

Shaft Generators for the MC and ME Engines

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Preface

The purpose of this paper is to provide detailed information about the various aspects related to the application of shaft generators on the MAN B&W MC and ME series of engines.

Shortly after introducing the first MC engines in 1982, MAN B&W Diesel started investigating the possibilities of using shaft generators on the engines, and several standardised shaft generator types were developed.

In this paper the individual types of shaft generators are defined and their physical configuration is described together with the interface with the diesel engine.

Given the nature of this paper, it can be used either to obtain a complete description of the relevant aspects or it can be used for reference.

1. Introduction

During the 1980s the use of shaft generators in conjunction with two-stroke diesel engines rapidly became a popular method of producing electric power for the various electricity consumers on board ships.

At that time most gensets were unable to operate on heavy fuel oil and, even if they were, the fuel oil prices were much higher than today, so because of the differences in efficiency of the two-stroke engine and the medium-speed genset engine, the use of a shaft generator often resulted in significant fuel cost savings.

Nowadays, a wide range of gensets, able to operate efficiently on heavy fuel oil and, at the same time, offering a high degree of reliability, are available, and it is tempting to ask whether the installation of a shaft generator is really economical?

This paper highlights a number of parameters which may influence the final selection of the electricity production plant. Beyond the fuel oil costs, it is important to consider a number of other parameters, some of them impossible to quantify, if we are to obtain a clear picture of the pros and cons of the shaft generator concept.

References show that a number of ship-owners still consider a shaft generator to be an attractive investment, e.g. on container vessels, product tankers, and shuttle tankers, and a number of different types and various physical configurations of shaft generators are available. The paper describes these types together with their interface with the two-stroke diesel engine, and examples are given of typical as well as special applications.

As an alternative to producing electricity, a Power Take Off can be used, for example, to drive a hydraulic pump directly. However, only a marginal number of PTO systems are made as direct drive sys-

tems, and they will not be discussed in this paper.

In the following, the term “shaft generator” is employed for any arrangement where a Power Take Off from the main engine or the shaftline is used to drive an alternator, i.e. for the purpose of producing electricity using the main engine as the prime mover.

2. Definitions and Designations

Basically, MAN B&W Diesel distinguish between three main categories of shaft generators:

- 1 PTO/GCR (Power Take Off/Gear Constant Ratio):
Consists of flexible coupling, step-up gear, torsionally rigid coupling, and alternator.
- 2 PTO/RCF (Power Take Off/Renk Constant Frequency):
Consists of flexible coupling, step-up gear, torsionally rigid couplings, RCF-gear, and alternator.
- 3 PTO/CFE (Power Take Off/Constant Frequency Electrical):
Consists of flexible coupling, step-up gear, torsionally rigid coupling, alternator, and electrical control equipment or, alternatively, a slow-running alternator with electrical control equipment.

The PTO/RCF and the PTO/CFE incorporate different kinds of frequency control systems which make it possible to produce electric power with constant electrical frequency at varying engine speed. The PTO/GCR has no frequency control system.

Shaft generators of all three categories can be installed either at the front end of the engine, at the side of the engine, or aft of the engine. Figure 1 shows, in principle, the various possibilities for the installation of a shaft generator.

The designations BW I ... BW IV are used to distinguish between the various physical configurations of the shaft generator system.

	Alternative types and layouts of shaft generator		Design	Seating	Total efficiency (%)
PTO/GCR	1		BW I/GCR	On engine (vertical generator)	92
	2		BW II/GCR	On tanktop	92
	3		BW III/GCR	On engine	92
	4		BW IV/GCR	On tanktop	92
PTO/RCF	5a		BW I/RCF	On engine (vertical generator)	88-91
	6a		BW II/RCF	On tanktop (vertical generator)	
	7a		BW III/RCF	On engine	
	8a		BW IV/RCF	On tanktop	
PTO/CFE	9a		BW I/CFE	On engine (vertical generator)	81-85
	10a		BW II/CFE	On tanktop	
	11a		BW III/CFE	On engine	
	12a		BW IV/CFE	On tanktop	
	13a		DMG/CFE	On engine	
	14a		SMG/CFE	On tanktop	

Fig. 1: Types of PTO

In MAN B&W Diesel terms, a 700 kW (60 Hz) shaft generator of the GCR type intended for installation at the side of an S50MC-C engine is thus designated:

BW III S50-C / GCR 700 - 60

In the following chapters, the three types of PTO (PTO/GCR, PTO/RCF, PTO/CFE) and the various possibilities for the configuration of the PTO (BW I ... BW IV) are described.

3. Categories of Shaft Generators

3.1 PTO/GCR (Power Take Off / Gear Constant Ratio)

The PTO/GCR is the simplest shaft generator, as no speed control or frequency control systems are incorporated. In the vast majority of cases, the PTO/GCR is used to produce electric power with a constant electrical frequency during the voyage. Since the frequency produced by the alternator is proportional to the speed of the engine, the engine must be operated at constant speed. This is only possible if a controllable pitch propeller is installed. When a fixed pitch propeller is used, the speed of the propeller, and thus of the engine, varies with the required speed of the ship and the resistance acting on the ship.

Alternatively, the PTO/GCR can be used for power production with floating frequency, e.g. between 50 and 60 Hz, which means that the speed of the main engine is allowed to vary between 83% and 100% of the speed at specified MCR (Maximum Continuous Rating). This also means that certain power consumers sensitive to frequency variations must be provided with power supply via a frequency converter or from a genset. The concept of long-term running with floating electrical frequency is only used in rare cases.

The PTO/GCR is unable to run in parallel with the auxiliary engines for long periods, because of the small engine speed variations of the main engine, which occur even in the constant speed mode of the controllable pitch propeller plant. Consequently, the PTO/GCR is often used to supply electric power to all power consumers during the voyage, with the gensets out of operation. During manoeuvring, which involves reducing the main engine speed, the PTO/GCR can be used as a separate power source for the bow thruster, which can often be run with floating frequency, with the gensets supplying electric power for all other power consumers.

The total efficiency of the PTO/GCR is around 92%.

Except for the PTO BW I/GCR and the PTO BW III/GCR, which are built directly onto the main engine, and is only produced by Renk in Germany, several manufacturers are able to supply the PTO/GCR system. Prices vary greatly with the physical configuration of the system and the different suppliers. The investment cost of a PTO/GCR is much smaller than the cost of a PTO/RCF or a PTO/CFE. On the other hand, the investment cost of the controllable pitch propeller required in combination with a PTO/GCR is higher than the cost of a fixed pitch propeller.

Finally, the operation of the engine at constant speed means reduced propeller efficiency at reduced propulsion load compared with a controllable pitch propeller running in combinator mode (reduced speed at reduced propulsion load) or a fixed pitch propeller. The thermal efficiency of the main engine is also slightly lower in constant speed mode than in combinator mode.

3.2 PTO/RCF (Power Take Off / Renk Constant Frequency)

The PTO/RCF includes an RCF speed controlled planetary gearbox developed by Renk, and the system is only available from Renk. Figure 2 illustrates the design principles of the RCF gearbox.

The RCF gearbox is an epicyclic gear with a hydrostatic superposition drive. The superposition drive comprises a hydrostatic motor controlled by an electronic control unit and driven by a built-on pump.

The hydrostatic system drives the annulus of the epicyclic gear in either direction of rotation, based on the detected output speed, and thus continuously varies the gear ratio over an engine speed variation of 30%. In the standard layout the constant output speed range of the gearbox is set between 100% and 70% of the engine speed at specified MCR.

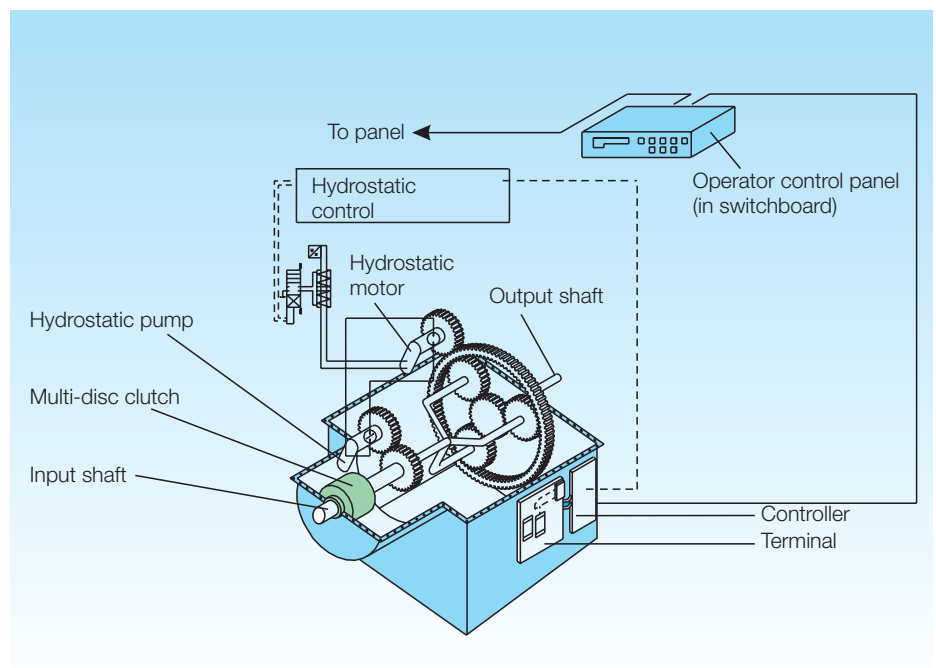


Fig. 2: PTO/RCF, developed by Renk

An electronic control system ensures that the control signals to the main electrical switchboard are identical to those of the gensets, and the PTO/RCF is able to operate alone or in parallel with the gensets throughout the complete constant output speed range of the gearbox. The PTO/RCF is therefore suitable for installation on ships with a fixed pitch propeller.

Internal control circuits and interlocking functions between the epicyclic gear and the electronic control box provide automatic control of the functions necessary for the satisfactory operation and protection of the RCF gear.

If any monitored value exceeds the normal operation limits, a warning or an alarm is given, depending on the origin, severity, and the extent of deviation from the permissible values. The cause of a warning or an alarm is shown on a digital display.

A multi-disc clutch, integrated into the RCF-gearbox input shaft, permits the engaging and disengaging of the epicyclic gear, and thus the alternator, from the main engine during operation.

Depending on the actual engine speed relative to the speed at specified MCR, the total efficiency varies between 88% and 91%.

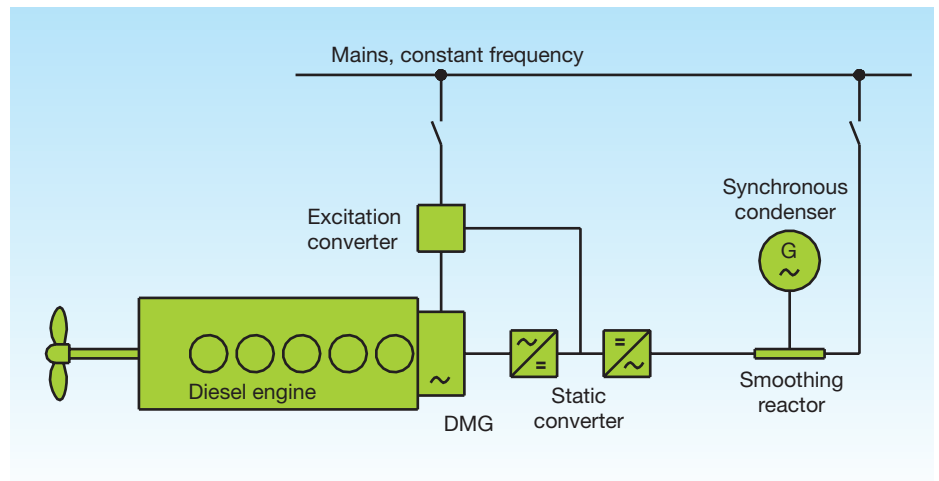


Fig. 3: PTO DMG/CFE

3.3 PTO/CFE (Power Take Off / Constant Frequency Electrical)

The PTO/CFE is, like the PTO/RCF, able to produce electricity with constant electrical frequency over a wide engine speed range. In the case of the PTO/CFE using a step-up gear, the alternator may have a built-in electronic converter, which ensures that corrections are made for the varying engine speed, and hence the varying alternator speed. Alternatively, and more usually, the electric power is produced with varying frequency and is afterwards converted by thyristor control to electric power with a constant frequency.

Over the years, different types of PTO/CFE based on step-up gears have been introduced, and a limited number of units have been built. However, to our knowledge, this type of shaft generator is not used for newbuildings at the moment. We therefore disregard the PTO/CFE based on a step-up gear in this paper.

The PTO/CFE can, alternatively, be made as a slow-running alternator coupled directly to the front end of the engine (DMG/CFE, Direct Mounted Generator) or installed with the rotor integrated into the intermediate shaft (SMG/CFE, Shaft

Mounted Generator). The slow-running generators are much larger than the generators running at high speed, but in return the flexible coupling and the step-up gear are omitted.

Again, additional electrical control equipment must be installed to provide thyristor control of the frequency. The DMG/CFE and the SMG/CFE are normally able to operate in parallel with the gensets at the full rated electric power, when the speed of the main engine is between 75% and 100% of the engine speed at specified MCR. Between 40% and 75% of the SMCR speed, the electric output of the PTO/CFE is reduced proportionately to the engine speed. Figure 3 shows the control principle for the DMG/CFE.

The SMG/CFE (Shaft Mounted Generator) is much more frequently used than the DMG/CFE (Direct Mounted Generator). One reason may be that the SMG/CFE is not subject to any limitations from the installation on the main engine.

The total efficiency of the slow running PTO/CFE types varies between 84% and 88%.

4. Physical Configuration

4.1 Front end installation (BW I)

In the BW I system, the step-up gear unit is bolted directly to the engine front end face and comprises a bevel gear, which allows the alternator to be placed vertically on top of the gear unit. See Figure 4. This compact design gear unit is only available from Renk.

A Geislinger elastic damping coupling is included in the delivery. The elastic elements in the Geislinger coupling are packages of steel springs, and the damping is provided by oil, which is squeezed from one oil chamber to another by the steel springs, when they deflect during operation. The oil also provides the necessary lubrication and cooling of the coupling. The Geislinger coupling is bolted to the front end of the crankshaft, and the input shaft of the gear unit is connected to the Geislinger coupling by a toothed coupling made as an integral part of the Geislinger coupling. Thanks to this design, the gear unit is isolated from axial movements of the crankshaft and protected against torsional excitations.

Additionally, the toothed coupling allows simple separation of the complete gear unit from the Geislinger coupling, and thus the crankshaft, by shifting the shaft which carries the main gear wheel forward in the axial direction. This procedure for disconnection is only to be used in the special event that it is required to completely disconnect the gear unit from the main engine.

Around the Geislinger coupling, between the crankcase space and the gear unit, space is available for a tuning wheel, a moment compensator or a torsional vibration damper, if required.

The gear unit, often referred to as a “crankshaft gear”, is bolted to the bedplate and framebox of the engine, and the weight of the gear wheels is, via bearings installed in the gearbox, transferred to the engine structure. Consequently, the crankshaft is

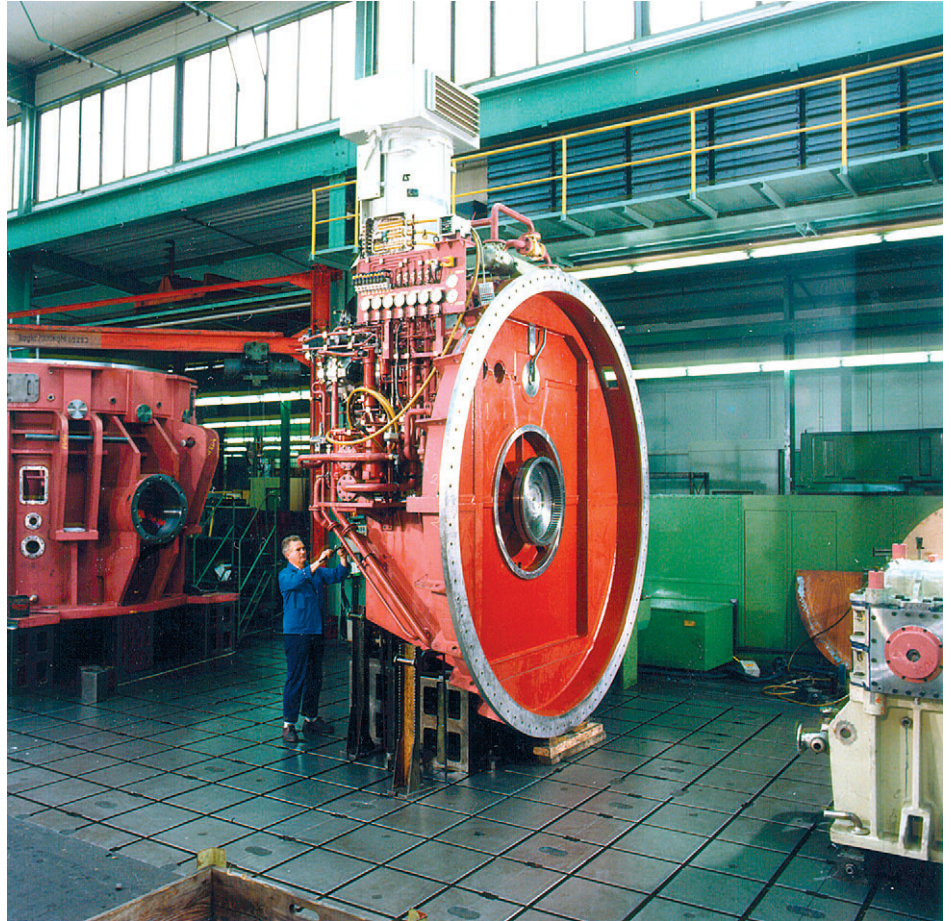


Fig. 4: PTO BW I S70/RCF 850-60 (Renk)

only loaded by the weight of the Geislinger coupling.

A multi-disc clutch is built into the RCF gearbox input shaft and ensures that the epicyclic RCF gear (if included) and the alternator, can be engaged or disengaged during operation of the main engine.

An electrically driven built-on lubricating oil stand-by pump supplements a gear driven pump when the engine is started and in the event of malfunctioning of the gear driven pump.

The PTO/RCF can be operated on the same type of oil as is used for the main engine lubricating oil system if the lube oil meets a minimum load level of 8 according to the standardised FZG Gear Test (DIN 51354).

In the case of the PTO BW I/RCF the RCF gear is integrated into the step-up / bevel gear unit and because the hydrostatic drive of the RCF gear requires a 5 µm filtration of the oil, the complete gear unit has a separate lubricating oil system including the oil supply to the Geislinger coupling.

For the PTO BW I/RCF, the shipyard must provide cooling water for the built-on lubricating oil cooler, electric power supply to the built-on lubricating oil stand-by pump, and cabling between the alternator and the switchboard. We further recommend that the shipyard installs an external lubricating oil filling system, including a dosage tank made in accordance with the specified volume of oil used for one gearbox oil change. See Figure 5.

The PTO BW I/GCR is lubricated and cooled by using the main engine lubricating oil system and it has to be ensured that the lube oil has a minimum FZG load level of 8. This means that the cooling water supply and the external lubricating oil filling system can be dispensed with. In this case, the capacities of the main engine's lubricating oil system with related coolers must be increased in accordance with the data given by the supplier of the shaft generator. The shipyard has to arrange the external wiring of the control system. The PTO BW I/GCR has not yet been produced.

The following preparations for the installation of the PTO system must be made on the engine. See also Figure 6.

- three machined blocks welded on to the front end face for alignment of the gear unit
- machined washers to be placed between the gearbox and the framebox to compensate for the small difference in length between the bedplate and the framebox
- rubber gasket to be placed between the gearbox and the framebox
- electronic axial vibration measuring system
- free flange end on lubricating oil inlet pipe (only for PTO BW I/GCR)
- oil return flange welded on to bedplate (only for PTO BW I/GCR).

	PTO BW I/RCF	PTO BW II/RCF	PTO BW III/RCF	PTO BW IV/RCF	PTO DMG/CFE	PTO SMG/CFE	PTO BW I/GCR	PTO BW II/GCR	PTO BW III/GCR	PTO BW IV/GCR
Cooling water supply to lub. oil cooler	x	x	x	x				x		x
Cooling water supply to alternator - if water cooled type is applied					(x)	(x)				
Lub. oil dosage tank (option)	(x)	(x)	(x)	(x)						
Electric power supply to lub. oil stand-by pump	x	x	x	x			x	x	x	x
Cabling between alternator and switchboard	x	x	x	x			x	x	x	x
External wiring of control system							x	x	x	x
Electric cabling					x	x				
Seating for gearbox		x		x				x		x
Seating for support bearing		(x)						(x)		
Seating for alternator				x						x
Seating for synchronous condenser unit					x	x				
Seating for static converter cubicles					x	x				
Seating for stator housing						x				

Fig. 5: Shipyard installations for PTO

4.2 Frontend installation (BW II)

The PTO BW II is placed in front of the engine but, in contrast to the PTO BW I, the gear unit is seated on a separate foundation on the tanktop.

Various gearbox manufacturers are able to supply the PTO BW II/GCR, whereas only Renk is able to supply the PTO BW II/RCF.

The installation length in front of the engine, and thus the engine room length requirement, naturally exceeds the length of the other shaft generator arrangements. However, there is some scope for limiting the space requirement, depending on the configuration chosen.

	PTO BW I/RCF	PTO BW II/RCF	PTO BW III/RCF	PTO BW IV/RCF	PTO DMG/CFE	PTO SMG/CFE	PTO BW I/GCR	PTO BW II/GCR	PTO BW III/GCR	PTO BW IV/GCR
Machined blocks welded on to engine front end face	x		x		x		x		x	
Machined washers to be placed between gearbox and frame box	x		x				x		x	
Rubber gasket to be placed between gearbox and frame box	x		x				x		x	
Steel shim to be placed between gearbox and frame box					x					
Electronic axial vibration measuring system	x	x	x		x		x	x	x	
Free flange end on lubricating oil inlet pipe			x				x		x	
Oil return flange welded to bedplate			x				x		x	
Brackets mounted on side of bedplate			x						x	
Intermediate shaft between crankshaft front end and flexible coupling		x						x		
Front end cover in two halves, with oil sealing arrangement		x						x		

Fig. 6: Engine preparations for PTO

Figure 7 shows a space optimised concept where the alternator is placed horizontally between the step-up gearbox and the front end of the engine and thus utilises the space which is anyway taken up by the flexible coupling.

A further reduction of the building-in length can be obtained by the use of a bevel gear in the step-up gearbox and a vertically placed alternator, see Figure 8.

A rubber type elastic damping coupling is installed at the gearbox input shaft outside the engine. The engine drives the shaft generator via an intermediate shaft, which is bolted to the front end of the crankshaft and passes through the engine front end cover, which is made in two halves with an oil sealing arrangement.

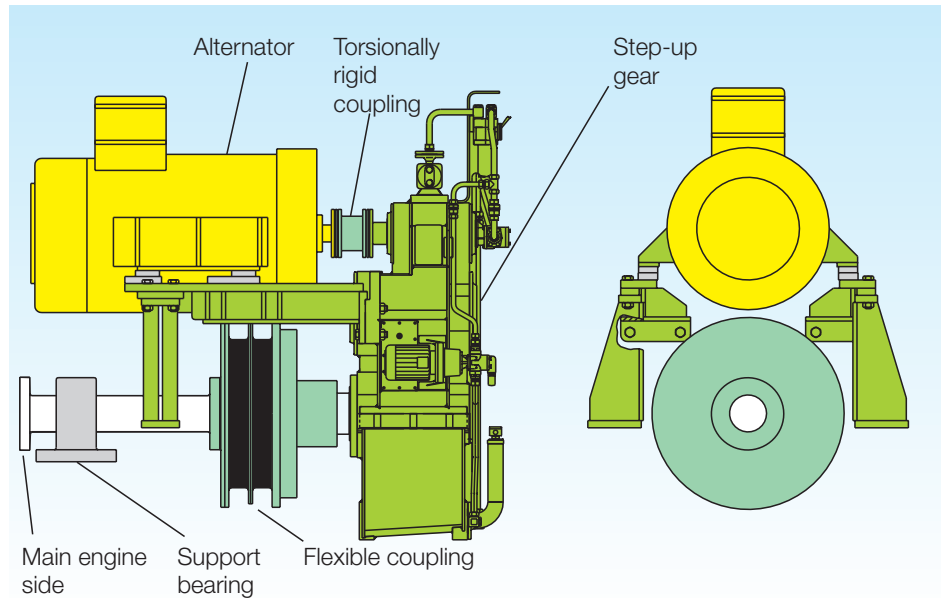


Fig. 7: PTO BW II/GCR (A. Friedr. Flender AG)

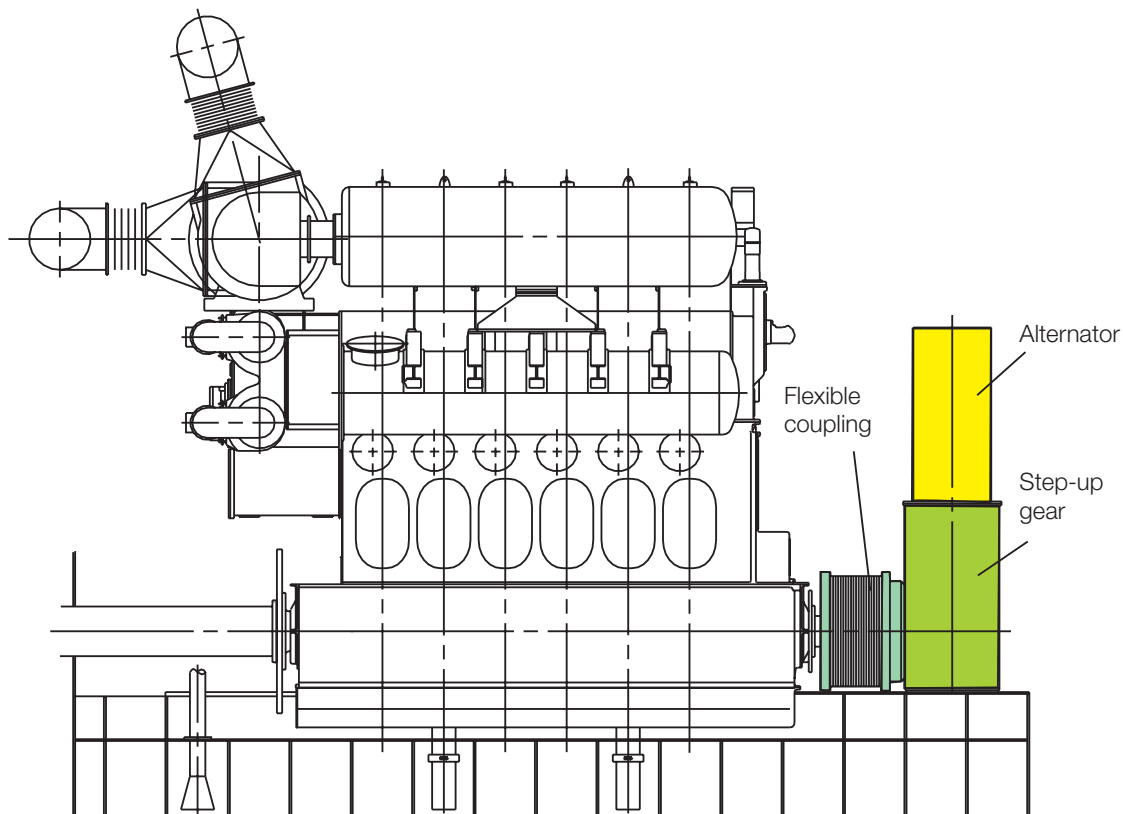


Fig. 8: PTO BW II/GCR (Renk)

Often a small support bearing has to be installed between the front end of the engine and the flexible coupling. Whether a support bearing is required can be determined from MAN B&W Diesel's specification of the permissible shear force and bending moment on the front end of the crankshaft.

The PTO BW II has its own lubricating oil system, and an electrically driven built-on lubricating oil stand-by pump supplements a gear driven pump at start of the engine and in the event of malfunctioning of the gear driven pump.

The gearbox and the support bearing are seated on the tanktop, and the shipyard has to make suitable foundations. The shipyard must also provide cooling water for the built-on lubricating oil cooler, electric power supply to the built-on lubricating oil stand-by pump and cabling between the alternator and the switchboard, as well as external wiring of the control system (except for the PTO BW II/RCF).

For the PTO BW II/RCF we recommend that the shipyard installs an external lubricating oil filling system, including a dosage tank made in accordance with the specified volume of oil used for one gearbox oil change.

The following preparations for the installation of the PTO system must be made on the engine:

- intermediate shaft between the engine and the flexible coupling
- front end cover in two halves with oil sealing arrangement
- electronic axial vibration measuring system.

4.3 Sidemounted installation (BWIII)

The investment cost of the PTO BW III is typically higher than for the other gear based shaft generators. However, we have adopted it as our standard, as it is the most compact system available, which means more space for cargo transportation, and a further advantage is that it is easy to install at the shipyard.

The gearbox is available as standard for the 42 MC engines and upwards including the ME engines. Standard sizes of alternators are 700, 1200, 1800 and 2600 kW, but others are available on request.

In the BW III system, the step-up gear unit is bolted directly to the engine front end face, and is designed to allow the alternator to be placed horizontally at the side of the engine. See Figure 9, which shows the PTO BW III/GCR. This compact design gear unit is only available from Renk.

A Geislinger elastic damping coupling is included in the delivery. The Geislinger coupling is described in Section 4.1.

The gear unit, often referred to as a "crankshaft gear", is bolted to the bed-plate and framebox of the engine, and the weight of the gear wheels is, via bearings, installed in the gearbox, transferred to the engine structure. Consequently, the crankshaft is only loaded by the weight of the Geislinger coupling.

The step-up gear of the PTO BW III/GCR is lubricated and cooled using the main engine lubricating oil system, so it requires no cooling water supply. The capacities of the main engine's lubricating oil system with related coolers are to be increased accordingly. A minimum FZG load level of 8 has to be observed for the lube oil.

A multi-disc clutch can be built into the gearbox output shaft ensuring that the alternator can be engaged or disengaged during operation of the main engine. The required operating oil pressure for the multi-disc clutch is supplied by a gear driven pump. On engine start-up and in the event of malfunctioning of the gear driven pump, an electrically driven built-on lubricating oil stand-by pump supplements the gear driven pump.

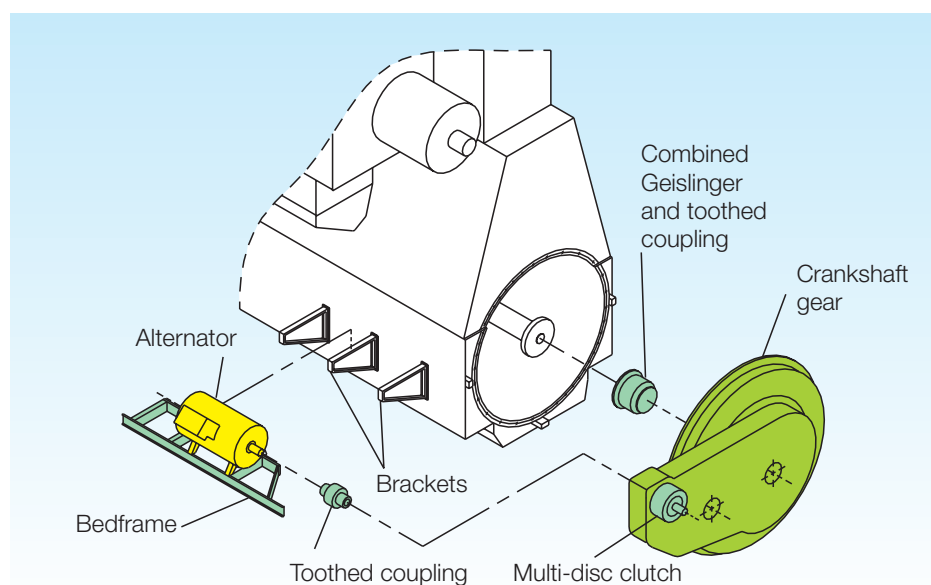


Fig. 9: PTO BW III/GCR (Renk)

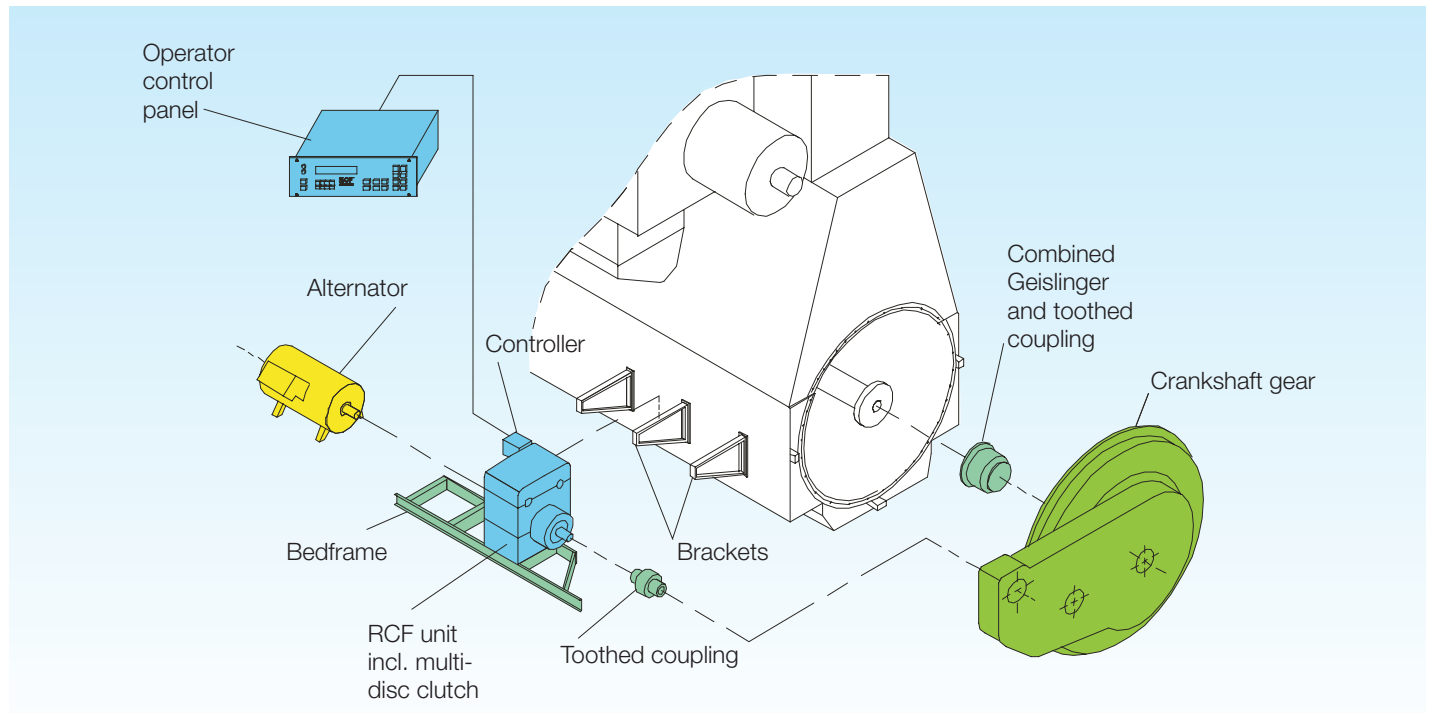


Fig. 10: PTO BW III/RCF (Renk)

The step-up gear (crankshaft gear) of the PTO BW III/RCF is, similar to the crankshaft gear of the PTO BW III/GCR, lubricated and cooled by using the main engine lubricating oil system. Figure 10 shows the PTO BW III/RCF.

The RCF gear, placed at the side of the engine, can be operated on the same type of oil as the main engine lubricating oil system. However, the hydrostatic drive of the RCF gear requires a $5\ \mu\text{m}$ filtration of the oil, and the RCF gear, consequently, has its own lubricating oil system.

A multi-disc clutch is built into the RCF gearbox, and an electrically driven lubricating oil stand-by pump, built on to the RCF gear, supplements a gear driven pump on engine start-up and in the event of malfunctioning of the gear driven pump.

For the PTO BW III/RCF the shipyard must provide cooling water for the lubricating oil cooler built on to the RCF gear, electric power supply to the lubricating oil stand-by pump built on to the RCF gear, and cabling between the alternator and the switchboard. We further recommend that the shipyard installs an external lubricating oil filling system, including a dosage tank made in accordance with the specified volume of oil used for one RCF-gear oil change.

The PTO BW III/GCR only requires electric power supply to the built-on lubricating oil stand-by pump and cabling between the alternator and the switchboard as well as external wiring of the control system.

The following preparations for the installation of the PTO BW III/GCR

system or the PTO BW III/RCF system must be made on the engine:

- three machined blocks welded on to the front end face for alignment of the gear unit
- machined washers to be placed between the gearbox and the framebox to compensate for the small difference in length between the bedplate and the framebox
- rubber gasket to be placed between the gearbox and the framebox
- electronic axial vibration measuring system
- free flange end on lubricating oil inlet pipe
- oil return flange welded on to bedplate
- brackets mounted on starboard side of bedplate to support the RCF gear (if installed) and the alternator.

4.4 Aftend installation (BW IV)

The PTO BW IV is placed aft of the engine and is made as a tunnel gear with a hollow shaft, which allows the intermediate shaft, including the flange, to pass through, see Figure 11.

A number of gearbox manufacturers are able to supply the PTO BW IV/GCR, whereas only Renk is able to supply the PTO BW IV/RCF, although it has not yet been produced.

The PTO BW IV can often be installed within the space already available around the shaftline aft of the engine, without increasing the total building-in length.

A hollow, segmented elastic damping coupling based on rubber elements is built around the shaft between the inter-

mediate shaft flange at the engine aft end and the hollow shaft of the tunnel gearbox. Some of the steel flanges used for the coupling are made in halves to allow them to be assembled around the shaft.

The flexible coupling only transfers the torque corresponding to the power of the shaft generator, since the intermediate shaft for the propeller is bolted directly to the thrust shaft of the engine.

The PTO BW IV has a separate lubricating oil system, and an electrically driven built-on lubricating oil stand-by pump supplements a gear driven pump on engine start-up and in the event of any malfunctioning of the gear driven pump.

The gearbox is seated on the tanktop, and the shipyard has to make suitable foundations, both for the gearbox and the

alternator. The shipyard must also provide cooling water for the built-on lubricating oil cooler, electric power supply for the built-on lubricating oil stand-by pump, and cabling between the alternator and the switchboard, as well as external wiring of the control system (except for the PTO BW IV/RCF).

No preparations for the installation of the PTO system are needed on the engine, but the intermediate shaft flange must be provided with additional bolt holes for the flexible coupling.

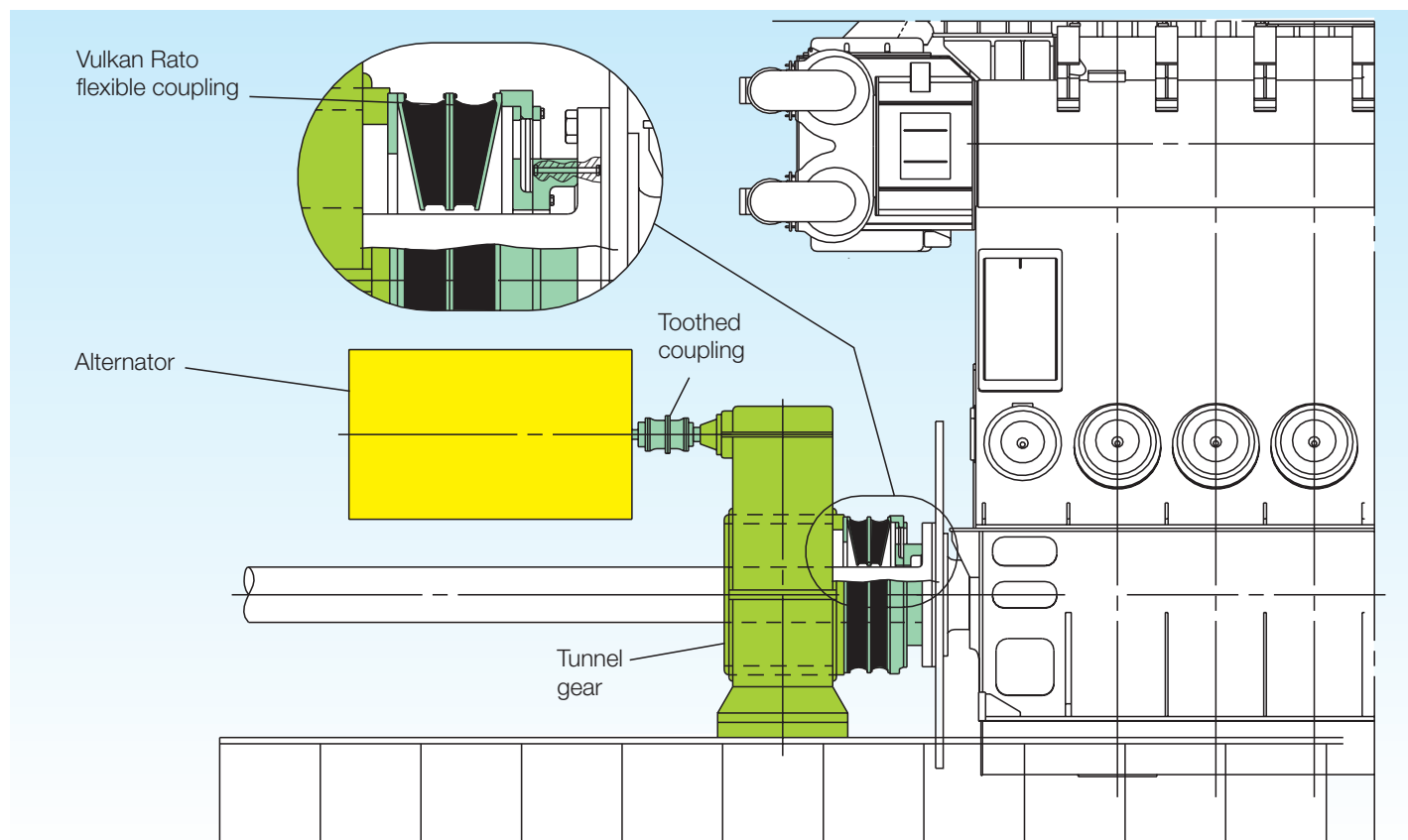


Fig. 11: PTO BW IV/GCR, Tunnel gear

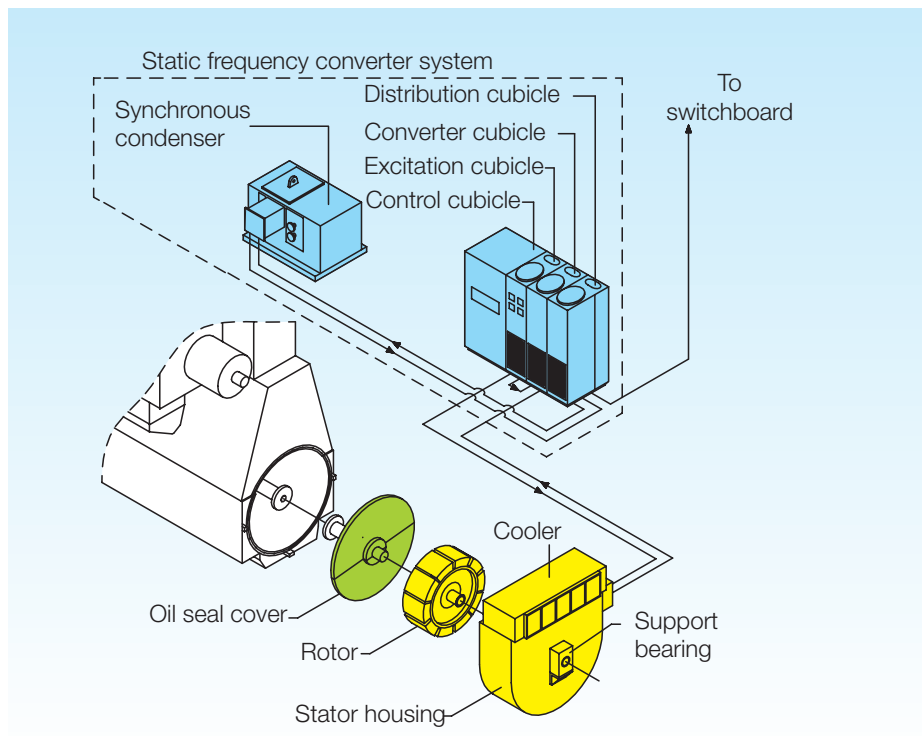


Fig. 12: PTO DMG/CFE

4.5 Front end installation(DMG/CFE)

The PTO DMG/CFE is a large slow-running alternator with its rotor mounted directly on the crankshaft and its stator housing bolted to the front end face of the engine. The PTO DMG/CFE does not include a gearbox, and no flexible coupling is required. See Figure 12. The alternator is separated from the crankcase by a plate and a labyrinth seal.

If the torsional characteristics of the shaft system require the application of an additional inertia mass on the crankshaft fore end, a tuning wheel can be installed, as illustrated in Figure 13. A front end mounted moment compensator or a torsional vibration damper may be installed in a similar way.

If the limits for shear force and bending moment acting on the fore end flange of the crankshaft are exceeded, the stator housing must be made with a front end

support bearing to reduce the load on the crankshaft.

The electrical frequency generated depends on the speed of the main engine and the number of poles. Since the size of the alternator, and thus the number of poles, is limited by the ship's hull, it is not possible, with the low speed of the two-stroke engine, for the alternator itself to produce electricity with a frequency of 50 Hz or 60 Hz. It is therefore necessary to use a static frequency converter system between the alternator and the main switchboard.

The static frequency converter system, see Figure 12, consists of a static part, i.e. thyristors and control equipment, and a rotary electric machine (synchronous condenser).

The three-phase alternating current is rectified and conducted to a thyristor inverter producing a three-phase alternating current with constant frequency.

Since the frequency converter system uses a DC intermediate link, it can supply no reactive power to the main switchboard. A synchronous condenser is used to supply this reactive power. The synchronous condenser consists of an ordinary synchronous alternator.

The DMG/CFE is normally able to operate in parallel with the gensets at the full rated electric power, when the speed of the main engine is between 75% and 100% of the engine speed at specified MCR. Between 40% and 75% of the SMCR speed, the electric output of the DMG/CFE is reduced proportionately to the engine speed.

The shipyard must provide seating for the synchronous condenser unit and the static converter cubicles, as well as cooling water, if a water cooled alternator is used, and electric cabling.

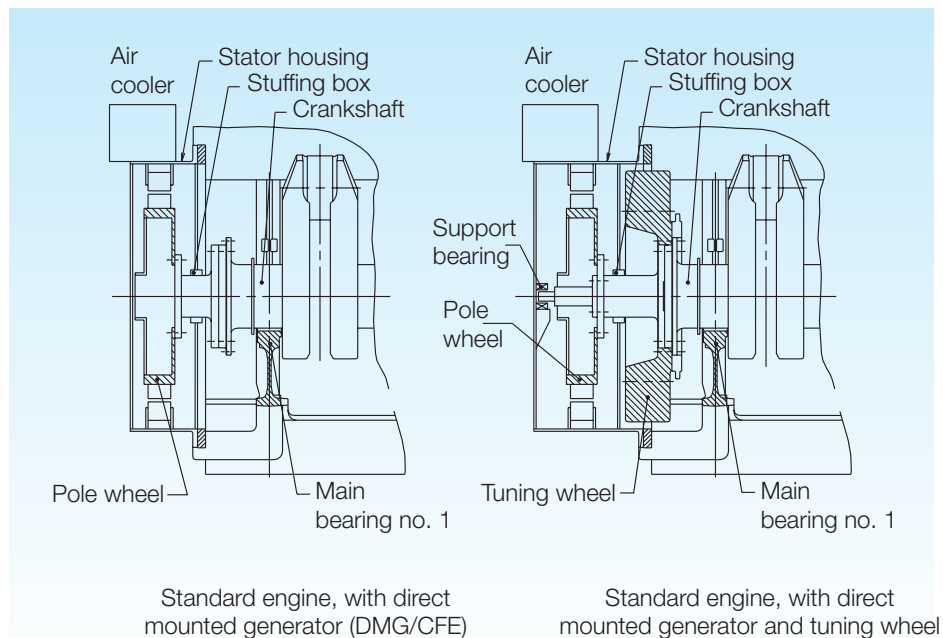


Fig. 13: PTO DMG/CFE

The following preparations for the installation of the PTO system must be made on the engine:

- three machined blocks welded on to the front end face for alignment of the stator housing
- steel shim to be placed between the stator housing and the framebox to compensate for the small difference in length between the bedplate and the framebox
- electronic axial vibration measuring system.

References show that at present the PTO DMG/CFE is very rarely used.

4.6 Attend installation (SMG/CFE)

The PTO SMG/CFE has the same working principle as the PTO DMG/CFE, but instead of being located on the front end of the engine, the alternator is installed aft of the engine, with the rotor integrated on the intermediate shaft. See Figure 14. This concept is much more frequently used than the PTO DMG/CFE, and has the advantages of a somewhat lower

price and a more straightforward design with no physical interface with the main engine.

In addition to the shipyard installations mentioned in Section 4.5 for the PTO DMG/CFE, the shipyard must provide the foundation for the stator housing in the case of the PTO SMG/CFE.

The engine needs no preparation for the installation of this PTO system.

Today, shaft alternators of type PTO SMG/CFE which are using PWM technology allowing the inverter to produce both the active and the reactive power, thus eliminating the need for the synchronous condenser, are on the market. Thereby, a simplification of the shaft generator system with respect to installation, operation, and maintenance is obtained.

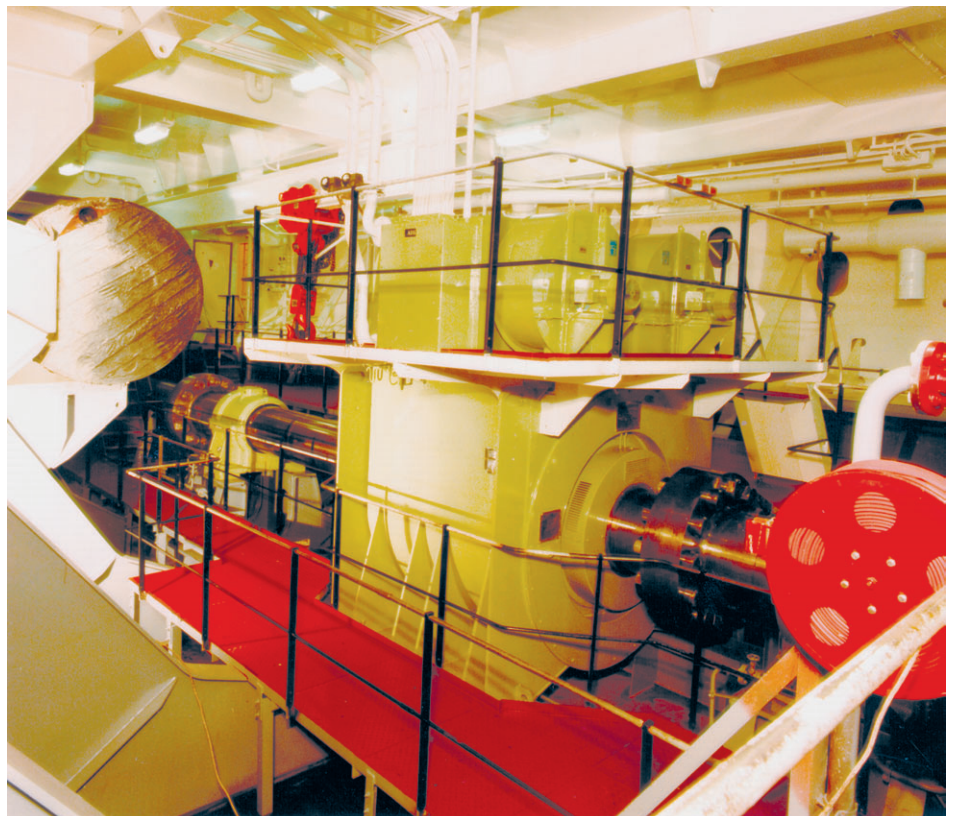


Fig. 14: PTO SMG/CFE 1300-60 (AEG)

5. Layout of Engine with Shaft Generator

Beyond the physical preparations of the engine for the installation of a shaft generator, the layout of the engine in terms of power and speed is also affected by the decision to install a shaft generator.

As an example the following describes how the installation of a shaft generator on an engine intended to drive a fixed pitch propeller influences the layout of the engine:

The specified maximum continuous rating (SMCR) of an engine without a shaft gen-

erator can be found on the basis of the propeller design point (PD) by incorporating the following factors, please refer to Figure 15:

- light running factor (normally 3-7% of the engine speed at PD is deducted)
- sea margin (traditionally 15% of the power at PD is added – following the heavy running propeller curve and giving the service propulsion point SP = S)
- engine margin (typically 10% of the power at MP = M = SMCR is added to the power at SP = S – following the heavy running propeller curve).

In most cases, the SMCR of an engine with a shaft generator is found by adding the maximum power consumed by the shaft generator to the specified propulsion MCR point (MP). See Figure 16.

Consequently, the engine with a shaft generator is specified with the maximum continuous rating (M), and the optimising point (O), located on a propeller curve placed to the left of the propeller curve (through MP) for heavy running propulsion without a shaft generator.

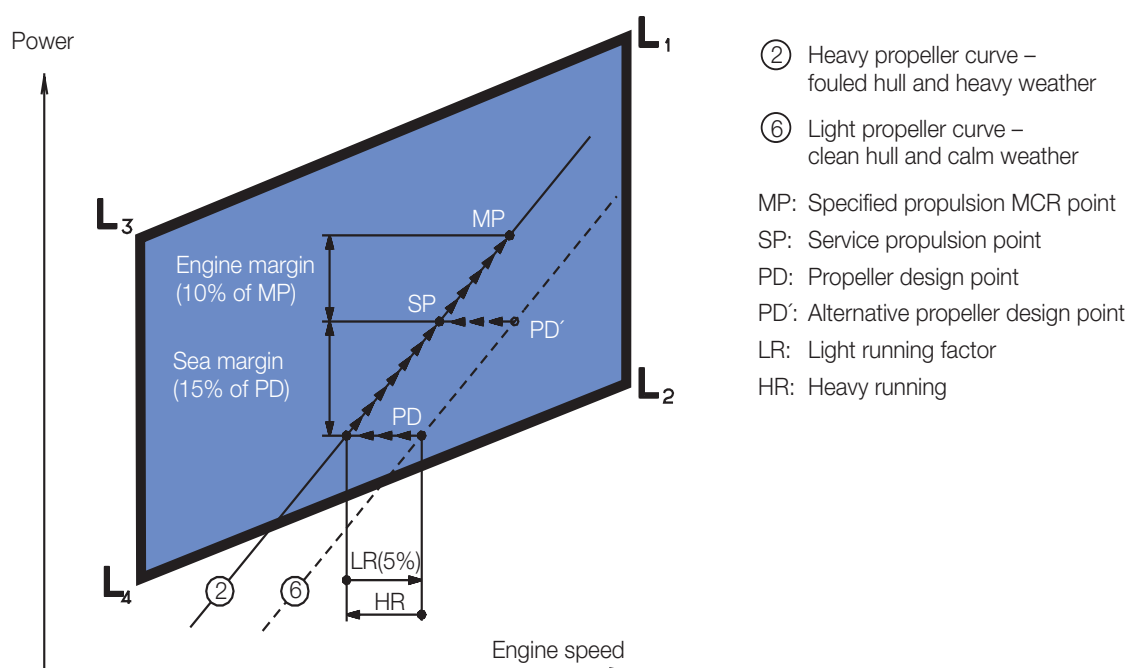
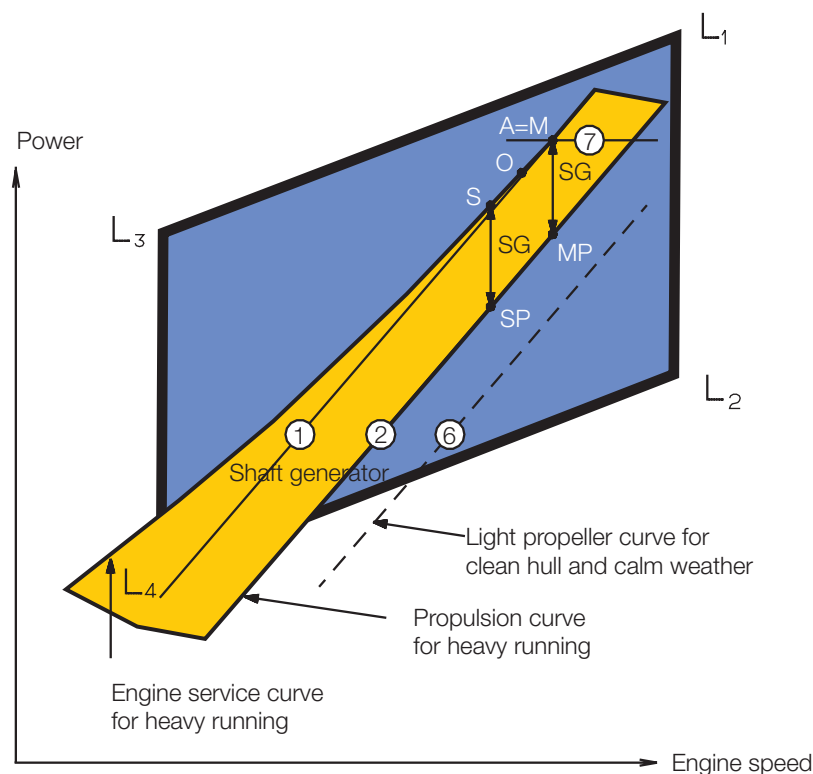


Fig. 15: Ship propulsion running points and engine layout

The above means that the installation of a shaft generator may involve that an engine with one more cylinder must be selected to ensure that the SMCR point is placed inside the top of the layout diagram. However, this, of course, entails extra costs and additional space requirements for the main engine.

To avoid selecting a main engine with one more cylinder, another solution is to restrict the load on the shaft generator when the engine is operated close to the SMCR.

More information about the layout of engines with and without shaft generators, as well as various examples, can be found in our paper P.254-01.04: Basic Principles of Ship Propulsion.



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

Definition of point A of load diagram:

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

Fig. 16: Engine layout with shaft generator (normal case)

6. Torsional Vibration

6.1 Engines with small shaft generators

The gear based shaft generator systems (PTO BW I ... BW IV) all incorporate a flexible coupling to protect the gears against hammering caused by torsional excitation from the engine.

Normally, when the power output of the shaft generator is less than 10 per cent of the main engine power, the vibration modes of the shaft generator system will not influence the vibration modes of the propulsion shaft system. This means that the main propulsion shaft system can be designed and determined regardless of whether a shaft generator is to be installed later on.

The PTO/GCR is normally designed to operate at 100% of the speed at specified MCR, and is therefore tuned so that the critical speed of significant T/V-orders is placed outside the range 80 - 120% of the speed at specified MCR.

Normally, the flexible couplings for the PTO/GCR types are selected on the basis of the misfiring conditions, and the normal service conditions will, consequently, usually be harmless to the flexible coupling and the gear.

In cases of misfiring, the 1st order excitation, which normally has a frequency close to the natural frequency of the 1-node vibration mode (the lowest natural frequency) occurring in the shaft generator branch, increases substantially, irrespective of the number of cylinders of the engine. This explains why it is essential to tune the natural frequency of the 1-node vibration mode in accordance with the engine speed.

The position of the natural frequency for the 1-node vibration mode in the shaft generator branch mainly depends on the flexible coupling's torsional flexibility and the inertia of the alternator.

As a rule of thumb, the lowest natural frequency of the shaft generator branch should not be less than 120%, or more than 80%, of the frequency corresponding to the main engine speed at specified MCR. This means that either undercritical or overcritical vibration conditions for 1st order excitation are obtained, with a satisfactory safety margin.

If a clutch for the alternator is incorporated in the PTO/GCR, the tuning of the PTO system is normally made as follows:

- **Alternator engaged:**
Overcritical running (1st order critical speed at 55 - 80% x SMCR speed)
- **Alternator disengaged**
Undercritical running (1st order critical speed above 120% x SMCR speed, higher orders to be considered).

The ideal way of tuning the PTO/RCF, which is normally designed to operate between 70% and 105% of the engine speed at specified MCR, is to have a flexible coupling which leads to a natural frequency, around 50 - 60% of the frequency which corresponds to the speed at specified MCR.

Should the natural frequency be higher, because of a more rigid coupling, the alternator must be declutched in the event of misfiring. The PTO/RCF is always made with a clutch built into the RCF gear, and operation during misfiring is often prohibited. In this case, the magnitude of the alternator's inertia must, when the alternator is declutched, permit the natural frequency of the shaft generator branch which remains coupled to the engine, to 'jump' to a sensibly higher frequency than the frequency which corresponds to 105% of the speed at specified MCR. In order to obtain this, it may be necessary to tune the inertia of the alternator by fitting an additional mass (tuning wheel) at the alternator side of the clutch.

The DMG/CFE and the SMG/CFE do not incorporate a gear or a flexible coupling

but, because of the inertia of the rotor, they may naturally influence the torsional layout of the shafting.

6.2 Engines with large shaft generators

Certain types of ships, such as shuttle tankers with high electricity consumption, may use one or more large shaft generators for the electricity production. The propulsion arrangement of a shuttle tanker with a large shaft generator normally comprises a controllable pitch propeller and a shaft clutch. See Section 11.1.

The torsional vibrations of such an installation are very complex, and require careful investigation of all possible operation modes during the design stage.

In general, the elastic coupling, or couplings, should be sufficiently flexible to ensure a natural frequency in the shaft generator system below 75% of the frequency which corresponds to the main engine speed to be used for operation of the shaft generator.

Alternatively, the shaft generator system can be designed to have a natural frequency of approximately 150% of the frequency which corresponds to the main engine operating speed.

The above will give main critical resonances in the shaft generator system (4th, 5th and 6th order) at very low speed or even below the minimum speed. Furthermore, the 1st and 2nd order excitation, which becomes dominant in case of misfiring, will have resonance outside the shaft generator operating speed. Such tuning of the natural frequencies will normally require very elastic couplings.

7. Engine Governing System

Basically, the following three types of governors can be used to control modern two-stroke camshaft diesel engines:

- conventional electronic governor with one speed pick-up and standard software
- advanced electronic governor with two or more speed pick-ups and special software
- mechanical-hydraulic governor (for small bore engines only).

The mechanical-hydraulic governor can be used for simple installations involving the 26-46MC engines, where it may provide sufficient governing abilities at an attractive cost. However, an electronic governor is also often used for the 26-46MC engines. All 50-98MC engines require an electronic governor.

The installation of a shaft generator with an electric output power of less than 15% of the main engine's power at specified MCR does not normally require special considerations in the selection of governor. However, if a PTO/GCR is installed together with a controllable pitch propeller, it may prove advantageous to use an electronic governor even on the smallest engine types to obtain the most stable engine speed conditions and, hence, the most stable frequency in the generated electricity.

For large shaft generators, the combination of a low natural frequency and a high moment of inertia in the alternator may require special facilities in the engine governor (i.e. the advanced governor) if instabilities in the system are to be avoided. For plants where the output power of the shaft generator exceeds 15% of the main engine's power, or a clutch or a flexible coupling is installed in the shaft line, we therefore recommend investigating whether an advanced electronic governor is needed.

For the electronically controlled ME engine, the governor functions are included in the Engine Control System and the control of an ME engine with shaft generator is comparable to the control of a camshaft controlled diesel engine with shaft generator and electronic governor.

8. Pros and Cons (shaft generators versus gensets)

In the following, a number of advantages and disadvantages related to the use of shaft generators are discussed:

8.1 Advantages—shaft generators

- **Small space requirement**
The shaft generator is installed close to the engine or the shaft line, and often takes up no further space than is already set aside for the engine installation. In particular, the PTO BW III (engine side mounted) and the PTO BW IV (tunnel gear) require little space for the installation. The SMG/CFE and the DMG/CFE need extra space elsewhere in the engine room for the synchronous condenser and the control cubicles
- **Low investment cost (PTO/GCR)**
The investment cost depends on the type and make of the shaft generator. Depending on the origin of the shaft generator, the PTO/GCR can be purchased at a relatively low price, whereas the frequency controlled types (PTO/RCF and PTO/CFE) are relatively expensive
- **Low installation cost**
The shaft generator requires no separate (or only a simple) foundation, no exhaust gas system and only a few connections to the auxiliary equipment. Furthermore, the time spent installing a shaft generator is normally short

- **Reliability**

Shaft generators are normally considered highly reliable, as is the main engine which drives the shaft generator

- **Low man-hour cost for maintenance**

The planned maintenance of a shaft generator during the first years of operation only involves regular checks of proper functioning and regular replacement of the lubricating oil and the oil filter, if the shaft generator has a separate lubricating oil system

- **Low spare parts cost**

The high reliability of shaft generators, together with the low spare parts consumption for planned maintenance, result in low spare parts costs

- **Long lifetime**

A shaft generator is generally not exposed to much wear, but of course components such as bearings, mechanically driven oil pumps, friction clutches, etc. need to be replaced or reconditioned after many years in operation

- **Low noise**

The noise level of a shaft generator is considerably lower than the noise level of a genset.

8.2 Disadvantages—shaft generators

- **No power production in harbour**

Whether a shaft generator is installed or not, the electric power consumption in harbour will generally have to be covered by a genset. However, in special cases where a clutch is installed in the shaft line, as on shuttle tankers with high electricity consumption for cargo pumping, it is possible to use the main engine and the shaft generator for electric power production in harbour

- **Higher load on main engine**
The load on the main engine, and thus the specific fuel oil consumption and the cylinder oil consumption, increase when a shaft generator is used
- **Reduced propeller and engine efficiency at low propulsion power for PTO/GCR**
If the PTO/GCR is used for power production with a fixed frequency, which is usually the case, the engine with a controllable pitch propeller must be operated at constant speed even at reduced load. The efficiency of the controllable pitch propeller and the engine would be higher if the engine was operated according to a combinator curve, where the speed was reduced at reduced load
- **No long-time parallel running ability for PTO/GCR**
The PTO/GCR cannot run in parallel with the gensets except during load take-over. This means that the power distribution between the electric power producers is not as flexible as with a pure genset installation
- **More complex shaft arrangement**
The installation of a shaft generator complicates the shaft arrangement. Gears and flexible couplings need not be installed for a two-stroke diesel engine used for propulsion if a shaft generator is not installed.

9. Economic Comparison

On the basis of the following data we have compared the operating costs, with and without a shaft generator, of a typical feeder container vessel.

The following alternatives have been compared:

Alternative 1: 1 x 7S50MC-C + PTO BW IV GCR/1200 + 2 x 7L16/24H

Alternative 2: 1 x 7S50MC-C + 3 x 7L16/24H

We have used the following ratings of the main engines:

Alternative 1: SMCR = 11,060 kW at 127 rpm
CP-Propeller running at constant speed

Alternative 2: SMCR = 9,760 kW at 127 rpm
CP-Propeller running at combinator curve

Propulsion load profile, Alternative 2:

- 90% load for 15% of time at sea
- 80% load for 40% of time at sea
- 70% load for 35% of time at sea
- 50% load for 10% of time at sea

In order to compare two vessels operating at exactly the same speed, the propulsion loads for Alternative 1 have been increased to compensate for the reduced propeller efficiency at part load, caused by the propeller operating at constant speed.

Time at sea: 250 days/year

Time in harbour: 115 days/year

Electric load at sea: 900 kW

Electric load in harbour: 500 kW

We have compared the two alternatives with respect to fuel oil costs and lubricating oil costs and found the following result:

Annual additional fuel and lube oil costs for Alternative 1= 9,500 USD/year

Details of the calculations are shown in Figures 17 and 18.

Additionally, we have analysed the maintenance costs for the two alternatives and estimate that the average annual maintenance costs for a long operating period are as follows:

Alternative 1:

Main engine, 7S50MC-C:	98,200 USD/year
Shaft generator, PTO BW IV S50-C/GCR 1200	500 USD/year
Gensets, 2 x 7L16/24H:	4,700 USD/year
Total annual maintenance costs:	103,400 USD/year

Alternative 2:

Main engine, 7S50MC-C:	98,200 USD/year
Gensets, 3 x 7L16/24H:	25,200 USD/year
Total annual maintenance costs:	123,400 USD/year
Annual saving in maintenance costs for Alternative 1:	20,000 USD/year

The maintenance costs include man-hours for overhaul with an hourly wage of 30 USD, and spare part costs in accordance with normal overhaul intervals. The maintenance costs also allow for 30% extra man-hours for unscheduled overhauls.

When the additional fuel and lube oil costs and the expected savings in maintenance costs are compared, Alternative 1 turns out to be 10,500 USD cheaper in operation per year than Alternative 2. However, the saving only represents around 1.0% of the total annual operating costs.

Assuming a 30,000 USD extra investment cost for the shaft generator compared with one extra 7L16/24H genset, the calculation shows a payback time for Alternative 1 (with shaft generator) of three years, using the Net Present Value method with a 3% rate of inflation and a 6% rate of interest.

However, the investment costs for the shaft generator and the genset may differ significantly depending on the origin of the shaft generator and the genset.

The installation costs may be expected to favour the shaft generator.

Other aspects also need to be considered, e.g. in some cases a shaft generator cannot be installed unless the engine is specified with one additional cylinder. The extra costs for the engine and its auxiliary equipment related to an additional cylinder, together with the economic impact of an increased engine room length, have not been evaluated.

To conclude, many factors influence the final economic result, and the final conclusion as to whether the installation of a shaft generator is attractive or not can only be made by the owner.

Machinery arrangement

7S50MC-C with PTO	
SMCR (kW)	11,060
Efficiency PTO (%)	92
2 x 7L16/24H gensets	

Basic data

Total days at sea	250
Total days in harbour	115
HFO price (USD/ton)	140
System oil price (USD/ton)	800
Cylinder oil price (USD/ton)	900

Load pattern

Load case	1	2	3	4	5	
Hours	900	2,400	2,100	600	2,760	
Propulsion power (kW)	8,780	7,833	6,916	5,142	0	
PTO mech. power (kW)	975	975	975	975	0	
Main engine power (kW)	9,755	8,808	7,891	6,117	0	
MEP (bar)	16.8	15.1	13.6	10.5	0	
SFOC (g/kWh)	168.4	168.0	168.2	170.4	0	
Genset power (kW _{el})	0	0	0	0	500	

Fuel oil consumption

Load case	1	2	3	4	5	Total	Cost (USD)
Hours	900	2,400	2,100	600	2,760		
Main engine power (kW)	9,755	8,808	7,891	6,117	0		
SFOC (g/kWh)	168.4	168.0	168.2	170.4	0		
Genset power (kW _{el})	0	0	0	0	500		
SFOC (g/kWh _{el})	0	0	0	0	202		
HFO (tons/year)	1,571	3,773	2,961	664	296	9,265	1,297,100

(SFOC: ref. LCV = 42,700 kJ/kg)

(HFO: ref. LCV = 40,200 kJ/kg)

System oil consumption

Load case	1	2	3	4	5	Total	Cost (USD)
Hours	900	2,400	2,100	600	2,760		
Main engine (kg/24h)	31	31	31	31	0		
Genset (kg/24h)	0	0	0	0	12		
System oil (tons/year)	1.2	3.1	2.7	0.8	1.4	9.2	7,360

Cylinder oil consumption (based on 1.02 g/kWh and Alpha ACC with 3% sulphur)

Load case	1	2	3	4	5	Total	Cost (USD)
Hours	900	2,400	2,100	600	2,760		
Cylinder oil (tons/year)	9.0	21.6	16.9	3.7	0.0	51.2	46,080

Total cost per year (USD) excl. maintenance cost

1,350,540

Fig. 17: 7S50MC-C with PTO

Machinery arrangement		Load pattern						
7S50MC-C without PTO		Load case	1	2	3	4	5	
SMCR (kW)	9,760	Hours	900	2,400	2,100	600	2,760	
Efficiency PTO (%)	–	Propulsion power (kW)	8,784	7,808	6,832	4,880	0	
3 x 7L16/24H gensets		PTO mech. power (kW)	0	0	0	0	0	
Basic data		Main engine power (kW)	8,784	7,808	6,832	4,880	0	
Total days at sea	250	MEP (bar)	16.2	14.8	13.2	9.9	0	
Total days in harbour	115	SFOC (g/kWh)	166.6	165.5	164.9	168.6	0	
HFO price (USD/ton)	140	Genset power (kW _{el})	900	900	900	900	500	
System oil price (USD/ton)	800	Fuel oil consumption						
Cylinder oil price (USD/ton)	900	Load case	1	2	3	4	5	Total
		Hours	900	2,400	2,100	600	2,760	Cost (USD)
		Main engine power (kW)	8,784	7,808	6,832	4,880	0	
		SFOC (g/kWh)	166.6	165.5	164.9	168.6	0	
		Genset power (kW _{el})	900	900	900	900	500	
		SFOC (g/kWh _{el})	205	205	205	205	202	
		HFO (tons/year)	1,576	3,765	2,925	642	296	9,204
		(SFOC: ref. LCV = 42,700 kJ/kg)						
		(HFO: ref. LCV = 40,200 kJ/kg)						
		System oil consumption						
		Load case	1	2	3	4	5	Total
		Hours	900	2,400	2,100	600	2,760	Cost (USD)
		Main engine (kg/24h)	31	31	31	31	0	
		Genset (kg/24h)	24	24	24	24	12	
		System oil (tons/year)	2.1	5.5	4.8	1.4	1.4	15.2
								12,160
		Cylinder oil consumption (based on 1.49 g/kWh at nominal MCR and reduced proportional to MEP at part load)						
		Load case	1	2	3	4	5	Total
		Hours	900	2,400	2,100	600	2,760	Cost (USD)
		Main engine power (kW)	8,784	7,808	6,832	4,880	0	
		Cylinder oil (tons/year)	8.1	19.1	14.6	3.0	0.0	44.8
								40,320
Total cost per year (USD) excl. maintenance cost		1,341,040						

Fig. 18: 7S50MC-C without PTO

10. Typical Applications

At present, the following shaft generators are most frequently installed:

PTO BW II/GCR

PTO BW III/GCR

PTO BW IV/GCR

PTO SMG/CFE

The PTO BW II/RCF and the PTO BW III/RCF are also installed from time to time.

Typically, the PTO BW II/GCR and the PTO BW IV/GCR are used on container vessels or chemical tankers with 26-50MC main engines (and CPP). The electrical output power is normally between 500 and 1200 kW. The PTO BW III/GCR is mostly used for the same ship types with 50-60MC main engines (and CPP), and the shaft generator normally has an electrical output power between 700 and 1800 kW.

The PTO SMG/CFE is often installed on large container vessels with 70-98MC main engines (and FPP) and a large number of reefer plugs. For large container vessels, the shaft generator will often be specified with an electric capacity of around 2,000-3,500 kW or even higher.

The PTO BW III/RCF has been used with all engines in the range from 42 to 90MC and can also be installed together with the K98MC/ME-C and K108ME-C engines. For small ships with the smallest MC engines (26-35MC) with FPP, the PTO BW II/RCF with a power of around 250-700 kW is occasionally used.

11. Special Applications

11.1 Shuttle tankers

Shuttle tankers, which load their cargo from storage facilities at the field or directly from the production platform, are widely used to serve offshore oil fields from which pipeline connections are not practicable.

High performance manoeuvring equipment is made necessary by the operating profile which, during loading of the ship, includes long periods of accurate dynamic positioning at the field, by using bow and stern thrusters as well as the main propeller. The time required for loading the oil depends on the loading facilities and may vary from one to ten days in each round trip.

Shuttle tankers with 3 x 1750 kW bow thrusters and 2 x 1750 kW stern thrusters to match the above requirements are in operation.

The large side thruster power installed on the vessels calls for equipment that can provide sufficient electricity production.

This means that large diesel generators or large shaft generators need to be installed on all shuttle tankers intended for dynamic positioning operation. In order to minimise the total installed power of the auxiliary power producers, cargo pumps driven by electric motors are normally installed. The cargo pumps are primarily used to unload the cargo in port but may also be used in the field to distribute oil among the segregated cargo tanks. The maximum power consumption of the cargo pumps is typically around 4-5,000 kW.

One propulsion system which meets the above-mentioned requirements is the diesel-mechanical system with two low speed main engines and shaft generators. Figure 19 shows an example of such an arrangement, where the shaft generators are placed in the shaftlines.

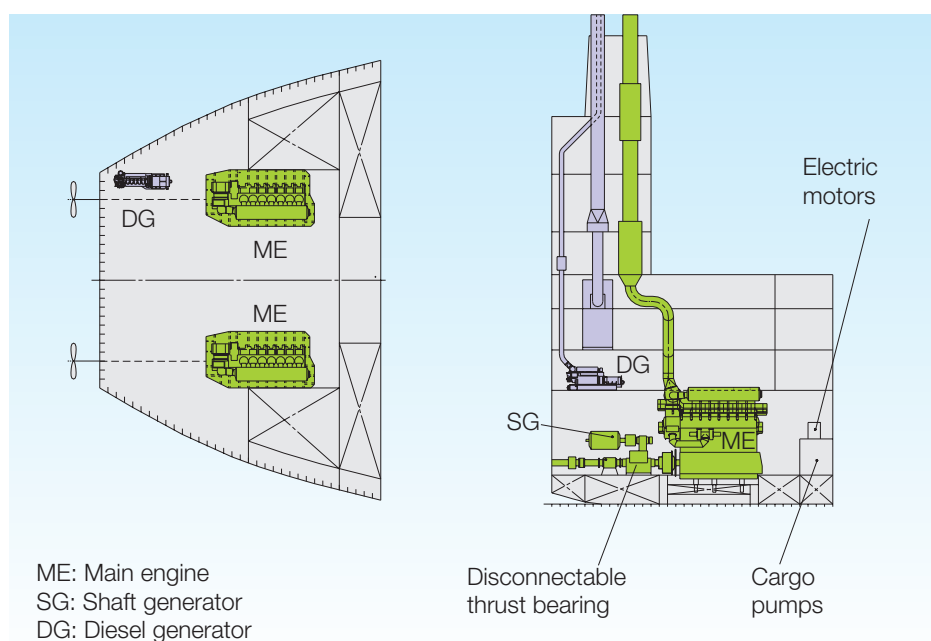


Fig. 19: Shuttle tanker engine room arrangement with shaft generators

Clutches are installed in the shaftlines aft of the shaft generators, and are used to disconnect the propeller from the main engine while in port, so that the main engine can be used for electric power production without turning the propeller.

When a clutch is positioned in the shaftline, an external thrust bearing is required, so that both forward and aftward thrust are transmitted to the tanktop, aft of the clutch. The clutch and the thrust bearing are normally made as a unit.

When a clutch is to be placed in the shaftline, a study of the engine acceleration behaviour must be performed, illustrating the outcome of an immediate loss of electrical load on the shaft generator with the propeller disconnected.

Such a study normally results in the setting of minimum requirements for the in-

ertia of the alternator as well as requirements for the control of the main engine, such as an advanced electronic governor and an additional overspeed shut-down system controlling a fuel cut-off device. As an additional safety feature it is recommended that the flexible couplings are made with a torsional limit device, so that in the event of breakage of the flexible elements, steel parts will transmit the torque until the safety system has shut down the engine.

In harbour, the speed, and thus the efficiency, of the cargo pumps can be controlled by varying the speed of the engine that drives the shaft generator and thus varying the electrical frequency (in a propulsion plant with two main engines, the other engine is at standstill and accessible for overhaul).

A frequency converter laid out for the ship's power consumption is required where the shaft generators are to be used for power supply for the general electrical consumption of the ship in all load conditions (harbour, steaming, and dynamic positioning) and where, in some of these load conditions, the engine speed is not kept at a constant level.

Alternatively, one diesel generator can be used to supply the electric power for the general electricity consumption when the engine speed is reduced.

In all cases, transformers are needed to provide voltage regulation between the alternators and the ship service switchboard.

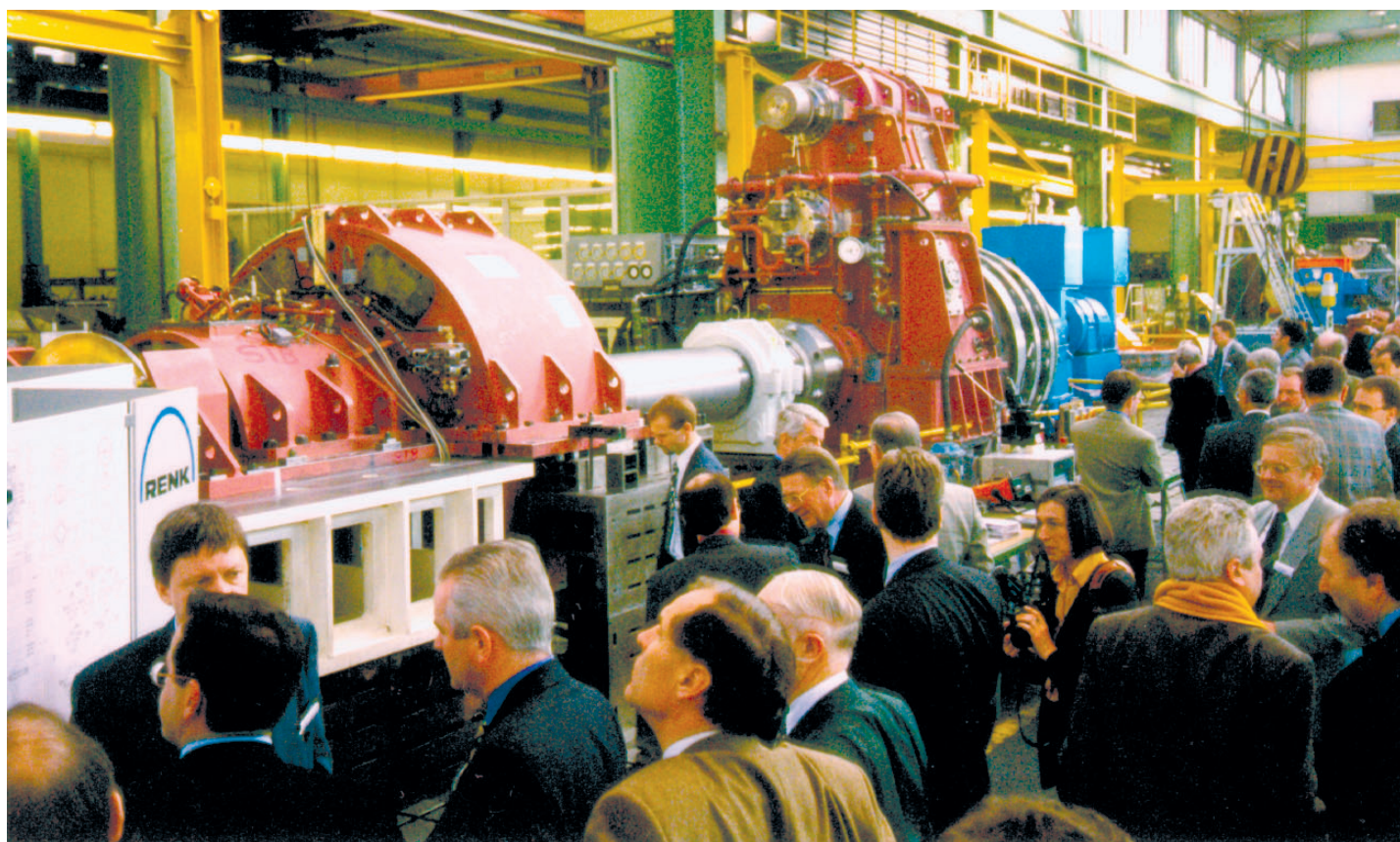


Fig. 20: An 8,600 kW PTO arrangement for a shuttle tanker, being tested at the Renk works

11.2 Auxiliary propulsion system

From time to time, an auxiliary propulsion system (Power Take Off / Power Take In) is requested, especially in connection with projects involving gas and chemical tankers with main engines in the range of S35-S42MC and equipped with a CP-propeller.

The auxiliary propulsion system must be capable of driving the CP-propeller by using the shaft generator as an electric motor while the main engine is stopped and disengaged. The electric power is produced by a number of gensets.

MAN B&W Diesel can offer a solution where the CP-propeller is driven by the alternator via a two-speed tunnel gear box. The main engine is disengaged by a clutch (Alpha Clutch) made as an integral part of the shafting. The clutch is installed between the tunnel gear box and the main engine, and conical bolts are used to connect and disconnect the main engine and the shafting. See Figure 21.

The Alpha Clutch is operated by hydraulic oil pressure which is supplied by the power pack used to control the CP-propeller.

A thrust bearing, which transfers the auxiliary propulsion propeller thrust to the engine thrust bearing when the clutch is disengaged, is built into the Alpha Clutch. When the clutch is engaged, the thrust is transferred statically to the engine thrust bearing through the thrust bearing built into the clutch.

To obtain high propeller efficiency in the auxiliary propulsion mode, and thus also to minimise the auxiliary power required, a two-speed tunnel gear, which provides lower propeller speed in the auxiliary propulsion mode, is used.

The two-speed tunnel gear box is made with a friction clutch which allows the propeller to be clutched in at full alternator/motor speed where the full torque is available. The alternator/motor is started in the de-clutched condition with a start transformer.

The requirements of some classification societies differ depending on whether the auxiliary propulsion system is to be used as a take home system (in the event of failure of the main engine at sea) or as an alternative propulsion system (take away from quay or alternative propulsion at low vessel speed).

The auxiliary propulsion system offered by MAN B&W Diesel fulfils the requirements of both alternatives, provided that sufficient electrical power for auxiliary propulsion of the vessel can be produced by the gensets.

The system can quickly establish auxiliary propulsion from the engine control room and/or bridge, even with unmanned engine room.

Re-establishing of normal operation requires attendance in the engine room and can be done within a few minutes.

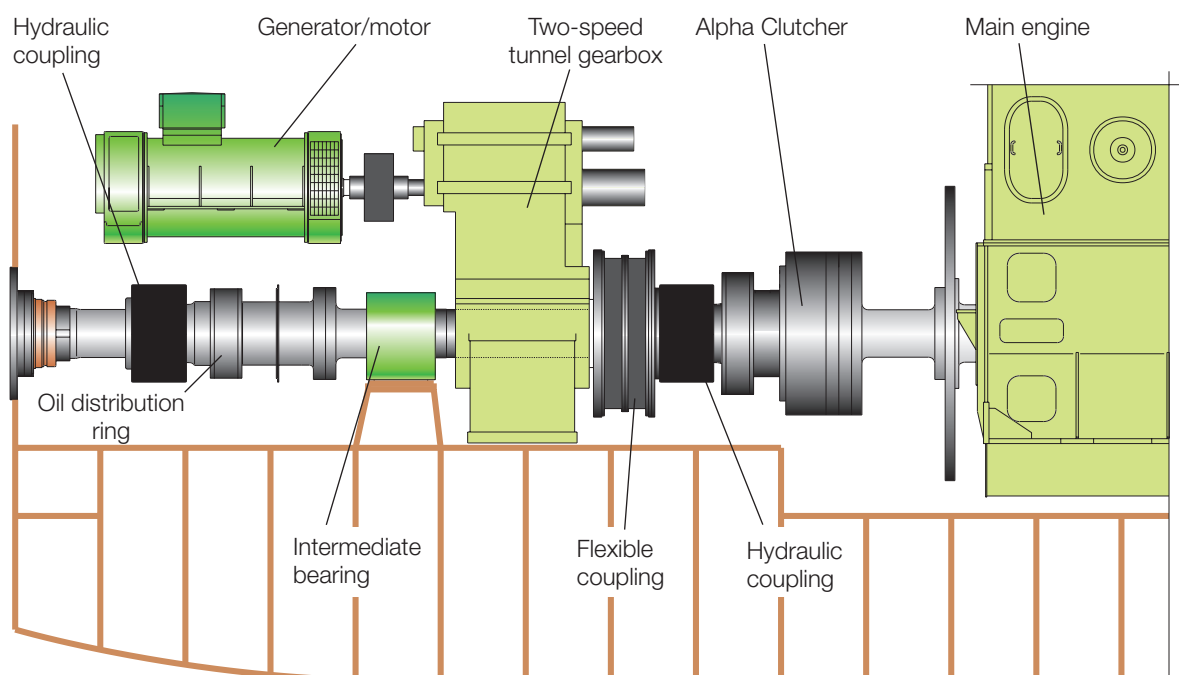


Fig. 21: Auxiliary propulsion system

12. Summary

A wide range of shaft generators are available for installation in combination with the two-stroke engines in MAN B&W Diesel's comprehensive engine programme.

The shaft generators are available with or without frequency control systems. Some of them use step-up gears, some of them do not.

The installation of a shaft generator affects the layout of the engine relative to the propeller, and the shaft generator must be included in the torsional vibration calculations. Shaft generators with normal electric capacity (less than 15% of the SMCR power) typically do not influence the requirements of the engine governing system. However, especially with shaft generators with no frequency control system, the stability of the engine speed needs to be considered.

Shaft generators can be used in special applications, including shuttle tanker propulsion arrangements where the engine can be disconnected from the propeller and used to drive a large alternator supplying electric power for the cargo pumps.

In rare cases, an auxiliary propulsion system is requested, in which the shaft generator is used as an electric motor to drive the propeller, with the main engine disconnected (the electric power is produced by a number of gensets), and MAN B&W Diesel is able to offer a tailor-made concept, including the CP-propeller.

References show that most MAN B&W two-stroke engines are at present installed without a shaft generator. This reflects the fact that many shipowners and shipyards rather than using a shaft generator, prefer the simple engine room arrangement with a directly coupled two-stroke engine for propulsion, and a number of gensets for electricity production

purposes. This may be because, in recent years, gensets have improved their cost effectiveness thanks to low prices, operation on heavy fuel oil, improved reliability and prolonged mean time between overhauls.

On the other hand, when surplus capacity is available from the main engine, a shaft generator is still a viable solution.

References covering the supply of gear based PTO systems from three major makers are listed below.

PTO/GCR	Engine type	Units
(Renk, A. Friedr. Flender AG, Newbrook)	(BW IV/GCR)	
	35MC	2
	42MC	10
	50MC	19
	60MC	17
	80MC	2
		50
	(BW III/GCR)	
	42MC	2
	50MC	21
	60MC	28
	70MC	4
		55
	(BW II/GCR)	
	26MC	16
	35MC	25
	42MC	4
	46 MC	4
	50MC	3
		52
	Total	157
PTO/RCF	Engine type	Units
(Renk)	(BW III/RCF)	
	42MC	5
	50MC	25
	60MC	44
	70MC	24
	80MC	18
		116
	(BW II/RCF)	
	26MC	5
	35MC	9
	42MC	1
	80MC	2
		17
	(BW I/RCF)	
	70MC	2
		2
	Total	135
PTO/CFE	Engine type	Units
(Renk)	(BW III/CFE)	
	60MC	6
	70MC	9
		15
	Total	15

Reference List (Renk, A. Friedr. Flender AG, Newbrook), as at 2004.01.21