Sulzer RT-flex96C into Containership Service*

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Summary

The paper reports primarily on the first Sulzer RT-flex96C electronically-controlled common-rail engines built for large container liners. The first eight- and 12-cylinder engines, of 45,760 and 68,640 kW output respectively, entered service in November and December 2004, and are the most powerful common-rail diesel engines so far built for any application.

Developed by Wärtsilä Corporation, the Sulzer RT-flex96C engine is proving popular for the new generation of large container liners currently being built.

The paper also reports on the service experience with Sulzer RTA96C engines, and the various design improvements made for easier manufacture, and even better piston-running behaviour. The electronically-controlled common-rail systems of the RT-flex engines make the engines much more flexible. Lower BSFC at normal service powers is already being obtained by adapted tuning.

The power available from RTA96C and RT-flex96C engines and their operating economy can also be significantly improved by the newly-developed Total Heat Recovery System.

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* This is a revised version of the paper presented at The Motor Ship Marine Propulsion Conference, Bilbao, January 2005.

Fig. 1: The 3700 TEU container ship Lars Mærsk *powered by a Sulzer 8RT-flex96C engine of 45,760 kW is seen here nearing completion at Odense Steel Shipyard A/S in Lindø, Denmark.*
[04#130]

Fig. 2: The 8450 TEU container ship P&O Nedlloyd Mondriaan *arriving in Southanpton in January 2005 on her maiden voyage from East Asia. Built for Reederei Blue Star GmbH by IHI Marine United Inc in Japan, the ship is propelled by the first Sulzer 12-cylinder RT-flex96C engine which, with a power of 68,640 kW, is the most powerful common-rail engine in the world. [05#014]*

Introduction

Sulzer RT-flex common-rail engines are becoming a major success. An increasing number are coming into service, and they are confirming that the new, electronically-controlled common-rail technology is today a most worthwhile step forward in low-speed engine development for ship propulsion.

At the end of December 2004, a total of 132 RT-flex engines were on order or had already been delivered, with an aggregate power of some 5832 MW. Of these 14 were already in normal commercial service with the first having already completed some three-and-a-half years' operation (Table 1). Orders have been received for all engine types currently offered.

The most recent, major landmarks have been the deliveries of the first ships with Sulzer RT-flex96C engines which are the most powerful common-rail diesel engines in the world. The 3700 TEU container ships *Lars Mærsk* and *Safmarine Nomazwe*, both with 45,760 kW eight-cylinder RT-flex96C engines, were delivered in November and December 2004 respectively from Odense Steel Shipyard A/S in Lindø, Denmark, to the Danish group A.P. Møller-Mærsk. The *P&O Nedlloyd Mondriaan* entered service in December powered by a 68,640 kW 12-cylinder engine. The *P&O Nedlloyd Mondriaan* is the first in a series of eight 8450 TEU container ships being built at I.H.I. Marine United Inc. in Japan for Reederei Blue Star GmbH in Germany for charter to P&O Nedlloyd BV.

The delivery of ships with RT-flex96C engines is the culmination of a project which began in 1993 to develop a common-rail fuel injection system for Sulzer low-speed marine engines, though electronically-controlled low-speed engines had been under development in Winterthur since 1981.

The successful introduction of Sulzer RT-flex engines has certainly demonstrated that common-rail fuel injection technology is not just something for what we in the marine industry regard as 'small engines' for cars, trucks, buses and rail traction, as well as the corresponding engines in marine propulsion.

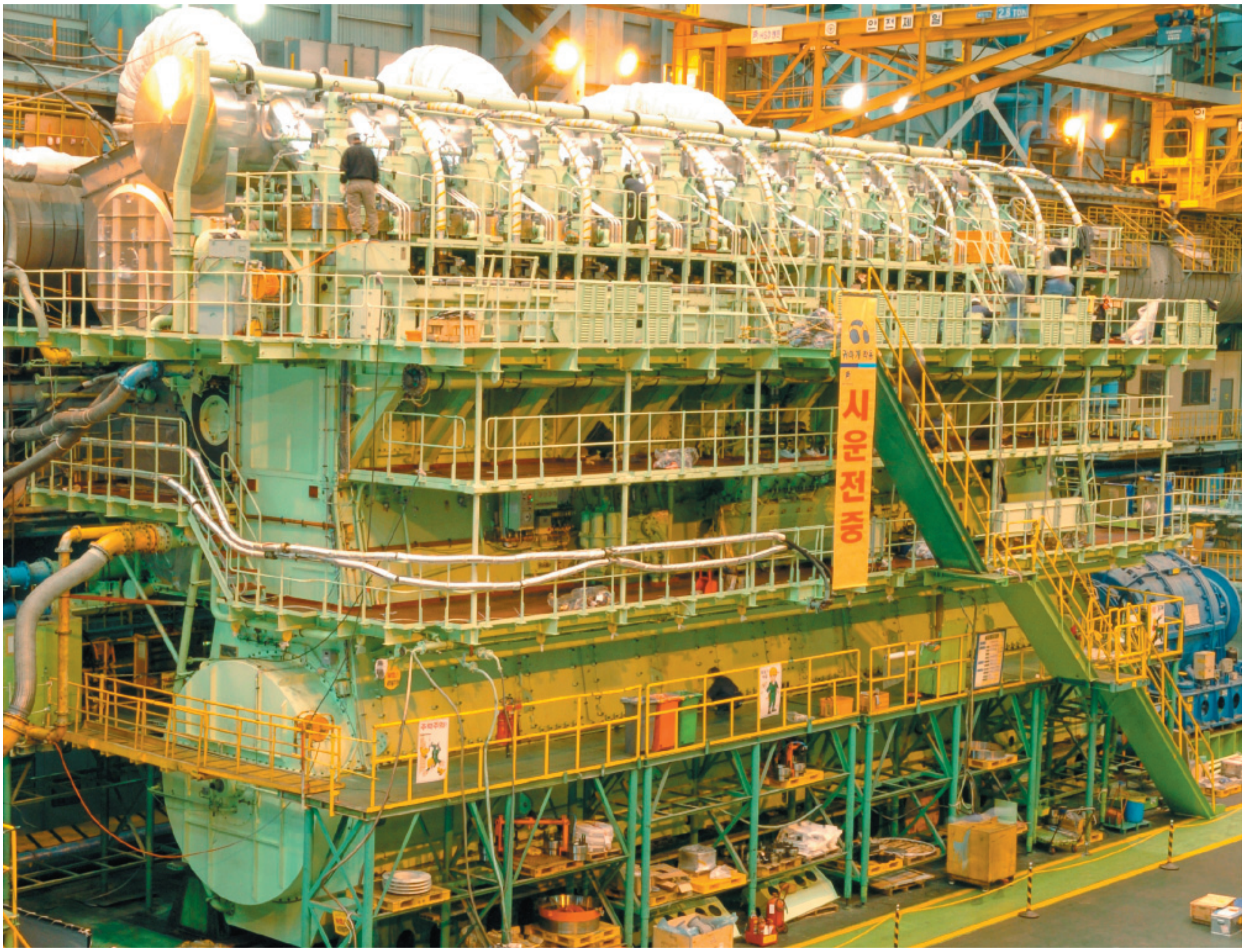
Furthermore RT-flex electronically-controlled common-rail engines developed by Wärtsilä Corporation are not being restricted to a few isolated ship types. They are proving to be suitable for almost any ocean-going ship type. Although the majority are being installed in container ships, they are also being used in quite a variety of ship types, including tankers, bulk carriers, reefers and multi-purpose carriers.

The great virtue of the RT-flex concept has clearly been the complete flexibility in engine setting given by the electronically-controlled common-rail systems. It is thus a tremendous progress from the fixed timing of the traditional camshaft.

Table 1: The first ships powered by Sulzer RT-flex electronically-controlled common-rail engines.

Ship	Size	Type	Engine	Date into service
Gypsum Centennial	47,950tdw	bulk carrier	6RT-flex58T-B	September 2001
Sea Lady	105,400tdw	tanker	6RT-flex58T-B	August 2003
Wladyslaw Orkan	30,000tdw	multi-purpose carrier	7RT-flex60C	November 2003
Carmel Ecofresh	13,200tdw	reefer	7RT-flex60C	November 2003
Chipolbrok Sun	30,000tdw	multi-purpose carrier	7RT-flex60C	February 2004
Carmel Bio-Top	13,200tdw	reefer	7RT-flex60C	April 2004
Chipolbrok Moon	30,000tdw	multi-purpose carrier	7RT-flex60C	April 2004
Safmarine Cameroun	2100TEU	container ship	9RT-flex60C	May 2004
Safmarine Nimba	2100TEU	container ship	9RT-flex60C	August 2004
Safmarine Kuramo	2100TEU	container ship	9RT-flex60C	November 2004
Lars Mærsk	3700TEU	container ship	8RT-flex96C	November 2004
Leopold Staff	30,000tdw	multi-purpose carrier	7RT-flex60C	November 2004
P&O Nedlloyd Mondriaan	8450TEU	container ship	12RT-flex96C	December 2004
Safmarine Nomazwe	3700TEU	container ship	8RT-flex96C	December 2004

Fig. 3: Another Sulzer12RT-flex96C engine being erected in Korea. The supply unit is at the middle of the engine and the rail unit is just below cylinder-top level.
[05#008]



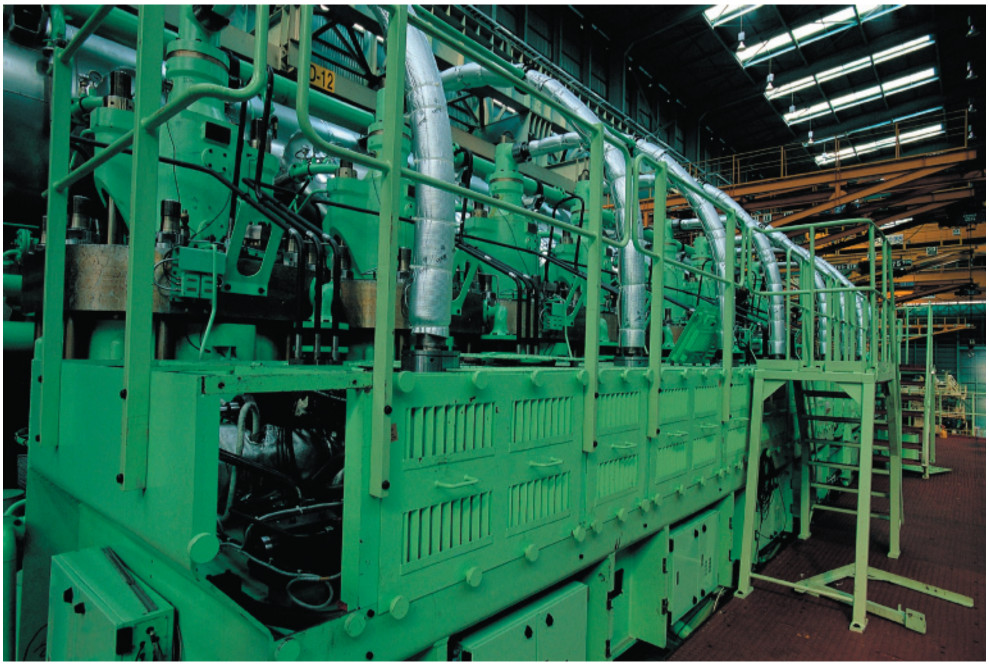


Fig. 4: Cylinder tops and rail unit of a Sulzer 8RT-flex96C engine with the electronic control units mounted on the front beneath the rail unit [04#034]

The RT-flex System

There are four common-rail systems on RT-flex engines: for heated fuel oil (nominally 1000 bar) ready for injection, control oil at a constant pressure of 200 bar, servo oil at pressures up to 200 bar, and engine starting air. Fuel oil and servo oil are delivered by a gear-driven supply unit (Fig. 5) mounted on the engine side, at the driving end for engines with up to seven cylinders and at a mid gear drive for greater cylinder numbers. The fuel supply pumps are at one side of the drive gear with the hydraulic servo-oil pumps on the other side. The numbers, size and arrangement of pumps are adapted to the engine type and cylinder number.

Control oil is delivered by duplicated motor-driven pumps (Fig. 6). Both servo and control oil are drawn from the engine lubricating oil system through an automatic self-cleaning fine filter.

The supply unit delivers to the common rails arranged in the rail unit mounted along the side of the cylinder covers (Fig. 4). A single rail unit is used for up to seven cylinders, with two units for engines with more cylinders. The RT-flex control system is arranged in a number of control units mounted on the outside of the rail unit.

Fuel rail pressure is regulated according to engine needs by suction control of the fuel supply pumps with helix-controlled filling volume regulation. Fuel is delivered from the fuel rail through a separate injection control unit for each engine cylinder (Fig. 7) to the standard fuel injection

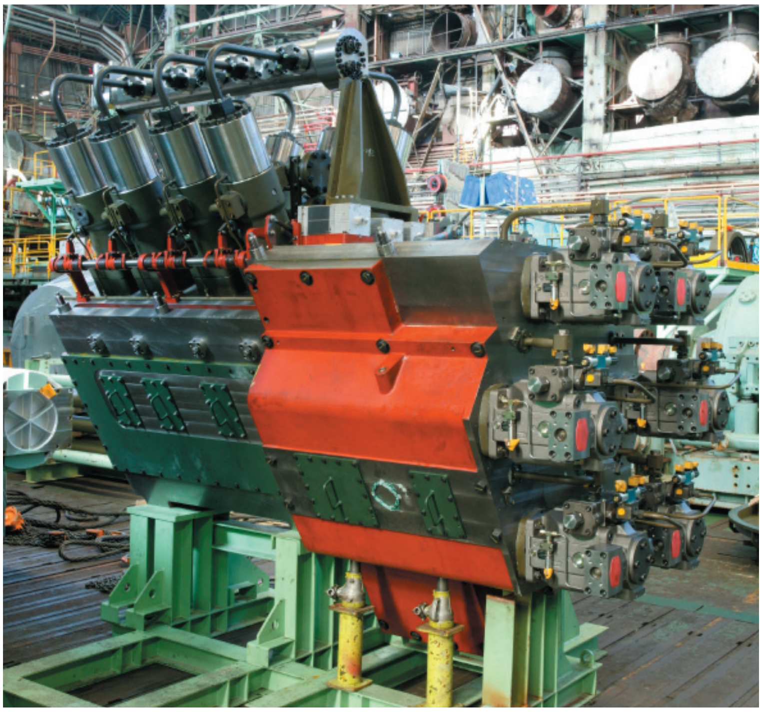


Fig. 5: Supply unit for a 12RT-flex96C engine with the fuel pumps in Vee-form arrangement on the left and servo oil pumps on the right of the central gear drive. [04#074]

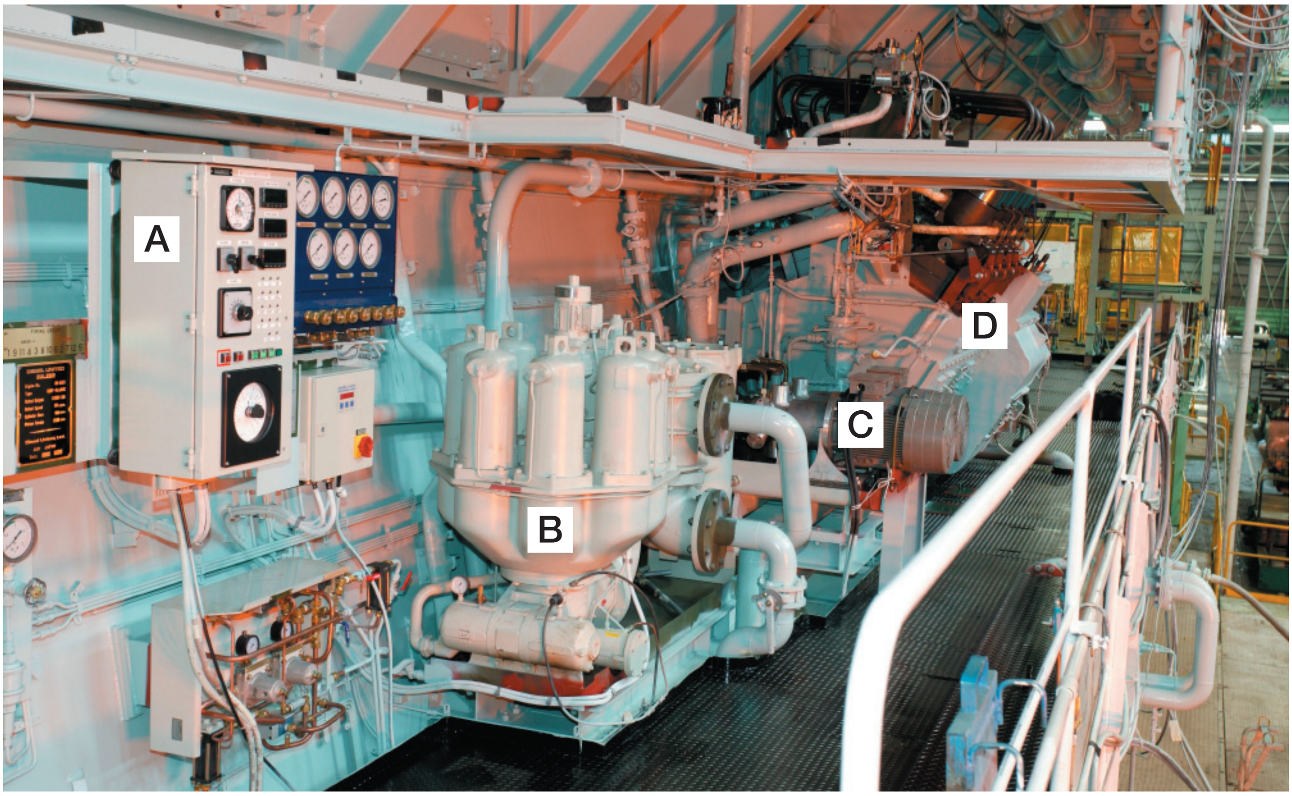


Fig. 6: Various RT-flex equipment on the half-platform of a 12RT-flex96C engine. From left to right, these include (A) the local engine control panel, (B) the automatic fine filter for servo and control oil, (C) the two electrically-driven control oil pumps and (D) the supply unit.
[04#113]

valves which are hydraulically operated by the high-pressure fuel oil. The injection control units, using quick-acting rail valves, regulate the timing of fuel injection, control the volume of fuel injected, and set the shape of the injection pattern.

The three fuel injection valves in each cylinder cover are separately controlled so that they may be programmed to operate separately or in unison as necessary. The possibility of separate operation of the multiple fuel injection valves in an engine cylinder is a unique feature of Sulzer RT-flex engines.

The common-rail system is purpose-built for operation on just the same grades of heavy fuel oil, namely up to 730 cSt viscosity, as are already standard for conventional engines, thus making it possible to combine the use of low-cost standard fuel with the advantages of the most

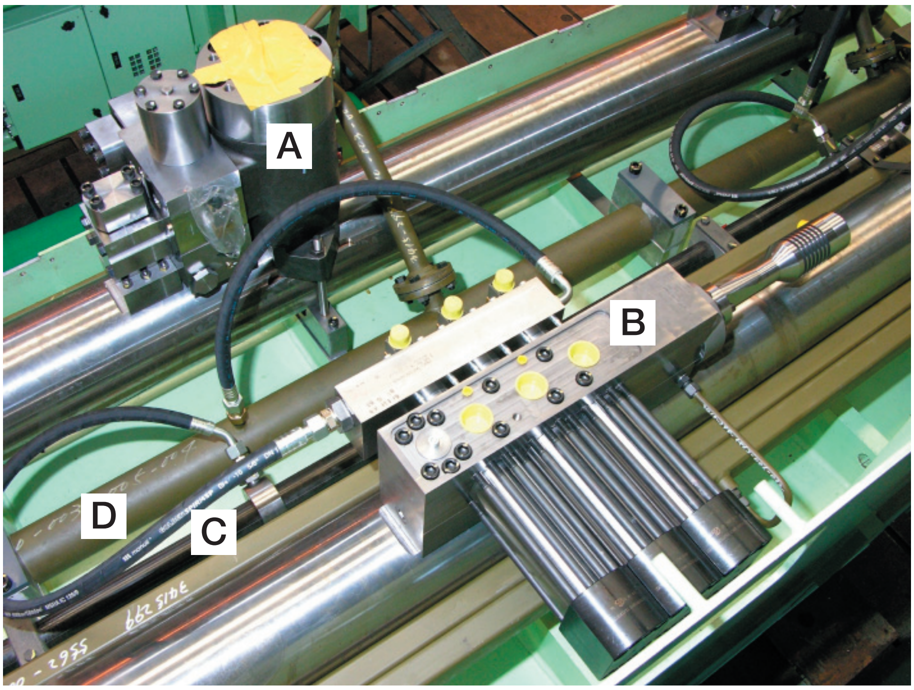


Fig. 7: Inside the rail unit of an RT-flex96C engine during assembly. The exhaust valve actuator (A) is mounted on the servo oil rail and the injection control unit (B) is on the fuel rail. Next to the fuel rail is the smaller control oil rail (C) and the return pipe for servo and control oil (D).
[04#114]

advanced electronically-controlled common-rail injection.

Exhaust valves are operated by a hydraulic 'push rod' as in RTA engines but the actuating energy now comes from the servo oil. There is thus complete flexibility in the timing and operation of the exhaust valves.

One of the features of the RT-flex common rail system is that the hardware is made in several Sizes, each of which can be applied to multiple engine types. Thus Size I systems are employed in RT-flex58T-B and RT-flex60C engines, and Size IV in RT-flex96C and RT-flex84T-D engines. This standardisation gives benefits in development time, manufacturing, and spare parts.

For the larger, RT-flex Size IV common-rail system in the RT-flex96C engines various design improvements were made, not just to suit the larger capacity required but also to facilitate manufacture. For example, single-piece rail pipes are used for fuel and servo oil.

RT-flex Benefits

The principal benefits of Sulzer RT-flex engines with their electronically-controlled common-rail systems are:

- Smokeless operation at all running speeds
- Very low, stable running speeds at 10% nominal speed
- Reduced part-load fuel consumption
- Easy engine setting for less maintenance
- Longer times between overhauls (TBO) expected, primarily through better load balance between cylinders and cleaner combustion at all loads.

Most of the benefits of the RT-flex system stem from the complete flexibility in engine setting possible with electronically-controlled common-rail systems. This can be illustrated in discussion of some of the quoted benefits.

It has become clear from the development of Sulzer RT-flex engines that common-rail technology has opened up a completely new era in the development of low-speed marine engines. The benefits of the flexibility in engine setting given by common-rail technology are certainly applicable to any ship type. They offer interesting ship power solutions for both today's and future ship needs.

Smokeless operation

Smokeless operation is a visible benefit of the flexible engine setting in RT-flex engines. Smokeless operation at all running speeds is achieved by maintaining the fuel injection pressure at the optimum level right across the engine speed range. In addition, selective shut-off of single injectors and an optimised exhaust valve timing help to keep smoke emissions below the visible limit at very low speeds. The selective shut off of injectors gives more balanced engine operation than cutting out whole cylinders as required by systems with individual fuel injection pumps.

The superior combustion performance indicated by smokeless operation also results in a cleaner engine with both less deposits of combustion residues inside and less fouling of exhaust-gas economisers.

The precision and flexibility in engine setting given by the RT-flex system also facilitates compliance with the NO_X regulation of Annex VI of the MARPOL 73/78 convention.

Flexible engine setting will allow further reduction in NO_X emissions. Selective injection patterns are expected to give an option of about 20 per cent lower NO_X emissions for times when lower NO_X emissions are required by local regulation. The lower NO_X emissions will incur a small increase in fuel consumption though greater fuel economy will be possible when operating elsewhere on the world's seas.

Steady, slow running

Common-rail injection also makes it possible for RT-flex engines to run steadily at very low speeds without smoke. Generally they are able to run steadily down to about ten per cent nominal speed. However, it was found possible for the first 12-cylinder RT-flex96C to run at just seven revolutions per minute owing to the high cylinder number. Such slow running is made achieved by the engines' precise control of injection, together with the use of higher injection pressures at low speed, while smokeless operation is ensured by also cutting out injectors at the very low speeds.

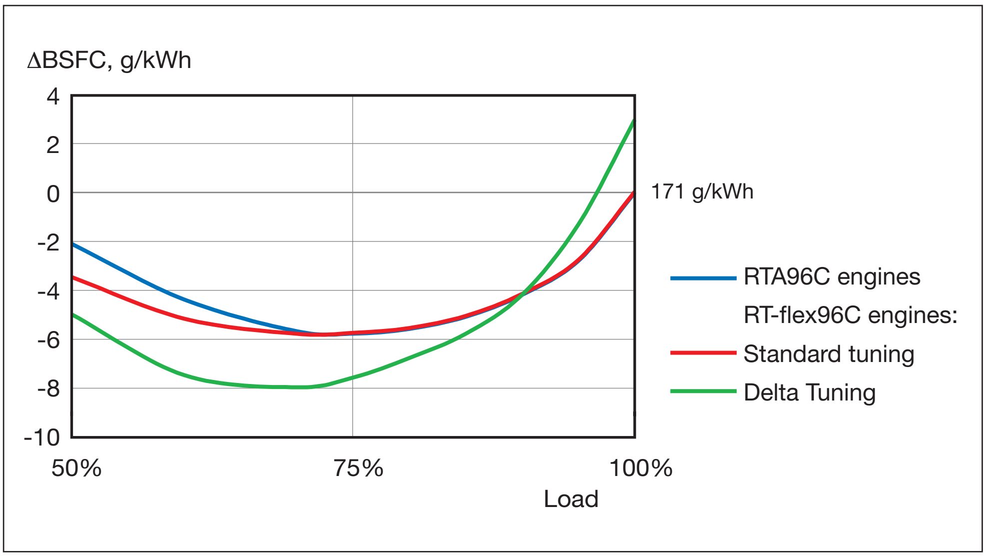


Fig. 8: The new alternative BSFC curve for Sulzer RT-flex96C engines given by Delta Tuning compared with the original BSFC curves. All curves shown are for engines complying with the IMO NO_X regulation. [04#102]

Lower fuel consumption

Advantage has been taken of the flexibility of engine setting with RT-flex engines to provide an alternative fuel consumption curve as standard to give lower BSFC (brake specific fuel consumption) in what is for many ships the main operating range (Fig. 8). With both BSFC curves, the engines comply with the NO_X regulation of Annex VI of the MARPOL 73/78 convention.

The BSFC is lowered in the mid- and low-load operating range by applying Delta Tuning. The consequent increase in NO_X in that operating range is compensated by reducing NO_X emissions in the high-load range. Delta Tuning was first applied to a series-built engine in the first RT-flex96C engine which was shop tested in April 2004. The results were most satisfactory. It was anticipated that the BSFC in the mid-load range could be reduced by some 2 g/kWh though this reduction varies between engine types. The BSFC measured during the shop testing of the 8RT-flex96C engine was, however, slightly better than expected.

Improved heat recovery

Flexible engine setting also has benefits for waste heat recovery. At very low engine loads exhaust gas temperatures usually fall below the critical temperature for sulphur corrosion in the exhaust-gas economiser. In RT-flex engines, however, the exhaust valve timing can be changed at very low engine loads to keep the exhaust valve temperature after the turbocharger above 150°C thereby avoiding the possibility of sulphur corrosion.

This is of special interest for the total heat recovery concept described below.

Service Experience

A total of 14 Sulzer RT-flex engines are now in service (see Table 1). The first is a 6RT-flex58T-B in the bulk carrier *Gypsum Centennial*, since September 2001 (Fig. 9). The tenth RT-flex delivered is a nine-cylinder RT-flex60C engine in the 2100 TEU container ship *Safmarine Kuramo* built at Volkswerft GmbH in Germany. It has an MCR output of 21,240 kW at 114 rev/min.

The first of the largest RT-flex engine type, an eight-cylinder RT-flex96C engine of 45,760 kW, went on sea trials at the end of October in the 3700 TEU container ship *Lars Mærsk* built at Odense Steel Shipyard A/S in Lindø, Denmark, for the Danish group A.P. Møller-Maersk. The most powerful electronically-controlled common rail engine, however, is the 12-cylinder RT-flex 96C engine of 68,640 kW and the first is installed in the *P&O Nedlloyd Mondriaan* and entered service in December 2004. This is the leadship in a series of eight 8450 TEU container ships being built at I.H.I. Marine United Inc. in Japan for Reederei Blue Star in Germany for charter to P&O Nedlloyd BV.

Although there are, as yet, only limited running hours with these large RT-flex96C engines, a good number of running hours has already been reached with the earlier RT-flex engines of the RT-flex58T-B and RT-flex60C types. By the end of 2004, the first 11 engines of these types had together accumulated well over 60,000 running hours. In general, their service experience has been very satisfactory. The RT-flex concept has proven its value and its practicality. As might be expected with new technology, there was a number of 'teething' problems with the first RT-flex engine in the bulk carrier *Gypsum Centennial*

Fig. 9: The 47,950tdw self-unloading bulk carrier Gypsum Centennial *of Gypsum Transportation Ltd powered by the first Sulzer RT-flex common-rail engine.*
[04#117]

during the first few months of operation but they were soon resolved. They have already been reported.

The 6RT-flex58T-B engine of the *Gypsum Centennial* has more than 18,000 running hours since entering service in September 2001. The engine was inspected thoroughly during the summer 2004 at 15,330 running hours. The complete RT-flex system was found to be in excellent condition with no problems.

It was noticeable that all the equipment for pumping, regulating and metering the heavy fuel oil or servo oil have had no difficulties with wear.

Similar experience has been obtained with other engines of the RT-flex58T-B and RT-flex60C types. The following engines naturally benefited from the lessons learned on board the *Gypsum Centennial* and generally had far fewer 'teething' problems. Although difficulties arose through improper installation and adjustment, these have also become less frequent as experience has been gained. In addition, where there have been cases of sensor failures, the problem has been solved by changing to sensors of higher specification.

There has been a single case of excessive wear in the common-rail fuel injection system of an RT-flex engine but that was caused by completely inadequate fuel treatment. The increased wear caused delayed injection and, in time, increased cylinder liner wear. Yet RT-flex engines are purpose-built for operation on just the same grades of heavy fuel oil, namely up to 730 cSt viscosity, as are already standard for conventional low-speed two-stroke engines and with just the same standard of fuel treatment. Experience on all the other ships with RT-flex engines has shown that, with normal fuel treatment, there is effectively no wear in the RT-flex fuel system.

The three RT-flex96C engines now in service have not yet accumulated sufficient running hours to enable comment to be made on the engines' behaviour. Although these are early days with these large-bore engines, their running behaviour is promising. There are a few 'teething' problems and once these are cured the engines are expected to give just the same high-standard of service as conventional engines.

Sulzer RT-flex96C – The Basic Engine

Although new electronically-controlled engine systems bring new, worthwhile benefits, engine reliability and durability over a long life which can extend to 30 years largely depend upon the basic engine itself.

Yet the RT-flex96C has a solid basis, being developed from the well-proven Sulzer RTA96C engine type. At the end of 2004, there were 165 RTA96C engines in service and on order, with an aggregate power of 9.43 million kW. Of these, there are at least 107 RTA96C engines in service with combined running hours of well over 1.5 million hours. They include all cylinder numbers from seven to 12, with the majority being ten- and 12-cylinder engines.

In general, the majority of these RTA96C engines are giving fairly satisfactory service.

For example, critical attention to piston-running behaviour has proven to be essential for engine reliability and long times between overhauls. In this respect the TriboPack technology, introduced by Wärtsilä in 1999 and now standard for all Sulzer low-speed engines built today, has given considerable benefit.

TriboPack technology involves a set of co-ordinated design measures which cover all aspects of the interaction between piston, piston rings and cylinder liner. It combines full, deep honing of the cylinder liner, optimised liner temperatures, anti-polishing ring, chromium-ceramic coating on the top piston ring, all piston rings pre-profiled, increased thickness of chromium layer in the piston ring grooves and multi-level cylinder lubrication.

Although individual TriboPack design measures have been employed in Sulzer RTA engines with good effect, it has been proven in service that only the complete package brings the full benefits. It is expected that this approach will enable times between overhauls to be extended to at least three years. More immediately, these design measures have resulted in cylinder liner wear rates of generally less than 0.04 mm/1000 hours while using cylinder lubricating oil feed rates of 1.0–1.4 g/kWh (0.7–1.0 g/bhph).

The lower wear rates have also allowed engine running costs to be substantially reduced by enabling lower cylinder oil feed rates without any increase in liner replacement costs.

Lower cylinder lubricating oil guide feed rates

Accordingly the guide feed rates for cylinder lubricating oil have been reduced for engines built to the TriboPack standard. The guide feed rate for engines without TriboPack is less than 1.4 g/kWh (1.0 g/bhph). This is reduced for engines built to the TriboPack standard to 1.1 g/kWh (0.8 g/bhph).

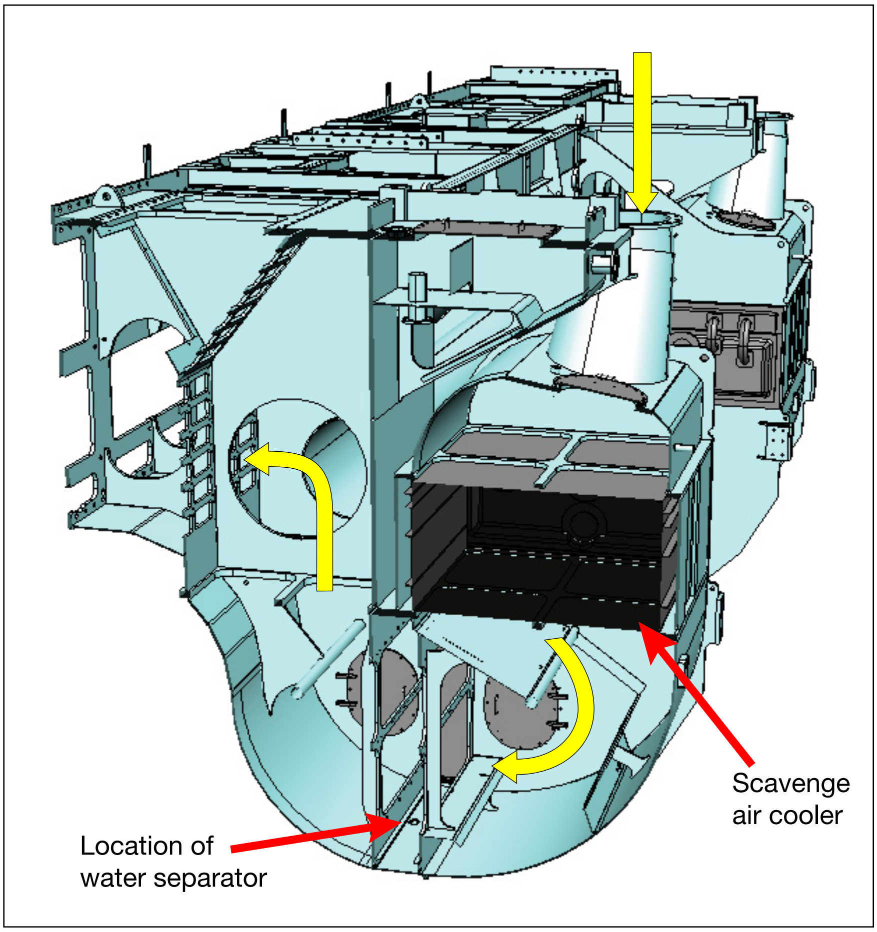
The cylinder oil feed rate can be reduced further to 0.9 g/kWh (0.7 g/bhph) after analysis of engine performance by a Wärtsilä service engineer who would then guide the step-by-step reduction in feed rate to this lower level.

This service experience is fully supported by engine tests at feed rates down to 0.8 g/kWh (0.6 g/bhph) without any problems. Both in-service and test results were obtained with the cylinder lubrication provided by the Sulzer load-dependent accumulator system which has been used for some 30 years. This load-dependent accumulator system gives a fairly flat specific feed rate over load in the range of 20–100 per cent load.

It should be noted that with the TriboPack standard, liner surface temperatures are mainly kept above the dew point so that the engines are fairly insensitive to fuel sulphur content. The above-mentioned guide feed rates are applicable to all fuel sulphur contents above 1.5 per cent. With TriboPack, there is no need to increase feed rates according to fuel sulphur content. Thus the quoted guide feed rates for Sulzer engines are highly competitive.

Nevertheless there are still cases of unsatisfactory piston-running performance. There was a problem with the quality of chromium-ceramic coated piston rings but it has already been corrected. There have also been problems caused by excessive condensed water carryover from the water separator after the scavenge air cooler. Improvements

Fig. 10: Cutaway view of the new underslung air receiver for RTA96C and RT-flex96C engines. Scavenge air (yellow arrows) from the turbochargers comes down the cylindrical duct on the right, through the horizontal air cooler, 180° round through the vertically-mounted water separator and exiting left to the engine cylinders. [04#138]



have been introduced in RTA96C engines to improve the removal of condensed water from the scavenge air flow: retrofit water separators with greater efficiency, improved sealing around the water separators and a more efficient drain system. Ships' engineers can also mitigate the problem by ensuring that the condensed water drain is clear and that the scavenge air cooler temperatures are suitable adjusted.

Additional design improvements

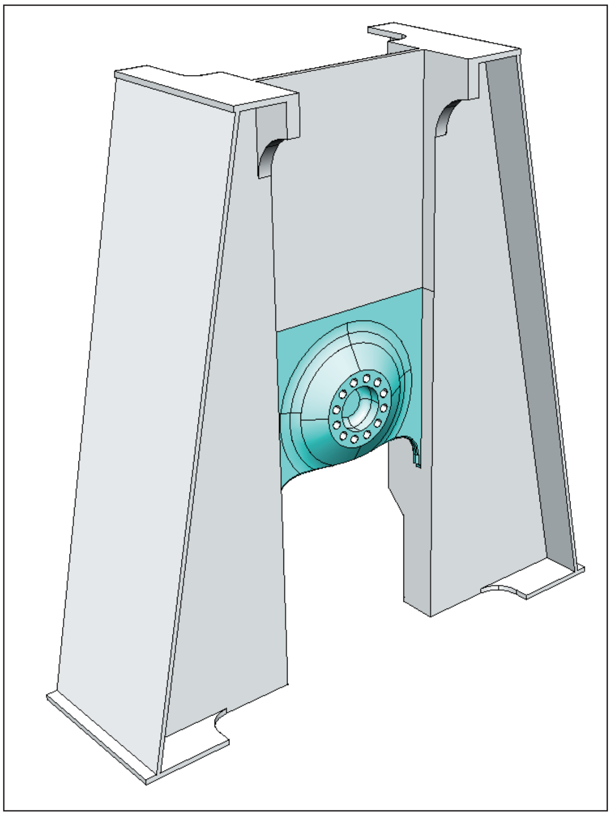
The margin for the performance of condensed water separation was most recently improved by introduction of an underslung air receiver for RTA96C and RT-flex96C engines (Fig. 10). In this major design modification, the scavenge air coolers are arranged horizontally beneath the turbochargers. The scavenge air is then swung round 180 degrees to the engine cylinders, in the process passing through the vertically arranged water separators.

The new, underslung receiver is of a simplified welded construction designed for easy assembly. The galleries are arranged for to facilitate cooler dismantling, while the cooler arrangement caters for easy and efficient cleaning of the cooler.

At the same time, the opportunity was taken while adapting the engine structure to the RT-flex system, to introduce certain modifications for better manufacture:

- The gear column is now of a single-walled design which has better access for welding and gives improved support to the gear wheels (Fig. 11).

Fig. 11 below: The revised design of gear column for RTA96C and RT-flex96C engines. [04#141]



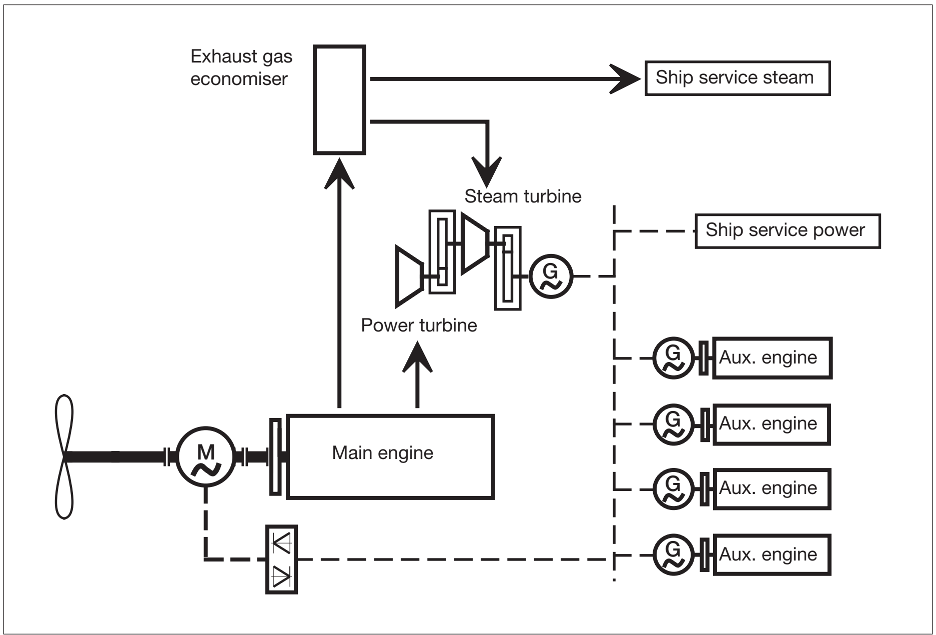


Fig. 12: Schematic of the Total Heat Recovery Plant for Sulzer RTA96C and RT-flex96C engines. [04#040]

- Plate thicknesses have been increased throughout the column.
- The newly-designed supports for fuel pumps in the RTA96C and for the supply unit in the RT-flex96C now benefit from a greater stiffness, elimination of stress concentrations, smooth transitions and better access to welding seams. Additionally all internal ribs in the column could be eliminated.

A new main bearing design has been successfully introduced and is giving good results in service. It continues to have thick shells with thick white metal running layers. However, a key/slot arrangement is employed for accurate location of the lower bearing shell with the bearing cover. Bearing clearances have been optimised. The geometry of the bearing is improved by a chamfer at the butt ends of the upper half bearing, and back relief of the lower shell at the fore and aft edges.

Test Results

The first RT-flex96C, an eight-cylinder engine, completed its factory acceptance test on 9 April 2004 at the works of Wärtsilä's licensee HSD Engine Co Ltd in Korea. The first 12-cylinder RT-flex96C engine followed suit on 7 June 2004 at the works of a Japanese licensee Diesel United Ltd.

Both series of tests were completed successfully. In each case, after the initial adjustments and running-in, the engines were subjected to extensive series of tests. Optimisation of the Sulzer RT-flex system with this size of engine was completed with the eight-cylinder RT-flex96C before the usual engine performance tests but additional tests were made with the 12-cylinder engine into various aspects of the engine performance with common-rail systems. Throughout the tests, both engines ran extremely satisfactorily, without any difficulties. Their performance fully met expectations.

The above-mentioned eight-cylinder RT-flex96C was the first series-built engine to employ Delta Tuning. The expected reduced fuel consumption levels were readily achieved. In fact, the measured BSFC values in the upper region were noticeably lower than the calculated values.

One of the benefits of the RT-flex system is that it has allowed very precise engine setting. The engines could therefore be readily adjusted to comply with the NO_X emission limit of the MARPOL 73/78 convention. The 12RT-flex96C engine was set for a weighted-average NO_X emission level of 16 g/kWh.

The shop tests with these two engines also included extensive stress measurements to confirm the calculated values with the various structural improvements.

With regard to the RT-flex system, the engines demonstrated that smoke emissions were considerably reduced, being below the visibility limit even at very low speeds. For all practical purposes, the engines can be regarded smokeless but, with the very large diameter of the exhaust uptake of this size of engines, this will always be a matter for subjective judgement.

Slow running was taken to a new 'low' during the testing of the 12-cylinder engine. Owing to its number of cylinders, it could run steadily at about 7 rev/min.

Heat Recovery for Economy and Less Emissions

Wärtsilä has developed a Total Heat Recovery Plant for Sulzer low-speed engines which provides a greater energy recovery as electrical power for additional ship propulsion and shipboard services (Fig. 12). The plant can be employed to gain benefits in terms of better fuel economy, reduced exhaust emissions or increased propulsion power.

In this concept, exhaust gas energy across the load range is increased by using a different turbocharger matching when engine air is drawn from the ambient air instead of from the engine-room. Usually marine engines are designed for intake temperatures of up to 45°C for tropical conditions with turbochargers drawing intake air from the engine room. If instead the intake air is drawn from outside the engine room thorough an air intake duct, the maximum intake temperature can be assumed to be no more than 35°C.

The lower air intake temperature allows the turbochargers to be rematched to return the thermal load of the engine back down to what prevails for the intake temperature at 45°C. The thermal load of the adapted engine will then be no greater than that of the usual engine so as not to jeopardise engine reliability.

The rematched turbochargers allow more exhaust gas to be branched off compared with the conventional tuning. Therefore the rematched system gives both an increased exhaust gas temperature for an exhaust gas economiser and an increased branched-off exhaust flow for an exhaust gas power turbine.

Exhaust energy can thus be recovered and applied in both a steam turbine and exhaust-gas power turbine to generate electrical power, equivalent to 11 per cent of engine power. The electrical power can be employed either in a shaft motor/generator or in supplying shipboard services. The generated power can thus contribute significant savings in both fuel costs and exhaust emissions (CO_2, NO_X, SO_X, etc.). The payback time would depend upon the installation design and its operating costs, but would be expected to be less than five years.

The Total Heat Recovery Plant also offers an attractive possibility for powering the larger container ships which need more propulsion power than is available from the 14-cylinder Sulzer RT-flex96C engine. The standard engine gives an MCR power of 80,080 kW, thereby having a continuous service output (85 per cent load) of 68,068 kW. At this engine rating, the Total Heat Recovery Plant would contribute a shaft power of 7390 kW. The combined service power for propulsion would therefore be 75,458 kW, equivalent to an engine MCR power of 88,770 kW for a plant without heat recovery.

Thus a single Sulzer 14RT-flex96C engine with a Total Heat Recovery Plant would be sufficient for the propulsion of single-screw container ships up to 12,000 TEU capacity. It thereby allows these larger ships to be powered by engines of well-established, proven design.

Conclusion

The Sulzer RT-flex96C combines the benefits of a proven, reliable engine with the completely flexible RT-flex common-rail system to give an optimum engine for containership propulsion both today and for the future. The RT-flex system also has the potential for adaptation to future needs.

At the same time, the Total Heat Recovery Plant extends the power of the 14-cylinder RT-flex96C engine to cater for larger sizes of container ships, allowing the same engine type to be applied to a greater number of ships.

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Most of the above technical papers and articles are available, with other information about Sulzer RTA and RT-flex engines, on the website *www.wartsila.com*.

Published February 2005 by:
Wärtsilä Switzerland Ltd
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