Everllence B&W
two-stroke
marine engines

Adverse Weather Condition functionality and minimum propulsion power

Contents

Adverse Weather Condition functionality and minimum propulsion power

The tightening requirements of the Energy Efficiency Design Index (EEDI) mean that the demand for energy efficiency of merchant vessels is continuously increasing. With the EEDI leading to reductions of the power on board, concerns about a possible lack of propulsion power during encounters of adverse weather have been expressed.

This paper gives a detailed description of the challenge of propulsion in harsh weather, and introduces the Adverse Weather Conditions (AWC) functionality. The AWC functionality extends the load diagram of the engine as long as required in an emergency. This increases the heavy running capability of the engine significantly and increases the minimum forward speed of the vessel in harsh weather, without requiring an increase of the engine power installed.

1. Introduction

In the merchant fleet, a two-stroke engine directly coupled to a fixed-pitch propeller is one of the most applied propulsion solutions due to the superior efficiency.

When a vessel with this propulsion system experiences added resistance in adverse weather, the torque required by the fixed-pitch propeller to maintain the rpm increases. In harsh cases, the torque required may exceed the torque limits of the main engine, causing the engine power output to be limited to a power below the maximum continuous rating (MCR).

With ever-tightening Energy Efficiency Design Index (EEDI) phases, aiming at reducing the emission of greenhouse gasses, the installed propulsion power for new vessels is decreasing. This means that less power is available for maintaining a safe course in adverse weather.

The Adverse Weather Condition (AWC) functionality introduced and described in this paper makes it possible to increase the engine load limits significantly and for longer periods under such conditions than previously possible. As a result, the percentage of accessible MCR power is increased for as long as an emergency in harsh weather requires it. This increases the attainable vessel speed, which helps to ensure the manoeuvring capacity of the vessel.

This paper elaborates on the background and advantages of the AWC functionality.
In addition, it presents a case study of the expected performance of a 50,000 dwt bulk carrier sailing in adverse weather with and without the AWC function.

Heavy running propeller

When sailing in adverse weather, the resistance that the vessel experiences increases, which means the propeller becomes "heavy running", i.e., it requires more torque to maintain the same rate of revolution.

A heavy running propeller is equivalent to the experience that a cyclist has when going uphill without changing gear. As the slope inclines, the cyclist has two options, either to provide a greater torque input to the pedals and hereby maintain the rpm of the wheels, or accept that an unchanged torque will result in lower rpm.

A similar experience of heavy running occurs when the same cyclist bikes on a flat road at a uniform speed and suddenly encounters a headwind. Because of the wind resistance, the cyclist has the same two options: Either to increase the torque input to the pedals and hereby maintain rpm or accept that an unchanged torque input reduces rpm.

The two-stroke engine has the same options, either to increase the engine torque and maintain the rate of revolution, or to maintain the torque and accept a reduction in the rate of revolution. Increasing the torque of an engine is, however, only possible to a certain extent within the limits of the engine load diagram – the AWC functionality extends these limits for the Everllence B&W two-stroke engine.

2. Background for AWC

If the fuel used to propel the vessel is not changed from traditional bunker oil to a less carbon-intensive fuel, the EEDI will reduce the allowable engine power that can be installed on board new vessels of an otherwise traditional design. Eq. 1 expresses the EEDI in a simplified form:

Eq. 1

$$EEDI = \frac{P \times C_F \times SFC}{capacity \times V_{ref}}$$

P is the main engine power and C_F is a carbon factor accounting for the amount of CO_2 emitted per mass of fuel utilised. SFC is the specific fuel consumption at 75% engine load, capacity is the vessel deadweight tonnage and V_{ref} is the vessel speed at 75% engine load in calm water with the hull as in sea trial conditions.

For a specific fuel type and vessel capacity, Eq. 1 reduces to Eq. 2:

Eq. 2

$$EEDI = \frac{P \times SFC}{V_{ref}}$$

From Eq. 2 it is clear that one way to reduce the attained EEDI is by reducing the main engine power or the specific fuel oil consumption, while maintaining the highest possible service speed. For more information on the EEDI, see Chapter 4 in [1].

For vessels with a low EEDI relative to their size, such as bulk carriers and tankers, the AWC function helps ensure that a safe course-keeping speed can be maintained during adverse weather conditions.

For general information on the propulsion of bulk carriers and tankers, see papers [2] and [3], respectively.

3. AWC and engine load diagrams

An engine load diagram defines the power and speed limits relative to the SMCR point specified within the engine layout diagram, see Figs. 1 and 2.

The load diagram is an important tool for describing an engine. Fig. 1 shows an engine load diagram in which numbered lines indicate the engine limits. The position of the SMCR point in the layout diagram for the engine design does not influence the appearance of the engine load diagram. The layout diagram merely shows the combinations of power and rpm for which it is possible to select the SMCR. See Chapter 3 in [1] for further notes.

Line 1: The engine layout curve, which passes through the 100% SMCR rpm and 100% SMCR power point. The curve coincides with line 2.

Line 2: The heavy propeller curve is the light propeller curve (line 6) shifted to the left by the propeller light running margin. The light running margin is included to account for added resistance due to wind, waves and hull fouling.

Line 3: Maximum continuous rpm.

Line 4: This line represents the torque/speed limit for continuous engine operation, which is mainly defined by the thermal load of the engine components. This limit can be extended temporarily by the AWC functionality described in this paper.

Line 5: Represents the maximum mean effective pressure (mep) acceptable for continuous operation.

Line 6: The light propeller curve for a clean hull and calm weather. This curve is often used for propeller layout.

Line 7: Maximum power for continuous operation. When increasing the rpm towards lines 3 and 9, the maximum power for continuous operation cannot exceed 100%.

Line 8: Normal overload operating limit of an engine without the AWC functionality.

Line 9: Maximum acceptable engine rpm under sea trial conditions.

Line 10: Power take-off (PTO) layout limit.

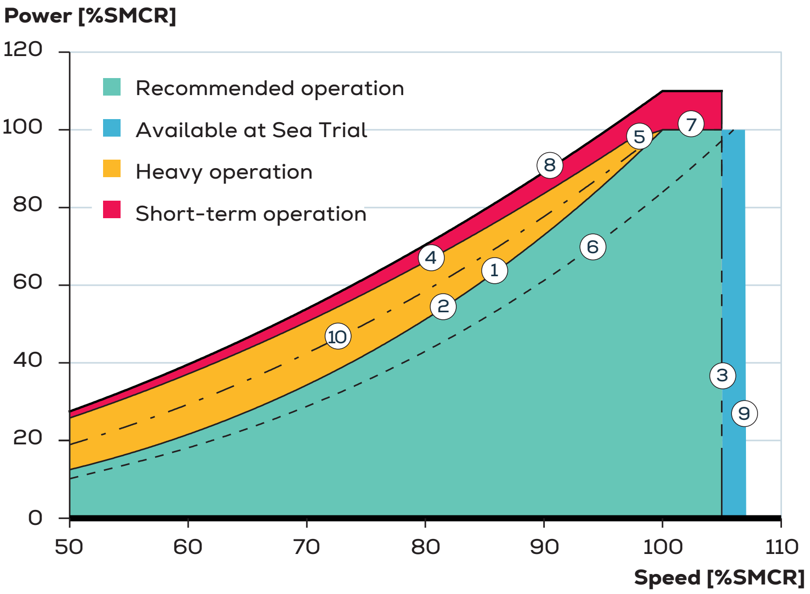

Fig. 1: Standard load diagram of Everllence B&W engines, showing line definitions 1 to 10

Recommended operation

The green area between lines 1, 3 and 7 is intended for continuous operation with propeller load only.

The yellow area between lines 1, 4 and 5 is intended for operation in shallow water, heavy weather and during acceleration, i.e., for non-steady operations without any strict time limitation.

The red area between lines 4, 5, 7 and 8 is intended for overload operation.

Increased limiter function and dynamic limiter function

As the vessel encounters heavier resistance, e.g., in a developing storm, the propeller torque, and thereby the engine torque, increases, shifting the light propeller curve (line 6) upwards and to the left of the original curve. The operating point thereby approaches the torque limiter (line 4) in the load diagram. In an emergency, the torque limiter can be exceeded by activating the Increased Limiter Function (ILF) from the bridge. This increases the fuel index by 10%, as standard, on any Everllence

B&W engine. In its traditional form, the ILF can only be used for 1 hour within a 12 hour period.

If the engine is equipped with the Dynamic Limiter Function (DLF), this will extend the operating area into the DLF area in the engine load diagram, see Fig. 2.

The DLF works by calculating the amount of air available in the engine cylinders before each combustion takes place. Once the mass of air is known, the engine control system (ECS) calculates the maximum allowable amount of fuel that can be injected into the combustion chamber without reaching the minimum acceptable air excess ratio. After approximately 30 minutes of DLF operation, the engine components need to cool down, and the engine gradually reduces the limits back to the normal fuel index limiter. Because the DLF is time-limited, it is not suitable for long-time heavy operation, as required when encountering adverse weather conditions. See the paper [4] for further information.

AWC functionality

The AWC functionality is an extension of the DLF and works according to the same principles by increasing the accessible torque when the ILF is activated. By installing the AWC functionality, it is possible to access an even higher percentage of the MCR at lower rpm, as illustrated in Fig. 3.

Fig. 3 shows an illustration of an engine load diagram with the AWC functionality added. As seen in the load diagram, the AWC function extends the operating area in the engine speed range from 60% to 97%.

The bollard pull curve in Fig. 3 represents the maximum propeller load when running ahead at zero advance speed. Based on experience, this curve typically lies 15% to 20% heavier than the light propeller curve, and is set to 17.5% in the figure.

The AWC functionality enables the engine to follow the bollard pull curve up to 80% power and 80% rpm, operating at 100% mean effective pressure in this point. This ensures that 80% of the SMCR power is available during adverse weather conditions, depending on the nature of the bollard pull curve and the propeller light running margin of the design.

Moreover, operation of the AWC functionality is not subject to any strict time limits, which means that it can be used for as long as required in an emergency. Initiatives have been taken to reduce the thermal load on engine components during utilisation of the AWC functionality, as described in the following.

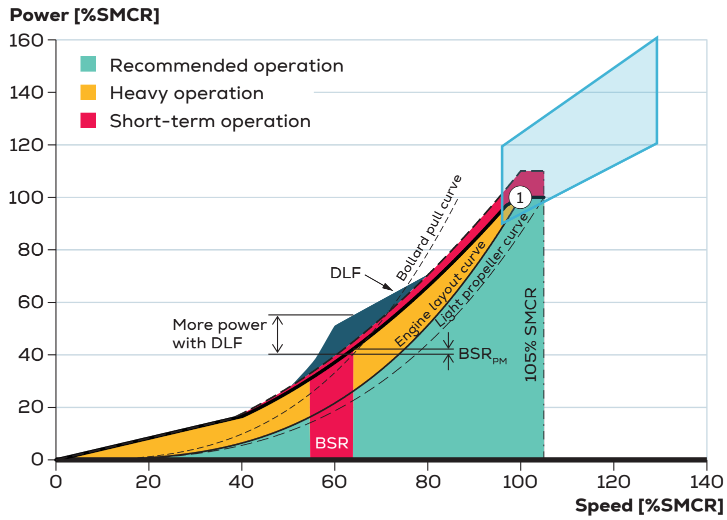

Fig. 2: Illustration of an engine load diagram with the addition of the DLF and the bollard pull curve. The load diagram is independent of the SMCR position within the engine layout diagram, shown in blue.

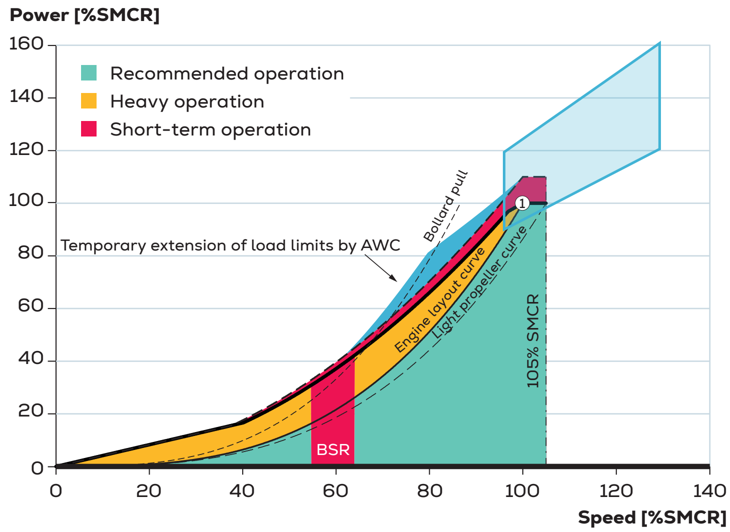

Fig. 3: Illustration of an engine load diagram with the AWC limiter applied. From right to left, the light propeller curve, engine layout curve, and the bollard pull curve.

Working principles of AWC

In principle, the AWC functionality increases the amount of fuel injected into the combustion chamber, thereby increasing the engine's torque output. The AWC function delays fuel injection, which limits the peak pressure and temperature in the combustion chamber. As a result, thermal loads on the piston crown, exhaust valve, cylinder liner, and cylinder cover are reduced and kept below the temperatures attained at SMCR.

Over the years, achievable turbocharger pressure ratios have increased significantly. This enables a higher scavenge air pressure and increases the excess air ratio, which reduces the thermal load on engine components.

The delayed fuel injection improves conditions in the combustion chamber but increases the SFOC by 3% to 4% compared with engine operation on the traditional torque limit curve.

The AWC functionality must be considered available for emergencies only. Frequent exposure to adverse weather conditions requiring the use of AWC will reduce guiding overhaul intervals, as is the case for other special engine configurations. The avoidance of adverse weather encounters should still be pursued through an adequate design light running margin, good seamanship, weather routing, etc.

The AWC functionality can be added as an Asset+ solution for the following single fuel engines:

- G45ME-C9.7
- S40ME-C9.5
- S50ME-C9.7
- S50ME-C10.7
- G50ME-C9.6
- G50ME-C10.7
- S60ME-C10.5
- G60ME-C10.5
- G70ME-C10.5
- G70ME-C10.58
- G70ME-C10.7

And following GI-engines:

- G70ME-C10.5
- G70ME-C10.58
- G70ME-C10.7

The updated AWC functionality increases automation and enhances the handling of load changes, resulting in improved safety and reliability. When the continuous operation limit is reached, the system now automatically permits operation beyond this limit – up to the AWC threshold. Previously, the the crew had to manually activate the AWC functionality This enhancement gives the crew more time to respond, preventing a sudden drop in engine speed that could compromise vessel manoeuvrability in adverse conditions.

Unless the operator override the reduction by pressing the “Increased Limitations” button on the bridge, the engine control system automatically and gradually reduces the operational threshold back to the normal continuous limit after a certain period, minimising stress on engine components. The increased operational limit can remain active for as long as required.

Additionally, load transitions are now smoother thanks to an updated load program. This program is specifically designed to handle variations caused by factors other than changes in the speed setpoint, thereby improving reliability and reducing stress on engine components.

The AWC functionality does not replace the requirement to design a propulsion system with a sufficient propeller light running margin. Everllence recommends a light running margin of 4% to 7%, and up to 10% in special cases. Examples of special cases include vessels with larger-than-usual PTOs, vessels operating in areas with very heavy weather conditions, and vessels operating in ice. Similarly, vessels with two fixed pitch propellers/main engines, where one propeller/one main engine for some reason is blocked/declutched from time to time, are considered special cases that can benefit from an increased light running margin.

The AWC functionality should not be applied to increase the power taken out through a shaft generator/PTO, as such operation is not considered an emergency. The installation of the AWC functionality does not alter the PTO layout limit as it is described in [1], Chapter 3.

AWC and influence on evaluation of minimum propulsion power

Lowering a vessel's installed power has been acknowledged as a method of achieving a lower EEDI value, however, it has also raised concerns that it could result in underpowered vessels with reduced manoeuvrability in heavy weather. As a result, the IMO has published an interim assessment method for determining the minimum propulsion power required to maintain a safe manoeuvrability in adverse conditions [5].

The evaluation of minimum propulsion power can be performed using assessment level 1 or assessment level 2. Assessment level 1 allows the minimum power line value (Eq. 3) to be calculed based on the vessel type and the deadweight, with coefficients a and b according to [5]. See Fig. 4.

Eq. 3

$$\text{Minimum power line value} = a \times \text{dwt} + b$$

- For tanker:
  a = 0.0652 and b = 5,960.2
- For dwt < 145,000 dwt:
  a = 0.0763 and b = 3,374.3
- For dwt ≥ 145,000 dwt:
  a = 0.0490 and b = 7,329.0

However, if the propulsion power installed is below the minimum power line value of assessment level 1, an evaluation on the vessel's design must be performed according to assessment level 2.

Assessment level 2 takes the actual capabilities of the propulsion plant into consideration. In other words, level 2 accounts for the engine load diagram along with the light running margin of the propeller, etc. As the AWC functionality extends the engine load limits for as long as required in an emergency, its application has a significant positive effect on the minimum speed that a vessel can maintain in this evaluation. This is illustrated in the subsequent case study of the 50,000 dwt bulk carrier.

If the vessel - despite the application of the AWC functionality - cannot fulfil the criteria of either assessment level, several options can be considered.

The propeller light running margin, i.e., the margin between the engine load limits and the calm water propeller curve, can be increased.

Alternative fuels that lower the EEDI, will allow for a more powerful engine. The hull lines, particularly the bow, can be refined to minimise resistance in general, and wave-induced resistance in particular.

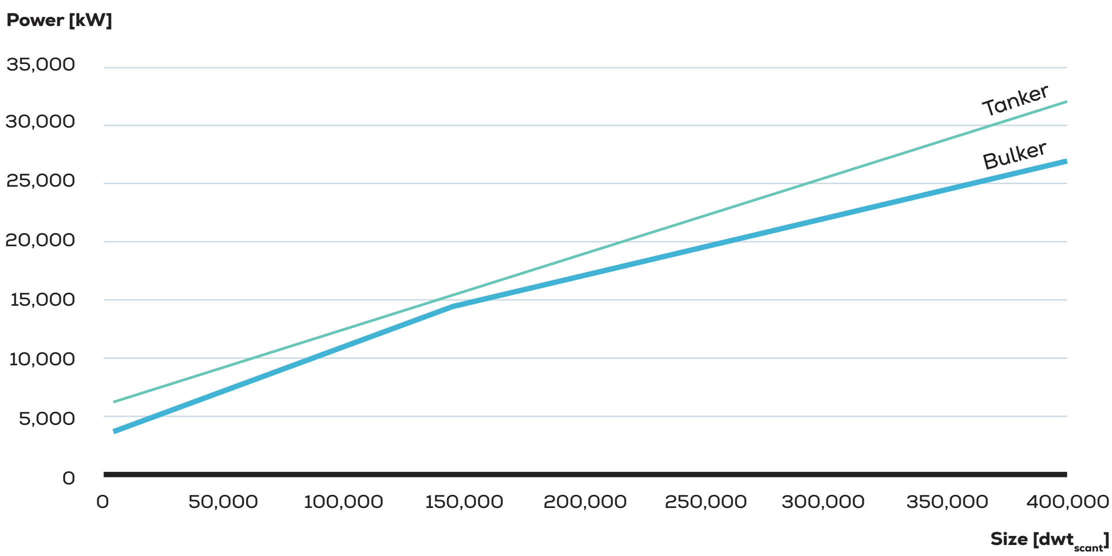

Fig. 4: Assessment level 1 [5] for fulfilling the minimum propulsion power requirements for tankers and bulk carriers as a function of scantling deadweight in line with Eq. 3

4. Case study on bulk carrier

The application and benefits of AWC, both with respect to rule compliance and actual performance, are demonstrated through a case study of a 50,000 dwt bulk carrier. The case study includes a theoretical evaluation of the propulsion plant's capabilities regarding minimum propulsion power. Furthermore, a practical evaluation of the bulk carrier operating fully laden, both with and without the AWC functionality, in a developing seaway has been performed to illustrate the effects of applying AWC.

The main particulars of the bulk carrier considered are given in Table 1. With the very low SMCR applied, calculations indicate that the vessel can fulfill EEDI phase 3 using a traditional bunker. Considering this SMCR, particular attention must be paid to the vessel's minimum propulsion power.

Fig. 5 shows an illustration of main engine loading while propelling the fully laden vessel in calm waters. The EEDI reference speed at 75% engine load with the hull as in sea trial condition, as considered here, is calculated to 13.3 knots.

Examples of minimum propulsion power evaluation with and without AWC

Following the simple Eq. 3, minimum propulsion power level 1, 7,189 kW is required for a 50,000 dwt bulk carrier, as can also be seen on Fig. 4. As the SMCR is lower than this value, an evaluation according to assessment level 2 is required.

Assessment level 2 in the latest version of [5] allows different methodologies to be applied for determining the operating point under the sea-state conditions required. The simplest approach is based on the solution of a one-degree-of-freedom manoeuvring equation in the longitudinal direction to demonstrate that the ship can maintain a speed of 2.0 knots through the water in wind and wave directions ranging from head seas to 30 degrees off the bow. In this methodology, Eq. 4 is applied to determine the added wave

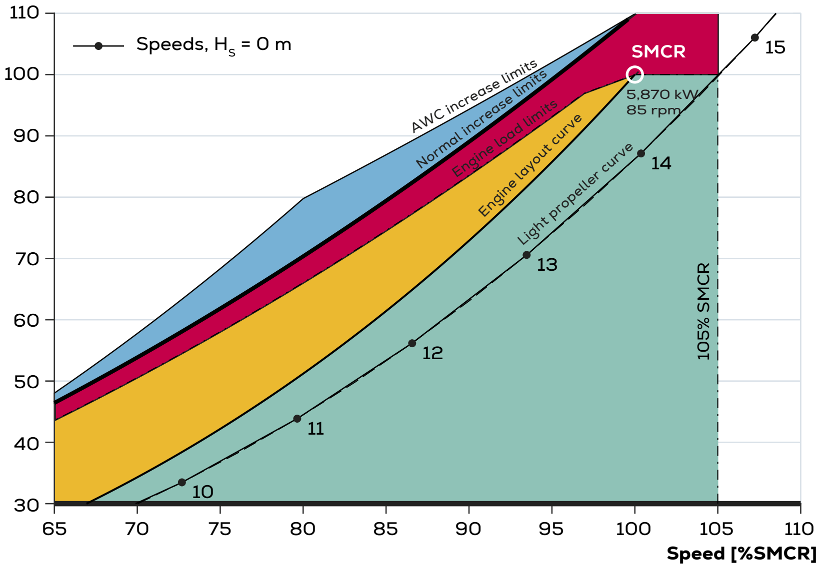

Fig. 5: Performance of the 50,000 dwt bulk carrier in calm water. Numbers along the black curve represent attainable vessel speeds in knots.

$$R_{add\ wave} = 1{,}336(5.3 + V_{vessel})\left(\frac{B \times d}{L_{pp}}\right)^{0.75} \times H_s^2 \quad \text{Eq. 4}$$

Table 1: Vessel particulars for a typical 50,000 dwt bulk carrier, EEDI phase 3 compliant

Scantling draught	m	13.1
Design draught	m	12.0
Length overall	m	183.0
Length between perpendicular	m	174.0
Block coefficient, L_{pp}	m	0.82
Breadth	m	32.2
Engine		6S50ME-C9
SMCR	kW	5,870
SMCR	rpm	85
Sea margin	%	15
Engine margin	%	10
Light running margin	%	5
Type of propeller		FPP
Propeller diameter	m	6.8

resistance, a method developed in the SHOPERA project [6] and JASNAOE [7], and now applied in [5].

- L_{PP} is the length between perpendiculars in m.
- V_{vessel} is the speed in m/s.
- B is the breadth of the vessel in m.
- d is the draught in m.
- H_S the significant wave height in m.

Propeller characteristics, which relate resistance to engine power, are obtained via the Wageningen B-series, while propulsion coefficients, such as the wake fraction and thrust deduction fraction are estimated using internal tools.

As the length between perpendiculars of the vessel is below 200 meters, $L_{PP} < 200$ m, the minimum propulsion power guideline requires the performance of the vessel to be evaluated at a significant wave height of $H_S = 4.5$ m and a wind speed of $V_{wind} = 19$ m/s, corresponding approximately to Beaufort 7.

In this sea state, the propeller curve is heavy running and shifts to the left compared to the calm water propeller curve illustrated in Fig. 6. As shown, the vessel complies with the minimum propulsion power guidelines without the AWC functionality, as it can maintain the minimum navigational speed[1] of four knots within the normal load diagram. In fact, the vessel can maintain almost 7 knots before crossing the torque limiter of the two-stroke main engine. This is well above the required minimum navigational speed.

However, to obtain additional safety, the AWC functionality has been developed. The functionality can be activated if the vessel encounters an emergency in a sea state more severe than that specified in assessment level 2 of the IMO guidelines [5], as the example in Fig. 7 illustrates.

In this example, $H_S = 5.5$ m and $V_{wind} = 19$ m/s are considered, corresponding approximately to Beaufort 8. Under these conditions, the vessels's performance is very different, as it is unable to maintain a for-

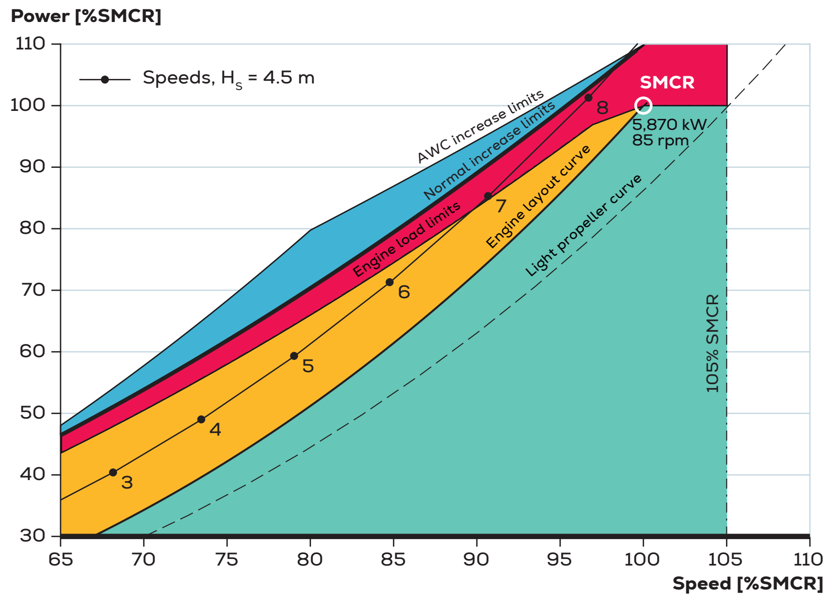

Fig. 6: Expected performance of 50,000 dwt bulk carrier in Beaufort 7. Numbers along the black speed curve represent the attainable vessel speeds in knots.

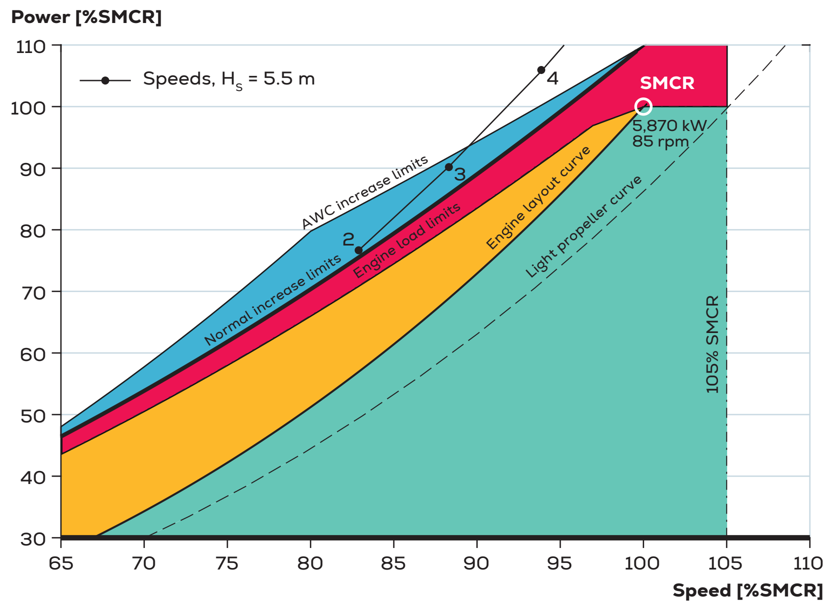

Fig. 7: Expected performance of 50,000 dwt bulk carrier in Beaufort 8. Numbers along the black speed curve represent the attainable vessel speeds in knots.

1. Depending on the area of the rudder, the requirement for minimum course keeping speed also set by the guideline in [1] may be stricter than the requirements for the minimum navigational speed.

ward speed of 2 knots within the traditional load diagram of the main engine. However, calculations show that the vessel can maintain a forward speed of 3 knots by activating the AWC functionality.

Influence of propeller light running margin

Fig. 8 illustrates the importance of a sufficient light running margin. In this calculation, all parameters are as listed in Table 1, except for the light running margin, which is reduced to 2%. A small light running margin of this order is not recommended for a new design, but a reduction of the light running margin may occur over time as the hull and propeller foul.

The reduced light running margin means that only 5 knots can be maintained within the normal engine load diagram in Beaufort 7. Compared to the performance of a propulsion plant with a 5% light running margin, as illustrated in Fig. 6, this is a reduction of 2 knots.

In situations, where a vessel is delivered with a 2% light running margin, a negative light running margin can be experienced as hull fouling increases. Such a negative light running margin will further reduce the vessel's speed capabilities in adverse weather conditions - even if the AWC functionality is activated.

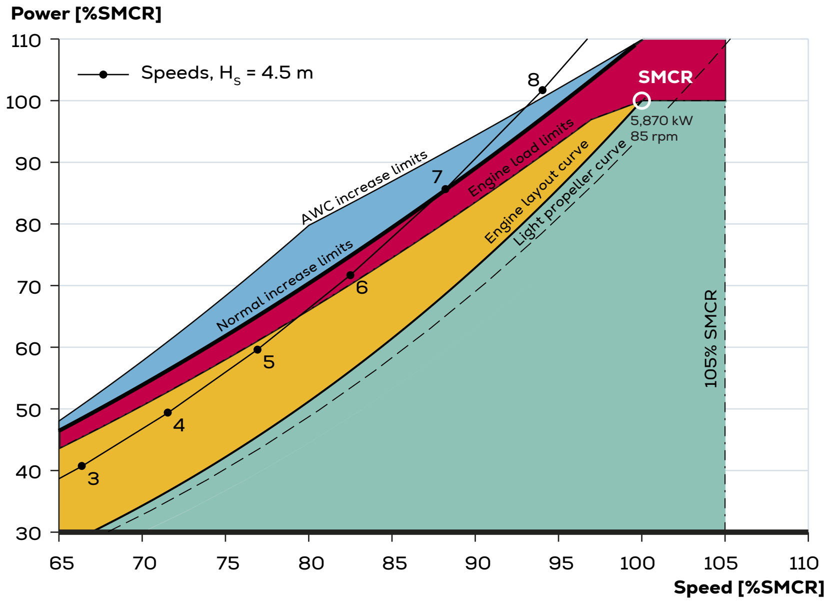

Fig. 8: Expected performance of 50,000 dwt bulk carrier in Beaufort 7 with reduced light running margin. Numbers along the black speed curve represent the attainable vessel speeds in knots.

Performance in a developing sea of Beaufort 7-8 with and without AWC

An evaluation has been performed of the bulk carrier described in Table 1 operating fully laden, both with and without the AWC functionality in a developing sea.

Fig. 9 illustrates the engine performance without AWC, whereas Fig. 10 illustrates the performance with AWC, when sailing in head seas. The development of the sea state, represented by the significant wave height, H_s, is included in the lower part of both figures together with the engine rpm.

The colour bar relates the sea state and engine rpm to the location of the operating point of the propeller/main engine in the engine load diagram illustrated in the upper part of the figures. In both situations, the telegraph is set to 82% of the maximum engine rpm when the vessel sets to sea.

In both cases, it is clearly identified that the propeller becomes increasingly heavy as the sea state develops, increasing the power required to maintain the same rpm. After three days of sailing, the significant wave height develops from approx. 3 m to 5 m.

In the case without AWC, this low-EEDI vessel is no longer able to maintain engine rpm once the torque-limiter is activated. At this point, the vessel maintains a speed through the water of 3.7 knots. As the engine operates at the maximum torque permitted, the rpm drops (light blue) until an equilibrium is established between the delivered thrust and the resistance, or until the wave height reduces.

Without AWC, the vessel's speed through the water drops to 2 knots as the wave height peaks.

After the peak in wave height (dark blue), the engine accelerates the vessel along the torque limiter curve. At a certain point, the telegraph setpoint is reached, and the torque, and thereby power, is reduced as the sea state eases, while the rpm is maintained at the setting.

In the case with AWC, the propeller is just as heavy running as it is without AWC during the third day of sailing. The difference becomes apparent as the significant wave height peaks (light blue). Because the AWC is activated, the normal torque-limiter does not limit the torque delivered. Therefore, the engine can deliver the increased torque required by the increasingly heavy running propeller as the sea state develops. Consequently, the rpm can be maintained at the setpoint. In this case, the extended AWC limits are not reached.

Not reaching the limits makes a significant difference, up to 80% of the SMCR power is delivered with AWC, whereas only 58% of the SMCR power is available without AWC during the peak wave height. This is also reflected in a significant difference in the vessel speed through the water – 4.2 knots can be maintained with AWC.

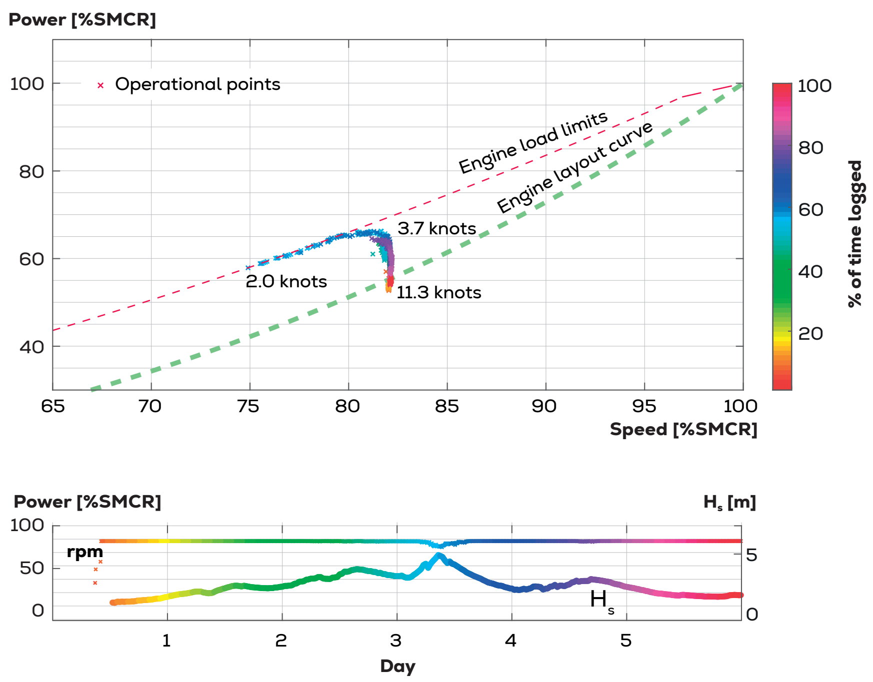

Fig. 9: Expected performance of 50,000 dwt bulk carrier in heads seas without AWC

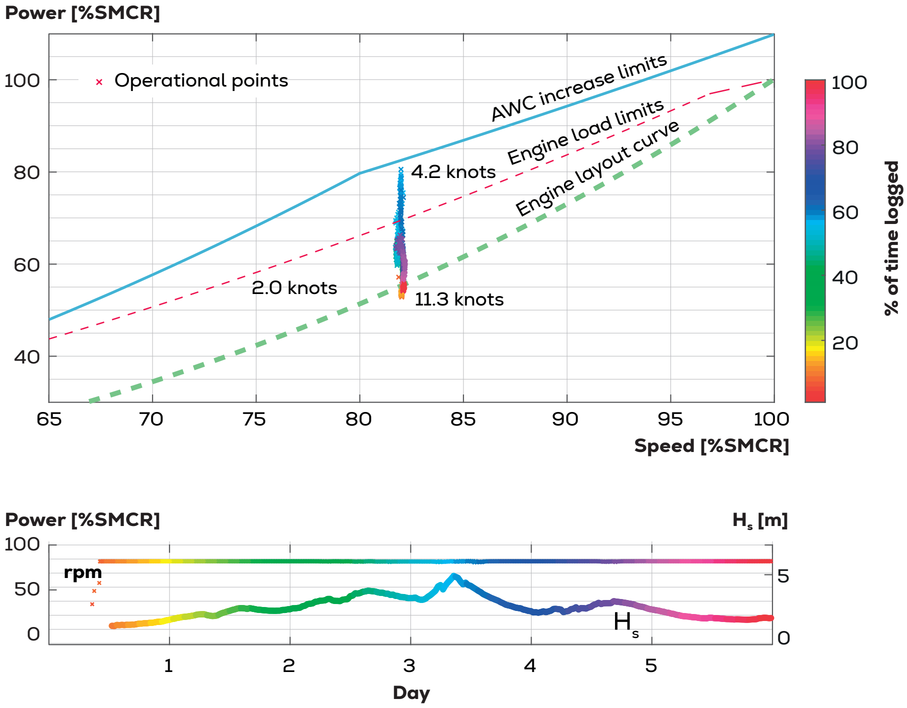

Fig. 10: Expected performance of 50,000 dwt bulk carrier in heads seas with AWC

5. Conclusion

When encountering adverse weather, the propeller becomes increasingly heavy running and requires an increased torque for the vessel to maintain a safe manoeuvring speed.

The increased torque demand can prevent an engine directly coupled to a fixed pitch propeller from delivering its full power, as the propeller may become so heavy running that the engine cannot reach its full rpm.

The AWC functionality extends the engine load limits in the range from 60% to 100% engine speed. Hereby, it is possible to access a higher percentage of the MCR at lower rpm and maintain a higher speed for as long as required in an emergency.

AWC is available for all new engine designs relevant to bulk carriers and tankers for which the EEDI is fully in phase. Application of AWC to other engine designs may also be possible, subject to an individual project evaluation by Everllence.

Reducing the power installed onboard is one way of meeting the increasingly stricter EEDI-requirements. The AWC functionality represents an alternative and possibly easier way for shipyards to achieve compliance with EEDI regulations while still fulfilling assessment level 2 of the IMO minimum propulsion power guidelines. In addition, even when compliant with minimum propulsion power assessment level 2, the AWC functionality can be utilised to increase a vessel's manoeuvrability beyond rule requirements.

A theoretical case study of a 50,000 dwt bulk carrier operating in a developing sea, both with and without the AWC functionality, shows that the attainable speed in heavy weather of Beaufort 8 can be approximately doubled through the AWC. Tests show a similar performance, depending on vessel type, size, light running margin, etc.

The AWC functionality should not be regarded as a remedy for a too small light running margin. The recommended light running margin of 4-7%, and up to 10% in special cases, remains unchanged.

As with other special engine configurations, frequent exposure to adverse weather conditions will reduce the guiding overhaul intervals. Therefore, it is not recommended to utilise the AWC functionality for other purposes.

For questions regarding the principles of the AWC functionality, please consult Everllence at MarineProject-Engineering2S@everllence.com. For ordering information, please consult our licensees.

6. References

[1] "Basic principles of ship propulsion", Everllence, 2023.

[2] "Propulsion trends in bulk carriers", Everllence, 2022.

[3] "Propulsion trends in tankers", Everllence, 2021.

[4] "Dynamic limiter function", Everllence, 2018.

[5] "Guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions", IMO, MEPC.1/Circ.850/Rev.3, 2021.

[6] "Draft revised guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions", IMO, MEPC 71-INF.28, 2017.

[7] "Supplementary information on the draft revised guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions", IMO, MEPC 71-INF.29, 2017.

Everllence
2450 Copenhagen SV, Denmark
P + 45 33 85 11 00
info@everllence.com
www.everllence.com