The MC Engines - News and Views

Introduction

The market leading MC engines, which date back to 1982, have over the years been subject to a continuous development to cater for changing market requirements.

This development has been described in detail in numerous papers over the years, and major milestones in this regard can be seen in Fig. 1.

The present MC programme ranges from 2,400 bhp for the smallest model, up to 93,120 bhp for the largest model, the 12K98MC-C. A reference list is shown in Fig. 2.

Engine Programme Development

New models have entered the MC programme when called for by the market. Recent examples are the S35MC, S42MC, S90MC-T and K98MC-C, of which the first two respond to the wish to further improve the propulsion efficiency of smaller propulsion plants by lowering the engine speed.

The S90MC-T caters for the power and speed requirements of VLCC's while, at the same time, offering the shortest engine length and a lower number of cylinders than our competitors' engines.

The K98MC-C offers the highest unit power available on the market today at the right engine speed as required by the very large and fast post-panamax container vessels which are now entering the worldwide containership fleet.

		Mk	mep bar	C_m
1981	L35MC introduced			
1982	Full L-MC programme	1	15.0	7.2
1984	L-MC updated	2	16.2	
1985	L42MC introduced			
1986	K-MC introduced S-MC introduced L-MC updated	 3	16.2 17.0	 7.6
1987	S26MC introduced			
1988	K-MC-C introduced		16.2	
1991	MC programme updated K and L-MC S-MC	 5 6	 17.0 18.0	8.0
1992	S26MC and L35MC updated		18.5	8.2
1993	S35MC and S90MC-T introduced K90MC/MC-C updated,	 6	 18.0	 8.0
1994	S42MC introduced			
1994	K98MC-C introduced	6	18.2	8.3
1995	K80MC-C	6	18.0	8.0
1996	L70MC updated	6	18.0	8.2
1996	S70MC-C, S60MC-C, S50MC-C and S46MC-C introduced		19.0 19.0	8.5 8.3

mep = mean effective pressure
c_m = mean piston speed

Fig. 1: MC engine programme development

	No. of engines	
Bore	On order or delivered	In service
90	126	81
80	344	318
70	497	395
60	1,098	919
50	747	541
42	137	108
35	707	554
26	138	121
Total	3,794	3,037

Total = 55,611,322 BHP
~ 40,874,322 kW

Fig. 2: Reference list as at 1st March 1996

Just recently, an S46MC-C engine has been introduced to cater for the needs of smaller tankers and bulk carriers.

The data for this engine are shown in Fig. 3 and a cross-section can be seen in Fig. 4.

The introduction of the S46MC-C is the result of the fierce competition in the market, where stringent cost awareness calls for engines that are virtually tailor-made for the application in question. The S46MC-C is intended for a range of smaller tankers and bulkers, where an S42MC and L or S50MC can also be used. However, the S46MC-C will extend the number of ideal combinations of power, speed and number of cylinders.

The provision of the right power and speed is a primary consideration in any ship project, so it is only natural that we occasionally see projects where the power required, including margins, is slightly above or below what is offered by the standard versions in the programme.

Whereas derating is a possibility where the power requirement is lower, we have also seen situations where higher power is required, particularly in projects in-

Power/ cylinder	1785 BHP 1310 kW
Speed	129 r/min
Mean effective pressure	19 bar
Stroke	1932 mm
Bore	460 mm
Stroke/bore ratio	4.2
Mean piston speed	8.3 m/s
SFOC	128 g/BHPh 174 g/kWh
Cylinders	4-8

Fig. 3: S46MC-C data

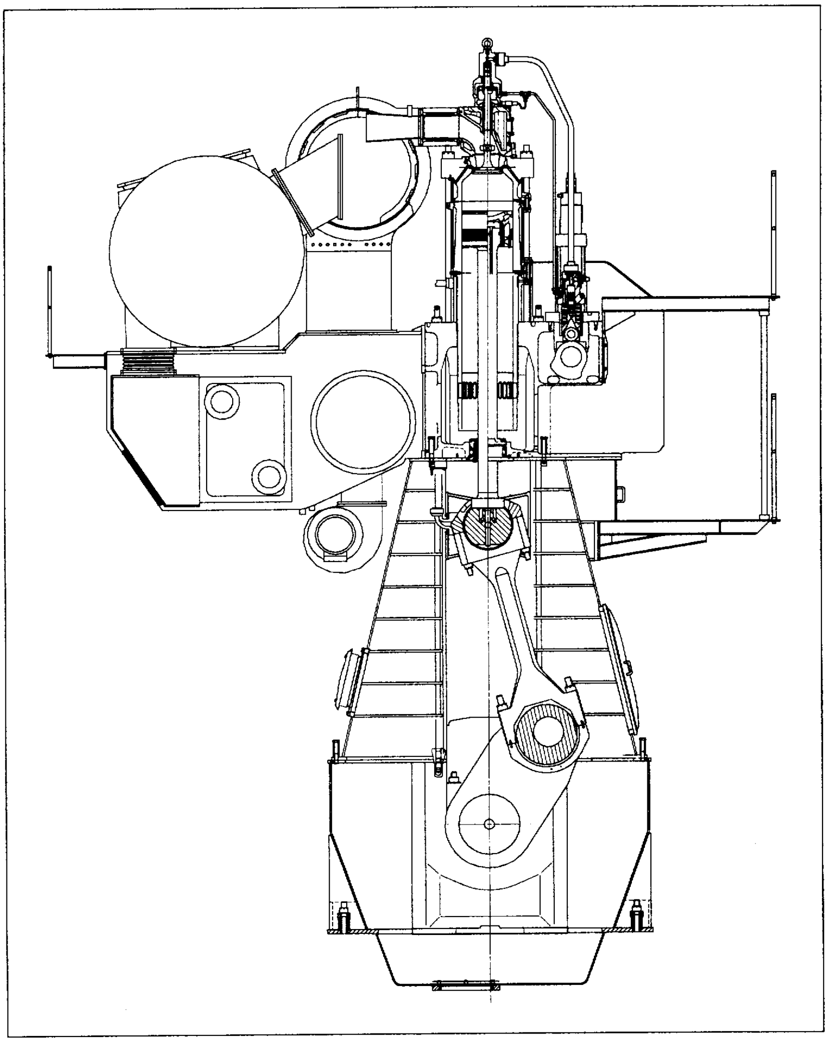

Fig. 4: S46MC-C cross-section

volving S50MC, S60MC and L/S70MC type engines.

The traditional step in such a situation would be to select an engine with one more cylinder, or to choose an engine with the next larger cylinder diameter.

However, apart from the physical constraints that this would involve, the industry is today facing an extremely high degree of cost awareness, which means that a larger and thus often a more expensive engine is not always acceptable.

Therefore, in a limited number of projects, we have marketed re-rated versions of the 50MC, 60MC and 70MC. The data for these new engines, being designated 50MC-C, 60MC-C and 70MC-C, shown in Fig. 5, are equivalent to what is normally known as the

Type designation		S50MC-C	S60MC-C	S70MC-C
Power/cylinder	BHP kW	2145 1580	3070 2255	4220 3105
Speed	r/min	127	105	91
Mean effective pressure	bar	19	19	19
Stroke	mm	2000	2400	2800
Bore	mm	500	600	700
Stroke/bore ratio		4.0	4.0	4.0
Mean piston speed	m/s	8.5	8.4	8.5
SFOC	g/BHPh g/kWh	126 171	125 170	124 169
Cylinders		4-8	4-8	4-8

Fig. 5: S50MC-C, S60MC-C and S70MC-C data

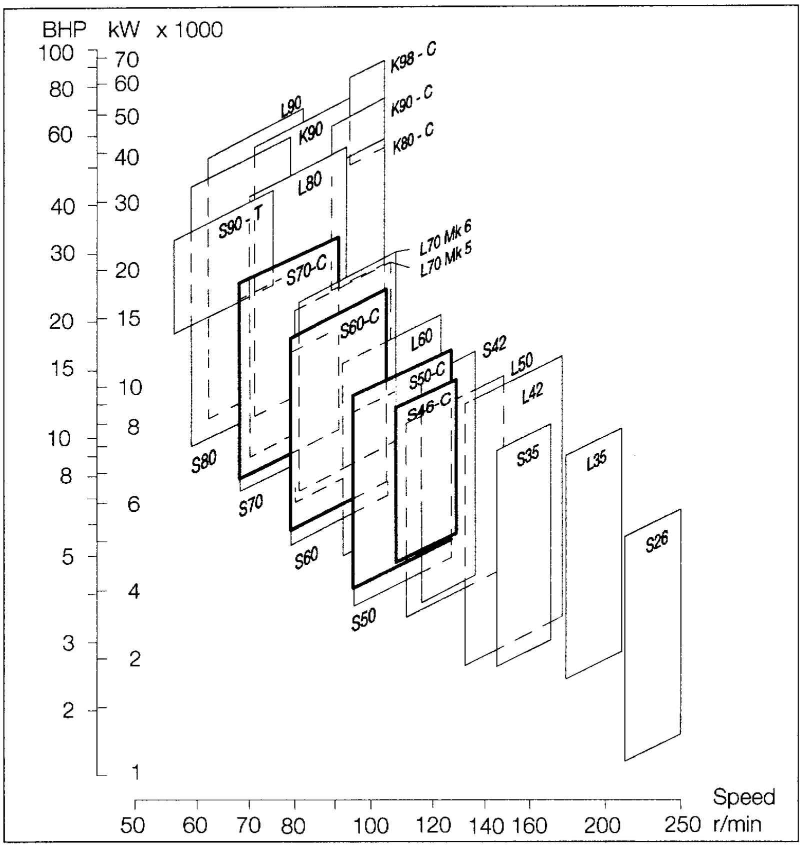

Fig. 6: The MC programme 1996

overload range but is allowed for continuous operation for the new engines.

The prerequisites that justify these engine ratings are modification of the turbocharging and scavenge air systems as well as certain modifications of the combustion chamber configuration and bearings.

As mentioned, it is only in certain projects that the higher ratings are needed. It was also mentioned that the cost awareness throughout the market makes it attractive to scrutinise any potential cost-saving modification.

The conclusion was that by optimising plate thicknesses, and introducing several other cost-saving features on the mid-range engines S50MC to S70MC, we can significantly lower the production cost of these engines.

In view of these market trends and investigation results, we are thus introducing an extended, even more competitive MC programme by including the S70MC-C, S60MC-C and S50MC-C type engines, see Fig. 5.

These types have been introduced as **compact** (C for compact) versions of the current types with the same cylinder bores, but with increased outputs corresponding to an increase in the mean effective pressure to 19 bar.

The length has been reduced, on the 6S50MC-C for instance by about 1,000 mm. The masses will also be lower; for instance, the mass of the 6S50MC-C will be more than 25 tons lower (i.e. reduced by 13%) than that of the 6S50MC. This also reduces the vibration excitations.

It is worth mentioning that the new MC-C engines can be 100% balanced.

In addition, the L70MC will be made available in a Mk 6 version with a power rating corresponding to an increase in the mean effective pressure to 18 bar. The L70MC Mk 6 version will complement the present L70MC Mk 5 version.

To recapitulate, engines with mep of 18 bar or above are referred to as Mk 6, and those with 17 bar are designated Mk 5.

All this means that the new MC programme, see Fig. 6, includes more engines than ever before and more engines than any other engine programme, whether two-stroke or four-stroke. The obvious result of this is that, whatever the requirements of the project, the engine is available in the MC programme.

New Engine Features

Until the early 1980s, the designers of two-stroke engines had many different ideas of how to design these engines. Since then, however, the designs have become much more uniform. One of the best known differences, the scavenging principle, was streamlined some 15 years ago when the loop scavenging principle was abandoned and all designers switched to the (MAN B&W) uni-flow scavenging principle.

Given this situation as well as the wish to further improve reliability and increase the times between overhauls, a number of features have been introduced.

In line with the use of higher mean effective pressures (mep), a higher piston topland and higher top rings, the uppermost featuring a pressure balanced design, have been introduced with the aim of further improving reliability and increasing the times between overhauls. Fig. 7 shows the changed design in comparison with the present design.

An important new feature is the introduction of three fuel valves per cylinder on large-bore MC engines. The utilisa-

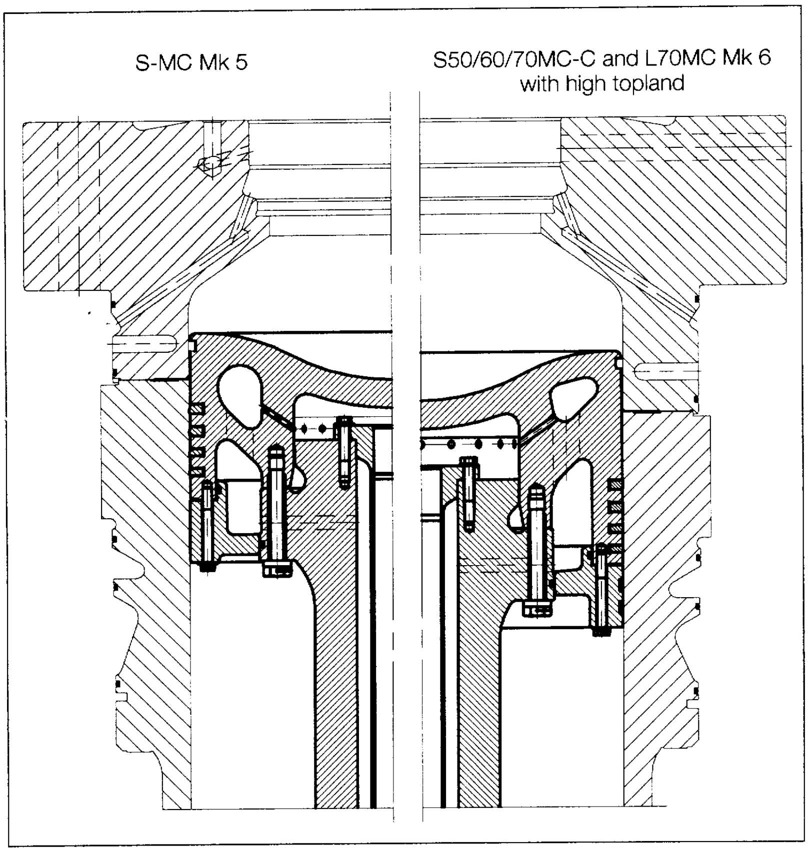

Fig. 7: Piston/ring pack assembly MC vs MC-C

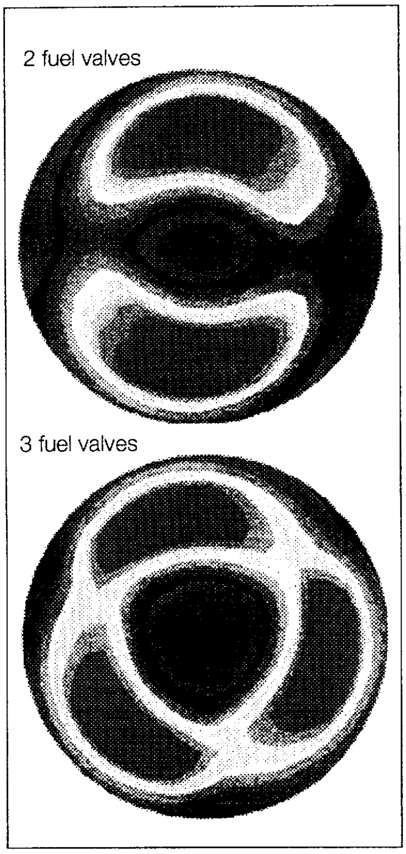

Fig. 8: Heat flux intensity on piston for K90MC-C with two and three fuel valves, respectively

tion of this configuration enables the temperature in the combustion chamber to be more evenly distributed, which is needed with the mep ratings used on the large engines of today.

Also a lower component temperature, giving added lifetime, has been realised with three fuel valves per cylinder.

The operating condition of cylinder liners and piston rings is to a great extent a function of the temperature along the liner. The upper part is particularly important and the three-fuel-valve feature will reduce thermal load while, at the same time, the pressure balanced piston ring and the high top-land ensure an appropriate pressure drop across the ring pack and control the temperature regime for the individual piston rings. Fig. 8 shows the heat flux intensity on the piston, with two and three fuel valves respectively.

For monitoring the temperature of the upper part of the liners, we offer embedded temperature sensors together with a recorder. Alarm and slow-down temperature settings will allow the operator to take proper action to restore proper running conditions if, for instance, a piston ring or a fuel valve is temporarily or permanently out of order.

Other features, such as an uncooled cylinder frame, serve to slightly increase the wall temperature on the lower part of the cylinder liner while, at the same time, lowering production costs. The increase in the wall temperature is aimed at counteracting the tendency towards cold corrosion in the lower part of the cylinder liner that has been experienced in a limited number of engines.

Fig. 9 shows a comparison of the new and the previous designs.

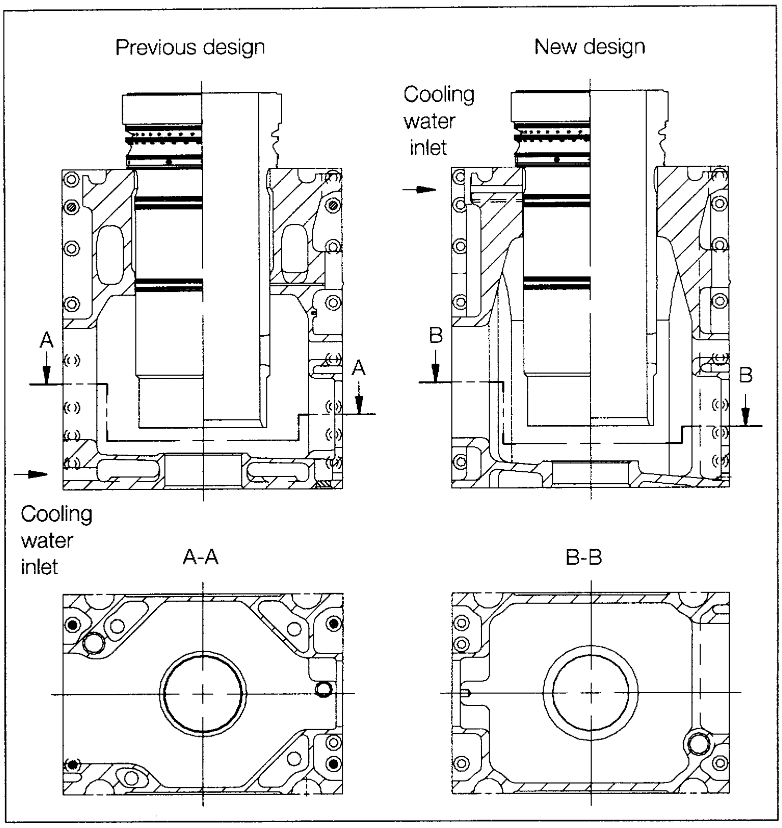

Fig. 9: Simplified cylinder frame shown together with the design used so far

Also a new, so-called "Umbrella Type", fuel oil pump design has been introduced.

This design, as is shown in Fig. 10, involves a new fuel pump sealing arrangement which eliminates the risk of fuel oil penetrating into the camshaft lube oil system, for which reason a separate camshaft lube oil system is no longer necessary.

As a consequence of the above, we have introduced the uni-lube oil system as standard, whereas the separate camshaft lube oil system is available as an option.

As the tank, filters, pumps, and the piping for the separate camshaft system have been omitted, the uni-lube oil system allows reductions in installation costs, maintenance and space compared with the separate main lube and camshaft lube oil systems used hitherto.

Another new feature, which is now being service-tested and is for release soon, is the fuel valve with variable opening pressure shown in Fig. 11.

As a consequence of the increase in combustion peak pressures over the years, the opening pressure required of the fuel valves has been increased to prevent blow back of gases into the fuel system.

At low loads this high opening pressure might lead to irregular injection, speed variations, and imply a risk of fouling of the engine gasways.

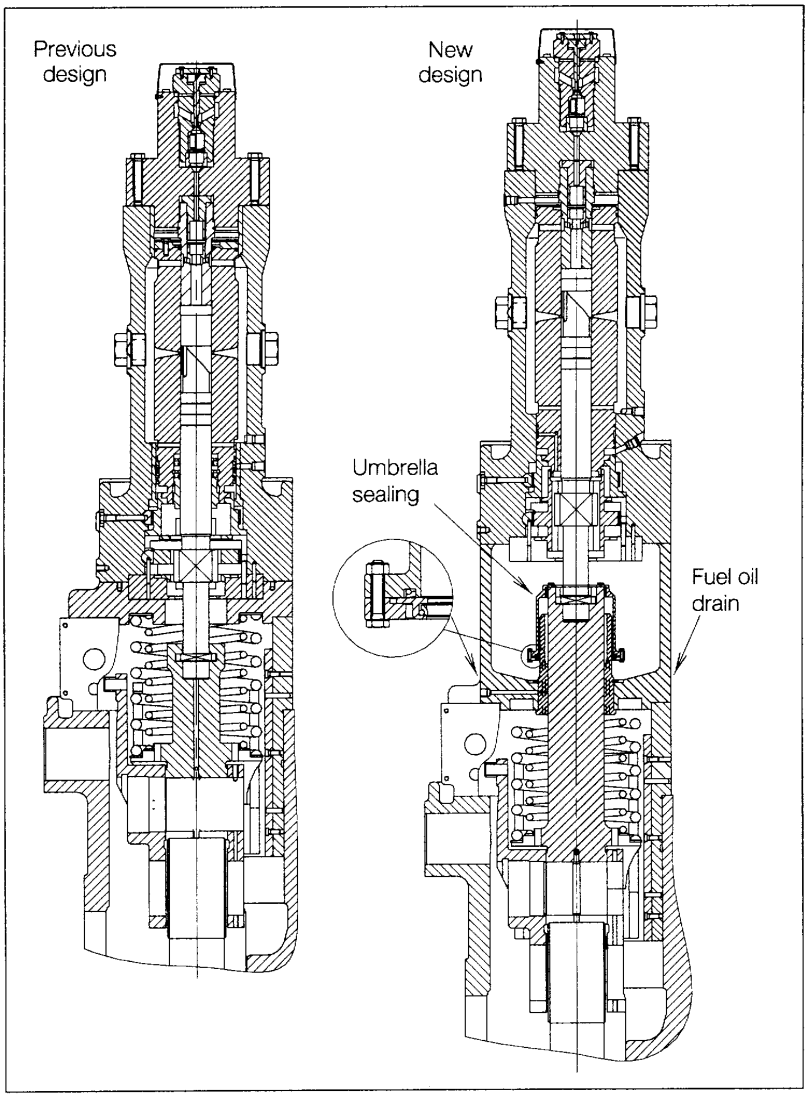

Fig. 10: Previous type and new umbrella-type of fuel injection pump

Low-load operation can therefore be improved by lowering the opening pressure in the relevant load range.

At low load, the opening pressure is controlled by the spring alone and, when the injection pressure increases at higher load, this higher pressure adds to the spring force, and the opening pressure increases.

Other attractive features are just on the verge of being introduced, and are presently undergoing verification tests on our research engine, the 4T50MX, installed at the MAN B&W Research Centre in Copenhagen. This engine features electronic control of fuel oil injection and exhaust valve actuation.

An example of such features is the cylinder pressure measuring system, which is based on instrumented cylinder cover studs.

The complete measuring system is shown in schematic form in Fig. 12. Each cylinder has two cylinder cover studs fitted with strain gauges placed in grooves, covered by a protecting layer. These two studs are placed close to the centreline of the engine in order to reduce the influence from guide forces, and the signals from the two studs are combined in the computer to reduce noise effects.

The signal to start data sampling is given by two optical transducers - one scanning TDC on cylinder 1, the other the 'Zebra' lines marked on the engine's crankshaft. This combination allows the reading of 600 pulses per revolution, thus providing data sampling at intervals of approx. 0.6 degree CA, or less, for each cylinder.

Data sampling is done by a multi-controller and a PC, which may be part of the general computing equipment of the ship. Subsequently, mean indicated pressure and firing pressure are calculated for each cylinder, and the engine speed is determined. The results of these calculations may be used as the direct input to CAPA (Computer Aided Performance Analysis) and, if desirable, a number of other parameters, such as compression pressure, maximum rate of pressure rise, ignition time, etc., may also be determined.

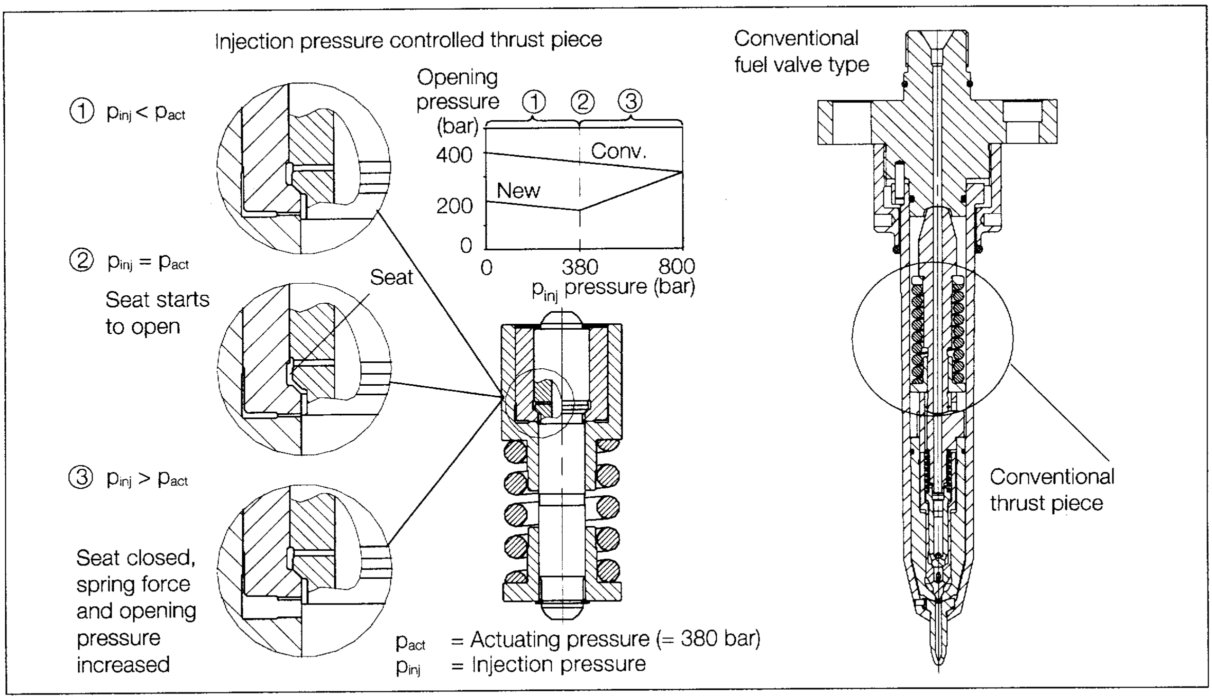

Fig. 11: Fuel valve with variable opening pressure

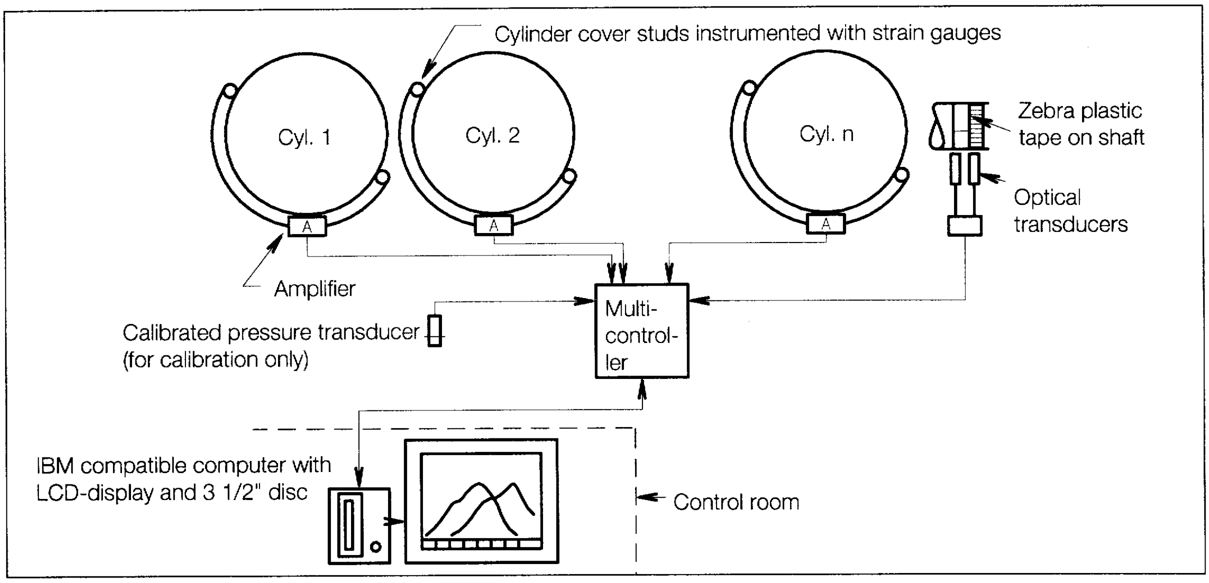

Fig. 12: Cylinder pressure measuring system

Computer Controlled Surveillance

By the end of the 80s, MAN B&W Diesel had successfully introduced two engine diagnosis systems in the market: MODIS-Geadit for four-stroke engines, and CAPA for two-stroke engines. On the basis of practical experience gained with these systems, we decided not only to combine the two systems, but also to incorporate additional modules for maintenance scheduling and spare parts logistics. This was the origin of a Computer Controlled Surveillance project which was started in 1991.

The system consists of the modules shown in Fig. 13.

All the modules are database controlled. They are delivered with data exactly matched to the existing plant configuration, but the user can also manage all the other units in the plant. Easy set-up functions are provided for this purpose. The system thus not only helps with engine operation, but can also be extended to function as a management tool for technical equipment for the entire ship.

The functions are organised in four modules:

- The **EDS** (Engine Diagnosis System), monitoring, trend and diagnosis system
- the **SPC** (Electronic Spare Parts Catalogue),
- the **MPS** (Maintenance Planning System), and
- the **SPO** (Spare Parts Stock Handling and Ordering System).

The **EDS** is an expert system for analysing engine operating data. Using the know-how and the experience of MAN B&W, the system is tailored to a marine engine system. The engine know-how is therefore permanently available on board, and the ship's crew is constantly informed of the condition of the engines. Irregularities in operating performance can thus be traced in time, and appropriate maintenance steps can be initiated.

The EDS is organised in three basic parts:

- Monitoring system
- Trend system
- Diagnosis system

The electronic spare parts catalogue (**SPC**) produces natural lists of spare parts for the various units, in the form of catalogues. These are hierarchically organised, i.e. they provide itemisation facilities at several levels, from graphic overview to subassembly groups and, finally, to individual parts. It is also possible to have further hierarchical levels, for example service packages.

The **MPS** is being introduced with the aim of changing from time-based maintenance to condition-based maintenance.

The main purpose of the MPS is to improve planning, instruction and reporting tools for the chief engineer. Time between overhauls is tailored to the specific engine condition, and this reduces the administrative work for the ship's personnel.

The **SPO** is a combined stock handling and spare parts ordering system that helps the engineering staff to guarantee and optimise the control of spare parts for the engines and any other equipment.

- If necessary, the tools can also be managed with the SPO.
- The SPO is a powerful database that manages stocks and orders.

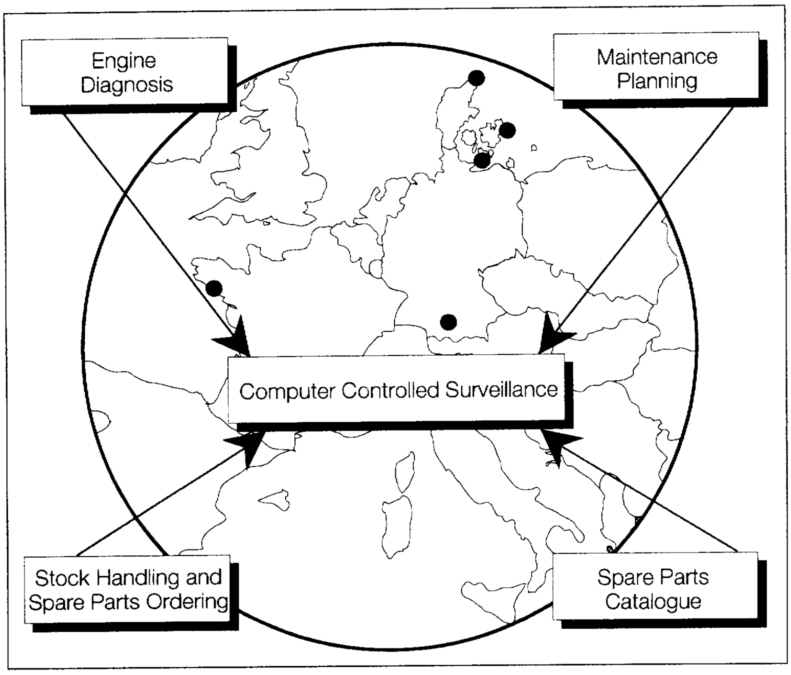

Fig. 13: Modules of MAN B&W Computer Controlled Surveillance system

Redundancy versus Reliability

The increased focus on safety and the environment has already resulted in demands for double hulls on all new tankers larger than 5,000 GT (OPA 90), in proposed sanctions on sailing without assistance from tugs in environmentally sensitive areas together with, for instance, proposals for limiting exhaust gas emissions.

The practice built up over many years of system development, as well as demands made during class approval tests of such systems, has in general resulted in extensive duplication of important components, for example in the auxiliary systems for the main engine, such as pumps, etc.

'Redundancy' is a term used in connection with the safeguarding of propulsion power. In connection with propulsion, it refers to an extra propulsion system which is not normally used, whether it duplicates the existing propulsion system or alternative propulsion systems are installed.

However, the word 'Redundancy' is also used in connection with systems which are partly or fully based on the systems normally employed to propel the ship. These systems are thus not redundant in the true sense of the word, but only involve a division of the necessary propulsion power into two or more units which will both be employed in normal service.

There are a number of alternatives for achieving full or partial redundancy of diesel-mechanical engine propulsion systems:

1) Two separate engine rooms, each with its own main engine and CP-propeller, duplication of all auxiliary equipment, including tanks, piping, control room, etc. Figs. 15 and 16 illustrate the point, compared to the traditional layout in Fig. 14.

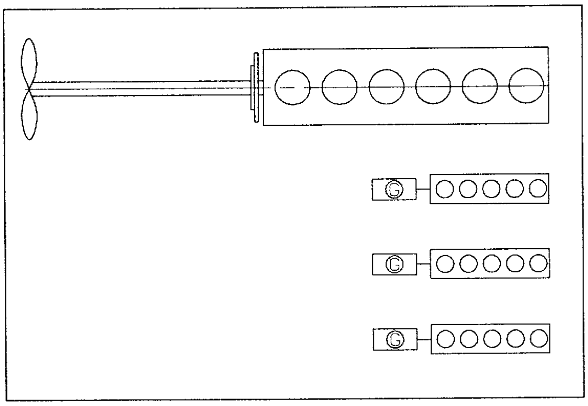

Fig. 14: 1 x low speed main engine with FP-propeller
3 x auxiliary engines

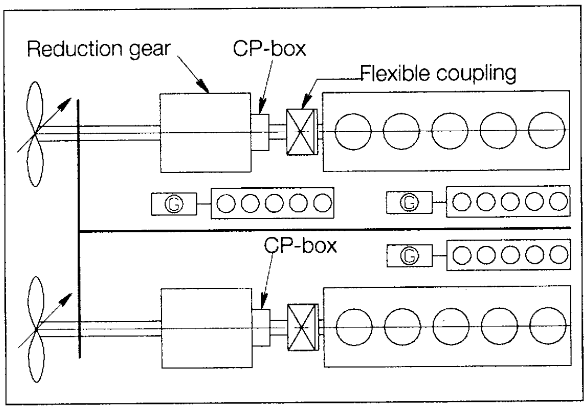

Fig. 15: 2 x medium speed main engines with flexible couplings, reduction gears and CP-propellers.
Fireproof and watertight partition bulkhead
2+1 auxiliary engines

2) One main engine + separate thrust bearing and toothed clutch or similar arrangement + tunnel gear with electric motor + external power supply for driving the electric motor. See Figs. 17, 18 and 19.

3) One main engine + one contra-rotating propeller + external power source for driving the outer propeller shaft. See Fig. 20.

4) One main engine + one or two water pump jets (for example, Schottel thrusters) + external power source for driving the water pump jets, Ref [3]. See Figs. 21 and 22.

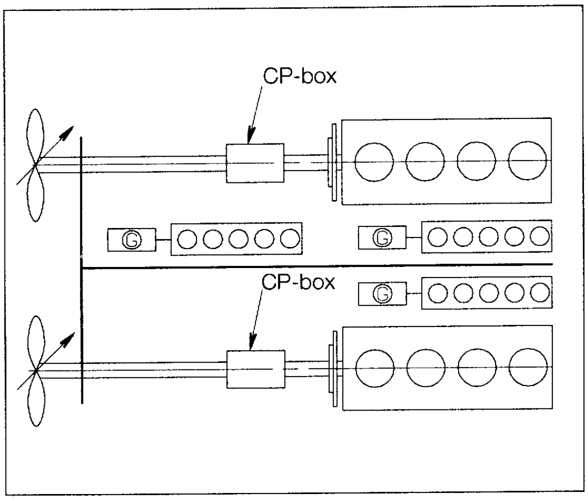

Fig. 16: 2 x low speed main engines with CP-propellers. Fireproof and watertight partition bulkhead. 2 + 1 auxiliary engines

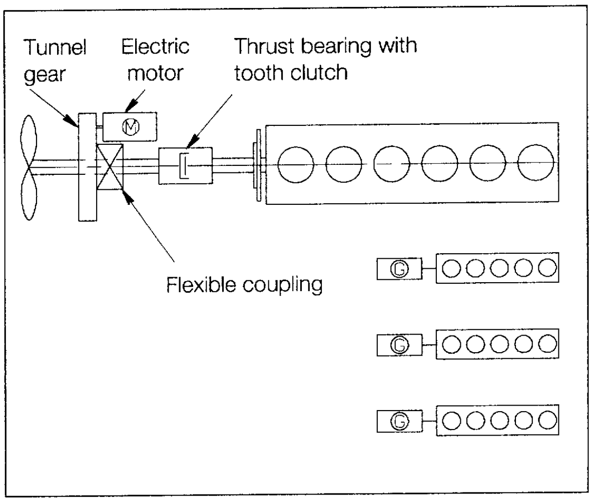

Fig. 17: 1 x low speed main engine with FP-propeller. Separate thrust bearing with tooth clutch, tunnelgear with electric motor. 3 x auxiliary engines

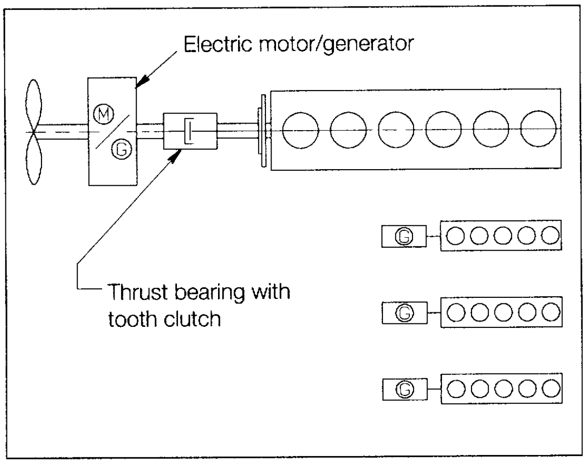

Fig. 18: 1 x low speed main engine with FP-propeller. Separate thrust bearing with tooth clutch, electric motor/generator with rotor coupled directly to the shafting
3 x auxiliary engines

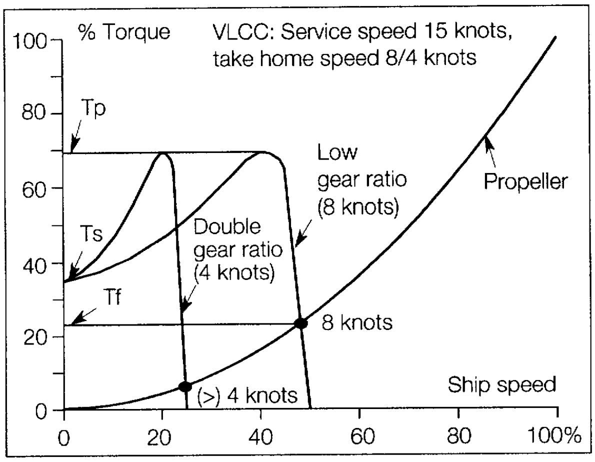

Fig. 19: Torque-speed curve for propeller/electric motor
Tf = Full load torque
Ts= Starting torque
Tp= Pull-out torque

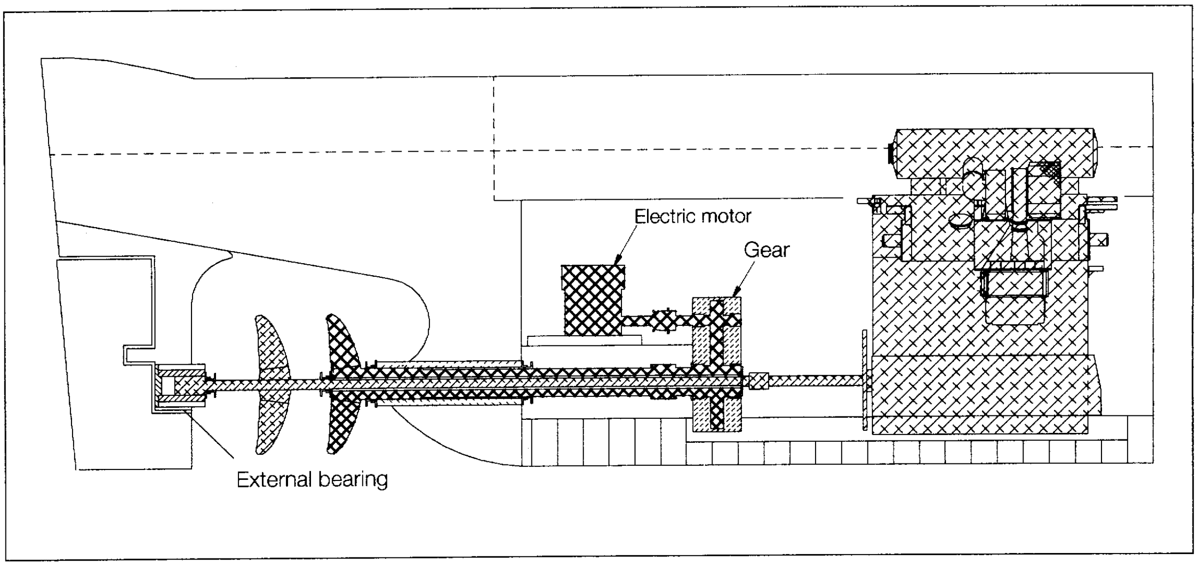

Fig. 20: 1 x low speed main engine with contra rotating propeller. External bearing for inner propeller shaft

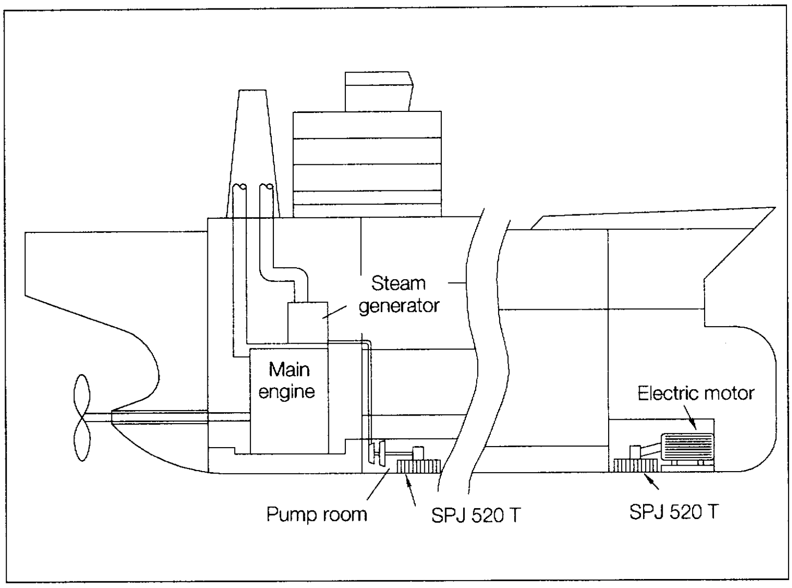

Fig. 21: 1 x low speed main engine,
1 x Schottel pump jet - electrically driven
1 x Schottel pump jet - steam driven

Generally, alternatives 1, 2 and 3 are vulnerable to grounding and collision damage to the stern of the ship. There is also the risk that the two propellers are damaged simultaneously (alternative 1).

A common characteristic of alternatives 2) and 3) is that they add a higher degree of complexity to the primary propulsion systems. This, in itself, involves a higher risk of failure in the total system.

Alternative 1 will, in a large merchant ship with a typical long distance voyage pattern, normally result in higher fuel consumption than in a conventional ship equipped with a low speed main engine and an FP-propeller. This is because of the interaction of a number of different factors like propulsion efficiency (including propeller efficiency), gear efficiency (if installed) and the engine's thermal efficiency. The result will be increased exhaust gas emission.

If the installation of two main engines results in more but smaller cylinder units, it will make greater demands on maintenance and will increase operating costs for manpower as well as spare parts, compared with a single-engine plant.

The twin-engine plant is not redundant in the strictest sense since both engines are employed in daily service and are thus not really stand-by systems. On the other hand, 50% extra power is available for the 'spare propulsion system'. The twin-engine plant requires the installation of CP-propellers for sailing on a single engine. This in itself involves an increased risk of failure.

For purposes of redundancy, such an engine room arrangement would require that all components and systems, including tanks and piping, were duplicated and physically separated by watertight and fireproof bulkheads.

Whether the main engines and the controls and auxiliary systems are duplicated or not, the ship is vulnerable to damage at the stern, since both propellers will very likely be damaged, and since the propulsion sources are close to each other.

Alternative 2 will involve consideration of whether the ship is to be equipped with an FP or CP-propeller. With an FP-propeller, the gear can be designed as a two-speed type for better adaptation to varying hull resistance.

Fig. 19 illustrates the torque-speed curves for a proposed layout of a two-speed tunnel gear driven by an asynchronous electric motor. In calm weather the ship speed will be eight knots whereas in bad weather the propeller torque curve will move upwards in the diagram and the gear is shifted to double ratio leading to a ship speed of four knots at the full load torque of the electric motor. In this way a power margin of a factor of eight compared to calm weather is obtained for propulsion at four knots.

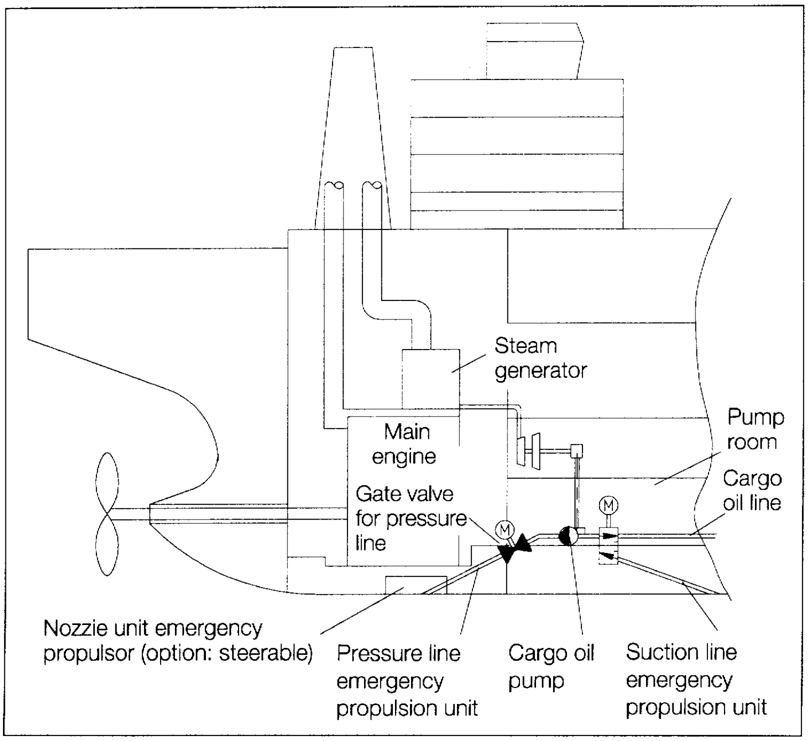

Fig. 22: Schottel pump jet - seawater driven

With a CP-propeller, a single-speed gear can be installed and the propeller pitch can be adjusted in accordance with the actual hull resistance.

The electrical power necessary for operating the spare propulsion system can be provided wholly or partly by the ship's auxiliary engines. For example, a large container ship will normally have sufficient GenSet power installed, while the electrical power production capacity of a VLCC in certain cases will have to be supplemented by the installation of an extra auxiliary engine.

This configuration is vulnerable in the event of damage to the propeller, stern tube and propeller shaft and, as such, is not completely redundant.

Alternative 3 can be designed in such a way that the inner propeller shaft is driven by the main engine and, for reasons of separation, is supported in the rudder horn instead of in the hollow outer propeller shaft, as done previously. The outer propeller shaft is supported in the stern tube and is driven by an electric motor which is powered by the diesel engine generators.

If electrically driven cargo pumps are installed on a VLCC instead of steam driven pumps, the total power installed for propulsion and electricity production may be reduced by about 30% by choosing alternative 3, Ref. [4].

The system is vulnerable in the event of damage to the contra rotating propeller arrangement and is therefore not completely redundant.

Alternative 4 is a truly redundant system, in that none of the components of the spare propulsion system are used in the normal propulsion of the ship. Water pump jets can be installed both fore and aft in the ship, so that the standby propulsion is not vulnerable in the event of damage to a single part of the ship. The power source can either be electrical (GenSets), pressurised steam or pumped water.

An additional benefit is that the water pump jets installed can function as bow and stern thrusters and thus make the installation of such thrusters superfluous.

With alternatives 2 and 4, it should be noted that the standby propulsion system must provide adequate power for controlling the ship in bad weather. This means that drifting of the ship with the wind and waves must be prevented in emergency situations. Typically, this will require some 1,000 to 3,000 kW, depending on the ship type.

Risk assessment

Typically, redundancy is advocated by certain medium speed engine designers to promote their products in the name of increased safety. It is obviously necessary in this context to try to quantify the risk by using different types of prime movers. Such quantification is difficult, but the figures published by insurance companies may prove helpful. In an article written by the Swedish Club ("Main engine damage - what can we learn for costs of USD 55,745,838?"), Ref. [2], the conclusion is clear. Vessels powered by medium speed engines account for the majority of costs due to main engine failure.

For easy reference, the essence of the article is shown in Fig. 23.

Representation in insured ships		Insurance costs
Two-stroke	67.1%	34.4%
Four-stroke	25.9%	56.2%

Fig. 23: Insurance expenses as published by Swedish Club 1995 (Ref. [2])

Considering the figures, medium speed engines account for insurance expenses that are approximately 4.3 times those of low speeds to rectify engine failure when corrected for the number of engines insured.

We are led to believe that the medium speed engines designed today are better than those designed 15 years ago. At least the makers say so; but then, so are low speed engines. Even so, with these figures in mind, redundancy may very well be needed in certain medium speed installations!

We believe in simplicity and reliability and try to observe these basic requirements. Low speed engines are the simplest, the safest and the best choice for containerships, tankers, bulkers, etc. on the high seas, whereas multi-engined medium speed installations are suitable for passenger ships, ferries and very specialised short-sea tonnage. Challenging that by referring to redundancy is basically misleading.

Emission Control

As is well known by now, MC engines can be delivered to comply with the IMO speed-dependent NO_x limit, measured according to the ISO 8178 test cycles E2/E3 for Heavy Duty Diesel Engines.

This is, in general, achieved by means of primary methods. Depending on the engine in question, modifications to injection equipment and/or water emulsification may be applied.

As has been described in other papers, we already have engines in service with NO_x emission levels far below that of IMO, for instance plants with catalysts, both in ships and on land.

Conclusion

The MC programme, now in its 15th year, is stronger than ever, thus being a fully matured engine programme.

Thanks to the upgradings and upratings introduced over the years, as well as the features now available, the MC programme is more attractive than ever.

This can also be attributed to the comprehensiveness of today's programme in terms of different models. The reliability and built-in redundancy leaves nothing to be desired. The "redundancy" advocated by makers who disguise their attempts as a safety crusade to gain market share, is a superfluous cost-adder and of no real interest.

References

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[2] Swedish Club News, No. 2, October 1995.

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[4] The application of counter rotating propellers for the E3 tanker, Howaldtswerke - Deutsche Werft AG, 1995.