TÜRK LOYDU

TL-R M

Requirements Concerning Machinery Installations

July 2019

These requirements are prepared by embedding related IACS Unified Requirements. In order to have consistency, the numbering of the requirements are kept as the same with related IACS Unified Requirements.

Unless otherwise specified, these Rules apply according to the implementation dates as defined in each requirement. See Rule Change Summary on TL website for revision details.

This latest edition incorporates all rule changes.

"General Terms and Conditions" of the respective latest edition will be applicable (see Rules for Classification and Surveys).

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TL-R M3 Speed governor and overspeed protective device

M3.1 Speed governor and overspeed protective device for main internal combustion engines

1. Each main engine is to be fitted with a speed governor so adjusted that the engine speed cannot exceed the rated speed by more than 15%.

2. In addition to this speed governor each main engine having a rated power of 220 kW and above, and which can be declutched or which drives a controllable pitch propeller, is to be fitted with a separate overspeed protective device so adjusted that the engine speed cannot exceed the rated speed by more than 20%. Equivalent arrangements may be accepted upon special consideration.
The overspeed protective device, including its driving mechanism, has to be independent from the required governor.

3. When electronic speed governors of main internal combustion engines form part of a remote control system, they are to comply with TL-R M43.8 and M43.10 or M47 and namely with the following conditions:
   - if lack of power to the governor may cause major and sudden changes in the present speed and direction of thrust of the propeller, back up power supply is to be provided;
   - local control of the engines is always to be possible, as required by M43.10, and, to this purpose, from the local control position it is to be possible to disconnect the remote signal, bearing in mind that the speed control according to TL-R M3.1, subparagraph 1, is not available unless an additional separate governor is provided for such local mode of control.
   - In addition, electronic speed governors and their actuators are to be type tested according to TL-R E10.

NOTE:
The rated power and corresponding rated speed are those for which classification of the installation has been requested.

M3.2 Speed governor, overspeed protective and governing characteristics of generator prime movers

1. Prime movers for driving generators of the main and emergency sources of electrical power are to be fitted with a speed governor which will prevent transient frequency variations in the electrical network in excess of ±10% of the rated frequency with a recovery time to steady state conditions not exceeding 5 seconds, when the maximum electrical step load is switched on or off.

   In the case when a step load equivalent to the rated output of a generator is switched off, a transient speed variation in excess of 10% of the rated speed may be acceptable, provided this does not cause the intervention of the overspeed device as required by 3.1.1

2. At all loads between no load and rated power the permanent speed variation should not be more than ±5% of the rated speed.

3. Prime movers are to be selected in such a way that they will meet the load demand within the ship's mains.

   Application of electrical load should be possible with 2 load steps and must be such that prime movers – running at no load – can suddenly be loaded to 50% of the rated power of the generator followed by the remaining 50% after an interval sufficient to restore the speed to steady state. Steady state conditions should be achieved in not more than 5 seconds.

   Steady state conditions are those at which the envelope of speed variation does not exceed +1% of the declared speed at the new power.

   Application of electrical load in more than 2 load steps can only be permitted, if the conditions within the ship's mains permit the use of such prime movers which can only be loaded in more than 2 load steps (see Fig. 1) and provided that this is already allowed for in the designing stage. This is to be verified in the form of system specifications to be approved and to be demonstrated at ship's trials. In this case, due consideration is to be given to the power required for the electrical equipment to be automatically switched on after black-out and to the sequence in which it is connected. This applies analogously also for generators to be operated in parallel and where the power has to be transferred from one generator to another in the event of any one generator has to be switched off.

4. Emergency generator sets must satisfy the governor conditions as per items 1 and 2 even when**:**

   a) their total consumer load is applied suddenly, or

   b) their total consumer load is applied in steps, subject to:
      - the total load is supplied within 45 seconds since power failure on the main switchboard
      - the maximum step load is declared and demonstrated
      - the power distribution system is designed such that the declared maximum step loading is not exceeded
      - the compliance of time delays and loading sequence with the above is to be demonstrated at ship's trials.

5. In addition to the speed governor, each prime mover driving an electric generator and having a rated power of 220 kW and above must be fitted with a separate overspeed protective device so adjusted that the speed cannot exceed the rated speed by more than 15%.

6. For a.c. generating sets operating in parallel, the governing characteristics of the prime movers shall be such that within the limits of 20% and 100% total load the load on any generating set will not normally differ from its proportionate share of the total load by more than 15% of the rated power of the largest machine or 25% of the rated power of the individual machine in question, whichever is the less.
   For an a.c. generating set intended to operate in parallel, facilities are to be provided to adjust the governor sufficiently fine to permit an adjustment of load not exceeding 5% of the rated load at normal frequency.

NOTE:
For guidance, the loading for 4-stroke diesel engines may be limited as given by Figure 1.

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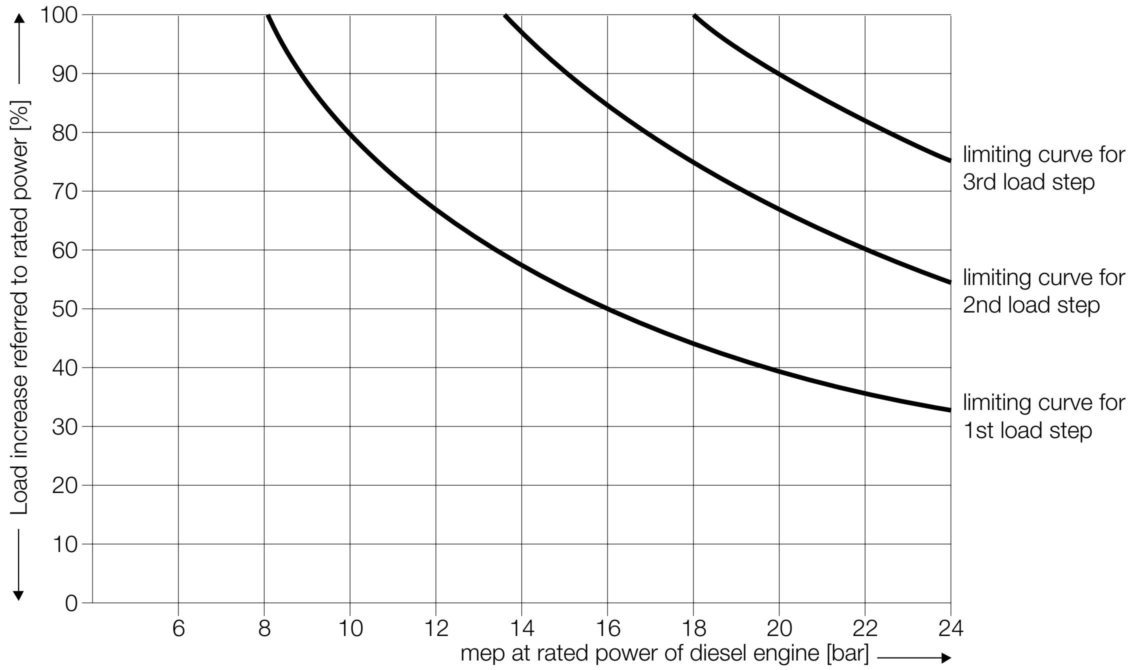

Fig. 1
Limiting curves for loading 4-stroke diesel engines step by step from no-load to rated power as function of the brake mean effective pressure

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TL- R M9 Crankcase explosion relief valves for crankcases of internal combustion engines

M9.1 Internal combustion engines having a cylinder bore of 200 mm and above or a crankcase volume of 0.6 m^3 and above shall be provided with crankcase explosion relief valves in accordance with TL- R M9.2 to TL- R M9.13 as follows:

M9.1.1 Engines having a cylinder bore not exceeding 250 mm are to have at least one valve near each end, but, over eight crankthrows, an additional valve is to be fitted near the middle of the engine.

M9.1.2 Engines having a cylinder bore exceeding 250 mm but not exceeding 300 mm are to have at least one valve in way of each alternate crankthrow, with a minimum of two valves.

M9.1.3 Engines having a cylinder bore exceeding 300 mm are to have at least one valve in way of each main crankthrow.

M9.2 The free area of each relief valve is to be not less than 45 cm^2.

M9.3 The combined free area of the valves fitted on an engine must not be less than 115 cm^2 per cubic metre of the crankcase gross volume.

M9.4 Crankcase explosion relief valves are to 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 the inrush of air thereafter.

M9.5 The valve discs in crankcase explosion relief valves are to be made of ductile material capable of withstanding the shock of contact with stoppers at the full open position.

NOTE

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

2. Engines are to be fitted with components and arrangements complying with Revision 3 of this requirement, except for M9.8, M9.9 and the second bullet point in M9.10, when:
   1) an application for certification of an engine is dated on/after 1 January 2006; or

   2) installed in new ships for which the date of contract for construction is on or after 1 January 2006.

   The requirements of M9.8, M9.9 and the second bullet point in M9.10 apply, in both cases above, from 1 January 2008.

3. The “contracted for construction” date means the date on which the contract to build the vessel is signed between the prospective owner and the shipbuilder. For further details regarding the date of “contract for construction”, refer to TL- PR 29.

M9.6 Crankcase explosion relief valves are to be designed and constructed to open quickly and be fully open at a pressure not greater than 0.02 N/mm^2 (0.2bar).

M9.7 Crankcase explosion relief valves are to be provided with a flame arrester that permits flow for crankcase pressure relief and prevents passage of flame following a crankcase explosion.

M9.8 Crankcase explosion relief valves are to type tested in a configuration that represents the installation arrangements that will used on an engine in accordance with UR M66.

M9.9 Where crankcase relief valves are provided with arrangements for shielding emissions from the valve following an explosion, the valve is to be type tested to demonstrate that the shielding does not adversely affect the operational effectiveness of the valve.

M9.10 Crankcase explosion relief valves are to be provided with a copy manufacturer's installation and maintenance manual that is pertinent to the size and type of valve being supplied for installation on a particular engine. The manual is to contain the following information:

- Description of valve with details of function and design limits.
- Copy of type test certification.
- Installation instructions.
- Maintenance in service instructions to include testing and renewal of any sealing arrangements.
- Actions required after a crankcase explosion.

M9.11 A copy of the installation and maintenance manual required by TL- R M9.10 is to be provided on board ship.

M9.12 Plans of showing details and arrangements of crankcase explosion relief valves are to be submitted for approval in accordance with TL- R M44.

M9.13 Valves are to be provided with suitable markings that include the following information:

- Name and address of manufacturer
- Designation and size
- Month/Year of manufacture
- Approved installation orientation

TL- R M10 Protection of internal combustion engines against crankcase explosions

M10.1 Crankcase construction and crankcase doors are to 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 required by TL- R M9. Crankcase doors are to be fastened sufficiently securely for them not be readily displaced by a crankcase explosion.

M10.2 Additional relief valves are to be fitted on separate spaces of crankcase such as gear or chain cases for camshaft or similar drives, when the gross volume of such spaces exceeds 0.6 m^3.

M10.3 Scavenge spaces in open connection to the cylinders are to be fitted with explosion relief valves.

M10.4 Crankcase explosion relief valves are to comply with TL- R M9.

M10.5 Ventilation of crankcase, and any arrangement which could produce a flow of external air within the crankcase, is in principle not permitted except for dual fuel engines where crankcase ventilation is to be provided in accordance with TL- R M59.3.2.(1).

M10.5.1 Crankcase ventilation pipes, where provided, are to be as small as practicable to minimise the inrush of air after a crankcase explosion.

M10.5.2 If a forced extraction of the oil mist atmosphere from the crankcase is provided (for mist detection purposes for instance), the vacuum in the crankcase is not to exceed 2.5 x 10^{-4} N/mm^2 (2.5 m bar).

M10.5.3 To avoid interconnection between crankcases and the possible spread of fire following an explosion, crankcase ventilation pipes and oil drain pipes for each engine are to be independent of any other engine.

Note:

1. The requirements of TL- R M10 are implemented for engines:

    i) when an application for certification of an engine is dated on or after 1 January 2015; or

    ii) which are installed in new ships for which the date of contract for construction is on or after 1 January 2015.

2. The "contracted for construction" date means the date on which the contract to build the vessel is signed between the prospective owner and the shipbuilder. For further details regarding the date of "contract for construction", refer to TL- PR 29.

M10.6 Lubricating oil drain pipes from the engine sump to the drain tank are to be submerged at their outlet ends.

M10.7 A warning notice is to be fitted either on the control stand or, preferably, on a crankcase door on each side of the engine. This warning notice is to specify that, whenever overheating is suspected within the crankcase, the crankcase doors or sight holes are not to be opened before a reasonable time, sufficient to permit adequate cooling after stopping the engine.

M10.8 Oil mist detection arrangements (or engine bearing temperature monitors or equivalent devices) are required:

- for alarm and slow down purposes for low-speed diesel engines of 2250 kW and above or having cylinders of more than 300 mm bore

- for alarm and automatic shutoff purposes for medium- and high-speed diesel engines of 2250 kW and above or having cylinders of more than 300 mm bore

Oil mist detection arrangements are to be of a type approved by classification societies and tested in accordance with TL- R M67 and comply with TL- R M10.9 to TL- R M10.20. Engine bearing temperature monitors or equivalent devices used as safety devices have to be of a type approved by classification societies for such purposes.

For the purpose of this requirement, the following definitions apply:

Low-Speed Engines means diesel engines having a rated speed of less than 300 rpm.

Medium-Speed Engines means diesel engines having a rated speed of 300 rpm and above, but less than 1400 rpm.

High-Speed Engines means diesel engines having a rated speed of 1400 rpm and above.

Note: For equivalent devices for high-speed engines, refer to TL- I SC 133.

M10.9 The oil mist detection system and arrangements are to be installed in accordance with the engine designer's and oil mist manufacturer's instructions/recommendations. The following particulars are to be included in the instructions:

- Schematic layout of engine oil mist detection and alarm system showing location of engine crankcase sample points and piping or cable arrangements together with pipe dimensions to detector.

- Evidence of study to justify the selected location of sample points and sample extraction rate (if applicable) in consideration of the crankcase arrangements and geometry and the predicted crankcase atmosphere where oil mist can accumulate.

- The manufacturer's maintenance and test manual.

- Information relating to type or in-service testing of the engine with engine protection system test arrangements having approved types of oil mist detection equipment.

M10.10 A copy of the oil mist detection equipment maintenance and test manual required by TL- R M10.9 is to be provided on board ship.

M10.11 Oil mist detection and alarm information is to be capable of being read from a safe location away from the engine.

M10.12 Each engine is to be provided with its own independent oil mist detection arrangement and a dedicated alarm.

M10.13 Oil mist detection and alarm systems are to be capable of being tested on the test bed and board under engine at standstill and engine running at normal operating conditions in accordance with test procedures that are acceptable to TL.

M10.14 Alarms and shutdowns for the oil mist detection system are to be in accordance with TL- R M35 and TL- R M36 and the system arrangements are to comply with TL- R M29 and TL- R M30.

M10.15 The oil mist detection arrangements are to provide an alarm indication in the event of a foreseeable functional failure in the equipment and installation arrangements.

M10.16 The oil mist detection system is to provide an indication that any lenses fitted in the equipment and used in determination of the oil mist level have been partially obscured to a degree that will affect the reliability of the information and alarm indication.

M10.17 Where oil mist detection equipment includes the use of programmable electronic systems, the arrangements are to be in accordance with TL requirements for such systems.

M10.18 Plans of showing details and arrangements of oil mist detection and alarm arrangements are to be submitted for approval in accordance with TL- R M44 under item 28.

M10.19 The equipment together with detectors is to be tested when installed on the test bed and on board ship to demonstrate that the detection and alarm system functionally operates. The testing arrangements are to be to the satisfaction of TL.

M10.20 Where sequential oil mist detection arrangements are provided the sampling frequency and time is to be as short as reasonably practicable.

M10.21 Where alternative methods are provided for the prevention of the build-up of oil mist that may lead to a potentially explosive condition within the crankcase details are to be submitted for consideration of TL. The following information is to be included in the details to be submitted for consideration:

- Engine particulars – type, power, speed, stroke, bore and crankcase volume.
- Details of arrangements prevent the build up of potentially explosive conditions within the crankcase, e.g., bearing temperature monitoring, oil splash temperature, crankcase pressure monitoring, recirculation arrangements.
- Evidence to demonstrate that the arrangements are effective in preventing the build up of potentially explosive conditions together with details of in-service experience.
- Operating instructions and the maintenance and test instructions.

M10.22 Where it is proposed to use the introduction of inert gas into the crankcase to minimise a potential crankcase explosion, details of the arrangements are to be submitted to TL for consideration.

TL- R M25 Astern power for main propulsion

M25.1 In order to maintain sufficient manoeuvrability and secure control of the ship in all normal circumstances, the main propulsion machinery is to be capable of reversing the direction of thrust so as to bring the ship to rest from the maximum service speed. The main propulsion machinery is to be capable of maintaining in free route astern at least 70% of the ahead revolutions[1].

M25.2 Where steam turbines are used for main propulsion, they are to be capable of maintaining in free route astern at least 70% of the ahead revolutions[1] for a period of at least 15 minutes. The astern trial is to be limited to 30 minutes or in accordance with manufacturer's recommendation to avoid overheating of the turbine due to the effects of "windage" and friction.

M25.3 For the main propulsion systems with reversing gears, controllable pitch propellers or electric propeller drive, running astern should not lead to the overload of propulsion machinery.

M25.4 Main propulsion systems are to undergo tests to demonstrate the astern response characteristics.
The tests are to be carried out at least over the manoeuvring range of the propulsion system and from all control positions. A test plan is to be provided by the yard and accepted by the surveyor. If specific operational characteristics have been defined by the manufacturer these shall be included in the test plan.

M25.5 The reversing characteristics of the propulsion plant, including the blade pitch control system of controllable pitch propellers, are to be demonstrated and recorded during trials.

1. The ahead revolutions as mentioned above are understood as those corresponding to the maximum continuous ahead power for which the vessel is classed.

Note:

1. This requirement is implemented on:
   (a) ships contracted for construction on or after 1 July 2018.
   (b) ships other than those specified in the preceding (a) on which astern testing is carried out in accordance with TL- R Z18 on or after 1 July 2018.
2. The "contracted for construction" date means the date on which the contract to build the vessel is signed between the prospective owner and the shipbuilder. For further details regarding the date of "contract for construction", refer to TL- PR 29.

TL- R M29 Alarm systems for vessels with periodically unattended machinery spaces

M29.1 Definition

The alarm system is intended to give warning of a condition in which deviation occurs outside the preset limits on selected variables. The arrangement of the alarm display should assist in identifying the particular fault condition and its location within the machinery space. Alarm systems, including those incorporating programmable electronic systems, are to satisfy the environmental requirements of TL- R E10.

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M29.2 General requirements

Where an alarm system is required by the Rules, the system is to comply with the conditions given in M29.2.1 - M29.2.10.

M29.2.1 The system is to be designed to function independently of control and safety systems so that a failure or malfunction in these systems will not prevent the alarm system from operating. Common sensors for alarms and automatic slowdown functions are acceptable as specified in TL- R M35 Table 1 and 2 as Gr 1.

M29.2.2 Machinery faults are to be indicated at the control locations for machinery.

M29.2.3 The system is to be so designed that the engineering personnel on duty are made aware that a machinery fault has occurred.

M29.2.4 If the bridge navigating officer of the watch is the sole watchkeeper then, in the event of a machinery fault being monitored at the control location for machinery, the alarm system is to be such that this watchkeeper is made aware when:

(i) a machinery fault has occurred,
(ii) the machinery fault is being attended to,
(iii) the machinery fault has been rectified. Alternative means of communication between the bridge area, the accommodation for engineering personnel and the machinery spaces may be used for this function.

M29.2.5 Group alarms may be arranged on the bridge to indicate machinery faults. Alarms associated with faults requiring speed reduction or the automatic shut down of propulsion machinery are to be separately identified.

M29.2.6 The alarm system should be designed with self monitoring properties. In so far as practicable, any fault in the alarm system should cause it to fail to the alarm condition.

M29.2.7 The alarm system should be capable of being tested during normal machinery operation. Where practicable means are to be provided at convenient and accessible positions, to permit the sensors to be tested without affecting the operation of the machinery.

M29.2.8 Upon failure of normal power supply, the alarm system is to be powered by an independent standby power supply, e.g. a battery. Failure of either power supply to the alarm system is to be indicated as a separate alarm fault. Where an alarm system could be adversely affected by an interruption in power supply, change-over to the stand by power supply is to be achieved without a break.

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M29.2.9

(a) Alarms are to be both audible and visual. If arrangements are fitted to silence audible alarms they are not to extinguish visible alarms.
(b) The local silencing of bridge or accommodation alarms is not to stop the audible machinery space alarm.
(c) Machinery alarms should be distinguishable from other audible alarms, i.e. fire, CO_2 flooding.
(d) The alarm system is to be so arranged that acknowledgement of visual alarms is clearly noticeable.

M29.2.10 If an alarm has been acknowledged and a second fault occurs before the first is rectified, then audible and visual alarms are to operate again.

Alarms due to temporary failures are to remain activated until acknowledged.

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TL- R M30 Safety systems for vessels with periodically unattended machinery spaces

M30.1 Definition

The safety system is intended to operate automatically in case of faults endangering the plant so that:
(i) normal operating conditions are restored (by starting of standby units), or
(ii) the operation of the machinery is temporarily adjusted to the prevailing conditions (by reducing the output of machinery), or
(iii) machinery and boilers are protected from critical conditions by stopping the machinery and shutting off the fuel to the boilers respectively (shutdown).

M30.2 General requirements

M30.2.1 Where a safety system is required by the Rules, the system is to comply with M30.2.2 - M30.2.8.

M30.2.2 Operation of the safety system shall cause an alarm.

M30.2.3 The safety system intended for the functions listed under M30.1 (iii) is to be independent of all other control and alarm systems so that failure or malfunction in these systems will not prevent the safety system from operating. For the safety systems intended for functions listed under M30.1(i) and (ii), complete independence of other control and alarm systems is not required.

M30.2.4 In order to avoid undesirable interruption in the operation of machinery, the system is to intervene sequentially after the operation of alarm system by:

Starting of standby units,
load reduction or shutdown, such that the least drastic action is taken first.

M30.2.5 The system should be designed to 'fail safe'. The characteristics of 'fail safe' of a system is to be evaluated on the basis not only of the safety system itself and its associated machinery, but also on the inclusion of the whole machinery installation as well as the ship.

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M30.2.6 Safety systems of different units of the machinery plant are to be independent. Failure in the safety system of one part of the plant is not to interfere with the operation of the safety system in another part of the plant.

M30.2.7 When the system has been activated, means are to be provided to trace the cause of the safety action.

M30.2.8 When the system has stopped a unit, the unit is not to be restarted automatically before a manual reset has been carried out.

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TL- R M31 Continuity of electrical power supply for vessels with periodically unattended machinery spaces

M31.1 The continuity of electrical power on vessels with periodically unattended machinery spaces is to be assured in accordance with M31.2 and M31.3.

M31.2 For vessels having the electrical power requirements normally supplied by one ship's service generator in case of loss of the generator in operation, there shall be adequate provisions for automatic starting and connecting to the main switchboard of a standby generator of sufficient capacity to permit propulsion and steering and to ensure the safety of the ship with automatic re-starting of the essential auxiliaries including, where necessary, sequential operations. This standby electric power is to be available automatically in not more than 45 seconds.

M31.3 For vessels having the electrical power requirements normally supplied by two or more ship's service generating sets operating in parallel, arrangements are to be provided (by load shedding, for instance) to ensure that in case of loss of one of these generating sets, the remaining ones are kept in operation without overload to permit propulsion and steering and to ensure the safety of the ship.

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TL-R M35 Alarms, remote indications and safeguards for main reciprocating I.C. engines installed in unattended machinery spaces

35.1 General

Alarms, remote indications and safeguards listed in Table 1 and 2 are respectively referred to cross-head and trunk-piston reciprocating i.c. engines.

35.2 Alarms

A system of alarm displays and controls is to be provided which readily ensures identification of faults in the machinery and satisfactory supervision of related equipment. This may be provided at a main control station or, alternatively, at subsidiary control stations. In the latter case, a master alarm display is to be provided at the main control station showing which of the subsidiary control stations is indicating a fault condition.

The detailed requirements covering communications of alarms from machinery spaces to the bridge area and accommodation for engineering personnel, are contained in M29.

35.3 Remote indications

Remote indications are required only for ships which are operated with machinery space unattended but under a continuous supervision from a position where control and monitoring devices are centralized, without the traditional watch service being done by personnel in machinery space.

35.4 Safeguards

35.4.1 Automatic start of standby pumps – slow down

A suitable alarm is to be activated at the starting of those pumps for which the automatic starting is required.

Note:

1. The requirements of M35 are implemented for engines:
   i) when an application for certification of an engine is dated on or after 1 July 2017; or
   ii) which are installed in new ships for which the date of contract for construction is on or after 1 July 2017.

2. The "contracted for construction" date means the date on which the contract to build the vessel is signed between the prospective owner and the shipbuilder. For further details regarding the date of "contract for construction", refer to TL-PR 29.

35.4.2 Automatic reduction of power

If overriding devices of the required automatic reduction of power are provided, they are to be so arranged as to preclude their inadvertent operation, and a suitable alarm is to be activated by their operation.

35.4.3 Automatic stop – shut down

If overriding devices of the required automatic stops are provided, they are to be so arranged as to preclude their inadvertent operation, and a suitable alarm is to be operated by their activation. When the engine is stopped automatically, restarting after restoration of normal operating conditions is to be possible only after manual reset, e.g. by-passing the control lever through the 'stop' position.
Automatic restarting is not permissible (see M30.2.8).

Table 1 Cross-head diesel engines

	Gr 1			Gr 2	Gr 3
Monitored parameters for cross-head diesel engines	**Remote Indication**	**Alarm activation**	**Slow down with alarm**	**Automatic start of standby pump with alarm**	**Shut down with alarm**
1.0 Fuel oil system					
Fuel oil pressure after filter (engine inlet)	x	low		x	
Fuel oil viscosity before injection pumps or Fuel oil temp before injection pumps		high low			
Leakage from high pressure pipes		x			
Level of fuel oil in daily service tank[1]		low			
Common rail fuel oil pressure		low			
2.0 Lubricating oil system					
Lub oil to main bearing and thrust bearing, pressure	x	low	x	x	x
Lub oil to crosshead bearing pressure[2]	x	low	x	x	x
Lub oil to camshaft pressure[2]		low		x	x
Lub oil to camshaft temp[2]		high			
Lub oil inlet temp		high			
Thrust bearing pads temp or bearing outlet temp		high	x		x
Main, crank, crosshead bearing, oil outlet temp or Oil mist concentration in crankcase[3]		high	x		
Flow rate cylinder lubricator. Each apparatus		low	x		
Level in lubricating oil tanks[4]		low			
Common rail servo oil pressure		low			
3.0 Turbocharger system					
Turbocharger lub oil inlet pressure[9]		low			
Turbocharger lub oil outlet temp each bearing[10]		high			
Speed of turbocharger[11]	x	high			
4.0 Piston cooling system					
Piston coolant inlet pressure[5]		low	x	x	
Piston coolant outlet temp each cylinder		high	x		
Piston coolant outlet flow each cylinder[8]		low	x		
Level of piston coolant in expansion tank		low			
5.0 Sea water cooling system					
Sea water pressure		low		x	

Gr 1 **Common sensor for indication, alarm, slow down**
Gr 2 **Sensor for automatic start of standby pump with alarm**
Gr 3 **Sensor for shut down**

Table 1 (continued)

	Gr 1			Gr 2	Gr 3
Monitored parameters for cross-head diesel engines	**Remote Indication**	**Alarm activation**	**Slow down with alarm**	**Automatic start of standby pump with alarm**	**Shut down with alarm**
6.0 Cylinder fresh cooling water system					
Cylinder water inlet pressure		low	x	x	
Cylinder water outlet temp (from each cylinder) or Cylinder water outlet temp (general)[6]		high	x		
Oily contamination of engine cooling water system[7]		x			
Level of cylinder cooling water in expansion tank		low			
7.0 Starting and control air systems					
Starting air pressure before main shut-off valve	x	low			
Control air pressure		low			
Safety air pressure		low			
8.0 Scavenge air system					
Scavenge air receiver pressure	x				
Scavenge air box temp (fire)		high	x		
Scavenge air receiver water level		high			
9.0 Exhaust gas system					
Exhaust gas temp after each cylinder	x	high	x		
Exhaust gas temp after each cylinder. Deviation from average.		high			
Exhaust gas temp before each T/C	x	high			
Exhaust gas temp after each T/C	x	high			
10.0 Fuel valve coolant					
Pressure of fuel valve coolant		low		x	
Temperature of fuel valve coolant		high			
Level of fuel valve coolant in expansion tank		low			
11.0 Engine speed/direction of rotation.	x				
Wrong way		x			
12.0 Engine overspeed					x
13.0 Control-Safety-Alarm system power supply failure		x			

1 High-level alarm is also required if no suitable overflow arrangement is provided.

2 If separate lub oil systems are installed.

3 When required by TL-R M10.8 or by SOLAS Reg. II-1/47.2.

4 Where separate lubricating oil systems are installed (e.g. camshaft, rocker arms, etc.), individual level alarms are required for the tanks.

5 The slow down is not required if the coolant is oil taken from the main cooling system of the engine.

6 Where one common cooling space without individual stop valves is employed for all cylinder jackets.

7 Where main engine cooling water is used in fuel and lubricating oil heat exchangers.

8 Where outlet flow cannot be monitored due to engine design, alternative arrangement may be accepted.

9 Unless provided with a self-contained lubricating oil system integrated with the turbocharger.

10 Where outlet temperature from each bearing cannot be monitored due to the engine/turbocharger design alternative arrangements may be accepted. Continuous monitoring of inlet pressure and inlet temperature in combination with specific intervals for bearing inspection in accordance with the turbocharger manufacturer's instructions may be accepted as an alternative.

11 Only required for turbochargers of Categories B and C. (see M73.5)

Table 2 Trunk-piston diesel engines

	Gr 1			Gr 2	Gr 3
Monitored parameters for trunk-piston diesel engines	**Remote Indication**	**Alarm activation**	**Slow down with alarm**	**Automatic start of standby pump with alarm**	**Shut down with alarm**
1.0 Fuel oil system					
Fuel oil pressure after filter (engine inlet)	x	low		x	
Fuel oil viscosity before injection pumps or Fuel oil temp before injection pumps[1]		high low			
Leakage from high pressure pipes		x			
Level of fuel oil in daily service tank[2]		low			
Common rail fuel oil pressure		low			
2.0 Lubrication oil system					
Lub oil to main bearing and thrust bearing, pressure	x	low		x	x
Lub oil filter differential pressure	x	high			
Lub oil inlet temp	x	high			
Oil mist concentration in crankcase[3]		high			x
Flow rate cylinder lubricator. Each apparatus		low	x		
Common rail servo oil pressure		low			
3.0 Turbocharger system					
Turbocharger lub oil inlet pressure[5]	x	low			
Turbocharger lub oil temperature each bearing[8]		high			
Speed of turbocharger[9]	x	high			
4.0 Sea Water cooling system					
Sea Water pressure	x	low		x	
5.0 Cylinder fresh cooling water system					
Cylinder water inlet pressure or flow	x	low	x	x	
Cylinder water outlet temp (general)[6]	x	high	x		
Level of cylinder cooling water in expansion tank		low			
6.0 Starting and control air systems					
Starting air pressure before main shut-off valve	x	low			
Control air pressure	x	low			

Gr 1 **Common sensor for indication, alarm, slow down**
Gr 2 **Sensor for automatic start of standby pump with alarm**
Gr 3 **Sensor for shut down**

Table 2 (continued)

	Gr 1			Gr 2	Gr 3
Monitored parameters for trunk-piston diesel engines	**Remote Indication**	**Alarm activation**	**Slow down with alarm**	**Automatic start of standby pump with alarm**	**Shut down with alarm**
7.0 Scavenge air system					
Scavenge air receiver temp		high			
8.0 Exhaust Gas system					
Exhaust gas temp after each cylinder[7]	x	high	x		
Exhaust gas temp after each cylinder. Deviation from average[7]		high			
9.0 Engine speed	x				
10.0 Engine overspeed					x
11.0 Control-Safety-Alarm system power supply failure		x			

1 For heavy fuel oil burning engines only.

2 High-level alarm is also required if no suitable overflow arrangement is provided.

3 When required by TL-R M10.8 or by SOLAS Reg. II-1/47.2. One oil mist detector for each engine having two independent outputs for initiating the alarm and shut-down would satisfy the requirement for independence between alarm and shut-down system.

4 If necessary for the safe operation of the engine.

5 Unless provided with a self-contained lubricating oil system integrated with the turbocharger.

6 Two separate sensors are required for alarm and slow down.

7 For engine power > 500 kW/cyl.

8 Where outlet temperature from each bearing cannot be monitored due to the engine/ turbocharger design alternative arrangements may be accepted. Continuous monitoring of inlet pressure and inlet temperature in combination with specific intervals for bearing inspection in accordance with the turbocharger manufacturer’s instructions may be accepted as an alternative.

9 Only required for turbochargers of Categories B and C. (see M73.5)

TL-R M36 Alarms and safeguards for auxiliary reciprocating internal combustion engines driving generators in unattended machinery spaces

M36.1 General

This requirement refers to trunk-piston reciprocating i. c. engines on fuel oil.

M36.2 Alarms

All monitored parameters for which alarms are required to identify machinery faults and associated safeguards are listed in Table 1.

All these alarms are to be indicated at the control location for machinery as individual alarms; where the alarm panel with individual alarms is installed on the engine or in the vicinity, common alarm in the control location for machinery is required.

For communication of alarms from machinery space to bridge area and accommodation for engineering personnel detailed requirements are contained in M29.

Note:

1. The requirements of M36 are implemented for engines:
   i) when an application for certification of an engine is dated on or after 1 July 2017; or
   ii) which are installed in new ships for which the date of contract for construction is on or after 1 July 2017.

2. The “contracted for construction” date means the date on which the contract to build the vessel is signed between the prospective owner and shipbuilder. For further details regarding the date of “contract for construction”, refer to TL-PR 29.

Table 1

Monitored parameters	Alarm	Shut down
Fuel oil leakage from high pressure pipes	x	
Lubricating oil temperature	high	
Lubricating oil pressure	low	x
Oil mist concentration in crankcase[3]	high	x
Pressure or flow of cooling water	low	
Temperature of cooling water or cooling air	high	
Level in cooling water expansion tank, if not connected to main system	low	
Level in fuel oil daily service tank	low	
Starting air pressure	low	
Overspeed activated		x
Fuel oil viscosity before injection pumps or fuel oil temp before injection pumps[1]	low high	
Exhaust gas temperature after each cylinder[2]	high	
Common rail fuel oil pressure	low	
Common rail servo oil pressure	low	
Speed of turbocharger[4]	high	

Notes:

1. For heavy fuel oil burning engines only.
2. For engine power above 500 kW/cyl.
3. When required by TL-R M10.8 or by SOLAS Reg. II-1/47.2. one oil mist detector for each engine having two independent outputs for initiating the alarm and shut-down would satisfy the requirement for independence between alarm and shut-down system.
4. Only required for turbochargers of Categories B and C. (see M73.5)

TL- R M40 Ambient conditions – Temperatures

M40.1 The ambient conditions specified under M40.2 are to be applied to the layout, selection and arrangement of all shipboard machinery, equipment and appliances as to ensure proper operation.

M40.2 Temperatures

Air

Installations, components	Location, arrangement	Temperature range (°C)
Machinery and electrical installations [1]	In enclosed spaces	0 to +45[2]
	On machinery components, boilers, In spaces subject to higher and lower temperatures	According to specific local conditions
	On the open deck	–25 to +45[2]

Water

Coolant	Temperature (°C)
Seawater	+32[2]
Charge air coolant inlet to charge air cooler	see TL- R M28

NOTES
1. Electronic appliances are to be suitable for proper operation even with an air temperature of +55°C.
2. TL may approve other temperatures in the case of ships not intended for unrestricted service.

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TL- R M44 Documents for the approval of diesel engines

1. Scope

The documents necessary to approve a diesel engine design for conformance to the Rules and for use during manufacture and installation are listed. The document flow between engine designer, TL approval centre, engine builder/licensee and TL's Surveyors is provided.

2. Definitions

Definitions relating to approval of diesel engines are given in Appendix 1.

3. Overview

3.1 Approval process

3.1.1 Type approval certificate

For each type of engine that is required to be approved, a type approval certificate is to be obtained by the engine designer. The process details for obtaining a type approval certificate are in Section 4. This process consists of the engine designer obtaining:

- drawing and specification approval,
- conformity of production,
- approval of type testing programme,
- type testing of engines,
- review of the obtained type testing results, and

Notes:

1. The requirements of TL- R M44 are implemented for engines for which the date of an application for type approval certification is dated on or after 1 July 2016.

2. The “date of application for type approval” is the date of documents accepted by TL as request for type approval certification of a new engine type or of an engine type that has undergone substantive modifications in respect of the one previously type approved, or for renewal of an expired type approval certificate.

3. Engines with an existing type approval on 1 July 2016 are not required to be re-type approved in accordance with this requirement until the current Type Approval becomes invalid. For the purpose of certification of these engines, the current type approval and related submitted documentation will be accepted in place of that required by this requirement until the current type approval expires or the engine type has undergone substantive modifications.

- evaluation of the manufacturing arrangements,

- issue of a type approval certificate upon satisfactorily meeting the Rule requirements.

3.1.2 Engine certificate

Each diesel engine manufactured for a shipboard application is to have an engine certificate. The certification process details for obtaining the engine certificate are in Section 5. This process consists of the engine builder/licensee obtaining design approval of the engine application specific documents, submitting a comparison list of the production drawings to the previously approved engine design drawings referenced in 3.1.1, forwarding the relevant production drawings and comparison list for the use of the Surveyors at the manufacturing plant and shipyard if necessary, engine testing and upon satisfactorily meeting the Rule requirements, the issuance of an engine certificate.

3.2 Document flow for diesel engines

3.2.1 Document flow for obtaining a type approval certificate

3.2.1.1 For the initial engine type, the engine designer prepares the documentation in accordance with requirements in Tables 1 and 2 and forwards to TL according to the agreed procedure for review.

3.2.1.2 Upon review and approval of the submitted documentation (evidence of approval), it is returned to the engine designer.

3.2.1.3 The engine designer arranges for a Surveyor to attend an engine type test and upon satisfactory testing TL issues a type approval certificate.

3.2.1.4 A representative document flow process for obtaining a type approval certificate is shown in Appendix 2, Figure 1.

3.2.2 Document flow for engine certificate

3.2.2.1 The engine type must have a type approval certificate. For the first engine of a type, the type approval process and the engine certification process (ECP) may be performed simultaneously.

3.2.2.2 Engines to be installed in specific applications may require the engine designer/licensor to modify the design or performance requirements. The modified drawings are forwarded by the engine designer to the engine builder/licensee to develop production documentation for use in the engine manufacture in accordance with Table 3.

3.2.2.3 The engine builder/licensee develops a comparison list of the production documentation to the documentation listed in Tables 1 and 2. An example comparison list is provided in Appendix 4. If there are differences in the technical content on the licensee's production drawings/documents compared to the corresponding licensor's drawings, the licensee must obtain agreement to such differences from the licensor using the template in Appendix 5.

If the designer acceptance is not confirmed, the engine is to be regarded as a different engine type and is to be subjected to the complete type approval process by the licensee.

3.2.2.4 The engine builder/licensee submits the comparison list and the production documentation to TL according to the agreed procedure for review/ approval.

3.2.2.5 TL returns documentation to the engine builder/licensee with confirmation that the design has been approved. This documentation is intended to be used by the engine builder/licensee and their subcontractors and attending Surveyors. As the attending Surveyors may request the engine builder/licensee or their subcontractors to provide the actual documents indicated in the list, the documents are necessary to be prepared and available for the Surveyors.

3.2.2.6 The attending Surveyors, at the engine builder/licensee/subcontractors, will issue product certificates as necessary for components manufactured upon satisfactory inspections and tests.

3.2.2.7 The engine builder/licensee assembles the engine, tests the engine with a Surveyor present. An engine certificate is issued by the Surveyor upon satisfactory completion of assembly and tests.

3.2.2.8 A representative document flow process for obtaining an engine certificate is shown in Appendix 2, Figure 2.

3.3 Approval of diesel engine components

Components of engine designer's design which are covered by the type approval certificate of the relevant engine type are regarded as approved whether manufactured by the engine manufacturer or sub-supplied. For components of subcontractor's design, necessary approvals are to be obtained by the relevant suppliers (e.g. exhaust gas turbochargers, charge air coolers, etc.).

3.4 Submission format of documentation

TL determines the documentation format: electronic or paper. If documentation is to be submitted in paper format, the number of copies is determined by TL.

4. Type approval process

The type approval process consists of the steps in 4.1 to 4.4. The document flow for this process is shown in Appendix 2, Figure 1.

The documentation, as far as applicable to the type of engine, to be submitted by the engine designer/licensor to TL is listed in Tables 1 and 2.

4.1 Documents for information Table 1

Table 1 lists basic descriptive information to provide TL an overview of the engine's design, engine characteristics and performance. Additionally, there are requirements related to auxiliary systems for the engine's design including installation arrangements, list of capacities, technical specifications and requirements, along with information needed for maintenance and operation of the engine.

4.2 Documents for approval or recalculation Table 2

Table 2 lists the documents and drawings, which are to be approved by TL.

4.3 Design approval/appraisal (DA)

DA's are valid as long as no substantial modifications have been implemented. Where substantial modifications have been made the validity of the DA's may be renewed based on evidence that the design is in conformance with all current Rules and statutory regulations (e.g. SOLAS, MARPOL). See also 4.6.

4.4 Type approval test

A type approval test is to be carried out in accordance with TL- R M71 and is to be witnessed by TL.

The manufacturing facility of the engine presented for the type approval test is to be assessed in accordance with TL- R M72.

4.5 Type approval certificate

After the requirements in M44.4.1 through M44.4.4 have been satisfactorily completed TL issues a type approval certificate (TAC).

4.6 Design modifications

After TL has approved the engine type for the first time, only those documents as listed in the tables, which have undergone substantive changes, will have to be resubmitted for consideration by TL.

4.7 Type approval certificate renewals

A renewal of type approval certificates will be granted upon:

4.7.1 Submission of information in either 4.7.1.1 or 4.7.1.2.

4.7.1.1 The submission of modified documents or new documents with substantial modifications replacing former documents compared to the previous submission(s) for DA.

4.7.1.2 A declaration that no substantial modifications have been applied since the last DA issued.

4.8 Validity of type approval certificate

TL reserves the right to limit the duration of validity of the type approval certificate. The type approval certificate will be invalid if there are substantial modifications in the design, in the manufacturing or control processes or in the characteristics of the materials unless approved in advance by TL.

4.9 Document review and approval

4.9.1 The assignment of documents to Table 1 for information does not preclude possible comments by TL.

4.9.2 Where considered necessary, TL may request further documents to be submitted. This may include details or evidence of existing type approval or proposals for a type testing programme in accordance with TL- R M71.

5. Certification process

The certification process consists of the steps in 5.1 to 5.5. This process is illustrated in Appendix 2, Figure 2 showing the document flows between the:

- engine designer/licensor,
- engine builder/licensee,
- component manufacturers,
- TL approval centre, and
- TL site offices.

For those cases when a licensor – licensee agreement does NOT apply, an "engine designer" shall be understood as the entity that has the design rights for the engine type or is delegated by the entity having the design rights to modify the design.

The documents listed in Table 3 may be submitted by:

- the engine designer (licensor),
- the manufacturer/licensee.

5.1 Document development for production

Prior to the start of the engine certification process, a design approval is to be obtained per 4.1 through 4.3 for each type of engine. Each type of engine is to be provided with a type approval certificate obtained by the engine designer/licensor prior to the engine builder/licensee beginning production manufacturing. For the first engine of a type, the type approval process and the certification process may be performed simultaneously.

The engine designer/licensor reviews the documents listed in Tables 1 and 2 for the application and develops, if necessary, application specific documentation for the use of the engine builder/licensee in developing engine specific production documents.

If substantive changes have been made, the affected documents are to be resubmitted to TL as per 4.6.

5.2 Documents to be submitted for inspection and testing

Table 3 lists the production documents, which are to be submitted by the engine builder/licensee to TL following acceptance by the engine designer/licensor. The Surveyor uses the information for inspection purposes during manufacture and testing of the engine and its components. See 3.2.2.3 through 3.2.2.6.

5.3 Alternative execution

If there are differences in the technical content on the licensee's production drawings/documents compared to the corresponding licensor's drawings, the licensee must provide to TL approval centre a “Confirmation of the licensor’s acceptance of licensee’s modifications” approved by the licensor and signed by licensee and licensor. Modifications applied by the licensee are to be provided with appropriate quality requirements. See Appendix 5 for a sample format.

5.4 Manufacturer approval

TL assesses conformity of production with TL’s requirements for production facilities comprising manufacturing facilities and processes, machining tools, quality assurance, testing facilities, etc. See TL- R M72. Satisfactory conformance results in the issue of a class approval document.

5.5 Document availability

In addition to the documents listed in Table 3, the engine builder/licensee is to be able to provide to the Surveyor performing the inspection upon request the relevant detail drawings, production quality control specifications and acceptance criteria. These documents are for supplemental purposes to the survey only.

5.6 Engine assembly and testing

Each engine assembly and testing procedure required according to relevant TL- Rs are to be witnessed by TL unless an Alternative Certification Scheme meeting the requirements of TL-R Z26 is agreed between manufacturer and TL.

Table 1 Documentation to be submitted for information, as applicable

No.	Item
1	Engine particulars (e.g. Data sheet with general engine information (see Appendix 3), Project Guide, Marine Installation Manual)
2	Engine cross section
3	Engine longitudinal section
4	Bedplate and crankcase of cast design
5	Thrust bearing assembly[1]
6	Frame/framebox/gearbox of cast design[2]
7	Tie rod
8	Connecting rod
9	Connecting rod, assembly[3]
10	Crosshead, assembly[3]
11	Piston rod, assembly[3]
12	Piston, assembly[3]
13	Cylinder jacket/ block of cast design[2]
14	Cylinder cover, assembly[3]
15	Cylinder liner
16	Counterweights (if not integral with crankshaft), including fastening
17	Camshaft drive, assembly[3]
18	Flywheel
19	Fuel oil injection pump
20	Shielding and insulation of exhaust pipes and other parts of high temperature which may be impinged as a result of a fuel system failure, assembly
	For electronically controlled engines, construction and arrangement of:
21	Control valves
22	High-pressure pumps
23	Drive for high pressure pumps
24	Operation and service manuals[4]
25	FMEA (for engine control system)[5]
26	Production specifications for castings and welding (sequence)
27	Evidence of quality control system for engine design and in service maintenance
28	Quality requirements for engine production
29	Type approval certification for environmental tests, control components[6]

FOOTNOTES:

1. If integral with engine and not integrated in the bedplate.
2. Only for one cylinder or one cylinder configuration.
3. Including identification (e.g. drawing number) of components.
4. Operation and service manuals are to contain maintenance requirements (servicing and repair) including details of any special tools and gauges that are to be used with their fitting/settings together with any test requirements on completion of maintenance.
5. Where engines rely on hydraulic, pneumatic or electronic control of fuel injection and/or valves, a failure mode and effects analysis (FMEA) is to be submitted to demonstrate that failure of the control system will not result in the operation of the engine being degraded beyond acceptable performance criteria for the engine. The FMEA reports required will not be explicitly approved by TL.
6. Tests are to demonstrate the ability of the control, protection and safety equipment to function as intended under the specified testing conditions per TL- R E10.

Table 2 Documentation to be submitted for approval, as applicable

No.	Item
1	Bedplate and crankcase of welded design, with welding details and welding instructions[1,2]
2	Thrust bearing bedplate of welded design, with welding details and welding instructions[1]
3	Bedplate/oil sump welding drawings[1]
4	Frame/framebox/gearbox of welded design, with welding details and instructions[1,2]
5	Engine frames, welding drawings[1,2]
6	Crankshaft, details, each cylinder No.
7	Crankshaft, assembly, each cylinder No.
8	Crankshaft calculations (for each cylinder configuration) according to the attached data sheet and TL- R M53
9	Thrust shaft or intermediate shaft (if integral with engine)
10	Shaft coupling bolts
11	Material specifications of main parts with information on non-destructive material tests and pressure tests[3]
	Schematic layout or other equivalent documents on the engine of:
12	Starting air system
13	Fuel oil system
14	Lubricating oil system
15	Cooling water system
16	Hydraulic system
17	Hydraulic system (for valve lift)
18	Engine control and safety system
19	Shielding of high pressure fuel pipes, assembly[4]
20	Construction of accumulators (for electronically controlled engine)
21	Construction of common accumulators (for electronically controlled engine)
22	Arrangement and details of the crankcase explosion relief valve (see TL- R M9)[5]
23	Calculation results for crankcase explosion relief valves (see TL- R M9)
24	Details of the type test program and the type test report)[7]
25	High pressure parts for fuel oil injection system[6]
26	Oil mist detection and/or alternative alarm arrangements (see TL- R M10)
27	Details of mechanical joints of piping systems (see TL- R P2)
28	Documentation verifying compliance with inclination limits (see TL- R M46)
29	Documents as required in TL- R E22, as applicable

FOOTNOTES:

1. For approval of materials and weld procedure specifications. The weld procedure specification is to include details of pre and post weld heat treatment, weld consumables and fit-up conditions.
2. For each cylinder for which dimensions and details differ.
3. For comparison with Society requirements for material, NDT and pressure testing as applicable.
4. All engines.
5. Only for engines of a cylinder diameter of 200 mm or more or a crankcase volume of 0.6 m^3 or more.
6. The documentation to contain specifications for pressures, pipe dimensions and materials.
7. The type test report may be submitted shortly after the conclusion of the type test.

Table 3 Documentation for the inspection of components and systems

- Special consideration will be given to engines of identical design and application

- For engine applications refer to TL- R M72

No.	Item
1	Engine particulars as per data sheet in Appendix 3
2	Material specifications of main parts with information on non-destructive material tests and pressure tests[1]
3	Bedplate and crankcase of welded design, with welding details and welding instructions[2]
4	Thrust bearing bedplate of welded design, with welding details and welding instructions[2]
5	Frame/framebox/gearbox of welded design, with welding details and instructions[2]
6	Crankshaft, assembly and details
7	Thrust shaft or intermediate shaft (if integral with engine)
8	Shaft coupling bolts
9	Bolts and studs for main bearings
10	Bolts and studs for cylinder heads and exhaust valve (two stroke design)
11	Bolts and studs for connecting rods
12	Tie rods
	Schematic layout or other equivalent documents on the engine of:[3]
13	Starting air system
14	Fuel oil system
15	Lubricating oil system
16	Cooling water system
17	Hydraulic system
18	Hydraulic system (for valve lift)
19	Engine control and safety system
20	Shielding of high pressure fuel pipes, assembly[4]
21	Construction of accumulators for hydraulic oil and fuel oil
22	High pressure parts for fuel oil injection system[5]
23	Arrangement and details of the crankcase explosion relief valve (see TL- R M9)[6]
24	Oil mist detection and/or alternative alarm arrangements (see TL- R M10)
25	Cylinder head
26	Cylinder block, engine block
27	Cylinder liner
28	Counterweights (if not integral with crankshaft), including fastening
29	Connecting rod with cap
30	Crosshead
31	Piston rod
32	Piston, assembly[7]
33	Piston head
34	Camshaft drive, assembly[7]
35	Flywheel
36	Arrangement of foundation (for main engines only)
37	Fuel oil injection pump
38	Shielding and insulation of exhaust pipes and other parts of high temperature which may be impinged as a result of a fuel system failure, assembly
39	Construction and arrangement of dampers
	For electronically controlled engines, assembly drawings or arrangements of:
40	Control valves

No.	Item
41	High-pressure pumps
42	Drive for high pressure pumps
43	Valve bodies, if applicable
44	Operation and service manuals[8]
45	Test program resulting from FMEA (for engine control system)[9]
46	Production specifications for castings and welding (sequence)
47	Type approval certification for environmental tests, control components[10]
48	Quality requirements for engine production

FOOTNOTES:

1. For comparison with Society requirements for material, NDT and pressure testing as applicable.
2. For approval of materials and weld procedure specifications. The weld procedure specification is to include details of pre and post weld heat treatment, weld consumables and fit-up conditions.
3. Details of the system so far as supplied by the engine manufacturer such as: main dimensions, operating media and maximum working pressures.
4. All engines.
5. The documentation to contain specifications for pressures, pipe dimensions and materials.
6. Only for engines of a cylinder diameter of 200 mm or more or a crankcase volume of 0.6 m^3 or more.
7. Including identification (e.g. drawing number) of components.
8. Operation and service manuals are to contain maintenance requirements (servicing and repair) including details of any special tools and gauges that are to be used with their fitting/settings together with any test requirements on completion of maintenance.
9. Required for engines that rely on hydraulic, pneumatic or electronic control of fuel injection and/or valves.
10. Documents modified for a specific application are to be submitted to TL for information or approval, as applicable. See 3.2.2.2, Appendix 4 and Appendix 5.

UR M44 - APPENDIX 1 - GLOSSARY

Term	Definition
Acceptance criteria	A set of values or criteria which a design, product, service or process is required to conform with, in order to be considered in compliance
Accepted	Status of a design, product, service or process, which has been found to conform to specific acceptance criteria
Alternative Certification Scheme (ACS)	A system, by which a society evaluates a manufacturer's quality assurance and quality control arrangements for compliance with Rule requirements, then authorizes a manufacturer to undertake and witness testing normally required to be done in the presence of a Surveyor.
Appraisal	Evaluation by a competent body
Approval	The granting of permission for a design, product, service or process to be used for a stated purpose under specific conditions based upon a satisfactory appraisal
Assembly	Equipment or a system made up of components or parts
Assess	Determine the degree of conformity of a design, product, service, process, system or organization with identified specifications, Rules, standards or other normative documents
Audit	Planned systematic and independent examination to determine whether the activities are documented, the documented activities are implemented, and the results meet the stated objectives
Auditor	Individual who has the qualifications and experience to perform audits
Certificate	A formal document attesting to the compliance of a design, product, service or process with acceptance criteria

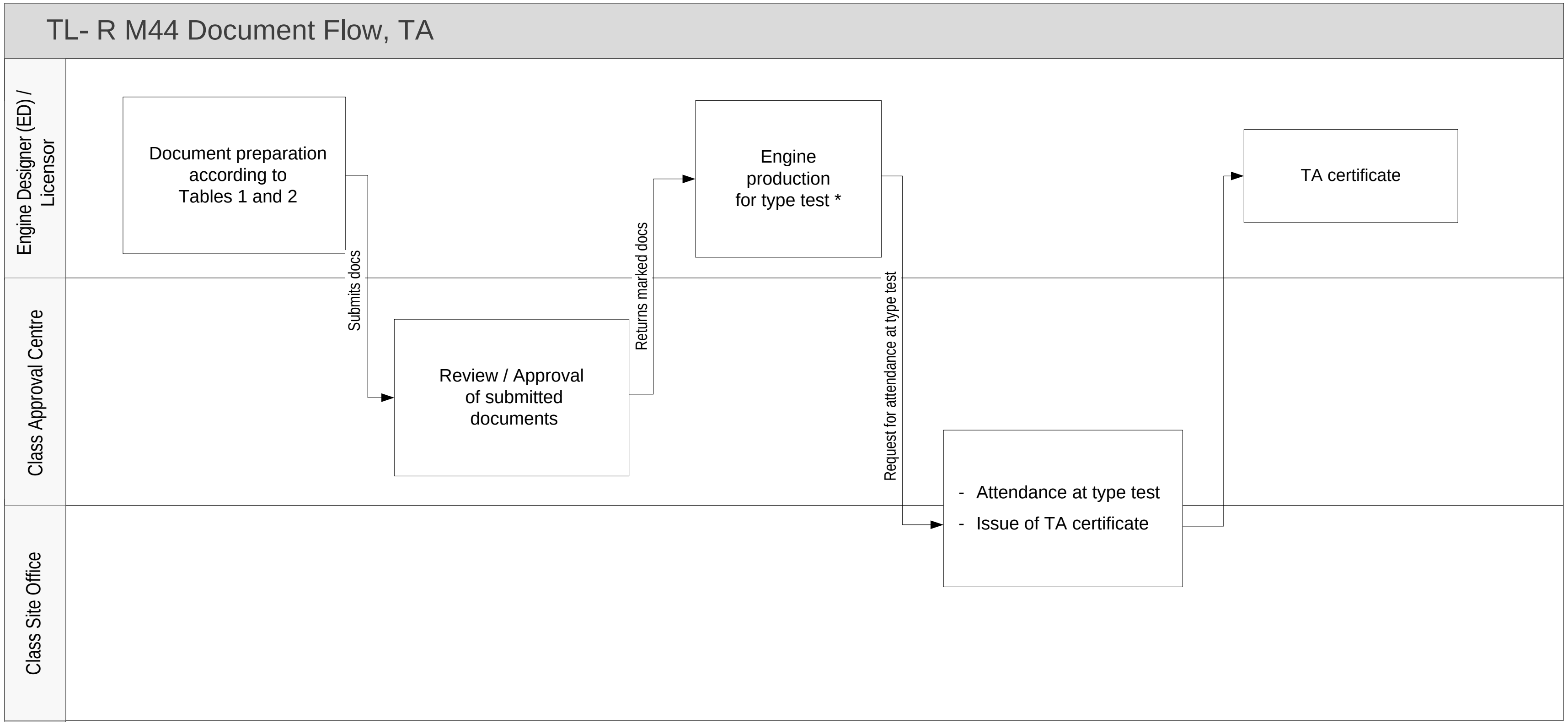
Term	Definition
Certification	A procedure whereby a design, product, service or process is approved in accordance with acceptance criteria
Class	Short for Classification Society
Class approval	Approved by TL
Classification	Specific type of certification, which relates to the Rules of TL
Competent body	Organization recognized as having appropriate knowledge and expertise in a specific area
Component	Part, member of equipment or system
Conformity	Where a design, product, process or service demonstrates compliance with its specific requirements
Contract	Agreement between two or more parties relating to the scope of service
Contractor	see Supplier
Customer	Party who purchases or receives goods or services from another
Design	All relevant plans, documents, calculations described in the performance, installation and manufacturing of a product
Design analysis	Investigative methodology selectively used to assess the design
Design appraisal	Evaluation of all relevant plans, calculations and documents related to the design
Design review	Part of the appraisal process to evaluate specific aspects of the design
Drawings approval/ plan approval	Part of the design approval process which relates to the evaluation of drawings and plans
Equipment	Part of a system assembled from components
Equivalent	An acceptable, no less effective alternative to specified criteria
Evaluation	Systematic examination of the extent to which a design, product, service or process satisfies specific criteria
Examination	Assessment by a competent person to determine compliance with requirements
Inspection	Examination of a design, product service or process by an Inspector
Inspection plan	List of tasks of inspection to be performed by the Inspector

Term	Definition
Installation	The assembling and final placement of components, equipment and subsystems to permit operation of the system
Manufacturer	Party responsible for the manufacturing and quality of the product
Manufacturing process	Systematic series of actions directed towards manufacturing a product
Manufacturing process approval	Approval of the manufacturing process adopted by the manufacturer during production of a specific product
Material	Goods supplied by one manufacturer to another manufacturer that will require further forming or manufacturing before becoming a new product
Modification	A limited change that does not affect the current approval
Modification notice	Information about a design modification with new modification index or new drawing number replacing the earlier drawing
Performance test	Technical operation where a specific performance characteristic is determined
Producer	See manufacturer
Product	Result of the manufacturing process
Prototype test	Investigations on the first or one of the first new engines with regard to optimization, fine tuning of engine parameters and verification of the expected running behaviour
Quality assurance	All the planned and systematic activities implemented within the quality system, and demonstrated as needed to provide adequate confidence that an entity will fulfil requirements for quality. Refer to ISO 9000 series
Regulation	Rule or order issued by an executive authority or regulatory agency of a government and having the force of law
Repair	Restore to original or near original condition from the results of wear and tear or damages for a product or system in service
Requirement	Specified characteristics used for evaluation purposes
Information	Additional technical data or details supplementing the drawings requiring approval
Revision	Means to record changes in one or more particulars of design drawings or specifications
Specification	Technical data or particulars which are used to establish the suitability of materials, products, components or systems for their intended use

Term	Definition
Substantive modifications or major modifications or major changes	Design modifications, which lead to alterations in the stress levels, operational behaviour, fatigue life or an effect on other components or characteristics of importance such as emissions
Subsupplier/subcontractor	One who contracts to supply material to another supplier
Supplier	One who contracts to furnish materials or design, products, service or components to a customer or user
Test	A technical operation that consists of the determination of one or more characteristics or performance of a given product, material, equipment, organism, physical phenomenon, process or service according to a specified procedure. A technical operation to determine if one or more characteristic(s) or performance of a product, process or service satisfies specific requirements
Traceability	Ability to follow back through the design and manufacturing process to the origin
Type approval	The establishment of the acceptability of a product through the systematic: 1. Evaluation of a design to determine conformance with specifications 2. Witnessing manufacture and testing of a type of product to determine compliance with the specification 3. Evaluation of the manufacturing arrangements to confirm that the product can be consistently produced in accordance with the specification
Type approval test	Last step of the type approval procedure. Test program in accordance with TL- R M71
Witness	Individual physically present at a test and being able to record and give evidence about its outcome

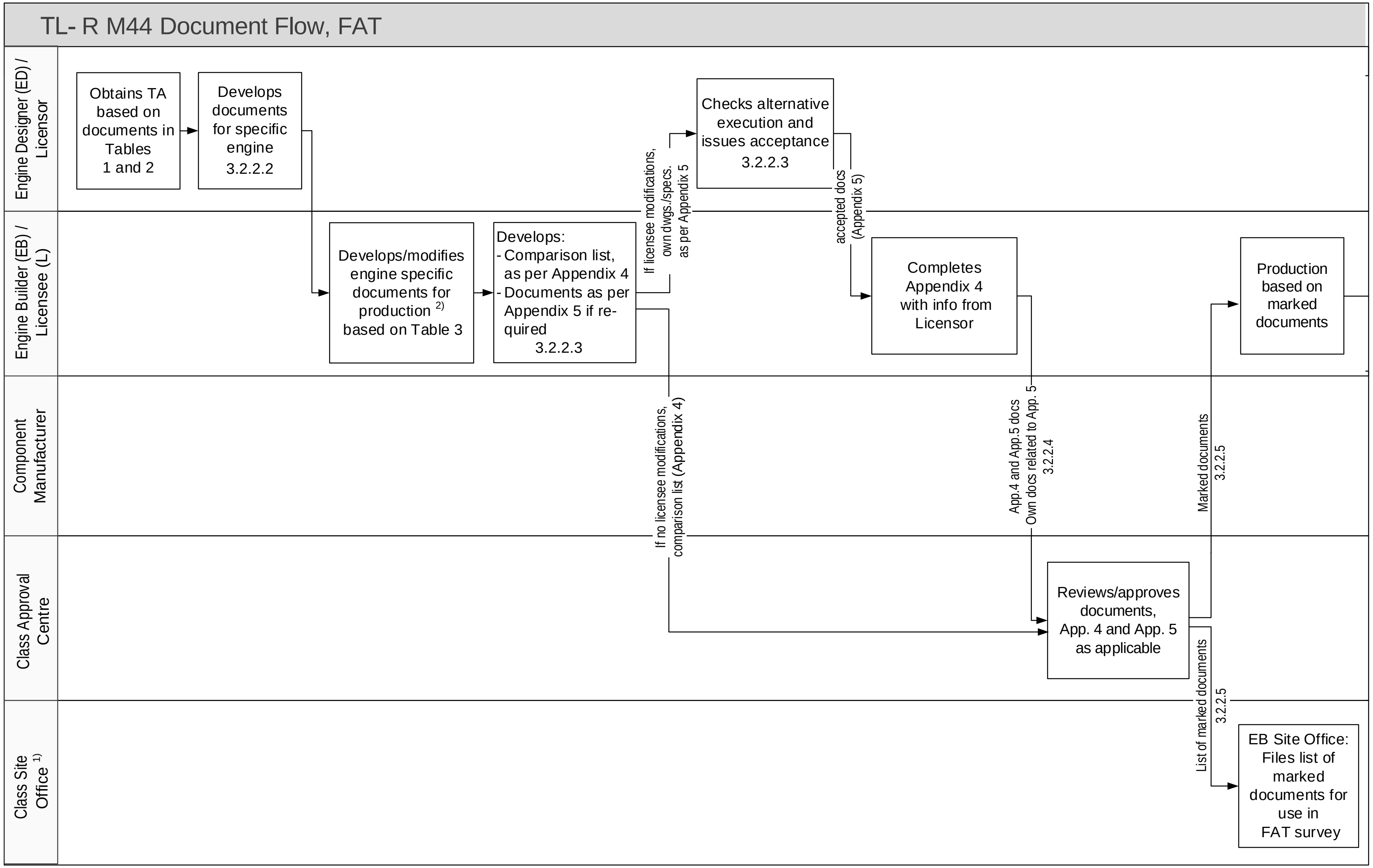
TL- R M44 - APPENDIX 2 - REPRESENTATIVE DOCUMENT FLOW DIAGRAMS

The document flow diagrams in this appendix are provided as an aid to all parties involved in the engine certification process as to their roles and responsibilities. Variations in the document flow may vary in response to unique issues with regard to various factors related to location, availability of components and surveys. In any case, the text in the requirement takes precedence over these flow diagrams.



* May also be produced by licensee

Figure 1 Type approval document flow



1) Class Site office with responsibility for engine builder and/or component manufacturers in different locations

2) For alternative execution, see 5.3

Figure 2 Engine certificate document flow

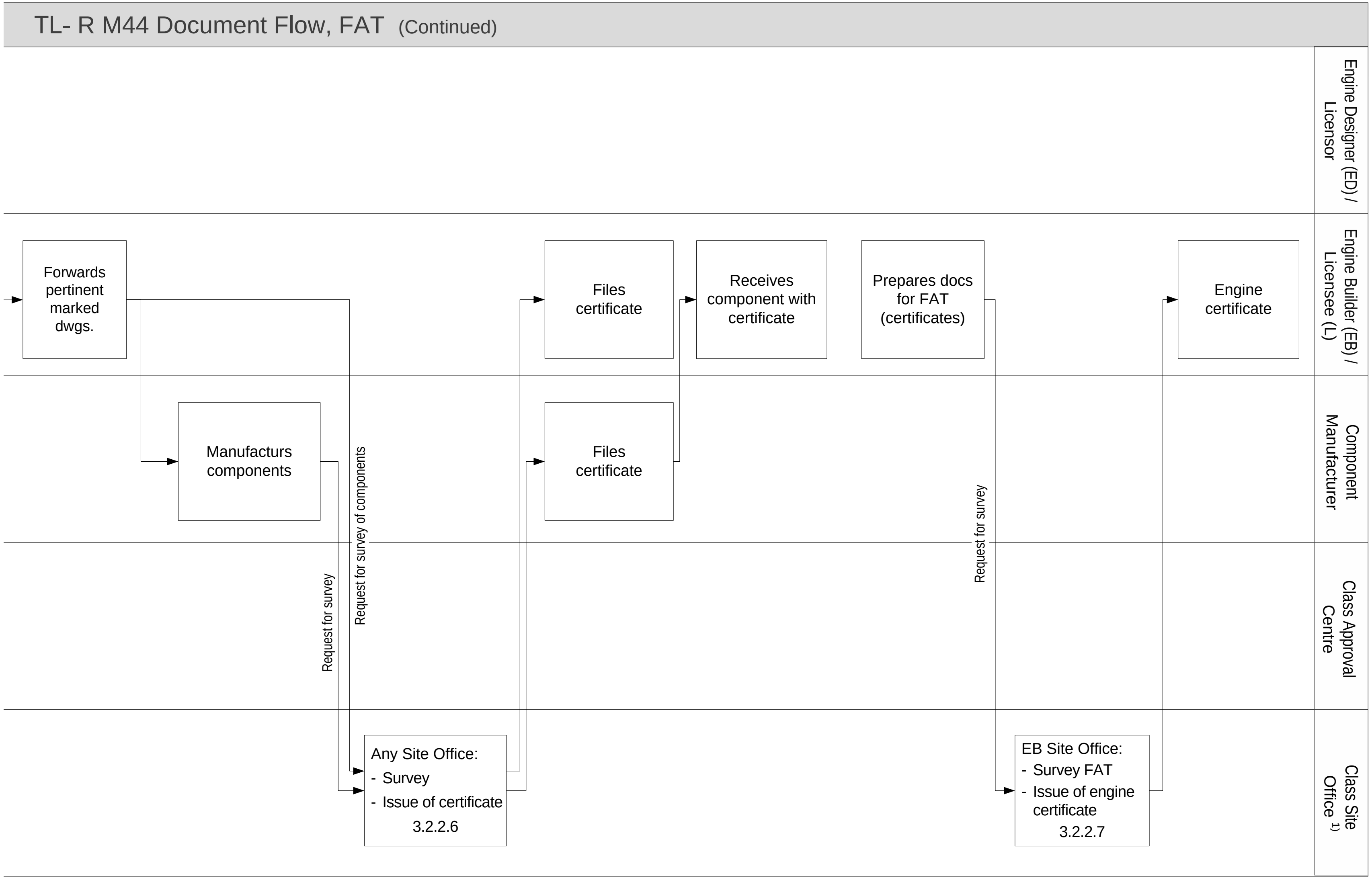


Figure 2 Engine certificate document flow (continued)

TL- R M44 - APPENDIX 3 - Internal Combustion Engine Approval Application Form and Data Sheet

Class Application number (if applicable): Engine Manufacturer's Application Identification Number:

General Data	
Engine Designer: Contact Person: Address:	Engine Manufacturer(s), Licensee(s) and/or Manufacturing Sites*Name Country

1. Document purpose *(select options from either 1a or 1b)*	
1a. Type Approval Application	
Service Requested	*Required activities†*
☐ New Type Approval	• *DA, TT, CoP*
☐ Renew Type Approval	• *CoP, if design change then amended or new certificate process to be followed*
☐ Amend Type Approval	• *DA & CoP, Further TT if previously approved engine has been substantively modified (as required by TL- R M71)*
☐ Design Evaluation	• *DA, TT, applicable where designer does not have production facilities, Type Approval to be granted to specific production facility once associated CoP has been completed*
☐ Update TA Supplement	• *Update to Supplement, only for minor changes not affecting the Type Approval Certificate*
☐ Other	• *e.g. National/Statutory Administration requirements i.e. MSC.81(70) for emergency engines*
For TA Cert amendments or Supplement updates, details of what is to be changed:	
For 'Other', Details of the requirements to be considered:	
1b. Addendum for Individual Engine FAT and Certification	
☐ Individual engine requiring FAT and Certification, only where the performance data for the engine being certified differs from the details provided on the original Type Approval Application. Only section 3b requires completion. Where changes to other sections are necessary, a new Type Approval Application may be required.	
Reference number of *Internal Combustion Engine Approval Application Form* previously submitted and reference number of the Type Approval Certificate.	*(Copy of original application form to be attached to this document)*

2. Existing documentation			
Previous Class Type Approval Certificate No. or related Design Approval No. *(if applicable)*			
Formerly issued documentation for engine *(E.g. previous type test reports, in-service experience justification reports, etc.)*	Issuing Body:	Document Type:	Document No.:
Existing Certification *(E.g. Manufacturer's quality certification ISO 9001 etc.)*	Issuing Body:	Document Type:	Document No.:

3. Design *(mark all that apply)*				
3a. Engine Particulars:				
Engine Type Manufactured Since‡:	Number of delivered marine engines‡:			
Application	☐ Direct drive Propulsion (☐ Single engine / ☐ Multi-engine installation)	☐ Auxiliary (☐ Aux. Services / ☐ Electric Propulsion)	☐ Emergency	
Mechanical Design	☐ 2-stroke	☐ 4-stroke	☐ In-line	☐ Vee (V-angle °) ☐ Other ( )
	☐ Cross-head	☐ Trunk-piston	☐ Reversible	☐ Non-reversible
	Cylinder bore(mm)		Length of piston stroke (mm)	
Supercharging	☐ Without supercharging	☐ With supercharging		
		☐ Without charge air cooling	☐ With charge air cooling	
		☐ Constant-pressure charging system	☐ Pulsating pressure charging system	
Valve operation	☐ Cam control	☐ Electronic control		
Fuel Injection	☐ Direct injection	☐ Indirect injection	☐ Cam controlled injection	☐ Electronically controlled injection

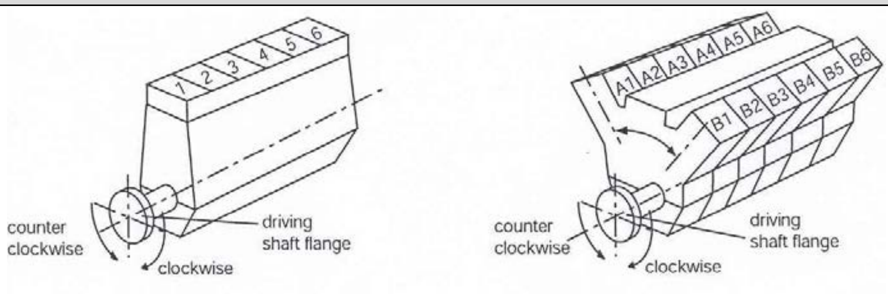
Fuel Types§ (Classification according to ISO 8216)	☐ Marine residual fuel cSt (Max. kinematic viscosity at 50°C) ☐ Marine distillate fuel DMA, DMB, DMC ☐ Marine distillate fuel DMX ☐ Low flashpoint liquid fuel (specify fuel type) ☐ Gas (specify gas type) ☐ Other (specify) ☐ Dual Fuel (specify combinations of fuels to be used simultaneously)

3b. Performance Data *(Related to: Barometric pressure 1,000 mbar; Air temperature 45°C; Relative humidity 60%; Seawater temperature 32°C)*	
Model reference No. (if applicable)	
Max. continuous rating	kW/cyl
Rated speed	1/min
Mean indicated pressure	MPa
Mean effective pressure	MPa
Max. firing pressure	MPa
Charge air pressure	MPa
Compression ratio	-
Mean piston speed	m/s

3c. Crankshaft				
Design	☐ Solid	☐ Semi-built	☐ Built	
Method of Manufacture	☐ Cast	☐ Forged ☐ Slab forged	☐ Approved die forged	☐ Continuous grain flow process
State approved forge/works name:				
Is the crankshaft hardened by an approved process which includes the fillet radii of crankpins and journals? ☐ Yes ☐ No If yes, state process:				
Crankshaft material specification: U.T.S. (N/mm²) Yield strength (N/mm²) Hardness value (Brinell/Vickers) Elongation (%)				

Dimensional Data	
If shrunk on webs, state shrinkage allowance (mm)	Yield strength of crankweb material (N/mm²)
Centre of gravity of connecting rod from large end centre (mm)	Radius of gyration of connecting rod (mm)
Mass of each crankweb (kg)	Centre of gravity of web from journal axis (mm)
Mass of each counterweight (kg)	Centre of gravity of each counterweight from journal axis (mm)
Axial length of main bearing (mm)	Main bearing working clearance (mm)
Mass of flywheel at driving end (kg)	Mass of flywheel at opposite end (kg)
Nominal alternating torsional stress in crankpin (N/mm²)	Nominal alternating torsional stress in crank journal (N/mm²)
Length between centres (Total length)(mm)	

3d. Firing order



State numbering system of cylinders from left to right as per above diagrams (as applicable)

Number of cylinders	Clockwise firing order	Counter-clockwise firing order

4. Engine Ancillary Systems		
4a. Turbochargers	☐Fitted	☐Not Fitted
Turbocharger oil supply by:	☐Engine lub. oil system	☐TC internal lub. oil system

No. of cylinders	No. of aux blowers	No. of charge air coolers	No. of TC	TC manufacturer & type	TC type approval certificate No.
				/ / / / / /	

4b. Speed governor

Engine application (Main/Aux/Emergency)	Manufacturer / type	Mode of operation	Type approval cert. No. (if electric / electronic gov.)
	/ / /		

4c. Overspeed protection

Independent overspeed protection available ☐ Yes ☐ No Mode of operation:

Manufacturer / type, if electronic: / Type approval certificate No.

4d. Electronic systems

Engine control and management system
Note: use Remarks section to identify when a different engine control system will be used for Type Test

Hardware: Manufacturer & Model: / Type approval certificate No.

Software: Name & Version: / Software conformity certificate No.

Additional electronic system 1: System function:

Manufacturer & type: / Type approval certificate No.

Additional electronic system 2: System function:

Manufacturer & type: / Type approval certificate No.

Additional electronic system 3: System function:

Manufacturer & type: / Type approval certificate No.

4e. Starting System

Type:

4f. Safety devices/functions

A flame arrestor or a bursting disk is installed in the starting air system:	before each starting valve	☐ Yes ☐ No
	in the starting air manifold	☐ Yes ☐ No

Crankcase relief valves available ☐ Yes ☐ No Manufacturer / type: /

Type approval certificate No.

No. of cyl.	Total crankcase gross volume incl. attachments (m^3)	Type & size (mm) of relief valve	Relief area per relief valve (mm^2)	No. of relief valves
		/ / / /		

Method used for detection of potentially explosive crankcase condition:

☐ Oil mist detector: Manufacturer / type: / Type approval certificate No.

☐ Alternative method: *(mark all that apply)*	☐ crankcase pressure monitoring	☐ bearing temperature monitoring	☐ other:
	☐ oil splash temperature monitoring	☐ recirculation arrangements	

Cylinder overpressure warning device available ☐ Yes ☐ No

Type: Opening pressure (bar):

4g. Attached ancillary equipment*(Mark all that apply)*

Engine driven pumps:

☐ Main lubricating oil pump	☐ Sea cooling water pump	☐ LT-fresh cooling water pump	
☐ HT-fresh cooling water pump	☐ Fuel oil booster pump	☐ Hydraulic oil pump	☐ Other ( )

Engine attached motor driven pumps:

☐ Lubricating oil pump	☐ Cooling fresh water pump	☐ Fuel oil booster pump
☐ Hydraulic oil pump	☐ Other ( )	

Engine attached cooler or heater:		
☐ Lubricating oil cooler	☐ Lubricating oil heater	☐ Fuel oil valve cooler
☐ Hydraulic oil cooler	☐ Cooling fresh water cooler	

Engine attached filter:			
Lubricating oil filter	☐ Single	☐ Duplex	☐ Automatic
Fuel oil filter	☐ Single	☐ Duplex	☐ Automatic

5. Inclination limits	Athwartships		Fore-and-aft	
(engine operation is safeguarded under the following limits)	Static	Dynamic	Static	Dynamic
Main & Auxiliary machinery	☐ 15.0°	☐ 22.5°	☐ 5.0°	☐ 7.5°
Emergency machinery	☐ 22.5°	☐ 22.5°	☐ 10.0°	☐ 10.0°
Emergency machinery on ships for the carriage of liquefied gas and liquid chemicals	☐ 30.0°	☐ 30.0°		

6. Main engine emergency operation		
At failure of one auxiliary blower, engine can be started and operated at partial load	☐ Yes	☐ No
At failure of one turbocharger, engine operation can be continued	☐ Yes	☐ No

7. References: *Additional Information Attached to Application*	
Document Name/Number	Summary of information contained in document

8. Further Remarks:

* All parties that affect the final complete engine (e.g. manufacture, modify, adjust) are to be listed. All sites where such work is carried out may be required to complete CoP assessment.

† DA = Design Appraisal, TT = Type Test, CoP = Assessment of Conformity of Production. See ‘Definitions’ at the end of this application form for more information.

‡ Only in case of TA Extension.

§ See ‘Definitions’ at the end of this application form for more information.

Completed By: Signature: ______________________

Company:

Job Title: Stamp:

Date:

Definitions:
Design Appraisal: Evaluation of all relevant plans, calculations and documents related to the design to determine compliance with the IACS and individual Societies' technical requirements. This includes requirements for all associated ancillary equipment and systems essential for the safe operation of the engine i.e. the Complete Engine. The Design Appraisal is recorded on a Supplement to the Type Approval Certificate. **Type Testing** requires satisfactory completion of testing of the Complete Engine against the requirements of TL's applicable engine Type Testing programme (based on minimum requirements of TL- R M71). Type testing is only applicable to the first in series; all engines are to complete factory acceptance and shipboard trials as defined by TL- R M51 and TL requirements. **Design Evaluation Certification** may be granted upon satisfactory completion of Design Appraisal and Type Testing. **Assessment of Conformity of Production** means the assessment of quality assurance, manufacturing facilities and processes and testing facilities, to confirm the manufacturer's capability to repeatedly produce the complete engine in accordance with the approved and type tested design. **Type Approval Certification** will be granted upon satisfactory completion of Design Appraisal, Type Testing and assessment of Conformity of Production of the complete engine. The Type Approval Certificate will incorporate outputs from the Design Appraisal, the Type Test and the Assessment of Conformity of Production. **Complete Engine** includes the control system and all ancillary systems and equipment referred to in the Rules that are used for safe operation of the engine and for which there are rule requirements, this includes systems allowing the use of different fuel types. The exact list of components/items that will need to be tested in together with the bare engine will depend on the specific design of the engine, its control system and the fuel(s) used but may include, but are not limited to, the following: (a) Turbocharger(s) (b) Crankcase explosion relief devices (c) Oil mist detection and alarm devices (d) Piping (e) Electronic monitoring and control system(s) – software and hardware (f) Fuel management system (where dual fuel arrangements are fitted) (g) Engine driven pumps (h) Engine mounted filters **Fuel Types**: All fuels that the engine is designed to operate with are to be identified on the application form as this may have impact on the requirements that are applicable for Design Appraisal and the scope of the tests required for Type Testing. Where the engine is to operate in a Dual Fuel mode, the combinations of fuel types are to be detailed. E.g. Natural Gas + DMA, Natural Gas + Marine Residual Fuel, the specific details of each fuel are to be provided as indicated in the relevant rows of the Fuel Types part of section 3a of this form.

UR M44 - APPENDIX 4 - Tabular Listing of Licensor's and Licensee's Drawing and Data

Licensee:______________________________ **Licensor:______________________________**
Licensee Engine No. :______________________________ **Engine type:______________________________**

No.	Components or System	Licensor			Licensee		Has Design been modified by Licensee?		If Yes, indicate following information	
		Dwg. No. & Title	Rev. No.	Date of Class Approval or Review	Dwg. No.	Rev. No.	Yes	No	Identification of Alternative approved by Licensor	Date of Class Approval or Review of Licensee Dwg.
1										
2										
3										
4										
5										
6										
7										
8										
9 ...										

I attest the above information to be correct and accurate.

Person in Charge (Licensee): ____________________________ ____________________________
Printed Name **Signature**

Date:____________________________________

TL- R M44 - APPENDIX 5 SAMPLE TEMPLATE FOR CONFIRMATION OF THE LICENSOR'S ACCEPTANCE OF LICENSEE'S MODIFICATIONS

Engine Licensee Proposed Alternative to Licensor's Design

Licensee information

Licensee:		Ref No.:	
Description:		Info No.:	
Engine type:		Main Section:	
Engine No.:		Plant Id.:	

Design Spec: ☐ General ☐ Specific Nos:

Licensor design:	*State relevant part or drawing. numbers. Insert drawing clips or pictures. Add any relevant information*	*Licensee Proposed Alternative*

	For example: • Differences in geometry • Differences in the functionality • Material • Hardness • Surface condition • Alternative standard • Licensee production information introduced on the drawing • Weldings or castings • etc.

Reason: ☐ Licensee's production ☐ Sub-supplier's production ☐ Cost down ☐ Tools	Interchangeability w. licensor design ☐ Yes ☐ No	Non-conformity Report Research, Assessment, Evaluation ☐ NCR ☐ RAE	Certified by licensee: Initials: Date:

Licensor comments

LoAE: ☐ Accepted as alternative execution *(Licensor undertakes responsibility)* ☐ No objection ☐ Not acceptable *(Licensee undertakes responsibility)*	**NCR:** ☐ Approved ☐ Conditionally approved ☐ Rejected	Certified by licensor: Initials: Date:

Licensor ref.:		Date:
Licensee ref.:		Date:

TL-R M46 Ambient conditions - Inclinations

M46.1 The ambient conditions specified under M46.2 are to be applied to the layout, selection and arrangement of all shipboard machinery, equipment and appliances to ensure proper operation.

M46.2 Inclinations

Installations, components	Angle of inclination [°][2]			
	Athwartships		Fore-and-aft	
	static	dynamic	static	dynamic
Main and auxiliary machinery	15	22,5	5[4]	7,5
Safety equipment, e.g. emergency power installations, emergency fire pump and their devices Switch gear, electrical and electronic appliances[1] and remote control systems	22,5[3]	22,5[3]	10	10

NOTES:

1. Up to an angle of inclination of 45° no undesired switching operations or operational changes may occur.

2. Athwartships and fore-end-aft inclinations may occur simultaneously.

3. In ships for the carriage of liquefied gases and of chemicals the emergency power supply must also remain operable with the ship flooded to a final athwartships inclination up to maximum of 30°.

4. Where the length of the ship exceeds 100m, the fore-and-aft static angle of inclination may be taken as 500/L degrees where L = length of the ship, in metres, as defined in TL-R S2.

The Society may consider deviations from these angles of inclination taking into consideration the type, size and service conditions of the ship.

TL- R M51 Factory Acceptance Test and Shipboard Trials of I.C. Engines

1. Safety precautions

1.1 Before any test run is carried out, all relevant equipment for the safety of attending personnel is to be made available by the manufacturer / shipyard and is to be operational.

1.2 This applies especially to crankcase explosive conditions protection, but also to overspeed protection and any other shut down function.

1.3 The overspeed protective device is to be set to a value, which is not higher than the overspeed value that was demonstrated during the type test for that engine. This set point shall be verified by the surveyor.

2. General

2.1 Before any official testing, the engines shall be run-in as prescribed by the engine manufacturer.

2.2 Adequate test bed facilities for loads as required in TL- R M51.3.3 shall be provided. All fluids used for testing purposes such as fuel, lubrication oil and cooling water are to be suitable for the purpose intended, e.g. they are to be clean, preheated if necessary and cause no harm to engine parts. This applies to all fluids used temporarily or repeatedly for testing purposes only.

2.3 The testing consists of workshop and shipboard (quay and sea trial) testing.

Notes:

1. This requirement – except for M51.4 – is implemented to engines with an application for certification dated on or after 1 July 2016.

   The requirement of M51.4 is implemented to engines:

   i) with an application for certification dated on or after 1 July 2016; or
   ii) installed on ships contracted for construction on or after 1 July 2016.

2. The “date of application for certification of the engine” is the date of whatever document TL requires/accepts as an application or request for certification of an individual engine.

3. The “contracted for construction” date means the date on which the contract to build the vessel is signed between the prospective owner and the shipbuilder. For further details regarding the date of “contract for construction”, refer to TL- PR 29.

2.4 Engines are to be inspected for:

- Jacketing of high-pressure fuel oil lines including the system used for the detection of leakage.

- Screening of pipe connections in piping containing flammable liquids.

- Insulation of hot surfaces by taking random temperature readings that are to be compared with corresponding readings obtained during the type test. This shall be done while running at the rated power of engine. Use of contact thermometers may be accepted at the discretion of the attending Surveyor. If the insulation is modified subsequently to the Type Approval Test, TL may request temperature measurements as required by TL- R M71.8.9.

2.5 These inspections are normally to be made during the works trials by the manufacturer and the attending surveyor, but at the discretion of TL parts of these inspections may be postponed to the shipboard testing.

3. Works trials (Factory Acceptance Test)

3.1 Objectives

The purpose of the works trials is to verify design premises such as power, safety against fire, adherence to approved limits (e.g. maximum pressure), and functionality and to establish reference values or base lines for later reference in the operational phase.

3.2 Records

3.2.1 The following environmental test conditions are to be recorded:

- Ambient air temperature

- Ambient air pressure

- Atmospheric humidity

3.2.2 For each required load point, the following parameters are normally to be recorded:

- Power and speed

- Fuel index (or equivalent reading)

- Maximum combustion pressures (only when the cylinder heads installed are designed for such measurement).

- Exhaust gas temperature before turbine and from each cylinder (to the extent that monitoring is required in TL- R M73 and TL- R M35/36)

- Charge air temperature

- Charge air pressure

- Turbocharger speed (to the extent that monitoring is required in TL- R M73)

3.2.3 Calibration records for the instrumentation are, upon request, to be presented to the attending Surveyor.

3.2.4 For all stages at which the engine is to be tested, the pertaining operational values are to be measured and recorded by the engine manufacturer. All results are to be compiled in an acceptance protocol to be issued by the engine manufacturer. This also includes crankshaft deflections if considered necessary by the engine designer.

3.2.5 In each case, all measurements conducted at the various load points are to be carried out at steady state operating conditions. However, for all load points provision should be made for time needed by the Surveyor to carry out visual inspections. The readings for MCR, i.e. 100% power (rated maximum continuous power at corresponding rpm) are to be taken at least twice at an interval of normally 30 minutes.

3.3 Test loads

3.3.1 Test loads for various engine applications are given below. In addition, the scope of the trials may be expanded depending on the engine application, service experience, or other relevant reasons.

Note:
Alternatives to the detailed tests may be agreed between the manufacturer and TL when the overall scope of tests is found to be equivalent.

3.3.2 Propulsion engines driving propeller or impeller only.

A) 100% power (MCR) at corresponding speed n_0: at least 60 min.

B) 110% power at engine speed $1.032n_0$: Records to be taken after 15 minutes or after steady conditions have been reached, whichever is shorter.

Note:
Only required once for each different engine/turbocharger configuration.

C) Approved intermittent overload (if applicable): testing for duration as agreed with the manufacturer.

D) 90% (or normal continuous cruise power), 75%, 50% and 25% power in accordance with the nominal propeller curve, the sequence to be selected by the engine manufacturer.

E) Reversing manoeuvres (if applicable).

Note:
After running on the test bed, the fuel delivery system is to be so adjusted that overload power cannot be given in service, unless intermittent overload power is approved by TL. In that case, the fuel delivery system is to be blocked to that power.

3.3.3 Engines driving generators for electric propulsion.

A) 100% power (MCR) at corresponding speed n_0: at least 60 min.

B) 110% power at engine speed n_0: 15 min. - after having reached steady conditions.

C) Governor tests for compliance with TL- R M3.1 and M3.2 are to be carried out.

D) 75%, 50% and 25% power and idle, the sequence to be selected by the engine manufacturer.

Note:
After running on the test bed, the fuel delivery system is to be adjusted so that full power plus a 10% margin for transient regulation can be given in service after installation onboard. The transient overload capability is required so that the required transient governing characteristics are achieved also at 100% loading of the engine, and also so that the protection system utilised in the electric distribution system can be activated before the engine stalls.

3.3.4 Engines driving generators for auxiliary purposes.

Tests to be performed as in UR M51.3.3.3.

3.3.5 Propulsion engines also driving power take off (PTO) generator.

A) 100% power (MCR) at corresponding speed n_0: at least 60 min.

B) 110% power at engine speed n_0: 15 min. - after having reached steady conditions.

C) Approved intermittent overload (if applicable): testing for duration as agreed with the manufacturer.

D) 90% (or normal continuous cruise power), 75%, 50% and 25% power in accordance with the nominal propeller curve or at constant speed n_0, the sequence to be selected by the engine manufacturer.

Note:
After running on the test bed, the fuel delivery system is to be adjusted so that full power plus a margin for transient regulation can be given in service after installation onboard. The transient overload capability is required so that the electrical protection of downstream system components is activated before the engine stalls. This margin may be 10% of the engine power but at least 10% of the PTO power.

3.3.6 Engines driving auxiliaries.

A) 100% power (MCR) at corresponding speed n_0: at least 30 min.

B) 110% power at engine speed n_0: 15 min. - after having reached steady conditions.

C) Approved intermittent overload (if applicable): testing for duration as agreed with the manufacturer.

D) For variable speed engines, 75%, 50% and 25% power in accordance with the nominal power consumption curve, the sequence to be selected by the engine manufacturer.

Note:
After running on the test bed, the fuel delivery system is normally to be so adjusted that overload power cannot be delivered in service, unless intermittent overload power is approved. In that case, the fuel delivery system is to be blocked to that power.

3.4 Turbocharger matching with engine

3.4.1 Compressor chart

Turbochargers shall have a compressor characteristic that allows the engine, for which it is intended, to operate without surging during all operating conditions and also after extended periods in operation.
For abnormal, but permissible, operation conditions, such as misfiring and sudden load reduction, no continuous surging shall occur.
In this section, *surging* and *continuous surging* are defined as follows:
Surging means the phenomenon, which results in a high pitch vibration of an audible level or explosion-like noise from the scavenger area of the engine.
Continuous surging means that surging happens repeatedly and not only once.

3.4.2 Surge margin verification

Category C turbochargers used on propulsion engines are to be checked for surge margins during the engine workshop testing as specified below. These tests may be waived if successfully tested earlier on an identical configuration of engine and turbocharger (including same nozzle rings).

For 4-stroke engines:

The following 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. The engine working characteristic established at workshop testing of the engine shall be plotted into the compressor chart of the turbocharger (established in a test rig). There shall be at least 10% surge margin in the full load range, i.e. working flow shall be 10% above the theoretical (mass) flow at surge limit (at no pressure fluctuations).

2. Sudden fuel cut-off to at least one cylinder shall not result in continuous surging and the turbocharger shall be stabilised at the new load within 20 seconds. For applications with more than one turbocharger the fuel shall be cut-off to the cylinders closest upstream to each turbocharger.

   This test shall be performed at two different engine loads:

   - The maximum 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. No continuous surging and the turbocharger shall be stabilised at the new load within 20 seconds when the power is abruptly reduced from 100% to 50% of the maximum continuous power.

3.5 Integration tests

For electronically controlled engines, integration tests are to be made to verify that the response of the complete mechanical, hydraulic and electronic system is as predicted for all intended operational modes and the tests considered as a system are to be carried out at the works. If such tests are technically unfeasible at the works, however, these tests may be conducted during sea trial. The scope of these tests is to be agreed with TL for selected cases based on the FMEA required in TL- R M44.

3.6 Component inspections

Random checks of components to be presented for inspection after works trials are left to the discretion of TL.

4. Shipboard trials

4.1 Objectives

The purpose of the shipboard testing is to verify compatibility with power transmission and driven machinery in the system, control systems and auxiliary systems necessary for the engine and integration of engine / shipboard control systems, as well as other items that had not been dealt with in the FAT (Factory Acceptance Testing).

4.2 Starting capacity

Starting manoeuvres are to be carried out in order to verify that the capacity of the starting media satisfies the required number of start attempts.

4.3 Monitoring and alarm system

The monitoring and alarm systems are to be checked to the full extent for all engines, except items already verified during the works trials.

4.4 Test loads

4.4.1 Test loads for various engine applications are given below. In addition, the scope of the trials may be expanded depending on the engine application, service experience, or other relevant reasons.

4.4.2 The suitability of the engine to operate on fuels intended for use is to be demonstrated.

Note:
Tests other than those listed below may be required by statutory instruments (e.g. EEDI verification).

4.4.3 Propulsion engines driving fixed pitch propeller or impeller.

A) At rated engine speed n_0: at least 4 hours.

B) At engine speed $1.032n_0$ (if engine adjustment permits, see 3.3.1): 30 min.

C) At approved intermittent overload (if applicable): testing for duration as agreed with the manufacturer.

D) Minimum engine speed to be determined.

E) The ability of reversible engines to be operated in reverse direction is to be demonstrated.

Note:
During stopping tests according to Resolution MSC.137 (76), see 4.5.1 for additional requirements in the case of a barred speed range.

4.4.4 Propulsion engines driving controllable pitch propellers.

A) At rated engine speed n_0 with a propeller pitch leading to rated engine power (or to the maximum achievable power if 100% cannot be reached): at least 4 hours.

B) At approved intermittent overload (if applicable): testing for duration as agreed with the manufacturer.

C) With reverse pitch suitable for manoeuvring, see TL- R M51.4.5.1 for additional requirements in the case of a barred speed range.

4.4.5 Engine(s) driving generator(s) for electrical propulsion and/or main power supply

A) At 100% power (rated electrical power of generator): at least 60 min.

B) At 110% power (rated electrical power of generator): at least 10 min.

Note:
Each engine is to be tested 100% electrical power for at least 60 min and 110% of rated electrical power of the generator for at least 10 min. This may, if possible, be done during the electrical propulsion plant test, which is required to be tested with 100% propulsion power (i.e. total electric motor capacity for propulsion) by distributing the power on as few generators as possible. The duration of this test is to be sufficient to reach stable operating temperatures of all rotating machines or for at least 4 hours. When some of the gen. set(s) cannot be tested due to insufficient time during the propulsion system test mentioned above, those required tests are to be carried out separately.

C) Demonstration of the generator prime movers' and governors' ability to handle load steps as described in TL- R M3.2.

4.4.6 Propulsion engines also driving power take off (PTO) generator.

A) 100% engine power (MCR) at corresponding speed n_0: at least 4 hours.

B) 100% propeller branch power at engine speed n_0 (unless already covered in A): 2 hours.

C) 100% PTO branch power at engine speed n_0: at least 1 hour.

4.4.7 Engines driving auxiliaries.

A) 100% power (MCR) at corresponding speed n_0: at least 30 min.

B) Approved intermittent overload: testing for duration as approved.

4.5 Torsional vibrations

4.5.1 Barred speed range

Where a barred speed range (bsr) is required, passages through this bsr, both accelerating and decelerating, are to be demonstrated. The times taken are to be recorded and are to be equal to or below those times stipulated in the approved documentation, if any. This also includes when passing through the bsr in reverse rotational direction, especially during the stopping test.

Note:
Applies both for manual and automatic passing-through systems.

The ship's draft and speed during all these demonstrations is to be recorded. In the case of a controllable pitch propeller, the pitch is also to be recorded.

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

TL- R M53 Calculations for I.C. Engine Crankshafts

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Note:

1. This requirement is applied to crankshafts whose application for design approval is dated on or after 1 July 2018.

M 53.1 GENERAL

1.1 Scope

These Rules for the design of crankshafts are to be applied to I.C. engines for propulsion and auxiliary purposes, where the engines are capable of continuous operation at their rated power when running at rated speed.

Where a crankshaft design involves the use of surface treated fillets, or when fatigue parameter influences are tested, or when working stresses are measured, the relevant documents with calculations/analysis are to be submitted to TL in order to demonstrate equivalence to the Rules.

1.2 Field of application

These Rules apply only to solid-forged and semi-built crankshafts of forged or cast steel, with one crankthrow between main bearings.

1.3 Principles of calculation

The design of crankshafts is based on an evaluation of safety against fatigue in the highly stressed areas.

The calculation is also based on the assumption that the areas exposed to highest stresses are :

- fillet transitions between the crankpin and web as well as between the journal and web,
- outlets of crankpin oil bores.

When journal diameter is equal or larger than the crankpin one, the outlets of main journal oil bores are to be formed in a similar way to the crankpin oil bores, otherwise separate documentation of fatigue safety may be required.

Calculation of crankshaft strength consists initially in determining the nominal alternating bending (see § M53.2.1) and nominal alternating torsional stresses (see § M53.2.2) which, multiplied by the appropriate stress concentration factors (see § M53.3), result in an equivalent alternating stress (uni-axial stress) (see § M53.5). This equivalent alternating stress is then compared with the fatigue strength of the selected crankshaft material (see § M53.6). This comparison will show whether or not the crankshaft concerned is dimensioned adequately (see § M53.7).

1.4 Drawings and particulars to be submitted

For the calculation of crankshafts, the documents and particulars listed below are to be submitted :

- crankshaft drawing
  (which must contain all data in respect of the geometrical configurations of the crankshaft)
- type designation and kind of engine
  (in-line engine or V-type engine with adjacent connecting-rods, forked connecting-rod or articulated-type connecting-rod)
- operating and combustion method
  (2-stroke or 4-stroke cycle/direct injection, precombustion chamber, etc.)
- number of cylinders

- rated power [kW]
- rated engine speed [r/min]
- direction of rotation (see. fig. 1)
- firing order with the respective ignition intervals and, where necessary,
- V-angle α_v [°] (see fig. 1)

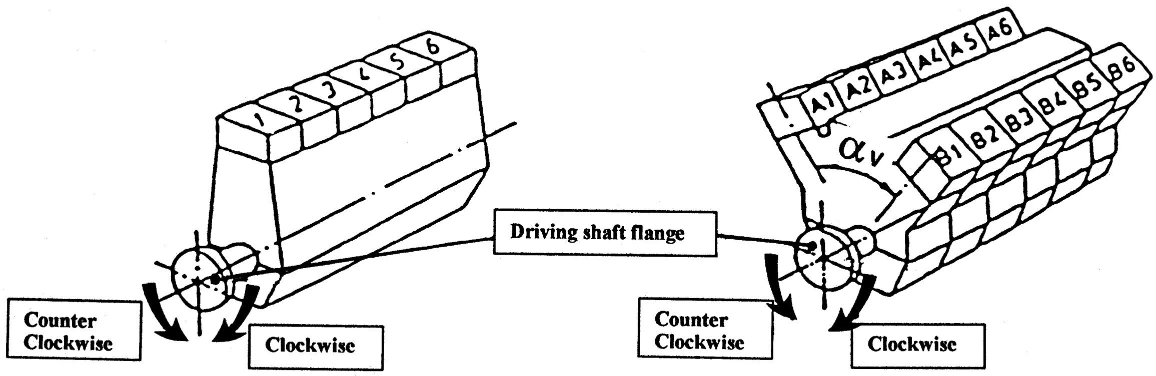


Fig. 1 – Designation of the cylinders

- cylinder diameter [mm]
- stroke [mm]
- maximum net cylinder pressure P_{max} [bar]
- charge air pressure [bar]
  (before inlet valves or scavenge ports, whichever applies)
- connecting-rod length L_H [mm]
- all individual reciprocating masses acting on one crank [kg]
- digitized gas pressure curve presented at equidistant intervals [bar versus Crank Angle] (at least every 5° CA)
- for engines with articulated-type connecting-rod (see fig. 2)
  - o distance to link point L_A [mm]
  - o link angle α_N [°]
- connecting-rod length L_N [mm]

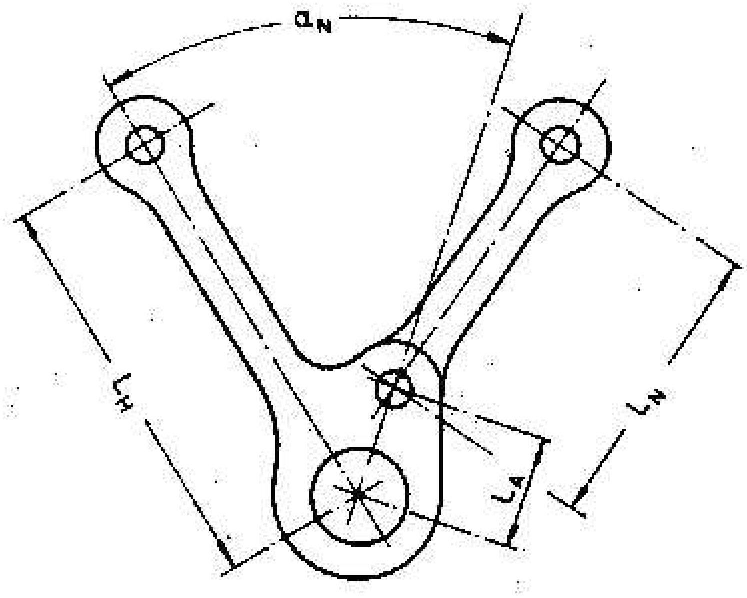


Fig. 2 – articulated-type connecting-rod

- details of crankshaft material
  - o material designation
    (according to ISO,EN,DIN, AISI, etc..)
  - o mechanical properties of material
    (minimum values obtained from longitudinal test specimens)
    - tensile strength [N/mm²]
    - yield strength [N/mm²]
    - reduction in area at break [%]
    - elongation A_5 [%]
    - impact energy – KV [J]
  - o type of forging
    (free form forged, continuous grain flow forged, drop-forged, etc… ; with description of the forging process)
- Every surface treatment affecting fillets or oil holes shall be specified so as to enable calculation according to Appendix V.
- Particulars of alternating torsional stress calculations, see item M 53.2.2.

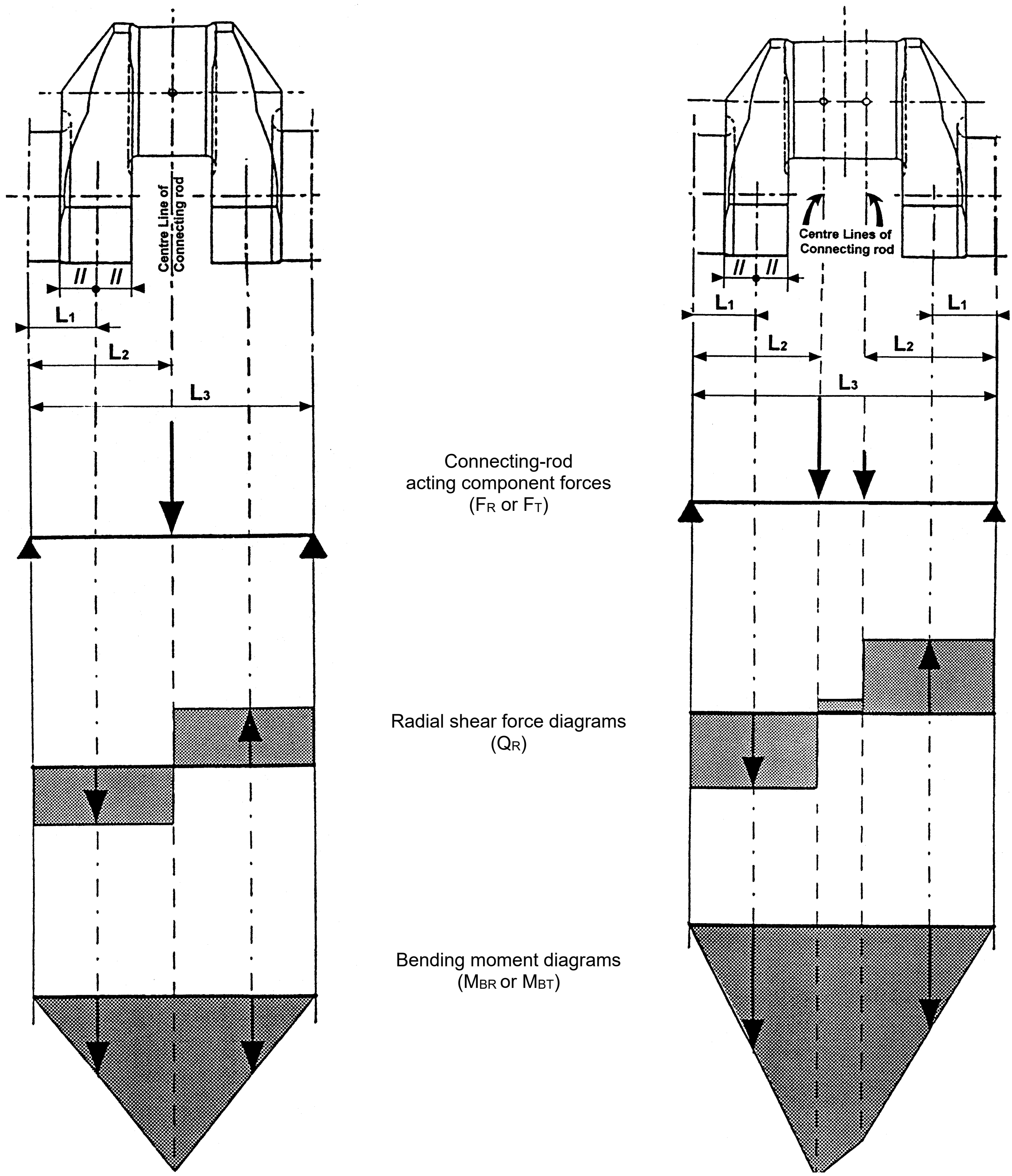


Fig. 3 Crankthrow for in line engine

Fig. 4 Crankthrow for V engine with 2 adjacent connecting-rods

L_1 = Distance between main journal centre line and crankweb centre
(see also Fig 5 for crankshaft without overlap)
L_2 = Distance between main journal centre line and connecting-rod centre
L_3 = Distance between two adjacent main journal centre lines

M 53.2 CALCULATION OF STRESSES

2.1 Calculation of alternating stresses due to bending moments and radial forces

2.1.1 Assumptions

The calculation is based on a statically determined system, composed of a single crankthrow supported in the centre of adjacent main journals and subject to gas and inertia forces. The bending length is taken as the length between the two main bearing midpoints (distance L_3, see fig. 3 and 4).

The bending moments M_{BR}, M_{BT} are calculated in the relevant section based on triangular bending moment diagrams due to the radial component F_R and tangential component F_T of the connecting-rod force, respectively (see fig. 3).

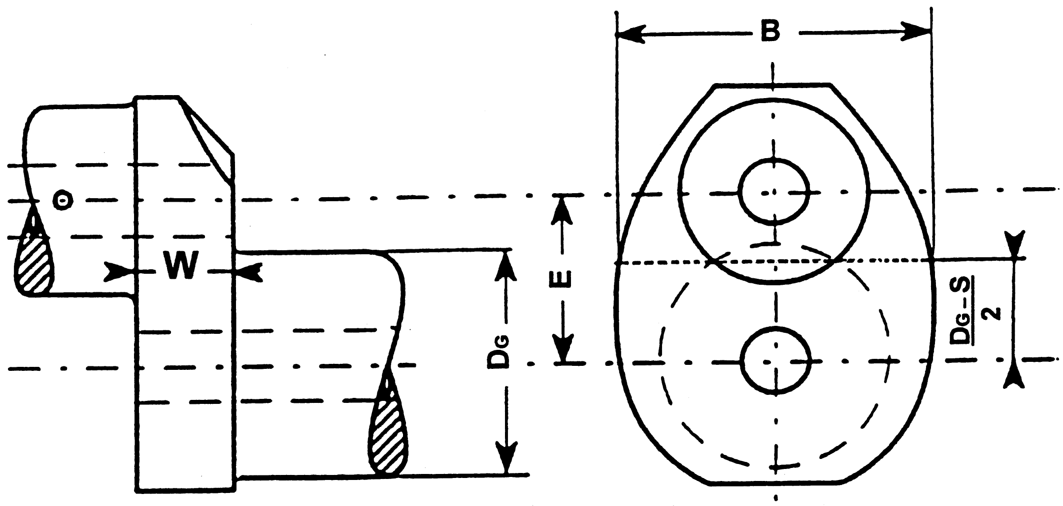
For crankthrows with two connecting-rods acting upon one crankpin the relevant bending moments are obtained by superposition of the two triangular bending moment diagrams according to phase (see fig. 4).

2.1.1.1 Bending moments and radial forces acting in web

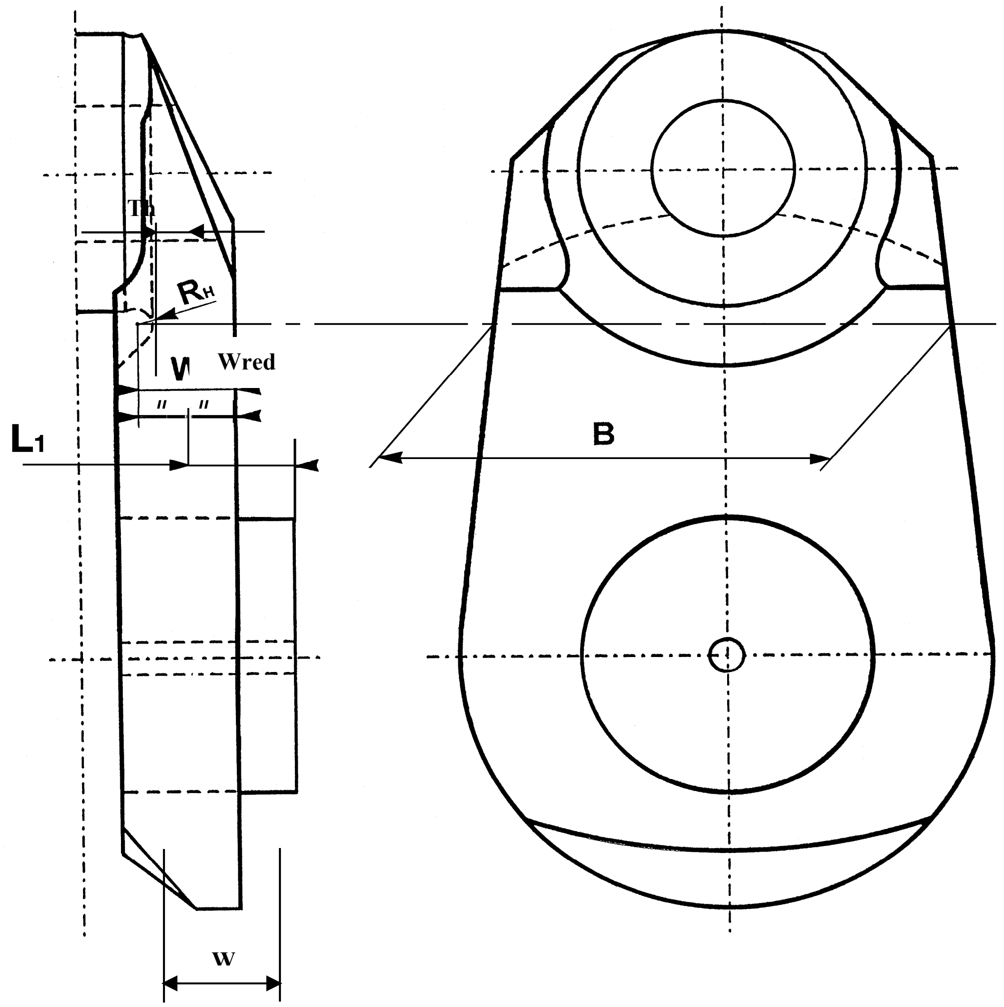
The bending moment M_{BRF} and the radial force Q_{RF} are taken as acting in the centre of the solid web (distance L_1) and are derived from the radial component of the connecting-rod force.

The alternating bending and compressive stresses due to bending moments and radial forces are to be related to the cross-section of the crank web. This reference section results from the web thickness W and the web width B (see fig. 5).

Mean stresses are neglected.



Overlapped crankshaft

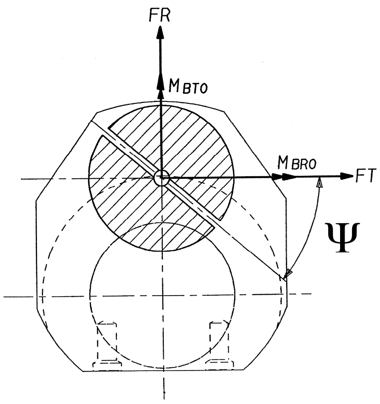


Crankshaft without overlap

Fig. 5 – Reference area of crankweb cross section

2.1.1.2 Bending acting in outlet of crankpin oil bore

The two relevant bending moments are taken in the crankpin cross-section through the oil bore.



M_{BRO} is the bending moment of the radial component of the connecting-rod force

M_{BTO} is the bending moment of the tangential component of the connecting-rod force

Fig. 6 – Crankpin section through the oil bore

The alternating stresses due to these bending moments are to be related to the cross-sectional area of the axially bored crankpin.

Mean bending stresses are neglected.

2.1.2 Calculation of nominal alternating bending and compressive stresses in web

The radial and tangential forces due to gas and inertia loads acting upon the crankpin at each connecting-rod position will be calculated over one working cycle.

Using the forces calculated over one working cycle and taking into account of the distance from the main bearing midpoint, the time curve of the bending moments M_{BRF}, M_{BRO}, M_{BTO} and radial forces Q_{RF} - as defined in M53 2.1.1.1 and 2.1.1.2 - will then be calculated.

In case of V-type engines, the bending moments - progressively calculated from the gas and inertia forces - of the two cylinders acting on one crankthrow are superposed according to phase. Different designs (forked connecting-rod, articulated-type connecting-rod or adjacent connecting-rods) shall be taken into account.

Where there are cranks of different geometrical configurations in one crankshaft, the calculation is to cover all crank variants.

The decisive alternating values will then be calculated according to:

$$X_N = \pm\frac{1}{2}\left[X_{max} - X_{min}\right]$$

where:

X_N is considered as alternating force, moment or stress

X_{max} is maximum value within one working cycle

X_{min} is minimum value within one working cycle

2.1.2.1 Nominal alternating bending and compressive stresses in web cross section

The calculation of the nominal alternating bending and compressive stresses is as follows:

$$\sigma_{BFN} = \pm \frac{M_{BRFN}}{W_{eqw}} \bullet 10^3 \bullet Ke$$

$$\sigma_{QFN} = \pm \frac{Q_{RFN}}{F} \bullet Ke$$

where:

σ_{BFN} [N/mm²] nominal alternating bending stress related to the web

M_{BRFN} [Nm] alternating bending moment related to the centre of the web (see fig. 3 and 4)

$$M_{BRFN} = \pm \frac{1}{2}\left[M_{BRFmax} - M_{BRFmin}\right]$$

W_{eqw} [mm³] section modulus related to cross-section of web

$$W_{eqw} = \frac{B \bullet W^2}{6}$$

Ke empirical factor considering to some extent the influence of adjacent crank and bearing restraint
with: Ke = 0.8 for 2-stroke engines
Ke = 1.0 for 4-stroke engines

σ_{QFN} [N/mm²] nominal alternating compressive stress due to radial force related to the web

Q_{RFN} [N] alternating radial force related to the web (see fig. 3 and 4)

$$Q_{RFN} = \pm \frac{1}{2}\left[Q_{RF_{max}} - Q_{RF_{min}}\right]$$

F [mm²] area related to cross-section of web

$$F = B \bullet W$$

2.1.2.2 Nominal alternating bending stress in outlet of crankpin oil bore

The calculation of nominal alternating bending stress is as follows:

where:

$$\sigma_{BON} = \pm \frac{M_{BON}}{W_e} \bullet 10^3$$

σ_{BON} [N/mm²] nominal alternating bending stress related to the crank pin diameter

M_{BON} [Nm] alternating bending moment calculated at the outlet of crankpin oil bore

$$M_{BON} = \pm\frac{1}{2}\left[M_{BO_{max}} - M_{BO_{min}}\right]$$

with

$$M_{BO} = (M_{BTO} \bullet \cos\psi + M_{BRO} \bullet \sin\psi)$$

and ψ [°] angular position (see fig. 6)

W_e [mm^3] section modulus related to cross-section of axially bored crankpin

$$W_e = \frac{\pi}{32}\left[\frac{D^4 - D_{BH}^4}{D}\right]$$

2.1.3 Calculation of alternating bending stresses in fillets

The calculation of stresses is to be carried out for the crankpin fillet as well as for the journal fillet.

For the crankpin fillet:

$$\sigma_{BH} = \pm(\alpha_B \bullet \sigma_{BFN})$$

where:

σ_{BH} [N/mm^2] alternating bending stress in crankpin fillet

α_B [-] stress concentration factor for bending in crankpin fillet (determination - see item M53.3)

For the journal fillet (not applicable to semi-built crankshaft):

$$\sigma_{BG} = \pm(\beta_B \bullet \sigma_{BFN} + \beta_Q \bullet \sigma_{QFN})$$

where:

σ_{BG} [N/mm^2] alternating bending stress in journal fillet

β_B [-] stress concentration factor for bending in journal fillet (determination - see item M53.3)

β_Q [-] stress concentration factor for compression due to radial force in journal fillet (determination - see item M53.3)

2.1.4 Calculation of alternating bending stresses in outlet of crankpin oil bore

$$\sigma_{BO} = \pm(\gamma_B \bullet \sigma_{BON})$$

where:

σ_{BO} [N/mm^2] alternating bending stress in outlet of crankpin oil bore

γ_B [-] stress concentration factor for bending in crankpin oil bore (determination - see item M53.3)

2.2 Calculation of alternating torsional stresses

2.2.1 General

The calculation for nominal alternating torsional stresses is to be undertaken by the engine manufacturer according to the information contained in item M 53.2.2.2.

The manufacturer shall specify the maximum nominal alternating torsional stress.

2.2.2 Calculation of nominal alternating torsional stresses

The maximum and minimum torques are to be ascertained for every mass point of the complete dynamic system and for the entire speed range by means of a harmonic synthesis of the forced vibrations from the 1st order up to and including the 15^{th} order for 2-stroke cycle engines and from the 0.5^{th} order up to and including the 12^{th} order for 4-stroke cycle engines. Whilst doing so, allowance must be made for the damping that exists in the system and for unfavourable conditions (misfiring [*] in one of the cylinders). The speed step calculation shall be selected in such a way that any resonance found in the operational speed range of the engine shall be detected.

Where barred speed ranges are necessary, they shall be arranged so that satisfactory operation is possible despite their existence. There are to be no barred speed ranges above a speed ratio of $\lambda \geq 0.8$ for normal firing conditions.

The values received from such calculation are to be submitted to TL.

The nominal alternating torsional stress in every mass point, which is essential to the assessment, results from the following equation:

$$\tau_N = \pm \frac{M_{TN}}{W_P} \bullet 10^3$$

$$M_{TN} = \pm \frac{1}{2}\left[M_{T\,max} - M_{T\,min}\right]$$

$$W_p = \frac{\pi}{16}\left(\frac{D^4 - D_{BH}{}^4}{D}\right) \quad \text{or} \quad W_p = \frac{\pi}{16}\left(\frac{D_G{}^4 - D_{BG}{}^4}{D_G}\right)$$

*) Misfiring is defined as cylinder condition when no combustion occurs but only compression cycle.

where:

τ_N [N/mm²] nominal alternating torsional stress referred to crankpin or journal

M_{TN} [Nm] maximum alternating torque

W_P [mm³] polar section modulus related to cross-section of axially bored crankpin or bored journal

M_{Tmax} [Nm] maximum value of the torque

M_{Tmin} [Nm] minimum value of the torque

For the purpose of the crankshaft assessment, the nominal alternating torsional stress considered in further calculations is the highest calculated value, according to above method, occurring at the most torsionally loaded mass point of the crankshaft system.

Where barred speed ranges exist, the torsional stresses within these ranges are not to be considered for assessment calculations.

The approval of crankshaft will be based on the installation having the largest nominal alternating torsional stress (but not exceeding the maximum figure specified by engine manufacturer).

Thus, for each installation, it is to be ensured by suitable calculation that this approved nominal alternating torsional stress is not exceeded. This calculation is to be submitted for assessment.

2.2.3 Calculation of alternating torsional stresses in fillets and outlet of crankpin oil bore

The calculation of stresses is to be carried out for the crankpin fillet, the journal fillet and the outlet of the crankpin oil bore.

For the crankpin fillet:

$$\tau_H = \pm(\alpha_T \bullet \tau_N)$$

where:

τ_H [N/mm²] alternating torsional stress in crankpin fillet

α_T [-] stress concentration factor for torsion in crankpin fillet (determination - see item M53.3)

τ_N [N/mm²] nominal alternating torsional stress related to crankpin diameter

For the journal fillet (not applicable to semi-built crankshafts):

$$\tau_G = \pm(\beta_T \bullet \tau_N)$$

where:

τ_G [N/mm^2] alternating torsional stress in journal fillet

β_T [-] stress concentration factor for torsion in journal fillet (determination - see item M53.3)

τ_N [N/mm^2] nominal alternating torsional stress related to journal diameter

For the outlet of crankpin oil bore:

$$\sigma_{TO} = \pm(\gamma_T \bullet \tau_N)$$

where:

σ_{TO} [N/mm^2] alternating stress in outlet of crankpin oil bore due to torsion

γ_T [-] stress concentration factor for torsion in outlet of crankpin oil bore (determination- see item M53.3)

τ_N [N/mm^2] nominal alternating torsional stress related to crankpin diameter

M 53.3 EVALUATION OF STRESS CONCENTRATION FACTORS

3.1 General

The stress concentration factors are evaluated by means of the formulae according to items M53.3.2, M53.3.3 and M53.3.4 applicable to the fillets and crankpin oil bore of solid forged web-type crankshafts and to the crankpin fillets of semi-built crankshafts only. It must be noticed that stress concentration factor formulae concerning the oil bore are only applicable to a radially drilled oil hole. All formulae are based on investigations of FVV (Forschungsvereinigung Verbrennungskraftmaschinen) for fillets and on investigations of ESDU (Engineering Science Data Unit) for oil holes.

Where the geometry of the crankshaft is outside the boundaries of the analytical stress concentration factors (SCF) the calculation method detailed in Appendix III may be undertaken.

All crank dimensions necessary for the calculation of stress concentration factors are shown in figure 7.

The stress concentration factor for bending (α_B, β_B) is defined as the ratio of the maximum equivalent stress (VON MISES) – occurring in the fillets under bending load – to the nominal bending stress related to the web cross-section (see Appendix I).

The stress concentration factor for compression (β_Q) in the journal fillet is defined as the ratio of the maximum equivalent stress (VON MISES) – occurring in the fillet due to the radial force – to the nominal compressive stress related to the web cross-section.

The stress concentration factor for torsion (α_T, β_T) is defined as the ratio of the maximum equivalent shear stress – occurring in the fillets under torsional load – to the nominal torsional stress related to the axially bored crankpin or journal cross-section (see Appendix I).

The stress concentration factors for bending (γ_B) and torsion (γ_T) are defined as the ratio of the maximum principal stress – occurring at the outlet of the crankpin oil-hole under bending and torsional loads – to the corresponding nominal stress related to the axially bored crankpin cross section (see Appendix II).

When reliable measurements and/or calculations are available, which can allow direct assessment of stress concentration factors, the relevant documents and their analysis method have to be submitted to TL in order to demonstrate their equivalence to present rules evaluation. This is always to be performed when dimensions are outside of any of the validity ranges for the empirical formulae presented in 3.2 to 3.4.

Appendix III and VI describes how FE analyses can be used for the calculation of the stress concentration factors. Care should be taken to avoid mixing equivalent (von Mises) stresses and principal stresses.

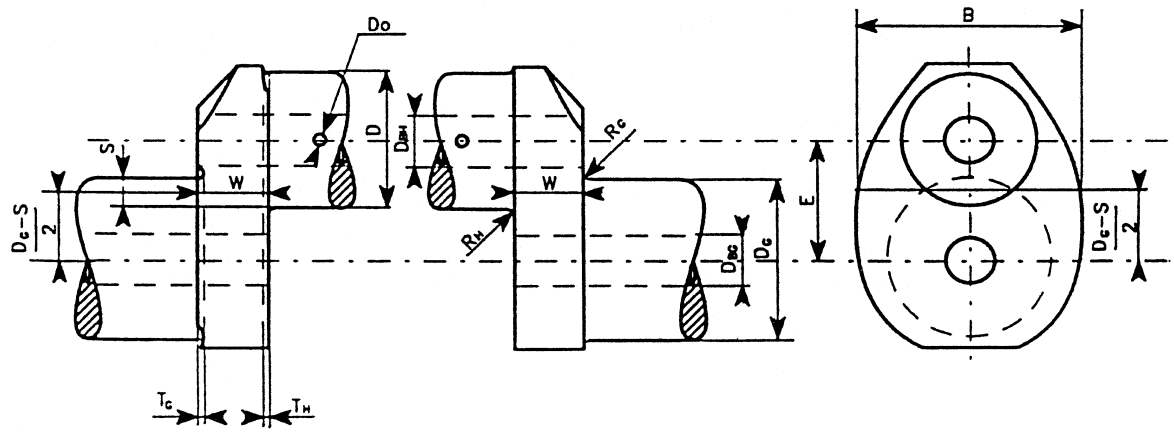


Fig. 7 – Crank dimensions

Actual dimensions:

D	[mm]	crankpin diameter
D_{BH}	[mm]	diameter of axial bore in crankpin
D_o	[mm]	diameter of oil bore in crankpin
R_H	[mm]	fillet radius of crankpin
T_H	[mm]	recess of crankpin fillet
D_G	[mm]	journal diameter
D_{BG}	[mm]	diameter of axial bore in journal
R_G	[mm]	fillet radius of journal
T_G	[mm]	recess of journal fillet
E	[mm]	pin eccentricity
S	[mm]	pin overlap $S = \frac{D + D_G}{2} - E$
W (*)	[mm]	web thickness
B (*)	[mm]	web width

(*) In the case of 2 stroke semi-built crankshafts:

- when $T_H > R_H$, the web thickness must be considered as equal to:

  $W_{red} = W - (T_H - R_H)$ [refer to fig. 5]

- web width B must be taken in way of crankpin fillet radius centre according to fig. 5

The following related dimensions will be applied for the calculation of stress concentration factors in:

Crankpin fillet	Journal fillet
$r = R_H / D$	$r = R_G / D$

$s = S/D$

$w = W/D$ crankshafts with overlap

W_{red}/D crankshafts without overlap

$b = B/D$

$d_o = D_O/D$

$d_G = D_{BG}/D$

$d_H = D_{BH}/D$

$t_H = T_H/D$

$t_G = T_G/D$

Stress concentration factors are valid for the ranges of related dimensions for which the investigations have been carried out. Ranges are as follows:

$$s \le 0.5$$
$$0.2 \le w \le 0.8$$
$$1.1 \le b \le 2.2$$
$$0.03 \le r \le 0.13$$
$$0 \le d_G \le 0.8$$
$$0 \le d_H \le 0.8$$
$$0 \le d_O \le 0.2$$

Low range of s can be extended down to large negative values provided that:

- If calculated f (recess) < 1 then the factor f (recess) is not to be considered (f (recess) = 1)

- If s < - 0.5 then f (s,w) and f (r,s) are to be evaluated replacing actual value of s by - 0.5.

3.2 Crankpin fillet

The stress concentration factor for bending (α_B) is:

$$\alpha_B = 2.6914 \bullet f(s, w) \bullet f(w) \bullet f(b) \bullet f(r) \bullet f(d_G) \bullet f(d_H) \bullet f(\text{recess})$$

where:

$$f(s,w) = -4.1883 + 29.2004 \bullet w - 77.5925 \bullet w^2 + 91.9454 \bullet w^3 - 40.0416 \bullet w^4 + (1-s) \bullet (9.5440 - 58.3480 \bullet w + 159.3415 \bullet w^2 - 192.5846 \bullet w^3 + 85.2916 \bullet w^4) + (1-s)^2 \bullet (-3.8399 + 25.0444 \bullet w - 70.5571 \bullet w^2 + 87.0328 \bullet w^3 - 39.1832 \bullet w^4)$$

$$f(w) = 2.1790 \bullet w^{0.7171}$$

$$f(b) = 0.6840 - 0.0077 \bullet b + 0.1473 \bullet b^2$$

$f(r) = 0.2081 \bullet r^{(-0.5231)}$

$f(d_G) = 0.9993 + 0.27 \bullet d_G - 1.0211 \bullet d_G^2 + 0.5306 \bullet d_G^3$

$f(d_H) = 0.9978 + 0.3145 \bullet d_H - 1.5241 \bullet d_H^2 + 2.4147 \bullet d_H^3$

$f(\text{recess}) = 1 + (t_H + t_G) \bullet (1.8 + 3.2 \bullet s)$

The stress concentration factor for torsion (α_T) is:

$$\alpha_T = 0.8 \bullet f(r,s) \bullet f(b) \bullet f(w)$$

where:

$f(r,s) = r^{(-0.322 + 0.1015 \bullet (1-s))}$

$f(b) = 7.8955 - 10.654 \bullet b + 5.3482 \bullet b^2 - 0.857 \bullet b^3$

$f(w) = w^{(-0.145)}$

3.3 Journal fillet (not applicable to semi-built crankshaft)

The stress concentration factor for bending (β_B) is:

$$\beta_B = 2.7146 \bullet f_B(s,w) \bullet f_B(w) \bullet f_B(b) \bullet f_B(r) \bullet f_B(d_G) \bullet f_B(d_H) \bullet f(\text{recess})$$

where:

$f_B(s,w) = -1.7625 + 2.9821 \bullet w - 1.5276 \bullet w^2 + (1-s) \bullet (5.1169 - 5.8089 \bullet w + 3.1391 \bullet w^2) + (1-s)^2 \bullet (-2.1567 + 2.3297 \bullet w - 1.2952 \bullet w^2)$

$f_B(w) = 2.2422 \bullet w^{0.7548}$

$f_B(b) = 0.5616 + 0.1197 \bullet b + 0.1176 \bullet b^2$

$f_B(r) = 0.1908 \bullet r^{(-0.5568)}$

$f_B(d_G) = 1.0012 - 0.6441 \bullet d_G + 1.2265 \bullet d_G^2$

$f_B(d_H) = 1.0022 - 0.1903 \bullet d_H + 0.0073 \bullet d_H^2$

$f(\text{recess}) = 1 + (t_H + t_G) \bullet (1.8 + 3.2 \bullet s)$

The stress concentration factor for compression (β_Q) due to the radial force is:

$$\beta_Q = 3.0128 \bullet f_Q(s) \bullet f_Q(w) \bullet f_Q(b) \bullet f_Q(r) \bullet f_Q(d_H) \bullet f(\text{recess})$$

where:

$f_Q(s) = 0.4368 + 2.1630 \bullet (1-s) - 1.5212 \bullet (1-s)^2$

$f_Q(w) = \dfrac{w}{0.0637 + 0.9369 \bullet w}$

$f_Q(b) = -0.5 + b$

$f_Q(r) = 0.5331 \bullet r^{(-0.2038)}$

$f_Q(d_H) = 0.9937 - 1.1949 \bullet d_H + 1.7373 \bullet d_H^2$

$f(\text{recess}) = 1 + (t_H + t_G) \bullet (1.8 + 3.2 \bullet s)$

The stress concentration factor for torsion (β_T) is:

$\beta_T = \alpha_T$

if the diameters and fillet radii of crankpin and journal are the same.

If crankpin and journal diameters and/or radii are of different sizes

$\beta_T = 0.8 \bullet f(r,s) \bullet f(b) \bullet f(w)$

where:

f (r,s), f (b) and f (w) are to be determined in accordance with item M 53.3.2. (see calculation of α_T), however, the radius of the journal fillet is to be related to the journal diameter:

$$r = \frac{R_G}{D_G}$$

3.4 Outlet of crankpin oil bore

The stress concentration factor for bending (γ_B) is:

$\gamma_B = 3 - 5.88 \bullet d_o + 34.6 \bullet d_o^2$

The stress concentration factor for torsion (γ_T) is:

$\gamma_T = 4 - 6 \bullet d_o + 30 \bullet d_o^2$

M 53.4 ADDITIONAL BENDING STRESSES

In addition to the alternating bending stresses in fillets (see item M 53.2.1.3) further bending stresses due to misalignment and bedplate deformation as well as due to axial and bending vibrations are to be considered by applying σ_{add} as given by table:

Type of engine	σ_{add}[N/mm²]
Crosshead engines	± 30 (*)
Trunk piston engines	± 10

(*) The additional stress of ± 30 N/mm² is composed of two components
1) an additional stress of ± 20 N/mm² resulting from axial vibration
2) an additional stress of ± 10 N/mm² resulting from misalignment / bedplate deformation

It is recommended that a value of ± 20 N/mm^2 be used for the axial vibration component for assessment purposes where axial vibration calculation results of the complete dynamic system (engine/shafting/gearing/propeller) are not available. Where axial vibration calculation results of the complete dynamic system are available, the calculated figures may be used instead.

M 53.5 CALCULATION OF EQUIVALENT ALTERNATING STRESS

5.1 General

In the fillets, bending and torsion lead to two different biaxial stress fields which can be represented by a Von Mises equivalent stress with the additional assumptions that bending and torsion stresses are time phased and the corresponding peak values occur at the same location (see Appendix I).

As a result the equivalent alternating stress is to be calculated for the crankpin fillet as well as for the journal fillet by using the Von Mises criterion.

At the oil hole outlet, bending and torsion lead to two different stress fields which can be represented by an equivalent principal stress equal to the maximum of principal stress resulting from combination of these two stress fields with the assumption that bending and torsion are time phased (see Appendix II).

The above two different ways of equivalent stress evaluation both lead to stresses which may be compared to the same fatigue strength value of crankshaft assessed according to Von Mises criterion.

5.2 Equivalent alternating stress

The equivalent alternating stress is calculated in accordance with the formulae given.

For the crankpin fillet:

$$\sigma_V = \pm\sqrt{(\sigma_{BH} + \sigma_{add})^2 + 3 \bullet \tau_H^2}$$

For the journal fillet:

$$\sigma_V = \pm\sqrt{(\sigma_{BG}+\sigma_{add})^2 + 3 \bullet \tau_G^2}$$

For the outlet of crankpin oil bore:

$$\sigma_V = \pm\frac{1}{3}\sigma_{BO} \bullet \left[1+2\sqrt{1+\frac{9}{4}\left(\frac{\sigma_{TO}}{\sigma_{BO}}\right)^2}\right]$$

where:

σ_V [N/mm²] equivalent alternating stress

for other parameters see items M53.2.1.3, M53.2.2.3 and M53.4.

M 53.6 CALCULATION OF FATIGUE STRENGTH

The fatigue strength is to be understood as that value of equivalent alternating stress (Von Mises) which a crankshaft can permanently withstand at the most highly stressed points. The fatigue strength may be evaluated by means of the following formulae.

Related to the crankpin diameter:

$$\sigma_{DW} = \pm K \bullet (0.42 \bullet \sigma_B + 39.3) \bullet \left[0.264 + 1.073 \bullet D^{-0.2} + \frac{785-\sigma_B}{4900} + \frac{196}{\sigma_B} \bullet \sqrt{\frac{1}{R_X}}\right]$$

with:

$R_X = R_H$ in the fillet area

$R_X = D_o/2$ in the oil bore area

Related to the journal diameter:

$$\sigma_{DW} = \pm K \bullet (0.42 \bullet \sigma_B + 39.3) \bullet \left[0.264 + 1.073 \bullet D_G^{-0.2} + \frac{785-\sigma_B}{4900} + \frac{196}{\sigma_B} \bullet \sqrt{\frac{1}{R_G}}\right]$$

where:

σ_{DW} [N/mm²] allowable fatigue strength of crankshaft

K [-] factor for different types of crankshafts without surface treatment. Values greater than 1 are only applicable to fatigue strength in fillet area.
= 1.05 for continuous grain flow forged or drop-forged crankshafts
= 1.0 for free form forged crankshafts (without continuous grain flow)

factor for cast steel crankshafts with cold rolling treatment in fillet area
= 0.93 for cast steel crankshafts manufactured by companies using a classification society approved cold rolling process

σ_B [N/mm²]   minimum tensile strength of crankshaft material

For other parameters see item M53.3.3.

When a surface treatment process is applied, it must be approved by TL. Guidance for calculation of surface treated fillets and oil bore outlets is presented in Appendix V.

These formulae are subject to the following conditions:

- surfaces of the fillet, the outlet of the oil bore and inside the oil bore (down to a minimum depth equal to 1.5 times the oil bore diameter) shall be smoothly finished.
- for calculation purposes R_H, R_G or R_X are to be taken as not less than 2 mm.

As an alternative the fatigue strength of the crankshaft can be determined by experiment based either on full size crankthrow (or crankshaft) or on specimens taken from a full size crankthrow. For evaluation of test results, see Appendix IV.

M 53.7 ACCEPTABILITY CRITERIA

The sufficient dimensioning of a crankshaft is confirmed by a comparison of the equivalent alternating stress and the fatigue strength. This comparison has to be carried out for the crankpin fillet, the journal fillet, the outlet of crankpin oil bore and is based on the formula:

$$Q = \frac{\sigma_{DW}}{\sigma_v}$$

where:

Q [-]   acceptability factor

Adequate dimensioning of the crankshaft is ensured if the smallest of all acceptability factors satisfies the criteria:

$$Q \geq 1.15$$

M 53.8 CALCULATION OF SHRINK-FITS OF SEMI-BUILT CRANKSHAFT

8.1 General

All crank dimensions necessary for the calculation of the shrink-fit are shown in figure 8.

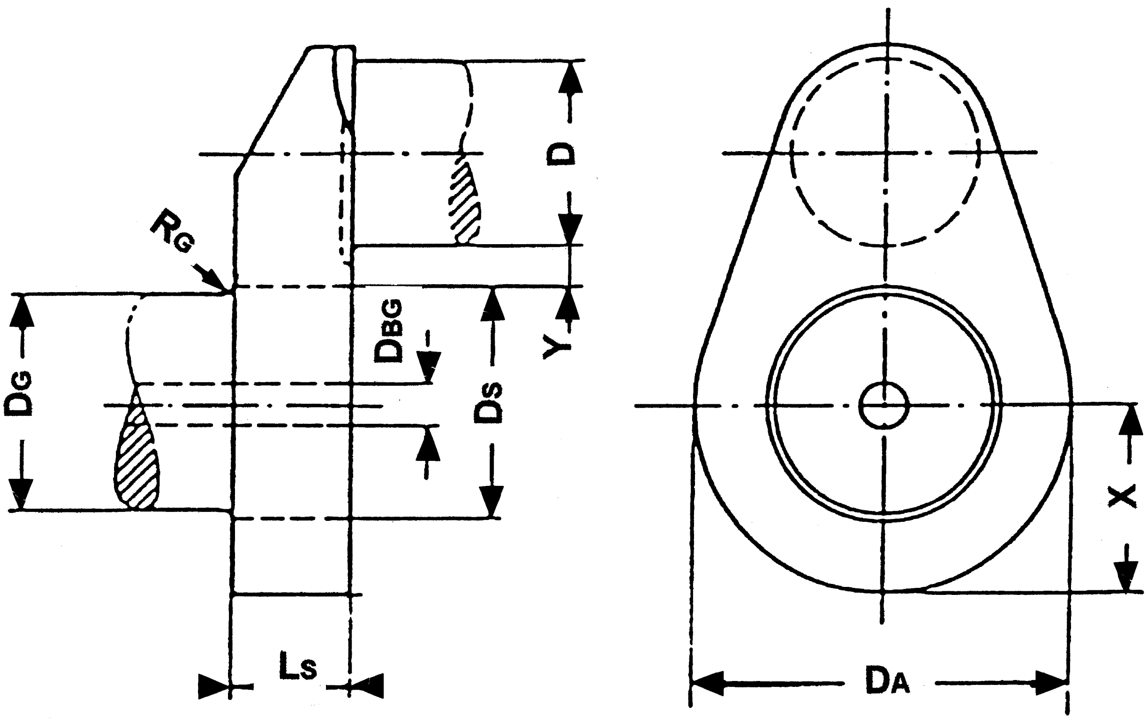


Fig. 8 – Crankthrow of semi-built crankshaft

where:

D_A [mm]	outside diameter of web or twice the minimum distance x between centre-line of journals and outer contour of web, whichever is less
D_S [mm]	shrink diameter
D_G [mm]	journal diameter
D_{BG} [mm]	diameter of axial bore in journal
L_S [mm]	length of shrink-fit
R_G [mm]	fillet radius of journal
y [mm]	distance between the adjacent generating lines of journal and pin $y \geq 0.05 \bullet D_S$ Where y is less than $0.1 \bullet D_S$ special consideration is to be given to the effect of the stress due to the shrink-fit on the fatigue strength at the crankpin fillet.

Respecting the radius of the transition from the journal to the shrink diameter, the following should be complied with:

$$R_G \geq 0.015 \bullet D_G$$

and

$$R_G \geq 0.5 \bullet (D_S - D_G)$$

where the greater value is to be considered.

The actual oversize Z of the shrink-fit must be within the limits Z_{min} and Z_{max} calculated in accordance with items M53.8.3 and 8.4.

In the case where 8.2 condition cannot be fulfilled then 8.3 and 8.4 calculation methods of Z_{min} and Z_{max} are not applicable due to multizone-plasticity problems.

In such case Z_{min} and Z_{max} have to be established based on FEM calculations.

8.2 Maximum permissible hole in the journal pin

The maximum permissible hole diameter in the journal pin is calculated in accordance with the following formula:

$$D_{BG} = D_S \bullet \sqrt{1 - \frac{4000 \bullet S_R \bullet M_{max}}{\mu \bullet \pi \bullet D_S^2 \bullet L_S \bullet \sigma_{SP}}}$$

where:

S_R [-]	safety factor against slipping, however a value not less than 2 is to be taken unless documented by experiments.
M_{max} [Nm]	absolute maximum value of the torque M_{Tmax} in accordance with M 53 2.2.2
μ [-]	coefficient for static friction, however a value not greater than 0.2 is to be taken unless documented by experiments.
σ_{SP} [N/mm^2]	minimum yield strength of material for journal pin

This condition serves to avoid plasticity in the hole of the journal pin.

8.3 Necessary minimum oversize of shrink-fit

The necessary minimum oversize is determined by the greater value calculated according to:

$$Z_{min} \geq \frac{\sigma_{sw} \bullet D_S}{E_m}$$

and

$$Z_{min} \geq \frac{4000}{\mu \bullet \pi} \bullet \frac{S_R \bullet M_{max}}{E_m \bullet D_S \bullet L_S} \bullet \frac{1 - Q_A^2 \bullet Q_S^2}{\left(1 - Q_A^2\right) \bullet \left(1 - Q_S^2\right)}$$

where:

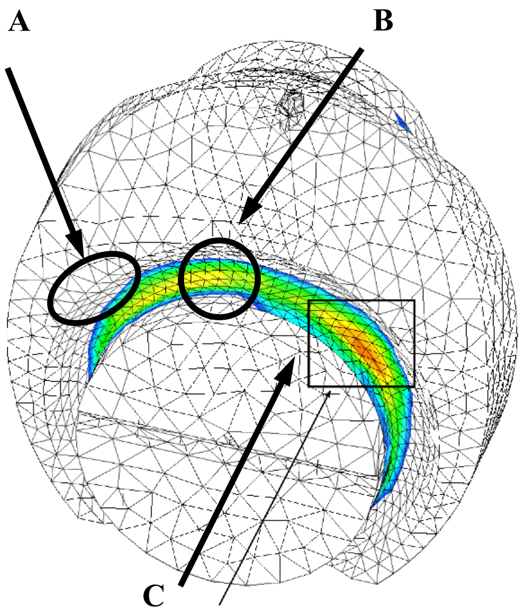
Z_{min}	[mm]	minimum oversize
E_m	[N/mm²]	Young's modulus
σ_{SW}	[N/mm²]	minimum yield strength of material for crank web
Q_A	[-]	web ratio, $Q_A = \frac{D_S}{D_A}$
Q_S	[-]	shaft ratio, $Q_S = \frac{D_{BG}}{D_S}$

8.4 Maximum permissible oversize of shrink-fit

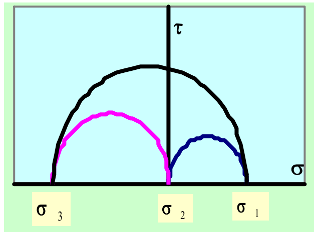
The maximum permissible oversize is calculated according to:

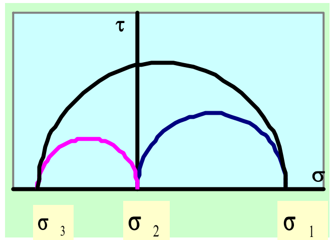
$$Z_{max} \leq D_S \bullet \left(\frac{\sigma_{SW}}{E_m} + \frac{0.8}{1000} \right)$$

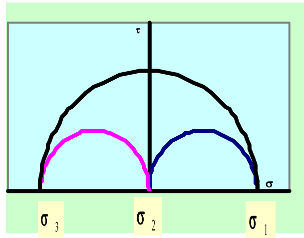
This condition serves to restrict the shrinkage induced mean stress in the fillet.



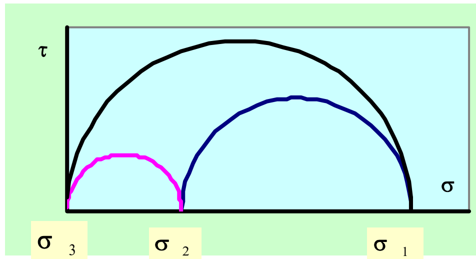
<table>
<tr><td></td><td>Stress</td><td>Max $\|\sigma_3\|$</td><td>Max σ_1</td><td></td></tr>
<tr><td rowspan="3">Torsional loading</td><td>Location of maximal stresses</td><td>**A**</td><td>**C**</td><td>**B**</td></tr>
<tr><td>Typical principal stress system

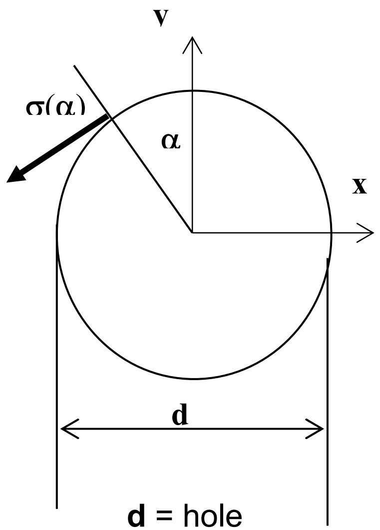
Mohr‘s circle diagram with $\sigma_2 = 0$</td><td>

$\|\sigma_3\| > \sigma_1$</td><td>

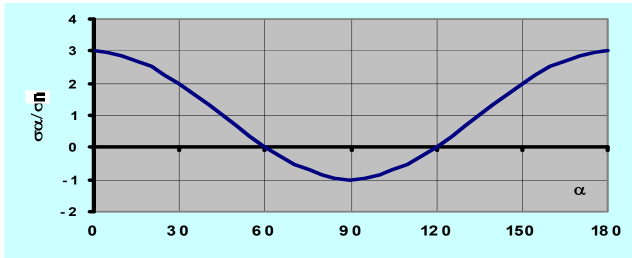
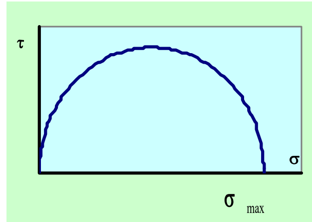
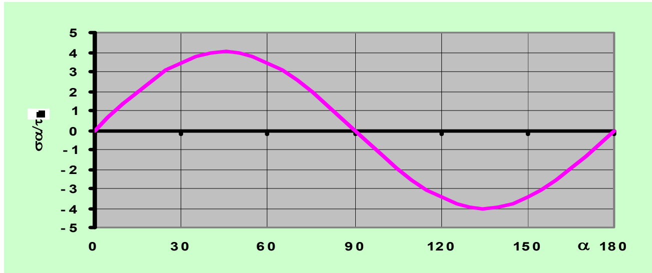
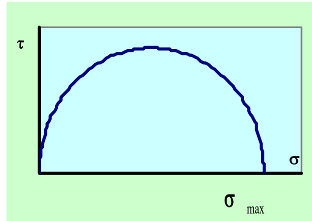
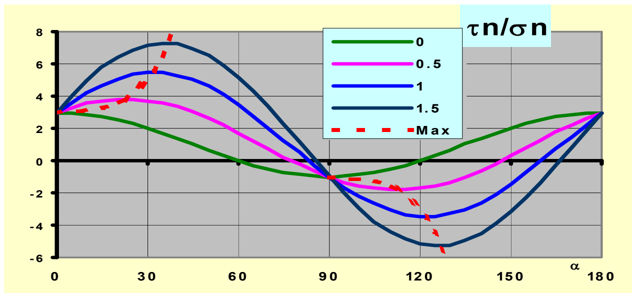
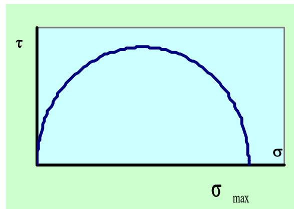
$\sigma_1 > \|\sigma_3\|$</td><td>

$\sigma_1 \approx \|\sigma_3\|$</td></tr>
<tr><td>**Equivalent stress** and **S.C.F**.</td><td colspan="3">$\tau_{equiv} = \frac{\sigma_1 - \sigma_3}{2}$
$\text{S.C.F.} = \frac{\tau_{equiv}}{\tau_n}$ for α_T, β_T</td></tr>
<tr><td rowspan="3">Bending loading</td><td>Location of maximal stresses</td><td>**B**</td><td>**B**</td><td>**B**</td></tr>
<tr><td>Typical principal stress system

Mohr‘s circle diagram with $\sigma_3 = 0$</td><td colspan="2">
</td><td>$\sigma_2 \neq 0$</td></tr>
<tr><td>Equivalent stress and **S.C.F**.</td><td colspan="3">$\sigma\,\text{equiv} = \sqrt{\sigma_1{}^2 + \sigma_2{}^2 - \sigma_1 . \sigma_2}$
$\text{S.C.F.} = \frac{\sigma\,\text{equiv}}{\sigma_n}$ for $\alpha_B, \beta_B, \beta_Q$</td></tr>
</table>



d = hole diameter

Stress type	Nominal stress tensor	Uniaxial stress distribution around the edge	Mohr‘s circle diagram
Tension	$\begin{bmatrix} \sigma n & 0 \\ 0 & 0 \end{bmatrix}$	$\sigma_\alpha = \sigma_n \gamma_B / 3 [1+2 \cos(2\alpha)]$ 	 $\gamma_B = \sigma_{max}/\sigma_n$ for $\alpha = k\pi$
Shear	$\begin{bmatrix} 0 & \tau n \\ \tau n & 0 \end{bmatrix}$	$\sigma_\alpha = \gamma_T \tau_n \sin(2\alpha)$ 	 $\gamma_T = \sigma_{max}/\tau_n$ for $\alpha = \frac{\pi}{4} + k\frac{\pi}{2}$
Tension + shear	$\begin{bmatrix} \sigma n & \tau n \\ \tau n & 0 \end{bmatrix}$	$\sigma_\alpha = \frac{\gamma_B}{3}\sigma_n\left\{1+2\left[\cos(2\alpha)+\frac{3}{2}\frac{\gamma_T}{\gamma_B}\frac{\tau_n}{\sigma_n}\sin(2\alpha)\right]\right\}$ 	 $\sigma_{max} = \frac{\gamma_B}{3}\sigma_n\left[1+2\sqrt{1+\frac{9}{4}\left(\frac{\gamma_T}{\gamma_B}\frac{\tau_n}{\sigma_n}\right)^2}\right]$ for $\alpha = \frac{1}{2}\mathrm{tg}^{-1}\left(\frac{3\gamma_T\tau_n}{2\gamma_B\sigma_n}\right)$

Guidance for Calculation of Stress Concentration Factors in the web fillet radii of crankshafts by utilizing Finite Element Method

Contents

1. General

The objective of the analysis is to develop Finite Element Method (FEM) calculated figures as an alternative to the analytically calculated Stress Concentration Factors (SCF) at the crankshaft fillets. The analytical method is based on empirical formulae developed from strain gauge measurements of various crank geometries and accordingly the application of these formulae is limited to those geometries.

The SCF's calculated according to the rules of this document are defined as the ratio of stresses calculated by FEM to nominal stresses in both journal and pin fillets. When used in connection with the present method in M53 or the alternative methods, von Mises stresses shall be calculated for bending and principal stresses for torsion.

The procedure as well as evaluation guidelines are valid for both solid cranks and semibuilt cranks (except journal fillets).

The analysis is to be conducted as linear elastic FE analysis, and unit loads of appropriate magnitude are to be applied for all load cases.

The calculation of SCF at the oil bores is not covered by this document.

It is advised to check the element accuracy of the FE solver in use, e.g. by modeling a simple geometry and comparing the stresses obtained by FEM with the analytical solution for pure bending and torsion.

Boundary Element Method (BEM) may be used instead of FEM.

2. Model requirements

The basic recommendations and perceptions for building the FE-model are presented in 2.1. It is obligatory for the final FE-model to fulfill the requirement in 2.3.

2.1. Element mesh recommendations

In order to fulfil the mesh quality criteria it is advised to construct the FE model for the evaluation of Stress Concentration Factors according to the following recommendations:

- The model consists of one complete crank, from the main bearing centerline to the opposite side main bearing centerline
- Element types used in the vicinity of the fillets:
  - 10 node tetrahedral elements
  - 8 node hexahedral elements
  - 20 node hexahedral elements
- Mesh properties in fillet radii. The following applies to ±90 degrees in circumferential direction from the crank plane:
- Maximum element size a=r/4 through the entire fillet as well as in the circumferential direction. When using 20 node hexahedral elements, the element size in the circumferential direction may be extended up to 5a. In the case of multi-radii fillet r is the local fillet radius. (If 8 node hexahedral elements are used even smaller element size is required to meet the quality criteria.)
- Recommended manner for element size in fillet depth direction
  - First layer thickness equal to element size of a
  - Second layer thickness equal to element to size of 2a
  - Third layer thickness equal to element to size of 3a
- Minimum 6 elements across web thickness.
- Generally the rest of the crank should be suitable for numeric stability of the solver.

- Counterweights only have to be modeled only when influencing the global stiffness of the crank significantly.
- Modeling of oil drillings is not necessary as long as the influence on global stiffness is negligible and the proximity to the fillet is more than 2r, see figure 2.1.
- Drillings and holes for weight reduction have to be modeled.
- Sub-modeling may be used as far as the software requirements are fulfilled.

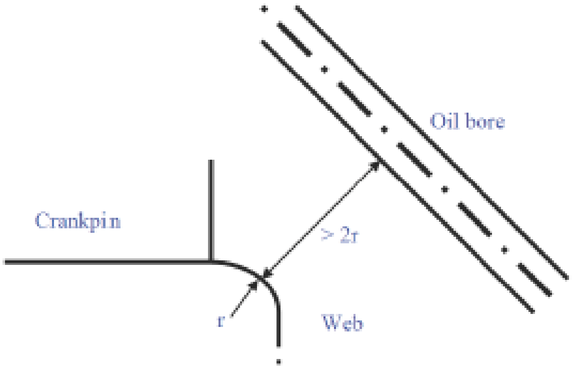


Figure 2.1. Oil bore proximity to fillet.

2.2. Material

UR M53 does not consider material properties such as Young's Modulus (*E*) and Poisson's ratio (ν). In FE analysis those material parameters are required, as strain is primarily calculated and stress is derived from strain using the Young's Modulus and Poisson's ratio. Reliable values for material parameters have to be used, either as quoted in literature or as measured on representative material samples.

For steel the following is advised: $E = 2.05 \cdot 10^5$ MPa and $\nu = 0.3$.

2.3. Element mesh quality criteria

If the actual element mesh does not fulfil any of the following criteria at the examined area for SCF evaluation, then a second calculation with a refined mesh is to be performed.

2.3.1. Principal stresses criterion

The quality of the mesh should be assured by checking the stress component normal to the surface of the fillet radius. Ideally, this stress should be zero. With principal stresses σ_1, σ_2 and σ_3 the following criterion is required:

$$\min(|\sigma_1|,|\sigma_2|,|\sigma_3|) < 0.03.\max(|\sigma_1|,|\sigma_2|,|\sigma_3|)$$

2.3.2. Averaged/unaveraged stresses criterion

The criterion is based on observing the discontinuity of stress results over elements at the fillet for the calculation of SCF:

- Unaveraged nodal stress results calculated from each element connected to a node_i should differ less than by 5 % from the 100 % averaged nodal stress results at this node_i at the examined location.

3. Load cases

To substitute the analytically determined SCF in UR M53 the following load cases have to be calculated.

3.1. Torsion

In analogy to the testing apparatus used for the investigations made by FVV the structure is loaded pure torsion. In the model surface warp at the end faces is suppressed.

Torque is applied to the central node located at the crankshaft axis. This node acts as the master node with 6 degrees of freedom and is connected rigidly to all nodes of the end face.

Boundary and load conditions are valid for both in-line and V-type engines.

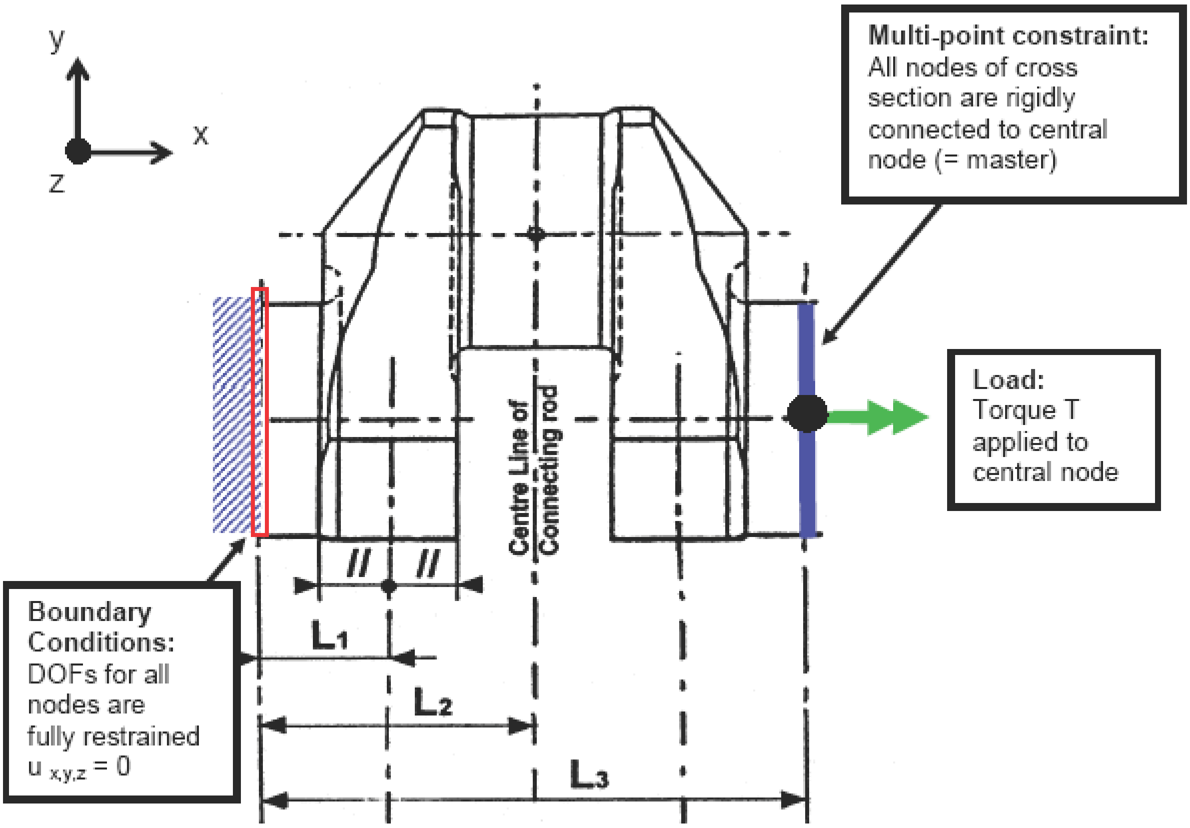


Figure 3.1 Boundary and load conditions for the torsion load case.

For all nodes in both the journal and crank pin fillet principal stresses are extracted and the equivalent torsional stress is calculated:

$$\tau_{equiv} = \max\left(\frac{|\sigma_1 - \sigma_2|}{2}, \frac{|\sigma_2 - \sigma_3|}{2}, \frac{|\sigma_1 - \sigma_3|}{2}\right)$$

The maximum value taken for the subsequent calculation of the SCF:

$$\alpha_T = \frac{\tau_{equiv,\alpha}}{\tau_N}$$

$$\beta_T = \frac{\tau_{equiv,\beta}}{\tau_N}$$

where τ_N is nominal torsional stress referred to the crankpin and respectively journal as per TL- R M53 2.2.2 with the torsional torque *T*:

$$\tau_N = \frac{T}{W_P}$$

3.2. Pure bending (4 point bending)

In analogy to the testing apparatus used for the investigations made by FVV the structure is loaded in pure bending. In the model surface warp at the end faces is suppressed.

The bending moment is applied to the central node located at the crankshaft axis. This node acts as the master node with 6 degrees of freedom and is connected rigidly to all nodes of the end face.

Boundary and load conditions are valid for both in-line- and V- type engines.

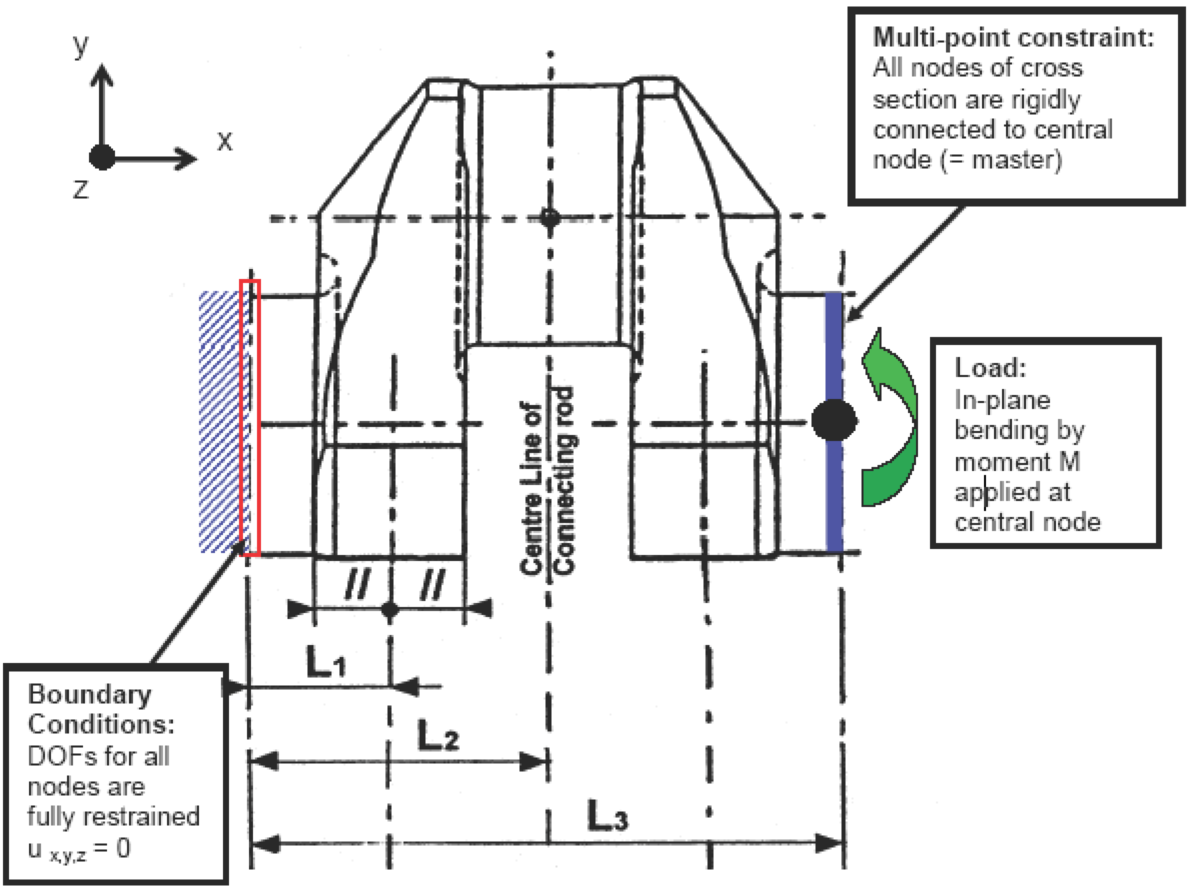


Figure 3.2 Boundary and load conditions for the pure bending load case.

For all nodes in both the journal and pin fillet von Mises equivalent stresses σ_{equiv} are extracted. The maximum value is used to calculate the SCF according to:

$$\alpha_B = \frac{\sigma_{equiv,\alpha}}{\sigma_N}$$

$$\beta_B = \frac{\sigma_{equiv,\beta}}{\sigma_N}$$

Nominal stress σ_N is calculated as per TL- UR M53 2.1.2.1 with the bending moment *M*:

$$\sigma_N = \frac{M}{W_{eqw}}$$

3.3. Bending with shear force (3-point bending)

This load case is calculated to determine the SCF for pure transverse force (radial force, β_Q) for the journal fillet.

In analogy to the testing apparatus used for the investigations made by FVV, the structure is loaded in 3-point bending. In the model, surface warp at the both end faces is suppressed. All nodes are connected rigidly to the centre node; boundary conditions are applied to the centre nodes. These nodes act as master nodes with 6 degrees of freedom.

The force is applied to the central node located at the pin centre-line of the connecting rod. This node is connected to all nodes of the pin cross sectional area. Warping of the sectional area is not suppressed.

Boundary and load conditions are valid for in-line and V-type engines. V-type engines can be modeled with one connecting rod force only. Using two connecting rod forces will make no significant change in the SCF.

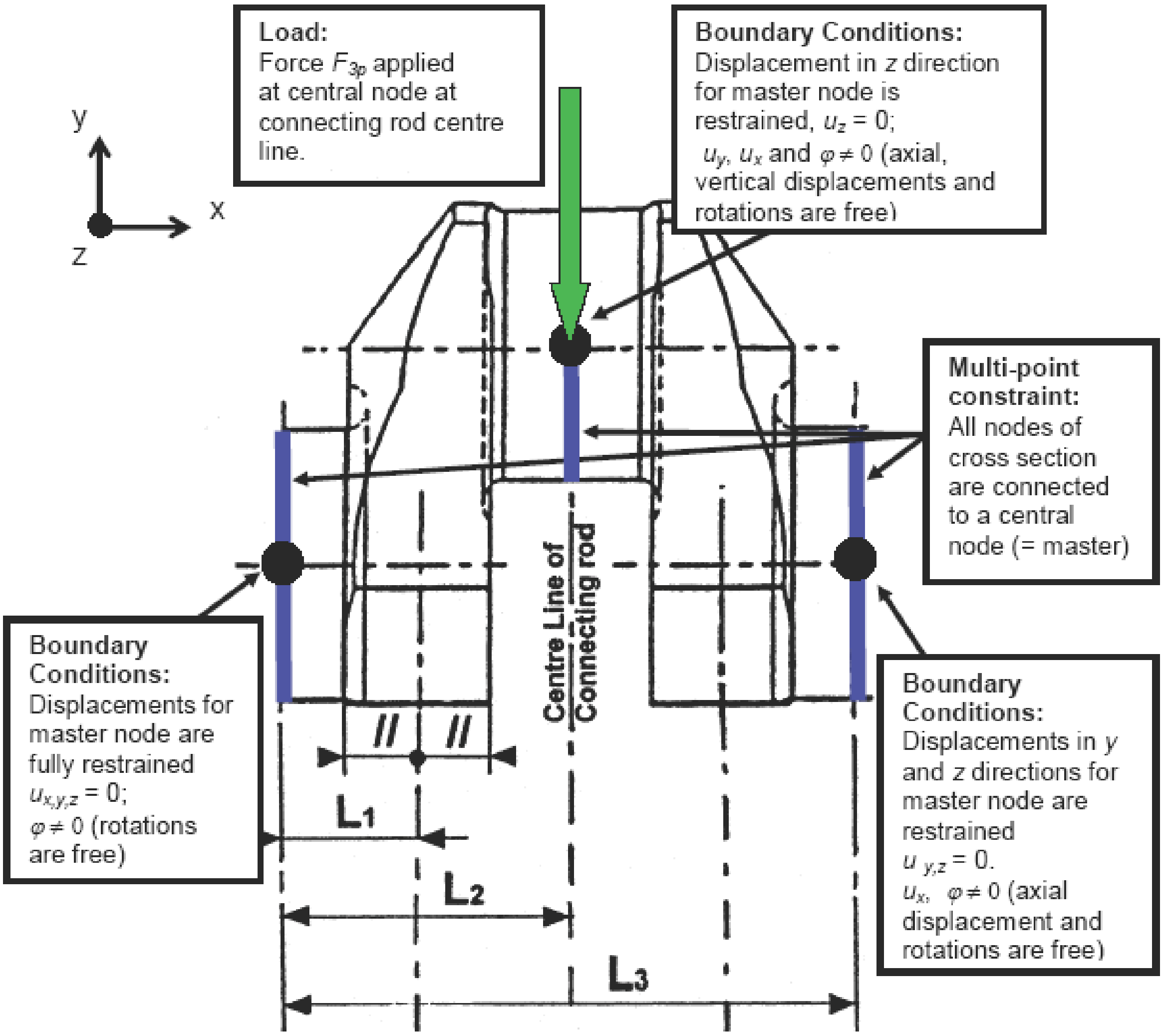


Figure 3.3. Boundary and load conditions for the 3-point bending load case of an inline engine.

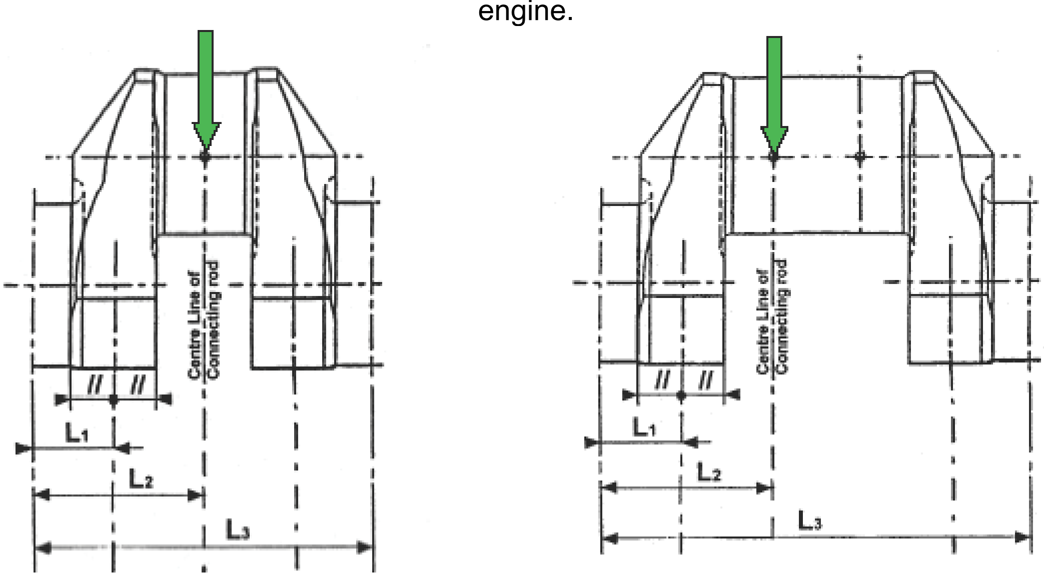


Figure 3.4 Load applications for in-line and V-type engines.

The maximum equivalent von Mises stress σ_{3P} in the journal fillet is evaluated. The SCF in the journal fillet can be determined in two ways as shown below.

3.3.1. Method 1

This method is analogue to the FVV investigation. The results from 3-point and 4-point bending are combined as follows:

$$\sigma_{3P} = \sigma_{N3P} . \beta_B + \sigma_{Q3P} . \beta_Q$$

where:

σ_{3P} as found by the FE calculation.

σ_{N3P} Nominal bending stress in the web centre due to the force F_{3P} [N] applied to the centre-line of the actual connecting rod, see figure 3.4.

β_B as determined in paragraph 3.2.

$\sigma_{Q3P} = Q_{3P} /(B.W)$ where Q_{3P} is the radial (shear) force in the web due to the force F_{3P} [N] applied to the centre-line of the actual connecting rod, see also figures 3 and 4 in M53.

3.3.2. Method 2

This method is not analogous to the FVV investigation. In a statically determined system with one crank throw supported by two bearings, the bending moment and radial (shear) force are proportional. Therefore the journal fillet SCF can be found directly by the 3-point bending FE calculation.

The SCF is then calculated according to

$$\beta_{BQ} = \frac{\sigma_{3P}}{\sigma_{N3P}}$$

For symbols see 3.3.1.

When using this method the radial force and stress determination in M53 becomes superfluous. The alternating bending stress in the journal fillet as per TL- R M53 2.1.3 is then evaluated:

$$\sigma_{BG} = \pm \left| \beta_{BQ} . \sigma_{BFN} \right|$$

Note that the use of this method does not apply to the crankpin fillet and that this SCF must not be used in connection with calculation methods other than those assuming a statically determined system as in M53.

Appendix IV

Guidance for Evaluation of Fatigue Tests

Contents

1. Introduction

Fatigue testing can be divided into two main groups; testing of small specimens and full-size crank throws. Testing can be made using the staircase method or a modified version thereof which is presented in this document. Other statistical evaluation methods may also be applied.

1.1. Small specimen testing

For crankshafts without any fillet surface treatment, the fatigue strength can be determined by testing small specimens taken from a full-size crank throw. When other areas in the vicinity of the fillets are surface treated introducing residual stresses in the fillets, this approach cannot be applied.

One advantage of this approach is the rather high number of specimens which can be then manufactured. Another advantage is that the tests can be made with different stress ratios (R-ratios) and/or different modes e.g. axial, bending and torsion, with or without a notch. This is required for evaluation of the material data to be used with critical plane criteria.

1.2. Full-size crank throw testing

For crankshafts with surface treatment the fatigue strength can only be determined through testing of full size crank throws. For cost reasons, this usually means a low number of crank throws. The load can be applied by hydraulic actuators in a 3- or 4- point bending arrangement, or by an exciter in a resonance test rig. The latter is frequently used, although it usually limits the stress ratio to $R = -1$.

2. Evaluation of test results

2.1. Principles

Prior to fatigue testing the crankshaft must be tested as required by quality control procedures, e.g. for chemical composition, mechanical properties, surface hardness, hardness depth and extension, fillet surface finish, etc.

The test samples should be prepared so as to represent the “lower end” of the acceptance range e.g. for induction hardened crankshafts this means the lower range of acceptable hardness depth, the shortest extension through a fillet, etc. Otherwise the mean value test results should be corrected with a confidence interval: a 90% confidence interval may be used both for the sample mean and the standard deviation.

The test results, when applied in M53, shall be evaluated to represent the mean fatigue strength, with or without taking into consideration the 90% confidence interval as mentioned above. The standard deviation should be considered by taking the 90% confidence into account. Subsequently the result to be used as the fatigue strength is then the mean fatigue strength minus one standard deviation.

If the evaluation aims to find a relationship between (static) mechanical properties and the fatigue strength, the relation must be based on the real (measured) mechanical properties, not on the specified minimum properties.

The calculation technique presented in Chapter 2.4 was developed for the original staircase method. However, since there is no similar method dedicated to the modified staircase method the same is applied for both.

2.2. Staircase method

In the original staircase method, the first specimen is subjected to a stress corresponding to the expected average fatigue strength. If the specimen survives 10^7 cycles, it is discarded and the next specimen is subjected to a stress that is one increment above the previous, i.e. a survivor is always followed by the next using a stress one increment above the previous. The increment should be selected to correspond to the expected level of the standard deviation.

When a specimen fails prior to reaching 10^7 cycles, the obtained number of cycles is noted and the next specimen is subjected to a stress that is one increment below the previous. With this approach, the sum of failures and run-outs is equal to the number of specimens.

This original staircase method is only suitable when a high number of specimens are available. Through simulations it has been found that the use of about 25 specimens in a staircase test leads to a sufficient accuracy in the result.

2.3. Modified staircase method

When a limited number of specimens are available, it is advisable to apply the modified staircase method. Here the first specimen is subjected to a stress level that is most likely well below the average fatigue strength. When this specimen has survived 10^7 cycles, this **same** specimen is subjected to a stress level one increment above the previous. The increment should be selected to correspond to the expected level of the standard deviation. This is continued with the same specimen until failure.
Then the number of cycles is recorded and the next specimen is subjected to a stress that is at least 2 increments below the level where the previous specimen failed.

With this approach, the number of failures usually equals the number of specimens.
The number of run-outs, counted as the highest level where 10^7 cycles were reached, also equals the number of specimens.

The acquired result of a modified staircase method should be used with care, since some results available indicate that testing a runout on a higher test level, especially at high mean stresses, tends to increase the fatigue limit. However, this "training effect" is less pronounced for high strength steels (e.g. UTS > 800 MPa).

If the confidence calculation is desired or necessary, the minimum number of test specimens is 3.

2.4. Calculation of sample mean and standard deviation

A hypothetical example of tests for 5 crank throws is presented further in the subsequent text. When using the modified staircase method and the evaluation method of Dixon and Mood, the number of samples will be 10, meaning 5 run-outs and 5 failures, i.e.:

Number of samples, $n=10$

Furthermore, the method distinguishes between

Less frequent event is failures $C=1$
Less frequent event is run-outs $C=2$

The method uses only the less frequent occurrence in the test results, i.e. if there are more failures than run-outs, then the number of run-outs is used, and vice versa.

In the modified staircase method, the number of run-outs and failures are usually equal. However, the testing can be unsuccessful, e.g. the number of run-outs can be less than the number of failures if a specimen with 2 increments below the previous failure level goes directly to failure. On the other hand, if this unexpected premature failure occurs after a rather high number of cycles, it is possible to define the level below this as a run-out.

Dixon and Mood's approach, derived from the maximum likelihood theory, which also may be applied here, especially on tests with few samples, presented some simple approximate equations for calculating the sample mean and the standard deviation from the outcome of the staircase test. The sample mean can be calculated as follows:

$$\overline{S_a} = S_{a0} + d \cdot \left(\frac{A}{F} - \frac{1}{2} \right)$$ when C=1

$$\overline{S_a} = S_{a0} + d \cdot \left(\frac{A}{F} + \frac{1}{2} \right)$$ when C=2

The standard deviation can be found by

$$s = 1.62 \cdot d \cdot \left(\frac{F \cdot B - A^2}{F^2} + 0.029 \right)$$

where:

S_{a0} is the lowest stress level for the less frequent occurrence

d is the stress increment

$F = \Sigma fi$

$A = \Sigma i \cdot fi$

$B = \Sigma i^2 \cdot fi$

i is the stress level numbering

fi is the number of samples at stress level i

The formula for the standard deviation is an approximation and can be used when

$$\frac{B \cdot F - A^2}{F^2} > 0.3 \quad \text{and} \quad 0.5 \cdot s < d < 1.5 \cdot s$$

If any of these two conditions are not fulfilled, a new staircase test should be considered or the standard deviation should be taken quite large in order to be on the safe side.

If increment *d* is greatly higher than the standard deviation *s*, the procedure leads to a lower standard deviation and a slightly higher sample mean, both compared to values calculated when the difference between the increment and the standard deviation is relatively small. Respectively, if increment *d* is much less than the standard deviation *s*, the procedure leads to a higher standard deviation and a slightly lower sample mean.

2.5. Confidence interval for mean fatigue limit

If the staircase fatigue test is repeated, the sample mean and the standard deviation will most likely be different from the previous test. Therefore, it is necessary to assure with a given confidence that the repeated test values will be above the chosen fatigue limit by using a confidence interval for the sample mean.

The confidence interval for the sample mean value with unknown variance is known to be distributed according to the *t*-distribution (also called *student's t-distribution*) which is a distribution symmetric around the average.

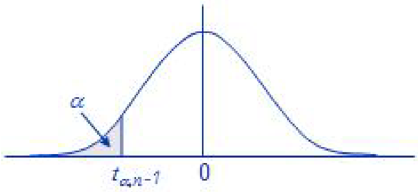


Figure 2.1. Student's t-distribution

The confidence level normally used for the sample mean is 90 %, meaning that 90 % of sample means from repeated tests will be above the value calculated with the chosen confidence level. The figure shows the *t*-value for (1 - α) · 100% confidence interval for the sample mean.

If S_a is the empirical mean and *s* is the empirical standard deviation over a series of *n* samples, in which the variable values are normally distributed with an unknown sample mean and unknown variance, the (1 - α) · 100% confidence interval for the mean is:

$$P\left(S_a - t_{\alpha,n-1} \cdot \frac{s}{\sqrt{n}} < S_{aX\%} \right) = 1 - \alpha$$

The resulting confidence interval is symmetric around the empirical mean of the sample values, and the lower endpoint can be found as:

$$S_{aX\%} = S_a - t_{\alpha,n-1} \cdot \frac{s}{\sqrt{n}}$$

which is the mean fatigue limit (population value) to be used to obtain the reduced fatigue limit where the limits for the probability of failure are taken into consideration.

2.6. Confidence interval for standard deviation

The confidence interval for the variance of a normal random variable is known to possess a chi-square distribution with *n - 1* degrees of freedom.

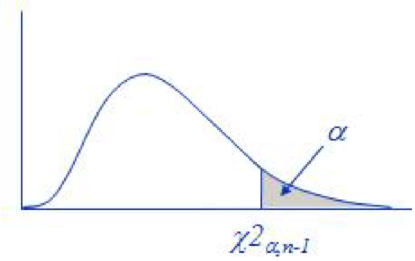


Figure 2.2. Chi-square distribution

The confidence level on the standard deviation is used to ensure that the standard deviations for repeated tests are below an upper limit obtained from the fatigue test standard deviation with a confidence level. The figure shows the chi-square for (1 - α) · 100% confidence interval for the variance.

An assumed fatigue test value from *n* samples is a normal random variable with a variance of σ^2 and has an empirical variance s^2. Then a (1 - α) · 100% confidence interval for the variance is:

$$P\left(\frac{(n-1)s^2}{\sigma^2} < \chi^2{}_{\alpha,n-1} \right) = 1 - \alpha$$

A (1 – α) · 100% confidence interval for the standard deviation is obtained by the square root of the upper limit of the confidence interval for the variance and can be found by

$$s_{X\%} = \sqrt{\frac{n-1}{\chi^2{}_{\alpha,n-1}}} \cdot s$$

This standard deviation (population value) is to be used to obtain the fatigue limit, where the limits for the probability of failure are taken into consideration.

3. Small specimen testing

In this connection, a small specimen is considered to be one of the specimens taken from a crank throw. Since the specimens shall be representative for the fillet fatigue strength, they should be taken out close to the fillets, as shown in Figure 3.1.

It should be made certain that the principal stress direction in the specimen testing is equivalent to the full-size crank throw. The verification is recommended to be done by utilising the finite element method.

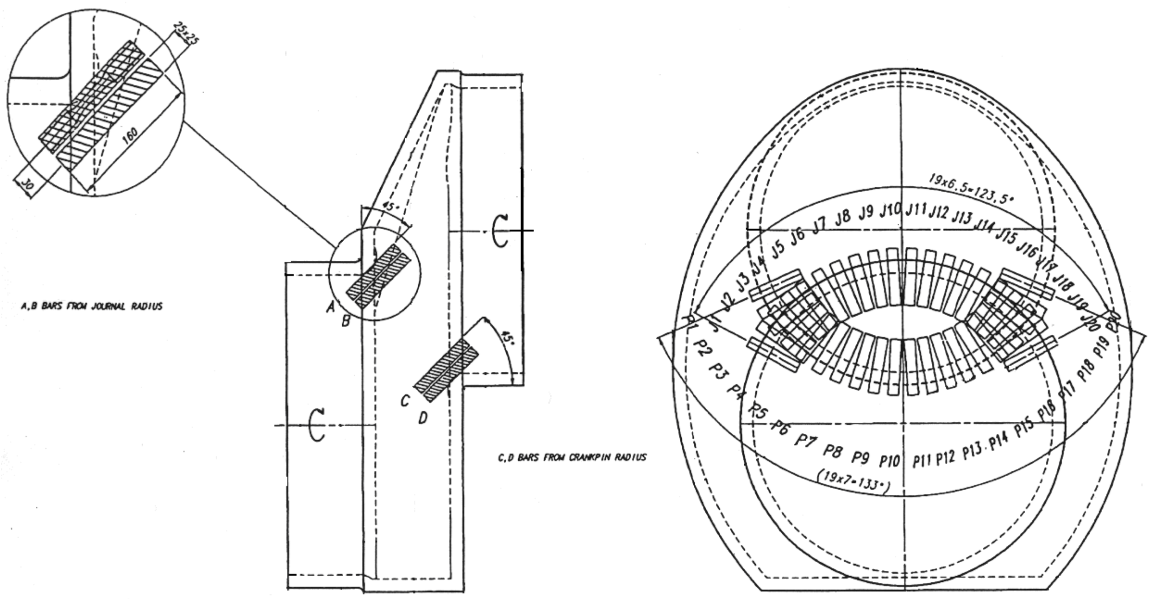


Figure 3.1. Specimen locations in a crank throw

The (static) mechanical properties are to be determined as stipulated by the quality control procedures.

3.1. Determination of bending fatigue strength

It is advisable to use un-notched specimens in order to avoid uncertainties related to the stress gradient influence. Push-pull testing method (stress ratio R = -1) is preferred, but especially for the purpose of critical plane criteria other stress ratios and methods may be added.

In order to ensure principal stress direction in push-pull testing to represent the full-size crank throw principal stress direction and when no further information is available, the specimen shall be taken in 45 degrees angle as shown in Figure 3.1.

A. If the objective of the testing is to document the influence of high cleanliness, test samples taken from positions approximately 120 degrees in a circumferential direction may be used. See Figure 3.1.

B. If the objective of the testing is to document the influence of continuous grain flow (cgf) forging, the specimens should be restricted to the vicinity of the crank plane.

3.2. Determination of torsional fatigue strength

A. If the specimens are subjected to torsional testing, the selection of samples should follow the same guidelines as for bending above. The stress gradient influence has to be considered in the evaluation.

B. If the specimens are tested in push-pull and no further information is available, the samples should be taken out at an angle of 45 degrees to the crank plane in order to ensure collinearity of the principal stress direction between the specimen and the full-size crank throw. When taking the specimen at a distance from the (crank) middle plane of the crankshaft along the fillet, this plane rotates around the pin centre point making it possible to resample the fracture direction due to torsion (the results are to be converted into the pertinent torsional values).

3.3. Other test positions

If the test purpose is to find fatigue properties and the crankshaft is forged in a manner likely to lead to cgf, the specimens may also be taken longitudinally from a prolonged shaft piece where specimens for mechanical testing are usually taken. The condition is that this prolonged shaft piece is heat treated as a part of the crankshaft and that the size is so as to result in a similar quenching rate as the crank throw.

When using test results from a prolonged shaft piece, it must be considered how well the grain flow in that shaft piece is representative for the crank fillets.

3.4. Correlation of test results

The fatigue strength achieved by specimen testing shall be converted to correspond to the full-size crankshaft fatigue strength with an appropriate method (size effect).

When using the bending fatigue properties from tests mentioned in this section, it should be kept in mind that successful continuous grain flow (cgf) forging leading to elevated values compared to other (non cgf) forging, will normally not lead to a torsional fatigue strength improvement of the same magnitude.
In such cases it is advised to either carry out also torsional testing or to make a conservative assessment of the torsional fatigue strength, e.g. by using no credit for cgf. This approach is applicable when using the Gough Pollard criterion. However, this approach is not recognised when using the von Mises or a multi-axial criterion such as Findley.

If the found ratio between bending and torsion fatigue differs significantly from $\sqrt{3}$, one should consider replacing the use of the von Mises criterion with the Gough Pollard criterion. Also, if critical plane criteria are used, it must be kept in mind that cgf makes the material inhomogeneous in terms of fatigue strength, meaning that the material parameters differ with the directions of the planes.

Any addition of influence factors must be made with caution. If for example a certain addition for clean steel is documented, it may not necessarily be fully combined with a *K*-factor for cgf. Direct testing of samples from a clean and cgf forged crank is preferred.

4. Full size testing

4.1. Hydraulic pulsation

A hydraulic test rig can be arranged for testing a crankshaft in 3-point or 4-point bending as well as in torsion. This allows for testing with any *R*-ratio.

Although the applied load should be verified by strain gauge measurements on plain shaft sections for the initiation of the test, it is not necessarily used during the test for controlling load. It is also pertinent to check fillet stresses with strain gauge chains.

Furthermore, it is important that the test rig provides boundary conditions as defined in Appendix III (section 3.1 to 3.3).

The (static) mechanical properties are to be determined as stipulated by the quality control procedures.

4.2. Resonance tester

A rig for bending fatigue normally works with an *R*-ratio of -1. Due to operation close to resonance, the energy consumption is moderate. Moreover, the frequency is usually relatively high, meaning that 10^7 cycles can be reached within some days. Figure 4.1 shows a layout of the testing arrangement.

The applied load should be verified by strain gauge measurements on plain shaft sections. It is also pertinent to check fillet stresses with strain gauge chains.

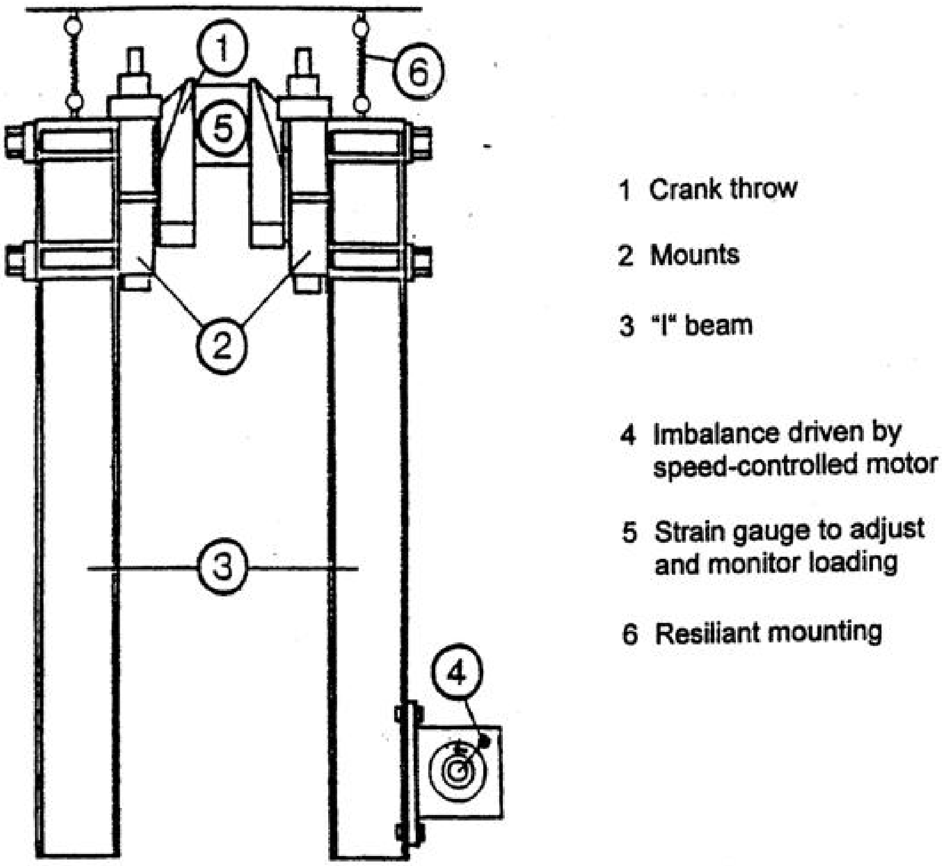


Figure 4.1. An example of testing arrangement of the resonance tester for bending loading

Clamping around the journals must be arranged in a way that prevents severe fretting which could lead to a failure under the edges of the clamps. If some distance between the clamps and the journal fillets is provided, the loading is consistent with 4-point bending and thus representative for the journal fillets also.

In an engine, the crankpin fillets normally operate with an R-ratio slightly above -1 and the journal fillets slightly below -1. If found necessary, it is possible to introduce a mean load (deviate from R = -1) by means of a spring preload.

A rig for torsion fatigue can also be arranged as shown in Figure 4.2. When a crank throw is subjected to torsion, the twist of the crankpin makes the journals move sideways. If one single crank throw is tested in a torsion resonance test rig, the journals with their clamped-on weights will vibrate heavily sideways.

This sideway movement of the clamped-on weights can be reduced by having two crank throws, especially if the cranks are almost in the same direction. However, the journal in the middle will move more.

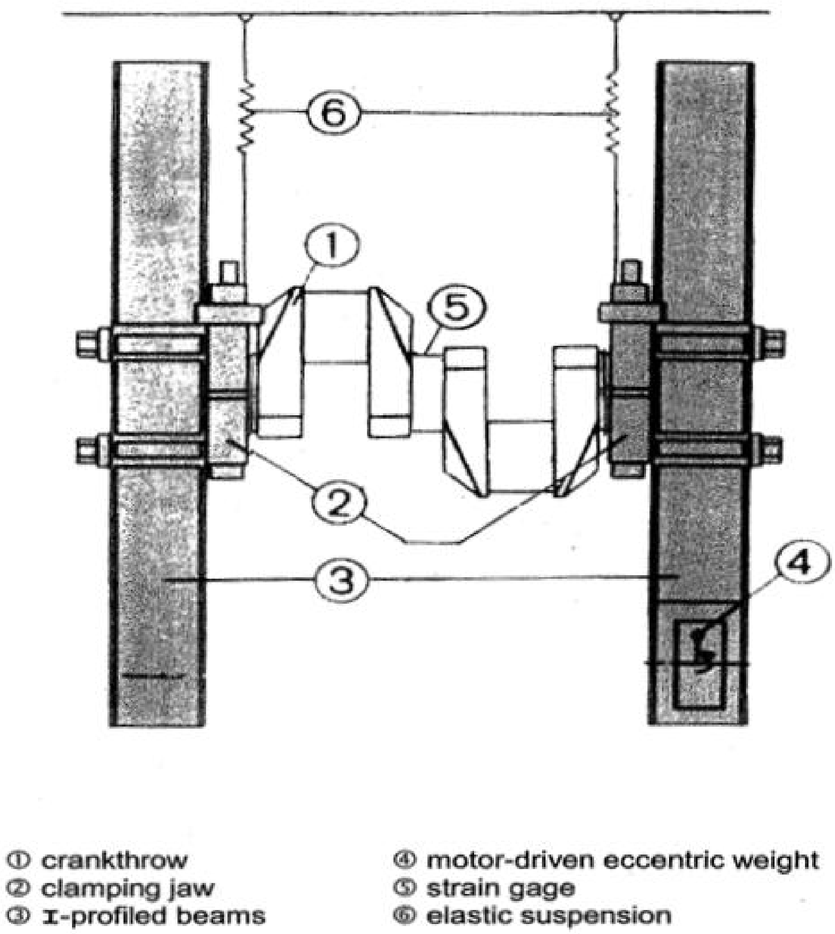


Figure 4.2. An example of testing arrangement of the resonance tester for torsion loading with double crank throw section

Since sideway movements can cause some bending stresses, the plain portions of the crankpins should also be provided with strain gauges arranged to measure any possible bending that could have an influence on the test results.

Similarly, to the bending case the applied load shall be verified by strain gauge measurements on plain shaft sections. It is also pertinent to check fillet stresses with strain gauge chains as well.

4.3. Use of results and crankshaft acceptability

In order to combine tested bending and torsion fatigue strength results in calculation of crankshaft acceptability, see TL- R M53.7, the Gough-Pollard approach can be applied for the following cases:

Related to the crankpin diameter:

$$Q = \left(\sqrt{ \left(\frac{\sigma_{BH}}{\sigma_{DWCT}} \right)^2 + \left(\frac{\tau_{BH}}{\tau_{DWCT}} \right)^2 } \right)^{-1}$$

where:

σ_{DWCT} fatigue strength by bending testing
τ_{DWCT} fatigue strength by torsion testing

Related to crankpin oil bore:

$$Q = \left(\sqrt{\left(\frac{\sigma_{BO}}{\sigma_{DWOT}}\right)^2 + \left(\frac{\tau_{TO}}{\tau_{DWOT}}\right)^2}\right)^{-1}$$

where:

σ_{DWOT} fatigue strength by bending testing
τ_{DWOT} fatigue strength by torsion testing

Related to the journal diameter:

$$Q = \left(\sqrt{\left(\frac{\sigma_{BG}}{\sigma_{DWJT}}\right)^2 + \left(\frac{\tau_{G}}{\tau_{DWJT}}\right)^2}\right)^{-1}$$

where:

σ_{DWJT} fatigue strength by bending testing
τ_{DWJT} fatigue strength by torsion testing

In case increase in fatigue strength due to the surface treatment is considered to be similar between the above cases, it is sufficient to test only the most critical location according to the calculation where the surface treatment had not been taken into account.

5. Use of existing results for similar crankshafts

For fillets or oil bores without surface treatment, the fatigue properties found by testing may be used for similar crankshaft designs providing:

- **Material:**
  - Similar material type
  - Cleanliness on the same or better level
  - The same mechanical properties can be granted (size versus hardenability)
- **Geometry:**
  - Difference in the size effect of stress gradient is insignificant or it is considered
  - Principal stress direction is equivalent. See Chapter 3.
- **Manufacturing:**
  - Similar manufacturing process

Induction hardened or gas nitrited crankshafts will suffer fatigue either at the surface or at the transition to the core. The surface fatigue strength as determined by fatigue tests of full size cranks, may be used on an equal or similar design as the tested crankshaft when the fatigue initiation occurred at the surface. With the similar design, it is meant that a similar material type and surface hardness are used and the fillet radius and hardening depth are within approximately ± 30 % of the tested crankshaft.

Fatigue initiation in the transition zone can be either subsurface, i.e. below the hard layer, or at the surface where the hardening ends. The fatigue strength at the transition to the core can be determined by fatigue tests as described above, provided that the fatigue initiation occurred at the transition to the core. Tests made with the core material only will not be representative since the tension residual stresses at the transition are lacking.

It has to be noted also what some recent research has shown: The fatigue limit can decrease in the very high cycle domain with subsurface crack initiation due to trapped hydrogen that accumulates through diffusion around some internal defect functioning as an initiation point. In these cases, it would be appropriate to reduce the fatigue limit by some percent per decade of cycles beyond 10^7. Based on a publication by Yukitaka Murakami “Metal Fatigue: Effects of Small Defects and Non-metallic Inclusions” the reduction is suggested to be 5 % per decade especially when the hydrogen content is considered to be high.

Guidance for Calculation of Surface Treated Fillets and Oil Bore Outlets

Contents

1. Introduction

This appendix deals with surface treated fillets and oil bore outlets. The various treatments are explained and some empirical formulae are given for calculation purposes. Conservative empiricism has been applied intentionally, in order to be on the safe side from a calculation standpoint.

Please note that measurements or more specific knowledge should be used if available. However, in the case of a wide scatter (e.g. for residual stresses) the values should be chosen from the end of the range that would be on the safe side for calculation purposes.

2. Definition of surface treatment

'Surface treatment' is a term covering treatments such as thermal, chemical or mechanical operations, leading to inhomogeneous material properties – such as hardness, chemistry or residual stresses – from the surface to the core.

2.1. Surface treatment methods

The following list covers possible treatment methods and how they influence the properties that are decisive for the fatigue strength.

Table 2.1. Surface treatment methods and the characteristics they affect.

Treatment method	Affecting
•Induction hardening	Hardness and residual stresses
•Nitriding	Chemistry, hardness and residual stresses
•Case hardening	Chemistry, hardness and residual stresses
•Die quenching (no temper)	Hardness and residual stresses
•Cold rolling	Residual stresses
•Stroke peening	Residual stresses
•Shot peening	Residual stresses
•Laser peening	Residual stresses
•Ball coining	Residual stresses

It is important to note that since only induction hardening, nitriding, cold rolling and stroke peening are considered relevant for marine engines, other methods as well as combination of two or more of the above are not dealt with in this document. In addition, die quenching can be considered in the same way as induction hardening.

3. Calculation principles

The basic principle is that the alternating working stresses shall be below the local fatigue strength (including the effect of surface treatment) wherein non-propagating cracks may occur, see also section 6.1 for details. This is then divided by a certain safety factor. This applies through the entire fillet or oil bore contour as well as below the surface to a depth below the treatment-affected zone – i.e. to cover the depth all the way to the core.

Consideration of the local fatigue strength shall include the influence of the local hardness, residual stress and mean working stress. The influence of the 'giga-cycle effect', especially for initiation of subsurface cracks, should be covered by the choice of safety margin.

It is of vital importance that the extension of hardening/peening in an area with concentrated stresses be duly considered. Any transition where the hardening/peening is ended is likely to have considerable tensile residual stresses.
This forms a 'weak spot' and is important if it coincides with an area of high stresses.

Alternating and mean working stresses must be known for the entire area of the stress concentration as well as to a depth of about 1.2 times the depth of the treatment. The following figure indicates this principle in the case of induction hardening. The base axis is either the depth (perpendicular to the surface) or along the fillet contour.

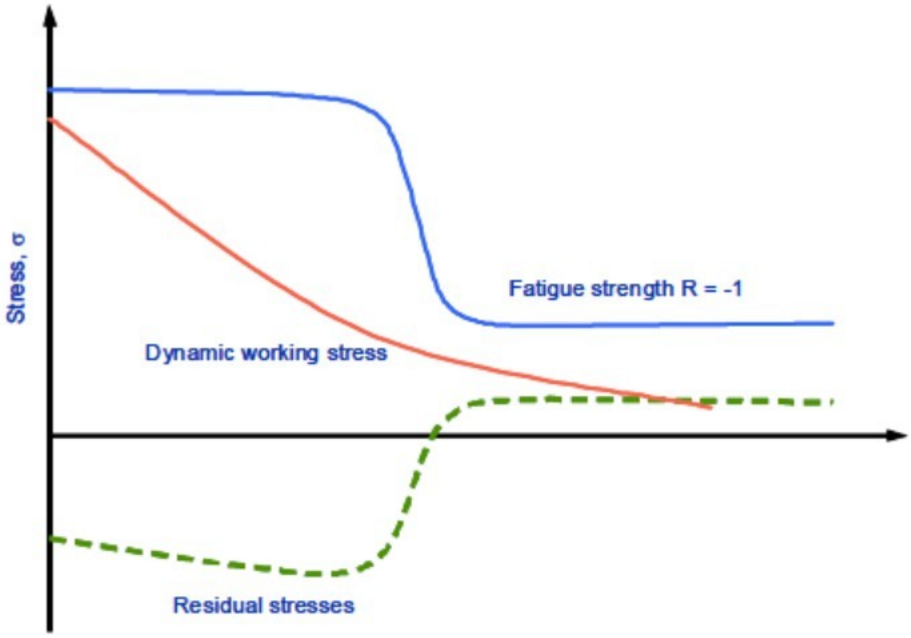


Figure 3.1. Stresses as functions of depth, general principles

The acceptability criterion should be applied stepwise from the surface to the core as well as from the point of maximum stress concentration along the fillet surface contour to the web.

3.1. Evaluation of local fillet stresses

It is necessary to have knowledge of the stresses along the fillet contour as well as in the subsurface to a depth somewhat beyond the hardened layer. Normally this will be found via FEA as described in Appendix III. However, the element size in the subsurface range will have to be the same size as at the surface. For crankpin hardening only the small element size will have to be continued along the surface to the hard layer.
If no FEA is available, a simplified approach may be used. This can be based on the empirically determined stress concentration factors (SCFs), as in M53.3 if within its validity range, and a relative stress gradient inversely proportional to the fillet radius.
Bending and torsional stresses must be addressed separately. The combination of these is addressed by the acceptability criterion.

The subsurface transition-zone stresses, with the minimum hardening depth, can be determined by means of local stress concentration factors along an axis perpendicular to the fillet surface. These functions $\alpha_{B\text{-}local}$ and $\alpha_{T\text{-}local}$ have different shapes due to the different stress gradients.

The SCFs α_B and α_T are valid at the surface. The local $\alpha_{B\text{-}local}$ and $\alpha_{T\text{-}local}$ drop with increasing depth. The relative stress gradients at the surface depend on the kind of stress raiser, but for crankpin fillets they can be simplified to $2/R_H$ in bending and $1/R_H$ in torsion. The journal fillets are handled analogously by using R_G and D_G. The nominal stresses are assumed to be linear from the surface to a midpoint in the web between the crankpin fillet and the journal fillet for bending and to the crankpin or journal centre for torsion.

The local SCFs are then functions of depth *t* according to Equation 3.1 as shown in Figure 3.2 for bending and respectively for torsion in Equation 3.2 and Figure 3.3.

$$\alpha_{B-local} = (\alpha_B - 1) \cdot e^{\frac{-2 \cdot t}{R_H}} + 1 - \left(\frac{2 \cdot t}{\sqrt{W^2 + S^2}} \right)^{\frac{0.6}{\sqrt{\alpha_B}}} \quad (3.1)$$

$$\alpha_{T-local} = (\alpha_T - 1) \cdot e^{\frac{-t}{R_H}} + 1 - \left(\frac{2 \cdot t}{D} \right)^{\frac{1}{\sqrt{\alpha_T}}} \quad (3.2)$$

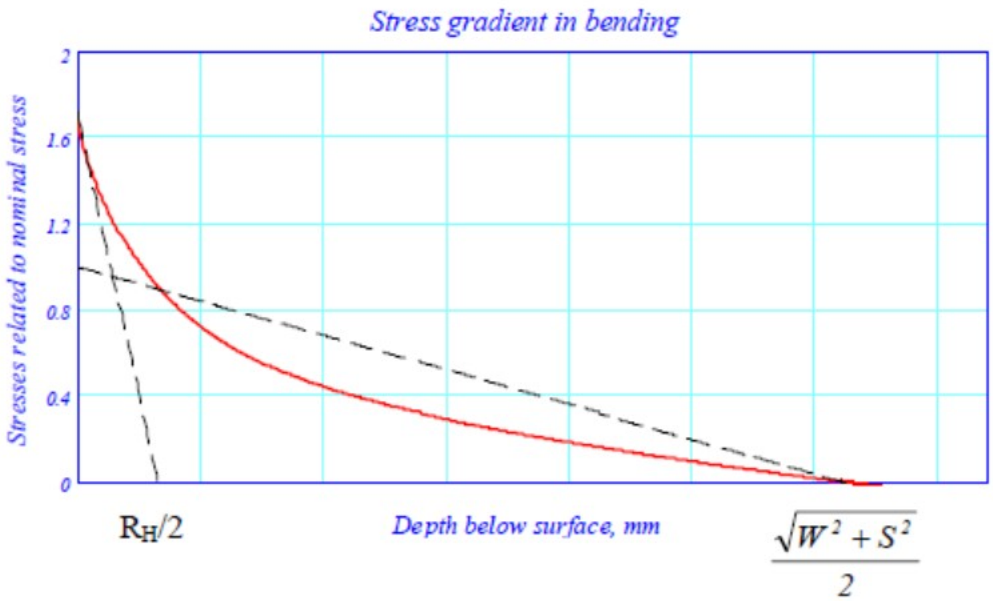


Figure 3.2. Bending SCF in the crankpin fillet as a function of depth. The corresponding SCF for the journal fillet can be found by replacing R_H with R_G

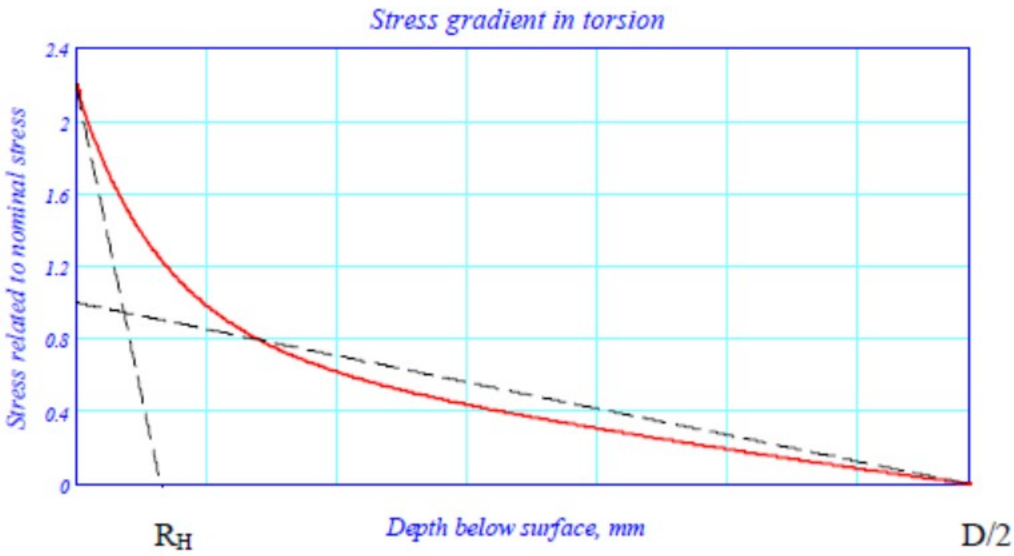


Figure 3.3. Torsional SCF in the crankpin fillet as a function of depth. The corresponding SCF for the journal fillet can be found by replacing R_H with R_G and D with D_G

If the pin is hardened only and the end of the hardened zone is closer to the fillet than three times the maximum hardness depth, FEA should be used to determine the actual stresses in the transition zone.

3.2. Evaluation of oil bore stresses

Stresses in the oil bores can be determined also by FEA. The element size should be less than 1/8 of the oil bore diameter D_o and the element mesh quality criteria should be followed as prescribed in Appendix III. The fine element mesh should continue well beyond a radial depth corresponding to the hardening depth.

The loads to be applied in the FEA are the torque – see Appendix III item 3.1 – and the bending moment, with four-point bending as in Appendix III item 3.2.

If no FEA is available, a simplified approach may be used. This can be based on the empirically determined SCF from M53.3 if within its applicability range. Bending and torsional stresses at the point of peak stresses are combined as in M53.5.

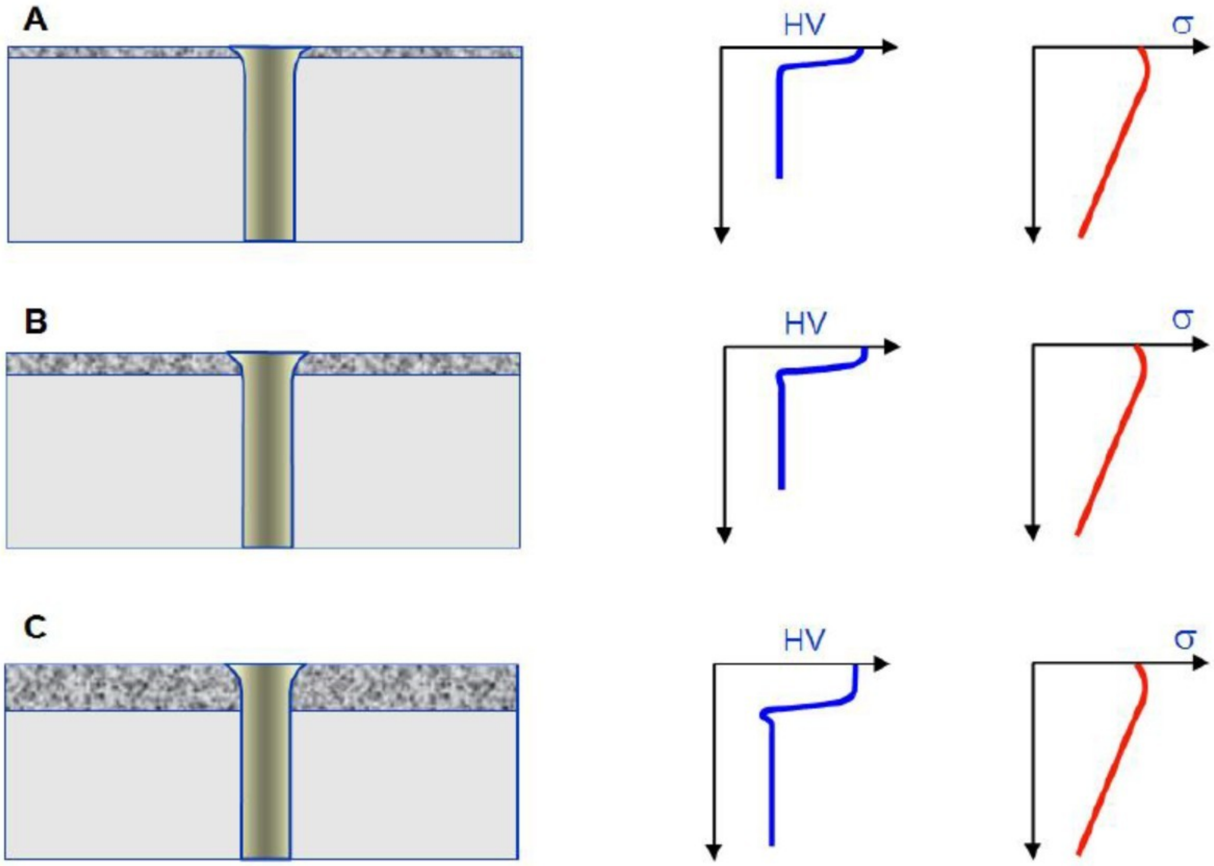


Figure 3.4. Stresses and hardness in induction hardened oil holes

Figure 3.4 indicates a local drop of the hardness in the transition zone between a hard and soft material. Whether this drop occurs depends also on the tempering temperature after quenching in the QT process.

The peak stress in the bore occurs at the end of the edge rounding. Within this zone the stress drops almost linearly to the centre of the pin. As can be seen from Figure 3.4, for shallow (A) and intermediate (B) hardening, the transition point practically coincides with the point of maximal stresses. For deep hardening the transition point comes outside of the point of peak stress and the local stress can be assessed as a portion ($1\text{-}2tH/D$) of the peak stresses where tH is the hardening depth.

The subsurface transition-zone stresses (using the minimum hardening depth) can be determined by means of local stress concentration factors along an axis perpendicular to the oil bore surface. These functions $\gamma_{B\text{-}local}$ and $\gamma_{T\text{-}local}$ have different shapes, because of the different stress gradients.

The stress concentration factors γ_B and γ_T are valid at the surface. The local SCFs $\gamma_{B\text{-}local}$ and $\gamma_{T\text{-}local}$ drop with increasing depth. The relative stress gradients at the surface depend on the kind of stress raiser, but for crankpin oil bores they can be simplified to $4/D_o$ in bending and $2/D_o$ in torsion. The local SCFs are then functions of the depth t:

$$\gamma_{B-local} = (\gamma_B - 1) \cdot e^{\frac{-4 \cdot t}{D_o}} + 1 \qquad (3.3)$$

$$\gamma_{T-local} = (\gamma_T - 1) \cdot e^{\frac{-2 \cdot t}{D_o}} + 1 \qquad (3.4)$$

3.3. Acceptability criteria

Acceptance of crankshafts is based on fatigue considerations; M53 compares the equivalent alternating stress and the fatigue strength ratio to an acceptability factor of $Q \geq 1.15$ for oil bore outlets, crankpin fillets and journal fillets. This shall be extended to cover also surface treated areas independent of whether surface or transition zone is examined.

4. Induction hardening

Generally, the hardness specification shall specify the surface hardness range i.e. minimum and maximum values, the minimum and maximum extension in or through the fillet and also the minimum and maximum depth along the fillet contour. The referenced Vickers hardness is considered to be **HV0.5...HV5**.

The induction hardening depth is defined as the depth where the hardness is 80% of the minimum specified surface hardness.

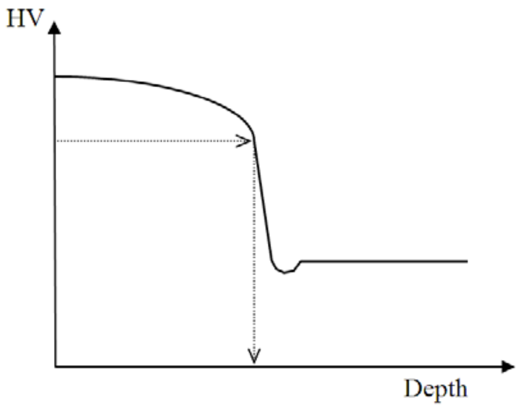


Figure 4.1. Typical hardness as a function of depth. The arrows indicate the defined hardening depth. Note the indicated potential hardness drop at the transition to the core. This can be a weak point as local strength may be reduced and tensile residual stresses may occur.

In the case of crankpin or journal hardening only, the minimum distance to the fillet shall be specified due to the tensile stress at the heat-affected zone as shown in Figure 4.2.

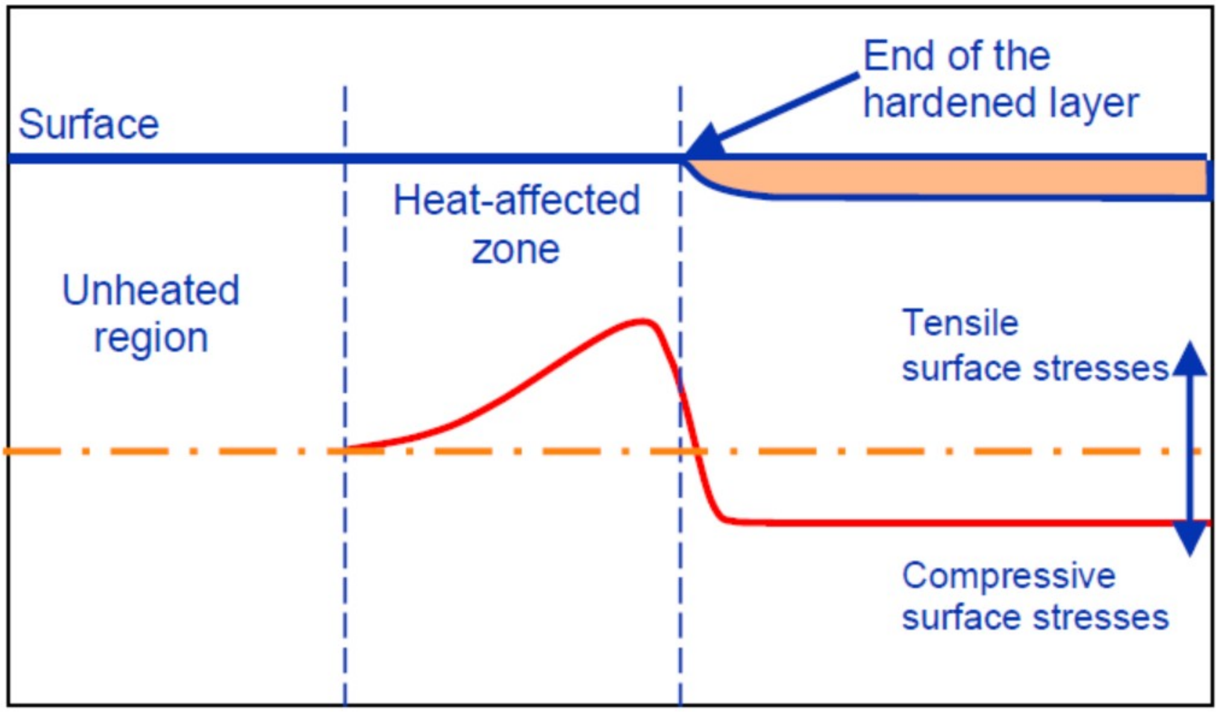


Figure 4.2. Residual stresses along the surface of a pin and fillet

If the hardness-versus-depth profile and residual stresses are not known or specified, one may assume the following:

- The hardness profile consists of two layers (see figure 4.1):
    - Constant hardness from the surface to the transition zone
    - Constant hardness from the transition zone to the core material
- Residual stresses in the hard zone of 200 MPa (compression)
- Transition-zone hardness as 90% of the core hardness unless the local hardness drop is avoided
- Transition-zone maximum residual stresses (von Mises) of 300 MPa tension

If the crankpin or journal hardening ends close to the fillet, the influence of tensile residual stresses has to be considered. If the minimum distance between the end of the hardening and the beginning of the fillet is more than 3 times the maximum hardening depth, the influence may be disregarded.

4.1. Local fatigue strength

Induction-hardened crankshafts will suffer fatigue either at the surface or at the transition to the core. The fatigue strengths, for both the surface and the transition zone, can be determined by fatigue testing of full size cranks as described in Appendix IV. In the case of a transition zone, the initiation of the fatigue can be either subsurface (i.e. below the hard layer) or at the surface where the hardening ends.
Tests made with the core material only will not be representative since the tensile residual stresses at the transition are lacking.

Alternatively, the surface fatigue strength can be determined empirically as follows where *HV* is the surface Vickers hardness. The Equation 4.1 provides a conservative value, with which the fatigue strength is assumed to include the influence of the residual stress. The resulting value is valid for a working stress ratio of *R* = -1:

$$\sigma_{Fsurface} = 400 + 0.5 \cdot (HV - 400) \qquad [MPa] \qquad (4.1)$$

It has to be noted also that the mean stress influence of induction-hardened steels may be significantly higher than that for QT steels.

The fatigue strength in the transition zone, without taking into account any possible local hardness drop, shall be determined by the equation introduced in TL- R M53.6. For journal and respectively to crankpin fillet applies:

$$\sigma_{Ftransition,cpin} = \pm K \cdot (0.42 \cdot \sigma_B + 39.3) \cdot \left[0.264 + 1.073 \cdot Y^{-0.2} + \frac{785 - \sigma_B}{4900} + \frac{196}{\sigma_B} \cdot \sqrt{\frac{1}{X}} \right] \qquad (4.2)$$

where:

$Y = D_G$	and $X = R_G$	*for journal fillet*
$Y = D$	and $X = R_H$	*for crankpin fillet*
$Y = D$	and $X = D_o/2$	*for oil bore outlet*

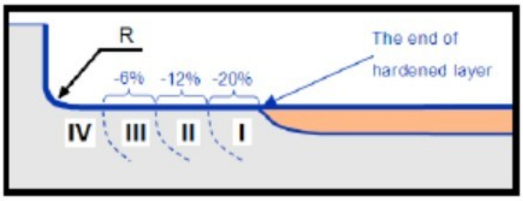
The influence of the residual stress is not included in 4.2.

For the purpose of considering subsurface fatigue, below the hard layer, the disadvantage of tensile residual stresses has to be considered by subtracting 20% from the value determined above. This 20% is based on the mean stress influence of alloyed quenched and tempered steel having a residual tensile stress of 300 *MPa*.
When the residual stresses are known to be lower, also smaller value of subtraction shall be used. For low-strength steels the percentage chosen should be higher.

For the purpose of considering surface fatigue near the end of the hardened zone – i.e. in the heat-affected zone shown in the Figure 4.2 – the influence of the tensile residual stresses can be considered by subtracting a certain percentage, in accordance with Table 4.1, from the value determined by the above formula.

Table 4.1. The influence of tensile residual stresses at a given distance from the end of the hardening towards the fillet

I.	0 to 1.0 of the max. hardening depth:	20%
II.	1.0 to 2.0 of the max. hardening depth:	12%
III.	2.0 to 3.0 of the max. hardening depth:	6%
IV.	3.0 or more of the max. hardening depth:	0%



5. Nitriding

The hardness specification shall include the surface hardness range (min and max) and the minimum and maximum depth. Only gas nitriding is considered. The referenced Vickers hardness is considered to be **HV0.5**.

The depth of the hardening is defined in different ways in the various standards and the literature. The most practical method to use in this context is to define the nitriding depth *tN* as the depth to a hardness of 50 *HV* above the core hardness.

The hardening profile should be specified all the way to the core. If this is not known, it may be determined empirically via the following formula:

$$HV(t) = HV_{core} + (HV_{surface} - HV_{core}) \cdot \left(\frac{50}{HV_{surface} - HV_{core}} \right)^{\left(\frac{t}{t_N}\right)^2} \qquad (5.1)$$

where:

t	=	The local depth
HV(t)	=	Hardness at depth *t*
HVcore	=	Core hardness (minimum)
HVsurface	=	Surface hardness (minimum)
tN	=	Nitriding depth as defined above (minimum)

5.1. Local fatigue strength

It is important to note that in nitrided crankshaft cases, fatigue is found either at the surface or at the transition to the core. This means that the fatigue strength can be determined by tests as described in Appendix IV.

Alternatively, the surface fatigue strength (principal stress) can be determined empirically and conservatively as follows. This is valid for a surface hardness of 600 *HV* or greater:

$$\sigma_{Fsurface} = 450MPa \qquad (5.2)$$

Note that this fatigue strength is assumed to include the influence of the surface residual stress and applies for a working stress ratio of *R* = -1.

The fatigue strength in the transition zone can be determined by the equation introduced in UR M53.6. For crankpin and respectively to journal applies:

$$\sigma_{Ftransition,cpin} = \pm K \cdot (0.42 \cdot \sigma_B + 39.3) \cdot \left[0.264 + 1.073 \cdot Y^{-0.2} + \frac{785 - \sigma_B}{4900} + \frac{196}{\sigma_B} \cdot \sqrt{\frac{1}{X}} \right] \qquad (5.3)$$

where:

$Y = D_G$ and $X = R_G$ *for journal fillet*
$Y = D$ and $X = R_H$ *for crankpin fillet*
$Y = D$ and $X = D_o/2$ *for oil bore outlet*

Note that this fatigue strength is **not** assumed to include the influence of the residual stresses.

In contrast to induction-hardening the nitrited components have no such distinct transition to the core. Although the compressive residual stresses at the surface are high, the balancing tensile stresses in the core are moderate because of the shallow depth. For the purpose of analysis of subsurface fatigue the disadvantage of tensile residual stresses in and below the transition zone may be even disregarded in view of this smooth contour of a nitriding hardness profile.

Although in principle the calculation should be carried out along the entire hardness profile, it can be limited to a simplified approach of examining the surface and an artificial transition point. This artificial transition point can be taken at the depth where the local hardness is approximately 20 *HV* above the core hardness. In such a case, the properties of the core material should be used. This means that the stresses at the transition to the core can be found by using the local SCF formulae mentioned earlier when inserting t=1.2tN.

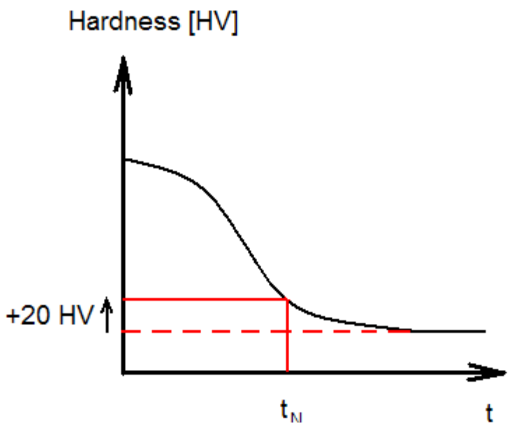


Figure 5.1. Sketch of the location for the artificial transition point in the depth direction

6. Cold forming

The advantage of stroke peening or cold rolling of fillets is the compressive residual stresses introduced in the high-loaded area. Even though surface residual stresses can be determined by X-ray diffraction technique and subsurface residual stresses can be determined through neutron diffraction, the local fatigue strength is virtually non-assessable on that basis since suitable and reliable correlation formulae are hardly known.

Therefore, the fatigue strength has to be determined by fatigue testing; see also Appendix IV. Such testing is normally carried out as four-point bending, with a working stress ratio of R = -1. From these results, the bending fatigue strength – surface- or subsurface-initiated depending on the manner of failure – can be determined and expressed as the representative fatigue strength for applied bending in the fillet.

In comparison to bending, the torsion fatigue strength in the fillet may differ considerably from the ratio $\sqrt{3}$ (utilized by the von Mises criterion). The forming-affected depth that is sufficient to prevent subsurface fatigue in bending, may still allow subsurface fatigue in torsion. Another possible reason for the difference in bending and torsion could be the extension of the highly stressed area.

The results obtained in a full-size crank test can be applied for another crank size provided that the base material (alloyed Q+T) is of the similar type and that the forming is done so as to obtain the similar level of compressive residual stresses at the surface as well as through the depth. This means that both the extension and the depth of the cold forming must be proportional to the fillet radius.

6.1. Stroke peening by means of a ball

The fatigue strength obtained can be documented by means of full size crank tests or by empirical methods if applied on the safe side. If both bending and torsion fatigue strengths have been investigated and differ from the ratio $\sqrt{3}$, the von Mises criterion should be excluded.

If only bending fatigue strength has been investigated, the torsional fatigue strength should be assessed conservatively. If the bending fatigue strength is concluded to be x% above the fatigue strength of the non-peened material, the torsional fatigue strength should not be assumed to be more than 2/3 of x% above that of the non-peened material.

As a result of the stroke peening process the maximum of the compressive residual stress is found in the subsurface area. Therefore, depending on the fatigue testing load and the stress gradient, it is possible to have higher working stresses at the surface in comparison to the local fatigue strength of the surface. Because of this phenomenon small cracks may appear during the fatigue testing, which will not be able to propagate in further load cycles and/or with further slight increases of the testing load because of the profile of the compressive residual stress. Put simply, the high compressive residual stresses below the surface ‘arrest’ small surface cracks.
This is illustrated in Figure 6.1 as gradient load 2.

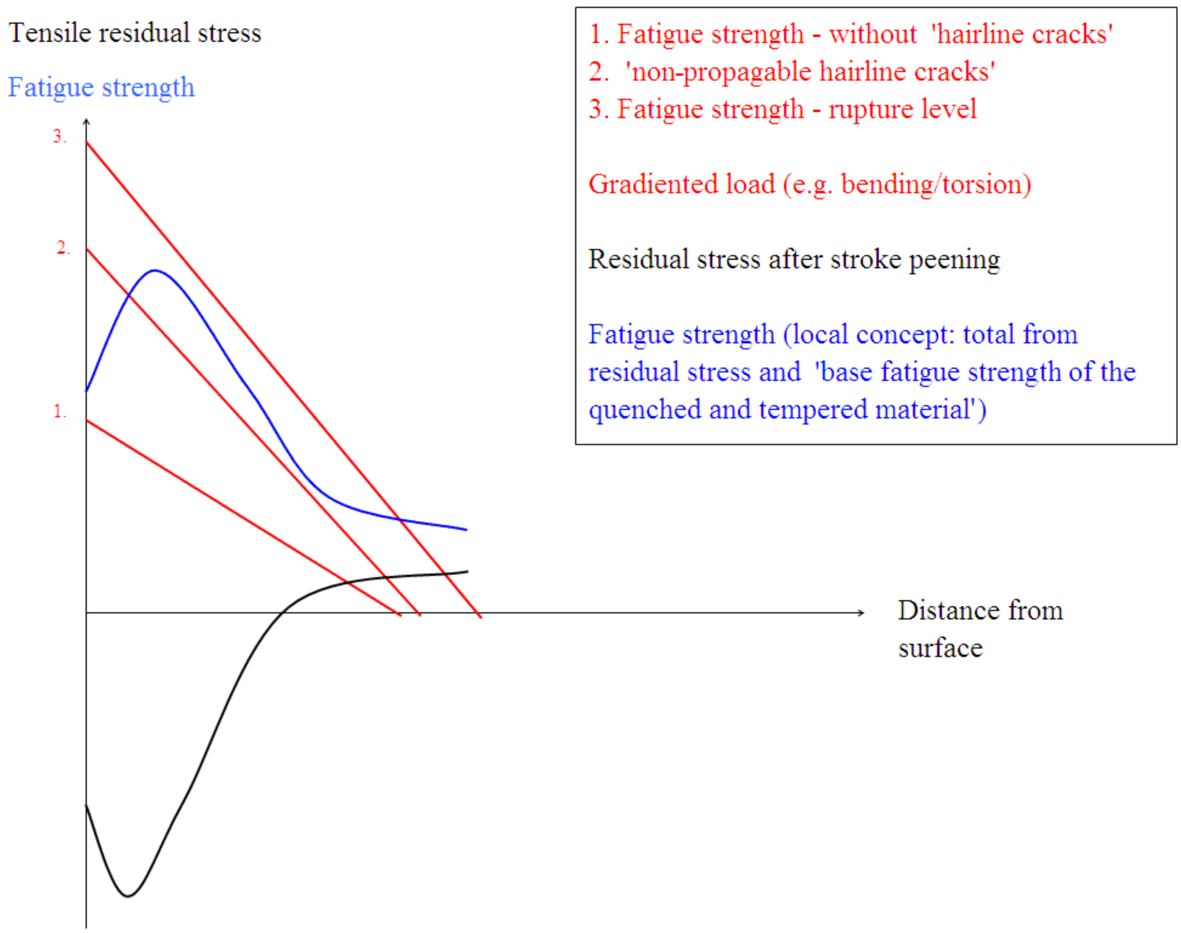


Figure 6.1. Working and residual stresses below the stroke-peened surface. Straight lines 1…3 represent different possible load stress gradients.

In fatigue testing with full-size crankshafts these small "hairline cracks" should not be considered to be the failure crack. The crack that is technically the fatigue crack leading to failure, and that therefore shuts off the test-bench, should be considered for determination of the failure load level. This also applies if induction-hardened fillets are stroke-peened.

In order to improve the fatigue strength of induction-hardened fillets it is possible to apply the stroke peening process in the crankshafts' fillets after they have been induction-hardened and tempered to the required surface hardness. If this is done, it might be necessary to adapt the stroke peening force to the hardness of the surface layer and not to the tensile strength of the base material. The effect on the fatigue strength of induction hardening and stroke peening the fillets shall be determined by a full-size crankshaft test.

6.1.1. Use of existing results for similar crankshafts

The increase in fatigue strength, which is achieved by applying stroke peening, may be utilized in another similar crankshaft if all of the following criteria are fulfilled:

- Ball size relative to fillet radius within ±10% in comparison to the tested crankshaft
- At least the same circumferential extension of the stroke peening

- Angular extension of the fillet contour relative to fillet radius within ±15% in comparison to the tested crankshaft and located to cover the stress concentration during engine operation
- Similar base material, e.g. alloyed quenched and tempered
- Forward feed of ball of the same proportion of the radius
- Force applied to ball proportional to base material hardness (if different)
- Force applied to ball proportional to square of ball radius

6.2. Cold rolling

The fatigue strength can be obtained by means of full size crank tests or by empirical methods, if these are applied so as to be on the safe side. If both, bending and torsion fatigue strengths have been investigated, and differ from the ratio $\sqrt{3}$, the von Mises criterion should be excluded.

If only bending fatigue strength has been investigated, the torsional fatigue strength should be assessed conservatively. If the bending fatigue strength is concluded to be x% above the fatigue strength of the non-rolled material, the torsional fatigue strength should not be assumed to be more than 2/3 of x% above that of the non-rolled material.

6.2.1. Use of existing results for similar crankshafts

The increase in fatigue strength, which is achieved applying cold rolling, may be utilized in another similar crankshaft if all of the following criteria are fulfilled:

- At least the same circumferential extension of cold rolling
- Angular extension of the fillet contour relative to fillet radius within ±15% in comparison to the tested crankshaft and located to cover the stress concentration during engine operation
- Similar base material, e.g. alloyed quenched and tempered
- Roller force to be calculated so as to achieve at least the same relative (to fillet radius) depth of treatment

Guidance for Calculation of Stress Concentration Factors in the Oil Bore Outlets of crankshafts through utilisation of the Finite Element Method

Contents

1. General

The objective of the analysis described in this document is to substitute the analytical calculation of the stress concentration factor (SCF) at the oil bore outlet with suitable finite element method (FEM) calculated figures. The former method is based on empirical formulae developed from strain gauge readings or photo-elasticity measurements of various round bars. Because use of these formulae beyond any of the validity ranges can lead to erroneous results in either direction, the FEM-based method is highly recommended.

The SCF calculated according to the rules set forth in this document is defined as the ratio of FEM-calculated stresses to nominal stresses calculated analytically. In use in connection with the present method in TL- R M53, principal stresses shall be calculated.

The analysis is to be conducted as linear elastic FE analysis, and unit loads of appropriate magnitude are to be applied for all load cases.

It is advisable to check the element accuracy of the FE solver in use, e.g. by modelling a simple geometry and comparing the FEM-obtained stresses with the analytical solution.

A boundary element method (BEM) approach may be used instead of FEM.

2. Model requirements

The basic recommendations and assumptions for building of the FE-model are presented in Subsection 2.1. The final FE-model must meet one of the criteria in Subsection 2.3.

2.1. Element mesh recommendations

For the mesh quality criteria to be met, construction of the FE model for the evaluation of stress concentration factors according to the following recommendations is advised:

- The model consists of one complete crank, from the main bearing centre line to the opposite side‘s main bearing centre line.
- The following element types are used in the vicinity of the outlets:
    - 10-node tetrahedral elements
    - 8-node hexahedral elements
    - 20-node hexahedral elements
- The following mesh properties for the oil bore outlet are used:
    - Maximum element size a = r / 4 through the entire outlet fillet as well as in the bore direction (if 8-node hexahedral elements are used, even smaller elements are required for meeting of the quality criterion)
    - Recommended manner for element size in the fillet depth direction
        - First layer’s thickness equal to element size of ***a***
        - Second layer’s thickness equal to element size of ***2a***
        - Third -layer thickness equal to element size of ***3a***
- In general, the rest of the crank should be suitable for numeric stability of the solver
- Drillings and holes for weight reduction have to be modelled

Submodeling may be used as long as the software requirements are fulfilled.

2.2. Material

TL- R M53 does not consider material properties such as Young's modulus (*E*) and Poisson's ratio (ν). In the FE analysis, these material parameters are required, as primarily strain is calculated and stress is derived from strain through the use of Young's modulus and Poisson's ratio. Reliable values for material parameters have to be used, either as quoted in the literature or measured from representative material samples.

For steel the following is advised: $E = 2.05 \cdot 10^5$ MPa and $\nu = 0.3$.

2.3. Element mesh quality criteria

If the actual element mesh does not fulfil any of the following criteria in the area examined for SCF evaluation, a second calculation, with a finer mesh is to be performed.

2.3.1. Principal -stresses criterion

The quality of the mesh should be assured through checking of the stress component normal to the surface of the oil bore outlet radius. With principal stresses σ_1, σ_2 and σ_3 the following criterion must be met:

$$\min\left(|\sigma_1|,|\sigma_2|,|\sigma_3|\right) < 0.03 \cdot \max\left(|\sigma_1|,|\sigma_2|,|\sigma_3|\right)$$

2.3.2. Averaged/unaveraged -stresses criterion

The averaged/unaveraged –stresses criterion is based on observation of the discontinuity of stress results over elements at the fillet for the calculation of the SCF:

- Unaveraged nodal stress results calculated from each element connected to a node i should differ less than 5 % from the 100 % averaged nodal stress results at this node i at the location examined.

3. Load cases and assessment of stress

For substitution of the analytically determined SCF in TL- R M53, calculation shall be performed for the following load cases.

3.1. Torsion

The structure is loaded in pure torsion. The surface warp at the end faces of the model is suppressed.

Torque is applied to the central node, on the crankshaft axis. This node acts as the master node with six degrees of freedom, and is connected rigidly to all nodes of the end face.

The boundary and load conditions are valid for both in-line- and V- type engines.

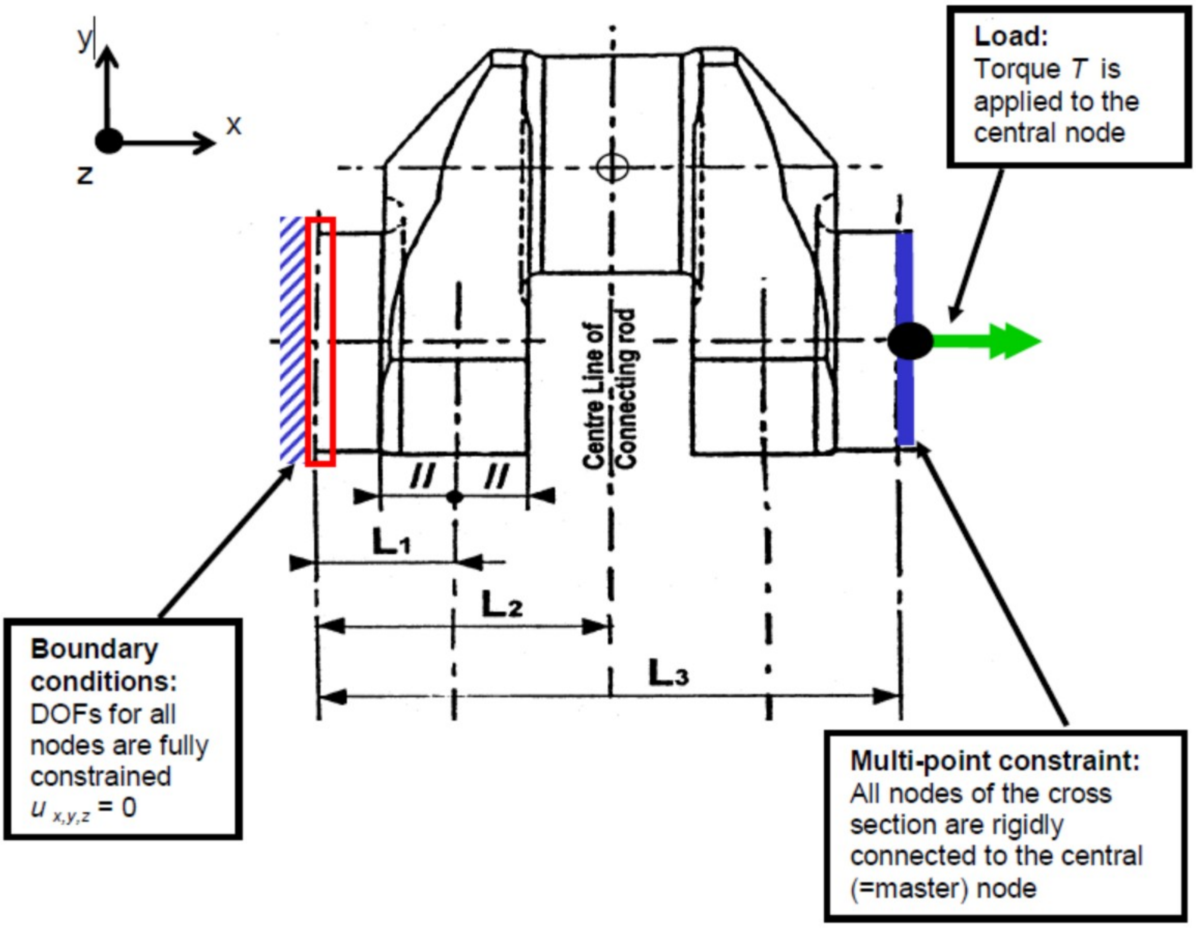


Figure 3.1 Boundary and load conditions for the torsion load case

For all nodes in an oil bore outlet, the principal stresses are obtained and the maximum value is taken for subsequent calculation of the SCF:

$$\gamma_T = \frac{\max\left(|\sigma_1|, |\sigma_2|, |\sigma_3|\right)}{\tau_N}$$

where the nominal torsion stress τ_N referred to the crankpin is evaluated per M53.2.2.2 with torque *T*:

$$\tau_N = \frac{T}{W_P}$$

3.2. Bending

The structure is loaded in pure bending. The surface warp at the end faces of the model is suppressed.

The bending moment is applied to the central node on the crankshaft axis. This node acts as the master node, with six degrees of freedom, and is connected rigidly to all nodes of the end face.

The boundary and load conditions are valid for both in-line- and V- type engines.

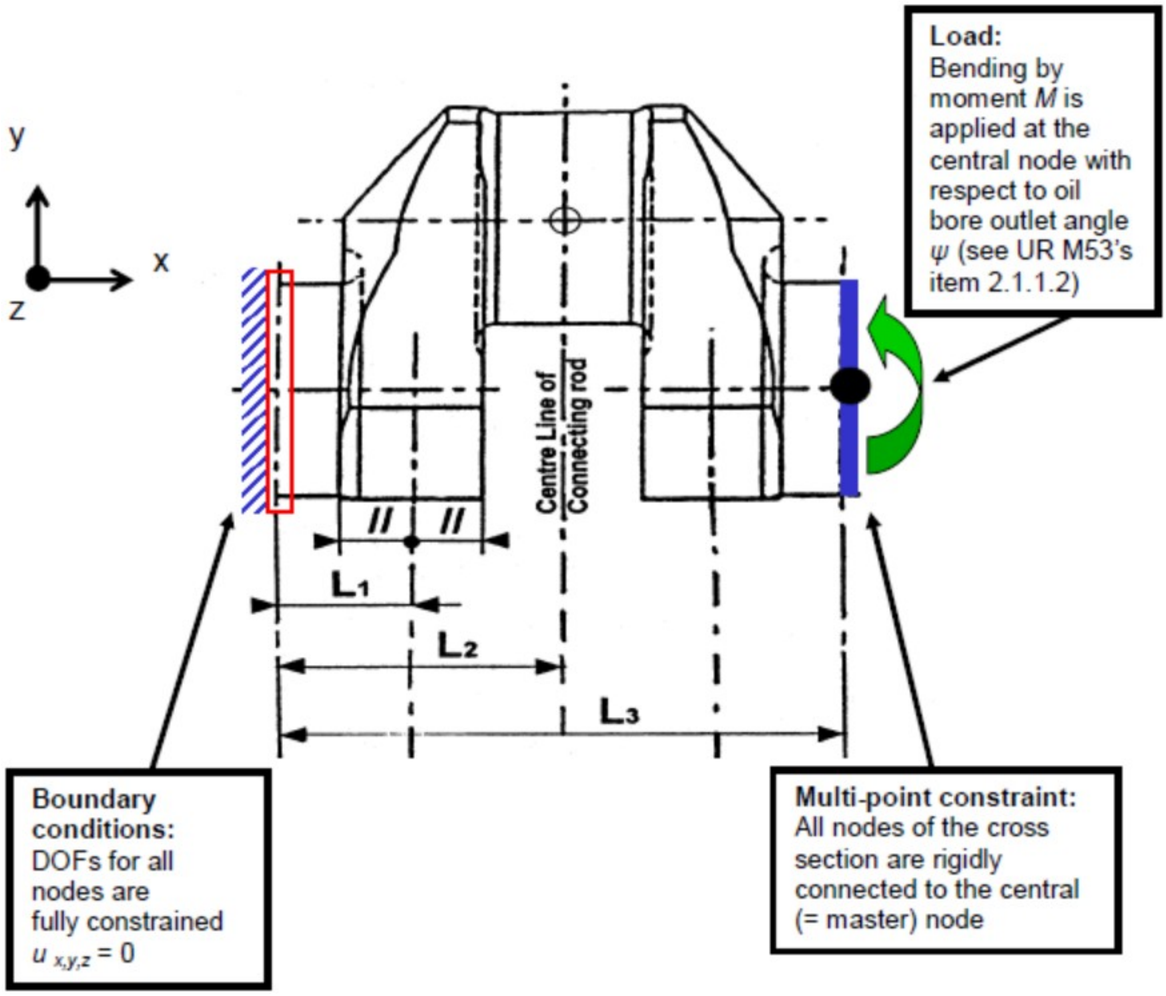


Figure 3.2. Boundary and load conditions for the pure bending load case

For all nodes in the oil bore outlet, principal stresses are obtained and the maximum value is taken for subsequent calculation of the SCF:

$$\gamma_B = \frac{\max(|\sigma_1|, |\sigma_2|, |\sigma_3|)}{\sigma_N}$$

where the nominal bending stress σ_N referred to the crankpin is calculated per M53.2.1.2.2 with bending moment *M*:

$$\sigma_N = \frac{M}{W_e}$$

TL- R M57 Use of ammonia as a refrigerant

1. Ammonia refrigerating machinery shall be installed in dedicated gastight compartments. Except for small compartments, at least two access doors are to be provided.

2. Compartments containing ammonia machinery (including process vessels) are to be fitted with:

   a) a negative ventilation system independent of ventilation systems serving other ship spaces and having a capacity not less than 30 changes per hour based upon the total volume of the space; other suitable arrangements which ensure an equivalent effectiveness may be considered;

   b) a fixed ammonia detector system with alarms inside and outside the compartment;

   c) water screens above all access doors, operable manually from outside the compartment;

   d) an independent bilge system.

3. At least two sets of breathing apparatus and protective clothings are to be available.

4. Ammonia piping is not to pass through accommodation spaces.

5. In case of ammonia plants of fishing vessels under 55 m in length or other ammonia plants with a quantity of ammonia not greater than 25 kg said plants are allowed to be located in the machinery space.

   The area where the ammonia machinery is installed is to be served by a hood with a negative ventilation system, so as not to permit any leakage of ammonia from dissipating into other areas in the space.

   A water spray system is to be provided for the said area.

   In addition previous items 2 b), 3 and 4 apply.

TL- R M59 Control and Safety Systems for Dual Fuel Diesel Engines

M59.1 Application

In addition to the requirements for oil firing diesel engines by the Classification Societies, and the requirements contained in chapter 5 and 16 of the IGC Code*, as far as found applicable, the following requirements are to be applied to dual-fuel diesel engines utilising high pressure Methane gas (NG: Natural Gas) fuel injection (hereinafter referred to as DFD engines).

M59.2 Operation mode

2.1 DFD engines are to be of the dual-fuel type employing pilot fuel ignition and to be capable of immediate change-over to oil fuel only.

2.2 Only oil fuel is to be used when starting the engine.

2.3 Only oil fuel is, in principle, to be used when the operation of an engine is unstable, and/or during manoeuvring and port operations.

2.4 In case of shut-off of the gas fuel supply, the engines are to be capable of continuous operation by oil fuel only.

M59.3 Protection of crankcase

3.1 Crankcase relief valves are to be fitted in way of each crankthrow. The construction and operating pressure of the relief valves are to be determined considering explosions due to gas leaks.

3.2 If a trunk piston type engine is used as DFD engine, the crankcase is to be protected by the following measures.

(1) Ventilation is to be provided to prevent the accumulation of leaked gas, the outlet for which is to be led to a safe location in the open through flame arrester.

(2) Gas detecting or equivalent equipment. (It is recommended that means for automatic injection of inert gas are to be provided).

(3) Oil mist detector.

3.3 If a cross-head type engine is used as DFD, the crankcase is to be protected by oil mist detector or bearing temperature detector.

M59.4 Protection for piston underside space of cross-head type engine

4.1 Gas detecting or equivalent equipment is to be provided for piston underside space of cross-head type engine.

M59.5 Engine Exhaust System

5.1 Explosion relief valves or other appropriate protection system against explosion are to be provided in the exhaust, scavenge and air inlet manifolds.

* International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk, mandatory under the 1983 amendments to 1974 SOLAS Convention.

▶

5.2 The exhaust gas pipes from DFD engines are not to be connected to the exhaust pipes of other engines or systems.

M59.6 Starting air line

6.1 Starting air branch pipes to each cylinder are to be provided with effective flame arresters.

M59.7 Combustion Monitoring

7.1 A failure mode and effect analysis (FMEA) examining all possible faults affecting the combustion process is to be submitted.

Details of required monitoring will be determined based on the outcome of the analysis. However, the following table may serve as guidance:

Faulty condition	Alarm	Aut. shut-off of the interlocked valves*
Function of gas fuel injection valves and pilot oil fuel injection valves	X	X
Exhaust gas temperature at each cylinder outlet and deviation from average	X	X
Cylinder pressure or ignition failure of each cylinder	X	X

* It is recommended that the gas master valve is also closed.

M59.8 Gas fuel supply to engine

8.1 Flame arresters are to be provided at the inlet to the gas supply manifold for the engine.

8.2 Arrangements are to be made so that the gas supply to the engine can be shut-off manually from starting platform or any other control position.

8.3 The arrangement and installation of the gas piping are to provide the necessary flexibility for the gas supply piping to accommodate the oscillating movements of DFD engine, without risk of fatigue failure.

8.4 The connecting of gas line and protection pipes or ducts regulated in 9.1 to the gas fuel injection valves are to provide complete coverage by the protection pipe or ducts.

M59.9 Gas fuel supply piping systems

9.1 Gas fuel piping may pass through or extend into machinery spaces or gas-safe spaces other than accommodation spaces, service spaces and control stations provided that they fulfil one of the following :

(1) The system complying with 16.3.1.1 of the IGC Code, and in addition, with (a), (b) and (c) given below.

▶

(a) The pressure in the space between concentric pipes is monitored continously. Alarm is to be issued and automatic valves specified in 16.3.6 of the IGC Code (hereinafter referred to as "interlocked gas valves") and the master gas fuel valves specified in 16.3.7 of the IGC Code (hereinafter referred to as "master gas valve") are to be closed before the pressure drops to below the inner pipe pressure (however, an interlocked gas valve connected to vent outlet is to be opened).

(b) Construction and strength of the outer pipes are to comply with the requirements of 5.2 of the IGC Code.

(c) It is to be so arranged that the inside of the gas fuel supply piping system between the master gas valve and the DFD engine is to be automatically purged with inert gas, when the master gas valve is closed; or

(2) The system complying with 16.3.1.2 of the IGC Code, and in addition, with (a) through (d) given below.

(a) Materials, construction and strength of protection pipes or ducts and mechanical ventilation systems are to be sufficiently durable against bursting and rapid expansion of high pressure gas in the event of gas pipe burst.

(b) The capacity of mechanical ventilating system is to be determined considering the flow rate of gas fuel and construction and arrangement of protective pipes or ducts, as deemed appropriate by TL.

(c) The air intakes of mechanical ventilating systems are to be provided with non-return devices effective for gas fuel leaks. However, if a gas detector is fitted at the air intakes, these requirements may be dispensed with.

(d) The number of flange joints of protective pipes or ducts is to be minimised; or

(3) Alternative arrangements to those given in paragraph 9.1(1) and (2) will be specially considered based upon an equivalent level of safety.

9.2 High pressure gas piping system are to be ensured to have sufficient constructive strength by carrying out stress analysis taking into account the stresses due to the weight of the piping system including acceleration load when significant, internal pressure and loads induced by hog and sag of the ships.

9.3 All valves and expansion joints used in high pressure gas fuel supply lines are to be of an approved type.

9.4 Joints on entire length of the gas fuel supply lines are to be butt-welded joints with full penetration and to be fully radiographed, except where specially approved by TL.

9.5 Pipe joints other than welded joints at the locations specially approved by TL are to comply with the appropriate standards recognised by TL, or those whose structural strength has been verified through tests and analysis as deemed appropriate by TL.

9.6 For all butt-welded joints of high pressure gas fuel supply lines, post-weld heat treatment are to be performed depending on the kind of material.

M59.10 Shut-off of gas fuel supply

10.1 In addition to the causes specified in 16.3.6 of the IGC Code, supply of gas fuel to DFD engines is to be shut off by the interlocked gas valves in case following abnormality occurs;

▶

(1) Abnormality specified in 7.1
(2) DFD engine stops from any cause
(3) Abnormality specified in 9.1 (1)(a)

10.2 In addition to the causes specified in 16.3.7 of IGC Code, the master gas valve is to be closed in case of any of the following:

(1) Oil mist detector or bearing temperature detector specified in 3.2(3) and 3.3 detects abnormality.
(2) Any kind of gas fuel leakage is detected.
(3) Abnormality specified in 9.1(1)(a)
(4) Abnormality specified in 11.1

10.3 The master gas valve is recommended to close automatically upon activation of the interlocked gas valves.

M59.11 Emergency stop of the DFD engines

11.1 DFD engine is to stopped before the gas concentration detected by the gas detectors specified in 16.2.2 of the IGC Code reached 60% of lower flammable limit.

M59.12 Gas fuel make-up plant and related storage tanks

12.1 Construction, control and safety system of high pressure gas compressors, pressure vessels and heat exchangers constituting a gas fuel make-up plant are so arranged as to the satisfaction of TL.

12.2 The possibility for fatigue failure of the high pressure gas piping due to vibration is to be considered.

12.3 The possibility for pulsation of gas fuel supply pressure caused by the high pressure gas compressor is to be considered.

◄◄

TL- R M66 Type Testing Procedure for Crankcase Explosion Relief Valves

1. Scope

1.1 To specify type tests and identify standard test conditions using methane gas and air mixture to demonstrate that TL requirements are satisfied for crankcase explosion relief valves intended to be fitted to engines and gear cases.

1.2 This test procedure is only applicable to explosion relief valves fitted with flame arresters.

Note:

Where internal oil wetting of a flame arrester is a design feature of an explosion relief valve, alternative testing arrangements that demonstrate compliance with this requirement may be proposed by the manufacturer. The alternative testing arrangements are to be agreed by TL.

2. Recognised Standards

2.1 EN 12874:2001: Flame arresters – Performance requirements, test methods and limits for use.

2.2 ISO/IEC EN 17025:2005: General requirements for the competence of testing and calibration laboratories.

2.3 EN 1070:1998: Safety of Machinery – Terminology.

2.4 VDI 3673: Part 1: Pressure Venting of Dust Explosions.

2.5 IMO MSC/Circular 677 – Revised Standards for the Design, Testing and Locating of Devices to Prevent the Passage of Flame into Cargo Tanks in Tankers.

Note:

1) Engines are to be fitted with components and arrangements complying with this requirement when:

i) the engine is installed on existing ships (i.e. ships for which the date of contract for construction is before 1 July 2008) and the date of application for certification of the engine (i.e. the date of whatever document TL requires/accepts as an application or request for certification of an individual engine) is on or after 1 July 2008; or

ii) the engine is installed on new ships (i.e. ships for which the date of contract for construction is on or after 1 July 2008).

2) The “contracted for construction” date means the date on which the contract to build the vessel is signed between the prospective owner and the shipbuilder. For further details regarding the date of “contract for construction”, refer to TL- PR 29.

3. Purpose

3.1 The purpose of type testing crankcase explosion relief valves is fourfold:

3.1.1 To verify the effectiveness of the flame arrester.

3.1.2 To verify that the valve closes after an explosion.

3.1.3 To verify that the valve is gas/air tight after an explosion.

3.1.4 To establish the level of over pressure protection provided by the valve.

4. Test facilities

4.1 Test houses carrying out type testing of crankcase explosion relief valves are to meet the following requirements:

4.1.1 The test houses where testing is carried out are to be accredited to a National or International Standard, e.g. ISO/IEC 17025, and are to be acceptable to the classification societies.

4.1.2 The test facilities are to be equipped so that they can perform and record explosion testing in accordance with this procedure.

4.1.3 The test facilities are to have equipment for controlling and measuring a methane gas in air concentration within a test vessel to an accuracy of ± 0.1%.

4.1.4 The test facilities are to be capable of effective point-located ignition of a methane gas in air mixture.

4.1.5 The pressure measuring equipment is to be capable of measuring the pressure in the test vessel in at least two positions, one at the valve and the other at the test vessel centre. The measuring arrangements are to be capable of measuring and recording the pressure changes throughout an explosion test at a frequency recognising the speed of events during an explosion. The result of each test is to be documented by video recording and by recording with a heat sensitive camera.

4.1.6 The test vessel for explosion testing is to have documented dimensions. The dimensions are to be such that the vessel is not “pipe like” with the distance between dished ends being not more than 2.5 times its diameter. The internal volume of the test vessel is to include any standpipe arrangements.

4.1.7 The test vessel is to be provided with a flange, located centrally at one end perpendicular to the vessel longitudinal axis, for mounting the explosion relief valve. The test vessel is to be arranged in an orientation consistent with how the valve will be installed in service, i.e., in the vertical plane or the horizontal plane.

4.1.8 A circular plate is to be provided for fitting between the pressure vessel flange and valve to be tested with the following dimensions:

a) Outside diameter of 2 times the outer diameter of the valve top cover.

b) Internal bore having the same internal diameter as the valve to be tested.

4.1.9 The test vessel is to have connections for measuring the methane in air mixture at the top and bottom.

4.1.10 The test vessel is to be provided with a means of fitting an ignition source at a position specified in item 5.3.

4.1.11 The test vessel volume is to be as far as practicable, related to the size and capability of the relief valve to be tested. In general, the volume is to correspond to the requirement in TL- R M9.3 for the free area of explosion relief valve to be not less than $115 cm^2/m^3$ of crankcase gross volume.

Notes:

1. This means that the testing of a valve having $1150 cm^2$ of free area, would require a test vessel with a volume of $10 m^3$.

2. Where the free area of relief valves is greater than $115\ cm^2/m^3$ of the crankcase gross volume, the volume of the test vessel is to be consistent with the design ratio.

3. In no case is the volume of the test vessel to vary by more than +15% to -15% from the design cm^2/m^3 volume ratio.

5. Explosion test process

5.1 All explosion tests to verify the functionality of crankcase explosion relief valves are to be carried out using an air and methane mixture with a volumetric methane concentration of 9.5% ±0.5%. The pressure in the test vessel is to be not less than atmospheric and is not to exceed the opening pressure of the relief valve.

5.2 The concentration of methane in the test vessel is to be measured at the top and bottom of the vessel and these concentrations are not to differ by more than 0.5%.

5.3 The ignition of the methane and air mixture is to be made at the centreline of the test vessel at a position approximately one third of the height or length of the test vessel opposite to where the valve is mounted.

5.4 The ignition is to be made using a maximum 100 joule explosive charge.

6. Valves to be tested

6.1 The valves used for type testing (including testing specified in item 6.3) are to be selected from the manufacturer's normal production line for such valves by TL witnessing the tests.

6.2 For approval of a specific valve size, three valves are to be tested in accordance with 6.3 and 7. For a series of valves item 9 refers.

6.3 The valves selected for type testing are to have been previously tested at the manufacturer's works to demonstrate that the opening pressure is in accordance with the specification within a tolerance of ± 20% and that the valve is air tight at a pressure below the opening pressure for at least 30 seconds.

Note:

This test is to verify that the valve is air tight following assembly at the manufacturer's works and that the valve begins to open at the required pressure demonstrating that the correct spring has been fitted.

6.4 The type testing of valves is to recognise the orientation in which they are intended to be installed on the engine or gear case. Three valves of each size are to be tested for each intended installation orientation, i.e. in the vertical and/or horizontal positions.

7. Method

7.1 The following requirements are to be satisfied at explosion testing:

7.1.1 The explosion testing is to be witnessed by TL surveyor.

7.1.2 Where valves are to be installed on an engine or gear case with shielding arrangements to deflect the emission of explosion combustion products, the valves are to be tested with the shielding arrangements fitted.

7.1.3 Successive explosion testing to establish a valve's functionality is to be carried out as quickly as possible during stable weather conditions.

7.1.4 The pressure rise and decay during all explosion testing is to be recorded.

7.1.5 The external condition of the valves is to be monitored during each test for indication of any flame release by video and heat sensitive camera.

7.2 The explosion testing is to be in three stages for each valve that is required to be approved as being type tested.

7.2.1 Stage 1:

7.2.1.1 Two explosion tests are to be carried out in the test vessel with the circular plate described in 4.1.8 fitted and the opening in the plate covered by a 0.05mm thick polythene film.

Note:

These tests establish a reference pressure level for determination of the capability of a relief valve in terms of pressure rise in the test vessel, see 8.1.6.

7.2.2 Stage 2:

7.2.2.1 Two explosion tests are to be carried out on three different valves of the same size. Each valve is to be mounted in the orientation for which approval is sought i.e., in the vertical or horizontal position with the circular plate described in 4.1.8 located between the valve and pressure vessel mounting flange.

7.2.2.2 The first of the two tests on each valve is to be carried out with a 0.05mm thick polythene bag, having a minimum diameter of three times the diameter of the circular plate and volume not less than 30% of the test vessel, enclosing the valve and circular plate. Before carrying out the explosion test the polythene bag is to be empty of air. The polythene bag is required to provide a readily visible means of assessing whether there is flame transmission through the relief valve following an explosion consistent with the requirements of the standards identified in Section 2.

Note:

During the test, the explosion pressure will open the valve and some unburned methane/air mixture will be collected in the polythene bag. When the flame reaches the flame arrester and if there is flame transmission through the flame arrester, the methane/air mixture in the bag will be ignited and this will be visible.

7.2.2.3 Provided that the first explosion test successfully demonstrated that there was no indication of combustion outside the flame arrester and there are no visible signs of damage to the flame arrester or valve, a second explosion test without the polythene bag arrangement is to be carried out as quickly as possible after the first test. During the second explosion test, the valve is to be visually monitored for any indication of combustion outside the flame arrester and video records are to be kept for subsequent analysis. The second test is required to demonstrate that the valve can still function in the event of a secondary crankcase explosion.

7.2.2.4 After each explosion, the test vessel is to be maintained in the closed condition for at least 10 seconds to enable the tightness of the valve to be ascertained. The tightness of the valve can be verified during the test from the pressure/time records or by a separate test after completing the second explosion test.

7.2.3 Stage 3:

7.2.3.1 Carry out two further explosion tests as described in Stage 1. These further tests are required to provide an average baseline value for assessment of pressure rise, recognising that the test vessel ambient conditions may have changed during the testing of the explosion relief valves in Stage 2.

8. Assessment and records

8.1 For the purposes of verifying compliance with the requirements of this requirement, the assessment and records of the valves used for explosion testing is to address the following:

8.1.1 The valves to be tested are to have evidence of design appraisal/approval by TL witnessing tests.

8.1.2 The designation, dimensions and characteristics of the valves to be tested are to be recorded. This is to include the free area of the valve and of the flame arrester and the amount of valve lift at 0.2bar.

8.1.3 The test vessel volume is to be determined and recorded.

8.1.4 For acceptance of the functioning of the flame arrester there is not to be any indication of flame or combustion outside the valve during an explosion test. This should be confirmed by the test laboratory taking into account measurements from the heat sensitive camera.

8.1.5 The pressure rise and decay during an explosion is to be recorded, with indication of the pressure variation showing the maximum overpressure and steady under-pressure in the test vessel during testing. The pressure variation is to be recorded at two points in the pressure vessel.

8.1.6 The effect of an explosion relief valve in terms of pressure rise following an explosion is ascertained from maximum pressures recorded at the centre of the test vessel during the three stages. The pressure rise within the test vessel due to the installation of a relief valve is the difference between average pressure of the four explosions from Stages 1 and 3 and the average of the first tests on the three valves in Stage 2. The pressure rise is not to exceed the limit specified by the manufacturer.

8.1.7 The valve tightness is to be ascertained by verifying from the records at the time of testing that an underpressure of at least 0.3bar is held by the test vessel for at least 10 seconds following an explosion. This test is to verify that the valve has effectively closed and is reasonably gas-tight following dynamic operation during an explosion.

8.1.8 After each explosion test in Stage 2, the external condition of the flame arrester is to be examined for signs of serious damage and/or deformation that may affect the operation of the valve.

8.1.9 After completing the explosion tests, the valves are to be dismantled and the condition of all components ascertained and documented. In particular, any indication of valve sticking or uneven opening that may affect operation of the valve is to be noted. Photographic records of the valve condition are to be taken and included in the report.

9. Design series qualification

9.1 The qualification of quenching devices to prevent the passage of flame can be evaluated for other similar devices of identical type where one device has been tested and found satisfactory.

9.2 The quenching ability of a flame arrester depends on the total mass of quenching lamellas/mesh. Provided the materials, thickness of materials, depth of lamellas/thickness of mesh layer and the quenching gaps are the same, then the same quenching ability can be qualified for different sizes of flame arresters subject to (a) and (b) being satisfied.

(a) $$\frac{n_1}{n_2} = \sqrt{\frac{S_1}{S_2}}$$

(b) $$\frac{A_1}{A_2} = \frac{S_1}{S_2}$$

Where:

n_1 = total depth of flame arrester corresponding to the number of lamellas of size 1 quenching device for a valve with a relief area equal to S_1

n_2 = total depth of flame arrester corresponding to the number of lamellas of size 2 quenching device for a valve with a relief area equal to S_2

A_1 = free area of quenching device for a valve with a relief area equal to S_1

A_2 = free area of quenching device for a valve with a relief area equal to S_2

9.3 The qualification of explosion relief valves of larger sizes than that which has been previously satisfactorily tested in accordance with Sections 7 and 8 can be evaluated where valves are of identical type and have identical features of construction subject to the following:

9.3.1 The free area of a larger valve does not exceed three times + 5% that of the valve that has been satisfactorily tested.

9.3.2 One valve of the largest size, subject to 9.3.1, requiring qualification is subject to satisfactory testing required by 6.3 and 7.2.2 except that a single valve will be accepted in 7.2.2.1 and the volume of the test vessel is not to be less than one third of the volume required by 4.1.11.

9.3.3 The assessment and records are to be in accordance with Section 8 noting that 8.1.6 will only be applicable to Stage 2 for a single valve.

9.4 The qualification of explosion relief valves of smaller sizes than that which has been previously satisfactorily tested in accordance with Sections 7 and 8 can be evaluated where valves are of identical type and have identical features of construction subject to the following:

9.4.1 The free area of a smaller valve is not less than one third of the valve that has been satisfactorily tested.

9.4.2 One valve of the smallest size, subject to 9.4.1, requiring qualification is subject to satisfactory testing required by 6.3 and 7.2.2 except that a single valve will be accepted in 7.2.2.1 and the volume of the test vessel is not to be more than the volume required by 4.1.11.

9.4.3 The assessment and records are to be in accordance with Section 8 noting that 8.1.6 will only be applicable to Stage 2 for a single valve.

10. The report

10.1 The test facility is to deliver a full report that includes the following information and documents:

10.1.1 Test specification.

10.1.2 Details of test pressure vessel and valves tested.

10.1.3 The orientation in which the valve was tested, (vertical or horizontal position).

10.1.4 Methane in air concentration for each test.

10.1.5 Ignition source.

10.1.6 Pressure curves for each test.

10.1.7 Video recordings of each valve test.

10.1.8 The assessment and records stated in 8.

11. Approval

11.1 The approval of an explosion relief valve is at the discretion of individual classification societies based on the appraisal of plans and particulars and the test facility's report of the results of type testing.

TL- R M67 Type Testing Procedure for Crankcase Oil Mist Detection and Alarm Equipment

1. Scope

1.1 To specify the tests required to demonstrate that crankcase oil mist detection and alarm equipment intended to be fitted to diesel engines satisfy TL requirements.

Note:
This test procedure is also applicable to oil mist detection and alarm equipment intended for gear cases.

2. Recognised Standards

2.1 TL- R E10 Test Specification for Type Approval.

3. Purpose

3.1 The purpose of type testing crankcase oil mist detection and alarm equipment is seven fold:

3.1.1 To verify the functionality of the system.

3.1.2 To verify the effectiveness of the oil mist detectors.

3.1.3 To verify the accuracy of oil mist detectors.

3.1.4 To verify the alarm set points.

3.1.5 To verify time delays between oil mist leaving the source and alarm activation.

3.1.6 To verify functional failure detection.

3.1.7 To verify the influence of optical obscuration on detection.

Note:

1) Engines are to be fitted with crankcase oil mist detection and alarm equipment complying with this requirement when:

   i) an application for certification of an engine is dated on/after 1 January 2007; or

   ii) installed in new ships for which the date of contract for construction is on or after 1 January 2007.

2) This requirement is implemented from 1 July 2016.

3) The “contracted for construction” date means the date on which the contract to build the vessel is signed between the prospective owner and the shipbuilder. For further details regarding the date of “contract for construction”, refer to TL- PR 29.

4. Test facilities

4.1 Test houses carrying out type testing of crankcase oil mist detection and alarm equipment are to satisfy the following criteria:

4.1.1 A full range of facilities for carrying out the environmental and functionality tests required by this procedure shall be available and be acceptable to the classification societies.

4.1.2 The test house that verifies the functionality of the equipment is to be equipped so that it can control, measure and record oil mist concentration levels in terms of mg/l to an accuracy of ± 10% in accordance with this procedure.

4.1.3 When verifying the functionality, test houses are to consider the possible hazards associated with the generation of the oil mist required and take adequate precautions. TL will accept the use of low toxicity, low hazard oils as used in other applications, provided it is demonstrated to have similar properties to SAE 40 monograde mineral oil specified.

5. Equipment testing

5.1 The range of tests is to include the following:

5.1.1 For the alarm/monitoring panel:

(a) Functional tests described in Section 6.

(b) Electrical power supply failure test.

(c) Power supply variation test.

(d) Dry heat test.

(e) Damp heat test.

(f) Vibration test.

(g) EMC test.

(h) Insulation resistance test.

(i) High voltage test.

(j) Static and dynamic inclinations, if moving parts are contained.

5.1.2 For the detectors:

(a) Functional tests described in Section 6.

(b) Electrical power supply failure test.

(c) Power supply variation test.

(d) Dry heat test.

(e) Damp heat test.

(f) Vibration test.

(g) EMC test where susceptible.

(h) Insulation resistance test.

(i) High voltage test.

(j) Static and dynamic inclinations.

6. Functional tests

6.1 All tests to verify the functionality of crankcase oil mist detection and alarm equipment are to be carried out in accordance with 6.2 to 6.6 with an oil mist concentration in air, known in terms of mg/l to an accuracy of ±10%.

6.2 The concentration of oil mist in the test chamber is to be measured in the top and bottom of the chamber and these concentrations are not to differ by more than 10%. See also 8.1.1.1.

6.3 The oil mist detector monitoring arrangements are to be capable of detecting oil mist in air concentrations of between

(a) 0 and 10% of the lower explosive limit (LEL) or

(b) between 0 and a percentage of weight of oil in air determined by the Manufacturer based on the sensor measurement method (e.g. obscuration or light scattering) that is acceptable to TL taking into account the alarm level specified in 6.4.

Note: The LEL corresponds to an oil mist concentration of approximately 50mg/l (~4.1% weight of oil in air mixture).

6.4 The alarm set point for oil mist concentration in air is to provide an alarm at a maximum level corresponding to not more than 5% of the LEL or approximately 2.5mg/l.

6.5 Where alarm set points can be altered, the means of adjustment and indication of set points are to be verified against the equipment manufacturer’s instructions.

6.6 The performance of the oil mist detector in mg/l is to be demonstrated. This is to include the following:

- range (oil mist detector)
- resolution (oil mist detector)
- sensitivity (oil mist detector)

Note:
Sensitivity of a measuring system: quotient of the change in an indication of a measuring system and the corresponding change in a value of a quantity being measured.

Resolution: smallest change in a quantity being measured that causes a perceptible change in the corresponding indication.

6.7 Where oil mist is drawn into a detector via piping arrangements, the time delay between the sample leaving the crankcase and operation of the alarm is to be determined for the longest and shortest lengths of pipes recommended by the manufacturer. The pipe arrangements are to be in accordance with the manufacturer's instructions/recommendations. Piping is to be arranged to prevent pooling of oil condensate which may cause a blockage of the sampling pipe over time.

6.8 It is to be demonstrated that the openings of detector equipment does not become occluded or blocked under continuous splash and spray of engine lubricating oil, as may occur in the crankcase atmosphere. Testing is to be in accordance with arrangements proposed by the manufacturer and agreed by TL. The temperature, quantity and angle of impact of the oil to be used is to be declared and their selection justified by the manufacturer.

6.9 Detector equipment may be exposed to water vapour from the crankcase atmosphere which may affect the sensitivity of the equipment and it is to be demonstrated that exposure to such conditions will not affect the functional operation of the detector equipment. Where exposure to water vapour and/or water condensation has been identified as a possible source of equipment malfunctioning, testing is to demonstrate that any mitigating arrangements such as heating are effective. Testing is to be in accordance with arrangements proposed by the manufacturer and agreed by TL.

Note:
This testing is in addition to that required by 5.1.2(e) and is concerned with the effects of condensation caused by the detection equipment being at a lower temperature than the crankcase atmosphere.

6.10 It is to be demonstrated that an indication is given where lenses fitted in the equipment and used in determination of the oil mist level have been partially obscured to a degree that will affect the reliability of the information and alarm indication as required by M10.16.

7. Detectors and alarm equipment to be tested

7.1 The detectors and alarm equipment selected for the type testing are to be selected from the manufacturer's normal production line by TL witnessing the tests.

7.2 Two detectors are to be tested. One is to be tested in clean condition and the other in a condition representing the maximum level of lens obscuration specified by the manufacturer.

8. Method

8.1 The following requirements are to be satisfied at type testing:

8.1.1 Oil mist generation is to satisfy 8.1.1.1 to 8.1.1.5.

8.1.1.1 The ambient temperature in and around the test chamber is to be at the standard atmospheric conditions defined in TL- R E10 Test Specification for Type Approval before any test run is started.

8.1.1.2 Oil mist is to be generated with suitable equipment using an SAE 40 monograde mineral oil or equivalent and supplied to a test chamber. The selection of the oil to be used is to take into consideration risks to health and safety, and the appropriate controls implemented. A low toxicity, low flammability oil of similar viscosity may be used as an alternative. The oil mist produced is to have an average (or arithmetic mean) droplet size not exceeding 5 μm. The oil droplet size is to be checked using the sedimentation method or an equivalent method to a relevant international or national standard. If the sedimentation method is chosen, the test chamber is to have a minimum height of 1m and volume of not less than $1m^3$.

Note:
The calculated oil droplet size using the sedimentation method represents the average droplet size.

8.1.1.3 The oil mist concentrations used are to be ascertained by the gravimetric deterministic method or equivalent. Where an alternative technique is used its equivalence is to be demonstrated.

Note:
For this test, the gravimetric deterministic method is a process where the difference in weight of a 0.8 μm pore size membrane filter is ascertained from weighing the filter before and after drawing 1 litre of oil mist through the filter from the oil mist test chamber. The oil mist chamber is to be fitted with a recirculating fan.

8.1.1.4 Samples of oil mist are to be taken at regular intervals and the results plotted against the oil mist detector output. The oil mist detector is to be located adjacent to where the oil mist samples are drawn off.

8.1.1.5 The results of a gravimetric analysis are considered invalid and are to be rejected if the resultant calibration curve has an increasing gradient with respect to the oil mist detection reading. This situation occurs when insufficient time has been allowed for the oil mist to become homogeneous. Single results that are more than 10% below the calibration curve are to be rejected. This situation occurs when the integrity of the filter unit has been compromised and not all of the oil is collected on the filter paper.

8.1.1.6 The filters require to be weighed to a precision of 0.1mg and the volume of air/oil mist sampled to 10ml.

8.1.2 For type approval by TL the testing is to be witnessed by authorised personnel from TL.

8.1.3 Oil mist detection equipment is to be tested in the orientation (vertical, horizontal or inclined) in which it is intended to be installed on an engine or gear case as specified by the equipment manufacturer.

8.1.4 Type testing is to be carried out for each type of oil mist detection and alarm equipment for which a manufacturer seeks classification approval. Where sensitivity levels can be adjusted, testing is to be carried out at the extreme and mid-point level settings.

9. Assessment

9.1 Assessment of oil mist detection equipment after testing is to address the following:

9.1.1 The equipment to be tested is to have evidence of design appraisal/approval by TL witnessing tests.

9.1.2 Details of the detection equipment to be tested are to be recorded and are to include:

- name of manufacturer;
- type designation;
- oil mist concentration assessment capability and alarm settings;
- The maximum percentage level of lens obscuration used in 7.2.

9.1.3 After completing the tests, the detection equipment is to be examined and the condition of all components ascertained and documented. Photographic records of the monitoring equipment condition are to be taken and included in the report.

10. Design series qualification

10.1 The approval of one type of detection equipment may be used to qualify other devices having identical construction details. Proposals are to be submitted for consideration.

11. The report

11.1 The test house is to provide a full report which includes the following information and documents:

11.1.1 Test specification.

11.1.2 Details of equipment tested.

11.1.3 Results of tests.

To include a declaration by the manufacturer of the oil mist detector of its:

- Performance, in mg/L;
- Accuracy, of oil mist concentration in air;
- Precision, of oil mist concentration in air;
- Range, of oil mist detector;
- Resolution, of oil mist detector;
- Response time, of oil mist detector;
- Sensitivity, of oil mist detector;
- Obscuration of sensor detection, declared as percentage of obscuration. 0% totally clean, 100% totally obscure;
- Detector failure alarm;

12. Acceptance

12.1 Acceptance of crankcase oil mist detection equipment is at the discretion of individual classification societies based on the appraisal plans and particulars and the test house report of the results of type testing.

12.2 The following information is to be submitted to classification societies for acceptance of oil mist detection equipment and alarm arrangements:

12.2.1 Description of oil mist detection equipment and system including alarms.

12.2.2 Copy of the test house report identified in 11.

12.2.3 Schematic layout of engine oil mist detection arrangements showing location of detectors/sensors and piping arrangements and dimensions.

12.2.4 Maintenance and test manual which is to include the following information:

(a) Intended use of equipment and its operation.

(b) Functionality tests to demonstrate that the equipment is operational and that any faults can be identified and corrective actions notified.

(c) Maintenance routines and spare parts recommendations.

(d) Limit setting and instructions for safe limit levels.

(e) Where necessary, details of configurations in which the equipment is and is not to be used.

TL- R M71 Type Testing of I.C. Engines

1. General

1.1 Type approval of I.C. engine types consists of drawing approval, specification approval, conformity of production, approval of type testing programme, type testing of engines, review of the obtained results, and the issuance of the Type Approval Certificate. The maximum period of validity of a Type Approval Certificate is 5 years. The requirements for drawing approval and specification approval of engines and components are specified in separate URs.

1.2 For the purpose of this requirement, the following definitions apply:

Low-Speed Engines means diesel engines having a rated speed of less than 300 rpm.

Medium-Speed Engines means diesel engines having a rated speed of 300 rpm and above, but less than 1400 rpm.

High-Speed Engines means diesel engines having a rated speed of 1400 rpm or above.

2. Objectives

2.1 The type testing, documented in this requirement is to be arranged to represent typical foreseen service load profiles, as specified by the engine builder, as well as to cover for required margins due to fatigue scatter and reasonably foreseen in-service deterioration.

2.2 This applies to:

- Parts subjected to high cycle fatigue (HCF) 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.

- Parts subjected to low cycle fatigue (LCF) such as “hot” parts when load profiles such as idle - full load - idle (with steep ramps) are frequently used.

- Operation of the engine at limits as defined by its specified alarm system, such as running at maximum permissible power with the lowest permissible oil pressure and/or highest permissible oil inlet temperature.

Notes:

1. This requirement is implemented for engines for which the date of application for type approval certification is dated on or after 1 July 2016.

2. The “date of application for type approval” is the date of the document accepted by TL as request for type approval certification of a new engine type or of an engine type that has undergone substantive modifications in respect of the one previously type approved, or for renewal of an expired type approval certificate.

3. Validity

3.1 Type testing is required for every new engine type intended for installation onboard ships subject to classification.

3.2 A type test carried out for a particular type of engine at any place of manufacture will be accepted for all engines of the same type built by licensees or the licensor, subject to each place of manufacture being found to be acceptable to TL.

3.3 A type of engine is defined by:

- bore and stroke
- injection method (direct or indirect)
- valve and injection operation (by cams or electronically controlled)
- kind of fuel (liquid, dual-fuel, gaseous)
- working cycle (4-stroke, 2-stroke)
- turbo-charging system (pulsating or constant pressure)
- the charging air cooling system (e.g. with or without intercooler)
- cylinder arrangement (in-line or V) [1)]
- cylinder power, speed and cylinder pressures [2)]

Notes:

1) One type test will be considered adequate to cover a range of different numbers of cylinders. However, a type test of an in-line engine may not always cover the V-version. Subject to TL's discretion, separate type tests may be required for the V-version. On the other hand, a type test of a V-engine covers the in-line engines, unless the bmep is higher.

Items such as axial crankshaft vibration, torsional vibration in camshaft drives, and crankshafts, etc. may vary considerably with the number of cylinders and may influence the choice of engine to be selected for type testing.

2) The engine is type approved up to the tested ratings and pressures (100% corresponding to MCR).

Provided documentary evidence of successful service experience with the classified rating of 100% is submitted, an increase (if design approved*) may be permitted without a new type test if the increase from the type tested engine is within:

- 5% of the maximum combustion pressure, or
- 5% of the mean effective pressure, or
- 5% of the rpm

Providing maximum power is not increased by more than 10%, an increase of maximum approved power may be permitted without a new type test provided engineering analysis and evidence of successful service experience in similar field applications (even if the application is not classified) or documentation of internal testing are submitted if the increase from the type tested engine is within:

- 10% of the maximum combustion pressure, or
- 10% of the mean effective pressure, or
- 10% of the rpm

* Only crankshaft calculation and crankshaft drawings, if modified.

De-rated engine

If an engine has been design approved, and internal testing per Stage A is documented to a rating higher than the one type tested, the Type Approval may be extended to the increased power/mep/rpm upon submission of an Extended Delivery Test Report at:

- Test at over speed (only if nominal speed has increased)
- Rated power, i.e. 100% output at 100% torque and 100% speed corresponding to load point 1., 2 measurements with one running hour in between
- Maximum permissible torque (normally 110%) at 100% speed corresponding to load point 3 or maximum permissible power (normally 110%) and speed according to nominal propeller curve corresponding to load point 3a., ½ hour
- 100% power at maximum permissible speed corresponding to load point 2, ½ hour

Integration Test

An integration test demonstrating that the response of the complete mechanical, hydraulic and electronic system is as predicted maybe carried out for acceptance of sub-systems (Turbo Charger, Engine Control System, Dual Fuel, Exhaust Gas treatment…) separately approved. The scope of these tests shall be proposed by the designer/licensor taking into account of impact on engine.

4. Safety precautions

4.1 Before any test run is carried out, all relevant equipment for the safety of attending personnel is to be made available by the manufacturer/shipyard and is to be operational, and its correct functioning is to be verified.

4.2 This applies especially to crankcase explosive conditions protection, but also over-speed protection and any other shut down function.

4.3 The inspection for jacketing of high-pressure fuel oil lines and proper screening of pipe connections (as required in M71.8.9 fire measures) is also to be carried out before the test runs.

4.4 Interlock test of turning gear is to be performed when installed.

5. Test programme

5.1 The type testing is divided into 3 stages:

1. Stage A - internal tests.
This includes some of the testing made during the engine development, function testing, and collection of measured parameters and records of testing hours. The

results of testing required by TL or stipulated by the designer are to be presented to TL before starting stage B.

2. Stage B - witnessed tests.
This is the testing made in the presence of TL personnel.

3. Stage C - component inspection.
This is the inspection of engine parts to the extent as required by TL.

5.2 The complete type testing program is subject to approval by TL. The extent the Surveyor's attendance is to be agreed in each case, but at least during stage B and C.

5.3 Testing prior to the witnessed type testing (stage B and C), is also considered as a part of the complete type testing program.

5.4 Upon completion of complete type testing (stage A through C), a type test report is to be submitted to TL for review. The type test report is to contain:

- overall description of tests performed during stage A. Records are to be kept by the builders QA management for presentation to TL.

- detailed description of the load and functional tests conducted during stage B.

- inspection results from stage C.

5.5 As required in M71.2 the type testing is to substantiate the capability of the design and its suitability for the intended operation. Special testing such as LCF and endurance testing will normally be conducted during stage A.

5.6 High speed engines for marine use are normally to be subjected to an endurance test of 100 hours at full load. Omission or simplification of the type test may be considered for the type approval of engines with long service experience from non-marine fields or for the extension of type approval of engines of a well-known type, in excess of the limits given in M71.3.

Propulsion engines for high speed vessels that may be used for frequent load changes from idle to full are normally to be tested with at least 500 cycles (idle - full load - idle) using the steepest load ramp that the control system (or operation manual if not automatically controlled) permits. The duration at each end is to be sufficient for reaching stable temperatures of the hot parts.

6. Measurements and recordings

6.1 During all testing the ambient conditions (air temperature, air pressure and humidity) are to be recorded.

6.2 As a minimum, the following engine data are to be measured and recorded:

- Engine r.p.m.

- Torque

- Maximum combustion pressure for each cylinder [1)]

- Mean indicated pressure for each cylinder [1)]

- Charging air pressure and temperature
- Exhaust gas temperature
- Fuel rack position or similar parameter related to engine load
- Turbocharger speed
- All engine parameters that are required for control and monitoring for the intended use (propulsion, auxiliary, emergency).

Notes:

[1] For engines where the standard production cylinder heads are not designed for such measurements, a special cylinder head made for this purpose may be used. In such a case, the measurements may be carried out as part of Stage A and are to be properly documented. Where deemed necessary e.g. for dual fuel engines, the measurement of maximum combustion pressure and mean indicated pressure may be carried out by indirect means, provided the reliability of the method is documented.

Calibration records for the instrumentation used to collect data as listed above are to be presented to - and reviewed by the attending Surveyor.

Additional measurements may be required in connection with the design assessment.

7. Stage A - internal tests

7.1 During the internal tests, the engine is to be operated at the load points important for the engine designer and the pertaining operating values are to be recorded. The load conditions to be tested are also to include the testing specified in the applicable type approval programme.

7.2 At least the following conditions are to be tested:

- Normal case:

  The load points 25%, 50%, 75%, 100% and 110% of the maximum rated power for continuous operation, to be made along the normal (theoretical) propeller curve and at constant speed for propulsion engines (if applicable mode of operation i.e. driving controllable pitch propellers), and at constant speed for engines intended for generator sets including a test at no load and rated speed.

- The limit points of the permissible operating range. These limit points are to be defined by the engine manufacturer.
- For high speed engines, the 100 hr full load test and the low cycle fatigue test apply as required in connection with the design assessment.
- Specific tests of parts of the engine, required by TL or stipulated by the designer.

8. Stage B - witnessed tests

8.1 The tests listed below are to be carried out in the presence of a Surveyor. The achieved results are to be recorded and signed by the attending Surveyor after the type test is completed.

8.2 The over-speed test is to be carried out and is to demonstrate that the engine is not damaged by an actual engine overspeed within the overspeed shutdown system set-point. This test may be carried out at the manufacturer's choice either with or without load during the speed overshoot.

8.3 Load points

The engine is to be operated according to the power and speed diagram (see Figure 1). The data to be measured and recorded when testing the engine at the various load points have to include all engine parameters listed in M71.6. 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 hour can be assumed per load point, however sufficient time should be allowed for visual inspection by the Surveyor.

8.4 The load points are:

- Rated power (MCR), i.e. 100% output at 100% torque and 100% speed corresponding to load point 1, normally for 2 hours with data collection with an interval of 1 hour. If operation of the engine at limits as defined by its specified alarm system (e.g. at alarm levels of lub oil pressure and inlet temperature) is required, the test should be made here.

- 100% power at maximum permissible speed corresponding to load point 2.

- Maximum permissible torque (at least and normally 110%) at 100% speed corresponding to load at point 3, or maximum permissible power (at least and normally 110%) and 103.2% speed according to the 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) is to be replaced with a load that corresponds to the specified overload and duration 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 has to 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. (Applicable to propulsion engines only).

- Part loads e.g. 75%, 50% and 25% of rated power and speed according to nominal propeller curve (i.e. 90.8%, 79.3% and 62.9% speed) corresponding to points 6, 7 and 8 or at constant rated speed setting corresponding to points 9, 10 and 11, depending on the intended application of the engine.

- Crosshead engines not restricted for use with C.P. propellers are to be tested with no load at the associated maximum permissible engine speed.

8.5 During all these load points, engine parameters are to be within the specified and approved values.

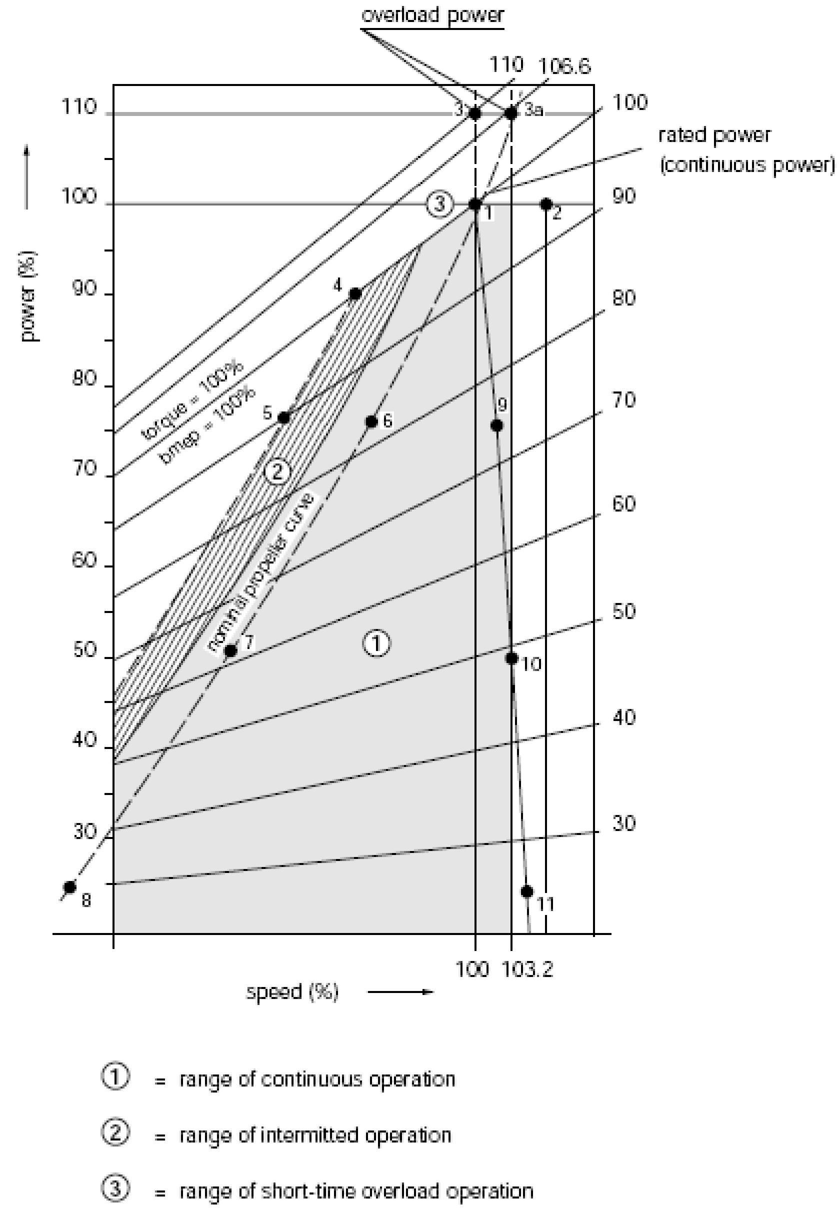


Figure 1 Load points

8.6 Operation with damaged turbocharger

For 2-stroke propulsion engines, the achievable continuous output is to be determined in the case of turbocharger damage.

Engines intended for single propulsion with a fixed pitch propeller are to be able to run continuously at a speed (r.p.m.) of 40% of full speed along the theoretical propeller curve when one turbocharger is out of operation. (The test can be performed by either by-passing the turbocharger, fixing the turbocharger rotor shaft or removing the rotor.)

8.7 Functional tests

- Verification of the lowest specified propulsion engine speed according to the nominal propeller curve as specified by the engine designer (even though it works on a water-brake). During this operation, no alarm shall occur.

- Starting tests, for non-reversible engines and/or starting and reversing tests, for reversible engines, for the purpose of determining the minimum air pressure and the consumption for a start.

- Governor tests: tests for compliance with TL- R M3.1 and M3.2 are to be carried out.

8.8 Integration test

For electronically controlled diesel engines, integration tests are to verify that the response of the complete mechanical, hydraulic and electronic system is as predicted for all intended operational modes. The scope of these tests is to be agreed with TL for selected cases based on the FMEA required in TL- R M44.

8.9 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 is to be inspected for jacketing of high-pressure fuel oil lines, including the system for the detection of leakage, and proper screening of pipe connections in piping containing flammable liquids.

- Proper insulation of hot surfaces is to be verified while running the engine at 100% load, alternatively at the overload approved for intermittent use. Readings of surface temperatures are to be done by use of Infrared Thermoscanning Equipment. Equivalent measurement equipment may be used when so approved by TL. Readings obtained are to be randomly verified by use of contact thermometers.

9. Stage C - Opening up for Inspections

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

9.2 High speed engines for marine use are normally to be stripped down for a complete inspection after the type test.

9.3 For all the other engines, after the test run the components of one cylinder for in-line engines and two cylinders for V-engines are to be presented for inspection as follows (engines with long service experience from non-marine fields can have a reduced extent of opening):

- piston removed and dismantled

- crosshead bearing dismantled

- guide planes

- connecting rod bearings (big and small end) dismantled (special attention to serrations and fretting on contact surfaces with the bearing backsides)

- main bearing dismantled

- cylinder liner in the installed condition

- cylinder head, valves disassembled

- cam drive gear or chain, camshaft and crankcase with opened covers. (The engine must be turnable by turning gear for this inspection.)

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

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

TL-R M72 Certification of Engine Components

1. General

1.1 The engine manufacturer is to have a quality control system that is suitable for the actual engine types to be certified by the Society. The quality control system is also to apply to any sub-suppliers. The Society reserves the right to review the system or parts thereof. Materials and components are to be produced in compliance with all the applicable production and quality instructions specified by the engine manufacturer. The Society requires that certain parts are verified and documented by means of Society Certificate (SC), Work Certificate (W) or Test Report (TR).

1.2 Society Certificate (SC)

This is a document issued by the Society stating:

- conformity with Rule requirements.
- that the tests and inspections have been carried out on the certified product itself, or on samples taken from the certified product itself.
- that the inspection and tests were performed in the presence of the Surveyor or in accordance with special agreements, i.e. ACS.

1.3 Work’s Certificate (W)

This is a document signed by the manufacturer stating:

- conformity with requirements.
- that the tests and inspections have been carried out on the certified product itself, or on samples taken from the raw material, used for the product to be certified.
- that the tests were witnessed and signed by a qualified representative of the applicable department of the manufacturer.

A Work’s Certificate may be considered equivalent to a Society Certificate and endorsed by the Society under the following cases:

- the test was witnessed by the Society Surveyor; or
- an Alternative Certification Scheme (ACS) agreement is in place between the Class Society and the manufacturer or material supplier; or
- the Work’s certificate is supported by tests carried out by an accredited third party that is accepted by the Society and independent from the manufacturer and/or material supplier.

Note:

1. This requirement is implemented to engines with an application for certification dated on or after 1 July 2017.

1.4 Test Report (TR)

This is a document signed by the manufacturer stating:

- conformity with requirements.
- that the tests and inspections have been carried out on samples from the current production.

1.5 The documents above are used for product documentation as well as for documentation of single inspections such as crack detection, dimensional check, etc. If agreed to by the Society, the documentation of single tests and inspections may also be arranged by filling in results on a control sheet following the component through the production.

1.6 The Surveyor is to review the TR and W for compliance with the agreed or approved specifications. SC means that the Surveyor also witnesses the testing, batch or individual, unless an ACS provides other arrangements.

1.7 The manufacturer is not exempted from responsibility for any relevant tests and inspections of those parts for which documentation is not explicitly requested by the Society. Manufacturing works is to be equipped in such a way that all materials and components can be consistently produced to the required standard. This includes production and assembly lines, machining units, special tools and devices, assembly and testing rigs as well as all lifting and transportation devices.

2. Parts to be documented

2.1 The extent of parts to be documented depends on the type of engine, engine size and criticality of the part.

2.2 Symbols used are listed in Table M72.1. A summary of the required documentation for the engine components is listed in Table M72.2.

M72.1 Symbols used in Table M72.2

Symbol	Description
C	chemical composition
CD	crack detection by MPI or DP
CH	crosshead engines
D	cylinder bore diameter (mm)
GJL	gray cast iron
GJS	spheroidal graphite cast iron
GS	cast steel
M	mechanical properties
SC	society certificate
TR	test report
UT	ultrasonic testing
W	work certificate
X	visual examination of accessible surfaces by the Surveyor

2.3 For components and materials not specified in Table M72.2, consideration will be given by the Society upon full details being submitted and reviewed.

M72.2 Summary of required documentation for engine components

Part [4), 5), 6), 7)]	Material properties [1)]	Non-destructive examination [2)]	Hydraulic testing [3)]	Dimensional inspection, including surface condition	Visual inspection (surveyor)	Applicable to engines:	Component certificate
Welded bedplate	W(C+M)	W(UT+CD)			fit-up + post-welding	All	SC
Bearing transverse girders GS	W(C+M)	W(UT+CD)			X	All	SC
Welded frame box	W(C+M)	W(UT+CD)			fit-up + post-welding	All	SC
Cylinder block GJL			W[9)]			CH	
Cylinder block GJS			W[9)]			CH	
Welded cylinder frames	W(C+M)	W(UT+CD)			fit-up + post-welding	CH	SC
Engine block GJL			W[9)]			>400 kW/cyl	
Engine block GJS	W(M)		W[9)]			>400 kW/cyl	
Cylinder liner	W(C+M)		W[9)]			D>300mm	
Cylinder head GJL			W			D>300mm	
Cylinder head GJS			W			D>300mm	
Cylinder head GS	W(C+M)	W(UT+CD)	W		X	D>300mm	SC
Forged cylinder head	W(C+M)	W(UT+CD)	W		X	D>300mm	SC
Piston crown GS	W(C+M)	W(UT+CD)			X	D>400mm	SC
Forged piston crown	W(C+M)	W(UT+CD)			X	D>400mm	SC
Crankshaft: made in one piece	SC(C+M)	W(UT+CD)		W	Random, of fillets and oil bores	All	SC
Semi-built crankshaft	See below	See below		See below	See below	All	SC
Crank throw	SC(C+M)	W(UT+CD)		W	Random, of fillets and shrink fittings	All	
Forged main journal and journals with flange	SC(C+M)	W(UT+CD)		W	Random, of shrink fittings	All	

M72.2 Summary of required documentation for engine components (continued)

Part [4), 5), 6), 7)]	Material properties [1)]	Non-destructive examination [2)]	Hydraulic testing [3)]	Dimensional inspection, including surface condition	Visual inspection (surveyor)	Applicable to engines:	Component certificate
Exhaust gas valve cage			W			CH	
Piston rod, if applicable	SC(C+M)	W(UT+CD) CD again after final machining (grinding)			Random	D>400mm	SC
Cross head	SC(C+M)	W(UT+CD) CD again after final machining (grinding and polishing)			Random	CH	SC
Connecting rod with cap	SC(C+M)	W(UT+CD)		W	Random, of all surfaces, in particular those shot peened	All	SC
Coupling bolts for crankshaft	SC(C+M)	W(UT+CD)		W	Random, of interference fit	All	SC
Bolts and studs for main bearings	W(C+M)	W(UT+CD)				D>300mm	
Bolts and studs for cylinder heads	W(C+M)	W(UT+CD)				D>300mm	
Bolts and studs for connecting rods	W(C+M)	W(UT+CD)		TR of thread making		D>300mm	
Tie rod	W(C+M)	W(UT+CD)		TR of thread making	Random	CH	SC
High pressure fuel injection pump body			W			D>300mm	
			TR			D≤300mm	
High pressure fuel injection valves (only for those not autofretted)			W			D>300mm	
			TR			D≤300mm	

M72.2 Summary of required documentation for engine components (continued)

Part 4), 5), 6), 7)	Material properties 1)	Non-destructive examination 2)	Hydraulic testing 3)	Dimensional inspection, including surface condition	Visual inspection (surveyor)	Applicable to engines:	Component certificate
High pressure fuel injection pipes including common fuel rail	W(C+M)		W for those that are not autofretted			D>300mm	
			TR for those that are not autofretted			D≤300mm	
High pressure common servo oil system	W(C+M)		W			D>300mm	
			TR			D≤300mm	
Cooler, both sides 8)	W(C+M)		W			D>300mm	
Accumulator of common rail fuel or servo oil system	W(C+M)		W			All engines with accumulators with a capacity of >0,5 l	
Piping, pumps, actuators, etc. for hydraulic drive of valves, if applicable	W(C+M)		W			>800 kW/cyl	
Engine driven pumps (oil, water, fuel, bilge)			W			>800 kW/cyl	
Bearings for main, crosshead, and crankpin	TR(C)	TR (UT for full contact between basic material and bearing metal)		W		>800 kW/cyl	

FOOTNOTES:

1. Material properties include chemical composition and mechanical properties, and also surface treatment such as surface hardening (hardness, depth and extent), peening and rolling (extent and applied force).

2. Non-destructive examination means e.g. ultrasonic testing, crack detection by MPI or DP.

3. Hydraulic testing is applied on the water/oil side of the component. Items are to be tested by hydraulic pressure at the pressure equal to 1.5 times the maximum working pressure. High pressure parts of the fuel injection system are to be tested by hydraulic pressure at the pressure equal to 1.5 maximum working pressure or maximum working pressure plus 300 bar, whichever is the less. Where design or testing features may require modification of these test requirements, special consideration may be given.

4. For turbochargers, see M73.

5. Crankcase safety valves are to be type tested in accordance with M66 and documented according to M9.

6. Oil mist detection systems are to be type tested in accordance with M67 and documented according to M10.

7. For Speed governor and overspeed protective devices, see M3.

8. Charge air coolers need only be tested on the water side.

9. Hydraulic testing is also required for those parts filled with cooling water and having the function of containing the water which is in contact with the cylinder or cylinder liner.

TL- R M73 Turbochargers

1. Scope

1.1 These requirements are applicable for turbochargers with regard to design approval, type testing and certification and their matching on engines.
Turbochargers are to be type approved, either separately or as a part of an engine. The requirements are written for exhaust gas driven turbochargers, but apply in principle also for engine driven chargers.

1.2 The requirements escalate with the size of the turbochargers. The parameter for size is the engine power (at MCR) supplied by a group of cylinders served by the actual turbocharger, (e.g. for a V-engine with one turbocharger for each bank the size is half of the total engine power).

1.3 Turbochargers are categorised in three groups depending on served power by cylinder groups with:

- Category A: ≤ 1000 kW
- Category B: > 1000 kW and ≤ 2500 kW
- Category C: > 2500 kW

2. Documentation to be submitted

2.1 Category A:

On request

- Containment test report.
- Cross sectional drawing with principal dimensions and names of components.
- Test program.

Notes:

1. This requirement, except for M73.4, is implemented to turbochargers with the date of application for certification of the new turbocharger type on or after 1 July 2016.

   The requirements of M73.4 are implemented to turbochargers with the date of application for certification of an individual turbocharger on or after 1 July 2016.

2. The “date of application for certification” is the date of whatever TL requires/accepts as an application or request for certification of a turbocharger.

2.2 Category B and C:

- Cross sectional drawing with principal dimensions and materials of housing components for containment evaluation.

- Documentation of containment in the event of disc fracture, see M73.3.2.

- Operational data and limitations as:

- Maximum permissible operating speed (rpm)

- Alarm level for over-speed

- Maximum permissible exhaust gas temperature before turbine

- Alarm level for exhaust gas temperature before turbine

- Minimum lubrication oil inlet pressure

- Lubrication oil inlet pressure low alarm set point

- Maximum lubrication oil outlet temperature

- Lubrication oil outlet temperature high alarm set point

- Maximum permissible vibration levels, i.e. self- and externally generated vibration

(Alarm levels may be equal to permissible limits but shall not be reached when operating the engine at 110% power or at any approved intermittent overload beyond the 110%.)

- Arrangement of lubrication system, all variants within a range.

- Type test reports.

- Test program.

2.3 Category C:

- Drawings of the housing and rotating parts including details of blade fixing.

- Material specifications (chemical composition and mechanical properties) of all parts mentioned above.

- Welding details and welding procedure of above mentioned parts, if applicable.

- Documentation*) of safe torque transmission when the disc is connected to the shaft by an interference fit, see M73.3.3.

- Information on expected lifespan, considering creep, low cycle fatigue and high cycle fatigue.

- Operation and maintenance manuals*).

*) Applicable to two sizes in a generic range of turbochargers.

3. Design requirements and corresponding type testing

3.1 General

3.1.1 The turbochargers shall be designed to operate under conditions given in M46 and M28. The component lifetime and the alarm level for speed shall be based on 45°C air inlet temperature.

3.1.2 The air inlet of turbochargers shall be fitted with a filter.

3.2 Containment

3.2.1 Turbochargers shall fulfil containment in the event of a rotor burst. This means that at a rotor burst no part may penetrate the casing of the turbocharger or escape through the air intake. For documentation purposes (test/calculation), it shall be assumed that the discs disintegrate in the worst possible way.

3.2.2 For category B and C, containment shall be documented by testing. Fulfilment of this requirement can be awarded to a generic range**) of turbochargers based on testing of one specific unit. Testing of a large unit is preferred as this is considered conservative for all smaller units in the generic range. In any case, it must be documented (e.g. by calculation) that the selected test unit really is representative for the whole generic range.

3.3.3 The minimum test speeds, relative to the maximum permissible operating speed, are:

- For the compressor: 120%.
- For the turbine: 140% or the natural burst speed, whichever is lower.

3.2.4 Containment tests shall be performed at working temperature.

3.2.5 A numerical analysis (simulation) of sufficient containment integrity of the casing based on calculations by means of a simulation model may be accepted in lieu of the practical containment test, provided that:

- The numerical simulation model has been tested and its suitability/accuracy has been proven by direct comparison between calculation results and the practical containment test for a reference application (reference containment test). This test shall be performed at least once by the manufacturer for acceptance of the numerical simulation method in lieu of tests.

- The corresponding numerical simulation for the containment is performed for the same speeds as specified for the containment test.

- Material properties for high-speed deformations are to be applied in the numeric simulation. The correlation between normal properties and the properties at the pertinent deformation speed are to be substantiated.

- The design of the turbocharger regarding geometry and kinematics is similar to the turbocharger that was used for the reference containment test. In general, totally new designs will call for a new reference containment test.

**) A generic range means a series of turbocharger which are of the same design, but scaled to each other.

3.3 Disc-shaft shrinkage fit

3.3.1 Applicable to Category C

3.3.2 In cases where the disc is connected to the shaft with interference fit, calculations shall substantiate safe torque transmission during all relevant operating conditions such as maximum speed, maximum torque and maximum temperature gradient combined with minimum shrinkage amount.

3.4 Type testing

3.4.1 Applicable to Categories B and C

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

3.4.3 Turbochargers are to be subjected to at least 500 load cycles at the limits of operation. This test may be waived if the turbocharger together with the engine is subjected to this kind of low cycle testing, see TL- R M71.

3.4.4 The suitability of the turbocharger for such kind of operation is to be preliminarily stated by the manufacturer.

3.4.5 The rotor vibration characteristics shall be measured and recorded in order to identify possible sub-synchronous vibrations and resonances.

3.4.6 The type test shall be completed by a hot running test at maximum permissible speed combined with maximum permissible temperature for at least one hour. After this test, the turbocharger shall be opened for examination, with focus on possible rubbing and the bearing conditions.

3.4.7 The extent of the surveyor’s presence during the various parts of the type tests is left to the discretion of TL.

4. Certification

4.1 The manufacturer shall adhere to a quality system designed to ensure that the designer’s specifications are met, and that manufacturing is in accordance with the approved drawings.

4.2 For category C, this shall be verified by means of periodic product audits of an Alternative Certification Scheme (ACS) by TL.

4.3 These audits shall focus on:

- Chemical composition of material for the rotating parts.
- Mechanical properties of the material of a representative specimen for the rotating parts and the casing.
- UT and crack detection of rotating parts.
- Dimensional inspection of rotating parts.
- Rotor balancing.

- Hydraulic testing of cooling spaces to 4 bars or 1.5 times maximum working pressure, whichever is higher.

- Overspeed test of all compressor wheels for a duration of 3 minutes at either 20% above alarm level speed at room temperature or 10% above alarm level speed at 45°C inlet temperature when tested in the actual housing with the corresponding pressure ratio. The overspeed test may be waived for forged wheels that are individually controlled by an approved non-destructive method.

4.4 Turbochargers shall be delivered with:

- For category C, TL certificate, which at a minimum cites the applicable type approval and the ACS, when ACS applies.

- For category B, a work's certificate, which at a minimum cites the applicable type approval, which includes production assessment.

4.5 The same applies to replacement of rotating parts and casing.

4.6 Alternatively to the above periodic product audits, individual certification of a turbocharger and its parts may be made at the discretion of TL. However, such individual certification of category C turbocharger and its parts shall also be based on test requirements specified in the above mentioned bullet points.

5. Alarms & Monitoring

5.1 For all turbochargers of Categories B and C, indications and alarms as listed in the table are required.

5.2 Indications may be provided at either local or remote locations.

Pos.	Monitored Parameters	Category of Turbochargers				Notes
		B		C		
		Alarm	Indication	Alarm	Indication	
1	Speed	High (4)	X (4)	High (4)	X (4)	
2	Exhaust gas at each turbocharger inlet, temperature	high (1)	X (1)	high	X	High temp. alarms for each cylinder at engine is acceptable (2)
3	Lub. oil at turbocharger outlet, temperature			high	X	If not forced system, oil temperature near bearings
4	Lub. oil at turbocharger inlet, pressure	low	X	low	X	Only for forced lubrication systems (3)

(1) For Category B turbochargers, the exhaust gas temperature may be alternatively monitored at the turbocharger outlet, provided that the alarm level is set to a safe level for the turbine and that correlation between inlet and outlet temperatures is substantiated.

(2) Alarm and indication of the exhaust gas temperature at turbocharger inlet may be waived if alarm and indication for individual exhaust gas temperature is provided for each cylinder and the alarm level is set to a value safe for the turbocharger.

(3) Separate sensors are to be provided if the lubrication oil system of the turbocharger is not integrated with the lubrication oil system of the diesel engine or if it is separated by a throttle or pressure reduction valve from the diesel engine lubrication oil system.

(4) On turbocharging systems where turbochargers are activated sequentially, speed monitoring is not required for the turbocharger(s) being activated last in the sequence, provided all turbochargers share the same intake air filter and they are not fitted with waste gates.

TL- R M78 Safety of Internal Combustion Engines Supplied with Low Pressure Gas

1 General

1.1 Scope

1.1.1 Type of engines

This requirement addresses the requirements for trunk piston internal combustion engines supplied with low pressure natural gas as fuel. This requirement is to be applied in association with other relevant TL internal combustion engine R's, as far as found applicable to the specific natural gas burning engine design.

The mandatory international codes for gas carriers (IGC Code) and for other ships burning low flashpoint fuels (IGF Code) must also be considered, as applicable.

Specific requirements of the IGF Code as referenced in this UR shall be applied to engine types covered by this requirement installed on any ship, regardless of type, size and trading area, as long as the IGC Code is not referenced or explicitly specified otherwise. Engines can be either dual fuel engines (hereinafter referred to as DF engines) or gas fuel only engines
(hereinafter referred to as GF engines).

Note:

1. This requirement is implemented for engines for which the date of an application for type approval certification is dated on or after 1 July 2019.

2. The "date of an application for type approval" is the date of documents accepted by TL as request for type approval certification of a new engine type or of an engine type that has undergone substantive modifications, as defined in TL- R M44, in respect of the one previously type approved, or for renewal of an expired type approval certificate.

3. Engines with an existing type approval on 1 July 2019 are not required to be re-type approved in accordance with this requirement until the current Type Approval becomes invalid. For the purpose of certification of these engines, the current type approval and related submitted documentation will be accepted in place of that required by this requirement until the current type approval expires or the engine type has undergone substantive modifications, as defined in TL- R M44.

Gas can be introduced as follows:

- into the air inlet manifold, scavenge space, or cylinder air inlet channel port; or
- mixed with air before the turbo-charger ("pre-mixed engines").

The gas / air mixture in the cylinder can be ignited by the combustion of a certain amount of fuel (pilot injection) or by extraneous ignition (sparking plug).

The scope of the UR is limited to natural gas fuelled engines

1.1.2 Applications

This UR covers the following applications, but is not limited to:

- Mechanical propulsion
- Generating sets intended for main propulsion and auxiliary applications.
- Single engine or multi-engine installations

1.2 Definitions

1.2.1 *Certified safe type* means electrical equipment that is certified in accordance with the recommendation published by the International Electrotechnical Commission (IEC), in particular publication IEC 60092-502:1999, or with recognized standards at least equivalent. The certification of electrical equipment is to correspond to the category and group for methane gas.

1.2.2 *Double block and bleed valves* means the set of valves referred to in:

- IGC Code, 16.4.5
- IGF Code, 2.2.9 and 9.4.4 to 9.4.6

1.2.3 Dual fuel engine ("DF engine") means an engine that can burn natural gas as fuel simultaneously with liquid fuel, either as pilot oil or bigger amount of liquid fuel (gas mode), and also has the capability of running on liquid diesel fuel oil only (Diesel mode).

1.2.4 Engine room is a machinery space or enclosure containing gas fuelled engine(s).

1.2.5 Gas means a fluid having a vapour pressure exceeding 2.8 bar absolute at a temperature of 37.8^{o}C.

1.2.6 Gas admission valve is a valve or injector on the engine, which controls gas supply to the cylinder(s) according to the cylinder(s) actual gas demand.

1.2.7 Gas engine means either a DF engine or a GF engine.

1.2.8 Gas fuel only engine ("GF engine") means an engine capable of operating on gas fuel only and not able to switch over to oil fuel operation.

1.2.9 Gas piping means piping containing gas or air / gas mixtures, including venting pipes.

1.2.10 Gas Valve Unit (GVU) is a set of manual shutoff valves, actuated shut-off and venting valves, gas pressure sensors and transmitters, gas temperature sensors and transmitters, gas pressure control valve and gas filter used to control the gas supply to each gas consumer. It also includes a connection for inert gas purging.

1.2.11 IGC Code means the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (as amended by IMO Resolution MSC.370(93)).

1.2.12 IMO means the International Maritime Organisation

1.2.13 IGF Code means the International Code of Safety for Ships Using Gases or other Low-Flashpoint Fuels (IMO Resolution MSC.391(95)).

1.2.14 Low pressure gas means gas with a pressure up to 10 bar

1.2.15 Lower Heating Value ("LHV") means the amount of heat produced from the complete combustion of a specific amount of fuel, excluding latent heat of vaporization of water.

1.2.16 Methane Number is a measure of resistance of a gas fuel to knock, which is assigned to a test fuel based upon operation in knock testing unit at the same standard knock intensity.

Note: Pure methane is used as the knock resistant reference fuel, that is, methane number of pure methane is 100, and pure hydrogen is used as the knock sensitive reference fuel, methane number of pure hydrogen is 0.

1.2.17 Pilot fuel means the fuel oil that is injected into the cylinder to ignite the main gas-air mixture on DF engines.

1.2.18 Pre-mixed engine means an engine where gas is supplied in a mixture with air before the turbocharger.

1.2.19 Recognized standards means applicable international or national standards acceptable to TL or standards laid down and maintained by an organisation which complies with the standards adopted by IMO and which are recognized by TL.

1.2.20 Safety Concept is a document describing the safety philosophy with regard to gas as fuel. It describes how risks associated with this type of fuel are controlled under reasonably foreseeable abnormal conditions as well as possible failure scenarios and their control measures.

Note: A detailed evaluation regarding the hazard potential of injury from a possible explosion is to be carried out and reflected in the safety concept of the engine.

1.3 Documents and drawings to be submitted

1.3.1 Documents and drawings to be submitted for the approval of DF and GF engines

The following documents are to be submitted for the approval of DF and GF engines, in addition to those required in TL- R M44.

No.	Item
1	Schematic layout or other equivalent documents of gas system on the engine
2	Gas piping system (including double-walled arrangement where applicable)
3	Parts for gas admission system[3)]
4	Arrangement of explosion relief valves (crankcase[1)], charge air manifold, exhaust gas manifold) as applicable
5	List of certified safe equipment and evidence of relevant certification
6	Safety concept (for information)
7	Report of the risk analysis[2)] (for information)
8	Gas specification (for information)

1.3.2 Documents and drawings to be submitted for the approval of DF engine

No.	Item
9	Schematic layout or other equivalent documents of fuel oil system (main and pilot fuel systems) on the engine
10	Shielding of high pressure fuel pipes for pilot fuel system, assembly
11	High pressure parts for pilot fuel oil injection system[3)]

1.3.3 Documents and drawings to be submitted for the approval of GF engine

No.	Item
12	Ignition system

1.3.4 Where considered necessary, TL may request further documents to be submitted.

Footnotes:
1) If required by TL- R M44.
2) See 1.4.
3) The documentation to contain specification of pressures, pipe dimensions and materials.

1.4 Risk analysis

1.4.1 Scope of the risk analysis

The risk analysis is to address:

- a failure or malfunction of any system or component involved in the gas operation of the engine
- a gas leakage downstream of the gas valve unit
- the safety of the engine in case of emergency shutdown or blackout, when running on gas
- the inter-actions between the gas fuel system and the engine.

Note: With regard to the scope of the risk analysis it shall be noted that failures in systems external to the engine, such as fuel storage or fuel gas supply systems, may require action from the engine control and monitoring system in the event of an alarm or fault condition. Conversely failures in these external systems may, from the vessel perspective, require additional safety actions from those required by the engine limited risk analysis required by this UR.

1.4.2 Form of the risk analysis

The risk analysis is to be carried out in accordance with international standard ISO 31010:2009: Risk management - Risk assessment techniques, or other recognized standards.

The required analysis is to be based on the single failure concept, which means that only one failure needs to be considered at the same time. Both detectable and non-detectable failures are to be considered. Consequences failures, i.e. failures of any component directly caused by a single failure of another component, are also to be considered.

1.4.3 Procedure for the risk analysis

The risk analysis is to:

a) Identify all the possible failures in the concerned equipment and systems which could lead:

    1) to the presence of gas in components or locations not designed for such purpose, and/or

    2) to ignition, fire or explosion.

b) Evaluate the consequences

c) Where necessary, identify the failure detection method

d) Where the risk cannot be eliminated, identify the corrective measures:

    1) in the system design, such as:

    - redundancies

- safety devices, monitoring or alarm provisions which permit restricted operation of the system

2) in the system operation, such as:

- initiation of the redundancy

- activation of an alternative mode of operation.

The results of the risk analysis are to be documented.

1.4.4 Equipment and systems to be analysed

The risk analysis required for engines is to cover at least the following aspects:

a) failure of the gas-related systems or components, in particular:

- gas piping and its enclosure, where provided

- cylinder gas supply valves

Note: Failures of the gas supply components not located directly on the engine, such as block-and-bleed valves and other components of the Gas Valve Unit (GVU), are not to be considered in the analysis.

b) failure of the ignition system (oil fuel pilot injection or sparking plugs)

c) failure of the air to fuel ratio control system (charge air by-pass, gas pressure control valve, etc.)

d) for engines where gas is injected upstream of the turbocharger compressor, failure of a component likely to result in a source of ignition (hot spots)

e) failure of the gas combustion or abnormal combustion (misfiring, knocking)

f) failure of the engine monitoring, control and safety systems

Note: Where engines incorporate electronic control systems, a failure mode and effects analysis (FMEA) is to be carried out in accordance with TL- R M44, Table 1, Footnote 5.

g) abnormal presence of gas in engine components (e.g. air inlet manifold and exhaust manifold of DF or GF engines) and in the external systems connected to the engines (e.g. exhaust duct).

h) changes of operating modes for DF engines

i) hazard potential for crankcase fuel gas accumulation, for engines where the space below the piston is in direct communication with the crankcase, refer to IGF Code 10.3.1.2

2. Design Requirements

2.1 General Principles

2.1.1 The manufacturer is to declare the allowable gas composition limits for the engine and the minimum and (if applicable) maximum methane number.

2.1.2 Components containing or likely to contain gas are to be designed to:

a) minimise the risk of fire and explosion so as to demonstrate an appropriate level of safety commensurate with that of an oil-fuelled engine;

b) mitigate the consequences of a possible explosion to a level providing a tolerable degree of residual risk, due to the strength of the component(s) or the fitting of suitable pressure relief devices of an approved type.

Also refer to the IGF Code 10.2 and 10.3.

Note:

1. Discharge from pressure relief devices shall prevent the passage of flame to the machinery space and be arranged such that the discharge does not endanger personnel or damage other engine components or systems”

2. Relief devices shall be fitted with a flame arrester.

2.2 Design Requirements

2.2.1 Gas piping

2.2.1.1 General

The requirements of this section apply to engine-mounted gas piping. The piping shall be designed in accordance with the criteria for gas piping (design pressure, wall thickness, materials, piping fabrication and joining details etc.) as given in the IGF Code chapter 7. For gas carriers, IGC Code chapter 5.1 to 5.9 and 16 applies.

2.2.2 Arrangement of the gas piping system on the engine

Pipes and equipment containing fuel gas are defined as hazardous area Zone 0 (refer to IGF Code 12.5.1).

The space between the gas fuel piping and the wall of the outer pipe or duct is defined as hazardous area Zone 1 (refer to IGF Code 12.5.2.6)

2.2.2.1 Normal “double wall” arrangement

The gas piping system on the engine shall be arranged according to the principles and requirements of the IGF Code 9.6. For gas carriers, IGC Code 16.4.3 applies.

The design criteria for the double pipe or duct are given in the IGF Code 9.8 and 7.4.1.4.

In case of a ventilated double wall, the ventilation inlet is to be located in accordance with the provisions of IGF Code, regulation 13.8.3. For gas carriers, IGC Code 16.4.3.2 applies.

The pipe or duct is to be pressure tested in accordance with TL- R P2.8.1 to ensure gas tight integrity and to show that it can withstand the expected maximum pressure at gas pipe rupture.

2.2.2.2 Alternative arrangement

Single walled gas piping is only acceptable:

a) for engines installed in ESD protected machinery spaces, as defined in IGF Code 5.4.1.2 and in compliance with other relevant parts of the IGF Code (e.g. 5.6);

b) in the case as per footnote 18 to paragraph 9.6.2 of IGF Code.

For gas carriers, the IGC Code applies.

In case of gas leakage in an ESD-protected machinery space, which would result in the shut-down of the engine(s) in that space, a sufficient propulsion and manoeuvring capability including essential and safety systems is to be maintained.

Therefore the safety concept of the engine is to clearly indicate application of the “double wall” or “alternative” arrangement.

Note: The minimum power to be maintained is to be assessed on a case-by-case basis from the operational characteristics of the ship.

2.2.3 Charge air system on the engine

The charge air system on the engine is to be designed in accordance with 2.1.2 above.
In case of a single engine installation, the engine is to be capable of operating at sufficient load to maintain power to essential consumers after opening of the pressure relief devices caused by an explosion event. Sufficient power for propulsion capability is to be maintained.

Note: Load reduction is to be considered on a case by case basis, depending on engine configuration (single or multiple) and relief mechanism (self-closing valve or bursting disk).

2.2.4 Exhaust system on the engine

The exhaust gas system on the engine is to be designed in accordance with 2.1.2 above.

In case of a single engine installation, the engine is to be capable of operating at sufficient load to maintain power to essential consumers after opening of the pressure relief devices caused by an explosion event. Sufficient power for propulsion capability is to be maintained.

Continuous relief of exhaust gas (through open rupture disc) into the engine room or other enclosed spaces is not acceptable.

2.2.5 Engine crankcase

2.2.5.1 Crankcase explosion relief valves

Crankcase explosion relief valves are to be installed in accordance with TL- R M9. Refer also to IGF Code 10.3.1.2.

2.2.5.2 Inerting

For maintenance purposes, a connection, or other means, are to be provided for crankcase inerting and ventilating and gas concentration measuring.

2.2.6 Gas ignition in the cylinder

2.2.6.1 Requirements of IGF Code 10.3 apply. For gas carriers, IGC Code 16.7 applies.

2.2.7 Control, monitoring, alarm and safety systems

The engine control system is to be independent and separate from the safety system.

The gas supply valves are to be controlled by the engine control system or by the engine gas demand.

Combustion is to be monitored on an individual cylinder basis.

In the event that poor combustion is detected on an individual cylinder, gas operation may be allowed in the conditions specified in IGF Code 10.3.1.6.

If monitoring of combustion for each individual cylinder is not practicable due to engine size and design, common combustion monitoring may be accepted.

Unless the risk analysis required by 1.4 of this UR proves otherwise, the monitoring and safety system functions for DF or GF engines are to be provided in accordance with Table 1 of this requirement in addition to the general monitoring and safety system functions given by TL..

Note: For DF engines, Table 1 applies only to the gas mode.

2.2.8 Gas admission valves

Gas admission valves shall be certified safe as follows:

1) The inside of the valve contains gas and shall therefore be certified for Zone 0.

2) When the valve is located within a pipe or duct in accordance with 2.2.2.1, the outside of the valve shall be certified for Zone 1.

3) When the valve is arranged without enclosure in accordance with the “ESD-protected machinery space” (see 2.2.2.2) concept, no certification is required for the outside of the valve, provided that the valve is de-energized upon gas detection in the space.

However, if they are not rated for the zone they are intended for, it shall be documented that they are suitable for that zone. Documentation and analysis is to be based on IEC 60079-10-1 or IEC 60092-502.

TABLE 1: Monitoring and Safety System Functions for DF and GF Engines

Parameter	Alarm	Automatic activation of the double block-and-bleed valves	Automatic switching over to oil fuel mode[1)]	Engine shutdown
Abnormal pressures in the gas fuel supply line	X	X	X	X [5)]
Gas fuel supply systems - malfunction	X	X	X	X [5)]
Pilot fuel injection or spark ignition systems - malfunction	X	X [2)]	X	X [2)5)]
Exhaust gas temperature after each cylinder - high	X	X [2)]	X	X [2)5)]
Exhaust gas temperature after each cylinder, deviation from average – low [3)]	X	X [2)]	X	X [2)5)]
Cylinder pressure or ignition - failure, including misfiring, knocking and unstable combustion	X	X [2)4)]	X [4)]	X [2)4)5)]
Oil mist concentration in crankcase or bearing temperature [6)] - high	X	X		X
Pressure in the crankcase – high [4)]	X	X	X	
Engine stops - any cause	X	X		
Failure of the control-actuating medium of the block and bleed valves	X	X	X	

Footnotes:

1) DF engine only, when running in gas mode

2) For GF engines, the double block-and-bleed valves and the engine shutdown may not be activated in case of specific failures affecting only one cylinder, provided that the concerned cylinder can be individually shutoff and the safe operation of the engine in such conditions is demonstrated by the risk analysis.

3) Required only if necessary for the detection of misfiring

4) In the case where the failure can be corrected by an automatic mitigation action, only the alarm may be activated. If the failure persists after a given time, the safety actions are to be activated.

5) GF engine only

6) Where required by TL- R M10

3. Specific Design Requirements

3.1 DF Engines

3.1.1 General

The maximum continuous power that a DF engine can develop in gas mode may be lower than the approved MCR of the engine (i.e. in oil fuel mode), depending in particular on the gas quality.

This maximum power available in gas mode and the corresponding conditions shall be stated by the engine manufacturer and demonstrated during the type test.

3.1.2 Starting, changeover and stopping

DF engines are to be arranged to use either oil fuel or gas fuel for the main fuel charge and with pilot oil fuel for ignition. The engines are to be arranged for rapid changeover from gas use to fuel oil use. In the case of changeover to either fuel supply, the engines are to be capable of continuous operation using the alternative fuel supply without interruption to the power supply.

Changeover to gas fuel operation is to be only possible at a power level and under conditions where it can be done with acceptable reliability and safety as demonstrated through testing.

Changeover from gas fuel operation mode to oil fuel operation mode is to be possible at all situations and power levels.

The changeover process itself from and to gas operation is to be automatic but manual interruption is to be possible in all cases.

In case of shut-off of the gas supply, the engines are to be capable of continuous operation by oil fuel only.

3.1.3 Pilot injection

Gas supply to the combustion chamber is not to be possible without operation of the pilot oil injection.

Note: Pilot injection is to be monitored for example by fuel oil pressure and combustion parameters.

3.2 GF Engines

3.2.1 Spark ignition system

In case of failure of the spark ignition, the engine is to be shut down except if this failure is limited to one cylinder, subject to immediate shut off of the cylinder gas supply and provided that the safe operation of the engine is substantiated by the risk analysis and by tests.

3.3 Pre-Mixed Engines

3.3.1 Charge air system

Inlet manifold, turbo-charger, charge air cooler, etc. are to be regarded as parts of the fuel gas supply system. Failures of those components likely to result in a gas leakage are to be considered in the risk analysis (see 1.4).

Flame arresters are to be installed before each cylinder head, unless otherwise justified in the risk analysis, considering design parameters of the engine such as the gas concentration in the charge air system, the path length of the gas-air mixture in the charge air system, etc.

4. Type Testing, Factory Acceptance Tests and Shipboard Trials

4.1 Type Testing

4.1.1 General

Type approval of DF and GF engines is to be carried out in accordance with TL- R M71, taking into account the additional requirements below.

4.1.2 Type of engine

In addition to the criteria given in TL- R M71.3.3 the type of engine is defined by the following:

- gas admission method (direct cylinder injection, charge air space or pre-mixed)
- gas supply valve operation (mechanical or electronically controlled)
- ignition system (pilot injection, spark ignition, glow plug or gas self-ignition)
- ignition system (mechanical or electronically controlled)

4.1.3 Safety precautions

In addition to the safety precautions mentioned in TL-R M71.4, measures to verify that gas fuel piping on engine is gas tight are to be carried out prior to start-up of the engine.

4.1.4 Test programme

The type testing of the engine is to be carried out in accordance with TL- R M71.5.

For DF engines, the load tests referred to in TL- R M71.5 are to be carried out in gas mode at the different percentages of the maximum power available in gas mode (see 3.1.1).

The 110% load tests are not required in the gas mode.

The influence of the methane number and LHV of the fuel gas is not required to be verified during the Stage B type tests. It shall however be justified by the engine designer through internal tests or calculations and documented in the type approval test report.

4.1.5 Measurements and records

In addition to the measurements and records required in TL-R M71.6, the following engine data are to be measured and recorded:

- Each fuel index for gas and diesel as applicable (or equivalent reading)
- Gas pressure and temperature at the inlet of the gas manifold
- Gas concentration in the crankcase

Additional measurements may be required in connection with the design assessment.

4.1.6 Stage A – internal tests

In addition to tests required in TL- R M71.7, the following conditions are to be tested:

- DF engines are to run the load points defined in TL-R M71.7 in both gas and diesel modes (with and without pilot injection in service) as found applicable for the engine type.
- For DF engines with variable liquid / gas ratio, the load tests are to be carried out at different ratios between the minimum and the maximum allowable values.
- For DF engines, switch over between gas and diesel modes are to be tested at different loads.

4.1.7 Stage B – witnessed tests

4.1.7.1 General

Gas engines are to undergo the different tests required in TL-R M71.8.

In case of DF engine, all load points must be run in both gas and diesel modes that apply for the engine type as defined by the engine designer (see 4.1.4). This also applies to the overspeed test.

In case of DF engines with variable liquid / gas ratio, the load tests are to be carried out at different ratios between the minimum and the maximum allowable values.

4.1.7.2 Functional tests

In addition to the functional tests required in TL- R M71.8.3, the following tests are to be carried out:

- For DF engines, the lowest specified speed is to be verified in diesel mode and gas mode.
- For DF engines, switch over between gas and diesel modes are to be tested at different loads.
- The efficiency of the ventilation arrangement of the double walled gas piping system is to be verified.
- Simulation of a gas leakage in way of a cylinder gas supply valve.

Engines intended to produce electrical power are to be tested as follows:

- Capability to take sudden load and loss of load in accordance with the provisions of TL- R M3.2.3
- For GF and premixed engines, the influences of LHV, methane number and ambient conditions on the dynamic load response test results are to be theoretically determined and specified in the test report. Referring to the limitations as specified in 2.1.2, the margin for satisfying dynamic load response is to be determined.

Note:

1. For DF engines, switchover to oil fuel during the test is acceptable.
2. Application of electrical load in more than 2 load steps can be permitted in the conditions stated in TL- R M3.2.3.

4.1.7.3 Integration Tests

GF and DF engines are to undergo integration tests to verify that the response of the complete mechanical, hydraulic and electronic engine system is as predicted for all intended operational modes. The scope of these tests is to be agreed with TL for selected cases based on the risk analysis required in 1.4 of this requirement, and shall at least include the following incidents:

- Failure of ignition (spark ignition or pilot injection systems), both for one cylinder unit and common system failure
- Failure of a cylinder gas supply valve
- Failure of the combustion (to be detected by e.g. misfiring, knocking, exhaust temperature deviation, etc.)
- Abnormal gas pressure
- Abnormal gas temperature[1)]

4.1.8 Stage C – Component inspection

Component inspection is to be carried out in accordance with the provisions of TL-R M71.9. The components to be inspected after the test run are to include also:

- gas supply valve including pre-chamber as found applicable
- spark igniter (for GF engines)
- pilot fuel injection valve (for DF engines)

Footnote:

1) This test may be carried out using a simulation signal of the temperature.

4.2 Factory Acceptance Test

4.2.1 General

Factory acceptance tests of DF and GF engines are to be carried out in accordance with UR M51, taking into account the additional requirements below.

For DF engines, the load tests referred to in TL- R M51.3.3 are to be carried out in gas mode at the different percentages of the maximum power available in gas mode (see 3.1.1). The 110% load test is not required in the gas mode.

4.2.2 Safety precautions

In addition to the safety precautions mentioned in TL- R M51.1, measures to verify that gas fuel piping on engine is gas tight are to be carried out prior to start-up of the engine.

4.2.3 Records

In addition to the records required in TL- R M51.3.2, the following engine data are to be recorded:

- Fuel index, both gas and diesel as applicable (or equivalent reading)
- Gas pressure and temperature

4.2.4 Test loads

Test loads for various engine applications are given in TL- R M51.3.3. DF engines are to be tested in both diesel and gas mode as found applicable. In addition the scope of the trials may be expanded depending on the engine application, service experience, or other relevant reasons.

4.2.5 Integration tests

GF and DF engines are to undergo integration tests to verify that the response of the complete mechanical, hydraulic and electronic system is as predicted for all intended operational modes.

The scope of these tests is to be agreed with TL for selected cases based on the risk analysis required in 1.4 of this requirement and shall at least include the following incidents:

- Failure of ignition (spark ignition or pilot injection systems), for one cylinder unit
- Failure of a cylinder gas supply valve
- Failure of the combustion (to be detected by e.g. misfiring, knocking, exhaust temperature deviation, etc.)
- Abnormal gas pressure
- Abnormal gas temperature

The above tests may be carried out using simulation or other alternative methods, subject to special consideration by TL.

4.3 Shipboard Trials

Shipboard trials are to be carried out in accordance with the provisions of TL-R M51.4.

For DF engines, the test loads required in TL- R M51.4.4 are to be carried out in all operating modes (gas mode, diesel mode, etc.).p