Engine Layout and Load Diagram

Engine Layout Diagram

An engine's layout diagram is limited by two constant mean effective pressure (mep) lines $L_1 - L_3$ and $L_2 - L_4$, and by two constant engine speed lines $L_1 - L_2$ and $L_3 - L_4$. The L_1 point refers to the engine's nominal maximum continuous rating, see Fig. 2.04.01.

Within the layout area there is full freedom to select the engine's specified SMCR point M which suits the demand for propeller power and speed for the ship.

On the horizontal axis the engine speed and on the vertical axis the engine power are shown on percentage scales. The scales are logarithmic which means that, in this diagram, power function curves like propeller curves (3rd power), constant mean effective pressure curves (1st power) and constant ship speed curves (0.15 to 0.30 power) are straight lines.

Specified maximum continuous rating (M)

Based on the propulsion and engine running points, as previously found, the layout diagram of a relevant main engine may be drawn-in. The SMCR point (M) must be inside the limitation lines of the layout diagram; if it is not, the propeller speed will have to be changed or another main engine type must be chosen. The selected SMCR has an influence on the turbocharger and its matching and the compression ratio.

For ME and ME-C/-GI engines, the timing of the fuel injection and the exhaust valve activation are electronically optimised over a wide operating range of the engine.

For ME-B engines, only the fuel injection (and not the exhaust valve activation) is electronically controlled over a wide operating range of the engine.

For a standard high-load optimised engine, the lowest specific fuel oil consumption for the ME and ME-C engines is optained at 70% and for MC/MC-C/ME-B engines at 80% of the SMCR point (M).

For ME-C-GI engines operating on LNG, a further SFOC reduction can be obtained.

Continuous service rating (S)

The continuous service rating is the power needed in service – including the specified sea margin and heavy/light running factor of the propeller – at which the engine is to operate, and point S is identical to the service propulsion point (SP) unless a main engine driven shaft generator is installed.

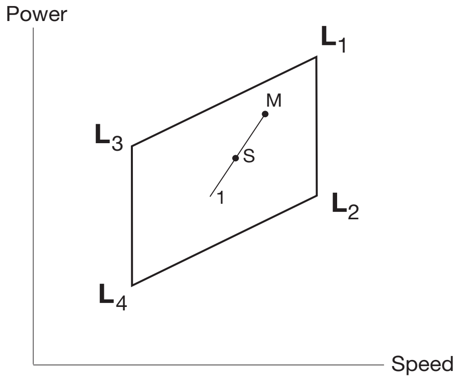


Fig. 2.04.01: Engine layout diagram

Engine Load Diagram

Definitions

The engine's load diagram, see Fig. 2.04.02, defines the power and speed limits for continuous as well as overload operation of an installed engine having a specified MCR point M that confirms the ship's specification.

The service points of the installed engine incorporate the engine power required for ship propulsion and shaft generator, if installed.

Operating curves and limits for continuous operation

The continuous service range is limited by four lines: 4, 5, 7 and 3 (9), see Fig. 2.04.02. The propeller curves, line 1, 2 and 6 in the load diagram are also described below.

Line 1:
Propeller curve through specified MCR (M), engine layout curve.

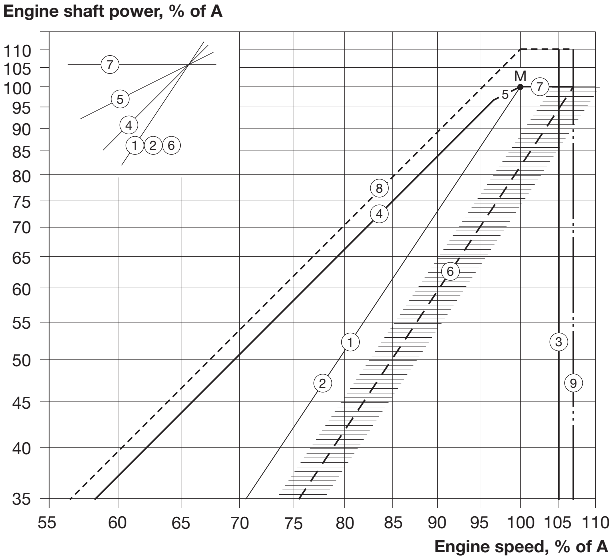
Line 2:
Propeller curve, fouled hull and heavy weather – heavy running.

Line 3 and line 9:
Line 3 represents the maximum acceptable speed for continuous operation, i.e. 105% of M.

During trial conditions the maximum speed may be extended to 107% of M, see line 9.

The above limits may in general be extended to 105% and during trial conditions to 107% of the nominal L_1 speed of the engine, provided the torsional vibration conditions permit.

The overspeed set-point is 109% of the speed in M, however, it may be moved to 109% of the *nominal speed* in L_1, provided that torsional vibration conditions permit.



Regarding 'i' in the power function $P = c \times n^i$, see page 2.01.

M	Specified MCR point
Line 1	Propeller curve through point M (i = 3) (engine layout curve)
Line 2	Propeller curve, fouled hull and heavy weather – heavy running (i = 3)
Line 3	Speed limit
Line 4	Torque/speed limit (i = 2)
Line 5	Mean effective pressure limit (i = 1)
Line 6	Propeller curve, clean hull and calm weather – light running (i = 3), for propeller layout. The hatched area indicates the recommended range (4.0-10.0%)
Line 7	Power limit for continuous running (i = 0)
Line 8	Overload limit
Line 9	Speed limit at sea trial

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Fig. 2.04.02: Standard engine load diagram

Line 4:
Represents the limit at which an ample air supply is available for combustion and imposes a limitation on the maximum combination of torque and speed.

Line 5:
Represents the maximum mean effective pressure level (mep), which can be accepted for continuous operation.

Line 6:
Propeller curve, clean hull and calm weather – light running, used for propeller layout/design.

Line 7:
Represents the maximum power for continuous operation.

Limits for overload operation

The overload service range is limited as follows:

Line 8:
Represents the overload operation limitations.

The area between lines 4, 5, 7 and the heavy dashed line 8 is available for overload running for limited periods only (1 hour per 12 hours).

Line 9:
Speed limit at sea trial.

Limits for low load running

As the fuel injection for ME engines is automatically controlled over the entire power range, the engine is able to operate down to around 15-20% of the nominal L_1 speed, whereas for MC/MC-C engines it is around 20-25% (electronic governor).

Recommendation

Continuous operation without limitations is allowed only within the area limited by lines 4, 5, 7 and 3 of the load diagram, except on low load operation for CP propeller plants mentioned in the previous section.

The area between lines 4 and 1 is available for operation in shallow waters, heavy weather and during acceleration, i.e. for non-steady operation without any strict time limitation.

After some time in operation, the ship's hull and propeller will be fouled, resulting in heavier running of the propeller, i.e. the propeller curve will move to the left from line 6 towards line 2, and extra power is required for propulsion in order to keep the ship's speed.

In calm weather conditions, the extent of heavy running of the propeller will indicate the need for cleaning the hull and possibly polishing the propeller.

Once the specified MCR has been chosen, the capacities of the auxiliary equipment will be adapted to the specified MCR, and the turbocharger specification and the compression ratio will be selected.

If the specified MCR is to be increased later on, this may involve a change of the pump and cooler capacities, change of the fuel valve nozzles, adjusting of the cylinder liner cooling, as well as rematching of the turbocharger or even a change to a larger size of turbocharger. In some cases it can also require larger dimensions of the piping systems.

It is therefore of utmost importance to consider, already at the project stage, if the specification should be prepared for a later power increase. This is to be indicated in the Extent of Delivery.

Extended load diagram for ships operating in extreme heavy running conditions

When a ship with fixed pitch propeller is operating in normal sea service, it will in general be operating in the hatched area around the design propeller curve 6, as shown on the standard load diagram in Fig. 2.04.02.

Sometimes, when operating in heavy weather, the fixed pitch propeller performance will be more heavy running, i.e. for equal power absorption of the propeller, the propeller speed will be lower and the propeller curve will move to the left.

As the low speed main engines are directly coupled to the propeller, the engine has to follow the propeller performance, i.e. also in heavy running propeller situations. For this type of operation, there is normally enough margin in the load area between line 6 and the normal torque/speed limitation line 4, see Fig. 2.04.02. To the left of line 4 in torque-rich operation, the engine will lack air from the turbocharger to the combustion process, i.e. the heat load limits may be exceeded and bearing loads might also become too high.

For some special ships and operating conditions, it would be an advantage - when occasionally needed - to be able to operate the propeller/main engine as much as possible to the left of line 6, but inside the torque/speed limit, line 4.

Such cases could be for:

- ships sailing in areas with very heavy weather
- ships operating in ice
- ships with two fixed pitch propellers/two main engines, where one propeller/one engine is declutched for one or the other reason.

The increase of the operating speed range between line 6 and line 4 of the standard load diagram, see Fig. 2.04.02, may be carried out as shown for the following engine Example with an extended load diagram for speed derated engine with increased light running.

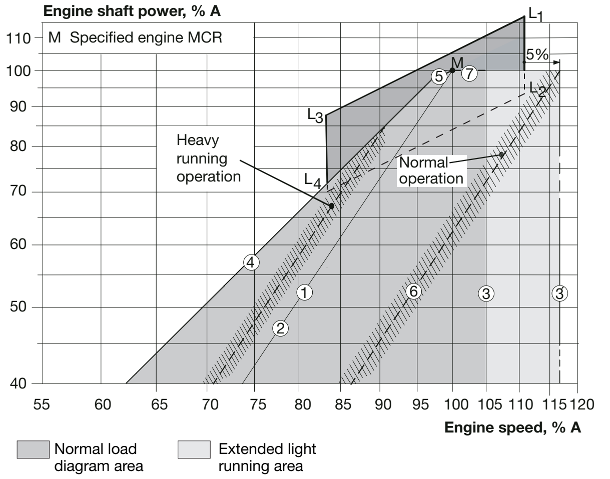
Extended load diagram for speed derated engines with increased light running

The maximum speed limit (line 3) of the engines is 105% of the SMCR (Specified Maximum Continuous Rating) speed, as shown in Fig. 2.04.02.

However, for speed and, thereby, power derated engines it is possible to extend the maximum speed limit to 105% of the engine's nominal MCR speed, line 3', but only provided that the torsional vibration conditions permit this. Thus, the shafting, with regard to torsional vibrations, has to be approved by the classification society in question, based on the extended maximum speed limit.

When choosing an increased light running to be used for the design of the propeller, the load diagram area may be extended from line 3 to line 3', as shown in Fig. 2.04.03, and the propeller/main engine operating curve 6 may have a correspondingly increased heavy running margin before exceeding the torque/speed limit, line 4.

A corresponding slight reduction of the propeller efficiency may be the result, due to the higher propeller design speed used.



Line 1: Propeller curve through SMCR point (M)
- layout curve for engine

Line 2: Heavy propeller curve
- fouled hull and heavy seas

Line 3: Speed limit

Line 3': Extended speed limit, provided torsional vibration conditions permit

Line 4: Torque/speed limit

Line 5: Mean effective pressure limit

Line 6: Increased light running propeller curve
- clean hull and calm weather
- layout curve for propeller

Line 7: Power limit for continuous running

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Fig. 2.04.03: Extended load diagram for speed derated engine with increased light running

Examples of the use of the Load Diagram

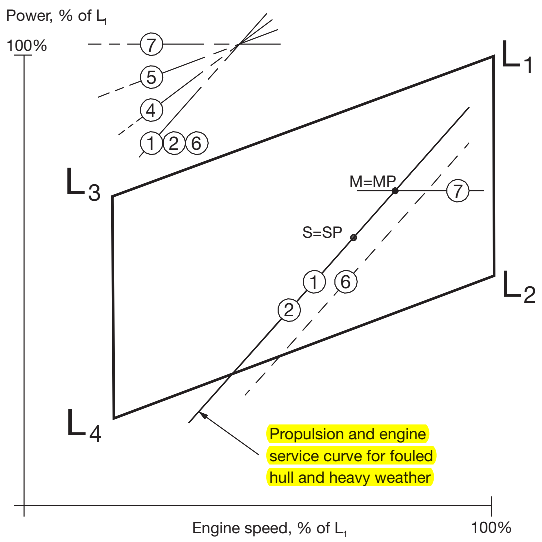
In the following are some examples illustrating the flexibility of the layout and load diagrams.

- Example 1 shows how to place the load diagram for an engine without shaft generator coupled to a fixed pitch propeller.
- Example 2 shows the same layout for an engine with fixed pitch propeller (example 1), but with a shaft generator.
- Example 3 is a special case of example 2, where the specified MCR is placed near the top of the layout diagram.
  In this case the shaft generator is cut off, and the GenSets used when the engine runs at specified MCR. This makes it possible to choose a smaller engine with a lower power output, and with changed specified MCR.
- Example 4 shows diagrams for an engine coupled to a controllable pitch propeller, with or without a shaft generator, constant speed or combinator curve operation.

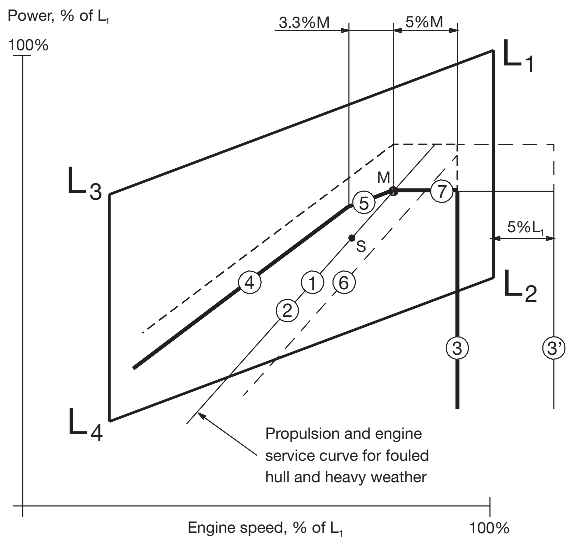
For a specific project, the layout diagram for actual project shown later in this chapter may be used for construction of the actual load diagram.

Example 1: Normal running conditions.
Engine coupled to fixed pitch propeller (FPP) and without shaft generator

Layout diagram



Load diagram



M Specified MCR of engine
S Continuous service rating of engine
MP Specified MCR for propulsion
SP Continuous service rating of propulsion

The specified MCR (M) and its propeller curve 1 will normally be selected on the engine service curve 2.

Once point M has been selected in the layout diagram, the load diagram can be drawn, as shown in the figure, and hence the actual load limitation lines of the diesel engine may be found by using the inclinations from the construction lines and the %-figures stated.

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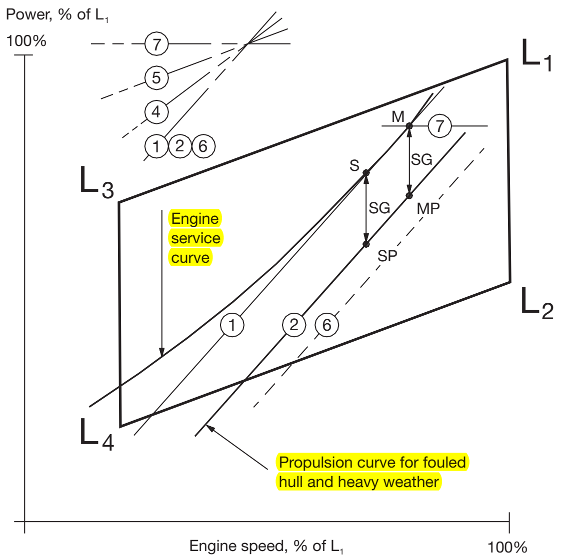
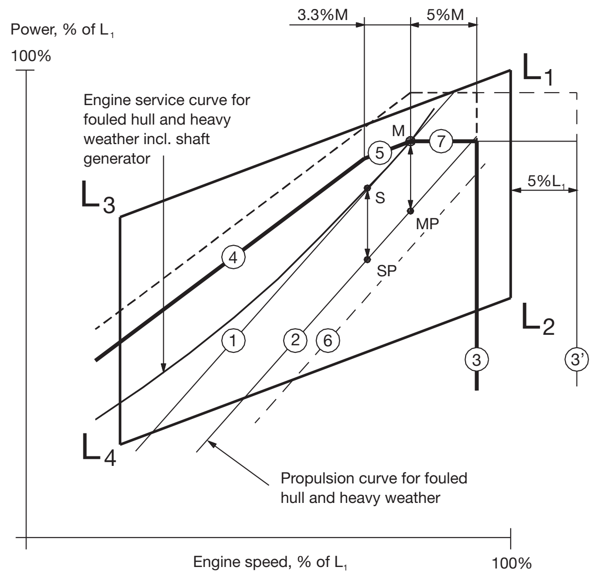
Fig. 2.04.04: Normal running conditions. Engine coupled to a fixed pitch propeller (FPP) and without a shaft generator

Example 2: Normal running conditions.
Engine coupled to fixed pitch propeller (FPP) and with shaft generator

Layout diagram



Load diagram



M	Specified MCR of engine
S	Continuous service rating of engine
MP	Specified MCR for propulsion
SP	Continuous service rating of propulsion
SG	Shaft generator power

In example 2 a shaft generator (SG) is installed, and therefore the service power of the engine also has to incorporate the extra shaft power required for the shaft generator's electrical power production.

In the figure, the engine service curve shown for heavy running incorporates this extra power.

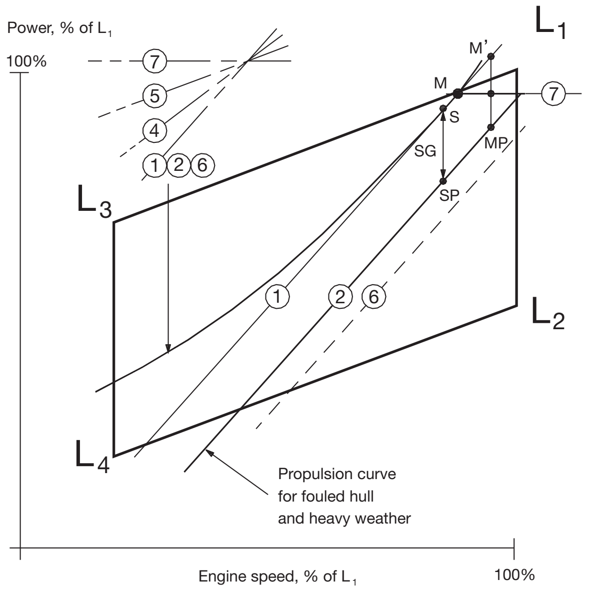
The specified MCR M will then be chosen and the load diagram can be drawn as shown in the figure.

178 05 48-8.9

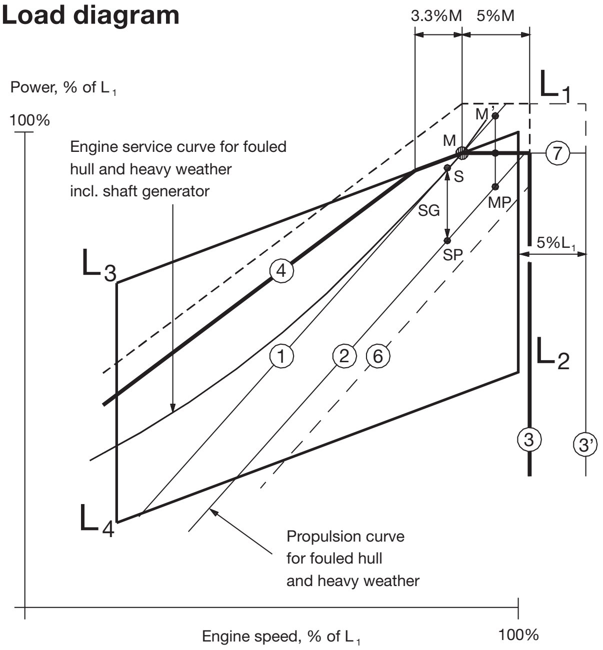
Fig. 2.04.06: Normal running conditions. Engine coupled to a fixed pitch propeller (FPP) and with a shaft generator

Example 3: Special running conditions.
Engine coupled to fixed pitch propeller (FPP) and with shaft generator

Layout diagram



Load diagram



M	Specified MCR of engine
S	Continuous service rating of engine
MP	Specified MCR for propulsion
SP	Continuous service rating of propulsion
SG	Shaft generator

Point M of the load diagram is found:

Line 1	Propeller curve through point S
Point M	Intersection between line 1 and line $L_1 - L_3$

Also for this special case in example 3, a shaft generator is installed but, compared to example 2, this case has a specified MCR for propulsion, MP, placed at the top of the layout diagram.

This involves that the intended specified MCR of the engine M' will be placed outside the top of the layout diagram.

One solution could be to choose a larger diesel engine with an extra cylinder, but another and cheaper solution is to reduce the electrical power production of the shaft generator when running in the upper propulsion power range.

In choosing the latter solution, the required specified MCR power can be reduced from point M' to point M as shown. Therefore, when running in the upper propulsion power range, a diesel generator has to take over all or part of the electrical power production.

However, such a situation will seldom occur, as ships are rather infrequently running in the upper propulsion power range.

Point M, having the highest possible power, is then found at the intersection of line $L_1 - L_3$ with line 1 and the corresponding load diagram is drawn.

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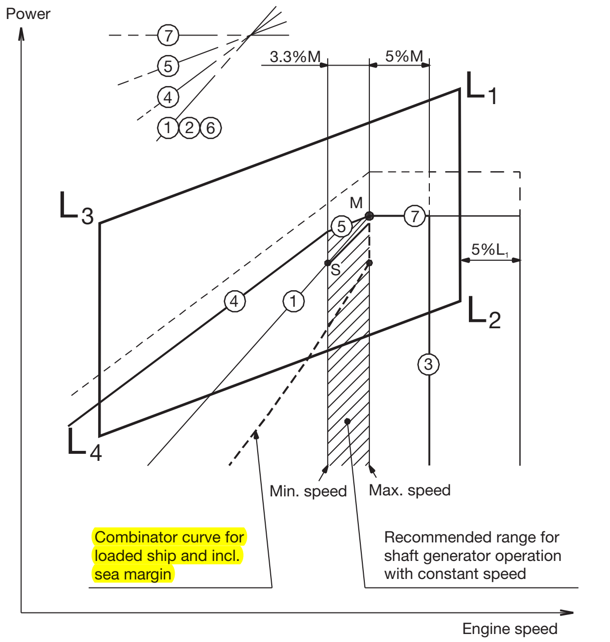
Fig. 2.04.07: Special running conditions. Engine coupled to a fixed pitch propeller (FPP) and with a shaft generator

Example 4: Engine coupled to controllable pitch propeller (CPP) with or without shaft generator



M Specified MCR of engine
S Continous service rating of engine

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Fig. 2.04.08: Engine with Controllable Pitch Propeller (CPP), with or without a shaft generator

Layout diagram - without shaft generator
If a controllable pitch propeller (CPP) is applied, the combinator curve (of the propeller) will normally be selected for loaded ship including sea margin.

The combinator curve may for a given propeller speed have a given propeller pitch, and this may be heavy running in heavy weather like for a fixed pitch propeller.

Therefore it is recommended to use a light running combinator curve (the dotted curve which includes the sea power margin) as shown in the figure to obtain an increased operation margin of the diesel engine in heavy weather to the limit indicated by curves 4 and 5.

Layout diagram - with shaft generator
The hatched area shows the recommended speed range between 100% and 96.7% of the specified MCR speed for an engine with shaft generator running at constant speed.

The service point S can be located at any point within the hatched area.

The procedure shown in examples 2 and 3 for engines with FPP can also be applied here for engines with CPP running with a combinator curve.

Load diagram
Therefore, when the engine's specified MCR point (M) has been chosen including engine margin, sea margin and the power for a shaft generator, if installed, point M may be used in the load diagram, which can then be drawn.

The position of the combinator curve ensures the maximum load range within the permitted speed range for engine operation, and it still leaves a reasonable margin to the limit indicated by curves 4 and 5.