Economiser energy control for increased service steam production

MAN Energy Solutions
Future in the making

MAN B&W low-speed two-stroke engines

Future in the making

Contents

With the ever-tighter IMO Energy Efficiency Design Index (EEDI) phases, the allowable main engine power installation reduces. As a consequence, the available exhaust gas energy for service steam production decreases. An oil-fired boiler can be used to cover the lack of steam, but at the cost of an increase of the total fuel consumption. In response to this, MAN Energy Solutions has developed the economiser energy control (EEC) feature. The EEC feature minimises the overall fuel consumption by allowing more exhaust gas energy to be extracted from the ME.

This paper provides detailed descriptions of the EEC feature available for MAN B&W low-speed two-stroke engines. In addition, an example showing how the EEC feature can reduce total fuel consumption is also provided.

Introduction

Steam plays an important role in the daily operation on board a vessel. On a vessel, steam is used for fuel heating, tank cleaning, fresh water generation, and air condition, etc.

A composite boiler generates the steam, preliminary using exhaust gas energy as the heat source. Accordingly, the steam production depends on the engine operation. At lower engine loads, this means that less exhaust energy is available and that less steam can be produced. If the main engine (ME) or auxiliary engines cannot cover the steam demand alone, an oil-fired boiler is used. However, this increases the total fuel consumption and lowers the total fuel efficiency of the vessel.

Moreover, the Energy Efficiency Design Index (EEDI) phases have been introduced over the last decade. The EEDI aims to reduce greenhouse gas emissions by limiting the allowed ME power installed in vessels. Lower power results in less available exhaust gas energy, and a greater need for additional steam production from an oil-fired boiler.

To minimise the operating time of the oil-fired boiler, and to improve engine optimisation and bypass control strategies, MAN Energy Solutions has introduced the economiser energy control (EEC) functionality for ME-C/ ME-B engines. The EEC design includes functionality for low-load (LL) or part-load (PL) operation of the ME.

The EEC feature works by an exhaust gas bypass (EGB) which increases the exhaust gas energy to the composite boiler, and hereby the steam production. The total fuel consumption of the vessel will decrease when using the EGB, since it only requires a small additional fuel amount for the ME, compared to using only the oil-fired boiler.

This paper gives an elaborate description of the EEC functionality. Furthermore, the paper demonstrates the benefit of the EEC functionality for the service steam production on an 82,000 dwt Kamsarmax bulk carrier. The bulk carrier has an EEDI phase-three optimised MAN B&W two-stroke engine.

The EEC functionality

For utilisation of the EEC feature, the engine must be equipped with an EGB valve on the exhaust gas receiver. When the EGB valve opens, exhaust gas bypasses the turbocharger(s) and flows to other consumers. The rate of flow bypassing the turbocharger is named “install EGB rate”. Depending on the engine mode and Tier III technology, some of this flow can be sent directly to the exhaust gas economiser (EGE), which will increase the service steam production. Fig. 1 shows the principle of a system with the EEC feature.

In the EGE system, the steam pressure is the control parameter. Two aspects affect the steam production: the amount of heat/power (fuel) consumed and the exhaust gas amount supplied to the EGE system. The amount of fuel depends on the specific maximum continuous rating (SMCR), and the vessel operating pattern. The amount of exhaust gas energy depends on the degree of EGB valve opening, engine tuning, and ambient temperature.

When opening the EGB valve, the exhaust gas amount to the turbocharger decreases, and the turbocharging efficiency drops. The turbocharging efficiency defines the enthalpy flow delivered by the turbocharger compressor to the cylinders (in terms of fresh air), divided by the enthalpy flow received by the turbocharger turbine from the cylinders (in terms of exhaust gas). If this ratio becomes too low, the combustion chamber temperatures easily exceed acceptable limits. Therefore, the EGB valve cannot be fully opened through the entire ME operating range.

Ambient conditions also have a large influence on the service steam production. As the ambient temperature increases, so does the service steam production. This means that the steam production in tropical conditions (ambient air temperature: 45°C, scavenge air cooling water temperature: 36°C) is greater than in ISO conditions (ambient air temperature: 25°C, scavenge air cooling water temperature: 25°C).

As the EGB valve lowers the turbocharging efficiency, volumetric scavenging is also lowered. The volumetric scavenging describes the volume of fresh air each cylinder receives during the scavenge process, divided by the swept volume of the cylinder. If this ratio becomes too low, scavenging is jeopardised. This is especially crucial for the exhaust valve component, which relies on the cooling effect of the fresh air during scavenging. In extreme cases, the fresh air hardly reaches the upper part of the cylinder liner during scavenging. Therefore, the EEC feature should not be used in tropical conditions, or at temperatures below winter conditions due to unnecessary wear and tear on the engine components.

All MAN B&W two-stroke engines either have an EGB valve installed, or can be equipped with one. If the EGB valve is not a standard component, and EEC is required, the respective design-specific order ID must be updated accordantly.

In the moment of writing, the EEC feature can only be utilised for engines with LL and PL SFOC optimisation. For HL SFOC optimised engines, there is no margin for the EEC feature. EEC retrofit is possible if the engine is LL or PL tuned, and an EGB is installed. If the engine is HL tuned, the turbocharger must be re-matched. For a retrofit project concerning EEC, contact PrimeServ at: PrimeServ-cph@man-es.com.

In the appendix, the table options for economiser energy control (EEC) shows the installed EGB rate, allowable EEC bypass rate, allowable EGB opening for EEC, and the EEC opening window for various Tier II and Tier III tunings.

An EEC report describing the increment of the steam production from an EGE can be requested from the Marine Project Engineering department at: MarineProjectEngineering2S@man-es.com.

The EEC feature can operate simultaneously with a shaft generator system without jeopardising the vessel manoeuvrability.

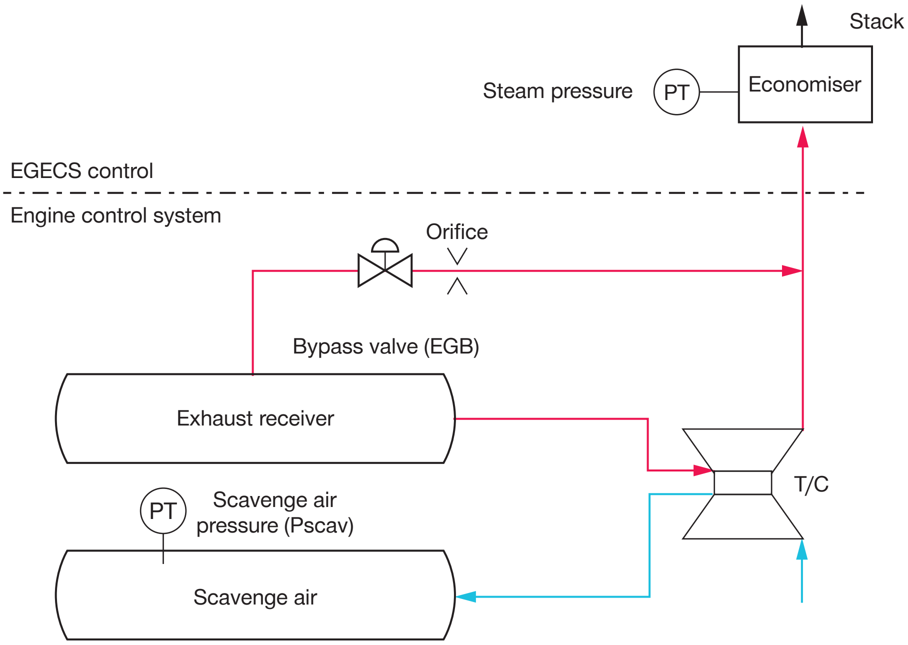

Fig. 1: Principle of a system with LL-EGB and PL-EGB basic modes (exhaust gas economiser control system (EGECS))

Vessel segments and EEC

Previously, the EEC functionality was mostly seen on vessels with a high service steam demand, and low ME power installed. These vessels were mainly bulk carriers sailing on high-viscosity HFO. Due to the high HFO viscosity, a large amount of service steam was required to ensure the correct HFO viscosity.

Therefore, the EEC functionality was a great tool for increasing service steam availability and securing steam production.

As the two-stroke engine becomes more efficient, less exhaust gas energy is available for steam production. As a further limitation to the steam production, the EEDI phases are meant to limit the installed ME power. This means that less ME power will be available for a broad range of vessel segments. Eventually, it will influence the steam availability on tanker and general cargo vessel segments. But the EEC functionality can counteract the low steam production.

Composite boiler

The purpose of the composite boiler is to transfer thermal energy to the steam cycle of the vessel. In the composite boiler, feed water changes from a saturated liquid phase to a saturated vapour phase. The composite boiler consists of two units: an EGE, and an oil-fired boiler. The EGE uses exhaust gas as the heat source, and the oil-fired boiler uses fuel oil as the heat source. The steam pressure of the EGE is normally in the range of 7.0–7.5 bara, but may be lower depending on the steam consumers.

When the exhaust gas from the ME cannot meet the steam demand on its own, the oil-fired boiler is started. This situation often occurs when the vessel accelerates at lower loads. Another situation lacking exhaust gas is at quay, where the auxiliary engines are the only power source of the vessel producing exhaust gas. When the vessel is at sea and the ME is running, the EEC feature can be utilised as an alternative to the oil-fired boiler, and fuel can be saved.

The composite boiler is placed after the ME, the auxiliary engines, and both units when more than one boiler is considered. It is most common to place the boiler after the ME, since the ME is more frequently operated on a voyage compared to the auxiliary engines.

The steam production from the oil-fired boiler can either be fixed or variable. The fixed operation boiler is often referred to as a single stage boiler. These oil-fired boilers often have one, two, or three fixed operating stages. The single-stage oil-fired boiler is often cheaper than the variable-stage oil-fired boiler.

As a standard design criterion, the composite boilers were previously designed to cover the service steam demand at 85–90% SMCR load at ISO conditions. As vessels started to slow steam to save fuel, the boiler design criterion has changed to approximately 75% SMCR load at ISO conditions. Eq. (1) estimates the amount of steam produced by the EGE.

- $\dot{m}_{exh}$ is the mass flow of exhaust gas after it has been mixed with the bypassed flow through the EGB valve. The allowable EEC bypass rate is given as a percentage of the installed EGB rate, which is a percentage of the total exhaust gas flow.
- $(T_{in}^{EGE} - T_{out}^{EGE})_{exh}$ is the temperature difference across the EGE on the exhaust gas side. Due to the distance between the ME and the EGE, a temperature drop is subtracted from the T_{in}^{EGE} value.
- $(h_{st} - h_{fw})$ is the enthalpy difference between saturated water (feed water) and saturated steam.
- $(1 - \frac{rad\%}{100\%}$ is the heat loss due to heat radiation to the environment. The radiation is normally 1% to 2%.
- C_P is the specific heat capacity of the exhaust gas.

The calculation uses a variable pinch point which depends on the ME load. It is based on a boiler matching load of 85% and a pinch point temperature of 15°C for Tier II main fuel mode at ISO conditions. It is important to note that the boiler-maker must confirm the steam figures.

Equation (1)

$$\dot{m}_{steam} = \frac{\dot{m}_{exh} \times C_p \times (T_{in}^{EGE} - T_{out}^{EGE})_{exh}}{(h_{st} - h_{fw})} \times \left(1 - \frac{rad\%}{100\%}\right)$$

EGE governing control

Two scenarios govern EGE operation:

- If the exhaust energy is higher than required, and too much steam is produced, a safety valve dumps the excess steam energy to the environment.
- If the exhaust energy is too low, and the steam production is too low, an auxiliary burner is started. When the auxiliary burner is operating, it is optimal to produce as much exhaust heat as possible to reduce the auxiliary burner oil consumption.

As mentioned, the EGB cannot be operated freely, since the ME has a limit on how much the EGB can be opened at a given load. For optimal control of the EGE steam production, the EGB must be controlled to a point where neither the steam dump valve nor the auxiliary burner is in operation. This gives a bypass valve operating range of the EGB as shown in the graph in Fig. 2.

The EGB may open freely within the area of the maximum and minimum allowable bypass area. However, the EGB is never fully closed. The minimum opening of the EGB hinders a radical change of the exhaust gas energy when the steam production increases beyond the steam setpoint.

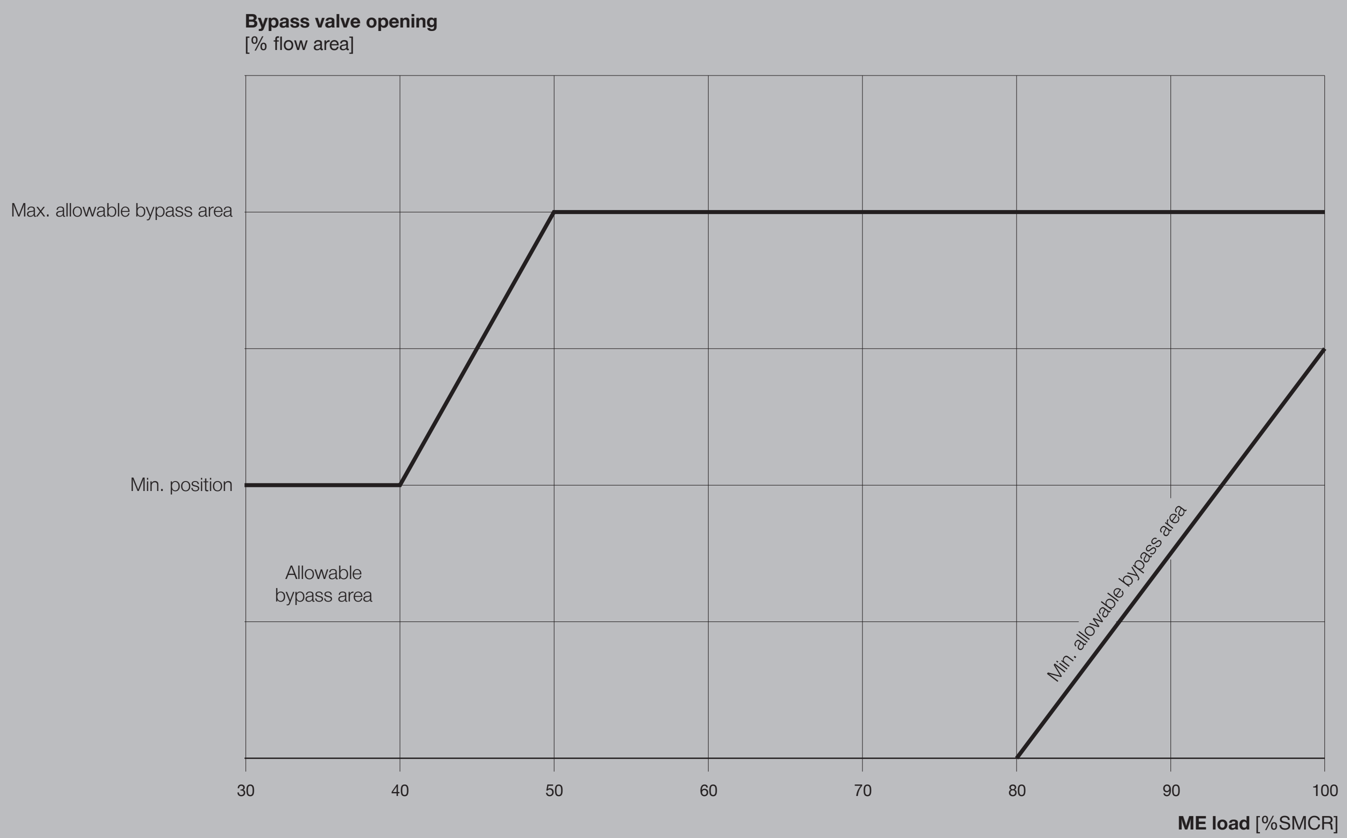

Fig. 2: Maximum and minimum allowable bypass area curves for EGB for all engines except sequential turbocharging

EEC control

The continuous control of the EEC feature includes both the engine control system (ECS), and the exhaust gas economiser control system (EGECS). From a design point of view, a steam pressure setpoint is selected. The EEC feature requires that the boiler manufacturer includes a continuous steam pressure controller in their system. The EGE system measures the steam pressure and calculates the difference between the setpoint and the measured actual steam pressure. If the difference is smaller than the setpoint, a gain signal is sent to the PID controller. The PID controller sends an increase exhaust gas energy (IEGE) signal to the ECS, which then adjusts the EGB valve opening to match the actual steam pressure with the setpoint. The EGB valve opening, and hereby the allowable bypass area, must match the governing control of the EGE. It means that an auxiliary burner must be started if the engine tuning does not allow an increased flow through the EGB. Fig. 3 shows a schematic of the EEC control.

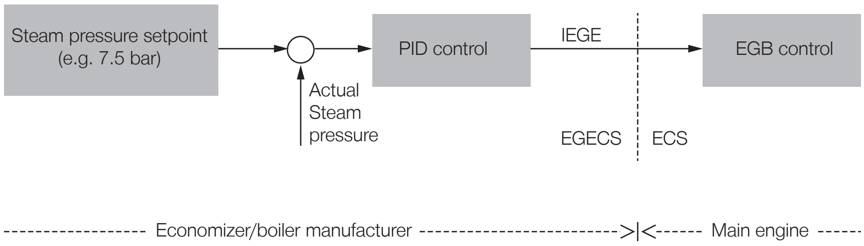

Fig. 3: Continuous steam pressure control strategy

Fig. 4 shows a potential control scenario of the service steam pressure for a given vessel.

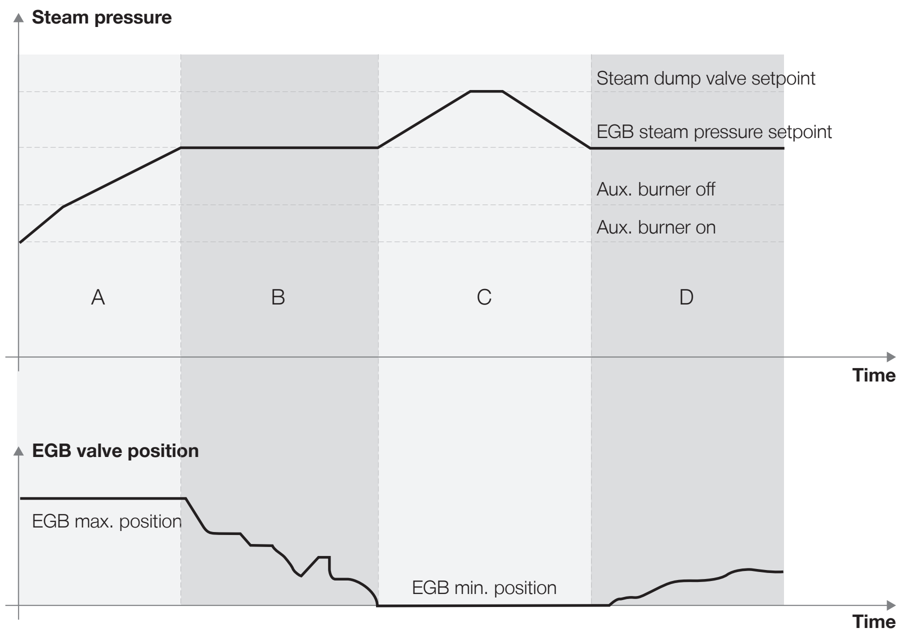

Fig. 4: Control scenario of the service steam pressure for a given vessel

A: The ME is started, and the oil-fired burner in the composite boiler is operating. The oil-fired burner stops when the service steam pressure reaches the setpoint.

B: The service steam pressure is kept at the setpoint by opening or closing the EGB valve.

C: The EGB valve is fully closed, or open to an extent defined by the engine tuning method. Service steam pressure builds up until the steam dump valve opens and reduces the pressure.

D: The service steam pressure is at the setpoint, and the EGB valve is in continuous operation.

Other possibilities to boost the available service steam

Depending on the vessel type, scenarios might occur where more service steam is needed than can be covered by the EEC feature. For example, this could be at ME operating loads where the EGB cannot be fully opened due to the EEC window restrictions.

If a vessel owner knows that situations with lacking service steam will occur, one solution could be to lower the setpoint of the service steam pressure from 7 bara to 5 bara. By lowering the steam output pressure, the saturation point of the steam moves to a lower temperature. Hereby, the service steam demand can easier be fulfilled, but at the cost of a lower service steam temperature. This solution is possible because most steam consumers only require a minimum steam temperature of approximately 130°C. The only consumers needing a higher steam pressure are the fuel oil heater for the ME, and possibly the auxiliary engines. HFO requires a steam temperature of approximately 165°C (7 bara) to achieve the correct fuel viscosity. As an alternative, an electrical heater could be used to achieve the correct temperature in the fuel tanks. In the last decade, the use of low-viscosity fuels such as VLSFO has gained more interest. The lower viscosity reduces the heating demand of the fuel, and gives the option to reduce the service steam pressure and increase steam production on the vessel.

A second approach is to integrate the separate auxiliary engine boiler into the ME composite boiler. Boiler solutions with an oil-fired part, ME EGE part, and EGE parts, for up to three auxiliary engines in one composite boiler, are available on the marine market.

Arctic bypass and EEC

Ambient air temperature and density are inversely proportional. This means, that if the ambient air temperature decreases, the air density of the air delivered by the turbocharger to the scavenge air will increase. The result is a higher combustion firing pressure.

At arctic temperatures, the density of the scavenge air might be so high that the combustion firing pressure is jeopardised. To reduce the scavenge air pressure, an arctic bypass can be installed. This bypass will bypass some of the exhaust gas energy going to the turbocharger, and hereby reduce the scavenge air density of the air delivered by the turbocharger compressor. The EEC function can be implemented on engines that have an arctic bypass. However, when the arctic bypass is activated, the EEC feature cannot be used. The arctic bypass is only active when Pscav is 0.1 bara to 0.2 bara above the Pscav reference curve. The arctic bypass is suitable for vessels operating in seawater with a temperature below -10°C, and for vessel with the ice-class 1A Super. If you are further interested in operation in arctic environments, see the MAN B&W paper: Ice Classed Ships – Main engine.

Case study of Kamsarmax bulk carrier

This section exemplifies the benefit of the EEC feature on an 82,000 dwt Kamsarmax bulk carrier. The boiler in the example is a composite boiler with a variable oil-fired burner. The vessel is equipped with an MAN B&W 6G50ME-C9.6 engine. The engine is optimised to meet EEDI phase-three compliance with an SMCR value of 7,882 kW at 82.9 rpm. The operating point, NCR, is 70% SMCR. Due to the lower operating point, part-load (PL) tuning has been chosen. The engine runs on HFO, which is the main fuel. Therefore, a scrubber must be used to lower the sulphur content of the exhaust gas to 0.5% S. The allowable EEC bypass rate is 1.5%, according to the table in the appendix.

Table 1 shows vessel particulars.

Vessel particulars

Design speed	knots	14.3
Sea margin	%	15
Engine margin	%	10
Scantling draft	m	14.8
Length, Lpp	m	228.8
Breadth	m	32.2
Type of propeller	-	FPP
Propeller diameter	m	7.7
Propeller blade No.	-	3
No. of propellers	-	1

Table 1: Vessel particulars for a typical 82,000 dwt Kamsarmax bulk carrier which ME is EEDI phase-three compliant

Through a steam balance, it is estimated that the service steam demand at ISO conditions at sea is 849 kg/h, and the service steam demand at winter conditions (ambient air temperature: 10°C, scavenge air cooling water temperature: 10°C) is 1,256 kg/h.

Fig. 5 shows the effect of applying the EEC feature at ISO conditions.

The lowest production of service steam takes place for the base case, which is the MAN B&W 6G50ME-C9.6-EGB-PL,

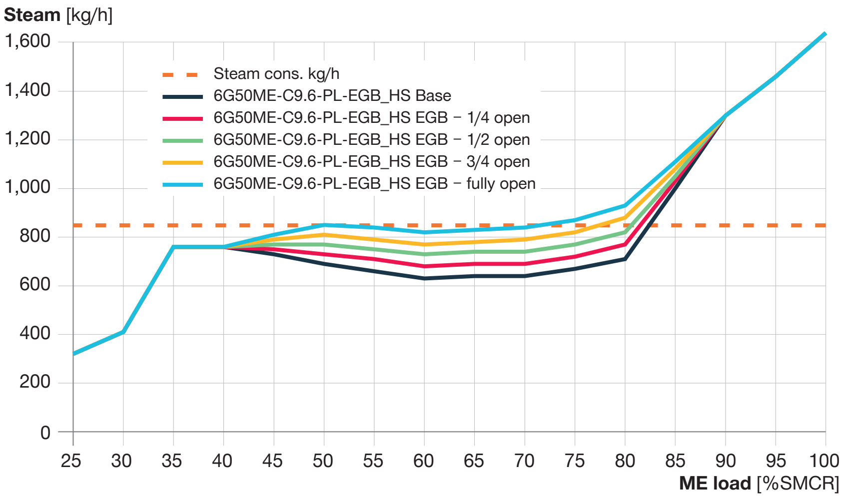

Fig. 5: EGE steam production at ISO conditions

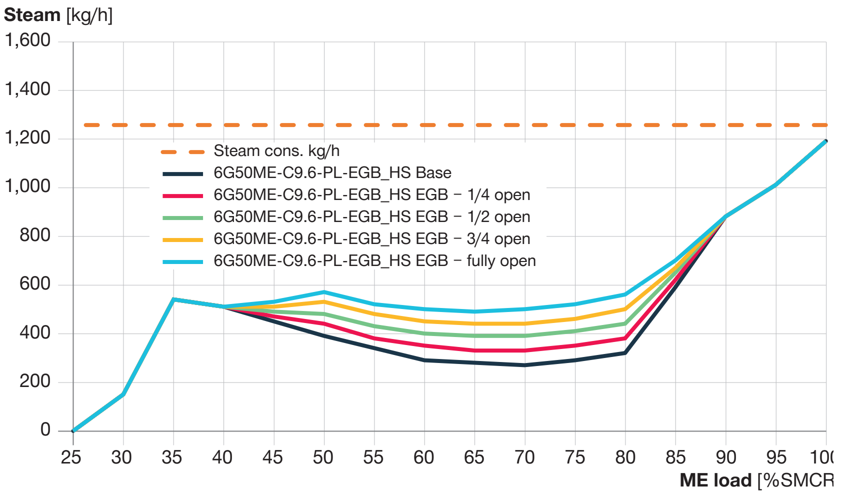

Fig. 6: EGE steam production at winter condition

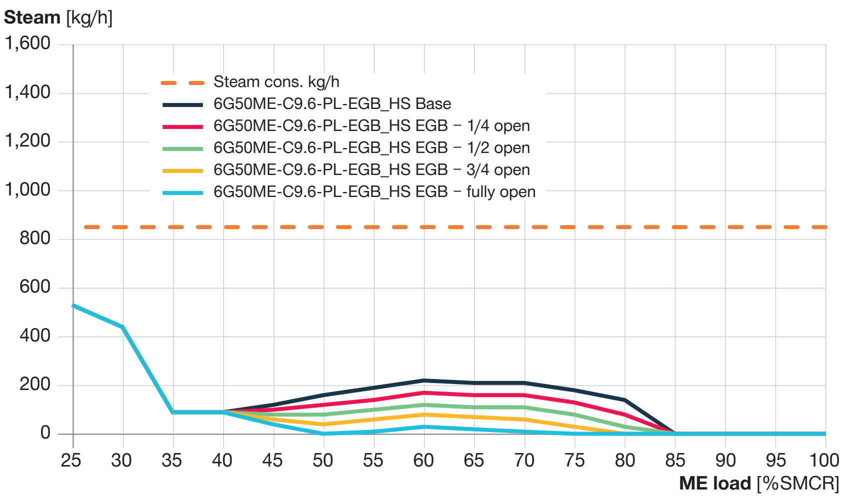

Fig. 7: Oil-fired steam production at ISO condition

that is, a part-load tuned engine, without the EEC functionality. The largest production of service steam is for the MAN B&W 6G50ME-C9.6-EGB-PL engine with the EEC feature, and the EGB fully open. By gradually opening the EGB, the steam production can be increased, but at the cost of an increased ME fuel oil consumption. By utilising the EEC functionality, the service steam demand is met at the NCR point at ISO conditions.

This steam production from the EGE follows the ambient temperatures. This means less steam is produced at winter conditions compare to ISO conditions. Fig. 6 shows this tendency.

At winter conditions, the oil-fired boiler must run to produce the 1,256 kg/h, at the NCR point. Figs. 7 and 8 show the use of an oil-fired boiler at ISO and winter conditions, respectively.

The EEC enables the EGE to utilise the high burning-efficiency of the ME to produce more service steam. The use of the EEC feature reduces the total fuel oil consumption (FOC) of the vessel. Table 2 shows the total FOC of the Kamsarmax bulk carrier for one year (6,000 hours equivalent to 250 days). The HFO price is estimated to 745.5 USD/tonnes at a given time of writing. It is important to note that the EEC feature reduces the total FOC by 28 tonnes per year, which means that the FOC savings are equivalent to 20,777 USD/yr.

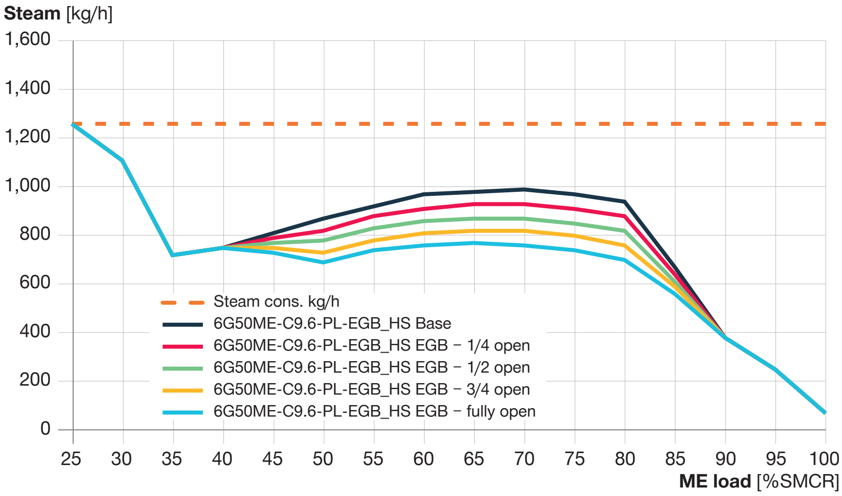

Fig. 8: Oil-fired steam production at winter condition

Yearly fuel oil consumption

Load	Operation	6G50ME-C9.6-EGB-PL (No EEC)			6G50ME-C9.6-EGB-PL (EEC)		
% SMCR	% of running hours	ME FOC tonnes/yr.	Oil-fired boiler tonnes/yr.	FOC total tonnes/yr.	ME FOC tonnes/yr.	Oil-fired boiler tonnes/yr.	FOC total tonnes/yr.
100	0.5	39.2	0.1	39.3	39.2	0.1	39.3
95	0	0.0	0.0	0.0	0.0	0.0	0.0
90	8	610.3	13.2	623.4	610.3	13.2	623.4
85	0	0.0	0.0	0.0	0.0	0.0	0.0
80	13.5	1006.2	55.3	1061.5	1010.7	41.1	1051.8
75	0	0.0	0.0	0.0	0.0	0.0	0.0
70	27.5	2028.8	118.8	2147.6	2041.8	91.0	2132.9
65	0	0.0	0.0	0.0	0.0	0.0	0.0
60	25	1846.8	105.8	1952.5	1864.5	82.8	1947.3
55	0	0.0	0.0	0.0	0.0	0.0	0.0
50	11.5	859.3	43.6	902.9	870.2	34.5	904.7
45	0	0.0	0.0	0.0	0.0	0.0	0.0
40	3.5	265.7	11.4	277.1	265.7	11.4	277.1
35	0	0.0	0.0	0.0	0.0	0.0	0.0
30	4	308.0	19.4	327.3	308.0	19.4	327.3
25	6.5	506.6	35.8	542.3	506.6	35.8	542.3
Total FOC (tonnes/yr.)				7,874.0			7,846.2
Total FOC cost (USD)				5,870,103			5,849,325

Table 2: Yearly fuel oil consumption of the 82,000-dwt Kamsarmax, and a typical operating profile at winter conditions

Conclusion

The EEC feature increases the service steam production from the EGE, while minimising the total FOC on the vessel. EEC can be equipped on all ME-C/B engines with part- or low-load tuning. EEC retrofit options for EEC are available for high-load tuned engines, as long as an EGB valve exists/is installed, and the turbochargers are re-matched according to the ME tuning. The EEC feature can operate simultaneously with other systems, such as shaft generators, without jeopardising the vessel manoeuvrability.

An EEC report, which in detail describes the increment of the steam production from the EGE can be obtained by contacting the Marine Project Engineering department at: MarineProjectEngineering2S@man-es.com.

Abbreviations

DSO	Design-specification order
ECS	Engine control system
EEC	Economiser energy control
EEDI	Energy efficiency design index
IEGE	Increase exhaust gas energy signal
EGB	Exhaust gas bypass
EGE	Exhaust gas economiser
EGECS	Exhaust gas economiser control system
FOC	Fuel oil consumption
LL	Low load
ME	Main engine
NCR	Normal continuous rating
PL	Part load
SMCR	Specific maximum continuous rating

Appendix

Options for economiser energy control (EEC)

The list is valid for the following fuel injection systems:

ME-C/B (diesel/HFO)
GI (methane)
GIE (ethane)
LGIP (liquid petroleum gas)
LGIM (liquid methanol)
GA (methane)

Conventional efficiency turbocharger matching

No option for EEC system.

High-efficiency turbocharger matching

Engine and Tier III technology	Mode	Installed EGB rate	Allowable EEC bypass rate	Allowable EGB opening for EEC
Tier II (sequential TC-tuning)	Tier II	3%**	3.0%	100%
Tier II (10.6 LL tuning)	Tier II	6%	3.0%	50%
Tier II (LL/PL EGB tuning)	Tier II	3%	3.0%	100%
EGRBP	Tier II	9%	0.0%	0%
EGRBP	Tier III		0.0%	0%
EGRTC	Tier II	3%**	3.0%	100%
EGRTC	Tier II (TCCO)		0.0%	0%
EGRTC	Tier III		0.0%	0%
LPSCR	Tier II	6%	3.0%	50%
LPSCR	Tier III		0.0%	0%
HPSCR	Tier II	3%	3.0%	100%
HPSCR	Tier III		3.0%	100%
EPT tuning	Tier II	3%**	3.0%	100%
EcoEGR	Tier II	9%	3.0%	33%
EcoEGR	Tier III		0.0%	0%
ME-GA EGR	Gas-Tier III	6%	0.0%	0%
ME-GA EGR	Diesel-Tier II		3.0%	50%
ME-GA EGR	Diesel-Tier III		0.0%	0%
Tier II (sequential TC-tuning) + SO_x scrubber	Tier II	1.5%**	1.5%	100%
Tier II (10.6 LL tuning) + SO_x scrubber	Tier II	6%	1.5%	25%
Tier II (LL/PL-EGB tuning) + SO_x scrubber	Tier II	3%	1.5%	50%
EGRBP + SO_x scrubber	Tier II	9%	0.0%	0%

Engine and Tier III technology	Mode	Installed EGB rate	Allowable EEC bypass rate	Allowable EGB opening for EEC
EGRBP + SO_x scrubber	Tier III		0.0%	0%
EGRTC + SO_x scrubber	Tier II	1.5%**	1.5%	100%
EGRTC + SO_x scrubber	Tier II (TCCO)		0.0%	0%
EGRTC + SO_x scrubber	Tier III		0.0%	0%
LPSCR + SO_x scrubber:				
In parallel (SO_x scrubber)	Tier II	6%	1.5%	25%
In parallel (LPSCR)	Tier III		0.0%	0%
Inline (SO_x scrubber)	Tier II	6%	1.5%	25%
Inline (SO_x scrubber + LPSCR)	Tier III		0.0%	0%
HPSCR + SO_x scrubber	Tier II	3%	1.5%	50%
HPSCR + SO_x scrubber	Tier III		1.5%	50%
EPT tuning + SO_x scrubber	Tier II	1.5%**	1.5%	100%
EcoEGR + SO_x scrubber	Tier II	9%	1.5%	16%
EcoEGR + SO_x scrubber	Tier III		0.0%	0%
ME-GA EGR + SO_x scrubber	Gas-Tier III	6%	0.0%	0%
ME-GA EGR + SO_x scrubber	Diesel-Tier II		1.5%	25%
ME-GA EGR + SO_x scrubber	Diesel-Tier III		0.0%	0%

Table 3: High-efficiency turbocharger matching

Allowable opening of EEC as a function of engine load:

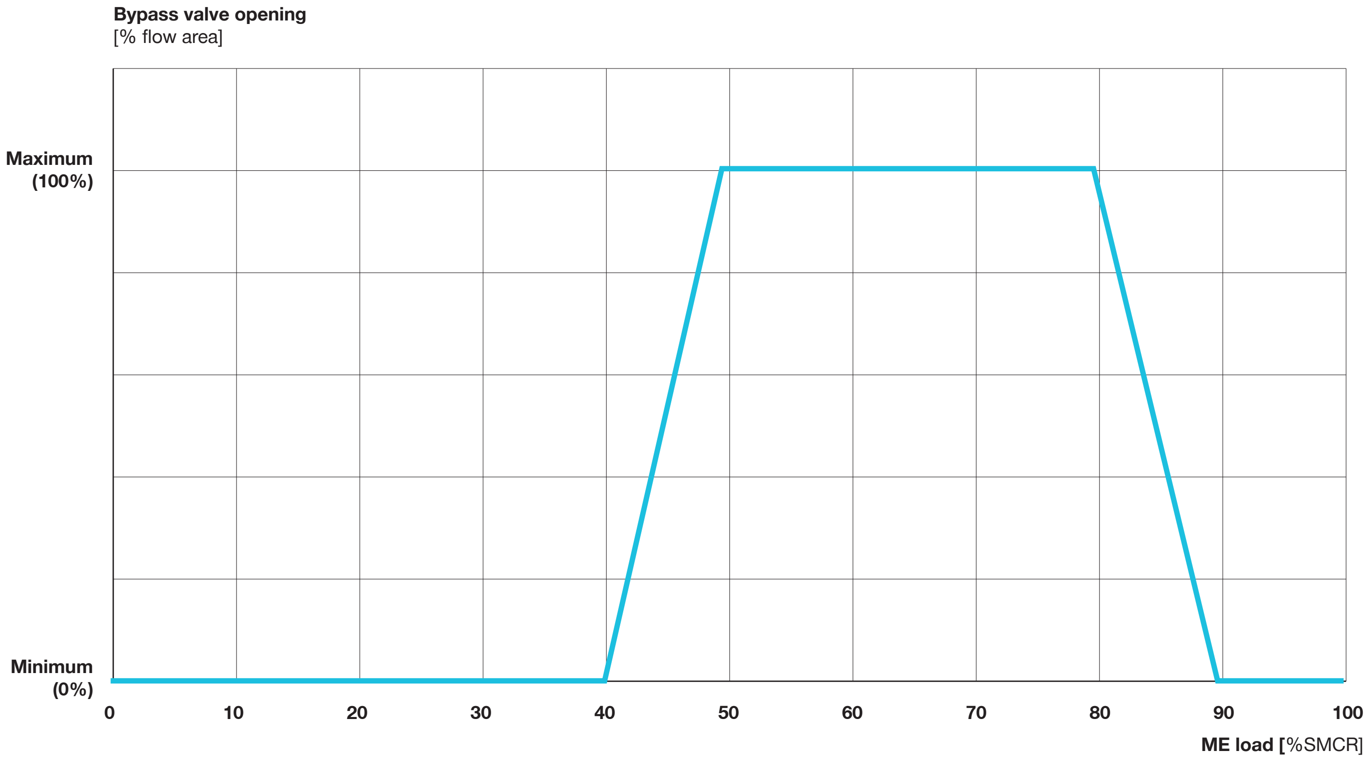

Fig. 9: Standard EEC opening for all engines except sequential turbocharging.

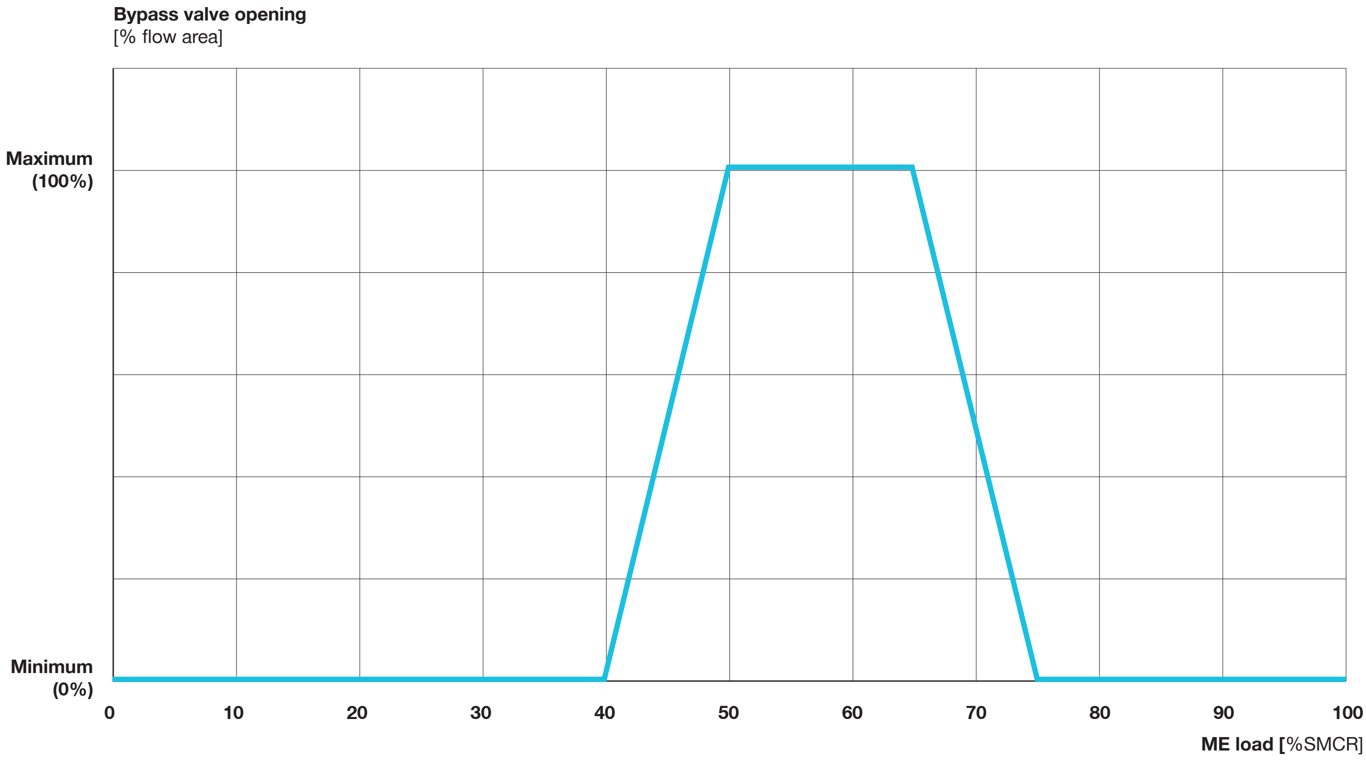

Fig. 10: Allowable EEC opening in case of sequential turbocharging tuning.

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