manufacturer's recommended values. The recommended values shall be stated in the operating instructions.

912 The lubricating oil filtration shall be as specified by the manufacturer.

913 The control and monitoring system used in the test shall be representative of the type approved control and monitoring system, to the extent related to the gas turbine (see E100). Deviations from the type approved control and monitoring system, and the reasons for the changes shall be presented to the Society's type approval centre in due time before testing.

914 The test shall document the lateral vibration behaviour in the range 0% to 100% of rated speed for all gas generator shafts. Vibration levels shall be recorded from zero to 100% of rated shaft speed, down to idle, and finally through coast down and stop.

If 100% speed can not be obtained due to ambient conditions, documented results from previous tests can substantiate the verification of upper speed range vibrations.

The measurements shall provide a reasonable match with analyses.

The Society may require additional measurements at certain specific speeds. In such cases, the readings shall be taken at steady state conditions.

915 The manufacturer shall provide the Society with the vibration acceptance criteria that shall be used during the test.

916 Broadband vibration measurements with frequency analyses presented by cascade plots shall be performed in addition to order tracking measurements.

917 The mechanical running test shall be considered complete if no damage occurs to the turbine, and tested functions and operating parameters are within specified limits and the vibration requirements are met. If, after the test, modifications to the design are considered necessary, a complete new test must be performed.

918 Performance test
See 918 to 921.

The performance test shall be carried out in a manner equivalent to standards recognised by the Society, e.g. ISO 2314 Gas turbines acceptance tests or ANSI and ASME PTC 22 Gas turbine power plant, performance test codes. In the case of conflict between the standards and these rules, these rules prevail.

A leak check shall be performed prior to all runs.

The engine shall be operated according to an estimated power/speed curve for the intended application (e.g. a waterjet curve for mechanical propulsion drive).

The data to be measured and recorded when testing the engine at the various load points, and shall include all major parameters for the engine operation (see also 600). The operating time per load point depends on the engine size (achievement of steady state condition) and on the time for collection of the operating values.

At least 4 load points shall be tested with approximately equal intervals (between 50% and 100% load).

The engine shall be tested for at least 4 hours at maximum load as limited by the control system. The load should not be limited by factors external to the gas turbine (e.g. test cell capacity).

For high speed, light craft and naval surface craft application, further testing may be required under certain circumstances, and will be mutually agreed upon between the Society and the manufacturer.

Engine and control system shall demonstrate trouble free running without load for a minimum of 20 minutes, before testing at load conditions.

919 The acceleration and deceleration test of the gas turbine according to the manufacturer internal procedure shall be witnessed by the Society. The parameters of the control system governing these sequences shall be in compliance with the approved sequences and time constants.
For dual fuel installations, the performance test shall be carried out using the least favourable fuel. Gas turbines intended for dual fuel service shall demonstrate the capability to change from one fuel to the other, e.g. liquid to gas, and vice versa, while at load specified in operating manual, without detrimental change in operational parameters.

Any deviations to the engine internals, e.g. blades, disks, combustors, bearings, etc. from that submitted to the Society during the design review, shall be presented to the Society's approval centre in due time before the actual test. The deviations shall be recorded in the test report. Additional testing and measurements may be required by the Society should there be significant changes to critical components e.g. blades, disks, combustors, bearings, etc.

**B 1000 Boroscope inspection and tear-down after testing**

Boroscope inspection shall be conducted following both type and certification test. Boroscope inspection may be required by the Society after sea trial.

In general no cracks or major wear shall be seen in rotating parts after testing of a new gas turbine. Minor cracks, indents or tear in uncritical stationary parts may be accepted based on documented acceptance criteria.

Boroscope inspection of the following parts shall be conducted to the extent allowed by engine design (e.g. boroscope ports placement):

- compressor (blades and nozzles)
- combustor
- fuel burners
- gas generator turbines (blades and nozzles)
- power turbine (blades and nozzles).

Proper instruments and necessary personnel shall be on site during the inspection.

Normally the boroscope inspection shall be taped or photographed, as documentation during the inspection. Documentation to be retained at the manufacturers, and made available to the Society upon request.

Further inspection up to and including tear-down of the turbine may be required by the attending surveyor, should there be cause to do so, such as damaged blades or nozzles, or any other parts mentioned in the boroscope inspection. Tear-down may also be required, should the turbine fail its test due to not meeting performance requirements, not meeting manufacturer’s specification, or if required by the surveyor.

A report summarising findings from inspection and tear-down shall be submitted for information.

**C. Inspection and testing**

**C 100 General**

The certification principles are described in Pt.4 Ch.2 Sec.2. The principles of manufacturing survey arrangement (MSA) are described in Pt.4 Ch.2 Sec.2 C100.

The manufacturer shall have in operation a certified quality system according to ISO 9000, or equivalent. Should the manufacturer not be in possession of a valid quality system certificate, an extended product audit covering the quality system elements which are in operation at the manufacturer's works shall be made. Based on this assessment a survey arrangement with the manufacturer may be established.

A manufacturing survey arrangement (MSA) shall be established specifying all details on component testing and inspection, including acceptance criteria.

**C 200 Certification of parts**

Engine parts, semi-finished products or materials shall be tested and certified according to the original engine manufacturer (OEM) requirements. This applies irrespective of the item being supplied by subcontractors or produced by the engine manufacturer.

**C 300 Production verification**

Production of power transmitting, heat exposed and pressurised components as given below, are as a minimum to be documented through the manufacturer's quality system:

- blades
- impellers
- disks
- shafts
- inter-stage coupling
— tie bolts
— combustors
— nozzles
— bearings
— gas generator casing
— power turbine casing
— gas generator rotor assembly
— power turbine rotor assembly
— Ancillaries such as pumps, electric motors, coolers, piping, valves etc. that are delivered as integral parts of the engine’s fuel oil, lubrication, hydraulic and pneumatic operation and cooling systems.

A minimum test requirement for lube oil, fuel and hydraulic systems is a pressure test to minimum 1.5 times the maximum working pressure of the system.

The manufacturer shall confirm the fulfilment of manufacturing quality requirements by a “certificate of conformity”.

302 A manufacturing survey arrangement (MSA) shall be established based on a product audit covering the following aspects:

— quality system documentation
— human resources
— equipment and facilities
— production methods and control routines
— purchasing and subcontracting
— production process control
— distribution and warehousing
— quality inspection and testing
— document control
— traceability
— non-conformity and corrective actions.

The audit shall ensure the capability to produce in accordance to the original engine manufacturer’s (OEM) specifications and common engineering standards in the gas turbine industry.

The following shall be available at the product audit:

— routing sheet or an instruction that dictates the step by step process by which the components shall be produced
— acceptance criteria for each step of the process.

All relevant documents concerning manufacturing, inspection and testing of the component in question shall be readily accessible.

DNV require traceability back to the material batch on each of the components listed in 301. The manufacturing of all components listed in 301 shall be audited prior to certifying the first engine.

Annual product audits shall be performed using spot checks to ensure that the basis for the MSA is maintained.

Within a four-year period, all components listed in 301 shall be evaluated through a product audit.

In case the manufacturer is certified by a recognised aviation authority, and the components are manufactured in accordance to the same quality system and procedures as components for aero gas turbines, DNV might reduce the involvement in the production phase.

D. Workshop testing

D 100 Application

101 This sub section covers procedures and requirements for certification testing of complete gas turbines. General considerations and requirements pertaining to certification testing are found in B400, B500, B600, B700 and B1000.

D 200 Certification testing

201 Each engine to be certified shall be tested in the factory, however see 206. The purpose of the factory testing shall verify the design premises such as performance, safety (against fire), adherence to maximum temperatures, speeds, pressures, functionality and product quality.

202 The gas turbine manufacturer shall prior to testing document that all instrumentation is calibrated.

203 For case by case approved engines the workshop testing may be extended up to the full type testing if found necessary by the Society.
204 The engine manufacturer shall compile all results in a test protocol that shall be endorsed by the attending surveyor and submitted to the Society for later reference.

205 Certification testing shall be performed on the complete gas turbine. In the case that the gas generator and the power turbine have been tested separately, the Society accepts that the certification testing of the complete gas turbine is performed on board (see I100 and I200).

206 The certification test shall include testing found necessary by the Society to demonstrate:

— starting, idling, acceleration, deceleration, stopping
— safe operating characteristics throughout its specified operating envelop.

The certification test shall simulate the conditions in which the engine is expected to operate in service, including typical start-stop cycles and load points, see D300 and D400.

The engine is normally to be run for at least 90 minutes at the maximum continuous power in service.

The certification test procedure shall be approved by the Society prior to testing.

207 Prior to the start of the certification test, the engine and the control and monitoring system shall demonstrate trouble free running at no load for 20 minutes.

208 Any deviation to the engine design and engine dressing from that of the type test shall be stated in the test report, together with the reason for the changes.

209 The control and monitoring systems used in the test shall be representative of the type approved control and monitoring system, to the extent related to the gas turbine. Deviations from the type approved control and monitoring system, and the reasons for the changes shall be presented to the Society's approval centre in due time before testing.

210 The certification test shall include vibration measurements. Broadband vibration measurements with frequency analyses presented by cascade plots shall be performed in addition to order tracking measurements. Vibration levels shall be recorded from zero to 100% of rated speed on all shafts (105% power turbine speed for generator drives), down to idle, and finally through coast down and stop. The steady state running time at maximum operating speed shall be at least one hour. The Society may require additional measurements at certain specific speeds. In such cases, the readings shall be taken at steady state conditions.

The manufacturer shall provide the Society with the vibration acceptance criteria that shall be used during the test.

211 Before and after test, lube oil shall be sampled for testing of contamination of metallic wear particles. The result shall be in accordance with the specification of the manufacturer.

D 300 Certification testing of propulsion engines

301 The testing described in 300 applies to certification of propulsion engines, and is additional to that required in 200.

302 In addition to the test profile defined in 207 the engine shall be tested at power levels to be agreed with the Society. The number of points should be sufficient to establish the speed – power relationship, and also be in accordance with the following (whichever is applicable):

a) The propeller curve based on the propeller law
   This applies if driving a fixed pitch propeller, water jet or controllable pitch propeller with variable r.p.m. and pitch limited to nominal value.

b) At constant speed
   This applies if driving a controllable pitch propeller with constant speed or an electric generator for propulsion.
   The operating time per load point depends on the engine size (achievement of steady state condition) and on the time for collection of the operating values. To be agreed prior to testing.

303 For plants with water jets that may experience air ingestion, the speed control system shall be checked with a sudden load shed from the maximum continuous power to 20%. The speed overshoot is not to trigger the overspeed protection function (no trip).

Guidance note:
The precise test details should take test facility capabilities into account. If the facilities are incapable of providing the load shed, alternative solutions may be agreed with the Society.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---
**D 400  Certification testing of engines for generating sets**

401 In addition to the tests described in 200, the requirements in Ch.2 Sec.4 shall be verified by testing incorporating the intended type of generator. If this cannot be done in the workshop, the test will be postponed to shipboard testing.

In case the tests were carried out in the type testing (see B814) with the intended type of generator, the test can be waived.

**D 500  Boroscope inspection**

501 Boroscope inspection shall be conducted following certification testing. See B1000 for particulars and requirements.

---

**E. Control and monitoring**

**E 100  Core engine controls**

101 Gas turbines shall be delivered with a type approved control and monitoring system, see Pt.4 Ch.9.

Control systems for gas turbines shall be certified in accordance with Pt.4 Ch.9 before being installed on board or being hooked up to the turbine.

In addition the following shall be submitted related to gas turbine approval:

- Schematics (e.g. logic flow charts), functional description and specifications to document requirements in E102 to E110.

The following shall be submitted upon request:

- transfer functions for control of turbine parameters
- results of open and closed loop simulation of turbine control parameters
- interface specification to control system superior to turbine control system.

102 The documentation of the control system shall as a minimum encompass the following:

- listing of all turbine control parameters such as vibration, temperature, speed, etc.
- alarms, step to idle and shutdowns (with set points as applicable)
- normal and abnormal stop and start sequence
- load control
- automatic purge cycle
- fuel control for normal running
- fuel control in abnormal shutdown
- other systems such as fire detection and prevention
- compressor surge control
- override functions (when applicable).

Which parameter that controls the maximum power depends on ambient conditions. The parameter that is in control to be presented in a diagram with ambient temperature on one axis and power on the other. The set point for the controlling parameter to be specified.

Minimum monitoring requirements are given in Table E1. Note that the table covers both core engine and gas turbine package with auxiliaries. Subject to consideration by the Society the parameter list may be adjusted to accommodate engine design issues. See also 201.
The control system shall be equipped with an uninterruptible power supply designed to function even under black-out conditions. Total loss of control system power shall lead to a controlled turbine shutdown.

Control systems shall be arranged so as to allow local control and operation of the gas turbine, irrespective of the state of the overall (e.g. vessel) control system.

### Table E1 Monitoring requirements

<table>
<thead>
<tr>
<th>Control parameter</th>
<th>Parameter value</th>
<th>Action 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clogged air intake filter, differential pressure</td>
<td>High</td>
<td>Alarm</td>
</tr>
<tr>
<td>Anti-icing system failure, pressure</td>
<td>Low</td>
<td>Alarm</td>
</tr>
<tr>
<td></td>
<td>Low-Low</td>
<td>Step to idle</td>
</tr>
<tr>
<td>Fuel service tank level</td>
<td>Low</td>
<td>Alarm</td>
</tr>
<tr>
<td></td>
<td>Low-Low</td>
<td>Step to idle</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Alarm</td>
</tr>
<tr>
<td>Lubricating oil, pressure</td>
<td>Low</td>
<td>Alarm</td>
</tr>
<tr>
<td></td>
<td>Low-Low</td>
<td>Alarm</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Shutdown</td>
</tr>
<tr>
<td>Lubricating oil, temperature</td>
<td>High</td>
<td>Alarm</td>
</tr>
<tr>
<td></td>
<td>High-High</td>
<td>Step to idle</td>
</tr>
<tr>
<td>Lubricating oil level</td>
<td>Low</td>
<td>Alarm</td>
</tr>
<tr>
<td>Clogged lubricating oil filter, differential pressure</td>
<td>High</td>
<td>Alarm</td>
</tr>
<tr>
<td>Fuel metering valve position out of synchronisation with command value. Displacement sensor</td>
<td>Deviation</td>
<td>Alarm 2)</td>
</tr>
<tr>
<td>Power turbine rotor overspeed</td>
<td>High</td>
<td>Alarm</td>
</tr>
<tr>
<td></td>
<td>High-High</td>
<td>Shutdown</td>
</tr>
<tr>
<td>Gas generator overspeed</td>
<td>High-High</td>
<td>Step to idle</td>
</tr>
<tr>
<td>Anti-surge system, if applicable</td>
<td>Indicated surge</td>
<td>Alarm</td>
</tr>
<tr>
<td>Flame out detection</td>
<td>Flame out</td>
<td>Shutdown</td>
</tr>
<tr>
<td>Vibration</td>
<td>High</td>
<td>Alarm</td>
</tr>
<tr>
<td></td>
<td>High-High</td>
<td>Shutdown</td>
</tr>
<tr>
<td>Inlet guide vanes, bleed valves, variable stator vanes actual position not in synchronisation with command value, as applicable</td>
<td>Alarm if anti surge system, otherwise step to idle</td>
<td></td>
</tr>
<tr>
<td>Power turbine inlet temperature</td>
<td>High</td>
<td>Alarm</td>
</tr>
<tr>
<td></td>
<td>High-High</td>
<td>Step to idle</td>
</tr>
<tr>
<td>Power turbine inlet temperature spread out of specification 3)</td>
<td>High</td>
<td>Alarm</td>
</tr>
<tr>
<td></td>
<td>High-High</td>
<td>See 3)</td>
</tr>
<tr>
<td>Bearing temperature (material or oil outlet)</td>
<td>High</td>
<td>Alarm</td>
</tr>
<tr>
<td></td>
<td>High-High</td>
<td>Step to idle</td>
</tr>
<tr>
<td>Thrust bearings temperature (material or oil outlet)</td>
<td>High</td>
<td>Alarm</td>
</tr>
<tr>
<td></td>
<td>High-High</td>
<td>Step to idle</td>
</tr>
<tr>
<td>Power loss of control and monitoring system</td>
<td>Shutdown</td>
<td></td>
</tr>
<tr>
<td>Loss of cooling air supply. 4)</td>
<td>Low</td>
<td>Alarm</td>
</tr>
<tr>
<td>Failure to ignite</td>
<td>Shutdown</td>
<td></td>
</tr>
<tr>
<td>Failure to reach idle speed</td>
<td>Shutdown</td>
<td></td>
</tr>
<tr>
<td>Compressor inlet pressure</td>
<td>Low</td>
<td>Step to idle</td>
</tr>
</tbody>
</table>

1) All “Step to Idle” to result in a “Shutdown” if the fault is still critical after a defined operation time at Idle. Provided it can be documented that safety is maintained “Step to Idle” might be replaced with

- “unloading to a safe power level”
- direct shutdown for auxiliary engines or multi engine propulsion application

2) Alarm might be replaced with shutdown for auxiliary engines or multi-engine propulsion applications

3) Normally, there shall be at least one temperature sensor per combustor and no less than six temperature sensors per engine. Action at Hi-Hi to be decided for each gas turbine type. Normally alarm or step to idle. Direct shutdown if the system can detect partial flameout.

4) If required, see B318.

**Note:** For requirement to monitoring of axial displacement and vibration, see F103. Proximity probes may be required to be fitted in gas turbine power turbine module or other locations along the driven high speed string.

---

103 The control system shall be equipped with an uninterruptible power supply designed to function even under black-out conditions. Total loss of control system power shall lead to a controlled turbine shutdown.

104 Control systems shall be arranged so as to allow local control and operation of the gas turbine, irrespective of the state of the overall (e.g. vessel) control system.
Starting sequence shall be discontinued and main fuel valve closed within a pre-determined time, when ignition has failed.

All gas turbine control systems shall implement purging as part of normal start up and start failure. The extent of purging required is subject to a case by case evaluation, but it should normally be of a duration sufficient to displace the exhaust system volume three times before attempting re-start.

Gas turbines for which standby duty must be expected, shall permit rapid starting.

Gas turbine control systems shall be provided with hardwired (or equivalently fast) overspeed protection preventing the turbine speed from exceeding the maximum permissible speed as defined by the manufacturer.

The fuel control system shall include shutoff valve, separate from the fuel control valve, that blocks all fuel flow to the turbine on any shutdown condition. The valve shall have means for local and remote tripping.

Gas turbines driving main or emergency electric generators, see Pt.4 Ch.2 Sec.4.

E 200 Monitoring and instrumentation system

For instrumentation and automation, including computer-based control and monitoring, reference is made to Pt.4 Ch.9. Additional monitoring and instrumentation system documentation shall be submitted for information as follows:

— documentation (e.g. P&ID’s and instrumentation lists) showing sensor ID, location, type, set-points and measuring limits. This shall as a minimum cover all parameters listed in Table E1
— instrument data sheets for core control and engine protective function sensors
— documentation on machinery protection hardware.

E 300 Safety system

Details of the manufacturers specified automatic safety devices, intended to safeguard against hazardous conditions arising in the event of malfunctions in the gas turbine installation, shall be submitted for approval together with the failure mode and effect analysis (FMEA), see B321.

E 400 Auxiliary system controls

The following turbine services shall be fitted with automatic temperature controls so as to maintain steady state conditions throughout the normal operating range of the main gas turbine:

— lubricating oil supply
— fuel oil supply (automatic control of oil fuel viscosity as alternative).

F. Arrangement

F 100 Alignment and reaction forces

Coupling alignment specification shall be submitted for approval. Thermal expansion and elastic deflections between gearbox and gas turbine shall be considered.

In case that the power turbine is fitted with a clearance adjustment by moving the power turbine axially, it shall be documented that the movements are within tolerances for any couplings.

Gas turbines shall be aligned so that the shear force, axial force and bending moment at the engine output shaft are within the specification for the engine.

For gas turbine drive train, the alignment shall be within the permissible values under all relevant operational conditions, see Table F1. It is assumed that there is always a flexible coupling between the gas turbine and any consumer.

For applications that may experience thrust load directional variations, an axial proximity probe for monitoring of vibration and position shall be fitted in the high speed driven string.

Operational and extreme loads as defined in Table F1 shall not cause the gas turbine to move permanently on its foundation.

F 200 Mounting in general

The loads given in Table F1 shall be considered in the design of the foundation system.

Preferably, the gas turbine casing shall not absorb deflections in vessel structure. This might however be accepted if it can be shown by calculations that casing deflections are within acceptable limits as specified by the gas turbine manufacturer.
The foundation system is normally to be designed with a minimum separation margin of 20% to dominant frequencies of the gas turbine and adjacent equipment. Calculations to be submitted.

### Table F1 Operational and extreme loads

<table>
<thead>
<tr>
<th>Operational loads</th>
<th>Extreme loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Mass. Maximum environmental conditions such as list and trim shall be</td>
<td>a) Forces derived from blade loss or, in the case of a centrifugal impeller,</td>
</tr>
<tr>
<td>considered for determination of mass reaction forces. (See Ch.1 of the Rules</td>
<td>parts from one blade root failure.</td>
</tr>
<tr>
<td>for Classification of Ships).</td>
<td>b) Any other extreme loads that may be relevant for the individual application,</td>
</tr>
<tr>
<td>b) Maximum operational acceleration loads.</td>
<td>e.g. for Naval Surface Craft see Pt.5 Ch.14.</td>
</tr>
<tr>
<td>c) Reaction forces due to engine torque (including short circuit torque in case</td>
<td></td>
</tr>
<tr>
<td>of electrical generators).</td>
<td></td>
</tr>
<tr>
<td>d) Forces transferred to foundation members due to deflection of ship structure.</td>
<td></td>
</tr>
<tr>
<td>e) Forces derived from thermal expansion of gas turbine or interfacing components.</td>
<td></td>
</tr>
<tr>
<td>f) Any other operational loads that may be significant for the individual</td>
<td></td>
</tr>
<tr>
<td>application, e.g. for Naval Surface Craft see Pt.5 Ch.14.</td>
<td></td>
</tr>
</tbody>
</table>

*Table F1 Operational and extreme loads*

<table>
<thead>
<tr>
<th>Operational loads</th>
<th>Extreme loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Gas turbine supports (struts) shall have documented a safety factor of minimum 2.5 against buckling.</td>
<td>a) Forces derived from blade loss or, in the case of a centrifugal impeller, parts from one blade root failure.</td>
</tr>
<tr>
<td>b) Stresses on foundation members shall be well below the fatigue curve for the material, and maximum deflections shall be within limitations set by the gas turbine and adjacent components (e.g. flexible coupling).</td>
<td>b) Any other extreme loads that may be relevant for the individual application, e.g. for Naval Surface Craft see Pt.5 Ch.14.</td>
</tr>
</tbody>
</table>

In case of extreme loads (right column), the foundation integrity shall be maintained.

**Guidance note:**

The foundation should be designed to take advantage of supports in the ship structure such as bulkheads and stiffeners.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

### F 300 Rigid mounting

**301** For mounting on epoxy resin, the surface pressure due to mass and bolt tension shall be within approved values for the applicable epoxy resin. Calculation of surface pressure due to peak loads can be required in special cases. The thickness of the epoxy resin shall be within the approved limitations. The epoxy resin shall be type approved.

**302** The pre-tension of the holding down bolts shall be specified with regard to tightening as well as the method. The friction forces shall be able to prevent dynamic movements in the base plate connection.

**303** Side and end stoppers are normally required. They are regarded as safety devices to prevent movement between engine and foundation caused by loosened bolts or excessive loads due to engine breakdown. End stoppers may be waived if fitted bolts or equivalent solutions are used.

### F 400 Resilient mounting

For dynamic analyses see G300.

**401** Resilient mounts to be type approved.

**402** All connections to the engine such as couplings, intake and exhaust ducts, fuel pipes lubricating oil pipes and electrical wires shall be designed for the maximum possible engine movements as limited by the elastic mounts.

**403** The resilient mounts shall be able to support the worst expected operational loads, see Table F1, without exceeding the approved specification.

**404** The static positions of the engine on the elastic mounts shall be calculated under consideration of the static loads listed in Table F1.

**405** Excessive movements due to extreme loads, see Table F1, shall be prevented by either dual characteristic mounts or by stoppers. The stoppers are not to be reached as a consequence of operational loads. For dual characteristic mounts the “second” level may be utilised provided that this is foreseen in the dynamic analysis.
F 500  Inlet and outlet passages

501  The air intake shall be arranged and located such that the risk of ingesting foreign objects is minimised.

   Guidance note:
   Depending on the arrangement, the Society may require that a grid be fitted on the air intake.

502  The air intake shall be arranged and located such that the risk of ingesting foreign objects is minimised.

503  Icing at air intake shall be prevented by suitable means.

504  When considered necessary, according to gas turbine makers’ requirements for inlet air quality, the air intake system shall incorporate an effective filtration system preventing harmful particles, including sea salt and harbour dust, from entering the compressor inlet. Pressure drop across filter to be monitored in accordance with Table E1.

   Guidance note:
   Maximum salt content entering the compressor is normally not to exceed 0.01 wppm

505  Air intakes shall be placed such that the ingestion of spray due to ship motion and weather is kept within acceptable limits. The air inlet ducts shall incorporate a system for drainage of water.

506  Air intakes and exhaust outlet shall be so arranged that re-ingestion of combustion gases are avoided.

507  The flow path of the inlet air shall be as straight and clean as possible, with a minimum of obstacles, sharp corners and duct curving. This shall minimise the creation of vortex flow, pressure drops and uneven air distribution in the compressor inlet. Inlet airflow analyses or model tests may be required in special cases.

508  Pressure losses in air intake and exhaust ducting are not to exceed the specifications of the gas turbine manufacturer.

509  Multi-engine installations are normally to have separate inlets and outlets for each gas turbine. Otherwise the inlets and outlets shall be arranged to ensure the following:

   — no induced circulation through a stopped engine
   — simultaneous operation of engines shall not harm the operation condition of any engine (e.g. due to intake underpressure, turbulence, etc.). CFD analyses or model tests will be required for common intakes.

510  In case of a heat exchanger mounted in the exhaust duct, it shall be ensured that the gas turbine back-pressure does not exceed the maximum value specified by the gas turbine manufacturer.

511  Welds in exhaust ducts are not to be located in areas with stress concentration such as corners and dimension changes.

F 600  Carbo blast system

601  The operation instruction of the carbo blast system shall ensure that the gas turbine’s hot section temperatures during blasting do not exceed maximum allowable operation temperatures. Risks for hot spots to be specially considered.

602  Back flow of hot gases into the carbo blast piping shall be prevented by suitable means.

603  Clogging of cooling passages must be avoided.

F 700  Gas turbine enclosure

701  An enclosure shall be fitted in case the insulation requirements in F802 are not fulfilled. The enclosure shall include a system for fire detection and automatic fire extinguishing (see F800). The design of the enclosure with ancillaries and control logic is the responsibility of OEM, or packager working to OEM specifications and interface requirements.

702  When an enclosure is fitted, the fans used for ventilation or cooling of the gas turbine shall have redundancy in technical design and physical arrangement. (2 times 100%). The electrical supply shall also be from two separate sources.

The distribution of ventilation air shall ensure that an acceptable temperature profile of the gas turbine is maintained, and that any combustible gas mixtures are evacuated.

No secondary damage shall occur due to overheating, in the case of emergency closing of the ventilation ducts.
703 Measures shall be taken to prevent health risk to personnel being exposed to release of fire extinguishing medium. Interlock on doors or equivalent barriers shall be provided to ensure that fire extinguishing medium hazardous to personnel is not released when personnel are inside the enclosure. Interlocks and similar safety precautions should not impair the effectiveness and reliability of the release functions. The enclosure tightness shall be such that any personnel staying in the engine room shall have sufficient time to evacuate if a fire extinguishing medium hazardous to personnel is released inside the enclosure.

**Guidance note:**
Carbon dioxide in excess of three percent by volume is considered hazardous to personnel.

---end-of-guidance-note---

704 In case personnel are allowed to enter the enclosure when the gas turbine is in operation, at least two exits should be arranged in the opposite ends of the enclosure, or in a manner providing easy escape routes from all relevant positions inside the enclosure.

Signboard to be displayed on all the enclosure doors to restrict or prohibit the entrance to the enclosure during operation.

F 800 Fire safety

801 These requirements are additional to the Rules for Classification of Ships Pt.4 Ch.10 and the Rules for Classification of HS, LC and NSC Pt.4 Ch.10.

802 Fire ignition shall be prevented through use of the following means:

— all surfaces that may reach a temperature of 220°C shall be insulated
— the insulation material shall be impervious to liquid fuel and vapour.
— flammable fluids shall be prevented from leaking onto hot surfaces (e.g. through insulation openings, joints and edges)

If it cannot be documented (normally by tests) that the above premises are fulfilled, an enclosure shall be fitted. For gas turbines not fitted inside an enclosure, fuel oil piping joints shall be screened or otherwise suitably protected to avoid fuel spray or leakage onto ignition sources in the machinery room.

Draining and venting must prevent unintended accumulation of flammable fluid and vapour in any hot sections of the engine. Automatic or interlocked means shall be provided for purging of liquid or gaseous fuel, before ignition commences or recommences after failure to start. In addition, the construction of the foundation structure should be such that drains and ventilation air are able to evacuate any accumulated flammable fluid or gaseous mixtures.

**Guidance note:**
Piping should be arranged so as to minimise the risk of fuel being gravity fed back into the turbine in case of fuel drain check valve failure. The requirement concerning draining and venting may be waived if the engine design itself can be proven to hinder unwanted fuel accumulation.

---end-of-guidance-note---

803 Fire detection

Gas turbines shall be provided with flame detectors in combination with either heat or smoke detector.

There shall be sufficient number of flame detectors, focusing on location that are prone to ignition, e.g. detector above the front end of turbine (cold end) looking at the fuel manifold and turbine hot section (2 detectors). One detector, viewing the turbine from below, pointing at the fuel metering valve and fuel lines. Fire detectors are required type approved. Type of detector and sensitivity shall reflect the expected ambient temperature and airflow under normal operation.

Alarm from two or more detectors shall be regarded as a confirmed fire.

804 A confirmed fire in an enclosure or the engine room shall initiate an alarm and automatically stop the fuel oil pumps (that are not engine driven) and quick closing valves as required in the Rules for Classification of Ships or the Rules for Classification of HS, LC and NSC Pt.4 Ch.6 Sec.5. Ventilation fans shall stop automatically upon confirmed fire. Where gas systems is provided for the automatic fire extinguishing systems, additional media should be provided to compensate for media lost until ventilation is stopped.

Dampers in any gas turbine enclosure shall be automatically closed upon confirmed fire. Dampers shall close in less than 15 s.

Supply and exhaust ducts for gas turbines may be accepted without dampers, provided their integrity is maintained throughout the spaces they penetrate. Supply ducts need not be fire insulated outside the machinery spaces, provided their integrity is maintained inside the machinery spaces.

805 An automatic fire extinguishing system shall be provided for any gas turbine enclosure. The system shall be designed based on a recognised standard e.g. “Rules for CO2 systems”, MSC/Circ. 848 (gas systems), IMO MSC/Circ.913 (water based systems) or MSC/Circ.668/728 (water based systems).
The system shall operate automatically upon a confirmed fire in the gas turbine enclosure and is additional to the main fire fighting system. Manual release should also be provided from a safe position outside the structural boundaries of the machinery room or a fire resistant enclosure.

The local fire extinguishing system for the enclosure is required in addition to the machinery space fire extinguishing system, which also must be designed to protect the enclosed space. However, other system designs that provide a backup for fire extinguishing inside the enclosure might be accepted.

Portable fire extinguishers, one 12 kg powder extinguisher or equivalent shall be positioned outside each entrance to the gas turbine enclosure.

Maximum two gas turbines are allowed to be fitted within a common enclosure. The following conditions prevail for a common enclosure:

- each gas turbine shall have a rating below 10 MW
- means shall be provided to prevent fuel spray from one gas turbine to hit the other
- in case of an emergency shutdown due to fire detection inside a common enclosure, redundant drivers shall maintain propulsion.

For enclosure requirements for ventilation and personnel safety, see F702.

G. System vibration

G 100 General

101 Vibration behaviour for gas turbines shall be evaluated on the following design levels:

- component, see B
- core engine, see B313/G
- system behaviour, see G.

The evaluation shall consist of a combination of analytical calculations and test measurements.

G 200 Documentation of vibration analysis

201 In vibration calculations the source of all essential data shall be listed. For data that cannot be given as constant parameters, the assumed parameter dependency and tolerance range shall be specified.

202 Lateral vibration calculations

The natural frequencies of the rotor-bearing-support system should not exist inside the normal speed range of the turbine from idle to trip speed, with a separation margin of 1.5%. If this should occur, calculations indicating that the response of the rotor will not exceed the manufacturers specified limits should be submitted for approval.

Bearing dynamic characteristics should take into account oil-film stiffness, damping and crosscoupling effects if applicable as a function of rotational speed, temperature, maximum to minimum clearances and shaft torque maximum to minimum values (Gear bearings). Calculations should specify rotor masses, rotor stiffness, bearing stiffness, cross coupled bearing stiffness, bearing damping, cross coupled bearing damping, bearing housing and base masses and stiffness. The calculation report should contain a summary of the total analysis.

As a minimum the analysis shall include plots of mode shapes for all natural modes of vibration which can be excited. If instability forces exist also stability margins shall be presented for the actual natural modes by for instance presentation of logarithmic decrements.

In the case that forced vibrations are required, the following applies.

Appropriate unbalance should be used in the analysis (commonly, maximum permissible residual unbalance). The unbalance should be located at shaft positions where the residual unbalance can occur (heavy disks).

Response plots indicating displacement should also show the locations of the couplings, bearings, and seals.

The minimum seal clearances should be noted on the plots.

Critical speeds preferably to be calculated by damped harmonic method or other methods to reveal the stability margins and to be verified by damped unbalance response analysis of the rotor. The response of critical speeds inside the operation range shall be confirmed by measurements. The excitation sources to be investigated by analytical methods as a minimum should be:

- unbalance in the rotor system
- oil film instabilities by input of bearing crosscoupling effects.

In addition the response to 2nd harmonic of synchronous speed should be evaluated.

203 Torsional vibration

a) Torsional resonance frequencies for the complete power turbine rotor train shall normally have a separation margin of 10% of any possible excitation frequency within the normal running range of the plant. If this
separation margin is not obtained, forced response calculations in conjunction with stress calculations are required to prove that failure of the shafting will not occur as a result of high cycle fatigue.

The excitation sources to be investigated by analytical methods should as a minimum be (if applicable):

- Synchronous (1. order) running frequencies for all applications
- Propeller pulses with respect to 1st and 2nd harmonics
- Waterjet pulses with respect to 1st harmonic

b) Impact torsional vibration calculations (if applicable):

- Clutching-in impacts, see Sec.1 A501 and G403.
- Load shed due to waterjet aeration.
- Short circuiting in generators (including short circuit torques 2-phase, 3 phase and misphasing if applicable), see Sec.1 G404.

For acceptance criteria, see Sec.1 G405.

G 300 Engine vibration

301 Extent and method of calculation of resiliently mounted engines, see also F400.

a) Resiliently mounted engines shall be calculated with respect to natural frequencies for all six degrees of freedom. The influence of the shaft connections (elastic couplings) and piping shall be accounted for.

b) Calculation of forced responses may be required if excitation frequencies (whole operating speed range) and natural frequencies are closer than 20% for ships and 30% for HSLC.

c) For HS, LC and NSC the response due to peak amplitude acceleration shall be calculated. All machinery shall be designed to operate under relevant acceleration due to heavy sea in vertical, transverse and longitudinal directions. Unless otherwise specified, the acceleration shall be considered as sine functions with peak amplitudes of 1g (vertical) and 0.5 g (transverse and longitudinal) and frequencies to be determined for the specific application.

Alternatively, a simplified approach may be used for ships:

Guidance note:
The dynamic response may be assumed as an addition of 20% to the static response due to the various conditions as calculated in F403

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

Special acceleration loads prevail for Naval Surface Craft. See Pt.5 Ch.14.

302 Acceptance criteria

a) The acceptance criteria for resilient mount deflections considering the combined static and dynamic responses are given in F403 and F405.

b) The acceptance criteria for engine connections such as couplings and piping are given in F402. If the gearbox also is resiliently mounted, the combined (relative) movements of engine and gearbox shall be considered for the coupling misalignment.

H. Installation inspections

H 100 Application

101 This sub section applies to the gas turbine installation with accessories.

102 In general the installation shall be in accordance with approved drawings and specifications fulfilling the requirements in F.

103 Unless otherwise stated, the surveyor shall supervise the conformity of the installation according to the requirements given in this sub section.

H 200 Assembly of gas turbines supplied in modules

201 The assembly of modules shall be done in accordance to the gas turbine manufacturer’s specification. In cases where the gas generator and the power turbine have not been tested together, the certification test (see D200, D300, and D400) shall be conducted on board.

H 300 Alignment and foundation

301 Alignment of engines

The engine shall be aligned in relation to the aligned shafting and gearbox, respectively. The approved shaft alignment specification shall be followed.
302 **Rigid fastening of engines**

a) The accuracy of the fit between chocks and mounting pad, respectively the base plate shall be better than
0.1 mm.

b) For mounting on epoxy resin, it must be verified that the resin is type approved. Mixing, casting and curing
shall be carried out in accordance with maker’s instructions.

303 **Resilient mounted engines and base frames**

a) The mounts shall be type approved.

b) When alignment is carried out, sink-in of the rubber should be accounted for in order to ensure the
following time-dependant items:

— approved distance or clearance to stoppers (or second level if dual characteristic mounts)
— that coupling alignment is within acceptable tolerances in the alignment specification.

Dependent on installation, allowed tolerances and experience with sink-in, the distances shall be verified
one or two weeks after fully loaded mounts.

c) All connections to the engine such as couplings, intake and exhaust ducts, fuel pipes lubricating oil pipes
and electrical wires shall be arranged to allow for the maximum possible engine movement as limited by
the elastic mounts. See Fig. 4.

![Fig. 4](image)

**Recommended arrangements of hoses and pipes**

H 400 **Inlet and outlet passages**

401 Bolts and nuts in the inlet ducting shall be properly secured, for example by welding. Weld slag to be
carefully removed from all welds in the inlet ducting.

402 It shall be verified that no leakage exist in exhaust ducting and flexible bellow. The vicinity of the
flexible bellow is not to include potentials for wear and chafe.

403 Welds in exhaust ducting shall be checked by relevant NDT method and be performed in accordance
with quality requirements in ISO 5817 or equivalent. The manufacturer’s acceptance criteria shall be fulfilled.

H 500 **On-engine ancillaries, including fuel and lubrication systems**

501 Use of flexible hoses in the fuel and lubrication system is only permitted where necessary in order to
allow for relative movements. Such flexible hoses shall be type approved, see Pt.4 Ch.6 Sec.7 D.

502 Every fluid system such as fuel oil, hydraulic oil, lubrication oil and cooling system that has been opened
after the workshop testing or has been connected to other systems on board, shall be flushed in accordance with
the manufacturer’s specification.

H 600 **Fire prevention**

601 Requirements for arrangement as defined in F800 shall be checked in situ.
602 In case of automatic release of a fire extinguishing medium hazardous to personnel inside the enclosure, leakage into the machinery room is not to endanger a safe escape of personnel. The enclosure shall be tested and inspected for deficiencies that may preclude satisfaction of this requirement.

H 700 Control and monitoring

701 All sensor signals to gas turbine control system and protection system to be verified loop checked and calibrated.

702 The control and monitoring instrumentation shall be installed in accordance with Pt.4 Ch.9 and checked accordingly.

I. Shipboard testing

I 100 General

101 The testing described in I applies to all gas turbines in addition to installation inspections as described in H. General considerations and requirements pertaining to the shipboard testing are found in B500, B600 and B700.

I 200 Quay trial

201 The quay trial procedure shall be approved by the Society prior to testing. The test purpose shall verify system integration, control system behaviour and the functioning of auxiliary systems.

202 The quay trial may be conducted at no-load or low-load condition.

203 Lubricating oil pressure and temperature shall be monitored and recorded during the test. The parameters shall be within the manufacturer's recommended values. The recommended values shall be stated in the operating instructions.

204 The lubricating oil filtration shall be as specified by the manufacturer. The filtration shall be verified through oil analysis and particle counting according to NAS 1638 or ISO 4406 or equivalent.

205 The quay trial shall be considered complete if no damage occurs to the turbine or associated auxiliaries, tested functions and operating parameters are within specified limits, and the manufacturer’s vibration requirements are met. If, after the test, modifications to the design are performed, a complete new quay trial must be performed.

I 300 Sea trial

301 The sea trial procedure shall be approved by the Society prior to testing.

The sea trial shall include testing found necessary by the Society to demonstrate:

— starting, idling, acceleration, deceleration, stopping
— safe operating characteristics throughout its specified operating envelope.

The sea trial must simulate the conditions in which the engine is expected to operate in service, including typical start-stop cycles.

As a minimum the engine is normally to be to be run for 4 hours at the maximum continuous power in service. For gas turbine installations incorporating back-up or emergency fuel supply and lubrication oil supply, the changeover of supplies shall be tested. Changeover of fuel supply shall be performed at full load.

There must be at least one false engine start, pausing for the manufacturer's specified minimum fuel drainage time, before attempting a normal start. Minimum time required for restart of engine shall be checked in order to verify that start can be achieved before thermal interlock occurs.

302 The sea trial shall include vibration measurements.

Broadband measurements with frequency analyses shall be performed and presented in cascade plots in addition to order tracking measurements. The recording shall be performed at a constant speed increase from zero to 100% of rated power turbine speed (105% for generator drives), down to idle, and finally through coast down and stop. The steady state running time at maximum operating speed shall be at least one hour.

When possible, vibration measurements shall be performed for all shafts in the entire permissible speed range. In special cases where the installation is of such character that the dynamic characteristic can be considered identical with the certification test set-up, only order tracking measurements will be required.

The manufacturer shall provide the Society with the vibration acceptance criteria that shall be used during the test.

303 The acceleration and deceleration of the gas turbine shall be witnessed by the Society. The parameters
of the control system governing these sequences shall be that of the sequences and time constants covered by
the type approval.

304  The temperature of hot surfaces shall be checked during full load testing, except when the engine is fitted
in an enclosure, see E401. Where surface temperatures exceed 220°C, remedial actions as described in E401
are required. It is advised to use thermographic analyses for documentation.

305  **Sea trial of mechanical drive propulsion engines**

In addition to the test profile defined in 301 the engine shall be tested at power levels agreed with the Society
prior to the sea trial. The number of points should be sufficient to establish the speed – power relationship.
Crash-stop conditions shall be tested from full speed ahead, this shall be performed in the fastest time permitted
by the controls of the gas turbine core engine.

306  **Sea trial of engines for generating sets**

Tests as necessary to verify requirements in Pt.4 Ch.2 Sec.4 shall be carried out if not performed during
certification test or type test together with the actual generator.

307  **Sea trials of engines for high speed, light craft and naval surface craft**

For high speed, light craft and naval surface craft, the test shall include full speed turn (shortest radius) in both
port and starboard directions. Vibration levels shall not increase significantly.

1400  **Boroscope inspection**

Boroscope inspection may be required by the Society after the sea trial. See B1000 for particulars and
requirements.
SECTION 3 STEAM TURBINES

A. General

A 100 Application

101 This section covers requirements applicable to steam turbines subject to certification, see Ch.2 Sec.1 and Sec.2, as well as turbine installation and shipboard testing.

102 The rules in B to E apply to the turbine, its components and its internal systems. The rules in F to I apply to the installation and the shipboard testing.

103 The steam turbine shall be delivered with a NV certificate that is based on the design approval in B, component certification in C and workshop testing in D.

A 200 Documentation

201 Drawings, data, specifications, calculations and other information shall be submitted as applicable according to Table A1 where:

A = for Approval
I = for Information
UR = Upon Request
NDT = Non-Destructive Testing.

For details about NDT specification, see Ch.2 Sec.3 A201.

202 For propulsion plants, torsional vibration calculations shall be submitted for approval. See Sec.1 A and G.

| Table A1 Documentation |
|-------------------------|-----------------|-----|-----------------|
| Item                    | Drawing | Material Specification | NDT | Miscellaneous/ Comments                     |
| General arrangement with internal arrangement | I | | |
| Longitudinal cross section showing rotors, bearings, seals and casings | I | | |
| Rotors                  | A | I | I |
| Coupling with bolts (see Ch.4 Sec.4) | A | A | |
| Typical blades and their fastening (for propulsion turbine) | I | I | I |
| Turbine casing including bolts | I | | I |
| Fastening of propulsion turbine | I | | I |
| Schematic steam flow (propulsion turbines) including all supply and exhaust points | I | | |
| Lubrication oil system | A | | |
| Control and monitoring system *) | A | | Including alarm set points and delay times |

Particulars shall be given as follows:
- maximum continuous rating MCR (kW and r.p.m.)
- maximum permissible over-speed (transient)
- inlet pressure and temperature at MCR (per turbine).
- maximum permissible rating (kW and rpm) for emergency operation with one turbine out of action (see also F206)

*) For requirements for documentation types, see Ch.9.

B. Design

B 100 General

101 For general design principles concerning machinery, see Ch.2 Sec.3. Special attention should be paid to Ch.2 Sec.3 A102. For general design requirements regarding piping and ancillary equipment, such as pipes, filters, coolers etc., see Ch.6 (Rules for Classification of Ships) and Ch.7, as found applicable.
B 200 Component design requirements

201 Rotors shall have a separation margin of normally at least 25% (of rated speed) between critical speed and operating speed range.

202 Turbines and condensers shall be able to withstand the temperature variations that can arise when starting, stopping and manoeuvring. The astern turbine shall be able to run for at least 30 minutes with steam according to design data without damage to the turbine or condenser.

203 The pipes of the gland-sealing system shall be self-draining, and precaution shall be taken against the possibility of condensed steam entering the glands and turbines. The steam supply to the gland sealing shall be fitted with an effective drain trap. In the air ejector re-circulating water system, the connection to the condenser shall be so located that water cannot impinge on the low pressure rotor or casing.

204 The casings shall be designed so as to provide containment in case of a blade loss. See Ch.2 Sec.3 A106. This requirement does not exempt the blade fastening from being designed so as to sustain any permissible over-speed.

205 All blades and other relevant moving parts shall have sufficiently large axial and radial clearances, so that no harmful interference with static members can occur under any operating condition.

C. Inspection and testing

C 100 General

101 The certification principles are described in Ch.2 Sec.2. The principles of manufacturing survey arrangement (MSA) are described in Ch.2 Sec.2 C100.

102 The manufacturer shall have a quality control system that is suitable for the type of turbine. This shall also cover subcontractors.

The extent of quality control that shall be documented to the Society by work (W) certificates, or to be inspected and certified by the Society (NV certificates) is given in the following.

If found necessary due to service experience, an extended scope of testing and inspection may be required.

103 Results from the testing and inspection shall be evaluated against the applicable NDT specifications as listed in Table A1.

104 The following documentation of material properties and NDT applies:

For propulsion turbines:

NV material certificate for:

— rotor
— individual discs
— couplings (see also Ch.4 Sec.4)

W certificate for:

— casing
— blades
— diaphragms
— steam valve casings.
— coupling bolts (test report).

For auxiliary turbines as above, but W certificates for all items except coupling bolts (test report).

NDT applies for items as listed in Table A1.

105 The control and monitoring systems for:

— steam turbines
— electronic engine management system

shall be certified according to Ch.9.

106 Hydraulic testing applies for both propulsion and auxiliary turbines as given in Table C1.

107 Devices for the attachment of heat insulation (bolts, hooks, etc.) shall be welded on to the turbine casing before the final heat treatment of the casing.
All rotors shall be dynamically balanced in minimum two planes.

### Table C1 Hydraulic testing

<table>
<thead>
<tr>
<th>Component</th>
<th>Test pressure</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.5 ( \times ) ( p )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 ( p )</td>
<td></td>
</tr>
<tr>
<td>Main flow valves</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>HP/LP crossover pipe</td>
<td>See Ch.6</td>
<td></td>
</tr>
<tr>
<td>Turbine casings</td>
<td>x</td>
<td>May be suitably subdivided. Not less than 2 bar</td>
</tr>
<tr>
<td></td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

1) \( p \) = working pressure.

#### D. Workshop testing

**D 100 General turbine tests**

101 The turbine shall be tested in the workshop and a complete test journal shall be given to the surveyor.

102 Turbines shall undergo running tests that cover the whole speed range up to 110% of rated speed. For propulsion turbines this applies to both ahead and astern operation.

103 Vibration levels shall be recorded in the whole speed range (up to 110%) at several speed settings.

104 The control and monitoring systems shall be tested according to Ch.9 Sec.1 as far as it has been arranged during the workshop testing.

105 Both before and after the test a lubricating oil sample shall be tested for traces of metallic particles, and a visual inspection of internal parts shall be carried out to the extent as requested by the surveyor.

106 For main propulsion turbines, the following inspection procedures apply after testing:

- Axial clearances in thrust bearing and clearances between blades and stationary parts shall be checked by sample testing after the test run. The measured clearances shall be compared with equivalent measurements made during assembly, and approved plans.
- The rotors shall be lifted. Bearings, blades, wires and shroud rings shall be examined, and it shall be verified that no damaging contact has taken place between rotating and stationary parts.

Scope of inspection of turbines for purposes other than main propulsion will be subject to special consideration. Opening up will normally only be required when any abnormalities are discovered during testing.

#### E. Control and monitoring

**E 100 General**

101 The requirements in E are additional to those given in Ch.9.

**E 200 Speed governing**

201 Turbines shall be equipped with speed governors. For propulsion turbines which incorporate a reversing gear, electric transmission, controllable pitch propeller or other free-coupling arrangement, the governor(s) shall be able to control the speed of any turbine that can become unloaded.

For auxiliary turbines driving generators, see Ch.2 Sec.4.

The speed governors shall be able to control the turbine speed so as to avoid any relevant load shed to activate the separate overspeed protective device.

202 In addition to the speed governor, a separate over-speed protection device shall be provided and shall be adjusted so as to avoid transient speed beyond 115% of rated speed or beyond the permissible transient speed, whichever is less.

Where two or more propulsion turbines are coupled to the same reduction gear, and without any free coupling device, only one over-speed protection device is required.

203 For propulsion turbines:

Automatic or semiautomatic control systems shall provide controlled load changes to avoid thermal shocks and other unacceptable transients.

**E 300 Safety functions and devices**

301 Arrangement shall be provided for shutting off the steam to the propulsion turbines by suitable hand trip gear situated at the manoeuvring stand and at the turbine itself. Hand tripping for auxiliary turbines shall be
arranged in the vicinity of the turbine over-speed protective device. (The hand trip gear is understood to be any device which is operated manually irrespective of the way the action is performed, i.e. mechanically or by means of external power).

302 Where exhaust steam from auxiliary systems is led to the propulsion turbine, the steam supply must be cut off at activation of the over-speed protective device.

303 To provide a warning to personnel in the vicinity of the exhaust end of steam turbines of excessive pressure, a sentinel valve or equivalent shall be provided at the exhaust end of all turbines. The valve discharge outlets shall be visible and suitably guarded if necessary. When, for auxiliary turbines, the inlet steam pressure exceeds the pressure for which the exhaust casing and associated piping up to exhaust valve are designed, means to relieve the excess pressure shall be provided.

304 Starting interlock shall be provided when turning gear is engaged.

E 400 Monitoring

401 For monitoring of propulsion steam turbines, see Table E1.

402 For monitoring of auxiliary steam turbines, see Table E2.

<table>
<thead>
<tr>
<th>Table E1 Control and monitoring of propulsion turbines</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>1.0 Lubricating oil</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>2.0 Bearings</strong></td>
</tr>
<tr>
<td><strong>3.0 Turbine speed</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>4.0 Condenser system</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>5.0 Cooling water</strong></td>
</tr>
<tr>
<td>(main condenser)</td>
</tr>
<tr>
<td><strong>6.0 Slow turning</strong></td>
</tr>
<tr>
<td>arrangement</td>
</tr>
<tr>
<td><strong>7.0 Gland steam</strong></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
**Table E1 Control and monitoring of propulsion turbines (Continued)**

<table>
<thead>
<tr>
<th>8.0 Hydraulic system</th>
<th>9.0 Vibration</th>
<th>10.0 Rotor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>Level</td>
<td>Axial displacement</td>
</tr>
<tr>
<td>IR, LA</td>
<td>HA</td>
<td>IR, HA</td>
</tr>
<tr>
<td>AS</td>
<td>SH</td>
<td>SH</td>
</tr>
</tbody>
</table>

Gr 1: Sensor(s) for indication, alarm, load reduction (common sensor permitted but with different set points and alarm shall be activated before any load reduction)

Gr 2: Sensor for automatic start of standby pump

Gr 3: Sensor for shut down

IL = Local indication – (presentation of values) in vicinity of the monitored component
IR = Remote indication – (presentation of values) in engine control room or another centralized control station such as the local platform/manoeuvring console
A = Alarm activated for logical value
LA = Alarm for low value
HA = Alarm for high value
AS = Automatic start of standby pump with corresponding alarm
LR = Load reduction, either manual or automatic, with corresponding alarm
SH = Shut down with corresponding alarm. May be manually (request for shut down) or automatically executed if not explicitly stated above.

For definitions of Load reduction (LR) and Shut down (SH), see Ch.1 of the Rules for Classification of Ships.

1) The shut down shall be so arranged as not to prevent admission of steam to the astern turbine for braking.

---

**Table E2 Control and monitoring of auxiliary turbines**

<table>
<thead>
<tr>
<th>System</th>
<th>Item</th>
<th>Gr 1 Indication</th>
<th>Gr 2 Automatic start of stand-by pump with alarm</th>
<th>Gr 3 Shut down with alarm</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 Lubricating oil</td>
<td>Inlet pressure (after filter)</td>
<td>IR or IL, LA</td>
<td></td>
<td>SH</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inlet temperature</td>
<td>IR or HA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Level in system tank</td>
<td>LA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0 Turbine speed</td>
<td>Overspeed</td>
<td></td>
<td>SH, if applicable, to be activated automatically, see 200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.0 Condenser system</td>
<td>Pressure</td>
<td>IR, HA</td>
<td>SH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.0 Steam inlet</td>
<td>Pressure</td>
<td>IL or IR, LA</td>
<td>SH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0 Rotor</td>
<td>Axial displacement</td>
<td>IR, HA</td>
<td>SH</td>
<td>When driving electric generator</td>
<td></td>
</tr>
</tbody>
</table>

Gr 1: Sensor(s) for indication, alarm, load reduction (common sensor permitted but with different set points and alarm shall be activated before any load reduction)

Gr 2: Sensor for automatic start of standby pump

Gr 3: Sensor for shut down

IL = Local indication – (presentation of values) in vicinity of the monitored component
IR = Remote indication – (presentation of values) in engine control room or another centralized control station such as the local platform/manoeuvring console
A = Alarm activated for logical value
LA = Alarm for low value
HA = Alarm for high value
AS = Automatic start of standby pump with corresponding alarm
LR = Load reduction, either manual or automatic, with corresponding alarm
SH = Shut down with corresponding alarm. May be manually (request for shut down) or automatically executed if not explicitly stated above.

For definitions of Load reduction (LR) and Shut down (SH), see Ch.1 of the Rules for Classification of Ships.

1) Only for turbines driving generators, may be omitted if LA for boiler steam pressure is provided.
F. Arrangement

F 100 General arrangement

101 The turbine exterior and the immediate environment shall be such as to prevent conceivable hazardous situations from occurring.
All exterior surface temperature shall be less than 220°C.

102 Non-return valves, or other approved means that will prevent steam and water returning to the turbines, shall be fitted in bled steam connections.

103 The fastening of the turbine shall be designed so as to cope with all forces due to thermal expansion, including inlet and outlet piping.

F 200 Arrangement of propulsion machinery

201 The turbine installation shall allow for efficient changeover between ahead and astern running. The manoeuvring system is not to cause any harmful effects.

202 Any probable single failure in any of the turbines is for an extended period of time not to result in loss of manoeuvrability, see 206.

203 Provision for turning continuously shall be arranged.

204 Efficient steam strainers shall be provided close to the inlets to ahead and astern high pressure turbines or alternatively at the inlets to manoeuvring valves.

205 Propulsion turbines shall be provided with a satisfactory emergency supply of lubricating oil that will come into use automatically when the pressure drops below a predetermined value. The emergency supply may be obtained from a gravity tank containing sufficient oil to maintain adequate lubrication until the turbine is brought to rest or by equivalent means. If emergency pumps are used these shall be arranged so that their operation is not affected by failure of the power supply. Suitable arrangement for cooling the bearings after stopping may also be required.

206 In single screw ships fitted with cross compound steam turbines, the arrangement shall be such as to enable safe navigation (minimum 40% of full speed along the theoretical propeller curve) when the steam supply to any one of the turbines is required to be isolated. For this emergency purpose the steam may be led directly to the L.P. turbine, and either the H.P. or M.P. turbine can exhaust directly to the condenser. Adequate arrangements and controls shall be provided for these operating conditions so that the pressure and temperature of the steam will not exceed those that the turbine and condenser can withstand safely.

Necessary pipes and valves for these arrangements shall be readily available and properly marked.
A fit up test is required, see H102.

Guidance note:
With reference to Ch.2 Sec.3 A106 these possible operation modes need not be tested during sea trial.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

The permissible power/speeds when operating without one of the turbines (all combinations) shall be specified and information provided on board.
The operation of the turbines under emergency conditions shall be assessed for the potential influence on shaft alignment and gear teeth loading conditions.

G. Vibrations

G 100 Torsional vibrations

101 For propulsion plants torsional vibrations calculations comprising the whole plant shall be submitted for approval.
The calculations shall contain determination of natural frequencies and corresponding critical speeds. Regarding assumptions on propeller excitation, see Sec.1 G302 h).
Speed ranges where gear hammer may occur, shall be barred for continuous operation. See Sec.1 G303 e).
H. Installation inspections

H 100 General

101 Alignment between turbine and gearbox shall be checked in the presence of the surveyor.

102 Proper functioning of safety functions and devices (see E300 and F200) is as far as practicable to be checked prior to the sea trial. A fit up test of all combinations of pipes and valves as required in F206 shall be performed prior to the first sea trials.

I. Shipboard testing

I 100 General

101 The turbines shall be tested according to an agreed programme. Upon completion of the sea trial, the complete test journal shall be given to the surveyor.

102 The control, safety and monitoring systems shall be tested according to E and Ch.9 Sec.1.

103 Turbine vibration levels shall be measured at the same positions as in D103. The results shall be compared, and in case of acceptance dispute, frequency analysed in order to eliminate turbine alien frequencies.

104 Oil filters shall be examined for metal particles after the sea trial.

105 The temperature of hot surfaces shall be checked during full load testing. Where surface temperatures exceed 220°C insulation of non-absorbent material covered by sheet metal shall be fitted. It is advised to use thermographic analyses for documentation.

I 200 Auxiliary turbines

201 Turbine generator sets shall be tested so as to verify that requirements in Ch.2 Sec.4 are met.

I 300 Propulsion turbines

301 The minimum full load test duration is 4 hours ahead and 20 minutes astern.

302 Gears shall be checked for possible gear hammering. See Ch.4 Sec.2 I200.
CHANGES – HISTORIC

Note that historic changes older than the editions shown below have not been included. Older historic changes (if any) may be retrieved through http://www.dnvgl.com.

January 2009 edition

Amendments January 2013

- **Sec.2 Gas turbines**
  - Adapted standardised formulation of certification and documentation requirements. The section is totally rearranged and some topics have been renamed.

Amendments July 2011

- **General**
  - The restricted use legal clause found in Pt.1 Ch.1 Sec.5 has been added also on the front page.

Amendments January 2011

- **Sec.1 Diesel Engines**
  - Table A2: The reference to Ch.1 has been updated.
  - Item B1001: The reference to Ch.1 has been updated.
  - Item B1202: The reference to Ch.1 has been updated.
  - Item C201: The Guidance Note has been deleted.
  - Item E202: The reference to Ch.1 has been updated.
  - Table E1: The reference to Ch.1 has been updated.
  - Table E2: The reference to Ch.1 has been updated.
  - Table E3: The reference to Ch.1 has been updated.
  - Item F301: The reference to Ch.1 has been updated.
  - Item G601: The reference to Ch.1 has been updated.

- **Sec.2 Gas Turbines**
  - Item B101: The reference to Ch.1 has been updated.
  - Item B328: The reference to Ch.1 has been deleted.
  - Table F1: The reference to Ch.1 has been updated.

- **Sec.3 Steam Turbines**
  - Table E1 and E2: The reference to Ch.1 has been updated.

Main changes coming into force 1 July 2009

- **Sec.1 Diesel Engines**
  - Monitoring of turbocharger lubrication oil outlet temperature has been brought in line with revised IACS UR M35 and the reported practices of other IACS members.
  - Inconsistency and redundancies in the rule text concerning the design of turbochargers have been removed.
  - Alignment with/inciporporating IACS UR M66 for “testing of crankcase safety valves” have been introduced.
  - Other editorial improvements and corrections of printing errors have been made.