RULES FOR CLASSIFICATION OF

Ships / High Speed, Light Craft and Naval Surface Craft

PART 4 CHAPTER 3

NEWBUILDINGS
MACHINERY AND SYSTEMS – MAIN CLASS

Rotating Machinery, Drivers

JANUARY 2009

This chapter has been amended since the main revision (January 2009), most recently in July 2011.
See "Changes" on page 3.

DET NORSKE VERITAS AS

FOREWORD

DET NORSKE VERITAS (DNV) is an autonomous and independent foundation with the objectives of safeguarding life, property and the environment, at sea and onshore. DNV undertakes classification, certification, and other verification and consultancy services relating to quality of ships, offshore units and installations, and onshore industries worldwide, and carries out research in relation to these functions.

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.

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Computer Typesetting (Adobe Frame Maker) by Det Norske Veritas

CHANGES

General

The present edition of the rules includes additions and amendments approved by the Executive Committee as of December 2008, and supersedes the July 2007 edition of the same chapter, including later amendments.

The rule changes come into force as indicated below.

This chapter is valid until superseded by a revised chapter.

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/incorporating IACS UR M66 for “testing of crankcase safety valves” have been introduced.
— Other editorial improvements and corrections of printing errors have been made.

Corrections and Clarifications

In addition to the above stated rule requirements, a number of corrections and clarifications have been made in the existing rule text.

CONTENTS

SECTION 1
DIESEL ENGINES

A. General

A 100 Application

101 This section covers requirements applicable to diesel, petrol, gas and dual fuel engines subject to approval, see Ch.2 Sec.1, as well as the engine installation and shipboard testing. However, for diesel engines with power less than 200 kW, the requirements of this section are limited to:

— jacketing of high-pressure fuel oil lines and screening of pipe connections in piping containing flammable liquids, see B700 and B1100
— insulation of hot surfaces, see B1100
— requirements for type testing as given in B1507
— requirements for workshop testing as given in D107
— requirements for monitoring of emergency generators (if applicable), see E700.

Installations intended for running on crude oil or gas, additional requirements are given in Pt.6 Ch.13 of the Rules for Classification of Ships.

102 The rules in B to E apply to the diesel engine, its components and its internal systems. The rules in F to I apply to the installation of the engine, the engine and its system dynamics (which is influenced by the engine), and the shipboard testing.

103 The diesel engine shall be delivered with a NV certificate that is based on the applicable elements of design approval in B, testing and inspection in C and the workshop testing in D.

For engines with rated power less than 200 kW, NV certificate need only be based on the applicable elements of design approval in B and workshop testing in D, see 101. The request for NV certificate may be waived, subject to conditions given in Ch.2 Sec.2 A 102.

104 Fig.1 shows the certification process for a diesel engine where the manufacturer is a licensee or producer of own design.

A licensee can apply for type approval or case by case approval when a design assessment has been issued and a type test has been carried out. This principle also applies for turbochargers and torsional vibration dampers produced under licence.

A licensee does not have to carry out a new type test for engines, turbochargers and dampers produced under licence when the licensor has already carried out a type test.

105 Engines driving generators in diesel electric propulsion systems are defined as propulsion engines.

A 200 Documentation of the engine

201 Drawings, data, specifications, calculations and other information shall be submitted as applicable according to Table A1 (except for items covered by a type approval) where:

A = for Approval
TA = Type Approval
I = for Information (these drawings need not be detailed)
UR = Upon Request
NDT = Non-Destructive Testing.

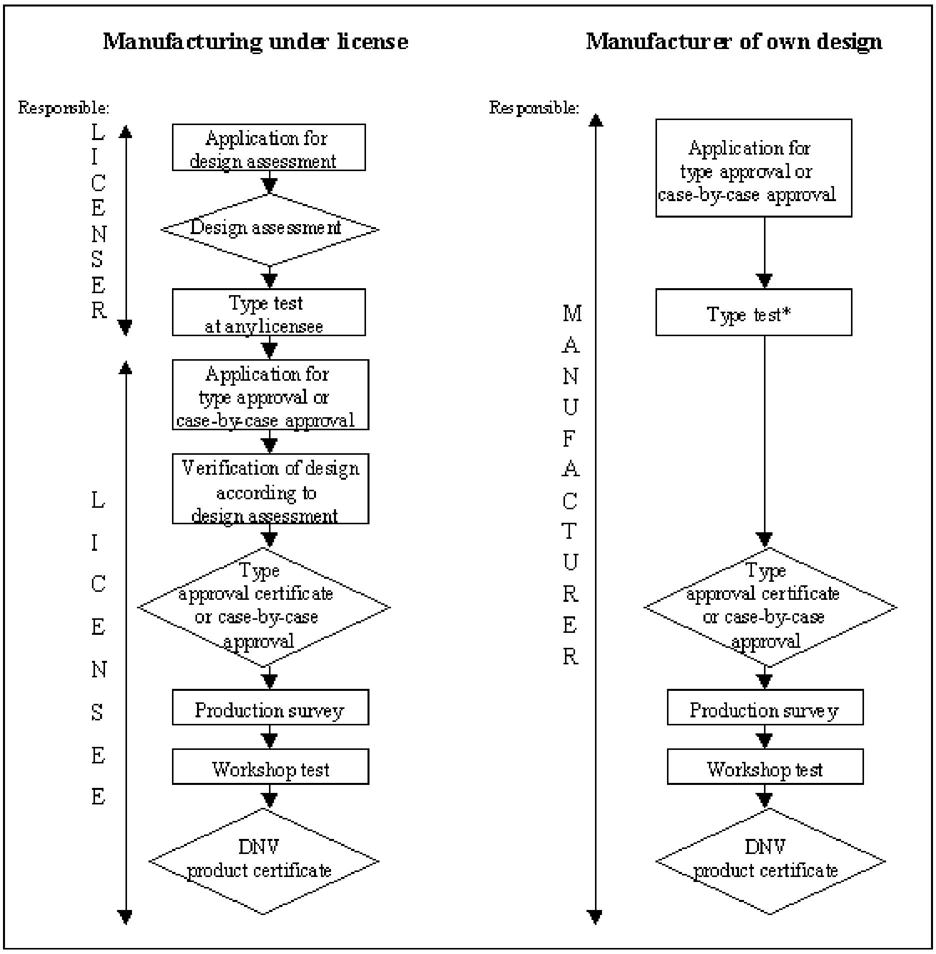
For details concerning NDT specifications, see Ch.2 Sec.3 A201.

UR is used for example when service experiences from similar designs indicate that a more thorough design review may be necessary.

202 The drawings shall have clear references to the applicable material specification. See also Ch.2 Sec.3 A200. When calculations are required, these shall substantiate the requirements given in B.

203 For components of welded construction and for repair welding, full details of joints shall be given and relevant welding procedure specifications shall be referred to on the drawings. In addition, the following shall be specified:

— filler metal particulars
— heat treatment after welding
— NDT with acceptance levels (preferably ISO 5817 for internal defects).



*) The type test may be postponed to the workshop test for case-by-case approvals

Fig. 1
Flow chart showing the certification process for diesel engines

Table A1 Documentation

Component	*Drawings*	*Material specification*	*Calculations*	*Miscellaneous for approval (A) or information (I)*	*Reference to design requirements*
Engine transverse section	I				
Engine longitudinal section	I				
Bedplate, framebox and cylinder frame of welded construction	A	A	UR	— Welding procedure specification (A), see 203 — Alignment specification (I) — NDT specification (A)	See B200
Main and crankpin bearings 4)	I	I			
Thrust bearing and structure 1)	A	A		— See 401 — Welding procedure specification (A), see 203	
Tie rod 4)	I	I			
Crankcase safety valve arrangement	A		A	See 301	See B300
Cylinder head assembly drawing 4)	I				
Cylinder head mounting assembly 4)	I				
Cylinder head bolts 4)	I	I			
Cylinder liner 4)	I	I			
Piston assembly drawing 4)	I				
Piston rod	I	I			
Crosshead assembly drawing, including guides	I			Alignment specification (I)	
Connecting rod, cast	A	A		NDT specification (I), see 304	See B507

Table A1 Documentation (Continued)

Component	*Drawings*	*Material specification*	*Calculations*	*Miscellaneous for approval (A) or information (I)*	*Reference to design requirements*
Connecting rod, forged 4)	I	I			
Connecting rod bolts 4)	A	A	UR	see 302	See B400
Crankshaft	A	A	UR	— NDT specification 4) (I) — allowable deflections (I) — alignment specification (I), see 303	See B502 to B506
Crankshaft bolts	A	A	UR	see 302	See B400 and B506
Counterweights including fastening 4)	I	I (of bolts if applicable)			
Thrust shaft	A	A			
Torsional vibration damper	A	A			See B1400
Axial vibration damper	I			see 309	
Camshaft drive assembly 4)	I				
Camshaft assembly drawing 4)	I				
High pressure parts for fuel oil injection system, including pipe couplings	A	I		see 306	See B700
Schematics of fuel oil system 3)	A			see 306	See B700
Shielding of fuel pipes	A				See B700
Schematic of hydraulic system for valve lift	A			Shielding, see 305	See B600
Turbocharger 5)	TA 6)	TA 6)	I	See 308	See B1200
Auxiliary blower arrangement	A				See B1300
Exhaust pipes, insulation	I				See B1100
Schematics of starting air system 3)	A			See 307	See B900
Schematics of charge air system 3)	A				See B800
Schematics of lubrication oil system 3)	A				See B1000
Schematics of cooling water system 3)	I				
Control and monitoring system including lists of alarms and shutdowns with set-points and delay times	A			See 310	See B300 and E
Electronic engine management system	A2)				See 311, 605 and E
Maintenance and operation manual 4)	I			Including maintenance schedule for the complete engine	
Type test program and type test report	A				B1500 - B1800
Documentation of arrangement	A			See 500	
Documentation of vibration	A			See 600	

1) Applicable when the engine thrust bearing is the main thrust bearing for the complete shafting system (taking propeller thrust).
2) To be approved, see also Ch.9 Sec.5.
3) Integrated in engine design.
4) Apply to engines with cylinder diameter > 150 mm.
5) Not applicable to turbochargers serving cylinder groups with combined power ≤1 000 kW
6) The turbocharger shall be type approved, either as a separate component or as an integral part of the diesel engine
7) For requirements concerning documentation, see Ch.9.

Particulars shall be submitted on the DNV form Diesel Engine Data Sheet No. 72.10a. Information is required as listed in Table A2.

Table A2 Engine particulars
Item
Maximum continuous output rating (kW and r.p.m.)
Intermittent overload rating (kW and r.p.m.), as specified by the manufacturer
Permissible rate of load increase and load decrease.Upon request, only applicable to HS, LC and NSC
Mean indicated pressure at maximum continuous output
Mean indicated pressure at overload rating
Maximum cylinder pressure at maximum continuous rating
Maximum cylinder pressure at intermittent overload rating
Valve timing angles
Compression pressure and charge air pressure at maximum continuous rating
Compression pressure and charge air pressure at intermittent overload rating
Cylinder diameter
Stroke
Number and arrangement of cylinders
Firing order or firing angles
Compression ratio
Mass of reciprocating parts per cylinder
Mass of rotating parts of the connecting rod referred to the crank radius
Unbalanced mass of one crank referred to crank radius (counterweights excluded)
Mass and angular position of each counterweight referred to crank radius
Data for calculation of torsional vibration, see G. Vibration
Auxiliary blower number and capacity (applicable for 2-stroke single propulsion engines), see B1300
Permissible bearing reactions in the engine (only applicable for direct coupled propulsion engines). To be used for evaluation of shaft alignment, see Ch.4 Sec.1 F400)
Permissible accelerations (movements) of the engine, applicable to HS, LC and NSC propulsion engines, see F304
Maximum inclination angles, see Rules for Classification of Ships Ch.1

A 300 Drawing particulars

301 The documentation of crankcase relief valve arrangement shall indicate

— make and type of valves
— the number of valves
— their position
— the free area of the relief valves
— the crankcase volume.

302 Drawings of bolts, such as connecting rod bolts and crankshaft bolts, shall show dimensions, thread type (including rolled or machined), material type and specifications as well as the tightening procedure and specification.

303 The crankshaft documentation submitted for approval shall contain drawings with details of

— fillets
— oil holes
— surface roughness
— dimensional tolerances for ovality, taper and parallelism.

Furthermore, the material specification shall contain

— type of material(s)
— forging or casting method
— cleanliness, preferably according to ISO 4967, (applicable for materials with minimum required tensile strength beyond 800 MPa)
— mechanical properties
— NDT specifications
— surface hardening (hardness and depth) of pins, journals and fillets as well as any other fillet treatment.

The allowable crank throw deflections for installation phase as well as the operational phase shall be specified.

304 The connecting rod drawings shall specify the material properties and NDT.

305 For engines with hydraulic lift of valves, an arrangement drawing shall be submitted.

306 The schematic drawing of the fuel oil system need only show design pressures and location of pumps, valves, filters and sensors.

The drawings of the high pressure fuel oil system shall describe all high pressure pipes and components, including specification of the actual pressures, dimensions and materials.

307 The required drawing of the starting air system shall show all the protective devices.

308 For turbochargers serving cylinder groups with combined power in excess of 1 000 kW the following documentation shall be submitted:

a) cross sectional drawing with principal dimensions
b) documentation of containment for disc fracture
c) operational data and limitations, at least:

  — maximum temporary r.p.m.
  — alarm level for r.p.m.
  — maximum temporary exhaust gas temperature before turbine
  — alarm level for exhaust gas temperature before turbine
  — maximum allowable compressor pressure ratio
  — minimum lubrication oil inlet pressure (alarm level).

Additionally, for turbochargers serving cylinder groups with combined power in excess of 2 500 kW, the following documentation shall be submitted:

— drawings of the rotating parts
— material specification of rotating parts including evaluation of the material properties versus the temperature it will be exposed to
— maximum lubrication oil outlet temperature (alarm level) as applicable, see Table E1
— maximum allowable list and trim (degrees), pitching and rolling (degrees/s)
— maximum allowable vibration level (both self- and externally generated)
— operation- and maintenance manual
— summary of life calculations (creep and low cycle fatigue) and summary of calculations/test results to document safety against high cycle fatigue
— documentation of safe torque transmission when the disc is connected to the shaft with interference fit (see B1204)
— type test program
— type test report.

309 Axial vibration dampers shall be documented by means of a sectional drawing and a system description of the adjustment.

310 A list of all shutdown and alarm levels and delay times (if applicable) shall be submitted for approval.

Scope of approval against requirements within this section is limited to verification of safe operation as addressed in B100 and compliance with sub-section E.

Approval of the control and monitoring system as such shall be based on the requirements of Ch.9. For necessary documentation of the system, see Ch.9.

311 Electronic engine management system is a collective term for electronic systems governing e.g. fuel oil injection, exhaust valve operation, operation of high pressure fuel oil injection pumps etc.

The documentation required per Table A1 shall provide a principal description of the system(s) as well as reference to valid type approval certificate for the associated software and hardware.

A 400 Additional documentation of propulsion engines

401 Unless given in the maintenance manual, the following shall be submitted for information:

— specification of maximum permissible wear of main thrust bearing (when integrated in the engine)
— tightening specification of connecting rod bolts.

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:

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.
   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 (kNm/rad) (considering the excitation frequency of 50 Hz or 60 Hz) by rated torque (kNm) exceeds 10, i.e. $K_{dyn}/T_o > 10$ 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.

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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).

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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.

102 Design calculations or test conditions shall be based on the maximum possible loads, i.e. permissible overloads, 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.

103 The engine loads to be considered are as follows:

a) Propulsion engines according to maximum continuous rating
b) Propulsion engines for HS, LC and NSC as for a) and, if applicable, according to the specified overload permitted for intermittent use.
c) Diesel generator sets and other auxiliary purposes according to maximum continuous power unless otherwise specified.

104 Design approval of diesel engines consists of both design analysis and testing. For some components, a combination of both testing and design calculations may be necessary, while others may be documented by either testing or calculations. The testing shall be arranged to represent typical load profiles as well as to cover for required safety factors due to wear and fatigue scatter and foreseen in-service deterioration. This applies in particular to parts subjected to high cycle fatigue such as connecting rods, cams, rollers and spring tuned dampers where higher stresses may be provided by means of elevated injection pressure, cylinder maximum pressure, etc.

Guidance note:

Design approval based on testing is especially suitable for small engines.

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105 Verification of safe operation of the engine as limited by alarms may be required during type testing. Such verification applies if there is any reason to believe that the engine can be damaged when operating close to the specified alarm set points.

106 The duration of the tests shall be selected to accumulate a relevant number of stress cycles. 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.

High cycle fatigue (typical for “cold parts”) shall be documented by analyses combined with running at the most relevant load (normally an elevated level) for at least 3 million cycles. Higher stresses and number of cycles will be necessary if the fatigue strength is influenced by fretting or possible defects in welds, etc.

Guidance note:

Design approval based on testing is especially suitable for small engines.

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107 After testing as mentioned in 102 to 106 the engine shall be disassembled for thorough inspection by a surveyor from the Society.

108 For engines of new designs or modifications of existing designs as:

- 5% increase of maximum combustion pressure or
- 5% increase of mean effective pressure or
- 5% increase of r.p.m. or
- change of structural integrity components or
- extended operational conditions

approval will only be given if either the engine:

- has been thoroughly tested during the development phase and or
- the test program has been extended to cover uncertainties in the design analysis and or
- the engine has proven reliable in service with the increased rating, for more than 2 500 running hours.

The extent of these elements is subject to special consideration.

109 In accordance with the general philosophy of DNV rules, the engine shall be proven to have inherent design margins in accordance with applicable requirements throughout this section of the rules. There is however one exemption from this philosophy as given herein.

Engines to be approved for intermittent overload rating need not be tested at loads in excess of the overload rating approved for intermittent use, see B1703 and D300. This exemption is subject to the following conditions:

- for all class notations except **Naval**, **Patrol**, **Yacht** and **Crew**, propulsion shall be provided by at least two engines
- the operational load profile, including limitation with respect to running hours at approved overload rating, shall be clearly stated in operation-/ maintenance manual and in the DNV Product Certificate
- the consequence (i.e. impact on engine integrity) of not adhering to the limitations on running hours at overload rating shall be clearly stated in the operation-/ maintenance manual.

B 200 Structural components

201 Bedplate, framebox and cylinder frame with integrated parts as crankcase doors are defined as structural components.

202 All welds in the bedplate, framebox and cylinder frame shall be designed to avoid fatigue cracking due to the stresses in operation. Full penetration welds are normally to be applied in the most fatigue exposed areas. Such areas are in particular those near the main and thrust bearings.

203 If partial penetration welds are applied in the most fatigue exposed areas, the weld dimensions including the maximum nose (root gap) shall be clearly defined. In addition, it shall be documented that the stated nose is acceptable.

Documentation of this may be based on relevant tests, service experience or by means of fracture mechanics calculations where the nominal stresses are found by e.g. finite element calculations.

The threshold value for crack propagation shall be taken as 2 ($MPa\sqrt{m}$), unless another value can be documented.

204 Acceptance levels on NDT of welds and repair welding of cast elements shall be based on the applicable working stress level.

B 300 Safety valves and crankcase ventilation

301 Engines with either:

— cylinder diameter of 200 mm and above, or
— a crankcase volume of 0.6 m^3 and above

shall be provided with crankcase explosion relief valves as shown in Table B1. Additional relief valves shall be fitted on separate spaces of crankcase such as gear or chain cases for camshaft or similar drives, when the gross volume of such space exceeds 0.6 m^3.

Further, scavenge spaces in open connection to the cylinders shall be fitted with explosion relief valves.

The relief valves shall be provided with flame arrestors that permit flow for crankcase pressure relief and prevent passage of flames following a crankcase explosion. This is in order to minimise the possibility of injury to personnel. There shall be no ducting of the outlet unless tests can verify that ducting does not compromise the valve's capability of arresting flames.

Table B1 Crankcase explosion relief valves		
Cylinder diameter D (mm)/ Crankcase volume V (m^3)	*Number of crank-throws*	*Number of safety valves*
$200 \leq D \leq 250$ or $V > 0.6$	≤ 8	One at each end of the engine
$200 \leq D \leq 250$	> 8	As above plus one near the middle of the engine
$250 < D \leq 300$		One in way of each alternate crank-throw, minimum 2
$D > 300$		One in way of each crank-throw

302 Crankcase explosion relief valves shall be type tested in accordance with IACS UR M66.

303 The free area of each crankcase safety valve shall not be less than 45 cm^2. The combined free area of the valves fitted on an engine shall not be less than 115 cm^2/m^3 of the crankcase gross volume.

Guidance note 1:

Each one of the safety valves required to be fitted, may be replaced by not more than two safety valves of smaller area, provided that the free area of each valve is not less than 45 cm^2.

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Guidance note 2:

The total volume of stationary parts within the crankcase may be discounted in estimating the crankcase gross volume (rotating and reciprocating components should be included in the gross volume).

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304 Crankcase explosion relief valves shall be designed and built to open quickly and be fully open at an overpressure of not more than 0.2 bar.

Crankcase explosion relief valves shall be provided with lightweight spring-loaded valve discs or other quick-acting and self closing devices to relieve a crankcase of pressure in the event of an internal explosion and to prevent inrush of air thereafter.

The valve discs in crankcase explosion relief valves shall be made of ductile material capable of withstanding the shock of contact with stoppers at the full open position.

305 Ventilation of crankcase and any arrangement that could produce a flow of external air within the crankcase, is in principle not permitted.

If a forced extraction of the oil mist atmosphere from the crankcase is provided (for mist detection purpose for instance), the vacuum in the crankcase shall not exceed 2.5 mbar.

To avoid interconnection between crankcases and possible spread of fire following an explosion, crankcase ventilation pipes and oil drain pipes for each engine shall be independent of any other engine.

Lubrication oil drain pipes from the engine sump to the drain tank shall be submerged at their outlet ends.

306 A warning notice shall be fitted on each side of the engine. This warning notice shall specify that, whenever overheating is suspected within the crankcase, the crankcase doors or sight holes shall not be opened before a reasonable time, sufficient to permit adequate cooling after stopping the engine.

307 Crankcase and crankcase doors shall be of sufficient strength to withstand anticipated crankcase pressures that may arise during a crankcase explosion taking into account the installation of explosion relief valves as required. Crankcase doors shall be fastened sufficiently securely for them not to be readily displaced by an explosion.

B 400 Bolt connections

401 The requirements in 400 apply to all important bolt connections such as:

— crankshaft bolts (connecting parts of crankshafts and for flywheel connections)
— connecting rod bolts.

For other bolt connections upon request

402 Bolt connections shall be designed to prevent fatigue. Particular attention must be given to possible fretting of joining surfaces. The bolt fatigue strength shall be assessed under due consideration to both stress concentrations and pre-stress.

B 500 Power transmitting parts

501 Crankshafts, connecting rods, crossheads and piston rods are defined as power transmitting parts. The respective bearings are also included here.

502 Requirements and calculation methods for crankshafts are described in Classification Note 41.3. These methods apply to solid or semi-built crankshafts of forged or cast steel, and with each crank throw between main bearings. Other types will be especially considered on basis of equivalence with the requirements mentioned above.

503 Classification Note 41.3 covers scantling of crankshafts based on an evaluation of safety against fatigue in the crank-pin fillets, journal fillets and in the oil bores. When applicable, highly stressed areas as for example fillets between offset crankpins, welds in journals etc. are subject to special consideration.

504 The fatigue criteria used in the Classification Note 41.3 assume that maximum respective minimum bending stresses occur simultaneously with the maximum respective minimum torsional stresses. Furthermore, it is assumed that the highest stress concentrations in bending and torsion occur at the same positions. These assumptions yield results that are somewhat on the safe side, and the required minimum calculated safety factor is 1.15. If properly documented, evaluation of fatigue under multi-axial stress conditions and with rotating principal stress axis may replace the criteria applied. However, the required safety factor would then be subject to special consideration.

505 Classification Note 41.3 also contains requirements for safety versus slippage of semi-built crankshafts. (Fully built crankshafts will be considered on basis of equivalence with these requirements.) The required minimum safety factor against slippage is 2.0. This is valid for the highest peak torque in the crankshaft and also taking the shrink fitting procedure into account. The maximum shrinkage amount is limited by the permissible amount of plastification of the web and journal materials.

506 For direct coupled propulsion engines (i.e. no elastic coupling) in ships strengthened for navigation in ice, the crankshaft and the crankshaft bolts shall be designed for the ice impact torques. The procedure for calculation of the applicable impact torque is given in Pt.5 Ch.1 of the Rules for Classification of Ships. The applicable impact torque is additional to the engine vibration torque and is of special importance for the safety against slippage.

507 Cast connecting rods shall have NDT requirements chosen so as to reject combinations of defect sizes and stresses resulting in stress intensity above 2 MPa $\sqrt{m}$. This also applies for repair welded zones.

B 600 Hydraulic oil system

601 Double piping or shielding including both end connections is required for engines with hydraulic lift of valves.

602 Use of flexible hoses in the hydraulic oil system is only permitted where necessary in order to allow for relative movements.

Flexible hoses with its couplings shall be type approved, see Ch.6 Sec.6 D.

B 700 Fuel oil system

701 All external high pressure fuel delivery lines between the high pressure fuel pumps and fuel injectors shall be protected with a jacketed piping system capable of containing fuel from a high pressure line failure. A jacketed pipe incorporates an outer pipe into which the high pressure fuel pipe is placed forming a permanent assembly. The jacketed piping system shall include a means for collection of leakage and arrangements shall be provided for an alarm to be given, in the case of a fuel line failure.

702 Pipe connections in fuel oil lines with pressure above 1.8 bar shall be screened or otherwise suitably protected to avoid as far as practicable oil spray or oil leakage onto potentially hot surfaces (see B1102), into machinery air intakes, or other sources of ignition. The number of joints in such piping shall be kept to a minimum.

703 Use of flexible hoses in the fuel oil system is only permitted where necessary in order to allow for relative movements. Flexible hoses with their couplings shall be type approved, see Ch.6 Sec.6 D.

B 800 Charge air system and cooler

801 The charge air system shall be designed to prevent water entering the engine. Water draining from a cooler leakage shall be possible.

Guidance note:
A hole in the bottom may be sufficient.

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802 In 2-stroke engines, charge air spaces in open connection to the cylinders shall be fitted with:

— safety valves which shall open quickly in case of an overpressure
— a connection to an approved fire-extinguishing system that is entirely separate from the fire-extinguishing system of the engine room.

B 900 Starting air system

901 In order to protect starting air mains against explosion arising from improper functioning of starting valve, the following devices shall be fitted:

— an isolation non-return valve or equivalent at the starting air supply connection to each engine
— a bursting disc or flame arrester
  — in way of the starting valve of each cylinder for direct reversing engines having a main starting manifold
  — at the supply inlet to the starting air manifold for non-reversing engines.

The bursting discs or flame arresters may be omitted for engines having a bore not exceeding 230 mm.

902 The pipes and valves, including the non-return valve, shall be designed to withstand the possible back pressure if a starting valve remains open.

903 Use of flexible hoses in the starting air system is only permitted where necessary in order to allow for relative movements.

Flexible hoses with their couplings shall be type approved, see Ch.6 Sec.6 D.

B 1000 Lubrication

1001 The lubrication oil pump(s) suction shall be arranged such that the required capacity and pressure is maintained under conditions as referred to in Ch.1 of the Rules for Classification of Ships.

1002 For single propulsion engines, at least two lubrication pumps shall be provided. For engines with power below 400 kW, see Ch.6 Sec.5 A104.

1003 Pipe connections in lubrication oil lines with pressure above 1.8 bar shall be screened or otherwise suitably protected to avoid as far as practicable oil spray or oil leakage onto potentially hot surfaces (see B1102), into machinery air intakes, or other sources of ignition. The number of joints in such piping shall be kept to a minimum.

1004 Use of flexible hoses in the lubrication oil system is only permitted where necessary in order to allow for relative movements.

Flexible hoses with their couplings shall be type approved, see Ch.6 Sec.6 D.

B 1100 Fire protection

1101 All exposed surfaces shall be kept below the maximum permissible temperature of 220°C.

Surfaces that reach higher temperatures shall be insulated with material having non oil-absorbing surface, or equivalently protected so that flammable fluids hitting the surface cannot be ignited.

1102 All pipe connections in piping containing flammable liquids with pressure above 1.8 bar shall be screened or otherwise suitably protected to avoid as far as practicable oil spray or oil leakage onto potentially hot surfaces. Any surface (with temperatures exceeding 220 degrees if not insulated) that are insulated by means, for which workmanship affects the efficiency of the insulation, are defined as potentially hot surfaces.

Guidance note 1:
Insulation by use of detachable lagging wrapped around hot exhaust manifold is an example of means where inadequate workmanship (during e.g. maintenance work onboard by crew) will expose hot spots. Water cooled exhaust manifold is on the other hand typically a mean of insulating, which may not be affected by workmanship, all depending on the design,(e.g. areas in way of flanged connections where the water is not sufficiently cooling the metal).

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Guidance note 2:

Any means applied to protect pipe connections as required per 1102 should not deteriorate when dismantled and re-assembled (during e.g. maintenance work). Proper re-assembly should normally be possible without the need of spare parts.

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B 1200 Turbocharger

1201 Turbochargers shall be type approved either separately or as a part of the diesel engine (see also A104 and Table A1) on basis of documentation as listed in A308.

For turbochargers served by cylinder groups with combined power in the range 1 000 kW< Power ≤ 2 500 kW, only 1203 needs to be documented.

Although there is no requirement for type approval or NV certificate, the requirement to containment in 1203 is also valid for turbochargers supplied by cylinders groups with combined power of 1 000 kW and less, see Ch.2 Sec.3 A106.

1202 The turbocharger shall be designed to operate under the conditions given in Ch.1 of the Rules for Classification of Ships.

The turbocharger component lifetime and the alarm level turbocharger speed shall be based on 45°C air inlet temperature, if otherwise not specified. See also B1207.

1203 The turbocharger shall be self-contained in case of rotor burst, see A308. This shall be verified by testing. Fulfilment of this requirement can be awarded to a series of turbochargers on the basis of containment validation for one specific unit. It must however be documented that the containment validation is representative for the complete series.

The minimum test speed (relative to alarm level speed) for validation of containment is as follows:

- 120% for compressor
- 140% or natural burst for turbine (whatever comes first).

In case these speeds can not be achieved due to interference between static and rotating parts, burst shall be validated at the highest achievable speed.

The requirement for documentation of containment can be reduced if the following is fulfilled:

- burst margin (tested or calculated) is higher than 40% for compressor and 60% for turbine, and
- a burst after design life is identified as extremely unlikely (life to be verified at the limit of operation as calculated in B1204).

Guidance note:

Containment testing of a large unit is preferred, as this is considered conservative for all smaller units of the same series.

Calculations may be accepted as an alternative to testing, provided that the calculation methodology is thoroughly validated by testing.

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1204 The materials in the rotating parts shall be able to withstand the stresses and strains and temperatures to which they will be exposed.

This shall be analysed with regard to stresses and strains and temperatures in the rotating parts and lifetime calculations of these parts:

a) The calculations shall be based on low cycle fatigue, high cycle fatigue and creep-rupture analyses as applicable and they shall cover the limits of operation (see Guidance note). As an alternative, reliability documented by operational experience may be accepted.

   In cases where the disc is connected to the shaft with interference fit, documentation is required to substantiate the disc's capability to transmit the required torque throughout the operation range, meaning: maximum speed, maximum torque, maximum gradient and minimum interference fit.

b) For a generic range of turbochargers, a calculation summary report in accordance with a) is normally to be submitted for one larger turbocharger. The report shall include objectives, brief description of method, limits of operation, assumptions and conclusion. The calculation methodology shall be representative for the complete series to be awarded. The type testing requirements apply to one selected size.

Guidance note:

The limits of operation are the operating conditions in which the (cyclic) stress range or strain range is maximum, i.e. which contribute to largest accumulated damage or shortest life, based on the criteria above and combined with temperature effect. Typical limits are alarm level speed, alarm level turbine inlet temperature, maximum permissible compressor inlet (or ambient) temperature for steady state operation and maximum permissible rates of acceleration and deceleration during start-up and shutdown operation. The limits of operation shall include any combination of the above which are realistic operating conditions, see also B1202. Load profile definition should be specified and documented.

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1205 The type test for a generic range of turbochargers, may be carried out at either on an engine (for which the turbocharger is foreseen) or in a test rig.

As part of the type test, the turbocharger shall be subjected to 200 to 500 load cycles at the limits of operation (see Guidance note to 1204).

The rotor vibration characteristic shall be measured and recorded. The result shall be within the maker's specification.

The extent of the DNV surveyor's presence shall be decided by DNV in consultation with the maker before the test.

The type test shall be completed by a hot running test at maximum temporary speed and maximum temporary temperature. The duration shall be at least one hour and the test shall be witnessed by a DNV surveyor.

After the test, the turbocharger shall be opened for examination.

The type test report, which includes the test objectives, procedures, acceptance criteria, results and conclusions, shall be submitted for approval.

The type test requirements might be reduced upon documentation of relevant operational experience.

1206 Turbochargers shall have a compressor characteristic that allows the diesel engine, for which the turbocharger is intended, to be operated without surging in all normal operating conditions, also after a long time in operation. For abnormal, but within permissible operating conditions, such as misfiring and sudden load reduction, no continuous surging shall occur.

1207 The replacement interval for rotating components shall in a conservative manner be based on considerations of creep, low cycle fatigue and creep-fatigue interactions (if applicable). See B1204.

In case the replacement interval or maintenance interval is based on an estimated operation profile stipulating continuous load less than 100% or compressor inlet temperature less than 45°C (for aluminium compressors), the estimated operation profile shall be presented in the operation manual and/or the maintenance manual. The consequences of exceeding the estimated loading, load cycles or compressor inlet temperature must be explicitly stated. The maintenance manual shall in such cases instruct the operator to contact the turbocharger maker for a re-evaluation of the maintenance interval and replacement interval.

Guidance note:

Change of trade is a typical situation where the conservativeness of the estimated operation profile must be considered.

Special considerations will apply in the case that due time for replacement of life-limiting parts is calculated by a monitoring system, where the actual operation conditions are used as input to a calculation program. Such life monitoring system shall be documented by a function description and submitted to DNV.

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For Type Approval of turbochargers, typical operation manual and maintenance manual shall be submitted for information.

B 1300 Auxiliary blower

1301 All single propulsion 2-stroke engines to be fitted with at least two auxiliary blowers.

1302 For single propulsion 2-stroke engines with only one turbocharger and intended for driving a fixed pitch propeller, the auxiliary blowers shall have a capacity sufficient to run the engine continuously with a speed (r.p.m.) of approximately 40% of full speed along the theoretical propeller curve.

1303 The engine speed at which the auxiliary blowers are stopped shall be selected under consideration of the necessity of passing quickly through a barred speed range, see G400.

B 1400 Torsional vibration dampers

1401 For torsional vibration dampers the following requirements apply:

a) Subcontracted dampers of standard design (including design concept) shall be type approved, see also Ch.2 Sec.2 B103.
b) Dampers of tailor made (unique) design may be case by case approved.
c) Dampers produced by the engine manufacturer shall be type approved either as a separate product or as a part of the engine.

1402 The drawings of torsional vibration dampers shall specify all details which deal with the functions and limitations of the damper.

For spring tuned dampers the spring materials and properties shall be specified.

For rubber and silicone type dampers in general and for some steel spring dampers the dynamic properties shall be documented by means of relevant type testing (e.g. in stationary or rotating pulsators where torque and twist are plotted).

1403 Torsional vibration dampers shall be specified with regard to damping, stiffness, permissible vibration level and heat load properties as functions of their main influence parameters. The tolerances of the damping and stiffness and the limitations of the influence parameters are also to be specified.

1404 The inspection and service intervals shall be specified by the manufacturer. The permissible limits for wear (spring tuned dampers), rubber and silicone condition, oil viscosity (viscous dampers), oil pressure (if oil supplied), etc. shall be specified.

1405 Spring tuned dampers shall be designed to avoid fretting in vital elements. For such dampers the springs shall be designed with a safety factor against high cycle fatigue of minimum 1.8 in general, but higher values apply for spring areas under tension stresses and hard contact with other parts. For designs where fretting in vital elements cannot be excluded, these elements shall be subjected to fatigue type testing. Stress levels and number of stress cycles will be especially considered, leading to specific intervals for either inspection or torsional vibration measurements. If the latter is selected, acceptance criteria shall be approved.

B 1500 Type testing

1501 Upon finalisation of every new type of engine, one engine shall be presented for type testing. For modifications, see 108 indicating a reduced scope of testing for modifications beyond stated limits.

1502 As mentioned in 100, the type testing might also serve partly the purpose of design documentation. A type test program can be established to verify a certain fitness for purpose, as e.g. frequent start - full load - stop sequences.

1503 The complete type testing program is subject to approval. The extent of presence by a surveyor should be agreed in each case. Testing prior to the official type testing (Stage B and C as described in 1700), is also considered as a part of the total type testing.

Upon completion of total type testing (stage A through C), a type test report shall be submitted to DNV for approval. The type test report shall contain:

- overall description of tests performed during stage A
- detailed description of the load- and functional tests conducted during stage B
- inspection/ inspection results form stage C

1504 Type testing is normally made for only one engine with a certain number of cylinders and considered representative for that type of engine ranging from a minimum to a maximum number of cylinders. However, for certain number of cylinders such items as axial crankshaft vibration, torsional vibration in camshaft drives, etc. may vary considerably from the selected engine for type testing. If found necessary, additional type tests to cover for such items may be postponed to the workshop testing or shipboard testing.

1505 The type testing should preferably be made with the kind of fuel oil for which the engine is intended. However, for engines intended for running on heavy fuel oil, the verification of the engine's suitability for this may be postponed to the sea trial.

1506 If no special fitness for purpose testing or design documentation testing apply, the type test program shall be arranged as given in 1700.

1507 Type testing of engines with rated power less than 200 kW is limited to the following:

- verification of compliance with requirements for jacketing of high-pressure fuel oil lines and screening of pipe connections in piping containing flammable liquids, see B1703 item 4).
- verification of compliance with requirements for insulation of hot surfaces, see B1703 item 4)
- if emergency generator, testing the safety system to the extent as integrated in the engine design (e.g. overspeed trip device), however limited to the requirements for such systems as given in E700.

B 1600 Type testing data collection

1601 All relevant equipment for safety of personnel shall be operational during the type testing.

1602 The following external particulars shall be recorded:

- ambient air temperature
- ambient air pressure
- atmospheric humidity

— external cooling water temperature
— fuel and lubrication oil characteristics.

1603 As a minimum the following engine data shall be measured and recorded:

— engine r.p.m.
— torque
— maximum combustion pressure for each cylinder
— mean indicated pressure for each cylinder
— lubrication oil pressure and temperature. The measurements shall cover all readings as required per Table E1 (reference is made to footnote 3), Table E2 or Table E3, whichever is applicable
— lubrication oil pressure and temperature at turbocharger inlet/ outlet as applicable, see Table E1
— cooling water pressure and temperatures
— exhaust gas temperature before and after turbine and, where required (see E400 and E600), from each cylinder. To be measured also if installed due to manufacturers minimum sensor delivery
— exhaust gas pressure before turbine [1)]
— r.p.m. of turbocharger (applicable when the turbocharger is served by a group of cylinders > 1 000 kW)
— charging air pressure
— charging air temperature before and after cooler
— jacket cooling temperature
— piston cooling temperature (in case of separate cooling medium).

1) The data need not necessarily be taken from the engine that is presented for type test - stage B (see B1701). Data recorded from development engines used during type test - stage A (see B1701) can be accepted. The combustion data must be recorded from a representative number of cylinder units, e.g. 1/3 of all cylinders.
These data shall presented to the attending surveyor in connection with type test - stage B, and included in the final type test report, see B1503.

1604 Calibration records for the instrumentation used to collect data as listed in 1603 shall be presented to - and accepted by the attending surveyor.

B 1700 Type testing program

1701 Unless otherwise approved (see 1500), the following assumptions apply:

— the investigations and measurements required for reliable engine operation have been carried out during internal tests by the engine manufacturer
— the acceptance 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.

The type test is subdivided into three stages:

Stage A - Internal tests

Functional tests and collection of operating values including test hours. The relevant results shall be presented to attending surveyor during the type test. Testing hours of components that shall be inspected after the type test, shall be stated.

Stage B - Type test

Type test in the presence of a surveyor.

Stage C - Component inspection

Component inspections by attending surveyor after completion of the test program.

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

1702 *Stage A - Internal tests*

During the internal tests the engine shall be operated at the load points important for the engine designer and the pertaining operating values shall be recorded. Concerning relevant load conditions to be tested, reference is made to B100.

At least the following conditions shall be tested:

1) *Normal case*

At least the following conditions shall be tested:

— the load points 25%, 50%, 75%, 100% and 110% of the maximum rated power:
  - i) along the normal (theoretical) propeller curve and at constant speed for propulsion engines (if applicable mode of operation)
  - ii) at constant speed for engines intended for generators sets including no load and full speed

— the limit points of the permissible operating range. These limit points shall be defined by the engine manufacturer.

2) *Operation with damaged turbocharger*

For crosshead propulsion engines, the achievable continuous output shall be determined in the case of turbocharger damage. Engines intended for single propulsion with fixed pitch propeller shall be able to run continuously at a speed (r.p.m.) of approximately 40% of full speed along theoretical propeller curve when one turbocharger is out of operation.

Guidance note:

The test can be performed either by:

- fixing the turbocharger rotor shaft, preventing the shaft from rotating or
- remove the rotating parts of the turbocharger (if possible it is sufficient to remove compressor wheel)

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1703 *Stage B - Type test*

During the type test, the tests listed below shall be carried out in the presence of a surveyor. The achieved results shall be recorded and signed by the attending surveyor after the type test is completed.

1) *Load points*

The engine shall be operated according to the power and speed diagram (see Fig.2). The data to be measured and recorded when testing the engine at the various load points shall include all major parameters for the engine operation (see also 1500). 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. Normally, an operating time of 0.5 to 1 hour can be assumed per load point.

The load points are:

— rated power, i.e. 100% output at 100% torque and 100% speed corresponding to load point 1
— 100% power at maximum permissible speed corresponding to load point 2
— maximum permissible torque (normally 110%) at 100% speed corresponding to load at point 3, or maximum permissible power (normally 110%) and speed according to nominal propeller curve corresponding to load point 3a. Load point 3a applies to engines only driving fixed pitch propellers or water jets. Load point 3 applies to all other purposes. Load point 3 (or 3a as applicable) shall be replaced with a load that corresponds to the specified overload approved for intermittent use. This applies where such overload rating exceeds 110% of MCR. Where the approved intermittent overload rating is less than 110% of MCR, subject overload rating shall replace the load point at 100% of MCR. In such case the load point at 110% of MCR remains.
— minimum permissible speed at 100% torque, corresponding to load point 4
— minimum permissible speed at 90% torque corresponding to load point 5
— part loads e.g. 75%, 50% and 25% of rated power and speed according to nominal propeller curve corresponding to points 6, 7 and 8 and at rated speed corresponding to points 9, 10 and 11.

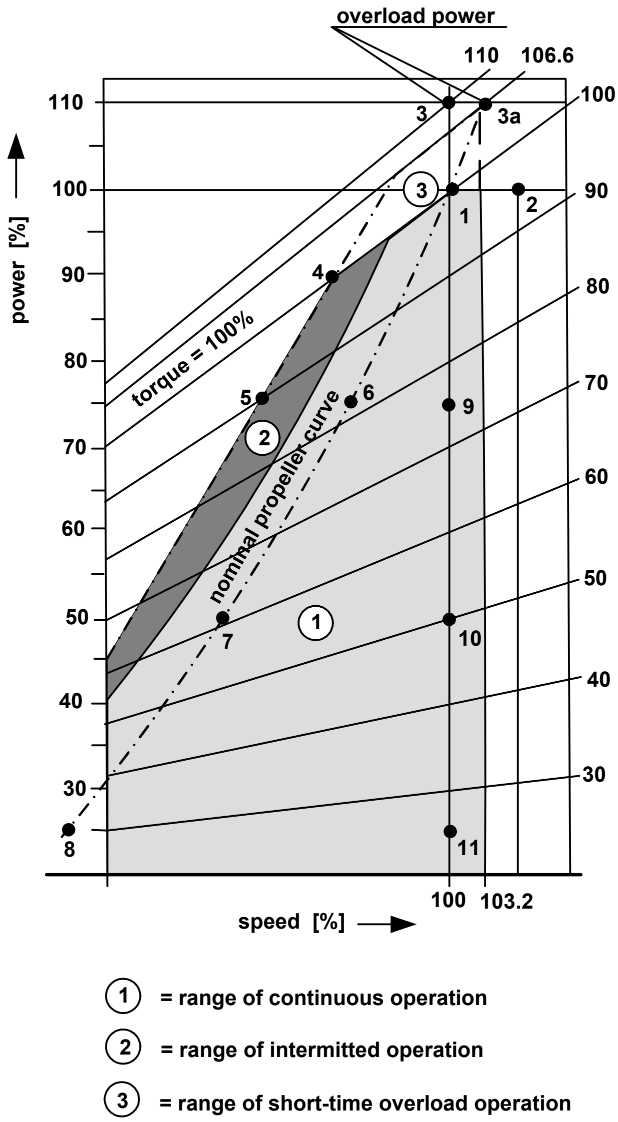

Fig. 2
Load points

At the power levels specified above all the data listed in 1600 shall be recorded.

Guidance note:

In order to establish proper baseline data as reference for any future condition monitoring, it is recommended that the measured maximum pressures, mean indicated pressures, exhaust temperatures and compression pressures are corrected to ISO conditions.

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a) The maximum pressure is not to exceed the approved maximum value
b) At the maximum continuous rating, the maximum pressure in the various cylinders is not to vary more than permitted by the engine designer, alternatively 3% of the maximum permissible value where no design specification applies
c) The maximum average exhaust temperature is not to exceed the specified limit.
d) The functioning of the charge air cooler drain shall be checked
e) The functioning of the cylinder lubricators shall be randomly checked
f) The jacket cooling and the piston cooling (when applicable) medium temperatures shall be checked versus engine specifications.

2) *Emergency operations*

Maximum achievable power when:

— operating along the nominal propeller curve
— operating with constant governor setting for rated speed

under conditions as stated in 1702 2).

3) *Functional tests*

a) Demonstration of reversing for reversible engines.
b) Testing the safety system to the extent as integrated in the engine design, however limited to the requirements for such systems as given in E. Functionality of overspeed trip device shall be verified by increasing engine speed until activation of trip device.

Guidance note:

For engines intended to be used for emergency services, supplementary tests according to the regulations of the flag Administration may be required.

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4) *Fire protection measures*

Verification of compliance with requirements for jacketing of high-pressure fuel oil lines, screening of pipe connections in piping containing flammable liquids and insulation of hot surfaces

— the engine shall be inspected for jacketing of high-pressure fuel oil lines, including system for detection of leakage (see B702), and proper screening of pipe connections in piping containing flammable liquids
— proper insulation of hot surfaces shall be verified while running the engine at 100% load, alternatively at the overload approved for intermittent use. Readings of surface temperatures shall be done by use of Infrared Thermoscanning Video Equipment. Equivalent measurement equipment may be used when so approved by the Society's Plan Approval Centre. Readings obtained shall be randomly verified by use of Contact Thermometers.

1704 *Stage C - Component inspection*

The crankshaft deflections shall be measured in the specified (by designer) condition (except for small engines where no specification exists).

After the test run the components of one cylinder for in-line engines and two cylinders for V-engines shall be presented for inspection as follows:

— piston removed and dismantled
— crosshead bearing dismantled
— guide planes
— crankpin bearing and main bearing dismantled (special attention to serrations)
— cylinder liner in the installed condition
— cylinder head, valves disassembled
— control gear, camshaft and crankcase with opened covers.

For V-engines, the cylinder units shall be selected from both cylinder banks and different crank throws.

If deemed necessary by the surveyor, further dismantling of the engine may be required.

C. Testing and Inspection

C 100 General

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

Guidance note:

It is advised to establish an MSA with sub-suppliers delivering materials or parts mentioned in 200 and 300. This applies also to those documented by work certificate (W) and test report (TR), and should at least verify that the premises for using W and TR are fulfilled.

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102 Material specification is described in Ch.2 Sec.3.

103 All specifications of welding procedures in parts for which certification is required shall be qualified according to a recognised standard or the rules of the Society.

C 200 Certification of parts

201 The manufacturer shall have a product quality control system suitable for the type of engine produced.

This system shall also cover activities performed by sub-contractors. The following paragraphs describe the required documentation in connection with DNV certification only.

A reduced extent of quality control documentation (as required in Table C1) can be agreed with the Society.

Such agreement should preferably be arranged in connection with type approval of the engine, and shall be settled in a MSA.

202 If found necessary due to service experience (generic problems), an extended scope of testing and inspection may be required.

203 Whenever NV is specified for testing or inspection (e.g. crack detection of crankshaft, see Table C1) a surveyor shall witness the test and or inspection and subsequently endorse the test or inspection report, as appropriate.

204 The control and monitoring systems for:

- diesel engines
- electronic engine management system (see A311)

shall be certified according to Ch.9.

C 300 Testing and inspection of parts

301 The testing and inspection described in 300 provides more details regarding the requirements in Table C1.

302 Results from the testing and inspection as required in 300 shall be evaluated against the applicable NDT specifications as listed in Table A1.

Where the corresponding NDT specification is not listed in Table A1, test and inspection results shall fulfil the revision of designer's specification valid at date of testing.

303 For cross-head engines, the bedplate, framebox and welded cylinder frame shall be tested, inspected and documented with regard to:

- chemical composition of the material
- mechanical properties of the material
- ultrasonic testing of welds and cast parts
- crack detection of welds and cast bearing girders by MPI or dye penetrant
- alignment report reviewed by the surveyor.

304 Cylinder or engine block, cylinder jacket or frame and exhaust valve housings shall be tested for leakage at the working pressure of the cooling medium.

305 Crankcase explosion relief valves shall be type tested in accordance with IACS UR M66.

306 Crankshaft bolts (the bolts used for the connection between different crankshaft sections when the crankshaft is supplied in more than one unit (larger crankshafts for cross-head engines)) and connecting rod bolts shall be tested, inspected and documented with regard to:

- chemical composition of the material
- mechanical properties
- crack detection.

307 Crankshafts shall be tested, inspected and documented with regard to:

- chemical composition of the material
- forging method (not applicable if cast)
- repair welding if applicable
- mechanical properties of the material
- ultrasonic testing (in a condition suitable for the purpose)
- surface hardening
- fillet treatment, i.e. surface hardening and rolling or peening
- crack detection by MPI or dye penetrant in web fillets, oil hole fillets, pin and journal surfaces
- dimensions such as shrinkage tolerance, ovality and parallelism for semi-built crankshafts and fillet radii generally
- surface finish.

308 Connecting rods shall be tested, inspected and documented with regard to:

- chemical composition of the material
- mechanical properties of the material
- ultrasonic testing and crack detection

— repair welding (if applicable)
— check of contact in serrations (if applicable).

309 Cylinder heads and cylinder liners shall be tested and documented with regard to:

— chemical composition of the material
— mechanical properties of the material
— NDT as per engine designer specification
— testing for leakage of cooling space to the working pressure.

310 Piston crowns for propulsion engines shall be tested and documented with regard to:

— chemical composition of the material
— mechanical properties of the material
— NDT as per engine designer specification
— testing of complete piston assembly for leakage of cooling space to the working pressure.

Table C1 Requirements for testing, inspection and certification, see 201
For definition of NV, W and TR, see Pt.1 Ch.1 Sec.4 of the Rules for Classification of Ships

Component	*Type of engine*	*Product certificate*	*Material certificate*	*Ultrasonic testing*	*Crack detection* [1)	*Leakage testing*	*Dimensional inspection*	*Other*
Welded bedplate, framebox and cylinder frame	Crosshead engines	NV	NV	W	NV [2)		W	See 303
Engine block	Trunk engines		W if cylinder power >500 kW			W		See 304
Crankcase safety valves	All							See 305
Cylinder jacket and frame	Propulsion engines					W		See 304
Exhaust valve housing	Propulsion engines					W		See 304
Bolts for crankshaft and connecting rod	All		W		W			See 306
Crankshaft	All	NV	NV	W	NV		NV	See 307
Connecting rod, forged	All		NV	W	W			See 308
Connecting rod, cast	All	NV	NV	W	NV			See 308
Crosshead	Crosshead propulsion engines		NV					
Cylinder head	All		NV	W [7)	W [7)	W [3)		See 309
Cylinder liners	Propulsion engines		W		W [7)	W		See 309
Piston crown	Propulsion engines		W	W [7)	W [7)	W [5)		See 310
Fuel oil piping including common rail [4)	All		TR	TR [2)	TR [2)			See 311
Turbocharger Served by cylinder groups where P [6) >2 500 kW		NV						See 312
Torsional vibration dampers (spring tuned)	All	NV if case-by-case approved						See 313

1) See 302.
2) Of cast parts and welds.
3) If cast.
4) If delivered integral with the diesel engine.
5) Of complete piston. Only relevant for water cooled slow speed pistons.
6) P refers to combined power (kW) of all cylinders in the group
7) Where applicable according to engine designer specification, see corresponding paragraph under C300

311 Fuel oil piping (high pressure, return pipes and low pressure) shall be tested, inspected and documented with regard to:

— chemical composition of the material

— mechanical properties of the material
— NDT as per engine designer specification

For common rail systems the above requirements are also valid for the control oil side.

312 Turbochargers served by groups of cylinders with combined power in excess of 2500 kW shall be tested, inspected and documented with regard to:

— chemical composition of the material of rotating parts [1)]
— mechanical properties of the material of a representative specimen for the rotating parts[1)] and, in special cases, documentation of heat treatment (temperature – time diagrams)
— NDT of rotating parts [1)]
— crack detection
— dimensional inspection of rotating parts [1)] (before assembly)
— dynamic balancing of rotating parts [1)] separately as well as complete rotating assembly
— overspeed test [2)] of all compressor wheels with a duration of 3 minutes at 20% above the alarm level speed at room temperature, or 10% above the alarm level speed at 45°C inlet temperature when tested in the actual housing with the maximum allowable pressure ratio.

In addition, the following test to be carried out:

The turbocharger shall be tested on the engine for which it is intended by a test run of 20 minutes at the maximum achievable engine power in workshop testing (or onboard for replacement turbocharger).

1) Rotating parts are turbine, compressor wheels and shaft.

2) If each forged compressor wheel is individually controlled by an approved non-destructive method, the overspeed test may be waived except for the wheel of the type test unit. For wheels without a bore, the overspeed test may be omitted.

The manufacturer's quality system shall ensure that the designer's specifications are met, and that manufacturing is in accordance to type approved drawings. The manufacturer's documentation of fulfilment of these requirements is normally to be verified by means of periodic DNV product audits.

313 Spring tuned torsional vibration dampers shall be tested, inspected and documented as stated in the approved specification, see also B1400.

314 Ancillaries not covered by Table C1 such as pumps, electric motors, coolers, piping, filters, valves, etc. that are delivered as integral parts of the fuel oil, lubrication, hydraulic and pneumatic operation and cooling systems on the engine, shall be checked as found relevant by the engine manufacturer.

C 400 Inspection during assembly

401 The engine manufacturer shall have implemented procedures to ensure, to the extent practicable, that impurities (e.g. welding consumables, clinker, chips, etc.) from production and assembly are removed from the engine prior to close-up of engine and final acceptance testing. Such procedures shall include proper flushing of engine's internal cooling and lubrication system.

402 Shielding of oil piping shall be inspected by the surveyor, see also H503.

403 Insulation of all surfaces expected to reach 220°C shall be inspected by the surveyor if the engine is delivered with insulation.

404 For crosshead engines the report on alignment of the bedplate, the crankshaft deflections, the guides and pistons shall be reviewed by the surveyor.

405 For propulsion engines with main thrust bearings integral with the engine, the clearance shall be documented.

406 A signboard shall be fitted in a clearly visible position on either side of each engine, warning against opening of a crankcase for a specific period of time after shutdown due to overheating. The time shall be sufficient to permit adequate cooling after stopping the engine. The notice is also to warn against restarting of an overheated engine until the cause of overheating has been found.

D. Workshop Testing

D 100 Application

101 All relevant equipment for safety of personnel shall be operational during the workshop testing.

102 Each engine to be certified shall be tested in the workshop. The purpose of the workshop testing shall verify the design premises such as performance, safety (against fire), adherence to maximum pressure, functionality, product quality and further to establish reference values or base lines for later reference in the operational phase.

103 Test program considered equivalent to that described in 200 to 500 may be agreed upon, and if so, settled in an MSA.

104 For case by case approved engines the workshop testing may be extended up to the full type testing if found necessary by the Society.

105 Unless otherwise stated in a MSA, the engine manufacturer shall compile all results in a test protocol that shall be endorsed by the attending surveyor and submit it to the Society for later reference.

106 After the required workshop testing, engines shall be blocked for output beyond the approved maximum rating, i.e. either the maximum continuous rating or the specified overload permitted for intermittent use. The setting of the blocking shall be made as applicable for the intended fuel. i.e. if an engine is intended for running on heavy fuel oil during the sea trial, the blocking after a workshop test on light diesel oil shall be set in accordance with the theoretical correlation between these fuel oils. If the sea trial full load testing will be made on light diesel oil, and the service is intended for heavy fuel oil, the blocking shall be made after the sea trial testing.

107 For engines with rated power less than 200 kW, scope of workshop testing is identical with that of type testing, see B1507.

D 200 General engine tests

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

202 The following external particulars shall be recorded:

- ambient air temperature
- ambient air pressure
- atmospheric humidity
- external cooling water temperature.

203 For each required load point, the following parameters shall be recorded:

- maximum combustion pressures, see 205
- exhaust gas temperature before turbine and, where required (see Table E1 and Table E2), from each cylinder
- charge air temperature
- charge air pressure
- turbocharger r.p.m., when applicable (see Table E1 and Table E2).

Calibration records for the instrumentation used to collect data as listed above shall, upon request, be presented to - and accepted by the attending surveyor.

204 The engine shall be run at its maximum continuous rating for a time period sufficient to achieve steady state condition of all engine parameters.

205 Unless otherwise approved, the maximum pressure shall be recorded for each cylinder at maximum continuous rating. It shall not exceed the maximum permissible value nor vary more than permitted by the engine designer, alternatively 3% of the maximum permissible value where no design specification applies.

206 During testing, the engine shall be checked visually for leakage of fuel and lubrication oils.

207 The safety systems to the extent as integrated in the engine design, shall be tested (e.g. a mechanical overspeed trip device, air intake shut down device (see E304), low and low-low lubrication oil pressure etc., see E. Control and Monitoring).

Proper functioning of the safety system may be verified by change of set points rather than actual change of parameter value. For the overspeed trip device a manipulation of set points is only acceptable when the real alarm level is within level previously tested for that engine type.

208 The engine shall be inspected for:

- jacketing of high-pressure fuel oil lines, including system for detection of leakage (see B702), and proper screening of pipe connections in piping containing flammable liquids
- proper insulation of hot surfaces shall be randomly verified with the readings obtained during type test (see B1704) while running the engine at 100% load, alternatively at the overload approved for intermittent use. Use of conventional contact thermometers may be accepted at discretion of the attending surveyor. However, if there has been made revisions to the insulation interface, reservation is made with regard to request for more enhanced measurements as conducted during type test.

D 300 Testing of propulsion engines

301 The testing described in 300 apply to propulsion engines in addition to 200.

302 The engine shall be tested at the following power levels (given in percentage of MCR):

50%, 75%, 90%, 100% and 110%, according to 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 (or permitted) to nominal value.

Or:

b) *The modified propeller curve*

This applies if driving a controllable pitch propeller that

— is intended to use a higher pitch than the nominal when running at reduced r.p.m. In this case, the load point with lowest r.p.m. at 100% of maximum continuous rated torque shall be added
— has a combinator pitch control using reduced pitch at lower speeds. In this case the pitch limitations have to be stated on a signboard for the purpose of manual operation.

Or:

c) *At constant speed*

This applies if driving a controllable pitch propeller with constant speed or a 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. Normally, an operating time of 0.5 to 1 hour can be assumed per load point.

303 Where the engine shall be certified for an intermittent overload rating, the test point at 110% of maximum continuous rating is replaced with a test point that corresponds to the specified overload approved for intermittent use.

This applies where such overload rating exceeds 110% of MCR. Where the approved intermittent overload rating is less than 110% of MCR, subject overload rating shall replace the load point at 100% of MCR. In such case the load point at 110% of MCR remains.

304 Engines with turbocharger that is served by cylinder groups with combined power in excess of 2 500 kW shall be tested with regard to surge margins.

For 4-stroke diesel engines, the following test shall be performed without indication of surging:

— with maximum continuous power and speed (= 100%), the speed shall be reduced with constant torque (fuel index) down to 90% power
— with 50% power at 80% speed (propeller characteristic for fixed pitch), the speed shall be reduced to 72% while keeping constant torque (fuel index).

For 2-stroke engines, the surge margin shall be demonstrated by at least one of the following methods:

1) Engine working line established at the workshop testing of engine (w/turbocharger) shall be plotted into the compressor map of the turbocharger. There shall be at least 15% surge margin in the full load range, i.e. working flow shall be 15% above the theoretical flow at surge limit (at constant pressure).
2) Sufficient surge margin to be demonstrated by sudden fuel cut-off to at least one cylinder. For applications with more than one turbocharger, cut the fuel supply to the cylinder closest upstream to each turbocharger.
   This test shall be performed at two different engine loads:
   — The max power permitted for one cylinder misfiring.
   — The engine load corresponding to a charge air pressure of about 0.6 bar (but without auxiliary blowers running).
3) Sufficient surge margin to be demonstrated by an abrupt (< 2 sec) reduction in power from MCR to 50% of MCR.

Acceptance criteria for alternative 2 and 3:

No continuous surging is accepted, and the turbocharger must stabilise itself at the new load within 20 seconds.

The above mentioned tests may be waived if successfully tested earlier on an identical configuration of engine and turbocharger.

305 For reversible engines the ability of starting astern shall be demonstrated.

306 The function of water drain from the charge air system shall be checked.

307 The function of the cylinder lubricators shall be randomly checked as applicable.

308 The jacket cooling and the piston cooling medium temperatures (when applicable) shall be checked versus engine specifications.

309 For plants with water jet the speed control system shall be checked with a sudden load shed from the maximum continuous power to zero load. The engine overspeed is not to release the overspeed protective device. This applies to all engines where the overspeed trip is set less than 15% above the rated speed for continuous power. This applies to all single engine plants regardless of overspeed trip setting.

The above test may be replaced by analysis provided that the calculation methodology has been adequately validated through relevant and realistic full load testing. Such validation shall be evaluated and accepted by the Society.

D 400 Testing of engines for auxiliary generating sets

401 The testing described in 400 is additional to 200.

402 The engine shall be tested at the following power levels (given in percentage of MCR):

50%, 75%, 100% and 110%, at constant speed.

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. Normally, an operating time of 0.5 to 1 hour can be assumed per load point.

403 The overspeed protective device shall be tested. It shall trip the engine prior to the maximum permissible speed. The speed governor shall be tested with the maximum relevant load shed without tripping due to overspeed. For generating sets tested as a unit, the load shed shall be instantaneous from 100% of maximum continuous rated torque to zero torque. If the engine is tested on a waterbrake this load-shed test may be postponed to testing on board.

D 500 Opening up after testing

501 If nothing else is specified in a manufacturing survey arrangement, the requirements in 502 to 505 apply.

502 All inspection covers shall be opened.

503 The crankshaft deflections shall be checked according to the manufacturer’s specification. The condition (hot or cold) shall be noted on the record.

504 For propulsion engines the following items apply:

— without surface hardened camshaft drive train, the drive train shall be checked
— cams and cam rollers shall be checked randomly
— one piston shall be removed for inspection of the unit
— one crosshead with bearing and guide to be checked
— one crankpin bearing shall be checked. In the case of serration, a thorough check for fretting shall be carried out
— one cylinder head shall be checked visually, valves disassembled and with NDT on indication of cracks
— one main bearing shall be checked.

If deemed necessary by the surveyor, further dismantling of the engine may be required.

505 For engines driving auxiliaries the extent of random checks of components to be presented for inspection after the workshop trials, shall be agreed with the surveyor.

E. Control and Monitoring

E 100 General

101 The requirements in E are additional to those given in Ch.9. For requirements related to design of the control and monitoring system in terms of:

— automatic control
— remote control
— safety system
— when, where and how to present alarms
— what kind of indication to be presented where
— system operation and maintenance
— power distribution

see Ch.9 Sec.3

102 Alarms and start of standby pumps shall be without delay, other than those necessary to filter normal parameter fluctuations, if not otherwise approved.

103 Engine exhaust gas monitoring shall serve the following purposes:

a) *Temperature surveillance of exhaust gas inlet to turbocharger:*
The temperature of the exhaust gas inlet to turbocharger shall not exceed the permissible values set by the turbocharger maker without the ship crew being notified. A pre-warning shall be given before the temperature rise to a level at which immediate response from crew is required in order to prevent turbocharger damage.

b) *Detection of harmful misfiring operation for engines with cylinder power > 130 kW:*
It shall be possible to detect misfiring operation where such running conditions could be harmful to the engine and or power transmission. Critical operation in misfiring will be identified through approval of torsional vibration analysis, see A600 and G300.
Given identification of critical misfiring operation, omission of requirement for individual exhaust gas temperature measurements can be accepted provided other means of monitoring critical running conditions for engine and power transmission (e.g. vibratory twist of elastic couplings at misfiring).
Where no critical running conditions are identified for the engine and power transmission, there will be no requirement for detection of misfiring operation, provided the power per cylinder is equal to or less then 500 kW.
For engines with power per cylinder of more than 500 kW, requirements for individual exhaust gas monitoring at each cylinder as given in Table E1 and E2 remains independent of detection of any critical misfiring operation.

104 Starting interlock shall be provided whenever the turning gear is engaged.

E 200 Speed governing

201 All engines shall be fitted with a speed governor so adjusted that the engine speed cannot continuously exceed the rated speed by more than 10%. For engines used as prime movers for electrical power generation, see additional requirements in Ch.2 Sec.4 A100.

202 When electronic speed governors of propulsion engines form part of a remote control system, they shall comply with Ch.1 (rules for ships) and Ch.9.

Electronic speed governors and their actuators shall be type tested according to standard for certification No. 2.4.

E 300 Overspeed protection

301 A separate overspeed protective device is required. The overspeed protective device may be substituted by an extra speed governor that is completely independent of the first governor and acting without delay.

302 Activation of the overspeed protection device shall cause either engine shutdown or limitation of rpm. This applies to both systems if the overspeed protection device is substituted by an extra speed governor. Activation of the overspeed protection system shall be identified in the control room.

303 The overspeed protective device shall be adjusted to ensure that the engine speed cannot exceed the maximum permissible speed as determined by the design, but not beyond 120% rated speed except for diesel engines driving generators where 115% of rated speed applies.

(IACS UR M3.1.2 and M3.2.5)

304 For engines operating in areas defined as gas hazardous zones or spaces (see applicable class notation), an additional device that automatically shuts the air inlet in case of overspeed. The shutting device shall activate at the same speed level as does the overspeed protective device required in 301. For engines with turbochargers that can suffer overspeed due to a sudden shut of air intake, the shutting device should be between the turbocharger and the engine.

E 400 Monitoring of propulsion engines

401 All single propulsion engines shall fulfil the following requirements. If there are more than two propulsion engines, and no additional class notation as **E0**, the requirements may be reduced subject to special considerations.

402 The propulsion engines shall be fitted with instrumentation and alarms according to Table E1 if not otherwise approved.

Table E1 Control and monitoring of propulsion engines						
System	*Item*	*Valid for engine type 1)*	*Gr 1 Indication alarm load reduction*	*Gr 2 Automatic start of stand-by pump with alarm 2)*	*Gr 3 Shut down with alarm*	*Comments*
1.0 Fuel oil system	Leakage from jacketed high pressure pipes	C, T	A			Level monitoring of leakage tank or equivalent
	Fuel oil pressure after filter (engine inlet)		LA			
2.0 Lubricating oil system	Lubrication oil to all bearings, inlet pressure 3)	C, T	IR, IL, LA, LR	AS	SH	LR is accepted as alternative to SH
	Lubrication oil to all bearings, inlet temperature		IR, IL, HA			
	Thrust bearing metal temperature	C	IR, HA, LR			
3.0 Turbocharger system	Turbocharger lubrication oil inlet pressure	C, T	IR, IL, LA			Applicable if separately forced lubrication or if turbocharger lubrication is part of engine main lubrication system but separated by pump, throttle or pressure reduction valve
	Turbocharger lubrication oil outlet temperature		IR, HA			Applicable only when the T/C is served by group of cylinders > 2 500 kW
	Speed of turbocharger		IR, HA			Applicable only when the T/C is served by group of cylinders > 1 000 kW
4.0 Piston cooling system	Piston coolant inlet pressure (common)	C	IR or IL, LA, LR	AS		Load reduction and automatic start of stand-by pump is not required if the coolant is oil taken from the main lubrication oil system of the engine
	Piston coolant outlet flow each cylinder		LR			
5.0 Cylinder cooling medium	Cylinder cooling inlet pressure or flow	C, T	IR or IL, LA, LR	AS		Monitoring of expansion tank level, with alarm at low level, is an acceptable alternative for engines with cylinder power < 130 kW
	Cylinder cooling outlet temperature		IR or IL, HA, LR			Temperature to be monitored for each cylinder if individual stop valves are fitted for the cylinder jackets, otherwise main outlet. Sensor location so as to enable alarm in event of closed valve
6.0 Starting and control air systems	Control air reservoir pressure (if arranged)	C, T	IR or IL, LA			
6.1 Pneumatic return of exhaust valve	Exhaust gas valve air spring pressure	C	IR or IL, LA			Pressure readings shall be taken at the supply line locally on the engine
7.0 Charge air system	Charge air pressure	C, T	IR			
	Charge air temperature, under each piston (fire detection)	C	LR			

Table E1 Control and monitoring of propulsion engines (Continued)

System	*Item*	*Valid for engine type [1]*	*Gr 1 Indication alarm load reduction*	*Gr 2 Automatic start of stand-by pump with alarm [2]*	*Gr 3 Shut down with alarm*	*Comments*
8.0 Exhaust gas system	Exhaust gas temp after each cylinder [4]	C, T	IR, HA, LR [5]			
	Exhaust gas temp after each cylinder. Deviation from average [4]		IR, HA, LR			Chosen load reduction depends on permissible misfiring condition
	Exhaust gas temp before T/C [6), 7]		IR, HA, LR			LR is only required when the T/C is served by group of cylinders > 2 500 kW
9.0 Hydraulic oil system	Leakage from jacketed high pressure pipes for hydraulic operation of valves	C, T	A			Level monitoring of leakage tank or equivalent
10.0/11.0 Engine speed/ direction of rotation	Engine speed/direction of rotation	C, T	IL, IR			
	Over speed protection		LR		SH	See 300. LR or SH, if applicable, shall be activated automatically
	Excessive time within barred speed range [8]	C	A			
12.0 Chain tension	Position feeler “sensor”	C	IL			Where applicable

Table E1 Control and monitoring of propulsion engines (Continued)

System	*Item*	*Valid for engine type 1)*	*Gr 1 Indication alarm load reduction*	*Gr 2 Automatic start of stand-by pump with alarm 2)*	*Gr 3 Shut down with alarm*	*Comments*
13.0 Crankcase explosive condition 9) 10)	Oil mist detection 11)	C	LR			
		T			SH	Shall be activated automatically
	Other systems than oil mist detection	C, T	LR		SH	Either LR or SH

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 engine component or system
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, either slow down (r.p.m. reduction) or alternative means of load reduction (e. g. pitch reduction), whichever is relevant.
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) C = Crosshead engine, T = Trunk engine.
2) To be provided when stand-by pump is required, see B1002 and Ch.1 of the Rules for Classification of Ships.
3) Pressure to be monitored for all inlets to main bearings, crosshead bearings, torsional vibration dampers and camshaft bearings where pressure may differ due to presence of pumps, throttles, rotor seals or pressure reduction valves.
4) Individual exhaust temperature when cylinder power > 130 kW. See 103 for possible omission of this requirement.
5) Alarm with request for load reduction to be given in case of excessive average exhaust gas temperature. This applies when there is no separate sensor before T/C, and the T/C is served by a group of cylinders > 1 000 kW. The alarm level shall be set with due considerations to safe operation of T/C.
6) Applicable only when the T/C is served by a group of cylinders > 1 000 kW and if no individual exhaust gas temperature for each cylinder.
7) Temperature measurement after turbine is accepted for T/C served by a group of cylinders < 2 500 kW, provided that the alarm levels are set to safeguard the T/C. The alarm level shall be substantiated by the T/C manufacturer.
8) When driving in barred speed range in excess of approved maximum duration set by torsional vibration level in the shafting (where deemed necessary, limitations in duration will be given in connection approval of torsional vibration analysis). This safety device will only be required when so stated in connection with approval of torsional vibration analysis.
9) For trunk engines:
Either a) 'Oil mist concentration' or b) 'Temperature monitoring of main- and crank bearings combined with crank case pressure monitoring'. Other methods, like e.g. ´crank case pressure monitoring´ combined with either 'Oil splash temperature deviation' or 'Metal particle detection' (shunt to filter), may be approved provided their capability with regard to risk of false alarms and speed of detection is proven.

For crosshead engines:
Oil mist concentration or temperature monitoring of main-, crank- and crosshead bearings together with other relevant positions, or other methods may be applied as additional measures of preventing crankcase explosions. These additional measures are optional
10) Applicable to engines of 2 250 kW and above, or with cylinder diameter > 300 mm.
11) Oil mist detectors shall be type tested in accordance with IACS UR M67.

E 500 Speed governing of diesel generator sets

501 For requirements concerning the speed governing of diesel generator sets, see Ch.2 Sec.4.

E 600 Monitoring of auxiliary engines

601 Instrumentation and alarms of auxiliary engines for main electrical power generation are required according to Table E2 if not otherwise approved.

For other auxiliary engines a less comprehensive outfit may be approved.

Table E2 Control and monitoring of auxiliary engines

System	*Item*	*Gr 1 Indication alarm load reduction*	*Gr 2 Automatic start of stand-by pump with alarm* [1]	*Gr 3 Shut down with alarm*	*Comment*
1.0 Fuel oil system	Leakage from jacketed high pressure pipes	A			Level monitoring of leakage tank or equivalent
2.0 Lubricating oil system	Lubrication oil to main bearings, inlet pressure	IR or IL, LA, LR	AS	SH	LR is accepted as alternative to SH for auxiliary engines other than driving generators
	Lubrication oil to main bearings, inlet temperature	IR or IL, HA			
3.0 Turbocharger system	Speed of turbocharger	IR or IL, HA			Applicable only when the T/C is served by group of cylinders > 1 000 kW
4.0 Cylinder cooling medium	Cylinder cooling inlet pressure or flow	IR or IL, LA	AS		Monitoring of expansion tank level, with alarm at low level, is an acceptable alternative for engines with cylinder power < 130 kW
	Cylinder cooling outlet temperature	IR or IL, HA, LR		SH	Either LR or SH
5.0 Exhaust gas system	Exhaust gas temp after each cylinder [2]	IR or IL, HA, LR [3]			SH may replace LR for electric power generating engines
	Exhaust gas temp after each cylinder. Deviation from average [2]	IR or IL, HA, LR			Chosen LR depends on permissible misfiring condition. SH may replace LR for electric power generating engines
	Exhaust gas temp before T/C [4], [5]	IR or IL, HA, LR			The LR is only required when the T/C is served by group of cylinders > 2 500 kW SH may replace LR for electric power generating engines
6.0 Hydraulic oil system	Leakage from jacketed high pressure pipes for hydraulic operation of valves	A			Level monitoring of leakage tank or equivalent
7.0/8.0 Engine speed/ direction of rotation	Engine speed	IR			For engines other than for electric power generation, local indication is an acceptable alternative
	Overspeed protection			SH	See 300. Either LR or SH. Shall be activated automatically
9.0 Crankcase explosive condition [6], [7]	Oil mist detection [8]			SH	Shall be activated automatically
	Other systems than oil mist detection	LR		SH	Either LR or SH

Table E2 Control and monitoring of auxiliary engines (Continued)

System	*Item*	*Gr 1 Indication alarm load reduction*	*Gr 2 Automatic start of stand-by pump with alarm 1)*	*Gr 3 Shut down with alarm*	*Comment*

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 engine component or system
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) To be provided when stand-by pump is required.
2) Individual exhaust temperature when cylinder power > 130 kW. See 103 for possible omission of this requirement.
3) Alarm with request for load reduction to be given in case of excessive average exhaust gas temperature. This applies when there is no separate sensor before T/C, and the T/C is served by a group of cylinders > 1 000 kW. The alarm level shall be set with due considerations to safe operation of T/C.
4) Applicable only when the T/C is served by a group of cylinders > 1 000 kW and if no individual exhaust gas temperature for each cylinder. The alarm level must be set with due considerations to safe operation of T/C.
5) Temperature measurement after turbine is accepted for T/C served by a group of cylinders < 2 500 kW, provided that the alarm levels are set to safeguard the T/C. The alarm level shall be substantiated by the T/C manufacturer.
6) Either a) 'Oil mist concentration' or b) 'Temperature monitoring of main- and crank bearings combined with crank case pressure monitoring'. Other methods, like e.g. ´crank case pressure monitoring´ combined with either 'Oil splash temperature deviation' or 'Metal particle detection' (shunt to filter), may be approved provided their capability with regard to risk of false alarms and speed of detection is proven.
7) Applicable to engines of 2 250 kW and above, or with cylinder diameter > 300 mm.
8) Oil mist detectors shall be type tested in accordance with IACS UR M67.

E 700 Monitoring of emergency generator prime movers

701 The requirements of 700 apply to engines used as prime movers for emergency generators.

702 Monitoring of emergency generator prime movers is required according to Table E3 if not otherwise approved.

703 If the emergency generator is used as harbour generator, monitoring system shall be installed as required by Table E2. When operating as emergency generator the safety devices shall not cause interruption of the emergency power supply, except for protective functions listed in Table E3.

704 Manual stop devices for the emergency generator prime mover shall only be arranged in the same room as it is located and in close vicinity to the entrance door to the room.

Table E3 Control and monitoring of engines for emergency generators

System	*Item*	*Gr 1 Indication alarm load reduction*	*Gr 2 Automatic start of stand-by pump with alarm 1)*	*Gr 3 Shut down with alarm*	*Comment*
1.0 Fuel oil system	Leakage from jacketed high pressure pipes	A			Level monitoring of leakage tank or equivalent
2.0 Lubricating oil system	Lubrication oil to main bearings, inlet pressure	IL, LA			
	Lubricating oil inlet temperature	IL, HA			HA applicable if ≥ 220 kW
4.0 Cylinder cooling medium	Cylinder cooling outlet temperature	IL, HA			
	Pressure or flow of cooling water	IL, LA			LA applicable if ≥ 220 kW
7.0/8.0 Engine speed	Engine speed	IL			
	Overspeed protection			SH	Applicable if ≥ 220 kW Shall be activated automatically
9.0 Crankcase explosive condition 2) 3)	Oil mist detection 4)	HA			
	Other systems than oil mist detection	A			

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 engine component or system
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.

1) To be provided when stand-by pump is required, see Ch.1 of the Rules for Classification of Ships.
2) Either a) 'Oil mist concentration' or b) 'Temperature monitoring of main- and crank bearings combined with crank case pressure monitoring'. Other methods, like e.g. ´crank case pressure monitoring´ combined with either 'Oil splash temperature deviation' or 'Metal particle detection' (shunt to filter), may be approved provided their capability with regard to risk of false alarms and speed of detection is proven.
3) Applicable to engines of 2 250 kW and above, or with cylinder diameter > 300 mm.
4) Oil mist detectors shall be type tested in accordance with IACS UR M67.

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.

204 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.

205 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

301 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.

302 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.

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

304 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

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

402 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.

403 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

501 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.

502 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.

503 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, see also B1102.

F 600 Crankcase ventilation pipes

601 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.

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G. Vibration

G 100 Symbols and definitions

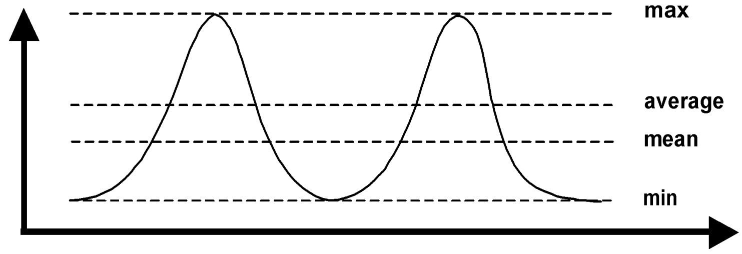
101 The following symbols are used in G:

n_0 = r.p.m. at maximum continuous power
n = r.p.m. at which vibration are considered
λ = 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.
τ = torsional stress (N/mm^2) corresponding to T
τ_v = torsional stress (N/mm^2) corresponding to T_v.

102 The *amplitude of vibratory torque* is defined as:

T_v = 0.5 (maximum torque - minimum torque) 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.

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

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

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:

$T_V = (T_{Vmisfiring} - T_{Videal})\ z/24 + T_{Videal}$

However, not less than T_{Videal}

z = 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_{Videal} 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.

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

f) 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.

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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 G1 Propeller excitation

Number of blades	*Blade frequency (%)*	*Double blade frequency (%)*
3	8	2
4	6	2
5	4	1.5
6	4	1.5

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 +/-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 unnecessary wide because this can result in a too slow passage with the consequence of higher vibratory stresses and more cycles.

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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 $(K_A - 1) \cdot T_0$ 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

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 Note 41.4.

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:

$T = T_0 \; [10\, e^{-t/0.4} \sin(\Omega\, t) - 5\, e^{-t/0.4} \sin(2\Omega\, t)]$
$\Omega/2\pi$ = the net frequency (50 or 60 Hz)
t = 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 T_{Kmax1} nor ΔT_{Kmax}.
Transient vibration as determined in 404 are not to exceed T_{Kmax2}.
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 $K_{AP} \cdot T_0$ or 1.5 T_0.

c) *Shafts*
For shafts that are designed on the basis of transient vibration as determined in 401, the torque amplitudes as well as number of equivalent cycles per passage are not to exceed the premises for the shaft design.

G 500 Axial vibration

501 *Extent and method of calculation*

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

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 seaway 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.3.

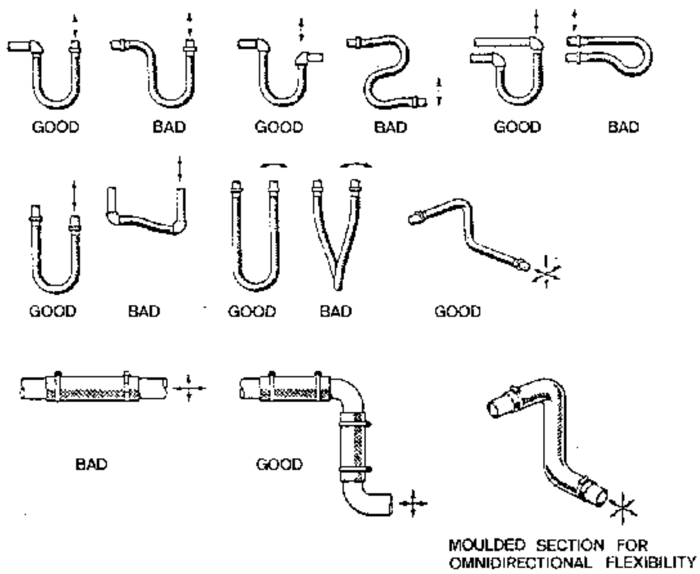

Fig. 3
Recommended arrangements of hoses and pipes

c) It shall be verified that the exhaust pipe compensators allow for the maximum possible engine movements.

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.

102 Unless otherwise stated, a surveyor shall attend the tests and inspections given in I.

I 200 General engine tests

201 The functioning of water drain from the charge air system shall be checked.

202 The functioning of the cylinder lubricators (when applicable) shall be randomly checked.

203 The engine shall be checked for any leakage of fuel oil, hydraulic oil or lubrication oil.

204 The suitability of the engine to burn heavy fuel oil or other special fuels shall be demonstrated, if the machinery installation is arranged to burn such fuels.

205 If the sea trial full load testing is made on light diesel, and the service is intended for heavy fuel, the mechanical blocking of the fuel rack shall be made after sea trial testing. The blocking shall limit the engine output to the approved value.

206 For engines run on heavy fuel, the maximum pressure shall be recorded for each cylinder at maximum continuous rating. It shall not exceed the maximum permissible value nor vary more than permitted by the engine designer, alternatively 3% of the maximum permissible value where no design specification applies.

207 Starting tests shall be made in order to document the required starting air energy capacity, see Ch.6 Sec.5 of the Rules for Classification of Ships.

208 The control, alarm and safety functions shall be tested, see Table E1, E2 and E3, except items integrated in the engine and verified during the workshop test, for compliance with the approved alarm list, ref. Table A1.

209 Insulation of hot surfaces as required in B1101 shall be checked during maximum load as defined in 301 by measuring surface temperature.

Guidance note:

Although use of conventional contact thermometers may be accepted at the discretion of the attending surveyor, it is advised to use Infrared Thermoscanning Video Equipment or similar for documentation. Such equipment may be required where there has been made revisions to the insulation interface.

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I 300 Testing of propulsion engines

301 The engines are normally to be tested for 4 hours at 100% power. Engines approved for intermittent overloading shall be tested at the approved overload for a duration sufficient to achieve steady state conditions for all operation parameters in the propulsion lines. If the engine cannot be loaded to 100% power at 100% rated speed due to propeller characteristics (fixed pitch or upper pitch limitation for controllable pitch) and ballast conditions, the following applies:

— 4 hours at 100% of rated engine speed.
— 30 minutes at 103.2% of rated engine speed or at the speed corresponding to 100% engine torque, whichever is less.

For small engines, and in particular engines for HS, LC and NSC, less than 4 hours at full load may be considered. The running time must be sufficient to reach steady state thermal conditions and to make all necessary records. A deviation from the normal 4 hours full load running has to be approved by the Society.

302 The lowest engine speed according to nominal propeller curve shall be determined for plants with fixed pitch propellers.

303 For two stroke engines the auxiliary blowers shall be checked for correct start and stop according to specification.

304 Reversible engines shall be tested with a minimum reversing engine speed of 70% of the rated forward speed for at least 10 minutes. If the above should conflict with a barred speed range, another suitable speed will apply.

Guidance note:

Reversible engines shall be tested with a reversing speed that is suitable for ordinary manoeuvring as well as for crash stop manoeuveres. Care shall be taken not to operate in conflict with a barred speed range that has to be passed through quickly.

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I 400 Testing of auxiliary engines

401 Engines for auxiliary purposes shall be tested at 100% power for a duration sufficient for conducting all related inspections or measurements, however not less than one hour.

402 Engines driving generators shall be tested according to requirements in Ch.2 Sec.4.

I 500 Steady state torsional vibration

501 Direct coupled engines with a barred speed range shall be checked for stable running at both lower and upper borders of the barred range. For controllable pitch propellers, this shall be tested with both zero and full pitch. The engine speed shall be stable and the fuel rack index to oscillate (maximum to minimum) less than 10% of the effective stroke (idle to full).

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 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.

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

603 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.

I 800 Opening up after testing

801 Unless otherwise approved, the following apply for propulsion engines supplied in sections and assembled onboard:

a) One crankpin bearing shall be checked. In the case of serrations, a thorough check for fretting shall be carried out.

b) One main bearing shall be checked. Crankshaft deflections shall be checked as per manufacturer's specification.

c) The camshaft drive of crosshead engines, when not surface hardened, shall be visually checked for wear (e.g. pits or scuffing).

d) One piston and cylinder head shall be removed for inspection. The inside of the cylinder liner shall be inspected.

e) One crosshead bearing and guide shall be checked.

f) The thrust bearing shall be checked.

For diesel engines supplied and installed in assembled condition, there are no requirements for opening up after testing unless there is any reason to suspect any abnormal wear of, or damage to, engine components.

SECTION 2
GAS TURBINES

A. General

A 100 Application

101 This section covers requirements applicable to gas turbines subject to certification, see Ch.2 Sec.1, as well as the engine installation and shipboard testing. These requirements apply to conventional gas turbines used as propulsion engines and driving auxiliaries, and are aimed at manufacturers, packagers, 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 The rules in B to E apply to gas turbine core engine. The rules in F, H and I apply to the installation of the gas turbine, the gas turbine and its system dynamics and the shipboard testing. The rules in G apply to both.

103 The gas turbine core engine shall be delivered with a NV certificate that is based on the design approval in B and E, production verification in C and work shop testing in D.

104 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 onboard 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.

105 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.

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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).

106 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.

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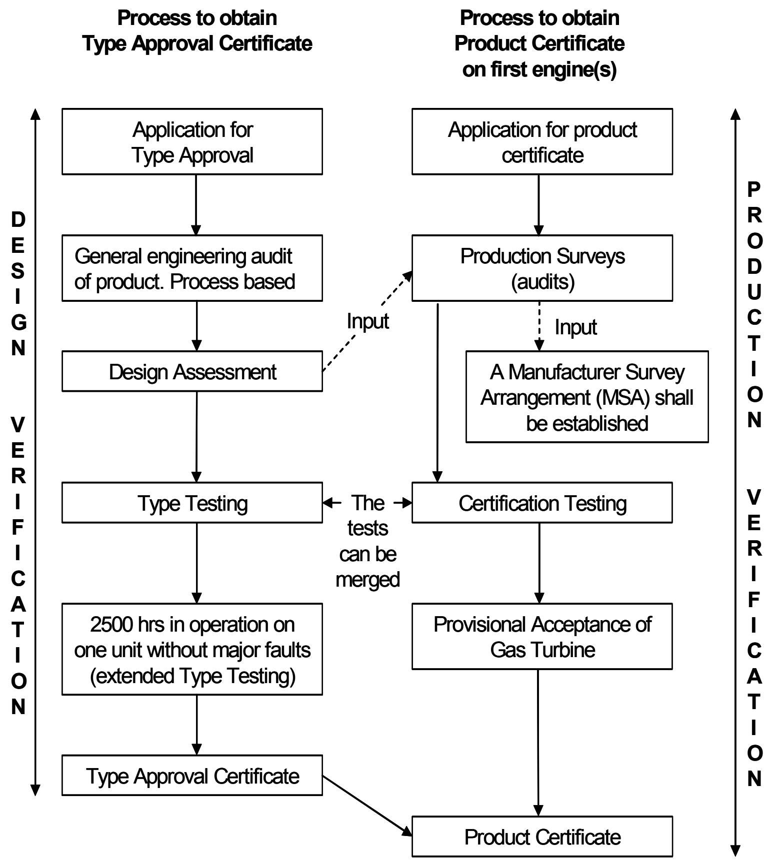

Fig. 1
Type approval and certification process for the first engine

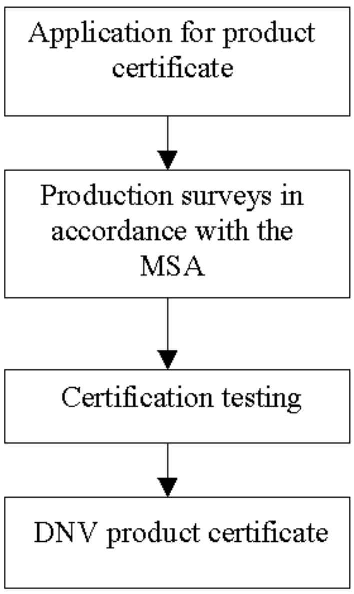

Fig. 2
Certification process for subsequent engines

A 200 Documentation

201 Drawings, data, specifications, calculations and other information shall be submitted as requested in 200 to 700. Table A1 lists the required submittals for core engine. In addition, the Society may require complementary information when faced with operational incidents, unconventional designs, modifications, upgrading, and change in application, change in working cycle, change in any major parameters or any other modified operating conditions.

Guidance note:

Detailed document requirements can be found in relevant paragraphs in B. Table A1 is meant as a general listing of documentation requirements.

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202 *Drawings and material specification*

The arrangement plans ought to contain as many details as practically possible in order to reduce the total number of plans. E.g. if details of sub-level items as listed in table A1 can be given on the arrangement plan, then separate drawings of these items need not to be submitted.

In general, the drawings shall include the material and main dimensions of components listed in Table A1. More details may be required in the individual paragraphs in B. Production drawings are not required.

In case the materials are manufacturer specific, the material properties, as chemical composition, yield strength, elongation, fatigue and creep properties etc. (relevant to the design review) shall be supplied upon request.

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

203 *Calculations*

When calculations are required, these shall substantiate requirements in these rules or OEM's own requirements.

In general, calculations shall include:

— objectives
— requirements/acceptance criteria
— description of method
— conditions
— assumptions
— conclusion.

204 For the purpose of these rules, the following definitions apply:

a) Engines driving generators in electric propulsion systems are defined as propulsion engines.

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

c) *Start-stop stress cycle* consists of a mission cycle or an equivalent representation of engine usage. It includes starting the engine, accelerating to maximum rated power, decelerating, and stopping.

d) *Time between overhaul.* This is 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 exceeded and lubricating (when applicable) and fuel oils specified in the type approval certificate have been used. All essential parts that are normally not carried onboard for regular onboard maintenance shall have a lifetime exceeding the TBO.

e) OEM means Original Equipment Manufacturer.

Table A1 Documentation Gas turbine core engine

Plans, analysis, particulars, specifications and components	*Drawings and specifications* [1)]	*Material specification*	*Calculations*	*Miscellaneous*	*Design and detailed documentation requirements*
General technical specifications	A				B301
General arrangement of gas turbine	I				B302
Section rotor assembly, including bearings and shaft design	I				B302/B303
Section showing blade, and blade fastening	I				B303
Seals with sealing arrangement	I	I			B303

Table A1 Documentation Gas turbine core engine (Continued)

Plans, analysis, particulars, specifications and components	*Drawings and specifications* 1)	*Material specification*	*Calculations*	*Miscellaneous*	*Design and detailed documentation requirements*
Bladed disks	A	A	I (blades) A (disks)		B304
Casing	A	A	I		B305
Variable guide vanes	I			I	B306
Bleed valves	I			I	B307
Bearing, rolling element	I	I	I	I	B308
Bearing, hydrodynamic	I	I			B309
Bearing, thrust	A	A	I		B310
Bearing housings	I				B311
Tie rod	A	A	I		B312
Rotors	A	A	A		B313
Shafts	A	A	A		B314
Combustor and flame tube	A	A	I	I	B315
Burners	I	I	UR		B316
Turbine nozzles	A	A	I		B317
Turbine internal air cooling system	I				B318
Starting systems	A				B319
Lubricating oil system	I		UR		B321/B320
Turbine fuel system	I				B322/B320
Fuel specification	I				B323
Control system 2)	A			I	B324
Monitoring system 2)	A				B325
Safety system 2)	A		A	A	B326
Performance	I		I		B327
FMEA	I				B328
Fire prevention	A	A			B329
Maintenance manuals	I				B330
Operating manual	I				B331
Test procedures	A				B332

A = for approval
I = for information
UR = upon request

1) Detailed sub-level drawings of components are not required. The requested drawing content is described in 202 and in B.

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

Table A2 Vibration analysis requirements for components

Component	*Analysis type*	*Reference to design requirements*
Bladed disks (I)	Natural frequencies and mode shapes, Campbell diagrams	B304
Rotors (A)	Natural frequencies, mode shapes and stability	B313

Table A3 Vibration measurement requirements for core engine and system

Test type	Measurements	Reference to test requirements
Type test	Verification of core engine lateral critical speeds and vibration levels during mechanical running test	B914 to B916
Certification test	Verification of core engine vibration levels	D211
Sea trial	Verification of core engine and system vibration levels	I203, I208
All tests	Verification of ancillaries and piping vibrations	B504

A 300 Documentation of vibration analysis (core and system)

301 Vibration analyses are required for components such as blades, impellers and rotors (vibration analysis of disks upon request). For reference to detailed rule requirements, see Table A1.

Detailed requirements for documentation of vibration analysis for core engine and system (i.e. including driven equipment) behaviour are described in G as follows:

Lateral vibrations, see G202
Torsional vibrations, see G203
Engine vibration, see G300.

These analyses are subject to approval.

Requirements for measurement verification of actual vibration behaviour for core engine and system are shown in Table A3.

A 400 Documentation of arrangement

401 The following plans and specifications shall be submitted:

a) Engine room arrangement with enclosure, ventilation system, gas turbine hook-ups and adjacent components.
b) Engine fastening arrangement with bolts, struts, base frame, stoppers, epoxy resin, metallic chocks or resilient mounts, as applicable. The following shall be included:

— bolt pre-tension calculations (see F302)
— epoxy resin surface pressure calculations (see F301)
— chock dimensions (see F301)
— "dynamic" and static calculations of resilient mounting (see F400)
— stress calculations for foundation members (see F201)
— buckling calculations for supports and struts, if applicable, (see F201)
— deflection calculations of gas turbine casing, if applicable (see F202)
— upon request, natural frequency calculations of foundation system (see F203).

c) Coupling alignment specification (see F101)
d) Arrangement plans of inlet and exhaust ducting (see F500). Specification of the following systems to be submitted (as applicable):

— filtration system
— silencer system
— expansion bellows.

e) Specification of anti-icing system (when applicable) including:

— drawings showing the anti-icing system (flow of hot gas, when applicable)
— 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.

f) Specification of water wash and carbo blast system (see also F600) to be submitted (when applicable).
g) Documents to verify compliance with F700. This may for instance be:

— drawings indicating location of doors
— drawings indicating location of equipment such as pumps, valve blocks, starting system, electrical panels, etc.
— drawings indicating location of fans and blowers in the ventilation system
— material specification for enclosure and fire dampers
— specification of measures to prevent personnel being exposed to fire extinguishing medium constituting a health hazard
— documentation of ventilation air distribution (upon request).

h) For gas turbines intended not to be fitted inside an enclosure, drawings indicating temperature profile on the skin and casing of the gas turbine from intake to exhaust (maximum). This shall include bleed air piping, with the maximum temperature.

A 500 Documentation of production verification

501 The following shall be submitted to DNV in due time before product audit (see C300):

— extent of own production and purchasing
— production schedule of relevant components
— type of certified quality system

— procedures and specifications as requested by the Society.

A 600 Documentation of fire safety

601 Fire safety documentation to be submitted as a minimum is as follows, (see E400):

— fire safety system description and philosophy
— drawings indicating location and type of fire (flame) detection, and fire extinguishing equipment in addition to requirements in the Rules for Classification of Ships Ch.10 and Ch.10 in the Rules for HS, LC and NSC
— arrangement of fuel spray shields, for gas turbines not fitted inside an enclosure
— special piping arrangement showing location of pipes, hoses, filters, valves and pumps in relation to potential ignition sources
— insulation type, method and arrangement
— drawing of fuel trays and handling of fuel and lubrication oil leaks.

In case of enclosure, the following shall be documented with respect to fire safety (see E400):

— type and capacity of the enclosure fire extinguishing medium to be specified
— compliance with a recognised standard (see E405) shall be documented
— specification of action sequence in case of fire (alarm, fuel shut off, closing of ventilation ducts, fire extinguishing, etc.).

A 700 Documentation for shipboard testing

701 Documentation for shipboard testing shall be submitted as follows:

— sea trial test program.

B. Design

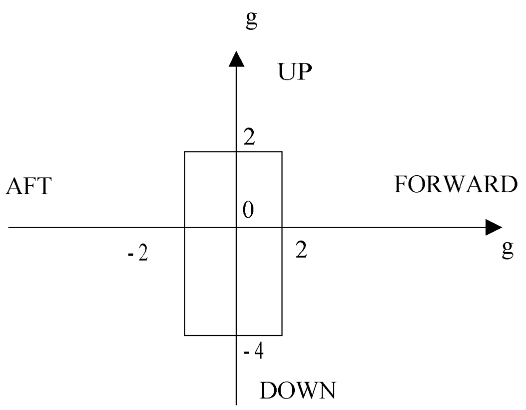
B 100 General

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

102 The design and construction shall enable the gas turbine to meet the general requirements in 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:



Normal operation

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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 2 500 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 *General technical specifications, features and operational modes*

A general technical description of the turbine shall be submitted, providing an overview of engine design and technical capabilities. This shall include key gas turbine parameters as given in Table B1, and the application constraints as given in table B2.

Instrumentation particulars shall be submitted in accordance with E200.

Table B1 Documentation of general technical specifications				
Mass (kg)				
Time between overhaul (hrs / cycles or equivalent hours)				
	RATING			
	IDLE	MCR ISO 1)	MCR 2)	PEAK 3)
Maximum continuous ratings (kW)				
Maximum air mass flow rate (kg/s)				
Temperature at all main sections of the gas turbine, see Fig. 3 (°C)				
Pressure at all main sections of the gas turbine, see Fig.3 (bar)				
Gas generator speed(s) (rpm)				
Power turbine speed (rpm)				
	NORMAL			PEAK
Maximum permissible rate of load increase and load decrease (kW/s)				
Maximum permissible rate of acceleration and deceleration (gas generator and power turbine) (r.p.m./s)				

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 B2 Application constraints	
Subject	*Unit*
Max allowable list and trim	(degrees)
Max allowable pitch and roll	(degrees/s)
Max allowable shear force on output shaft	(N)
Max allowable axial force on output shaft	(N)
Max allowable bending moment at output shaft	(Nm)
Max allowable acceleration loads, see B102	(g)
Fuel type designation	
Max allowable salt content in inlet air	(wppm)

302 *General arrangement*

General arrangement drawings of the gas turbine shall include the following:

— gas generator rotor(s)
— high pressure turbine rotor
— power turbine rotor
— bearings
— seals
— combustion chamber
— blades
— disks
— guide vanes
— shafts.

A sectional representation, incorporating the listed components, is preferred included in one drawing, see also A202.

303 *Rotor assembly*

This drawing shall incorporate all rotating components and their fittings. The drawing is subject for approval if it includes data requested for approval for the individual components. Otherwise it is subject for information. See also A202.

304 *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 shall include analysshall 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.

305 *Casing*

The gas turbine 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.

306 *Variable guide vanes (VGV)*

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.

307 *Bleed valves and variable bleed valves*

Bleed valves shall be documented through drawings, indicating their position, and size. A logic diagram for the bleed valve control to be submitted for information.

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.

308 *Rolling element bearings*

Design documentation of rolling element bearings, containing the following, shall be submitted for approval:

- details of bearings, such as major dimensions, materials, grade of precision 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 to be specified for information:

- 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 B305. 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.

309 *Hydrodynamic bearings*

The following documentation shall be submitted for information:

- 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 to be presented.

310 *Thrust bearings*

Documentation on thrust bearings shall be provided as given in 308 or 309 (as applicable), depending on bearing type. Irrespective of bearing type, thrust force calculations shall be submitted for information. 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.

311 *Bearing housing for hydrodynamic bearings*

Drawings of bearing housing design shall be submitted for information.

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 hydrodynamic 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.

312 *Tie rods*

Whenever tie rods are used in rotors, drawings shall be submitted for approval. The drawings shall include material properties, and heat treatment where applicable.

Calculation of tie rod strength for all applicable steady state and transient load cases shall be submitted for information.

313 *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.

The following documentation shall be submitted for approval.

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 304. Blade loss will be acceptable provided it can be proven that the blade or blades loss can be contained, see 306 for details. The inspection and replacement procedure to be applied in such cases shall be submitted upon request.

314 *Shafts*

Drawing and information of shafts shall be submitted as follows:

a) Drawings showing the main dimensions, stress raisers, and materials submitted for approval.

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.

315 *Combustor and flame tube*

Drawing and information of the combustor and flame tube shall be submitted as follow:

a) Drawings containing main dimensions and materials specification shall be submitted for approval. Drawings of combustors shall be sufficiently detailed to allow correlation with CFD (computational fluid dynamics) calculations or flow visualisation if needed.

b) Combustor description and designation to be submitted for information.

c) Documentation on combustor cooling method (film cooling, impingement cooling, etc.) shall be presented for information.

d) Calculations showing the combined stress (thermal, pressure, and external loads) at critical locations, taking into consideration stress raisers, shall be calculated and presented for information. Cyclic thermal loads (including transient conditions) and cooling effects shall be taken into account in the calculations. The calculation results shall include expected combustor life.

e) Where thermal barriers are used, the locations shall be shown on the combustor 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 and presented for information.

f) Results from CFD calculations shall be submitted upon request.

g) Results of thermal paint tests shall be submitted.

h) Maximum allowable temperature spread at outlet plane shall be submitted for information.

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 is the mean temperature in the outlet plane
= T_2 is the compressor exit temperature.

A typical combustor will have a temperature traverse quality in the order of 20%.

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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 316), 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 E401.

316 *Burners*

Sectional drawings of the burners shall be submitted for information. The drawings shall specify the dimensions and material, as well as respective flow paths of fuel and air.

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

The maximum mass flow rate of the fuel and the expected airflow (fuel air ratio) shall be documented 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.

317 *Turbine nozzles*

Turbine nozzle design documentation shall be submitted for approval or information as indicated:

— dimensional drawing, including material properties (for approval)
— pressure loads (for information)
— thermal loads (for information)
— stress due to expansion limitations (for information)
— cooling system* (for information)
— coatings.* (for information).

* Documentation indicating presence, if applicable. Particulars such as 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 nozzle(s) shall consider the elements listed above and take into account the effects of both loss of coating and cooling (independently), and shall be submitted for information.

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 by documentation.

318 *Turbine internal air cooling system*

Turbine cooling system documentation to be submitted for approval is:

— drawing of the cooling system for the gas turbine
— 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. (Only if installed, see below).

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.

319 *Starting systems*

Documentation submitted for approval shall, as a minimum, be as follows:

a) Electric starting system:

   — drawings describing the system
   — starting torque required
   — motor power and speed
   — starting logic and set points
   — disengaging speed.

b) Pneumatic start system:

   — drawings describing the 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:

   — drawings describing the 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 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.

320 *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 E400.

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

321 *Lubricating oil system*

The following lubricating oil system documentation shall be submitted for information:

- drawing of the lubricating oil system for the gas turbine
- piping and instrumentation diagrams (or equivalent) and instrumentation listing
- drawings shall indicate 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).

Gas turbine lubrication 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 lube 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 lube oil system.

Heat balance calculations for the lubricating 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.

322 *Turbine fuel system*

The following fuel system documentation shall be submitted for information:

- piping and instrumentation diagrams (or equivalent)
- 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.

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Gas turbine 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.

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If biocides are needed, the type used shall be accepted by the engine manufacturer.

323 *Fuel specification*

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.

324 *Core engine controls*

See E100.

325 *Monitoring and instrumentation system*

See E200.

326 *Safety system*

See E300 and E400.

327 *Performance*

Documentation of the performance shall in addition to the specifications listed in 301, include the following:

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 (η_t) and the quasidimensionless massflow group $m\sqrt{T_{05}}/p_{05}$ 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.

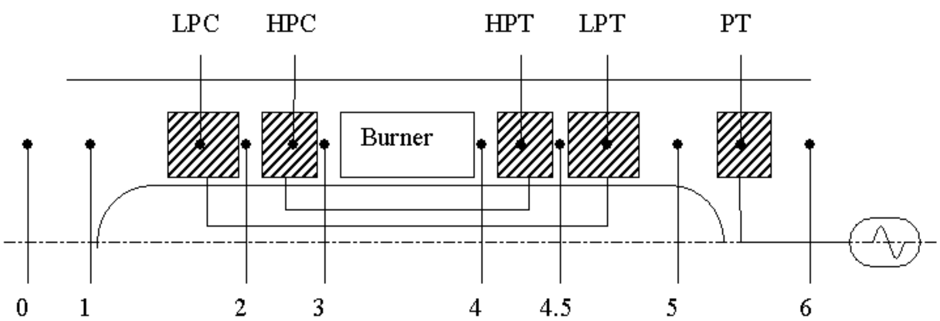

Fig. 3
Station numbering, basic cycle

328 *Failure mode and effect analysis (FMEA)*

An FMEA of the gas turbine shall be submitted for information. This 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.

329 *Fire prevention*

See E400 and F700.

330 *Maintenance*

Maintenance manuals shall be submitted for information. As a minimum, the contents shall be as follows:

— 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.

331 *Operating manual*

Operation manual shall be submitted for information.

332 *Test procedures*

Test procedures for the type test, certification test and shipboard test shall be submitted for approval. The procedures shall include acceptance criteria, and methods of evaluating parameters, such as, power, when calculating ISO equivalent power referred to actual measured power. See also 400.

B 400 Engine testing

401 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 A104.

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 A105 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 B3 Engine and system data acquisition

Parameter	*Type test*	*Certification test*	*Quay trial*	*Sea trial*
Power (thermodynamic) 1)	X	X	X 5)	X 5)
Gas generator, and power turbine speed 2)	X	X	X	X
Shaft torque at drive end (power turbine output)	X	X		
Electrical power at drive end (generator set only)			X	X
Compressor inlet pressure and temperature 1)	X	X	X	X
Compressor discharge pressure and temperature 1)	X	X	X	X
Turbine inlet temperature 1) 6)	X	X	X	X
Gas generator exit pressure and temperature 1)	X	X	X	X
Gas generator exit gas temperature spread	X	X	X	X
Power turbine exhaust pressure and temperature 1)	X	X	X	X
Lubrication oil temperature and pressure 4)	X	X	X	X

Table B3 Engine and system data acquisition (Continued)

Parameter	*Type test*	*Certification test*	*Quay trial*	*Sea trial*
Fuel temperature and pressure, at the fuel inlet	X	X	X	X
Hydraulic fluid pressure	X			X
Coolant temperature and pressure 4)				X
Temperature of external surfaces of the engine	X			X
Bearing metal temperatures 7)	X	X	X	X
Intake pressure loss	X	X		X
Exhaust pressure loss	X	X		X
Vibration levels	X	X	X	X
Position of variable stator vanes, or bleed valve opening, as applicable	X	X		X

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.

814 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.

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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.

920 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.

921 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

1001 Boroscope inspection shall be conducted following both type and certification test.

Boroscope inspection may be required by the Society after sea trial.

1002 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).

1003 Proper instruments and necessary personnel shall be on site during the inspection.

1004 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.

1005 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.

1006 A report summarising findings from inspection and tear-down shall be submitted for information.

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 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.

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

C 200 Certification of parts

201 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

301 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.

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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 can not 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 Ch.9.

Control systems for gas turbines shall be certified in accordance with 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.

Table E1 Monitoring requirements

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

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”
or
— direct shutdown for auxiliary engines or multi engine propulsion applications

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 the 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.

105 Starting sequence shall be discontinued and main fuel valve closed within a pre-determined time, when ignition has failed.

106 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.

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

108 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.

109 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.

110 For gas turbines driving main or emergency electric generators, see Ch.2 Sec.4.

E 200 Monitoring and instrumentation system

201 For instrumentation and automation, including computer-based control and monitoring, reference is made to 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

301 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 B328.

E 400 Fire safety

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

402 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 can not 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.

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403 *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.

404 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 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.

405 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.

E 500 Auxiliary system controls

501 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

101 For coupling alignment requirements, see Ch.4 Sec.4 .

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.

102 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.

103 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

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

202 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.

203 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	
Operational loads	*Extreme loads*
a) Mass. Maximum environmental conditions such as list and trim shall be considered for determination of mass reaction forces. (See Ch.1 of the Rules for Classification of Ships). b) Maximum operational acceleration loads. c) Reaction forces due to engine torque (including short circuit torque in case of electrical generators). d) Forces transferred to foundation members due to deflection of ship structure. e) Forces derived from thermal expansion of gas turbine or interfacing components. f) Any other operational loads that may be significant for the individual application, e.g. for Naval Surface Craft see Pt.5 Ch.14.	a) Forces derived from blade loss or, in the case of a centrifugal impeller, parts from one blade root failure. b) Any other extreme loads that may be relevant for the individual application, e.g. for Naval Surface Craft see Pt.5 Ch.14.
A combination of the above loads shall be considered	
The following prevails for the worst expected operational loads (left column): a) Gas turbine supports (struts) shall have documented a safety factor of minimum 2.5 against buckling. 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). 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---of---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.

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502 The inlet ducting and components in way of inlet airflow, such as filters, silencers and anti-icing devices shall be constructed and mounted to minimise the risk of loose parts entering the gas turbine.

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

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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.

Any active measures fitted in the ducts shall have a fail to safe action as to the integrity of the turbine.

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 E401 are not fulfilled.

The enclosure shall include a system for fire detection and automatic fire extinguishing (see E400).

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.

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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.

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 15%. 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):

— Synchronus (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.

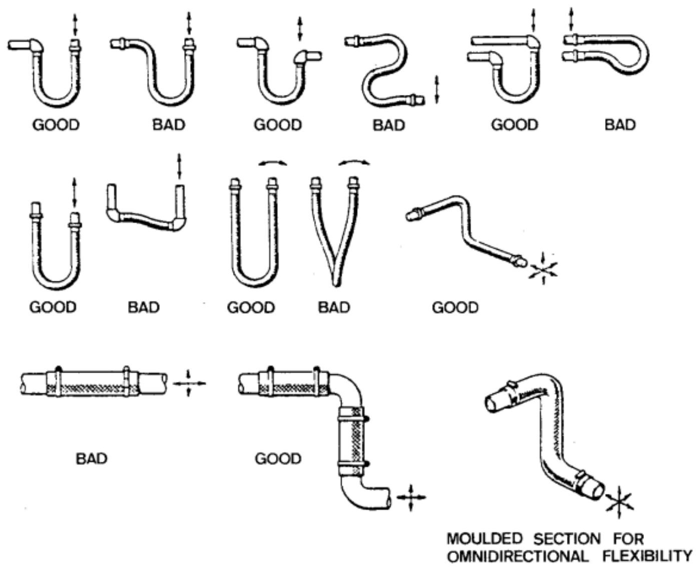

Fig. 4
Recommended arrangements of hoses and pipes

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 Ch.6 Sec.6 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 E400 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 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 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.

I 400 Boroscope inspection

401 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	Calculation of critical speeds. A for propulsion turbines UR for auxiliary
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.

108 All rotors shall be dynamically balanced in minimum two planes.

Table C1 Hydraulic testing			
Component	*Test pressure*		*Comments*
	1.5 p 1)	*2 p* 1)	
Main flow valves		x	
HP/LP crossover pipe			See Ch.6
Turbine casings	x		May be suitably subdivided. Not less than 2 bar
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 E1 Control and monitoring of propulsion turbines

System	*Item*	*Gr 1 Indication alarm load reduction*	*Gr 2 Automatic start of stand-by pump with alarm*	*Gr 3 Shut down with alarm*	*Comment*
1.0 Lubricating oil	Inlet pressure (after filter)	IR, IL, LA	AS	SH [1)]	
	Inlet temperature	IR, HA			
	Filter differential pressure	IR, HA			
	Level in system tank	LA			
2.0 Bearings	Bearing temperature	IR, HA			
3.0 Turbine speed	Overspeed	(LR)		SH	LR or SH, if applicable, to be activated automatically, see 200
4.0 Condenser system	Vacuum	IR, LA		SH	
	Vacuum pump stopped		AS		
	Level	IR, HA	AS	SH	
	Level	IR, LA			If non-cavitating condensate pump
	Salinity	HA			
5.0 Cooling water (main condenser)	Inlet/outlet differential pressure	IR, LA	AS		
6.0 Slow turning arrangement	Overspeed			SH	
7.0 Gland steam	Inlet pressure to turbine	IR, LA, HA			
	Exhaust fan stopped	A			

Table E1 Control and monitoring of propulsion turbines (Continued)

8.0 Hydraulic system	Pressure	IR, LA	AS		
9.0 Vibration	Level	HA		SH	
10.0 Rotor	Axial displacement	IR, HA		SH	

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

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

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.