2 Engine Layout and Load Diagrams

Propulsion and Engine Running Points

Propeller curve

The relation between power and propeller speed for a fixed pitch propeller is as mentioned above described by means of the propeller law, i.e. the third power curve:

$P_b = c \times n^3$, in which:

P_b = engine power for propulsion
n = propeller speed
c = constant

The power functions $P_b = c \times n^i$ will be linear functions when using logarithmic scales.

Therefore, in the Layout Diagrams and Load Diagrams for diesel engines, logarithmic scales are used, making simple diagrams with straight lines.

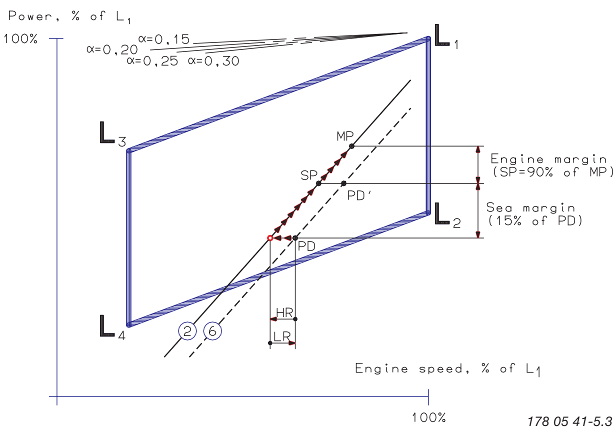
Propeller design point

Normally, estimations of the necessary propeller power and speed are based on theoretical calculations for loaded ship, and often experimental tank tests, both assuming optimum operating conditions, i.e. a clean hull and good weather. The combination of speed and power obtained may be called the ship's propeller design point (PD), placed on the light running propeller curve 6. See Fig. 2.01. On the other hand, some shipyards, and/or propeller manufacturers sometimes use a propeller design point (PD') that incorporates all or part of the so-called sea margin described below.

Fouled hull

When the ship has sailed for some time, the hull and propeller become fouled and the hull's resistance will increase. Consequently, the ship speed will be reduced unless the engine delivers more power to the propeller, i.e. the propeller will be further loaded and will be heavy running (HR).

As modern vessels with a relatively high service speed are prepared with very smooth propeller and hull surfaces, the fouling after sea trial, therefore, will involve a relatively higher resistance and thereby a heavier running propeller.



Line 2 Propulsion curve, fouled hull and heavy weather (heavy running), recommended for engine layout
Line 6 Propulsion curve, clean hull and calm weather (light running), for propeller layout
MP Specified MCR for propulsion
SP Continuous service rating for propulsion
PD Propeller design point
HR Heavy running
LR Light running

Fig. 2.01: Ship propulsion running points and engine layout

Sea margin at heavy weather

If, at the same time the weather is bad, with head winds, the ship's resistance may increase compared to operating at calm weather conditions.

When determining the necessary engine power, it is therefore normal practice to add an extra power margin, the so-called sea margin, see Fig. 2.02 which is traditionally about 15% of the propeller design (PD) power.

Engine layout (heavy propeller)

When determining the necessary engine speed considering the influence of a heavy running propeller for operating at large extra ship resistance, it is recommended - compared to the clean hull and calm weather propeller curve 6 - to choose a heavier propeller curve 2 for engine layout, and the propeller curve for clean hull and calm weather in curve 6 will be said to represent a "light running" (LR) propeller, see area 6 on Figs. 2.07a and 2.07b.

Compared to the heavy engine layout curve 2 we recommend to use a light running of **3.0-7.0%** for design of the propeller, with 5% as a good average.

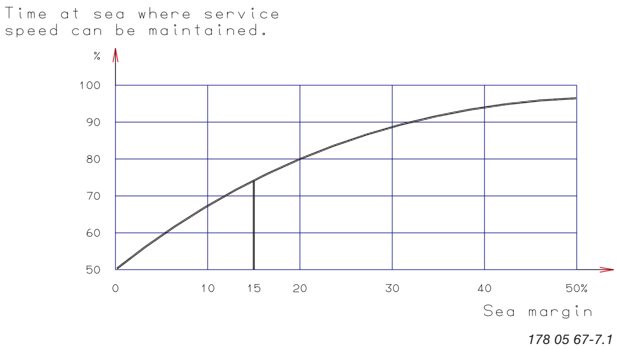


Fig. 2.02: Sea margin based on weather conditions in the North Atlantic Ocean. Percentage of time at sea where the service speed can be maintained, related to the extra power (sea margin) in % of the sea trial power.

Engine margin

Besides the sea margin, a so-called "engine margin" of some 10% is frequently added. The corresponding point is called the "specified MCR for propulsion" (MP), and refers to the fact that the power for point SP is 10% lower than for point MP, see Fig. 2.01. Point MP is identical to the engine's specified MCR point (M) unless a main engine driven shaft generator is installed. In such a case, the extra power demand of the shaft generator must also be considered.

Note:
Light/heavy running, fouling and sea margin are overlapping terms. Light/heavy running of the propeller refers to hull and propeller deterioration and heavy weather and, – sea margin i.e. extra power to the propeller, refers to the influence of the wind and the sea. However, the degree of light running must be decided upon experience from the actual trade and hull design.

Influence of propeller diameter and pitch on the optimum propeller speed

In general, the larger the propeller diameter, the lower is the optimum propeller speed and the kW required for a certain design draught and ship speed, see curve D in Fig. 2.03.

The maximum possible propeller diameter depends on the given design draught of the ship, and the clearance needed between the propeller and the aft-body hull and the keel.

The example shown in Fig. 2.03 is an 80,000 dwt crude oil tanker with a design draught of 12.2 m and a design speed of 14.5 knots.

When the optimum propeller diameter D is increased from 6.6 m to 7.2. m, the power demand is reduced from about 9,290 kW to 8,820 kW, and the optimum propeller speed is reduced from 120 r/min to 100 r/min, corresponding to the constant ship speed coefficient $\alpha = 28$ (see definition of α in next section).

Once an optimum propeller diameter of maximum 7.2 m has been chosen, the pitch in this point is given for the design speed of 14.5 knots, i.e. P/D = 0.70.

However, if the optimum propeller speed of 100 r/min does not suit the preferred / selected main engine speed, a change of pitch will only cause a relatively small extra power demand, keeping the same maximum propeller diameter:

- going from 100 to 110 r/min (P/D = 0.62) requires 8,900 kW i.e. an extra power demand of 80 kW.
- going from 100 to 91 r/min (P/D = 0.81) requires 8,900 kW i.e. an extra power demand of 80 kW.

In both cases the extra power demand is only of 0.9%, and the corresponding 'equal speed curves' are α =+0.1 and α =-0.1, respectively, so there is a certain interval of propeller speeds in which the 'power penalty' is very limited.

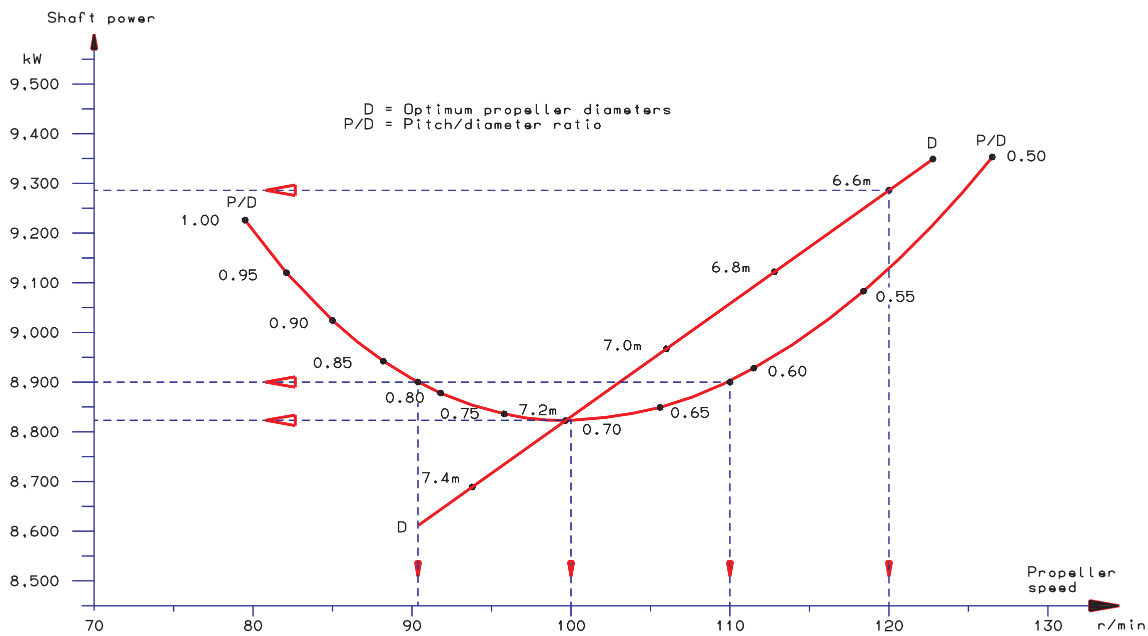


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Fig. 2.03: Influence of diameter and pitch on propeller design

Constant ship speed lines

The constant ship speed lines α, are shown at the very top of Fig. 2.04. These lines indicate the power required at various propeller speeds to keep the same ship speed provided that the optimum propeller diameter with an optimum pitch diameter ratio is used at any given speed, taking into consideration the total propulsion efficiency.

Normally, the following relation between necessary power and propeller speed can be assumed:

$$P_2 = P_1 (n_2/n_1)^{\alpha}$$

where:
P = Propulsion power
n = Propeller speed, and
α = the constant ship speed coefficient.

For any combination of power and speed, each point on lines parallel to the ship speed lines gives the same ship speed.

When such a constant ship speed line is drawn into the layout diagram through a specified propulsion MCR point "MP_1", selected in the layout area and parallel to one of the α-lines, another specified propulsion MCR point "MP_2" upon this line can be chosen to give the ship the same speed for the new combination of engine power and speed.

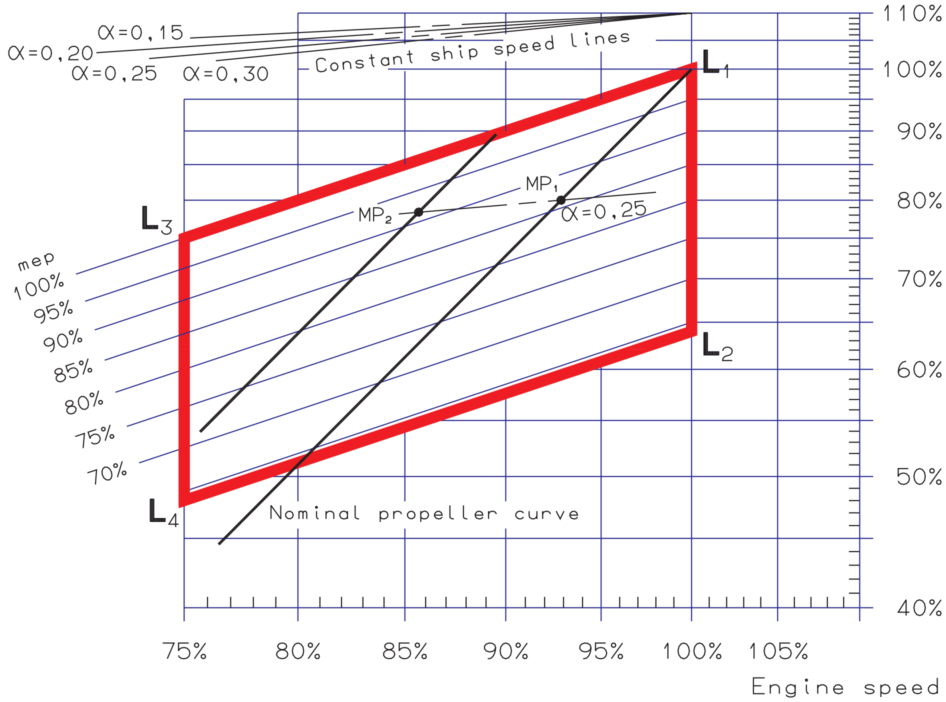
Fig. 2.04 shows an example of the required power speed point MP_1, through which a constant ship speed curve α = 0.25 is drawn, obtaining point MP_2 with a lower engine power and a lower engine speed but achieving the same ship speed.

Provided the optimum pitch/diameter ratio is used for a given propeller diameter the following data applies when changing the propeller diameter:

for general cargo, bulk carriers and tankers
α = 0.25 -0.30

and for reefers and container vessels
α = 0.15 -0.25

When changing the propeller speed by changing the pitch diameter ratio, the α constant will be different, see above.



178 05 66-7.0

Fig. 2.04: Layout diagram and constant ship speed lines

Engine Layout Diagram

The layout procedure has to be carefully considered because the final layout choice will have a considerable influence on the operating condition of the main engine throughout the whole lifetime of the ship. The factors that should be conisdered are operational flexibility, fuel consumption, obtainable power, possible shaft generator application and propulsion efficiency.

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, see Fig. 2.04. The L_1 point refers to the engine's nominal maximum continuous rating.

Please note that the areas of the layout diagrams are different for the engines types, see Fig. 2.05.

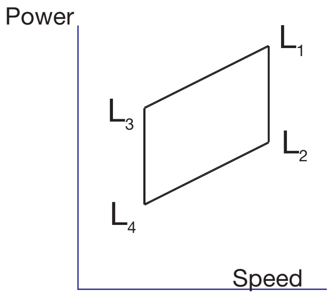
Within the layout area there is full freedom to select the engine's specified MCR point M which suits the demand of propeller power and speed for the ship.

On the X-axis the engine speed and on the Y-axis the engine power are shown in 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.

Fig. 2.06 shows, by means of superimposed diagrams for all engine types, the entire layout area for the MC-programme in a power/speed diagram. As can be seen, there is a considerable overlap of power/speed combinations so that for nearly all applications, there is a wide section of different engines to choose from all of which meet the individual ship's requirements.

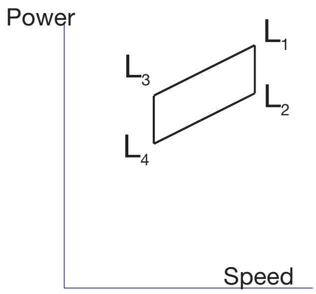
Specified maximum continuous rating, SMCR = "M"

Based on the propulsion and engine running points, as previously found, the layout diagram of a relevant main engine may be drawn-in. The specified MCR 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. Yet, in special cases point M may be located to the right of the line L_1-L_2, see "Optimising Point".



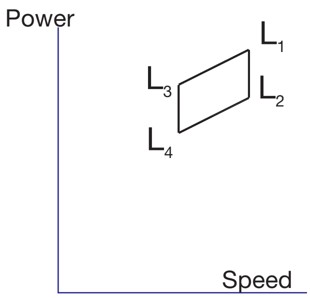
Layout diagram of 100 - 64% power and 100 - 75% speed range valid for the types:

L90MC-C, K90MC, S80MC-C, S80MC, L80MC, S70MC-C, S70MC, L70MC, S60MC-C, S60MC, L60MC, S50MC-C, S50MC, L50MC, L42MC



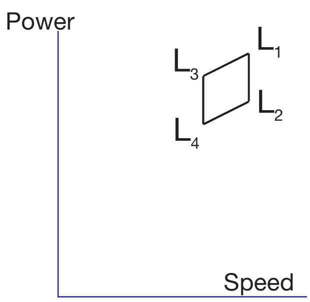
Layout diagram of 100 - 80% power and 100 - 80% speed range valid for the types:

S90MC-C



Layout diagram of 100 - 80% power and 100 - 85% speed range valid for the types:

K90MC-C, K80MC-C, S46MC-C, S42MC, S35MC, L35MC, S26MC

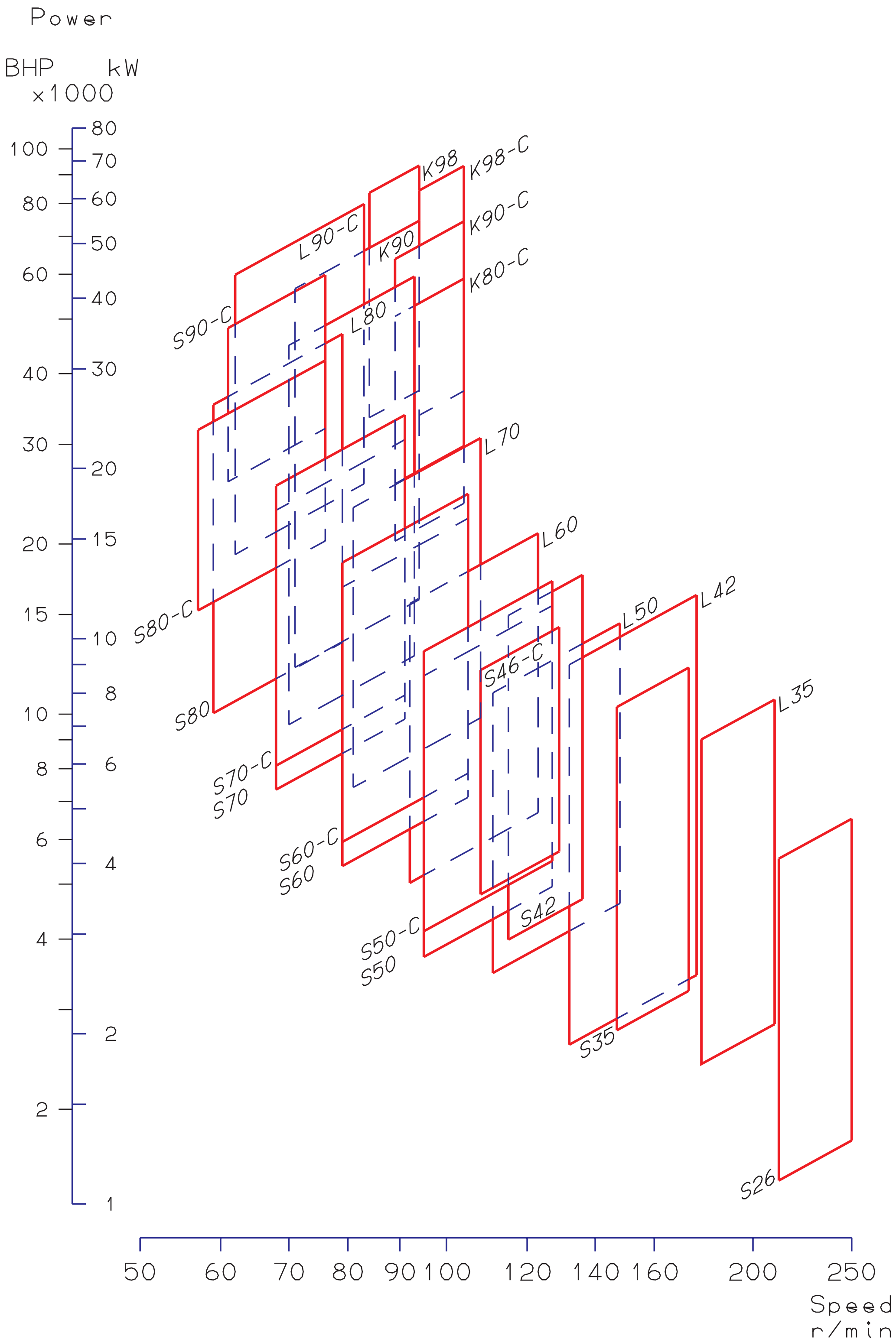


Layout diagram of 100 - 80% power and 100 - 90% speed range valid for the types:

K98MC, K98MC-C

178 13 85-1.4

Fig. 2.05: Layout diagram sizes



178 13 80-2.8

Fig. 2.06: Layout diagrams of the two-stroke engine MC-programme as per January 2000

Continuous service rating (S)

The Continuous service rating is the power at which the engine is normally assumed to operate, and point S is identical to the service propulsion point (SP) unless a main engine driven shaft generator is installed.

Optimising point (O)

The optimising point O is the rating at which the turbocharger is matched, and at which the engine timing and compression ratio are adjusted.

On engines with Variable Injection Timing (VIT) fuel pumps, the optimising point (O) can be different than the specified MCR (M), whereas on engines without VIT fuel pumps “O” has to coincide with “M”.

The large engine types have VIT fuel pumps as standard, but on some types these pumps are an option. Small-bore engines are not fitted with VIT fuel pumps.

Type	With VIT	Without VIT
K98MC	Basic	
K98MC-C	Basic	
S90MC-C	Basic	
L90MC-C	Basic	
K90MC	Basic	
K90MC-C	Basic	
S80MC-C	Basic	
S80MC	Basic	
L80MC	Basic	
S70MC-C	Optional	Basic
S70MC	Basic	
L70MC	Basic	
S60MC-C	Optional	Basic
S60MC	Basic	
L60MC	Basic	
S50MC-C	Optional	Basic
S50MC	Basic	
S46MC-C		Basic
S42MC		Basic
L42MC		Basic
S35MC		Basic
L35MC		Basic
S26MC		Basic

Engines with VIT

The optimising point O is placed on line 1 of the load diagram, and the optimised power can be from 85 to 100% of point M's power, when turbocharger(s) and engine timing are taken into consideration. When optimising between 93.5% and 100% of point M's power, 10% overload running will still be possible (110% of M).

The optimising point O is to be placed inside the layout diagram. In fact, the specified MCR point M can, in special cases, be placed outside the layout diagram, but only by exceeding line L_1-L_2, and of course, only provided that the optimising point O is located inside the layout diagram and provided that the specified MCR power is not higher than the L_1 power.

Engine without VIT
Optimising point (O) = specified MCR (M)

On engine types not fitted with VIT fuel pumps, the specified MCR – point M has to coincide with point O.

Load Diagram

Definitions

The load diagram, Figs. 2.07, defines the power and speed limits for continuous as well as overload operation of an installed engine having an optimising point O and a specified MCR point M that confirms the ship's specification.

Point A is a 100% speed and power reference point of the load diagram, and is defined as the point on the propeller curve (line 1), through the optimising point O, having the specified MCR power. Normally, point M is equal to point A, but in special cases, for example if a shaft generator is installed, point M may be placed to the right of point A on line 7.

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

Limits for continuous operation

The continuous service range is limited by four lines:

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

If, in special cases, A is located to the right of line L_1-L_2, the maximum limit, however, is 105% of L_1.

During trial conditions the maximum speed may be extended to 107% of A, 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 A, however, it may be moved to 109% *of the nominal speed* in L_1, provided that torsional vibration conditions permit.

Running above 100% of the nominal L_1 speed at a load lower than about 65% specified MCR is, however, to be avoided for extended periods. Only plants with controllable pitch propellers can reach this light running area.

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 7:
Represents the maximum power for continuous operation.7

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).

A	100% reference point
M	Specified MCR point
O	Optimising point
Line 1	Propeller curve through optimising point (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
Line 7	Power limit for continuous running (i = 0)
Line 8	Overload limit
Line 9	Speed limit at sea trial

Point M to be located on line 7 (normally in point A)

Regarding "i" in the power functions $P_b = c \times n^i$, see page 2.01

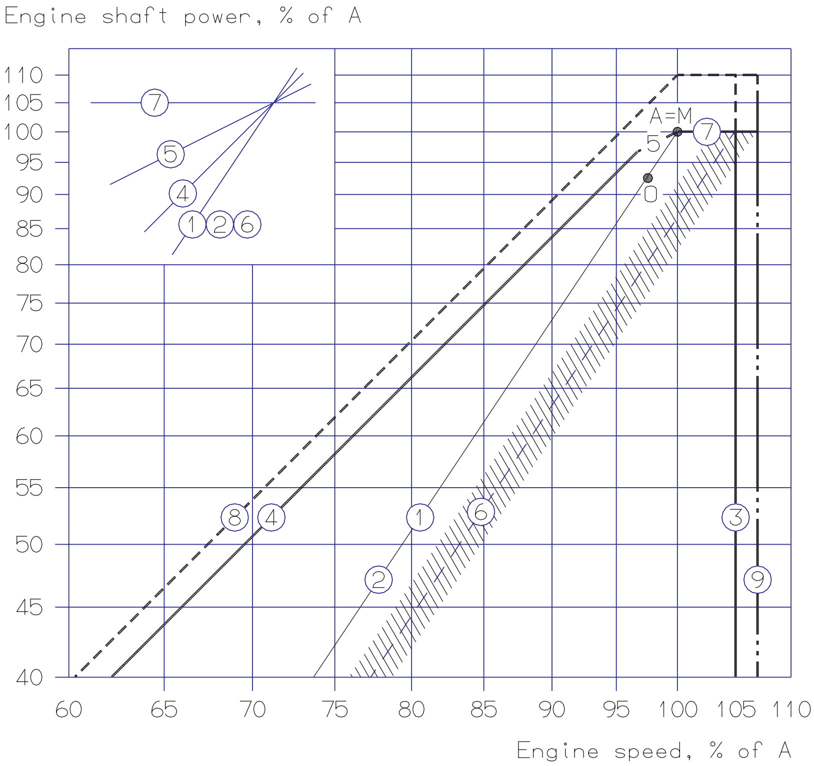
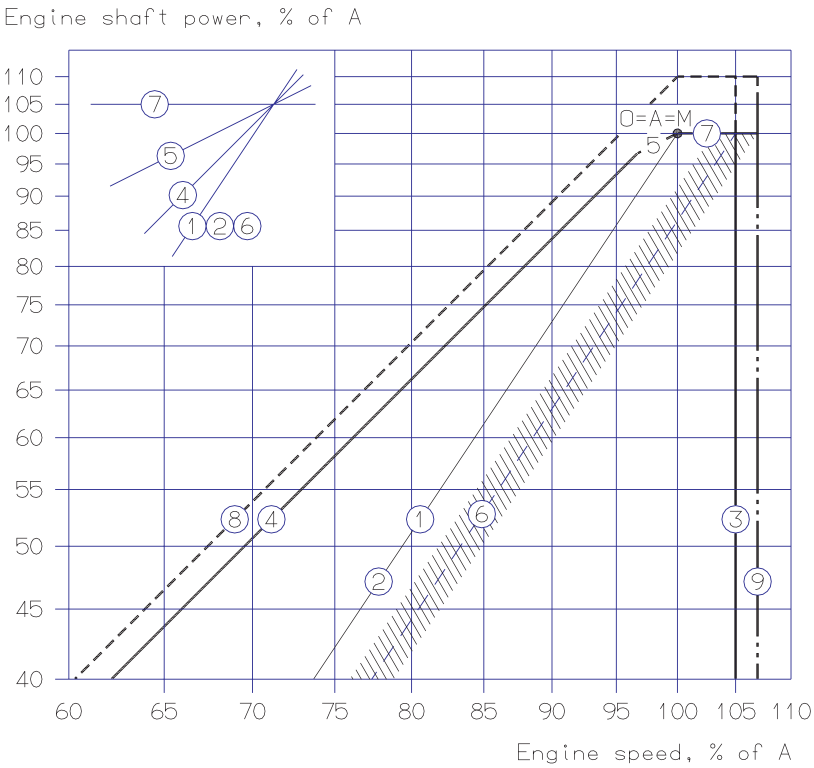


Fig. 2.07a: Engine load diagram for engine with VIT

178 05 42-7.3



178 39 18-4.1

Fig. 2.07b: Engine load diagram for engine without VIT

Recommendation

Continuous operation without limitations is allowed only within the area limited by lines 4, 5, 7 and 3 of the load diagram, except 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 (and the optimising point) has been chosen, the capacities of the auxiliary equipment will be adapted to the specified MCR, and the turbocharger etc. will be matched to the optimised power, however considering the specified MCR.

If the specified MCR (and/or the optimising point) is to be increased later on, this may involve a change of the pump and cooler capacities, retiming of the engine, 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.

Examples of the use of the Load Diagram

In the following see Figs. 2.08 - 2.13, are some examples illustrating the flexibility of the layout and load diagrams and the significant influence of the choice of the optimising point O.

The upper diagrams of the examples 1, 2, 3 and 4 show engines **with** VIT fuel pumps for which the optimising point O is normally different from the specified MCR point M as this can improve the SFOC at part load running. The lower diagrams also show engine **wihtout** VIT fuel pumps, i.e. point A=O.

Example 1 shows how to place the load diagram for an engine without shaft generator coupled to a fixed pitch propeller.

In example 2 are diagrams for the same configuration, here with the optimising point to the left of the heavy running propeller curve (2) obtaining an extra engine margin for heavy running.

As for example 1 example 3 shows the same layout for an engine with fixed pitch propeller, but with a shaft generator.

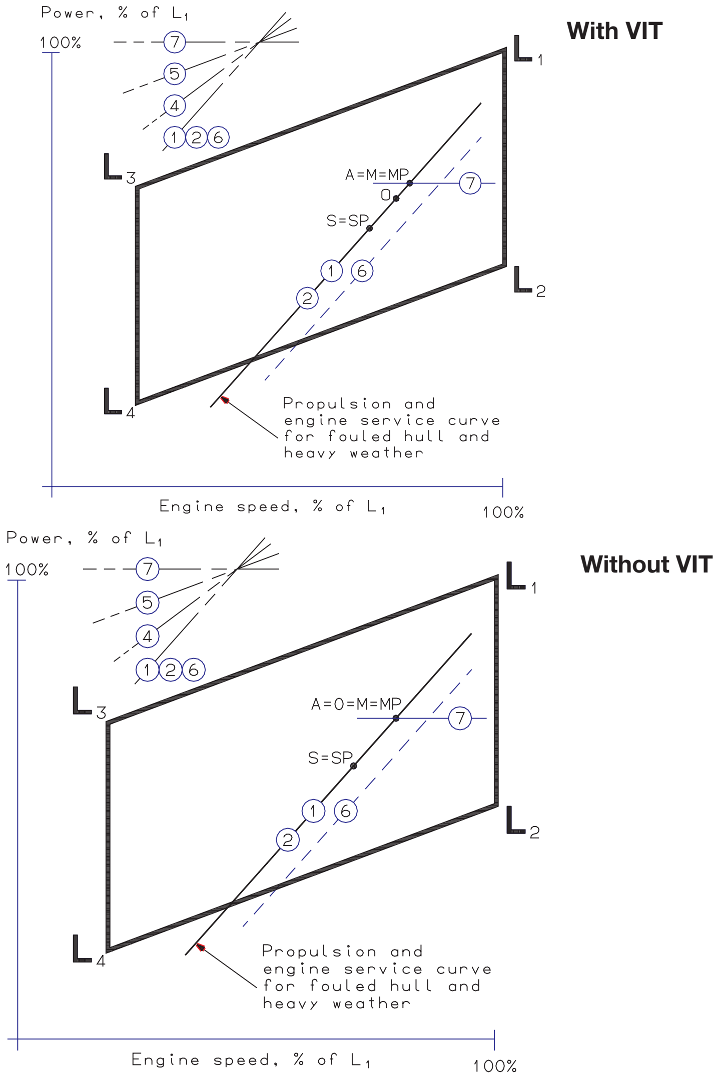
Example 4 shows a special case with a shaft generator. In this case the shaft generator is cut off, and the GenSets used when the engine runs at specified MCR. This makes it possible to choose a smaller engine with a lower power output.

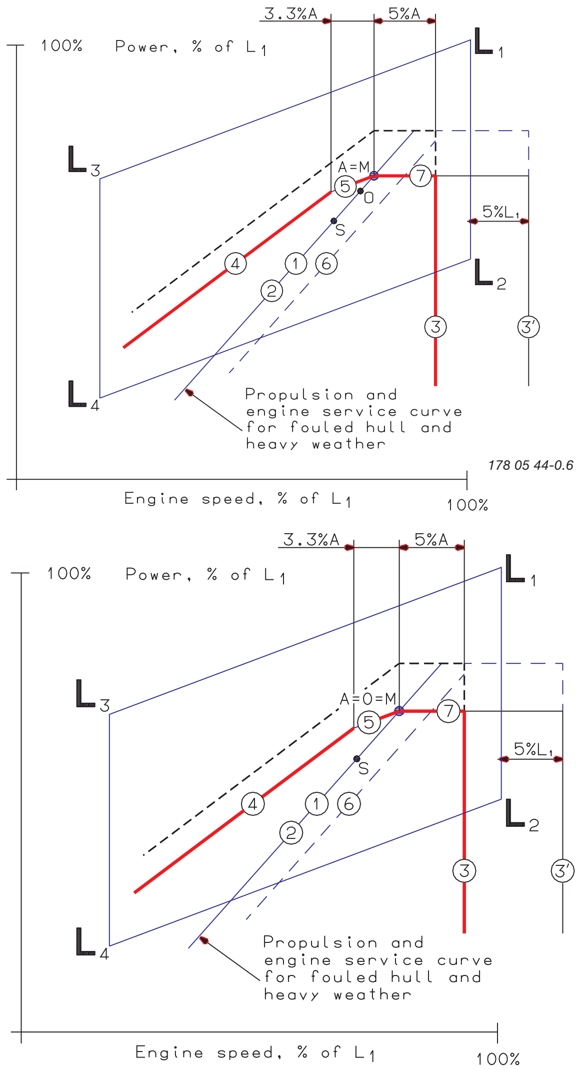
Example 5 shows diagrams for an engine coupled to a controllable pitch propeller, with or without a shaft generator, (constant speed or combinator curve operation).

Example 6 shows where to place the optimising point for an engine coupled to a controllable pitch propeller, and operating at constant speed.

For a project, the layout diagram shown in Fig. 2.14 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





M Specified MCR of engine
S Continuous service rating of engine
O Optimising point of engine
A Reference point of load diagram
MP Specified MCR for propulsion
SP Continuous service rating of propulsion

Point A of load diagram is found:
Line 1 Propeller curve through optimising point (O) is equal to line 2
Line 7 Constant power line through specified MCR (M)
Point A Intersection between line 1 and 7

178 39 20-6.1

Fig. 2.08a: Example 1, Layout diagram for normal running conditions, engine with FPP, without shaft generator

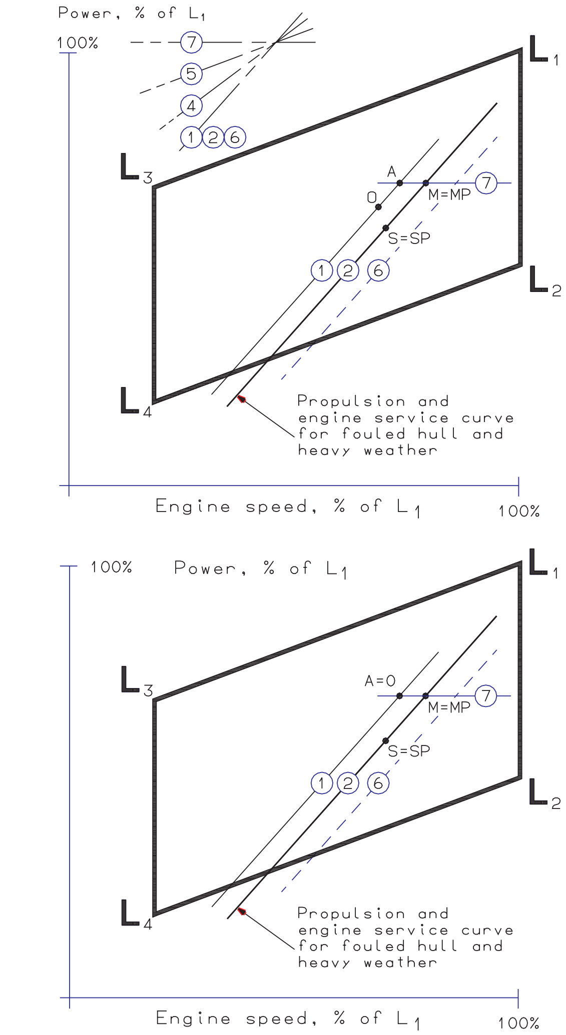
Fig. 2.08b: Example 1, Load diagram for normal running conditions, engine with FPP, without shaft generator

For engines with VIT, the optimising point O and its propeller curve 1 will normally be selected on the engine service curve 2, see the upper diagram of Fig. 2.08a.

For engines without VIT, the optimising point O will have the same power as point M and its propeller curve 1 for engine layout will normally be selected on the engine service curve 2 (for fouled hull and heavy weather), as shown in the lower diagram of Fig. 2.08a.

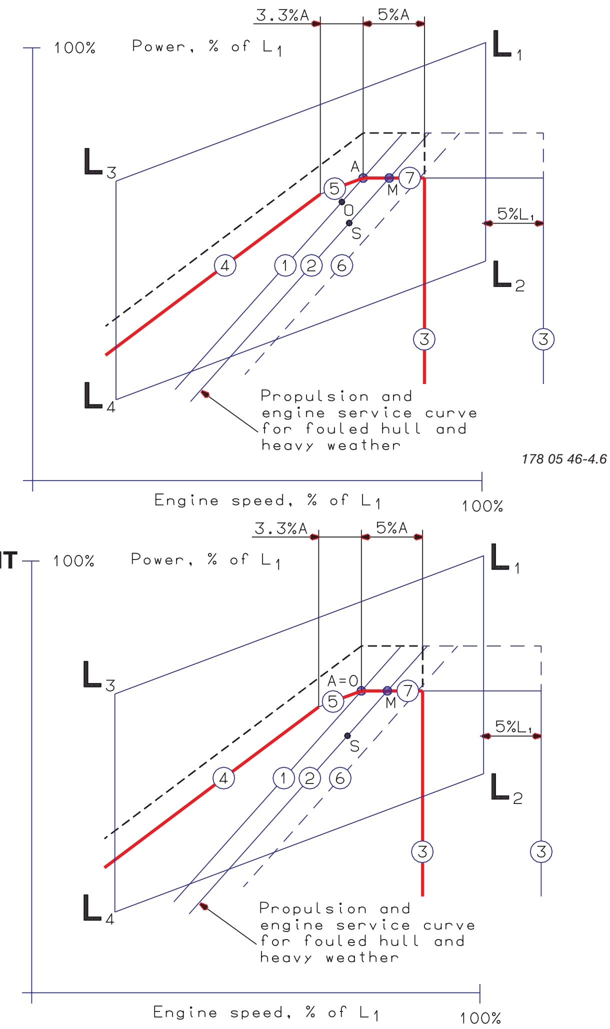
Point A is then found at the intersection between propeller curve 1 (2) and the constant power curve through M, line 7. In this case point A is equal to point M.

Example 2:
Special running conditions. Engine coupled to fixed pitch propeller (FPP) and without shaft generator



M Specified MCR of engine
S Continuous service rating of engine
O Optimising point of engine
A Reference point of load diagram
MP Specified MCR for propulsion
SP Continuous service rating of propulsion

Fig. 2.09a: Example 2, Layout diagram for special running conditions, engine with FPP, without shaft generator



Point A of load diagram is found:

Line 1 Propeller curve through optimising point (O) is equal to line 2
Line 7 Constant power line through specified MCR (M)
Point A Intersection between line 1 and 7

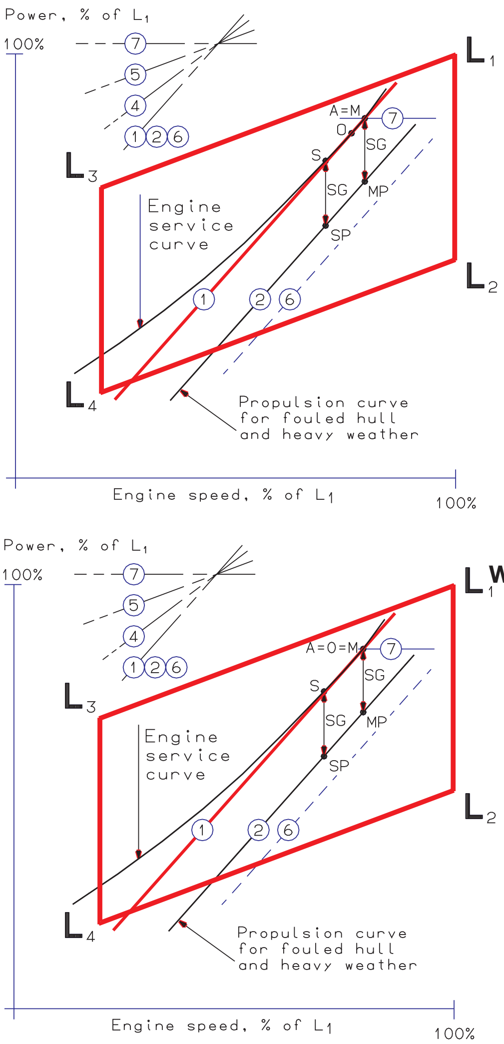
178 39 23-1.0

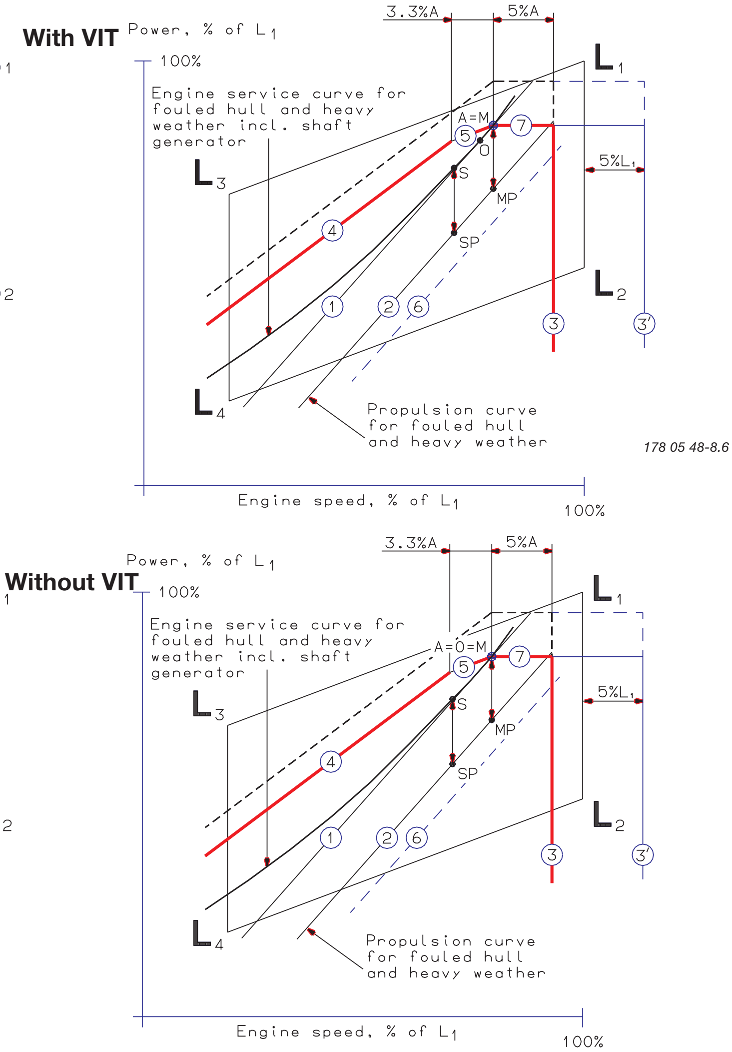
Fig. 2.09b: Example 2, Load diagram for special running conditions, engine with FPP, without shaft generator

Once point A has been found in the layout diagram, the load diagram can be drawn, as shown in Fig. 2.08b 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.

A similar example 2 is shown in Figs. 2.09. In this case, the optimising point O has been selected more to the left than in example 1, obtaining an extra engine margin for heavy running operation in heavy weather conditions. In principle, the light running margin has been increased for this case.

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





M	Specified MCR of engine
S	Continuous service rating of engine
O	Optimising point of engine
A	Reference point of load diagram
MP	Specified MCR for propulsion
SP	Continuous service rating of propulsion
SG	Shaft generator power

Point A of load diagram is found:

Line 1	Propeller curve through optimising point (O)
Line 7	Constant power line through specified MCR (M)
Point A	Intersection between line 1 and 7

178 39 25-5.1

Fig. 2.10a: Example 3, Layout diagram for normal running conditions, engine with FPP, without shaft generator

Fig. 2.10b: Example 3, Load diagram for normal running conditions, engine with FPP, with shaft generator

In example 3 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.

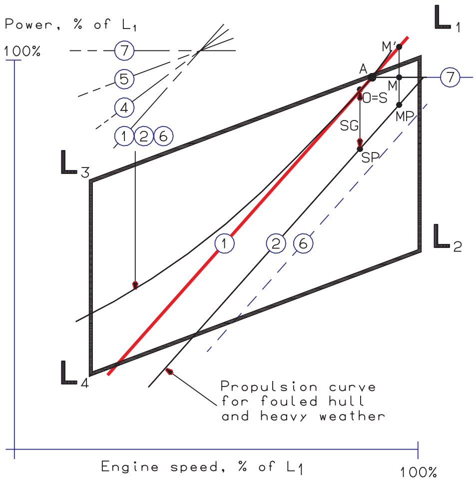
In Fig. 2.10a, the engine service curve shown for heavy running incorporates this extra power.

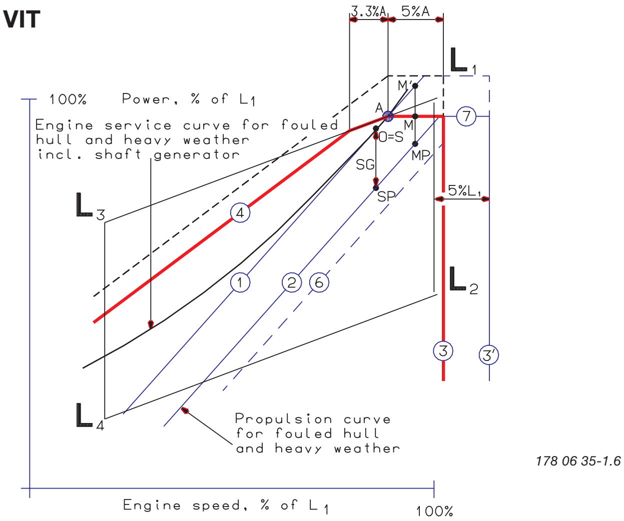
The optimising point O will be chosen on the engine service curve as shown, but can, by an approximation, be located on curve 1, through point M.

Point A is then found in the same way as in example 1, and the load diagram can be drawn as shown in Fig. 2.10b.

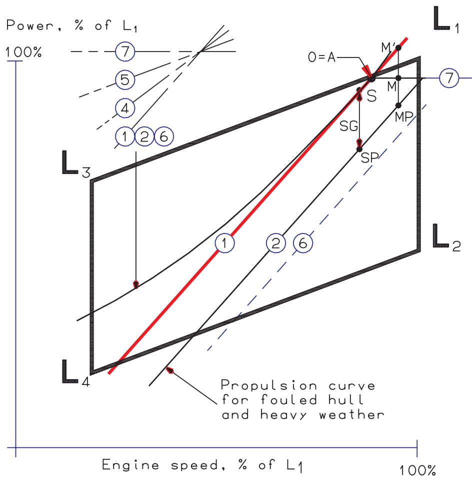
Example 4:
Special running conditions. Engine coupled to fixed pitch propeller (FPP) and with shaft generator

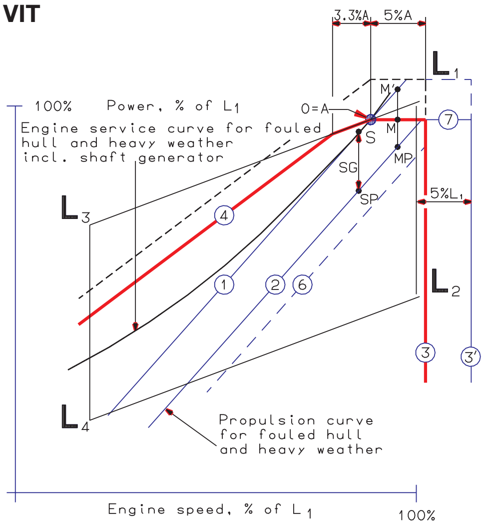
With VIT





Without VIT





M	Specified MCR of engine
S	Continuous service rating of engine
O	Optimising point of engine
A	Reference point of load diagram
MP	Specified MCR for propulsion
SP	Continuous service rating of propulsion
SG	Shaft generator

Point A of load diagram is found:

Line 1	Propeller curve through optimising point (O) or point S
Point A	Intersection between line 1 and line L_1 - L_3
Point M	Located on constant power line 7 through point A (O = A if the engine is without VIT) and with MP's speed.

178 39 28-0.2

See text on next page.

Fig. 2.11a: Example 4. Layout diagram for special running conditions, engine with FPP, with shaft generator

Fig. 2.11b: Example 4. Load diagram for special running conditions, engine with FPP, with shaft generator

Example 4:

Also in this special case, a shaft generator is installed but, compared to Example 3, this case has a specified MCR for propulsion, MP, placed at the top of the layout diagram, see Fig. 2.11a.

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

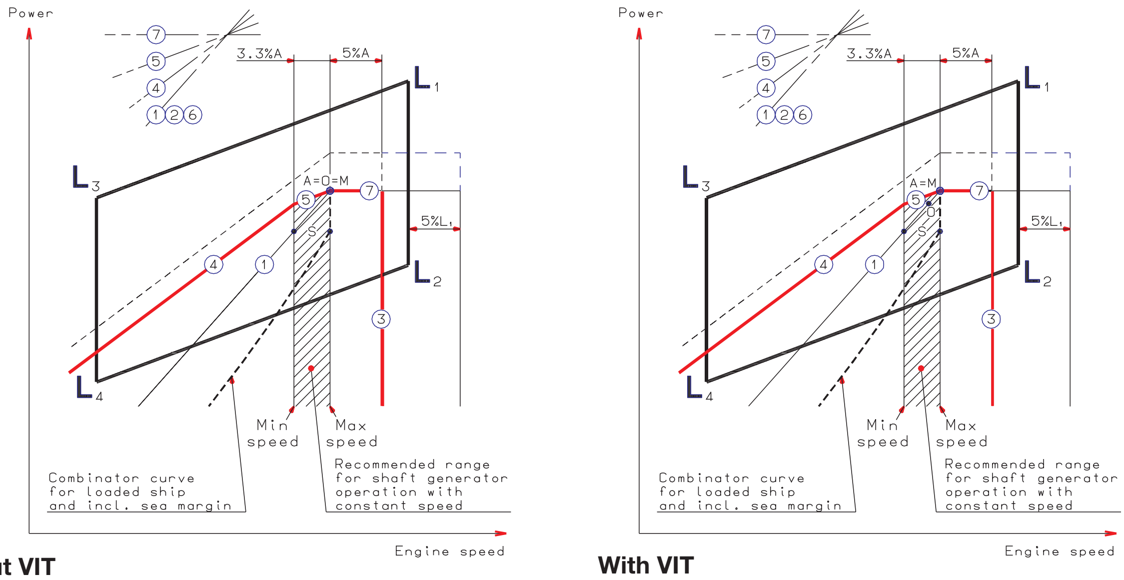
One solution could be to choose a larger diesel engine with an extra cylinder, but another and cheaper solution is to reduce the electrical power production of the shaft generator when running in the upper propulsion power range.

In choosing the latter solution, the required specified MCR power can be reduced from point M' to point M as shown in Fig. 2.11a. 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 A, having the highest possible power, is then found at the intersection of line L_1-L_3 with line 1, see Fig. 2.11a, and the corresponding load diagram is drawn in Fig. 2.11b. Point M is found on line 7 at MP's speed.

Example 5:
Engine coupled to controllable pitch propeller (CPP) with or without shaft generator



Without VIT

M Specified MCR of engine
S Continuous service rating of engine

With VIT

O Optimising point of engine
A Reference point of load diagram

178 39 31-4.1

Fig. 2.12: Example 5: Engine with Controllable Pitch Propeller (CPP), with or without shaft generator

Fig. 2.12 shows two examples: on the left diagrams for an engine without VIT fuel pumps (A = O = M), on the right, for an engine with VIT fuel pumps (A = M).

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 as shown in Fig. 2.12 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 in Fig. 2.12 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 3 and 4 for engines with FPP can also be applied here for engines with CPP running with a combinator curve.

The optimising point O for engines with VIT may be chosen on the propeller curve through point A = M with an optimised power from 85 to 100% of the specified MCR as mentioned before in the section dealing with optimising point O.

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 as point A of 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.

Example 6 will give a more detailed description of how to run constant speed with a CP propeller.

Example 6: Engines with VIT fuel pumps running at constant speed with controllable pitch propeller (CPP)

Fig. 2.13a Constant speed curve through M, normal and correct location of the optimising point O

Irrespective of whether the engine is operating on a propeller curve or on a constant speed curve through M, the optimising point O must be located on the propeller curve through the specified MCR point M or, in special cases, to the left of point M.

The reason is that the propeller curve 1 through the optimising point O is the layout curve of the engine, and the intersection between curve 1 and the maximum power line 7 through point M is equal to 100% power and 100% speed, point A of the load diagram - in this case A=M.

In Fig. 2.13a the optimising point O has been placed correctly, and the step-up gear and the shaft generator, if installed, may be synchronised on the constant speed curve through M.

Fig. 2.13b: Constant speed curve through M, **wrong position** *of optimising point O*

If the engine has been service-optimised in point O on a constant speed curve through point M, then the specified MCR point M would be placed outside the load diagram, and this is not permissible.

Fig. 2.13c: Recommended constant speed running curve, lower than speed M

In this case it is assumed that a shaft generator, if installed, is synchronised at a lower constant main engine speed (for example with speed equal to O or lower) at which improved CP propeller efficiency is obtained for part load running.

In this layout example where an improved CP propeller efficiency is obtained during extended periods of part load running, the step-up gear and the shaft generator have to be designed for the applied lower constant engine speed.

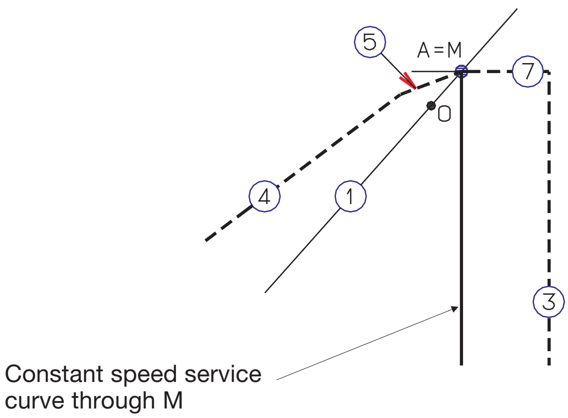


Fig. 2.13a: Normal procedure

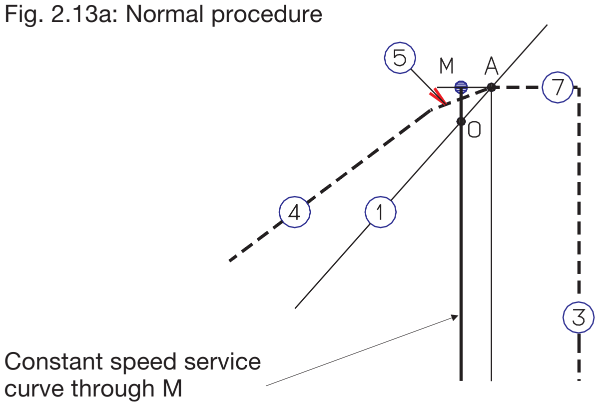


Fig. 2.13b: Wrong procedure

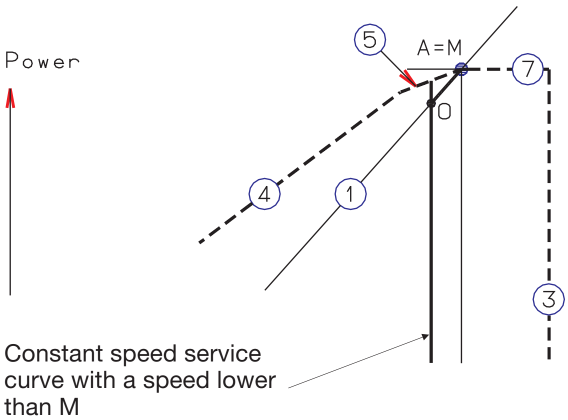


Fig. 2.13c: Recommended procedure

Engine speed

Logarithmic scales

M: Specified MCR
O: Optimised point
A: 100% power and speed of load diagram (normally A=M)

178 19 69-9.0

Fig. 2.13: Running at constant speed with CPP

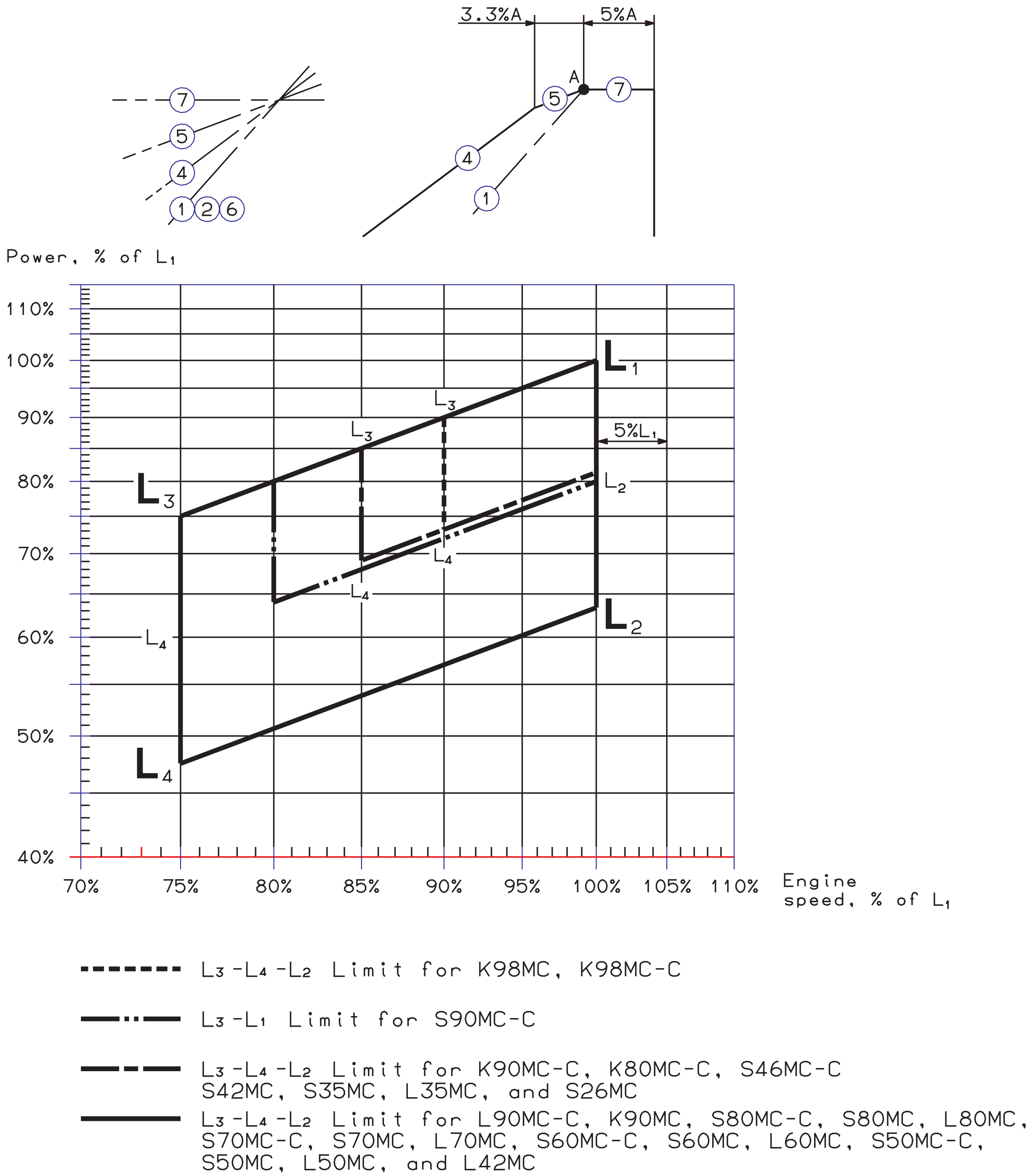


Fig. 2.14 contains a layout diagram that can be used for construction of the load diagram for an actual project, using the %-figures stated and the inclinations of the lines.

178 46 87-5.0

Fig. 2.14: Diagram for actual project

Emission Control

IMO NO_x emission limits

All MC engines are delivered so as to comply with the IMO speed dependent NO_x limit, measured according to ISO 8178 Test Cycles E2/E3 for Heavy Duty Diesel Engines.

The Specific Fuel Oil Consumption (SFOC) and the NO_x are interrelated parameters, and an engine offered with a guaranteed SFOC and also guaranteed to comply with the IMO NO_x limitation will be subject to a 5% fuel consumption tolerance.

30-50% NO_x reduction

Water emulsification of the heavy fuel oil is a well proven primary method. The type of homogenizer is either ultrasonic or mechanical, using water from the freshwater generator and the water mist catcher. The pressure of the homogenised fuel has to be increased to prevent the formation of the steam and cavitation. It may be necessary to modify some of the engine components such as the fuel pumps, camshaft, and the engine control system.

Up to 95-98% NO_x reduction

This reduction can be achieved by means of secondary methods, such as the SCR (Selective Catalytic Reduction), which involves an after-treatment of the exhaust gas.

Plants designed according to this method have been in service since 1990 on four vessels, using Haldor Topsøe catalysts and ammonia as the reducing agent, urea can also be used.

The compact SCR unit can be located separately in the engine room or horizontally on top of the engine. The compact SCR reactor is mounted before the turbocharger(s) in order to have the optimum working temperature for the catalyst.

More detailed information can be found in our publications:

P. 331 Emissions Control, Two-stroke Low-speed Engines
P. 333 How to deal with Emission Control.

Specific Fuel Oil Consumption

Engine with from 98 to 50 cm bore engines are as standard fitted with high efficiency turbochargers. The smaller bore from 46 to 26 cm are fitted with the so-called "conventional" turbochargers

High efficiency/conventional turbochargers

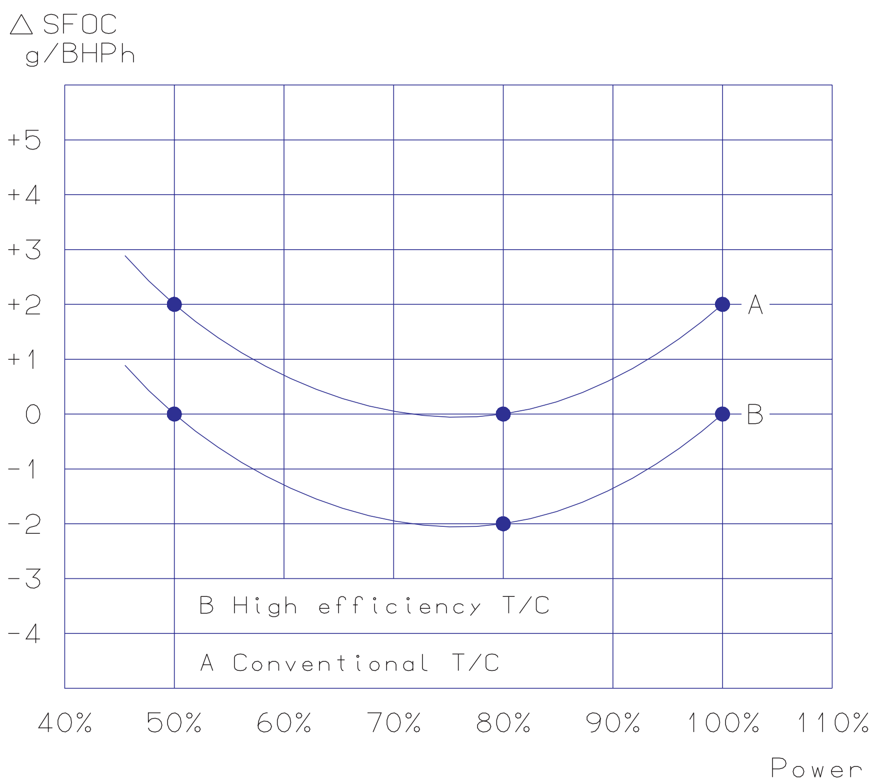
Some engine types are as standard fitted with high efficiency turbochargers but can alternatively use conventional turbochargers. These are: S70MC-C, S70MC, S60MC-C, S60MC, L60MC, S50MC-C, S50MC and L50MC.

The *high efficiency turbocharger* is applied to the engine in the basic design with the view to obtaining the lowest possible Specific Fuel Oil Consumption (SFOC) values.

With a *conventional turbocharger* the amount of air required for combustion purposes can, however, be adjusted to provide a higher exhaust gas temperature, if this is needed for the exhaust gas boiler. The matching of the engine and the turbocharging system is then modified, thus increasing the exhaust gas temperature by 20 °C.

This modification will lead to a 7-8% reduction in the exhaust gas amount, and involve an SFOC penalty of up to 2 g/BHPh, see the example in Fig. 2.15.

The calculation of the expected specific fuel oil consumption (SFOC) can be carried out by means of the following figures for fixed pitch propeller and for controllable pitch propeller, constant speed. Throughout the whole load area the SFOC of the engine depends on where the optimising point O is chosen.



178 47 08-1.0

Fig. 2.15: Example of part load SFOC curves for the two engine versions

SFOC at reference conditions

The SFOC is based on the reference ambient conditions stated in ISO 3046/1-1986:

1,000 mbar ambient air pressure
25 °C ambient air temperature
25 °C scavenge air coolant temperature

and is related to a fuel oil with a lower calorific value of 10,200 kcal/kg (42,700 kJ/kg).

For lower calorific values and for ambient conditions that are different from the ISO reference conditions, the SFOC will be adjusted according to the conversion factors in the below table provided that the maximum combustion pressure (P_{max}) is adjusted to the nominal value (left column), or if the P_{max} is not re-adjusted to the nominal value (right column).

		With P_{max} adjusted	Without P_{max} adjusted
Parameter	Condition change	SFOC change	SFOC change
Scav. air coolant temperature	per 10 °C rise	+ 0.60%	+ 0.41%
Blower inlet temperature	per 10 °C rise	+ 0.20%	+ 0.71%
Blower inlet pressure	per 10 mbar rise	- 0.02%	- 0.05%
Fuel oil lower calorific value	rise 1% (42,700 kJ/kg)	-1.00%	- 1.00%

With for instance 1 °C increase of the scavenge air coolant temperature, a corresponding 1 °C increase of the scavenge air temperature will occur and involves an SFOC increase of 0.06% if P_{max} is adjusted.

SFOC guarantee

The SFOC guarantee refers to the above ISO reference conditions and lower calorific value, and is guaranteed for the power-speed combination in which the engine is optimised (O).

The SFOC guarantee is given with a margin of 5% for engines fulfilling the IMO NO_x emission limitations.

As SFOC and NO_x are interrelated paramaters, an engine offered without fulfilling the IMO NO_x limitations only has a tolerance of 3% of the SFOC.

Examples of graphic calculation of SFOC

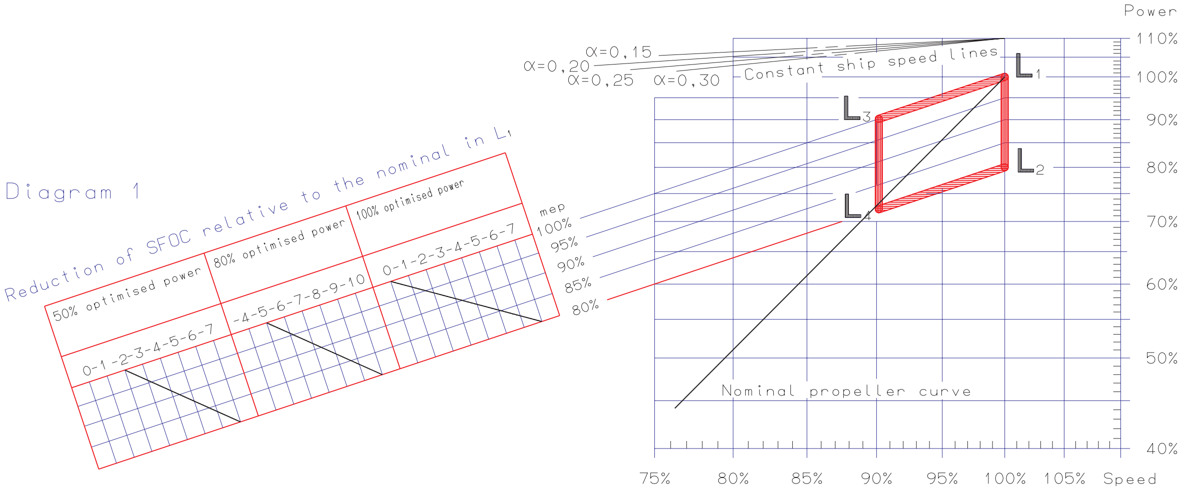
Diagram 1 in the following figures are valid for fixed pitch propeller and constant speed, respectively, shows the reduction in SFOC, relative to the SFOC at nominal rated MCR L_1.

The solid lines are valid at 100, 80 and 50% of the optimised power (O).

The optimising point O is drawn into the above-mentioned Diagram 1. A straight line along the constant mep curves (parallel to L_1-L_3) is drawn through the optimising point O. The line intersections of the solid lines and the oblique lines indicate the reduction in specific fuel oil consumption at 100%, 80% and 50% of the optimised power, related to the SFOC stated for the nominal MCR (L_1) rating at the actually available engine version.

The SFOC curve for an engine with conventional turbocharger is identical to that for an engine with high efficiency turbocharger, but located at 2 g/BHPh higher level.

In Fig. 2.24 an example of the calculated SFOC curves are shown on Diagram 2, valid for two alternative engine ratings: O_1 = 100% M and O_2 = 85%M for a 6S70MC-C with VIT fuel pumps.



178 44 22-7.1

Engine	kW/cyl.	BHP/cyl.	r/min
6-12K98MC	5720	7780	94
6-12K98MC-C	5710	7760	104

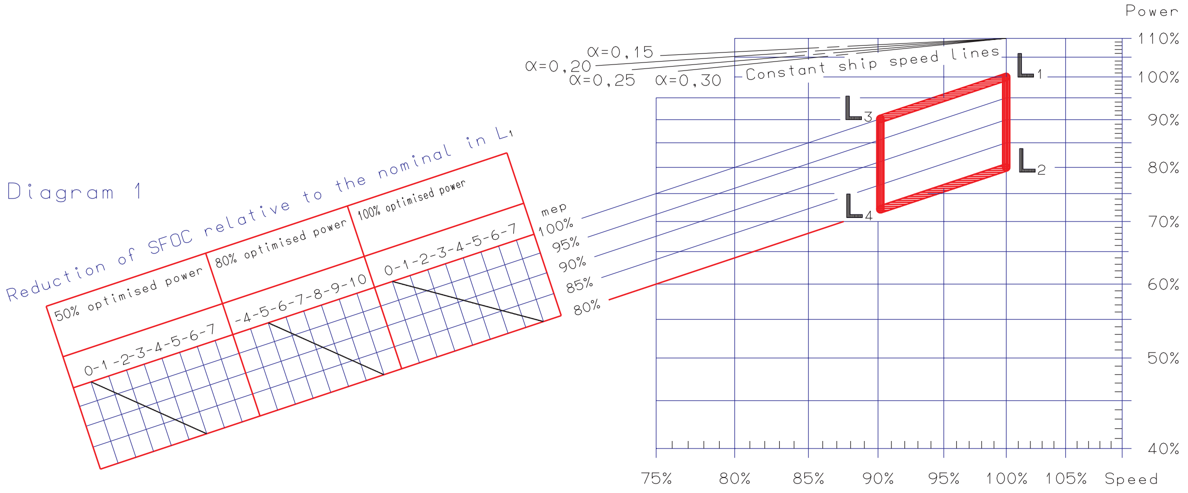
SFOC in g/BHPh at nominal MCR (L_1)	
g/kWh	**g/BHPh**
171	**126**
171	**126**

Data optimising point (O):	
Power: 100% of (O)	BHP
Speed: 100% of (O)	r/min
SFOC found:	g/BHPh

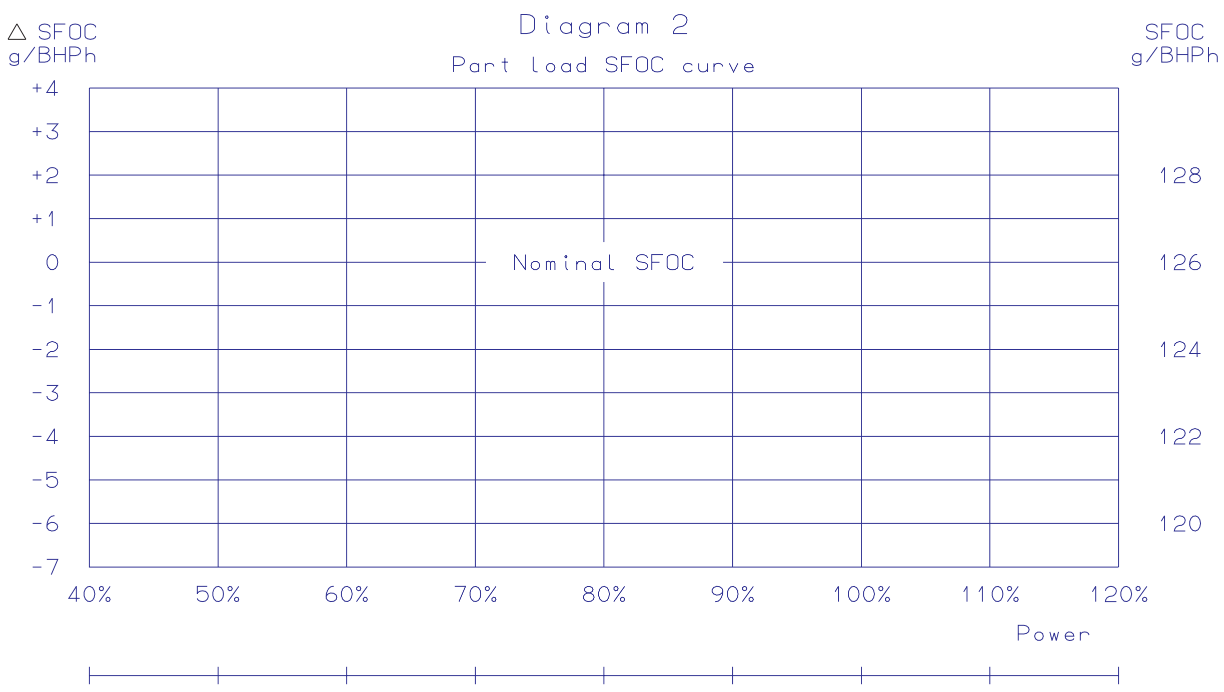
178 87 11-3.0

These figures are valid both for engines with fixed pitch propeller and for engines running at constant speed.

Fig. 2.16a: SFOC for ***engines with fixed pitch propeller****, K98MC and K98MC-C*

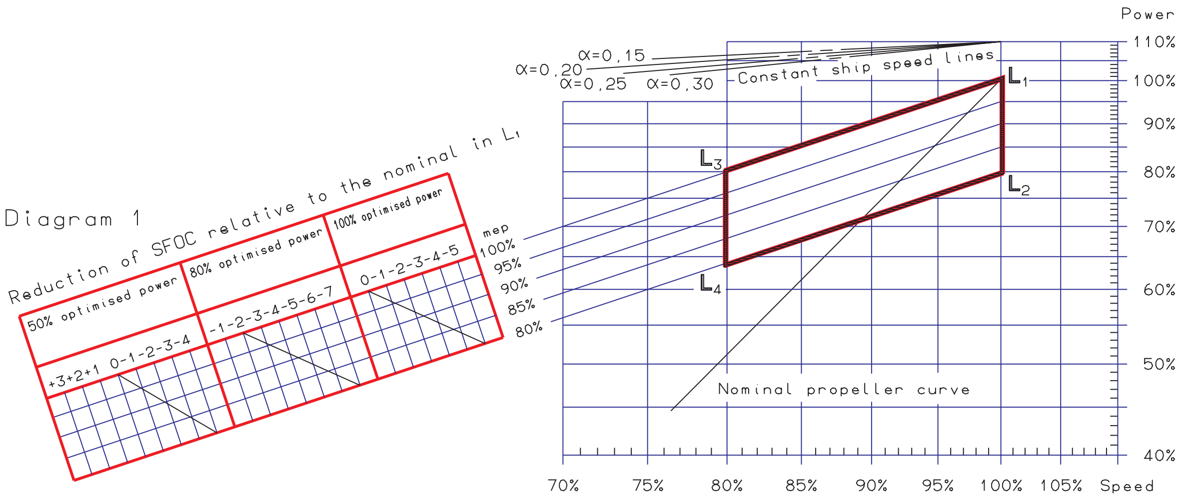


178 44 22-7.0



178 44 22-7.1

*Fig. 2.16b: SFOC for **engines with constant speed,** K98MC and K98MC-C*

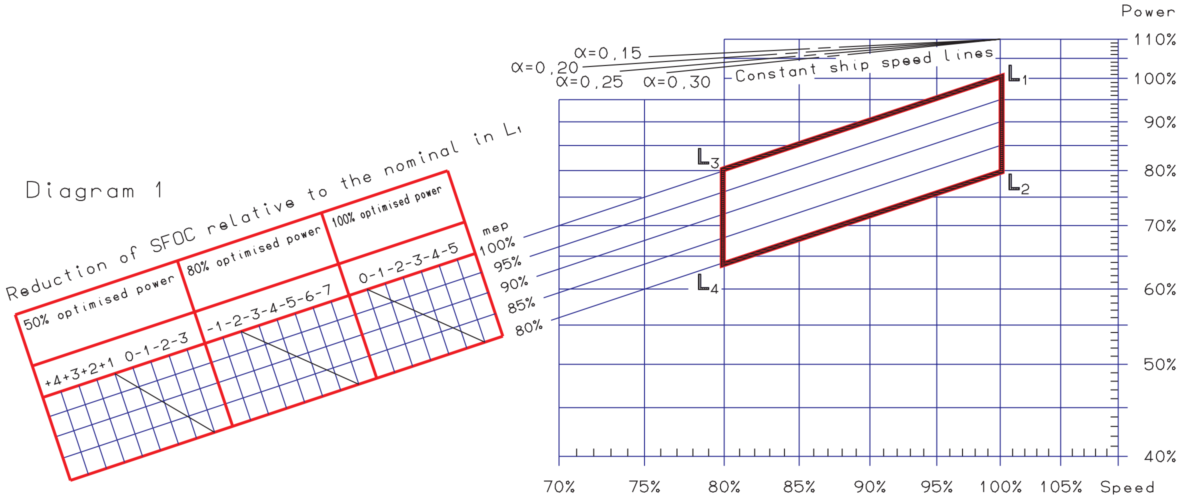


178 37 74-4.0

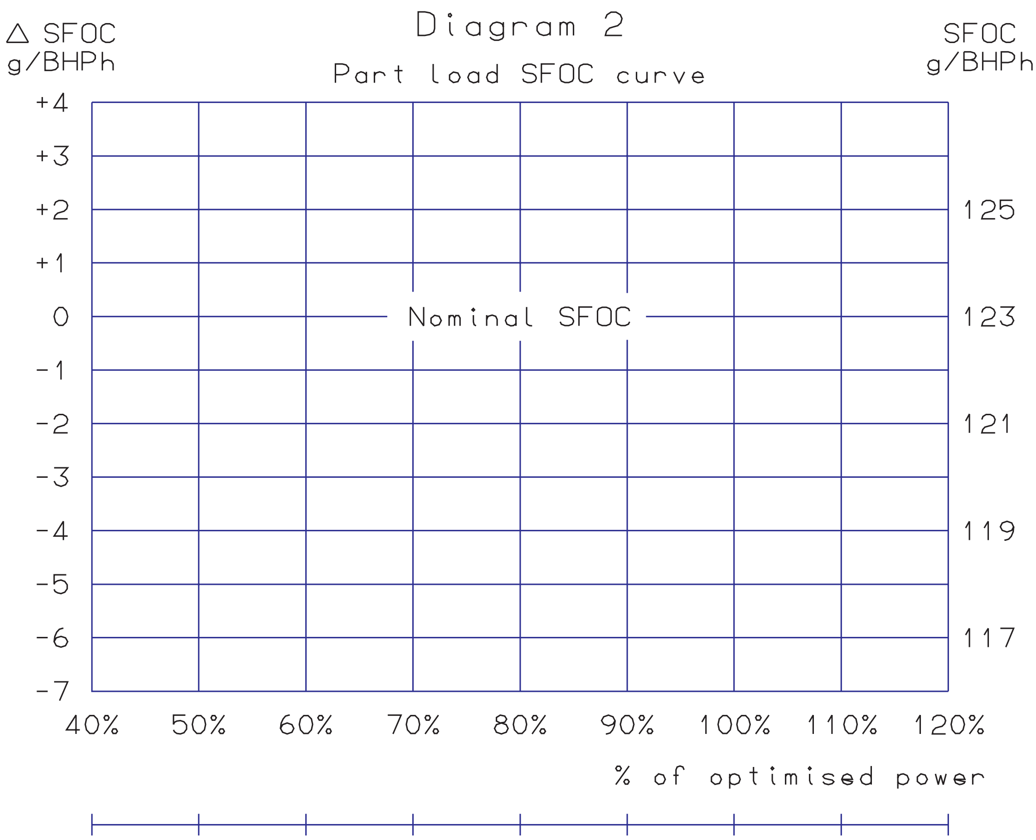
Engine	kW/cyl.	BHP/cyl.	r/min	SFOC in g/BHPh at nominal MCR (L_1) g/kWh	SFOC in g/BHPh at nominal MCR (L_1) g/BHPh
6-9S90MC-C	4890	6650	76	167	**123**

178 87 12-5.0

Fig. 2.17a: Example of SFOC for ***engines with fixed pitch propeller****, S90MC-C*

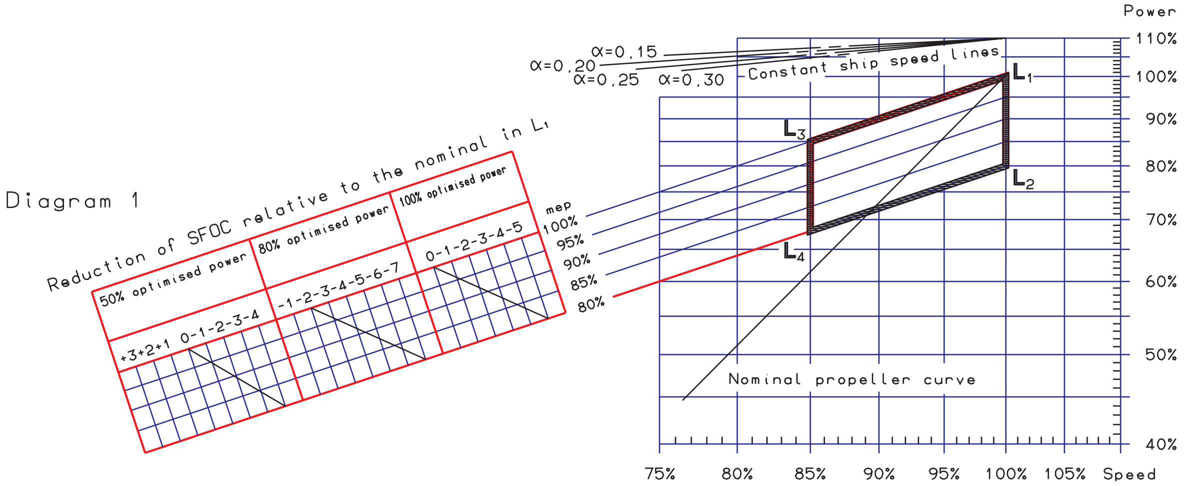


178 37 75-6.0



178 11 68-5.0

Fig. 2.17b: Example of SFOC for ***engines with constant speed,*** *S90MC-C*



178 06 87-7.0

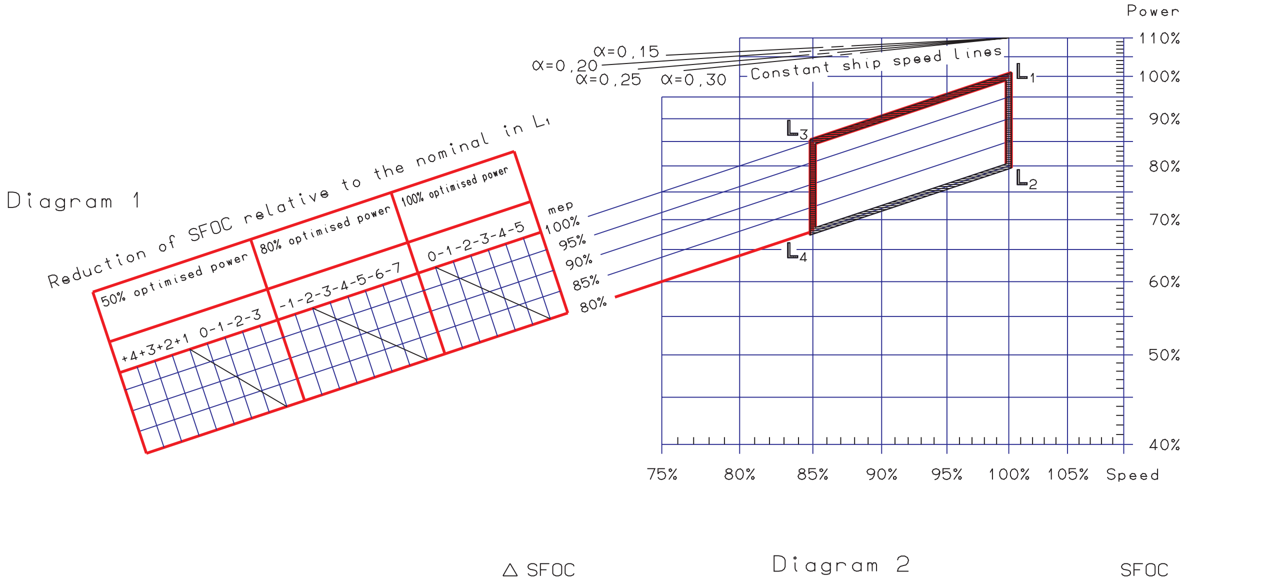
)Engine	kW/cyl.	BHP/cyl.	r/min	SFOC in g/BHPh at nominal MCR (L_1)	
				g/kWh	**g/BHPh**
6-12K90MC-C	4560	6210	104	171	**126**
6-12K80MC-C	3610	4900	104	171	**126**

Data optimising point (O):	
Power: 100% of (O)	BHP
Speed: 100% of (O)	r/min
SFOC:	g/BHPh

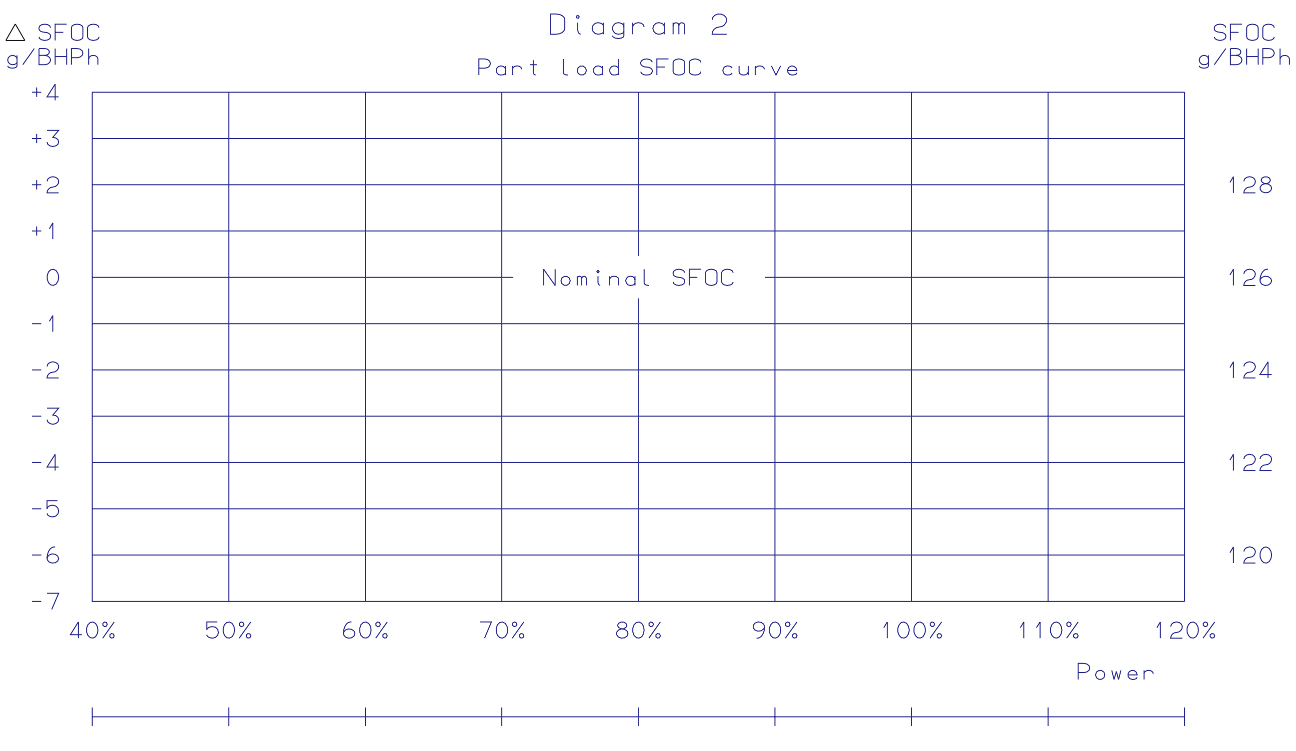
178 87 13-7.0

178 39 35-1.0

Fig. 2.18a: Example of SFOC for ***engines with fixed pitch propeller,*** *K90MC-C and K80MC-C*

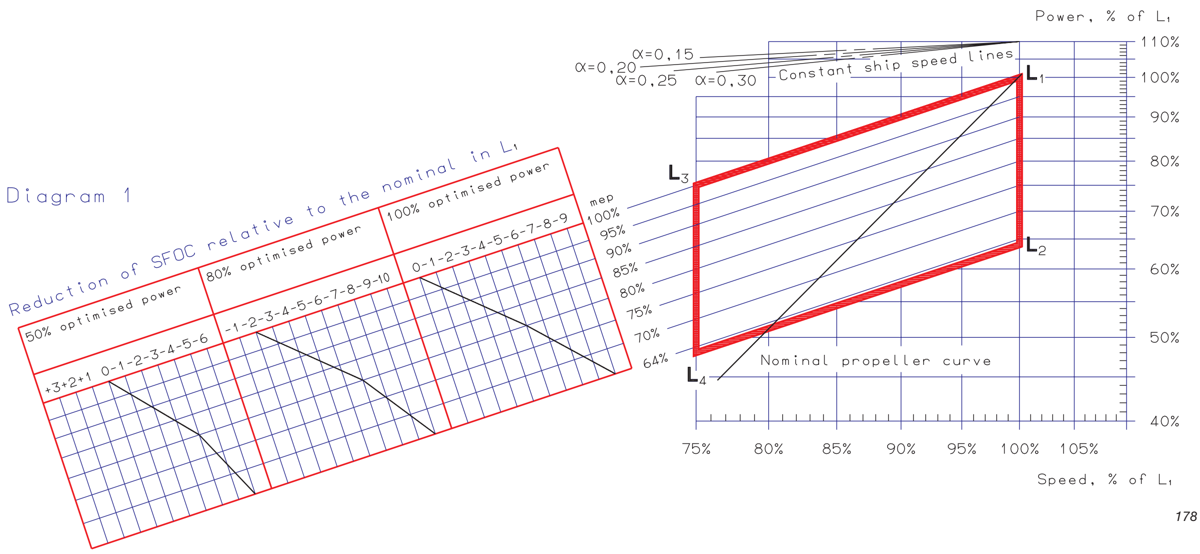


178 06 89-0.0



178 44 22-7.1

Fig. 2.18b: Example of SFOC for ***engines with constant speed,*** *K90MC-C and K80MC-C*



178 15 92-3.0

Engine	kW/cyl.	BHP/cyl.	r/min	SFOC in g/BHPh at nominal MCR (L_1)			
				Turbochargers			
				High efficiency		Conventional	
				g/kWh	**g/BHPh**	g/kWh	**g/BHPh**
6-12L90MC-C	4890	6650	83	167	**123**		
4-12K90MC	4570	6220	94	171	**126**		
6-8S80MC-C	3880	5280	76	167	**123**		
4-9S80MC	3840	5220	79	167	**123**		
4-12L80MC	3640	4940	93	174	**128**		
4-8S70MC-C*	3105	4220	91	169	**124**	171	**126**
4-8S70MC	2810	3820	91	169	**124**	171	**126**
4-8L70MC	2830	3845	108	174	**128**		
4-8S60MC-C*	2255	3070	105	170	**125**	173	**127**
4-8S60MC	2040	2780	105	170	**125**	173	**127**
4-8L60MC	1920	2600	123	171	**126**	174	**128**
4-8S50MC-C*	1580	2145	127	171	**126**	174	**128**
4-8S50MC	1430	1940	127	171	**126**	174	**128**
4-8L50MC	1330	1810	148	173	**127**	175	**129**
4-12L42MC*	995	1355	176			177	**130**

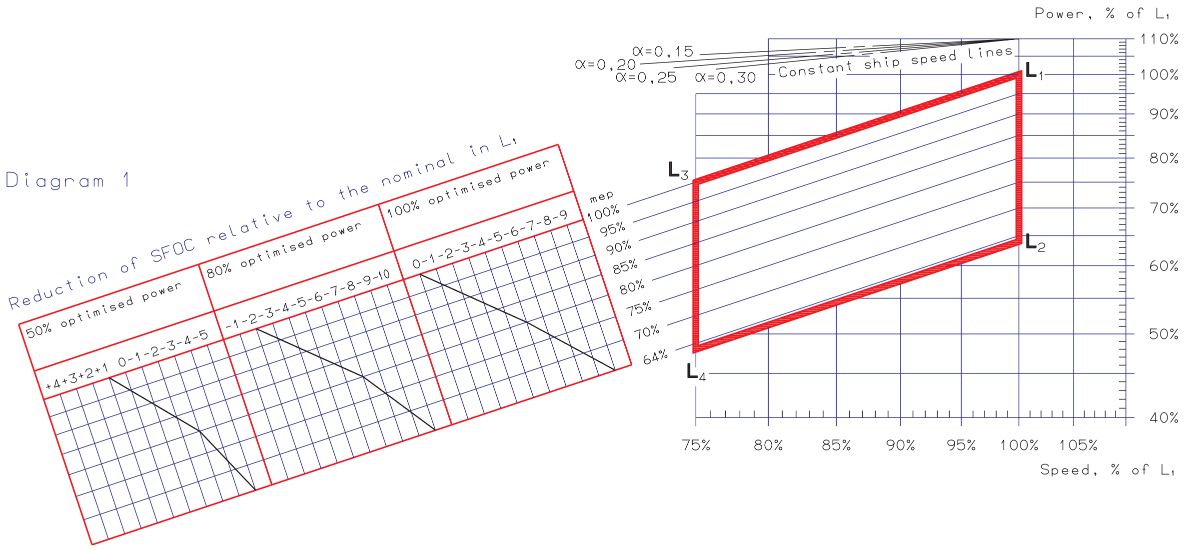
* Note: Engines without VIT fuel pumps have to be optimised at the specified MCR power

These figures are valid both for engines with fixed pitch propeller and for engines running at constant speed.

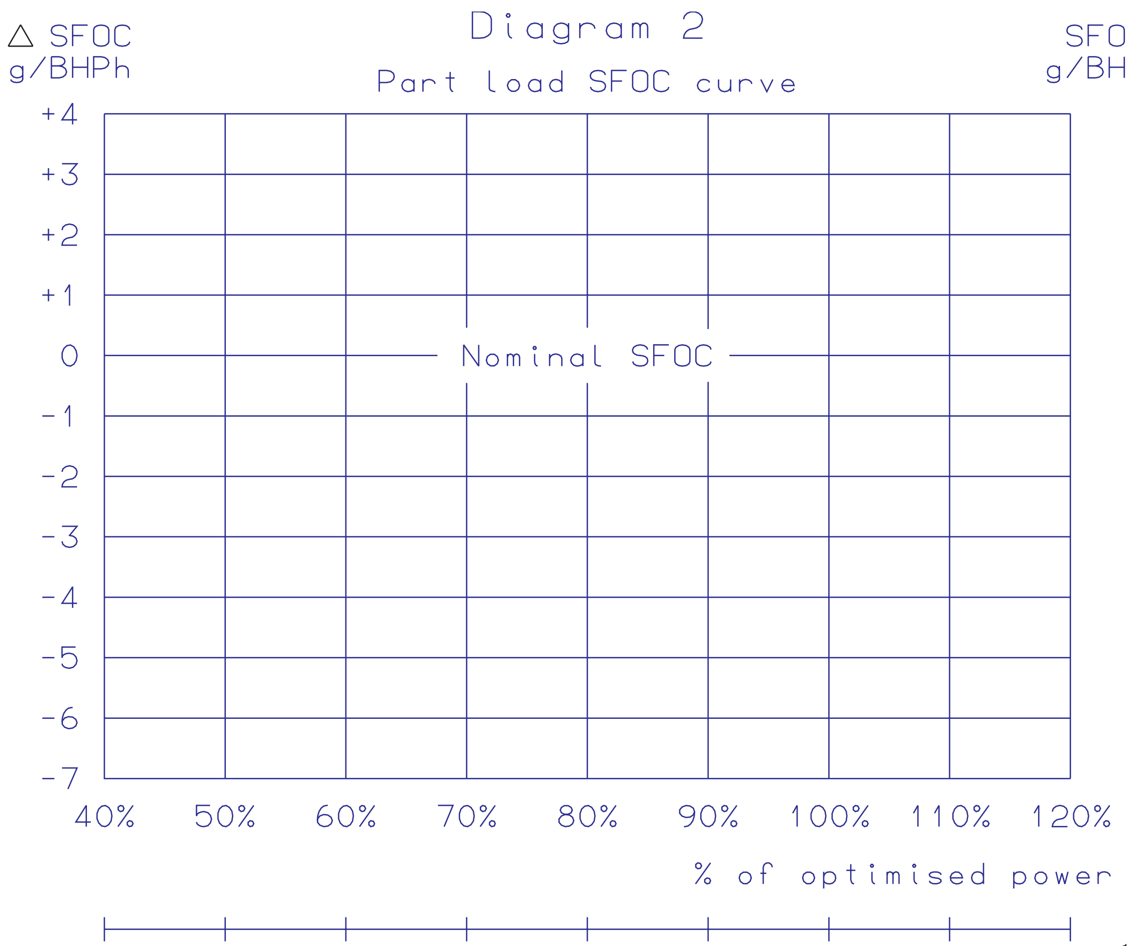
Data optimising point (O):	
Power: 100% of (O)	BHP
Speed: 100% of (O)	r/min
SFOC found:	g/BHPh

178 43 63-9.0

Fig. 2.19a: Example of SFOC for ***engines with fixed pitch propeller****, L90 - L42*

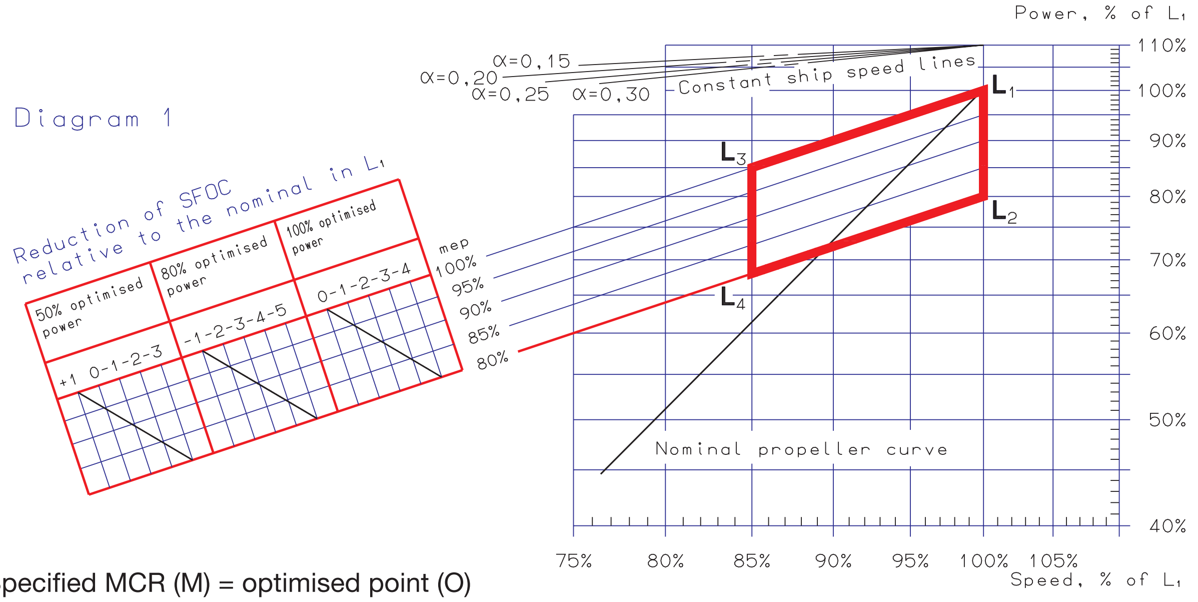


178 15 91-1.0



178 43 63-9.0

*Fig. 2.19b: Example of SFOC for **engines with constant speed**, L90 - L42*



Specified MCR (M) = optimised point (O)

178 06 88-9.0

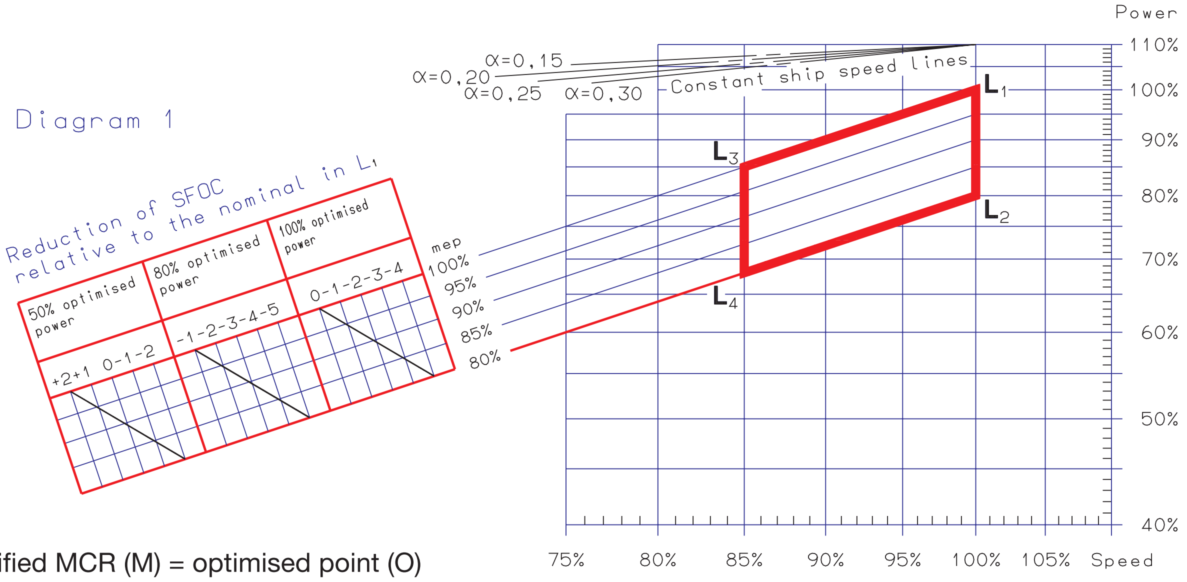
SFOC in g/BHPh at nominal MCR (L_1)					
Engine	kW/cyl.	BHP/cyl.	r/min	g/kWh	**g/BHPh**
4-8S46MC-C	1310	1785	129	174	**128**
4-12S42MC	1080	1470	136	177	**130**
4-12S35MC	740	1010	173	178	**131**
4-12L35MC	650	880	210	177	**130**
4-12S26MC	400	545	250	179	**132**

178 87 15-0.0

Data optimising point (O):	
Power: 100% of (O)	BHP
Speed: 100% of (O)	r/min

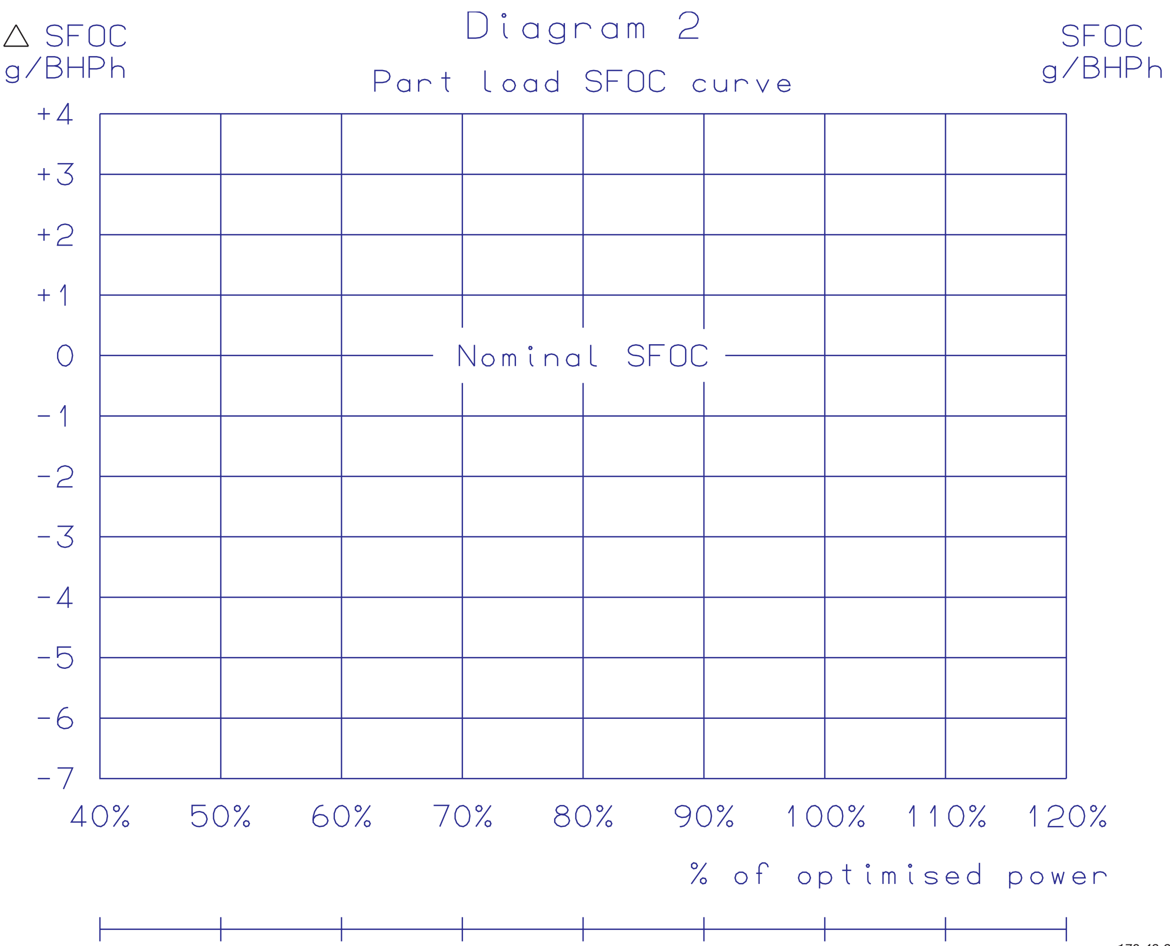
These figures are valid both for engines with fixed pitch propeller and for engines running at constant speed.

Fig. 2.20a: Example of SFOC for ***engines with fixed pitch propeller****, S46MC-C, S42MC, S/L35MC and S26MC*



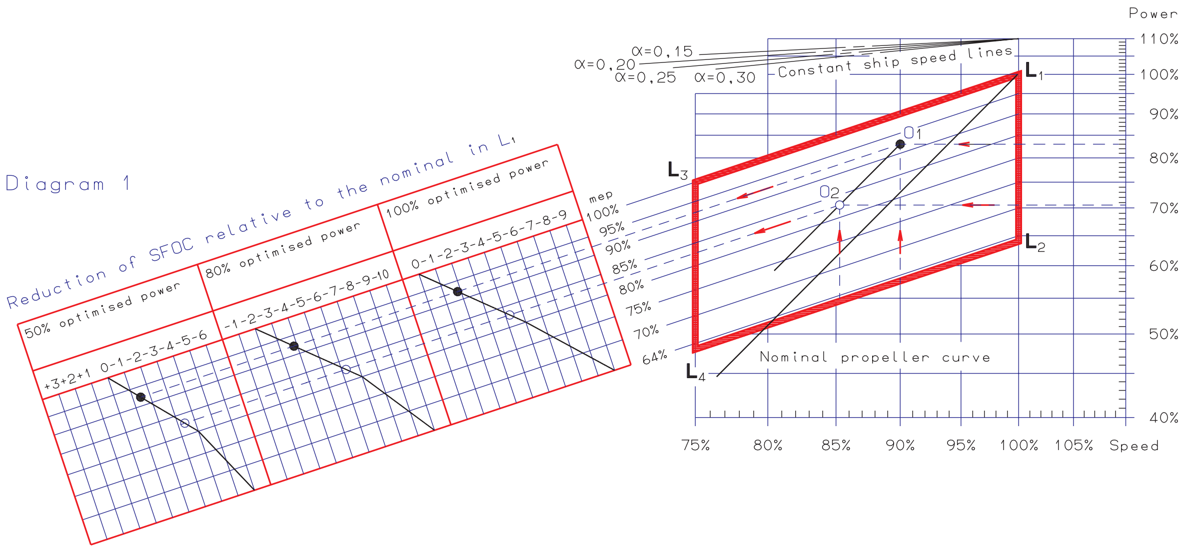
Specified MCR (M) = optimised point (O)

178 06 90-0.0



178 43 63-9.0

Fig. 2.20b: Example of SFOC for ***engines with constant speed****, S46MC-C, S42MC, S/L35MC and S26MC*



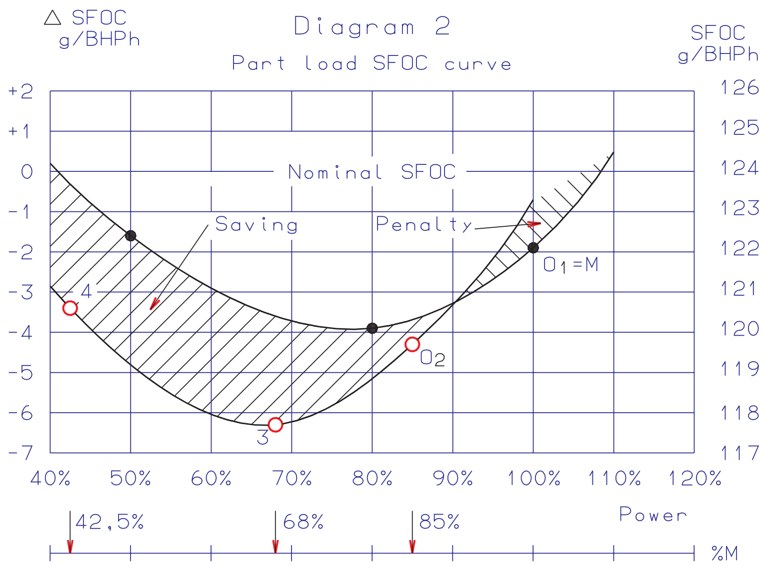
178 15 88-8.0

Data at nominal MCR (L1): 6S70MC-C		
100% Power:	25,320	BHP
100% Speed:	91	r/min
High efficiency turbocharger:	124	g/BHPh

Data of optimising point (O)	O1	O2
Power: 100% of O	21,000 BHP	17,850 BHP
Speed: 100% of O	81.9 r/min	77.4 r/min
SFOC found:	122.1 g/BHPh	119.7 g/BHPh

178 43 66-4.0

Note: Engines without VIT fuel pumps have to be optimised at the specified MCR power



O_1: Optimised in M
O_2: Optimised at 85% of power M
Point 3: is 80% of O_2 = 0.80 x 85% of M = 68% M
Point 4: is 50% of O_2 = 0.50 x 85% of M = 42.5% M

178 43 67-6.0

Fig. 2.21: Example of SFOC for 6S70MC-C with fixed pitch propeller, high efficiency turbocharger and VIT fuel pumps

Fuel Consumption at an Arbitrary Load

Once the engine has been optimised in point O, shown on this Fig., the specific fuel oil consumption in an arbitrary point S_1, S_2 or S_3 can be estimated based on the SFOC in points "1" and "2".

These SFOC values can be calculated by using the graphs for fixed pitch propeller (curve I) and for the constant speed (curve II), obtaining the SFOC in points 1 and 2, respectively.

Then the SFOC for point S_1 can be calculated as an interpolation between the SFOC in points "1" and "2", and for point S_3 as an extrapolation.

The SFOC curve through points S_2, to the left of point 1, is symmetrical about point 1, i.e. at speeds lower than that of point 1, the SFOC will also increase.

The above-mentioned method provides only an approximate figure. A more precise indication of the expected SFOC at any load can be calculated by using our computer program. This is a service which is available to our customers on request.

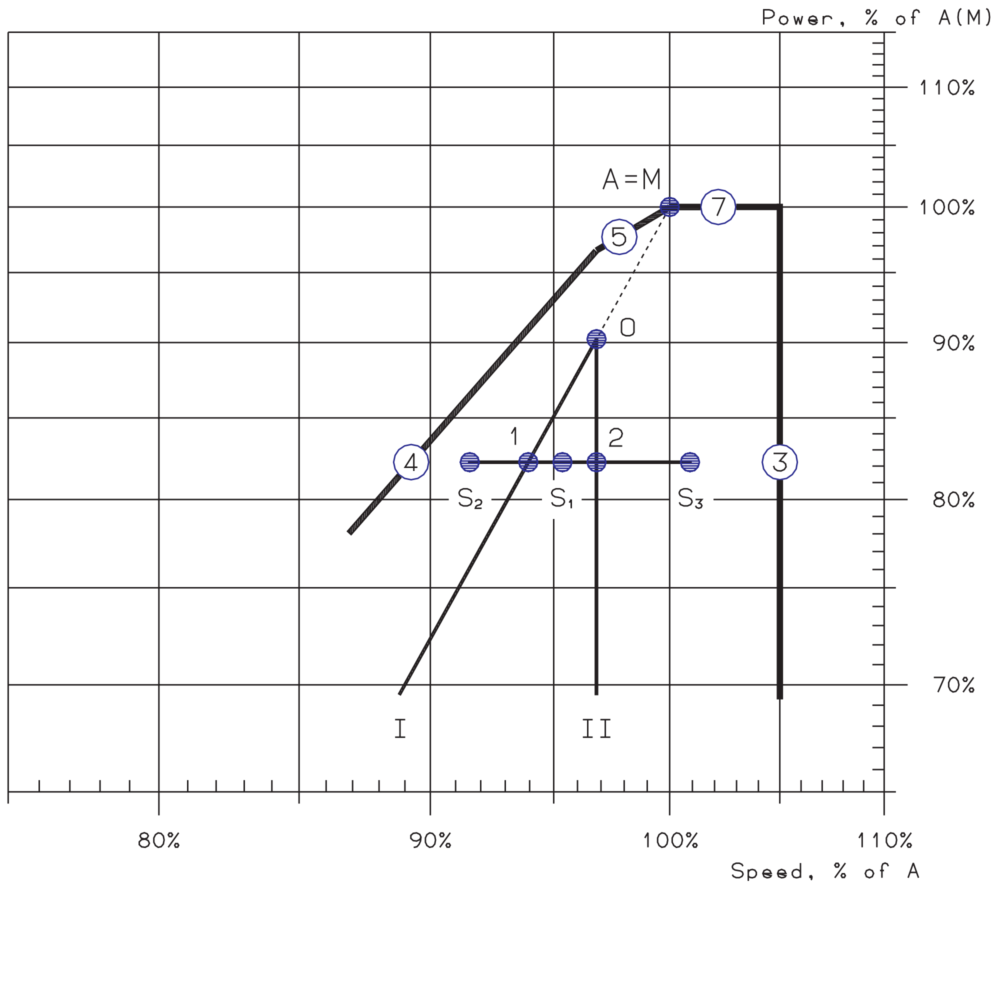


Fig. 2.22: SFOC at an arbitrary load