Engine layout and load diagram

Engine layout limitations

As Fig. 2.03.01 shows, an engine's layout diagram is limited by:

1. Constant mean effective pressure (MEP) lines (L_1– L_3 and L_2– L_4)
2. Constant engine speed lines (L_1– L_2 and L_3– L_4).

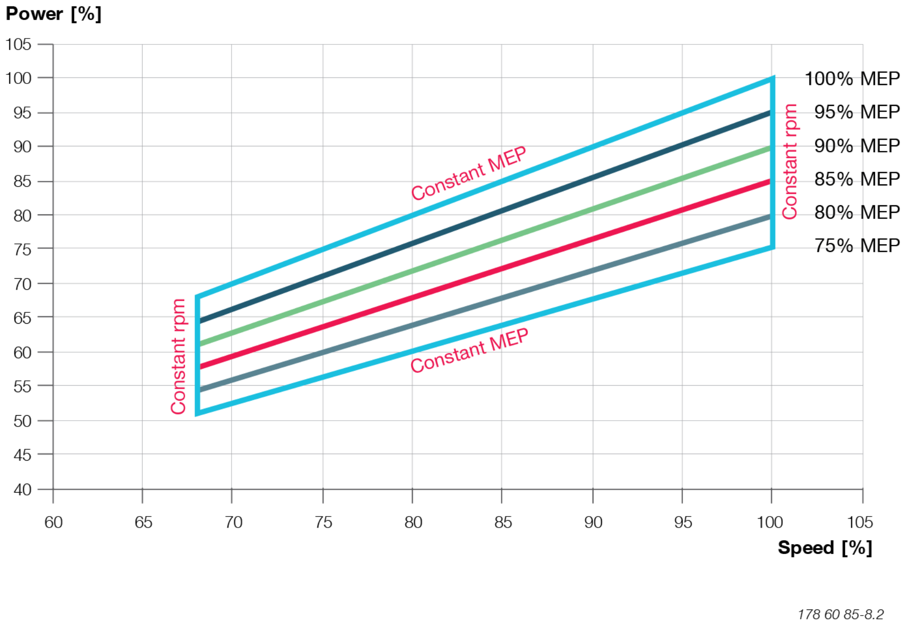

Fig. 2.03.01: Engine layout diagram with limits

Within the layout area, there is complete freedom to select the engine's specified maximum continuous rating (SMCR), point MP, which suits the ship's demand for power and speed.

The nominal maximum continuous rating (NMCR) of an engine design is equivalent to L_1 in the layout area.

The effective power, P, of a combustion engine is proportional to the mean effective pressure, pe, and engine speed, n. The expression for P, where c is a constant, is:

$P= c \times p_e \times n$

For constant mean effective pressure (MEP), the power is proportional to the speed:

$P= c \times n^1$ (for constant MEP)

When running with a fixed pitch propeller (FPP), the power can be expressed according to the propeller law as:

$P= c \propto n^3$ (propeller law)

Although the proportionality, $P \propto k \times V^3$. between the required power and the cubic, i.e. $n_i = 3$, of the speed is often referred to as a law, it is an assumption valid only for frictional resistance. If the ship has sufficient engine power for

2.03 Engine layout and load diagram

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operating at elevated speeds, the wave making resistance must be considered. At elevated ship speeds, V, the exponent can be higher, for example, $P \propto k \times V^4$.

Normally, estimates of the necessary propeller power and speed, n, are based on theoretical calculations for the design condition of the ship, and often also on computer simulations along with experimental tank tests. Calculations and simulations are based on optimum operating conditions, that is, a clean hull, good weather and calm seas.

Specified maximum continuous rating within the layout area

Based on the propulsion and engine running points, the layout diagram of the relevant main engine can be drawn in a power-speed diagram like in Fig. 2.03.01. The SMCR, point MP, must be placed inside the limitation lines of the layout diagram. Otherwise, the propeller speed has to be changed, or another main engine type must be chosen. The selected SMCR influences the mechanical design of the engine, for example, turbocharger, piston shims, liners, and fuel valve nozzles.

Once the specified SMCR has been chosen, the engine design, and the capacities of the auxiliary equipment will be adapted to the SMCR, as reflected in CEAS reports.

If the SMCR is changed later on, it may involve a change of:

- shafting system
- vibrational characteristics
- pump and cooler capacities
- fuel valve nozzles
- piston shims
- cylinder liner cooling, and lubrication.

Furthermore, it may be necessary to re-match the turbocharger, or even to change to a different size of turbocharger. Sometimes, such a change also requires a piping system of larger dimensions. If the specification has to be prepared for a later change of SMCR, it is important to consider this already at the project stage. It can be an option to design the ship with a derated engine, and auxiliaries (coolers, pumps and pipe dimensions, shafting, and so on) that are sufficient for a later uprating of the engine. This engine is termed a dual-rated engine. Note, that EEDI regulations must permit this.

If a dual-rated engine is ordered, it is beneficial to carry out the testing necessary to get the IMO technical file for the alternative SMCR during shop testing of the engine. When testing is done before ship delivery, the more expensive in-ship testing of the engine is avoided. For all fuel variants of the ME-C engines, the timing of fuel injection and the timing of 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.

Various tunings are available for pure Tier II engines. These tunings allow optimisation of an engine for the specific needs of a project. There are no tunings available for Tier III engines. See the later section “Example of SFOC curves”.

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Engine load diagram and limitations

Definitions

A load diagram defines the power and speed limits for continuous and overload operation of the installed engine, see Fig. 2.03.02.

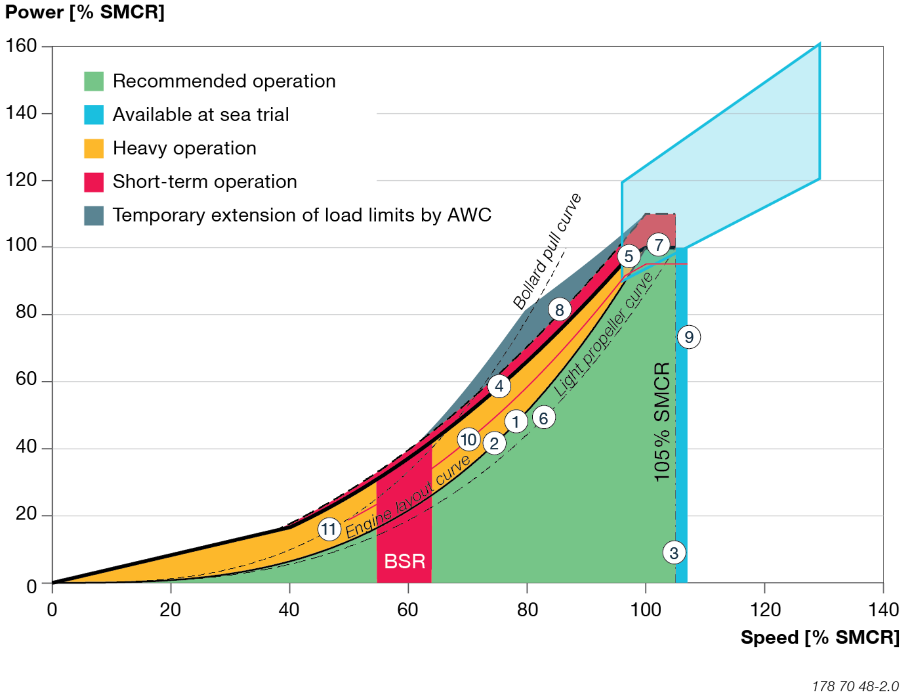

Fig. 2.03.02: Engine load diagram with adverse weather condition (AWC) function for SMCR placed within the layout diagram (light blue)

The specified MCR, point MP, of the engine corresponds to the ship specification. The service points of the installed engine incorporate the engine power required for ship propulsion, and by the shaft generator.

Operating curves and limits

The lines on Fig. 2.03.02 describe the service range of the engine. We will refer to these lines throughout section 2.03. The location of the SMCR point within the layout diagram does not affect the appearance of the load diagram. The SMCR point alone defines the load diagram, since all specifications utilise the maximum capabilities of the engine design. See the later section on "Derating for lower specific fuel oil consumption".

Line 1:
Engine layout curve, per definition passing through 100% SMCR rpm, and 100% SMCR power. This curve coincides with the "heavy propeller curve", line 2. An engine without PTO will typically operate to the right of this curve about 95% of the time.

Line 2:
Heavy propeller curve, the light propeller curve (line 6) shifted with the light running margin to account for heavy weather, and fouled hull.

Line 3:
Maximum rpm for continuous operation. For engines with an SMCR on the line L_1-L_2 in the layout diagram, up to 105% of L_1-rpm can be utilised. If the SMCR is sufficiently speed derated, 110% of SMCR rpm, but no more than 105% of L_1-rpm, can be utilised for standard engines. Torsional vibration conditions must permit the rpm values.

If the SMCR (MP) is sufficiently speed derated, and if torsional vibration conditions permit it, more than 110% speed is possible by choosing the “extended load diagram”. The extended load diagram is described later in this chapter.

Line 4:
Torque/speed limit of the engine, limited mainly by the thermal load on the engine.

Line 5:
Represents the maximum mean effective pressure (MEP) level acceptable for continuous operation. Note, that this is only a limit at high loads, and engine speeds. At lower speeds, line 4 is a stricter limit.

Line 6:
Light propeller curve for clean hull, and calm weather, often used for propeller layout. The light running margin is the rpm margin (in percent) between the engine layout curve (lines 1 and 2) and the light propeller curve.

Line 7:
Represents the maximum power for continuous operation. Note that when increasing rpm towards lines 3 and 9, the maximum power for continuous operation cannot exceed 100%.

Line 8:
The area between lines 4, 5, 7 and line 8 represents the overload operation limit of the engine. Overload running is possible only for limited periods, 1 hour out of every 12 hours, as the resulting thermal load on the engine is high.

Line 9:
Maximum acceptable rpm at sea trial conditions with clean hull and propeller in calm water. 110% of SMCR rpm, but no more than 107% of L_1-rpm if permitted by torsional vibrations.

If point M / the SMCR of the engine is sufficiently speed derated, more than 110% speed is possible by choosing “Extended load diagram” which is described later in this chapter.

Line 10:
PTO layout limit. This curve describes the maximum combined power required by the light propeller curve and the PTO at a given rpm with a shaft generator/PTO. The PTO layout limit is to be considered when dimensioning the system. This layout limit ensures operational margin to line 4, see the subsequent section “Shaft generator/PTO layout, governor stability and integration”.

Line 11:
Bollard pull propeller curve. The heaviest propeller curve possible at zero advance speed. The bollard pull curve is typically 15 to 20% heavier than the light propeller curve, values may vary for individual designs.

AWC area
Extended overload operation limits of engines equipped with the adverse weather conditions function, the AWC function. The AWC function increases the percentage of engine power that can be developed with a heavy propeller, as long as required in an emergency.

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When the function is activated, the electronic control of the ME engine alters the cyclic process of the combustion to reduce the negative effects of developing a high engine torque at low rpm. It is done at the cost of an increased specific fuel oil consumption. Due to the resulting SFOC increase, AWC is not to be considered a replacement for an adequate light running margin. See the later section “AWC function” for a further description of this function.

Limits for low-speed running

As the fuel injection for ME engines is automatically controlled over the entire power range, the engine is able to operate down to approximately 15-20% of the nominal L_1 speed, depending on the actual propulsion system. Absolute values of minimum speed must be determined at the sea trial.

Recommendation for operation

The area between lines 1, 3 and 7 is available for continuous operation without limitation.

The area between lines 1, 4 and 5 is available for operation in shallow waters, in heavy weather, and during acceleration, that is for non-steady operation without any strict time limitation.

The area between lines 4, 5, 7 and 8 is available for overload operation for 1 out of every 12 hours.

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

In calm weather conditions, the extent of heavy running of the propeller can indicate the need for cleaning the hull, and/or polishing the propeller.

Passage of a barred speed range

If the engine and shaft line has a barred speed range (BSR), it is usually a class requirement that it can be passed quickly. The quickest way to pass the BSR is the following:

1. Set the rpm setting to a value just below the BSR
2. Wait while the ship accelerates to a ship speed corresponding to the rpm setting
3. Increase the rpm setting to a value above the BSR.

Sometimes, for example in certain manoeuvring situations inside a harbour, or at sea in adverse conditions, it may not be possible to follow the procedure for passing the BSR. Either because there is no time to wait for the ship speed to build up, or because high ship resistance makes it impossible to achieve a ship speed corresponding to the engine rpm setting. In such cases, it can be necessary to pass the BSR at low ship speed.

The most basic guidance on avoiding slow passing of the BSR is to avoid a BSR that extends higher than 60% engine rpm, while specifying a light running margin within the recommendation. If so, it is normally possible to achieve a sufficiently quick passage of the BSR in relevant conditions.

A more detailed approach is to ensure a BSR power margin, BSR_{PM}, of at least 10% in the design.

$BSR_{PM} = ((P_L - P_P)/P_P*100$

Here, P_P is the power required by the bollard pull propeller curve at the upper end of the BSR, whereas P_L is the power limit for continuous operation within the engine load diagram, line 4 in Fig. 2.03.02. As such, the BSR_{PM} expresses the excess engine power in the upper range of the BSR, and hereby the ship’s capability to pass it.

If a ship faces challenges with passing the BSR, a special function termed the "dynamic limiter function" (DLF) may be specified for diesel cycle engines. The DLF can for shorter periods increase the index limits of the engine, and ensure a faster passage of the BSR.

For 5- and 6- cylinder engines with short shaft lines, such as on many bulkers and tankers, the BSR may extend high up in the rpm range. Special attention must be given to ensure that the BSR can be passed quickly. 5- and 6- cylinder engines are as standard delivered with the DLF functionality.

For support regarding passage of the BSR, contact MAN Energy Solutions, Copenhagen at MarineProjectEngineering2s@man-es.com.

Shaft generator/PTO layout, governor stability, interface, and integration

For the dimensioning and layout of a two-stroke propulsion plant with power take-off (PTO)/shaft generator, two aspects are important to consider for the design:

- PTO layout limit: prevention of engine overload
- Governor stability evaluation: prevention of engine speed hunting, and potentially also engine overspeed

Both aspects and their interactions will be clarified in detail in the following sections. See the flowchart in Fig. 2.03.03 for an overview of the considerations needed for a specific plant.

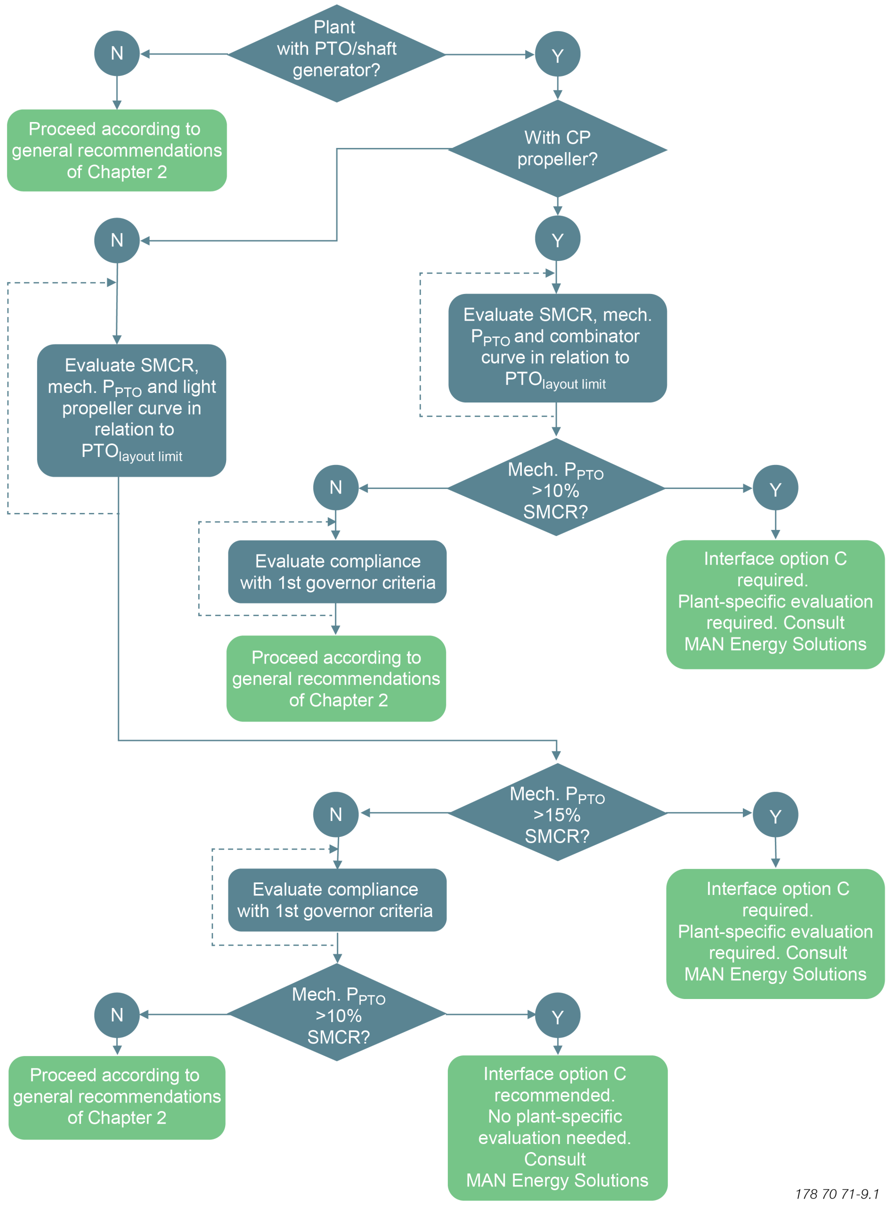

Fig. 2.03.03: Flowchart for determining evaluations needed, depending on plant characteristics

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2.03 Engine layout and load diagram

It is a prerequisite for a successful governor stability evaluation that the criteria of the PTO layout limit is fulfilled, and conversely. It is important to consider both aspects as illustrated by the flowchart. At the end of this section, considerations for the protection of the engine towards overload in service is given.

PTO layout limit

In the load diagram in Fig. 2.03.02, line 10 represents the "$PTO_{layout\ limit}$". Line 10 describes the maximum combined power required by the light propeller curve and the PTO at a given speed, *n*, when a shaft generator/PTO is installed. The minimum value of the following three equations governs the "$PTO_{layout\ limit}$". Observe the speed interval for which the second equation is applicable:

$$\mathrm{PTO}_{\mathrm{layout\ \ limit}} = \begin{cases} P_{SMCR} \times \left(\dfrac{n}{n_{SMCR}}\right)^{2.4}, & \text{for } n \in 50\% \text{ to } 96.2\% \text{ of } SMCR \\ P_{SMCR} \times 0.95 \times \left(\dfrac{n}{n_{SMCR}}\right), & \text{for } n \in 96.2\% \text{ to } 100\% \text{ of } SMCR \\ P_{SMCR} \times 0.95, & \text{for } n > 100\% \text{ of } SMCR \end{cases}$$

As marked in Fig. 2.03.02, the maximum design PTO power at a given speed is the vertical difference between line 6 (the light propeller/combinator curve of a propeller) and line 10 (the $PTO_{layout\ limit}$). PTO operation is not possible below 50% of SMCR-speed. Table 2.03.01 shows the relative PTO power available when sea conditions allow operation along the light propeller curve. At engine speeds above 50% of SMCR, the relative PTO power is given as a function of the light running margin.

Designing the combined power of the PTO and propeller according to the $PTO_{layout\ limit}$ ensures that the PTO can be operated in conditions less ideal than sea trial conditions. Note that neither the torque/speed limit (line 4) nor the MEP limit (line 5) is used for the layout of the PTO capacity.
With increased heavy running, the electric power taken off with the PTO must be decreased gradually not to push the operational point outside the engine limits. In severe cases, fouling and sea conditions alone are enough to shift the propeller curve to line 4. It these cases, the PTO cannot be utilised without overloading the engine, and the auxiliary engines must deliver all the electric energy.

It can be beneficial to increase the SMCR power and/or the light running margin for ships with a large electrical consumption, which often operate at high speeds/engine loads, or in areas with frequent encounters of adverse weather conditions. This will increase the margin from the light propeller curve to the $PTO_{layout\ limit}$ and ensure a higher availability of the PTO.

Increasing the SMCR power of the engine, while maintaining a constant propeller pitch, results in an increase of the light running margin. See Table 2.03.01 at the end of this section. When evaluating the possibility for an increase of SMCR power, compliance with EEDI regulations must be considered. See the application examples in main section “Examples of the use of load diagrams”.

For information on PTO power available at a given propeller speed as a function of the propeller light running margin, see the later section "PTO layout table".

Governor stability for plants with PTO

A PTO connected to the electric grid will deliver constant power, and introduce negative damping of the engine speed. If a vessel encounters, for example, large waves, the speed through water and the engine speed will drop. Therefore, the frequency drive will load the PTO with a higher torque to deliver the same electrical power. The torque increase enhances the speed drop experienced, and conversely for a speed increase.
To ensure a stable engine speed during operation, MAN Energy Solutions has established guidelines on governor stability for the maximum PTO power allowed.
These guidelines must be considered along with the PTO layout limit. It means that the maximum allowable PTO power to design for at any engine speed is determined as the minimum of the two aspects.

First governor stability criteria

The first governor stability criteria depicted on Fig. 2.03.04 represents a minimum with respect to governor stability at lower speeds. The criteria are valid for plants where the mechanical power of the PTO does not exceed 15% SMCR power for fixed pitch propeller (FPP) plants and 10% SMCR power for controllable pitch propeller (CPP) plants.

Fig. 2.03.04 shows three limits, which establish the first governor stability criteria for:

- FPP plants (blue solid curve)
- CPP plants, and engines with bore sizes smaller than 80 cm (orange solid curve)
- CPP, and 80-bore engines or larger (grey solid curve)

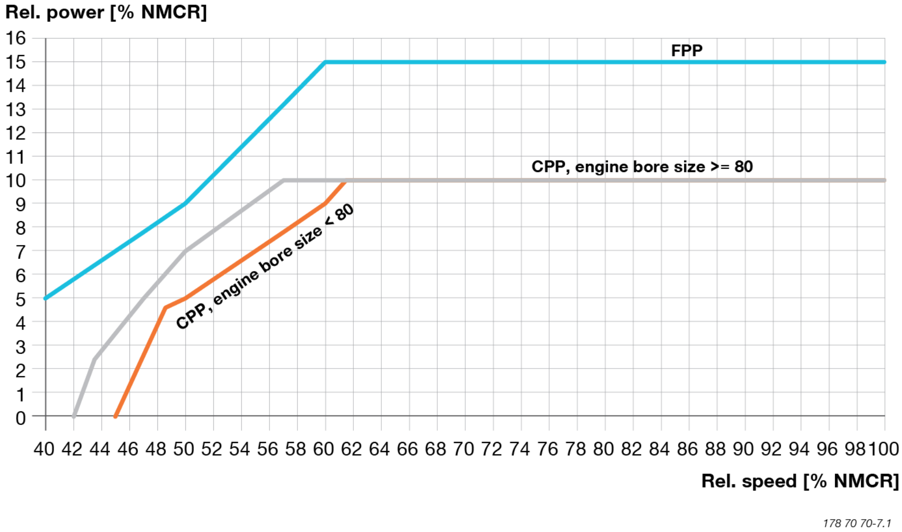

Fig. 2.03.04: First governor stability criteria for maximum mechanical PTO which ensure an acceptable governor performance and stability without interface option C. The limits relate to NMCR and are independent of the choice of SMCR

FPP		CPP < 80		CPP >= 80	
[%NMCR]	[%NMCR]	[%NMCR]	[%NMCR]	[%NMCR]	[%NMCR]
100	15.0	100.0	10.0	100.0	10.0
60	15.0	61.5	10.0	60.0	10.0
57	13.2	60.0	9.0	57.0	10.0
50	9.0	57.0	7.8	50.0	7.0
47	7.8	50.0	5.0	47.0	5.0
40	5.0	48.6	4.6	45.0	3.5
		47.0	2.6	43.5	2.4
		45.0	0.0	42.0	0.0

Table 2.03.01: First governor stability criteria for maximum mechanical PTO ensuring acceptable governor performance and stability without interface option C. The limits relate to NMCR and FPP plants, CPP plants and engines with bore sizes smaller than 80 cm, and CPP plants with 80-bore engines or larger

The limits in Fig. 2.03.04 are based on NMCR power and speed, not SMCR power and speed. This is because stability is related closely to the actual speed and the physical parameters of the engine, i.e., power and inertia, rather than the choice of SMCR.

MAN Energy Solutions must be consulted for a plant-specific PTO layout and design evaluation, if the maximum mechanical PTO load on the shaft is higher than:

- 15% of SMCR power for FPP plants,
- or 10% for CPP plants,
- or if the plant does not fulfil the first governor stability criteria.

Interface option C described in the next section is mandatory for these plants.

For FPP plants, where the mechanical PTO power exceeds 10% of SMCR power, Interface option C is recommended.

PTO operation is in any case not possible below 50% of SMCR speed.

Interfaces for PTO and PTI – integration of power management and engine control

There is an interface between the power management system (PMS) and the main engine control system (ECS) with the purpose to:

- ensure the best utilisation of the PTO
- prevent power blackout
- protect the engine against overload.

A standard handshake interface is offered, and if a trip of the PTO can cause a power blackout (i.e., the PTO is an essential power supply), it is a requirement. If the PTO cannot cause a power blackout, the standard interface without handshake can be used as an alternative.

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The interface with handshake has the three configuration options shortly described as Option A, B, and C:

Option A: With a signal indicating if PTO is allowed or not

Option B: For PTOs with a speed dependent maximum power output

This interface option includes an advanced engine speed-holding function to ensure that a minimum engine speed is kept corresponding to the current PTO power. This is to prevent blackout when the PTO is the sole provider of power. If Option B is not selected, the engine speed-holding function will use a constant minimum engine speed (independent of the current PTO power).

Option C: For PTOs with a large output relative to the main engine power, see further information in the next section.

It is possible to enable more configuration options for the same engine, for example, A+B or A+B+C. For further reading, refer to the separate interface specification between ECS and PMS.

For PTOs with the option to also act as PTI, it is a requirement that the interface is used for both PTO and PTI operation.

PTO interface option C

For plants with a shaft generator more powerful than ordinary, Interface option C can be installed between the engine control system (ECS) and the power management system (PMS) to increase the maximum PTO power. This interface improves the integration of ECS and PMS, and enhances governor stability. A plant-specific evaluation is performed for each application of interface option C. See also the next sections for other benefits of Interface option C.

The plant-specific PTO layout and design evaluation may lead to changes in the control equipment. For example, an increase of signals from the plant and requirements to the design of engine-driven mechanical components in the form of turning and tuning wheels. The evaluation may also lead to changes in the use of the PTO or set restrictions for the rotational speed while taking out maximum power.

Fixed pitch propellers
For plants with FPP, interface option C is:

- Required if the mechanical power of the PTO exceeds 15% of SMCR
- Recommended if the mechanical power of the PTO exceeds 10% of SMCR

Application of Interface option C requires consultation of MAN Energy Solutions for a plant-specific PTO layout and design evaluation. By applying Interface option C, at least 20% of SMCR power is available for PTO within certain speed limitations. An even larger ratio may be available for PTO and can be investigated as part of a plant-specific PTO layout and design evaluation.

Controllable pitch propellers
For plants with CPP, further considerations are necessary regarding governor stability, as when the propeller pitch is reduced. For CPP plants, Interface option C is:

- Required if the mechanical power of the PTO exceeds 10% of SMCR.
- Recommended if the mechanical power of the PTO exceeds 5% of SMCR

Based on a plant-specific evaluation, specific limits may be set to the minimum engine speed at which manoeuvring can be performed while sustaining the maximum PTO power.

For plants, where the mechanical PTO power exceeds 10% of SMCR, a plant-specific evaluation includes the risk of overspeed if a total electric load loss occurs on the PTO during engine operation in constant speed mode.

Load sharing and overload protection in service

Designing according to the PTO layout limit does not protect the engine from overload during PTO operation in combination with a fouled hull, or an encounter of heavy seas. With the standard interfaces between the engine and remote control, it is the responsibility of the crew to balance the load between PTO and gensets to avoid overload of the engine during conditions with increased hull resistance.

Besides ensuring governor stability, interface option C provides signals for the PMS to automate load sharing between the main engine PTO and gensets. The extended interface will help ensuring higher utilisation rates of the PTO, thus reducing genset running hours. If supplying power solely by the PTO, it will also reduce the risk of blackout without overloading the engine.

For support regarding layout of PTO/PTI and plant-specific evaluations, contact MAN Energy Solutions, Copenhagen at MarineProjectEngineering2s@man-es.com.

Options for accounting for PTO in the EEDI

Two options exist for including a PTO in the vessel EEDI, as described in the EEDI guideline MEPC.364(79) and the IACS procedure PR38:

In option 1, the power of the main engine, PME, used for calculating the EEDI is determined as:

$P_{ME} = 0.75 \times (P_{SMCR} - P_{PTO})$, with the limitation that $0.75 \times P_{PTO} \leq P_{AE}$.

Here, P_{PTO} is the nameplate PTO power and P_{AE} is the auxiliary power calculated as a percentage of P_{SMCR}. For the alternative option 2, the power available for propulsion is limited to: $P_{LIM,\ propulsion} = P_{SMCR} - P_{PTO}$, and P_{ME} used in the EEDI calculation is $0.75 \times P_{LIM,\ propulsion}$, see Fig. 2.03.05.

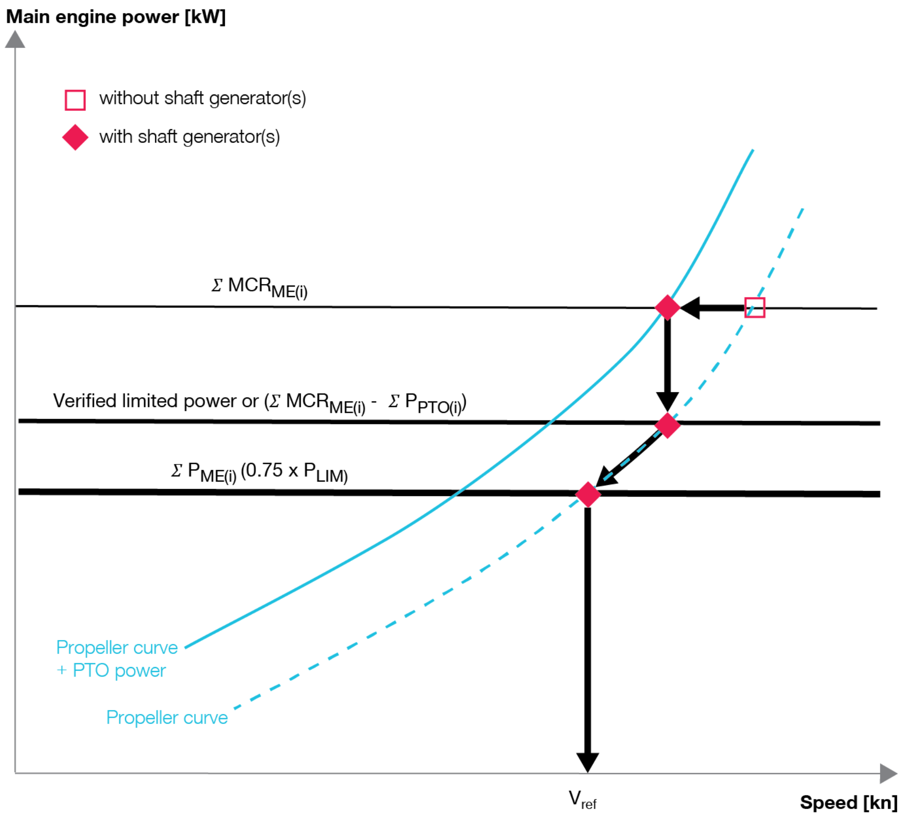

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Fig. 2.03.05: The principle of PTO option 2 for the EEDI calculation

With an extension to PTO interface option C, it is possible for the engine control system (ECS) to support PTO option 2 in the EEDI calculation. The support of PTO option 2 is only performed by the ECS, and for a plant with PTO interface option C, no further cabling or functionalities are necessary in the power management system (PMS).

The PMS sends the actual mechanical power of the PTO ($P_{PTO,\ actual}$) to the ECS. The ECS ensures that the actual total engine power ($P_{LIM,\ engine}$) in service is limited to the fixed limit for propulsion power ($P_{LIM,\ propulsion}$) plus the actual PTO power ($P_{PTO,\ actual}$):

$$P_{LIM,\ engine} = P_{LIM,\ propulsion} + P_{PTO,\ actual}$$

The value of the power limitation for maximum propulsion power ($P_{LIM,\ propulsion}$) is fixed and can in no circumstances be lifted or modified. When the PMS informs the ECS that PTO operation is needed, and this is acknowledged by the ECS, an engagement offset of approx. 5% of P_{SMCR} is added to the actual $P_{LIM,\ engine}$ to allow load transfer to the PTO. As long as the PTO is engaged, the engagement offset is added to the $P_{LIM,\ engine}$ to allow load fluctuations for the PTO. The combined power output of the engine, $P_{PTO,\ actual}$ and $P_{LIM,\ propulsion}$, is logged continuously. Since the engine can deliver the full P_{SMCR}, when full PTO power is exploited, the engine is certified as usual in accordance with P_{SMCR}. Furthermore, the SFOC of the engine is not affected by the application of PTO option 2 for EEDI, and auxiliary capacities cannot be reduced as the engine remains able to develop 100% power.

The engine load diagram in Fig. 2.03.06 is based on an SMCR with a fixed limitation for propulsion power determined as: $P_{LIM,\ propulsion} = P_{SMCR} - P_{PTO}$. In an actual example of the PTO power in service ($P_{PTO,\ actual}$), a variable limitation is used for the total engine power: ($P_{LIM,\ engine} = P_{LIM,\ propulsion} + P_{PTO,\ actual}$), thereby ensuring that the fixed limitation for propulsion power ($P_{LIM,\ propulsion}$) is not exceeded.

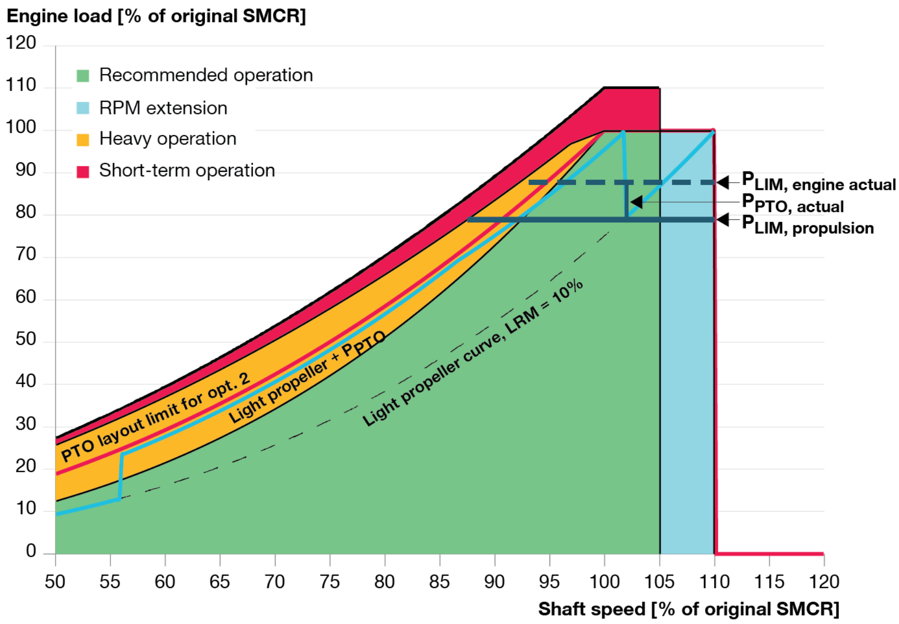


Fig. 2.03.06: Example of an engine load diagram based on an SMCR with a fixed limitation for propulsion power

Recommendations for designing propulsion plants for PTO option 2 for EEDI

The PTO layout guidance for this application deviates from MAN Energy Solutions' standard PTO layout guidance as described previously in Chapter 2: The propulsion and PTO power in total is to be designed for 100% of P_{SMCR}, and not the maximum 95% of P_{SMCR} recommended for standard PTO layouts.

The difference between the guidelines is reflected in the PTO layout limit for option 2 in Fig. 2.03.06, where N_{rel} is the speed relative to the speed at SMCR (N_{SMCR}):

PTO layout limit for option 2 = $100 \times (N_{rel}/100)^{2.4}$

The special PTO layout limit for option 2 is necessary since it is not possible to exploit the 5% power margin of the standard guideline for heavy running of the propeller, because the propulsion power will be limited to $P_{LIM,\ propulsion}$ regardless of whether the propeller is heavy running or not.

Instead, the higher power allowed under the EEDI by applying PTO option 2 for plants with high PTO power capacities provides an inherent service margin for PTO power.

The limitations for PTO power relative to P_{SMCR}, as described previously in section 2.03 of the Project Guide, prevail irrespective of the use of PTO option 2 for EEDI. It means that for fixed pitch propeller plants, a PTO power of up to 15% of P_{SMCR} is possible without plant-specific evaluations, and up to 10% of P_{SMCR} for controllable pitch propellers.

If the amount of resistance added to the propeller makes it so heavy running that the limited propulsion power ($P_{LIM,\ propulsion}$) is encountered at a shaft speed below SMCR (N_{SMCR}), the engine cannot be loaded to 100% P_{SMCR}. In this case, the combined propulsion and PTO power will be subject to the limits for continuous operation of the engine.

It is recommended to have a speed margin in the design for heavy running of the propeller. The propeller light running margin can be increased to a level where $P_{LIM,\ propulsion}$, along the light propeller curve, and P_{PTO} combined is reached at speeds above N_{SMCR}. Such a margin is included in the light propeller curve for the example in Fig. 2.03.06, where $P_{LIM,\ propulsion}$, along the light propeller curve, + P_{PTO} attains 100% engine load at 102% speed.

The engine cannot necessarily attain 100% engine load in light sea trial condition as a result of the combined propulsion and PTO power. This will be the case if the maximum allowable speed along the light propeller curve regarding engine or torsional vibration conditions is below the speed at which $P_{LIM,\ propulsion}$ is reached.

It is recommended to design the propeller and intermediate shaft to the full torque of P_{SMCR}. If a winding failure occurs on the PTO, or similar, which results in a total load loss for the PTO, the shafting can instantaneously experience the full engine torque before the fuel index can be regulated to correspond to $P_{LIM,\ propulsion}$. The shafting system cannot be designed as for an engine with an SMCR corresponding to $P_{LIM,\ propulsion}$ due to the higher torque available from the higher power installed.

For examples on the application of PTO option 2 for EEDI, see the concluding examples in the latter part of this section. For support regarding layout of PTO/PTI, classification and application of PTO option 2 for EEDI, contact MarineProjectEngineering2s@man-es.com

AWC functionality

The AWC functionality is only available for single fuel diesel engines equipped with high-efficiency turbochargers. The AWC function is introduced for ME-C 10.5 and 9.7 engines. If the AWC function is installed, it can be activated by pushing the “Increase limitation”-button, found on all ME-C engines.

There is no limitation on the duration of engine operation in the area of the AWC function. As such, the increased power produced may be utilised when evaluating a ship designs compliance with IMO minimum propulsion power requirements.

Ice-classed ships are designed to operate in ice, and ice operation is therefore not an emergency running condition. The AWC functionality is therefore not applicable for compliance with ice-class power requirements, or similar requirements that the ship is designed for (not emergency). For ice-classed ships, the standard, or if selected, the rpm-extended load diagram, should be applied as usual.

Based on the same argument as for ice-classed ships, the AWC functionality does not increase the power available for PTO. The reason is that the operation of a PTO is not an emergency running condition. A PTO installation must still comply with the PTO layout limits, and the governor stability criteria.

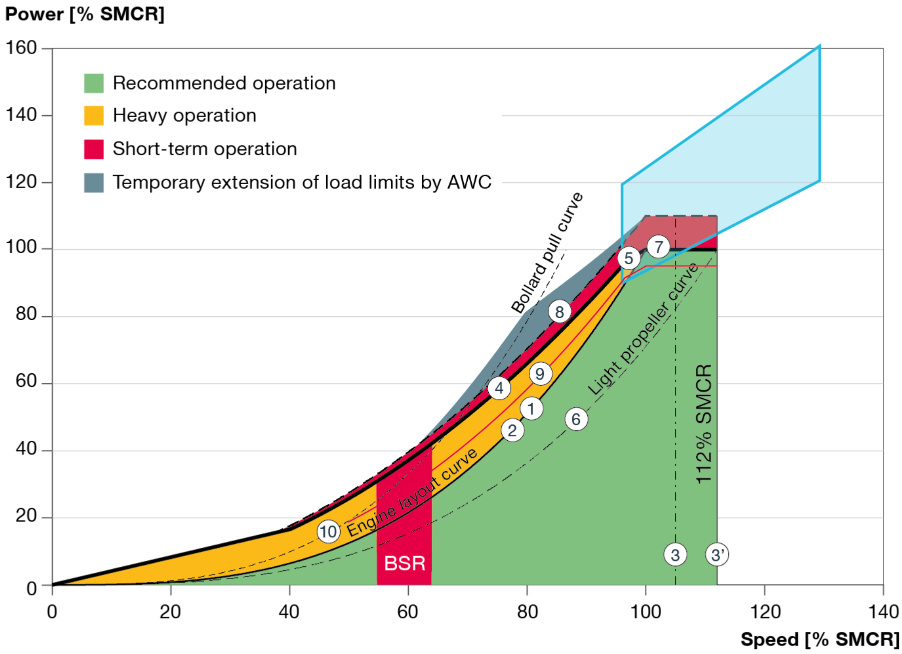
As a countermeasure to the temperature increase from heavy running, the AWC functionality alters the cyclic process of the combustion by changing the fuel injection timing and the exhaust valve timing. This improves thermal conditions in the combustion chamber at a cost of an increased SFOC. The SFOC penalty depends on the specific load conditions. Due to the increased SFOC, the AWC functionality should not be considered a replacement for an adequate light running margin.

When the engine is not running heavier than the normal load diagram, the AWC functionality has no effect and does not affect the SFOC or emissions.

For ships frequently operating in adverse weather conditions, an increased light running margin combined with an extended load diagram will ensure a lower SFOC during (such) encounters of adverse weather than the AWC function. See the later section about extended load diagrams. For specific enquiries towards the availability of the AWC functionality, contact MarineProjectEngineering2s@man-es.com. For specific projects applying AWC, send the torsional vibration calculation (TVC) to MAN Energy Solutions, Copenhagen at RDCPH@man-es.com.

Rpm-extended load diagram

When a ship with fixed pitch propeller operates in normal sea service, it will in general operate around the design/light propeller curve (line 6) as shown on the standard load diagram in Fig. 2.03.07.



178 70 83-9.0

Fig. 2.03.07: Rpm-extended load diagram for a speed derated engine with an extreme increase of the light running margin

Sometimes, when operating in heavy weather or ice, the performance of the fixed pitch propeller will be characterised as more heavy running. 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 a fixed pitch propeller 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. It requires that the light running margin is within recommendations, see Fig. 2.03.02.

For some ships and operating conditions, it would be an advantage – when occasionally needed – to have a maximum margin for the torque increase from the light propeller curve (line 6) to the torque/speed limit (line 4).

If the vessel has a fixed pitch propeller which requires a high light running margin, an rpm-extended load diagram is relevant. Torsional vibration conditions must permit this, and the classification society in question must approve the solution.

The high light running margin, and rpm-extended load diagram is especially relevant when at least two of the listed cases apply to the ship:

- Sailing in areas with frequent encounters of heavy weather, especially for low-powered ships with blunt bows
- Sailing for long periods in shallow or otherwise restricted waters

- A high ice class
- Two fixed pitch propellers/two main engines, where one propeller/one engine is declutched/stopped for some reason
- Large electric loads and according to PTO capacity.

See the examples in the following section about application of the rpm-extended load diagram.

Combinator curves for CPP propulsion plants

In principle, a controllable pitch propeller (CPP) can load the engine in any point within the load diagram. It means that the engine can operate along a combinator curve with optimised pitch settings and propeller speed, making it possible to operate the total propulsion system with optimum efficiency.

There are three modes for operating a ship with a CPP, as reflected in Fig. 2.03.08:

- Constant engine speed (generator mode) – red line
- Fixed combinator curve – black curve (6)
- Adaptive combinator curve - this mode continuously adapts/controls pitch and rpm, typically based on a combinator curve

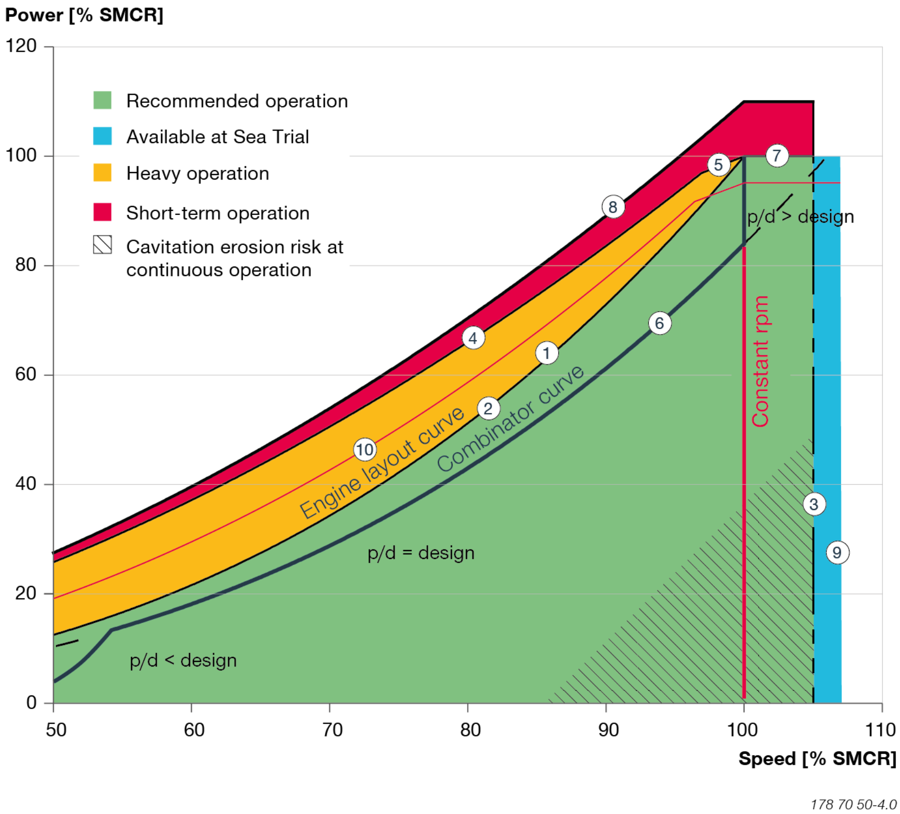


Fig. 2.03.08: Combinator curve and engine load diagram. The constant rpm curve can also be referred to as the generator curve. The exact speed of the generator curve will depend on the gear ratio of the PTO

Recommendations will be given regarding:

- Two-stroke engines coupled directly with a CPP without PTO

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- Additional recommendation for two-stroke engines coupled directly with a CPP and PTO

Controllable pitch propeller operating without PTO

Constant engine speed mode

For plants without PTO, the constant speed mode is typically used for, but not limited to, manoeuvring as the ship approaches port. Operating the engine at high speed and low pitch ensures the maximum margin to the load limitations of the engine and the fastest response to any load change.

It is recommended avoiding continuous operation in the low-load area of the engine and at high propeller speed close to SMCR speed, due to:

- Potential risk of erosive pressure side cavitation
- Relatively higher losses of propeller and engine

Fixed combinator curve

A fixed combinator curve implies that the engine operates at a certain speed and the CPP load controller sets an associated pitch, depending on the setting of the machinery telegraph. When operating along a combinator curve, the shaft speed is reduced at lower loads. This will reduce the losses of the propeller and the engine at lower loads and increase the propulsion plant efficiency.

Fig. 2.03.09 shows a typical fixed combinator curve, which consists of two constant speed parts and one combinator part

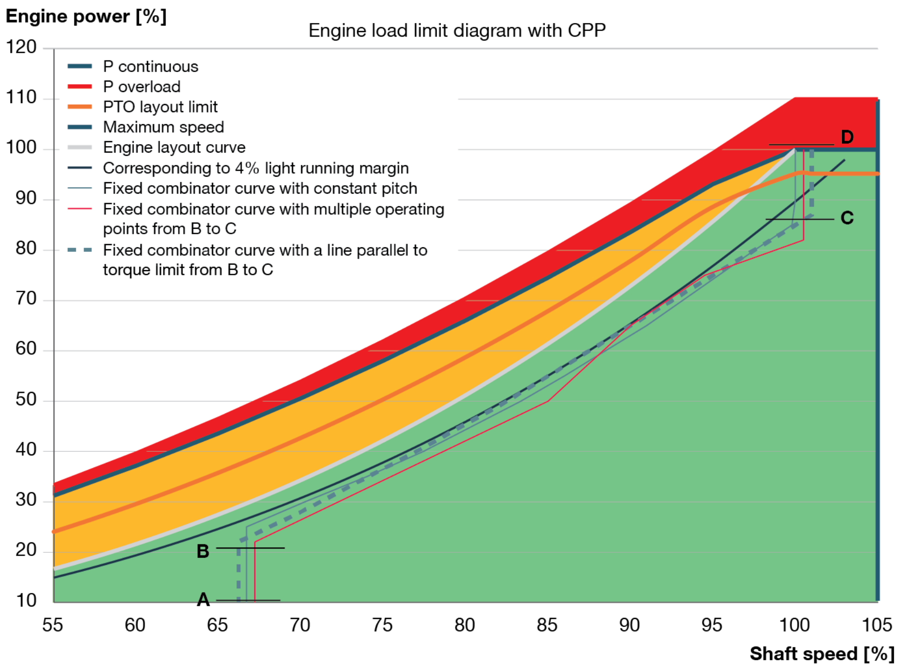

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Fig. 2.03.09: Typical fixed combinator curves for controllable pitch propellers without PTO

2.03 Engine layout and load diagram

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The minimum constant speed part (point A to B) is typically placed after the upper end of a barred speed range (BSR), if any. The maximum constant speed part (point C to D) with an increased pitch is typically laid out as the SMCR speed, so only the pitch is increased to attain 100% load. However, up to 105% of the SMCR speed is available, as for an engine connected to a fixed pitch propeller (FPP).

The combinator part (point B to C), is the part of the combinator curve that connects the constant speed parts. Usually, the propeller design point is within the range of the combinator part. The pitch can be constant along this part, or it can follow a preset combination of speeds and different pitch settings.

During the encounter of heavy weather, or fouling of the hull, the response from a fixed combinator curve is similar to that of an FPP propeller curve.

The torque required from the propeller increases when the resistance of the hull increases, which leads to a heavier running engine and higher SFOC. The result is higher thermal loading of the engine. To achieve an adequate margin, it is recommended that any arbitrary point along the fixed combinator curve follows the recommendation of the FPP light running margin (LRM). This margin is 4–7%, and in special cases up to 10%, except for the typical increase of pitch at SMCR speed to reach maximum engine power.

When reaching the engine limits for continuous operation, the propeller pitch must be reduced, if the engine speed is not to be reduced.

Adaptive combinator curve

Typically, adaptive or dynamic combinator curves are based on fixed combinator curves, and they can be applied to vessels experiencing resistance variations.

For long-term operation of plants with an adaptive combinator curve/propeller pitch, it is recommended loading the engine no heavier than the engine layout curve (line 1 or 2).

Short-term loading of the engine beyond the engine layout curve and up to the limits of continuous operation (line 4) is available for acceleration, peak wave resistance, etc., without adjusting the pitch. When reaching the limit for continuous operation, the pitch must be reduced to maintain the engine speed.

The pitch adjustment capabilities of a CPP together with the adaptive combinator curve enable an operating curve where the engine is not operated heavier than given by the engine layout curve. Furthermore, the benefits are that the SFOC does not increase as a result of engine heavy running, and that the thermal load of the engine is reduced.

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Controllable pitch propeller operating with PTO

Constant engine speed mode (generator mode)

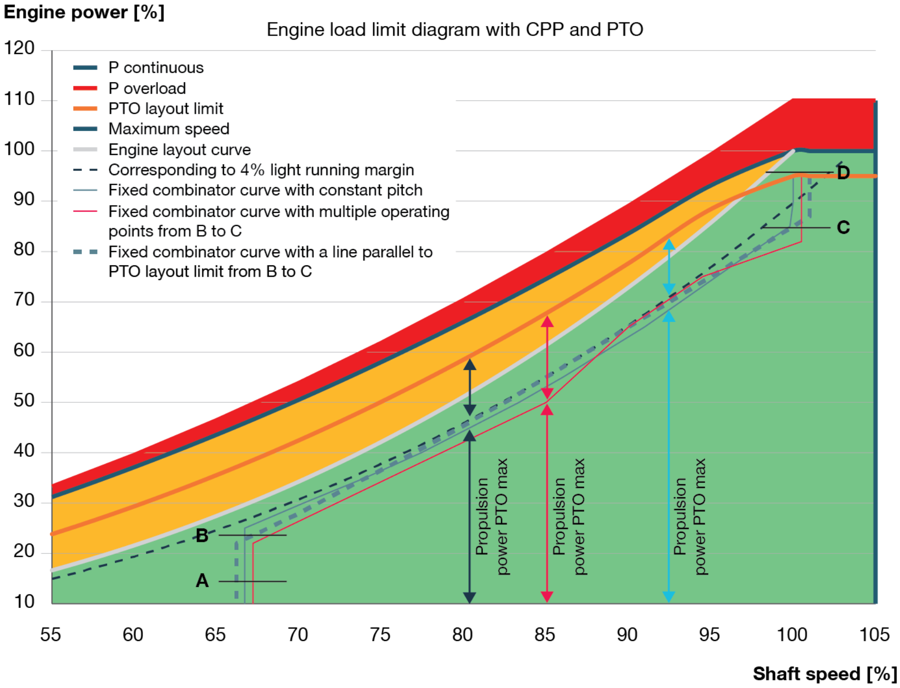
A constant engine speed is mainly relevant when operating a synchronous PTO connected to a grid without a frequency converter, or for manoeuvring.

For plants with a PTO exceeding 10% of the SMCR power, the margin towards engine overspeed during a total loss of shaft generator load at zero or low pitch should be considered. See the section on governor stability, and for further information contact MarineProjectEngineering2S@man-es.com.

Fixed combinator curve

For CPP propulsion plants with PTO and a fixed combinator curve, it is recommended designing the combinator curve so that the combined load of propulsion power and maximum PTO output is within the PTO layout limit (line 10 in Fig. 2.03.08) at any speed.

For any combinator curve, the margin between the propulsion power design points and the PTO layout limit should be large enough to cover the maximum PTO mechanical power within the PTO layout limit at any speed. See Fig. 2.03.10.



178 70 73-2.0

Fig. 2.03.10: Typical fixed combinator curve for controllable pitch propellers with PTO

Although the power of the intended PTO is within the PTO layout limit for a combinator curve heavier than 4% LRM, the recommendation of a combinator curve corresponding to at least 4% LRM prevails, for any point on the combinator curve. Some CPP plants have a PTO capacity larger than required at sea because the main engine driven PTO supplies power to the thrusters during manoeuvring. In such cases, the maximum PTO power required at sea can be considered the margin between the combinator curve and the PTO layout limit (line 10). However, the general recommendation of 4–7% LRM, up to 10% in special cases, prevails.

Adaptive combinator curve

Assuming that the full PTO capacity at a given speed is not utilised for plants with an adaptive combinator curve/propeller pitch. In this case, it is recommended not to operate with a combined load of propeller and PTO, which is heavier than the engine layout curve (line 1, 2 in Fig. 2.03.08).

Short-term loading of the engine beyond the layout curve and up to the limits of continuous operation (line 4) is available for acceleration, start of heavy electric consumers, etc., without adjusting the pitch.

The dynamic capabilities of the CP propeller can reduce the level of heavy running by reducing the propeller torque to counter a torque increase of driving a PTO. This will reduce the SFOC not only for the power taken out for the grid, but also for the power used to propel the vessel.

Examples of the use of load diagrams

In the following, various examples illustrate the flexibility of the layout and load diagrams.

Example 1: Engine coupled to FPP without PTO

In this example, which represents a typical application of marine two-stroke engines, typical values of 7%, engine margin, and 15% sea margin are included. A light running margin in the higher range of the recommended 4–7% (up to 10% in special cases) is displayed for the sake of the example.

The maximum speed acceptable for an engine with a standard load diagram is the minimum value of 110% SMCR-speed or 105% L_1-speed. If torsional vibration conditions permit it, 107% of the SMCR-speed will be available for continuous operation, even if the light propeller curve extends beyond the layout diagram, see Fig. 2.03.11.

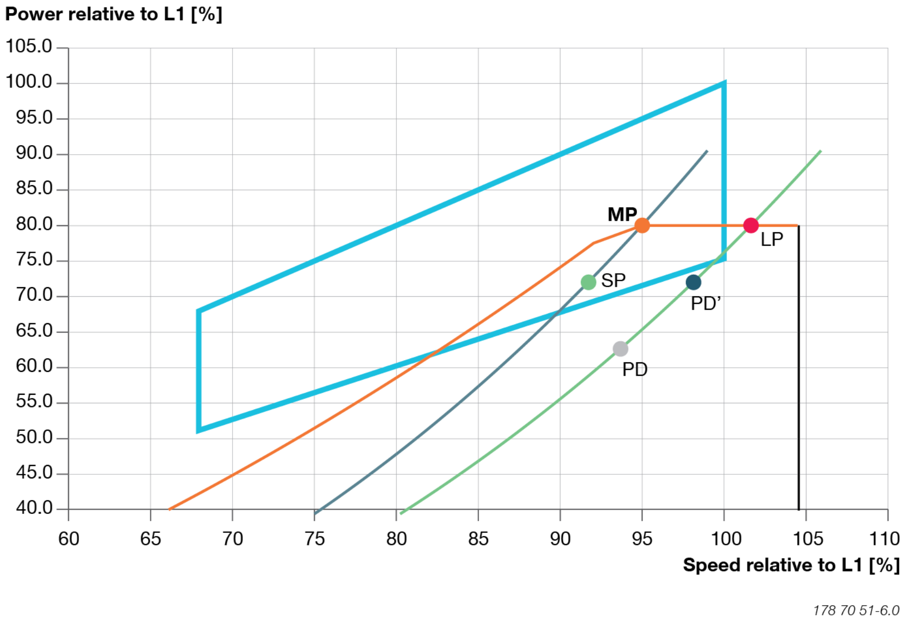
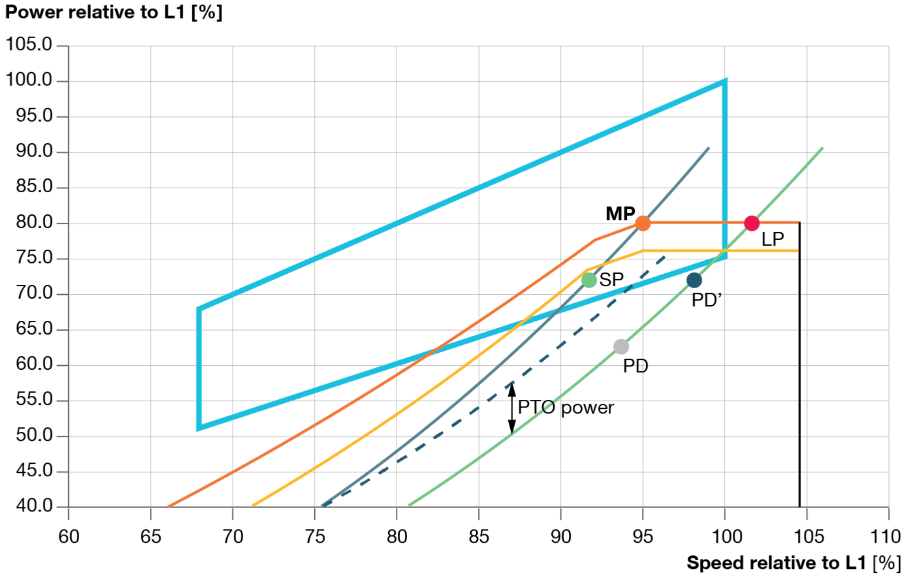


Fig. 2.03.11: Engine coupled to a fixed pitch propeller without shaft generator. The load diagram is the result of selecting the MP/SMCR within the layout area, 15% sea margin, 10% engine margin, and 7% light running margin.

Example 2: Engine coupled to FPP with PTO

In this example, the SMCR is determined by using the regular method for determining PD and adding margins. Thereafter, it is investigated whether the desired PTO of 9% of the SMCR can be accommodated within the PTO layout limit.

As seen on Fig. 2.03.12, the power of the light propeller curve plus the power of the PTO lies well within the PTO layout limit (line 10 in Fig. 2.03.08), which is up to 102% of the SMCR speed (96% relative to L_1 on Fig. 2.03.12). At a shaft speed above this, the PTO output must be reduced.



178 70 52-8.0

Fig. 2.03.12: Engine coupled to a fixed pitch propeller, and shaft generator. The load diagram is the result of selecting the MP/SMCR within the layout area, the PTO layout limit, and light propeller curve plus PTO power (dashed).

Since the PTO power is less than 10% of the SMCR power, only first governor stability criteria should be considered. There is no need for further considerations about the impact of the PTO towards governor stability. As an example of evaluating according to the first governor stability criteria, consider a 6S60ME-C10 engine and:

- NMCR (L1) of 14,940 kW at 105 rpm (80% of L1 as on Fig. 2.03.12)
- SMCR of 11,950 kW at 99.8 rpm (95% of L1 as on Fig. 2.03.12).

For a mechanical PTO power of:

- 9% of SMCR, which corresponds to: 0.09 x 11,905 = 1,070 kW
- available in a speed range from 80 - 102% of SMCR
  which is: 80% x 95% = 76% to 102% x 95% = 97% of NMCR.

Absolute		**Relative to SMCR**		**Relative to NMCR**	
Speed [rpm]	Power [kW]	Speed [%]	Power [%]	Speed [%]	Power [%]
101.8	1070	102	9.0	97	7.2
79.8	1070	80	9.0	76	7.2
59.9	800	60	6.7	57	5.4

Table 2.03.02: Values of PTO realtive to an SMCR of 11950 kW at 99.8 rpm relative to NMCR of 14940 kW at 105 rpm.

This is plotted relative to the first governor stability criteria, as this PTO power represents 7.2% of the power at NMCR. The PTO is available down to 60% of SMCR speed, and it delivers a constant torque between 60% and 80% of SMCR speed. It means that the PTO delivers a reduced power proportional to the speed reduction, compared to the speed at which the nominal PTO power is available: 60%/80% x 1070 = 800 kW. This corresponds to 5.4% of NMCR power and 60% x 95% = 57% of the NMCR speed. This is depicted in Fig. 2.3.13.

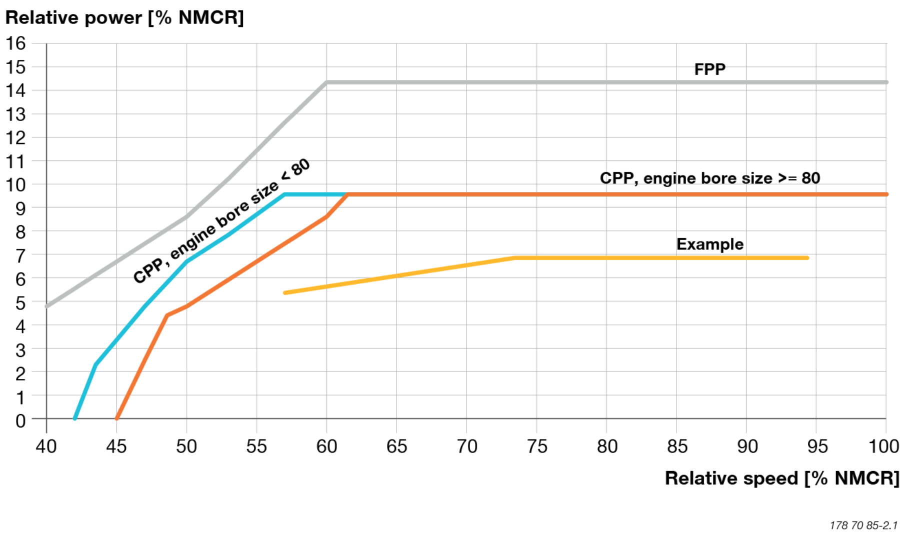


Fig. 2.03.13: First governor stability criteria for maximum mechanical PTO and PTO power in the example with an 6S60ME-C10, see table 2.

2.03 Engine layout and load diagram

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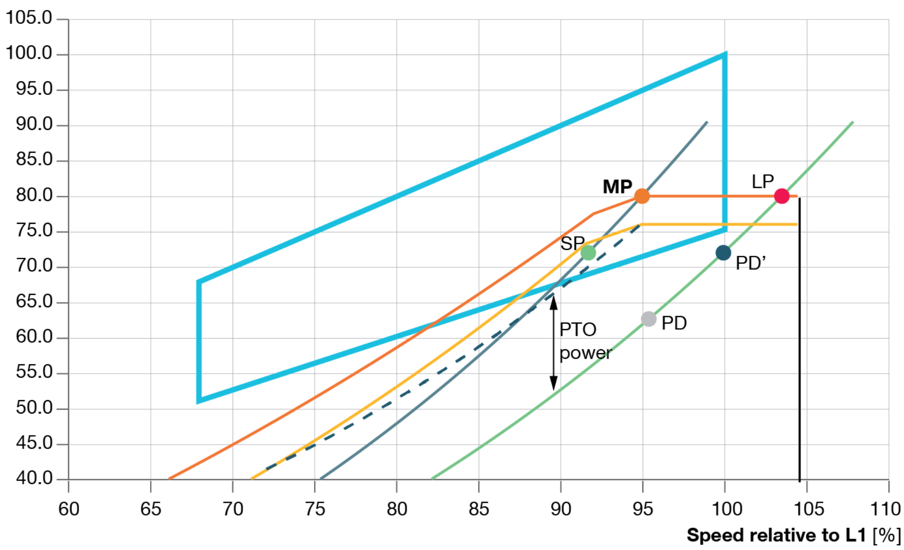
Example 3: Engine coupled to FPP with PTO, and increased light running margin

In this example, a PTO of 18% of the SMCR is desired, which represents a larger percentage of the SMCR power than considered in example 2.

To accommodate the larger PTO in a desired range of 80–100% of the SMCR-speed (75–95% on Fig. 2.03.14), the light running margin is increased to 9%. For the present SMCR located at 95% of the L_1-speed, a 9% light running margin is still within the limit given by the minimum value of 110% SMCR-speed, or 105% L_1-speed.

As the PTO power exceeds 15% of the SMCR power, interface option C between the power management system and the engine control system is a prerequisite for applying the PTO to ensure sufficient governor stability. A plant specific evaluation of the governor stability is part of the application of interface option C.



178 70 54-1.0

Fig. 2.03.14: Engine coupled to a fixed pitch propeller and shaft generator. The load diagram is the result of selecting the MP/SMCR within the layout area, the PTO layout limit (line 10), and the light propeller curve plus the PTO power (dashed).

Example 4: Engine coupled to FPP with PTO, increased SMCR power, and rpm-extended load diagram

In this case, an increase of the PTO power to 24% of the SMCR power is considered. If considering the same absolute propeller curve as in example 3, the power cannot be accommodated within the PTO layout limit. For the sake of example, it is not desirable to increase the propeller light running margin further by decreasing the propeller pitch since it affects the propeller efficiency negatively.

To accommodate the higher power of the PTO, the SMCR power is increased by 7% while the SMCR-speed is maintained. This results in an engine that delivers a higher torque, see Fig. 2.03.15. The SMCR increase has the consequence that the propeller light running margin at 100% of SMCR power now corresponds to 11.5% - without changing the propeller pitch.

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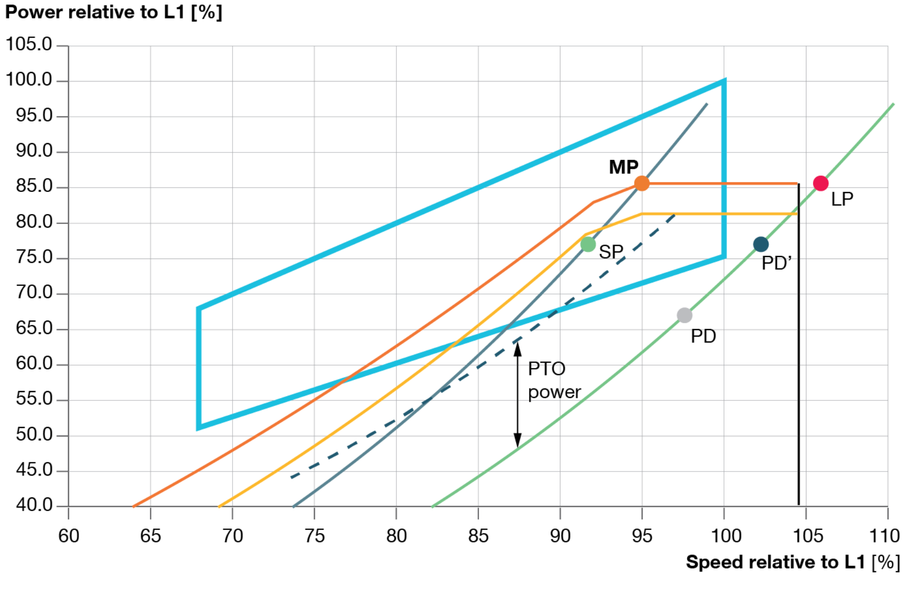

Fig. 2.03.15: Engine coupled to a fixed pitch propeller, and a very large shaft generator of 24% of SMCR. The load diagram is the result of selecting the MP/SMCR within the layout area, the PTO layout limit (line 10), and the light propeller curve plus the PTO power (dashed line).

In this example, the light propeller curve will deliver 100% power at 111.5% of SMCR speed, or 106% of L_1-speed. This is beyond the criteria of the minimum value of 110% of SMCR-speed, or 105% of L_1-speed.

For speed-derated engines, it is possible to extend the maximum speed limit to maximum 105% of the engine's L_1/L_2 speed (line 3 in Fig. 2.03.08), but only if the torsional vibration conditions permit this. Thus, with respect to torsional vibrations, the shafting has to be approved by the classification society in question, based on the selected extended maximum speed limit.

When choosing an increased light running margin, the load diagram area may be extended from line 3 to line 3', as shown in Fig. 2.03.07.

The increased light propeller curve (line 6), may have a correspondingly increased light running margin before exceeding the torque/speed limit (line 4).

In this example, the rpm extension of the load diagram will have limited effect. Relative to the SMCR, 105% of L_1-speed corresponds to 110.5%. Thereby, 100% power will not be available for continuous operation only by loading the engine with the propeller and with the hull as in sea trial condition.

For further speed-derated engines, the effects of the rpm-extended load diagram will be greater.

As for sea trial, 107% of L_1-speed is available for demonstrating full power, if torsional vibration conditions permits, see Fig. 2.03.02. In this example, it corresponds to 112.5% of the SMCR. If 100% power is to be available only for propeller load for continuous operation, the SMCR must be further speed derated, that is, the SMCR point will be moved further to the left in the layout diagram in Fig. 2.03.15.

As the PTO power exceeds 15% of the SMCR power, interface option C between the power management system and the engine control system is a prerequisite for applying the PTO to ensure sufficient governor stability. A plant specific evaluation of the governor stability is part of the application of interface option C.

Example 5: Engine coupled to CPP without PTO

If a controllable pitch propeller (CPP) is applied, the combinator curve (of the propeller) will normally be selected for a loaded ship including sea margin. For a given propeller speed, the combinator curve may have a given propeller pitch, and it may be heavy running in heavy weather like for a fixed pitch propeller.

Therefore, it is recommended using a light running combinator curve observing the recommendations for the light running margin for a fixed pitch propeller. For plants equipped with dynamic combinator curves adapting the propeller pitch continuously, it is recommended to seeking an operational point corresponding to the recommendations for the light running margin for fixed pitch propellers.

See Fig. 2.03.16 for a typical combinator curve corresponding to 5% light running margin along the constant pitch part of the combinator curve. Even without a PTO, some combinator curves are designed not to exceed 100% of the SMCR-speed, as represented by the dashed line. The engine does not prevent the combinator curve from continuing at constant pitch beyond 100% of the SMCR-speed. However, the general speed limits of the engine must be observed and torsional vibration conditions must permit it.

Sea and engine margins can in general be considered the same as for FP propellers. However, as the pitch can be reduced in an encounter of adverse weather conditions, there are no reasons for applying the AWC functionality.

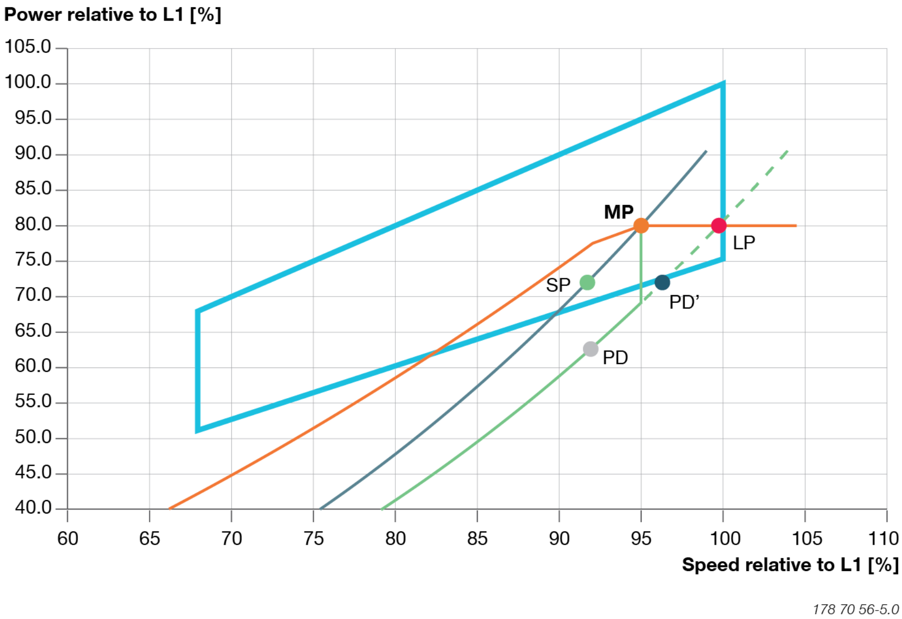

Fig. 2.03.16: Engine coupled to a controllable pitch propeller without shaft generator. The load diagram is the result of selecting the MP/SMCR within the layout area.

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Example 6: Engine coupled to CPP with PTO

In this example, a PTO of 15% of the SMCR is desired which requires a combinator curve corresponding to 7% light running margin to accommodate the PTO within the PTO layout limit, see Fig. 2.03.17.

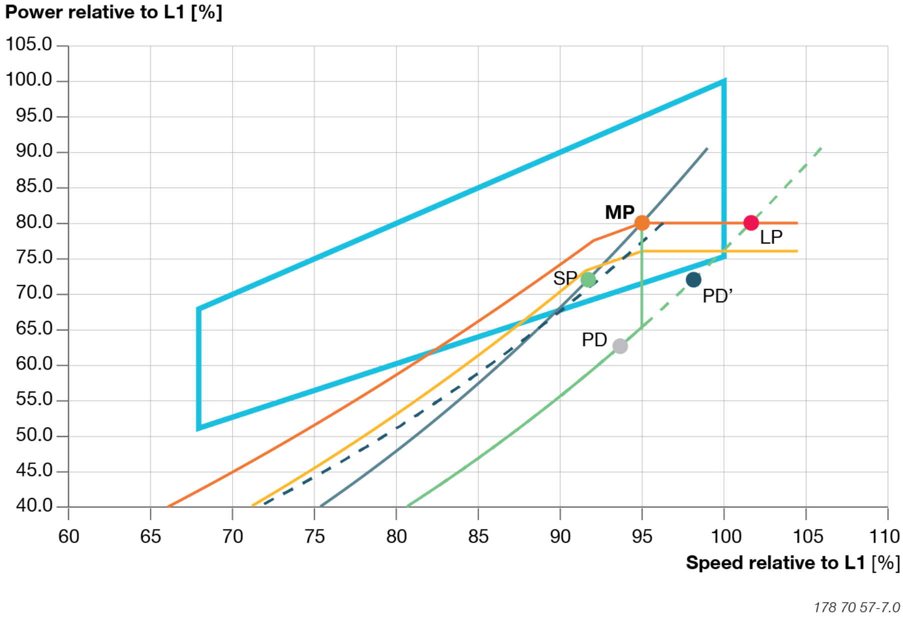

Fig. 2.03.17: Engine coupled to a controllable pitch propeller with a shaft generator corresponding to 15% of the SMCR power. The load diagram is the result of selecting the MP/SMCR within the layout area.

As for a fixed pitch propeller, the combined load of the combinator curve and PTO power must lie within the PTO layout limit.

Even if the pitch of the CP propeller can be reduced to accommodate the PTO, when full PTO power is needed, it may be an advantage to increase the SMCR power as in example 4, if high ratios of PTO power are to be available. Especially if full utilisation of the PTO power is foreseen for the major part of the operational time.

As the PTO power exceeds 10% of the SMCR power, interface option C between the power management system and the engine control system is a prerequisite for applying the PTO to ensure sufficient governor stability for a CPP plant. A plant-specific evaluation of the governor stability is part of the application of interface option C. For CPP plants, this evaluation also considers the margin against overspeed if a total load loss takes place on the PTO, while the propeller is at zero pitch. This scenario can take place during manoeuvring if the PTO drives the thrusters.

Contact Marine Project Engineering2S@man-es.com for enquires and assistance with the layout of the engine.

Example 7: Utilisation of PTO option 2 for EEDI on an LPG carrier

The following two examples consider the application and impact of applying PTO option 2 for EEDI. Consider an LPG carrier with a 6G60ME-C10.5-LGIP engine with:

- SMCR of 11,200 kW at 90 rpm
- 10% propeller light running margin
- PTO with 2,070 kWe power
- Considering a 90% efficiency, this results in: P_{PTO} = 2,300 kW mechanic load.

This example covers the basics of what is shown in the previous Fig. 2.03.06.

The SMCR of 11,200 kW and P_{PTO} = 2,300 kW implies that:

$P_{LIM,\ propulsion} = P_{SMCR} - P_{PTO} = 11{,}200 - 2{,}300 = 8{,}900$ kW

Whereby, P_{ME} used in the EEDI calculation is:

$P_{ME,\ opt.\ 2} = 0.75 \times P_{LIM,\ propulsion} = 6{,}675$ kW

This can be compared to the value attained by applying option 1:

$P_{ME,\ opt.\ 1} = 0.75 \times (P_{SMCR} - P_{PTO})$

$\updownarrow$

$P_{ME,\ opt.\ 1} = 0.75 \times (P_{SMCR} - P_{AE} / 0.75) = 0.75 \times (11{,}200 - 530 / 0.75) = 7{,}870$ kW

Example 8: Utilisation of PTO option 2 for EEDI on a Kamsarmax (82k dwt) bulk carrier

Consider a Kamsarmax bulk carrier with a 6S60ME-C10.5 engine with:

- SMCR in L4 of 9,000 kW at 84 rpm
- 7% propeller light running margin
- PTO with 900 kWe power, a replacement for one of the typically three auxiliary engines
- Considering a 90% efficiency, this results in P_{PTO} = 1,000 kW mechanic load.

The SMCR of 9,000 kW and P_{PTO} = 1,000 kW imply that:

$P_{LIM,\ propulsion} = P_{SMCR} - P_{PTO} = 9{,}000 - 1{,}000 = 8{,}000$ kW

$P_{ME,\ opt.\ 2} = 0.75 \times P_{LIM,\ propulsion} = 6{,}000$ kW

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This can be compared to the value attained by applying option 1:

$P_{ME,\ opt.\ 1} = 0.75 \times (P_{SMCR} - P_{PTO})$

↕

$P_{ME,\ opt.\ 1} = 0.75 \times (P_{SMCR} - P_{AE} / 0.75) = 0.75 \times (9{,}000 - 450 / 0.75) = 6{,}300$ kW

If the vessel had to attain the same EEDI as per PTO option 2 for EEDI without the PTO, the SMCR of the engine should be approx. 8,000 kW. However, this rating would imply a change of engine selection to a 5S60ME-C10.5 with SMCR of 8,000 kW at 84 rpm.

Fig. 2.03.18 shows the difference between limitations for continuous loading for these two different ratings, when applying the same absolute propeller with a light running margin of 7% to the original SMCR.

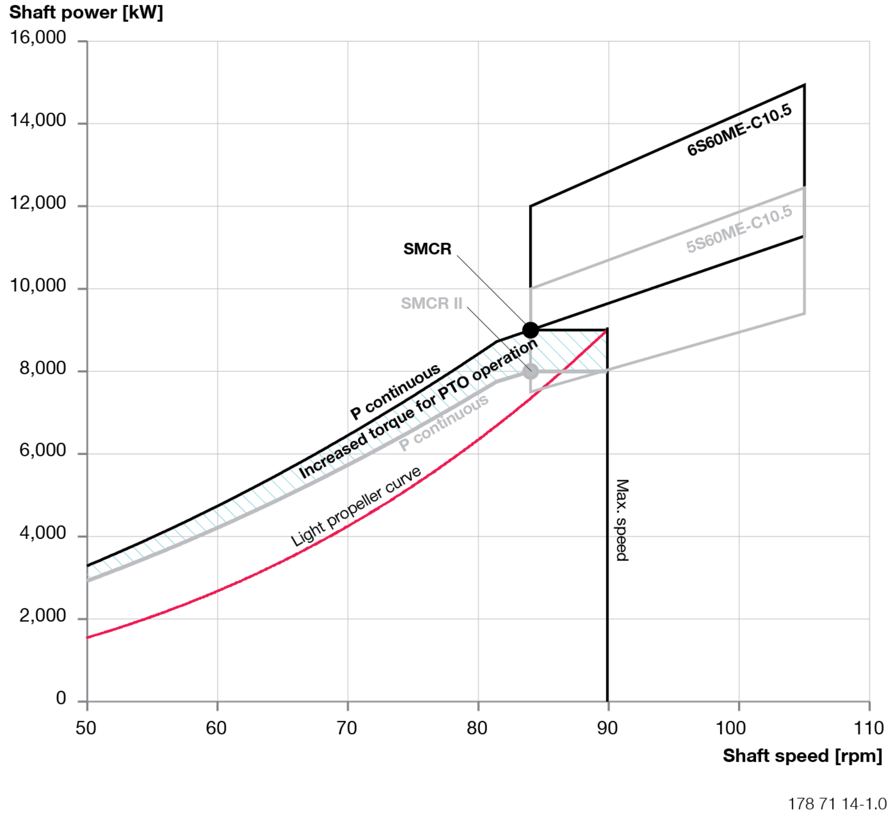

Fig. 2.03.18: Difference in limits for continuous loading of engines with an SMCR of 9,000 kW at 84 rpm relative to an SMCR of 8,000 kW at 84 rpm. By applying PTO option 2 for EEDI for the high SMCR, it is possible to attain the same EEDI value as for the low SMCR without PTO.

Furthermore, it illustrates that by applying PTO option 2 for EEDI, it is possible to apply an engine with a higher rating than otherwise applicable. This would enable a higher torque for the same EEDI value as without PTO, thereby ensuring that there is a good margin for operation of the PTO in calm waters and less ideal conditions alike. This allows for a high utilisation rate of the PTO in service to the benefit of the overall plant efficiency. In this specific example, the derating extent for the 6S60ME-C10.5 engine is furthermore greater than for the 5S60ME-C10.5 engine, resulting in a lower SFOC.

PTO layout table

Maximum (mechanical) PTO power [% of SMCR power] as a function of engine speed and propeller light running margin							
Engine speed [% of SMCR]	Propeller light running margin [%]						
	4%	5%	6%	7%	8%	9%	10%
50%	7.8	8.1	8.5	8.7	9.0	9.3	9.6
51%	8.1	8.4	8.7	9.0	9.3	9.6	9.9
52%	8.3	8.7	9.0	9.3	9.7	10.0	10.3
53%	8.6	8.9	9.3	9.6	10.0	10.3	10.6
54%	8.8	9.2	9.6	9.9	10.3	10.6	11.0
55%	9.0	9.4	9.8	10.2	10.6	11.0	11.3
56%	9.3	9.7	10.1	10.5	10.9	11.3	11.7
57%	9.5	10.0	10.4	10.8	11.2	11.6	12.0
58%	9.7	10.2	10.7	11.1	11.6	12.0	12.4
59%	9.9	10.4	10.9	11.4	11.9	12.3	12.8
60%	10.1	10.7	11.2	11.7	12.2	12.7	13.1
61%	10.4	10.9	11.5	12.0	12.5	13.0	13.5
62%	10.6	11.2	11.7	12.3	12.8	13.3	13.8
63%	10.8	11.4	12.0	12.6	13.1	13.7	14.2
64%	11.0	11.6	12.3	12.9	13.5	14.0	14.6
65%	11.1	11.8	12.5	13.1	13.8	14.4	14.9
66%	11.3	12.1	12.8	13.4	14.1	14.7	15.3
67%	11.5	12.3	13.0	13.7	14.4	15.0	15.6
68%	11.7	12.5	13.2	14.0	14.7	15.3	16.0
69%	11.8	12.7	13.5	14.2	15.0	15.7	16.4
70%	12.0	12.9	13.7	14.5	15.3	16.0	16.7
71%	12.1	13.0	13.9	14.7	15.5	16.3	17.1
72%	12.3	13.2	14.1	15.0	15.8	16.6	17.4
73%	12.4	13.4	14.3	15.2	16.1	16.9	17.8
74%	12.5	13.5	14.5	15.5	16.4	17.3	18.1
75%	12.6	13.7	14.7	15.7	16.6	17.6	18.4
76%	12.7	13.8	14.9	15.9	16.9	17.9	18.8
77%	12.8	14.0	15.1	16.1	17.2	18.2	19.1
78%	12.9	14.1	15.2	16.3	17.4	18.4	19.4
79%	13.0	14.2	15.4	16.5	17.7	18.7	19.8

Maximum (mechanical) PTO power [% of SMCR power] as a function of engine speed and propeller light running margin							
80%	13.0	14.3	15.5	16.7	17.9	19.0	20.1
81%	13.1	14.4	15.7	16.9	18.1	19.3	20.4
82%	13.1	14.5	15.8	17.1	18.3	19.5	20.7
83%	13.1	14.5	15.9	17.3	18.6	19.8	21.0
84%	13.1	14.6	16.0	17.4	18.8	20.0	21.3
85%	13.1	14.7	16.1	17.6	19.0	20.3	21.6
86%	13.1	14.7	16.2	17.7	19.1	20.5	21.8
87%	13.0	14.7	16.3	17.8	19.3	20.7	22.1
88%	13.0	14.7	16.4	18.0	19.5	21.0	22.4
89%	12.9	14.7	16.4	18.1	19.6	21.2	22.6
90%	12.8	14.7	16.4	18.1	19.8	21.4	22.9
91%	12.8	14.6	16.5	18.2	19.9	21.6	23.1
92%	12.6	14.6	16.5	18.3	20.0	21.7	23.4
93%	12.5	14.5	16.5	18.4	20.2	21.9	23.6
94%	12.4	14.5	16.5	18.4	20.3	22.1	23.8
95%	12.2	14.4	16.4	18.4	20.4	22.2	24.0
96%	12.0	14.2	16.4	18.4	20.4	22.3	24.2
97%	11.0	13.3	15.5	17.6	19.7	21.7	23.6
98%	9.4	11.8	14.1	16.3	18.4	20.4	22.4
99%	7.8	10.2	12.6	14.8	17.0	19.1	21.2
100%	6.1	8.6	11.0	13.4	15.6	17.8	19.9
101%	3.4	6.0	8.5	10.9	13.2	15.4	17.6
102%	0.7	3.3	5.9	8.4	10.8	13.1	15.3
103%	0.0	0.6	3.3	5.8	8.3	10.6	12.9
104%	0.0	0.0	0.6	3.2	5.7	8.1	10.5
105%	0.0	0.0	0.0	0.5	3.1	5.6	8.0
106%	0.0	0.0	0.0	0.0	0.5	3.0	5.5
107%	0.0	0.0	0.0	0.0	0.0	0.4	3.0
108%	0.0	0.0	0.0	0.0	0.0	0.0	0.4
109%	0.0	0.0	0.0	0.0	0.0	0.0	0.0
110%	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 2.03.03: Maximum (mechanical) PTO power (a percentage of SMCR power) as a function of engine speed, and propeller light running margin

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