The Sulzer RT-flex Common-Rail System Described

Summary

This paper provides a description of the Sulzer RT-flex electronically-controlled common-rail system embodied in Sulzer RT-flex low-speed marine engines. It covers the main elements of the RT-flex system – the supply unit, rail unit and electronic control system. The system's benefits are reviewed, together with its reliability and built-in redundancy. It also provides a reference to the RT-flex chronology leading up to the 12RT-flex96C – the world's most powerful common-rail engine.

Contents

Introduction

Although common-rail fuel injection is certainly not a new idea, it has only become truly practical in recent years through the use of fully-integrated electronic control based on high-performance computers which allow the best use to be made of the flexibility possible with common-rail injection.

The traditional camshaft has the considerable limitation of fixed timing given mechanically by the cams. Although Sulzer low-speed engines have long had the benefits of double valve-controlled fuel injection pumps with variable injection timing (VIT), and a degree of variable exhaust valve timing being achieved hydraulically in the VEC system, the variation in timing so obtained has been very limited.

Instead electronically-controlled common-rail systems have been adopted in the new Sulzer RT-flex engines to give complete control of the timing, rate and pressure of fuel injection and the exhaust valve operation, allowing patterns of operation which cannot be achieved by purely mechanical systems.

Rather than 'electronically controlled', it would be more accurate to describe Sulzer RT-flex engines as being computer controlled. This is because in the RT-flex system, engine functions are fully programmable, perhaps limited only by the designers' imagination and the laws of nature. The challenge is to use this freedom to create practical benefits for engine users.

The common-rail concept was adopted also because it has the advantage that the functions of pumping and injection control are separated. This allows a straightforward approach to the mechanical and hydraulic aspects of the design, with a steady generation of fuel oil supply at the desired pressure ready for injection. The common-rail concept also has the unique advantage that it allows the fuel injection valves to be individually controlled. Usually there are three fuel injection valves in each cylinder cover, and in the Sulzer RT-flex engines they are operated mostly in unison but under certain circumstances they are operated separately for optimum combustion performance.

The common-rail concept thus provides an ideal basis for the application of a fully-integrated electronic control. The combined flexibilities of common rail and electronic control provide improved low-speed operation, engine acceleration, balance between cylinders, load control, and longer times between overhauls. They also ensure better combustion at all operating speeds and loads, giving benefits in lower fuel consumption, lower exhaust emissions in terms of both smokeless operation at all operating speeds and less NO_X emissions, and also a cleaner engine internally with less deposits of combustion residues. Engine diagnostics are built into the system, improving engine monitoring, reliability and availability.

As the common-rail system is built specifically for

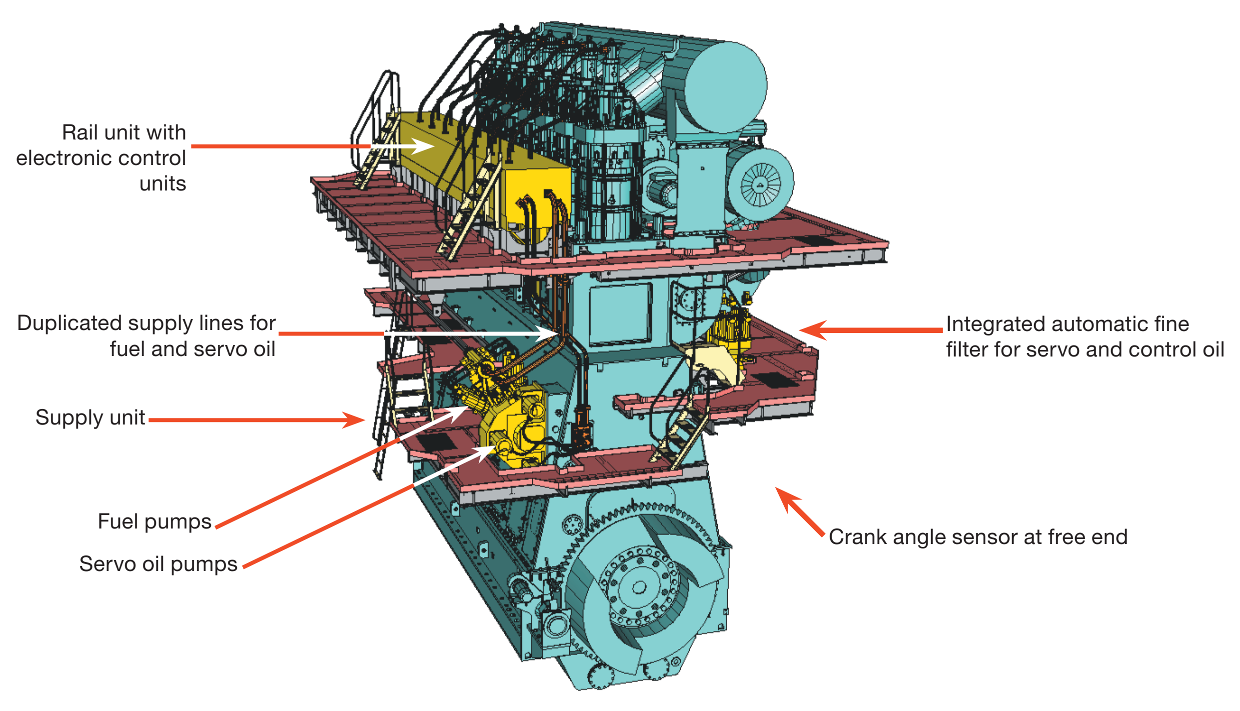


Fig. 1: Principal elements of the common-rail system on a Sulzer RT-flex engine. Note that there are variations on this arrangement in the various RT-flex engine types depending upon the engine type and number of cylinders. [02#072]

reliable operation on heavy fuel oil, it detracts nothing from the well-established economy of low-speed marine diesel engines but rather opens up new possibilities for even better economy, ease of operation, reliability, times between overhauls and lower exhaust emissions.

It is more than ten years since development of the Sulzer RT-flex common-rail system began and more than 20 years since the first tests were made with electronically-controlled fuel injection in Winterthur, Switzerland.

The early camshaftless systems developed for Sulzer engines relied on integral electronic control but used individual, hydraulically-operated fuel injection pumps. However the change in injection concept from the individual, hydraulically-operated fuel injection pumps to a common-rail system in 1993 was made because the system with individual pumps did not offer potential for further technological development despite it having integral electronic control. Electronic control was found to be insufficient by itself and a new fuel injection concept was recognised as essential. Common rail was seen as the road ahead and it is applied in Sulzer RT-flex engines.

Sulzer RT-flex engines are thus notably different from other electronically-controlled low-speed diesel engines today as Sulzer RT-flex engines are unique in combining the benefits of both common-rail systems and electronic control.

Sulzer RT-flex system

Sulzer RT-flex engines are essentially standard Sulzer RTA low-speed two-stroke marine diesel engines except that, instead of the usual camshaft and its gear drive, fuel injection pumps, exhaust valve actuator pumps, reversing servomotors, and all their related mechanical control gear, they are equipped with a common-rail system for fuel injection and exhaust valve actuation, and full electronic control of engine functions.

There are four principal elements in the Sulzer RT-flex

Table 1: Sulzer RT-flex engine programme 2004

Engine Type	RT-flex50	RT-flex58T-B	RT-flex60C	RT-flex68T-B	RT-flex84T-D	RT-flex96C
Bore, mm	500	580	600	680	840	960
Stroke, mm	2050	2416	2250	2720	3150	2500
Power, R1 kW/cyl	1620	2180	2360	3070	4200	5720
Speed, rpm	124	105	114	95	76	102
BMEP, bar	19.5	19.5	19.5	19.6	19.0	18.6
Piston speed, m/s	8.5	8.5	8.6	8.6	8.0	8.5
No. cylinders	5–8	5–8	5–9	5–8	5–9	6–12, 14
RT-flex Size	0	I	I	II	IV	IV

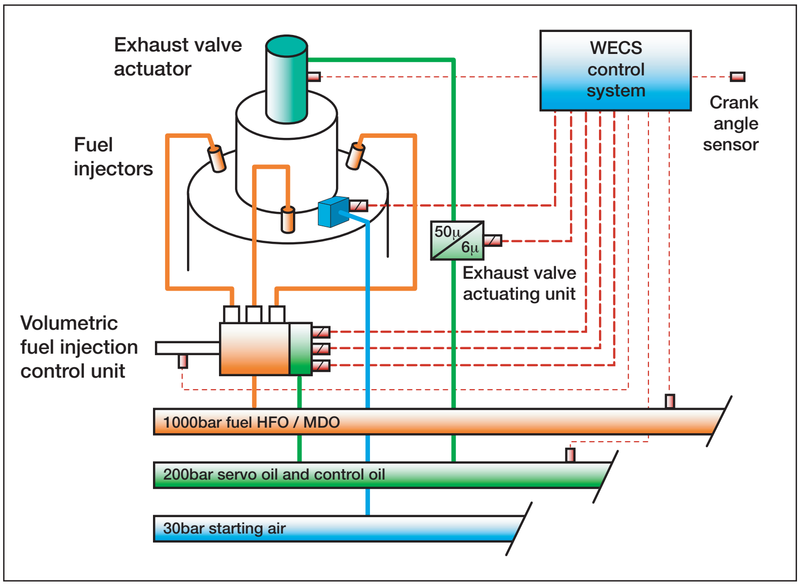


Fig. 2: Schematic of the common-rail systems in Sulzer RT-flex engines. [02#007]

common-rail system: the rail unit along the side of the cylinders, the supply unit on the side of the engine, a filter unit for the servo oil, and the integrated electronic control system, including the crank angle sensor.

The RT-flex engines are thus equipped with common-rail systems for:

- heated fuel oil at pressures up to 1000 bar,
- servo oil at pressures up to 200 bar,
- control oil at a constant pressure of 200 bar,
- engine starting air system.

RT-flex Sizes

The hardware in the RT-flex system is being developed in four principal sizes for the six engine types currently in the programme (see Table 1). The six RT-flex engine types cover a power range of 8100 to 80,080 kW (11,000 to 108,920 bhp).

This illustrates one of the advantages of the common-rail system in that hardware is standardised for groups of engine types, not just for the various cylinder numbers.

Supply unit

Fuel and servo oil are supplied to the common-rail system from the supply unit which is driven through gearing from the engine crankshaft.

In the first few RT-flex engines, the supply unit is on the exhaust side of the engine so that it could be lower down without interfering with access to the crankcase. However, for all subsequent engines, the location of the supply unit has since been standardised on the front of the engine (on the same side as the rail unit) and at about mid height. This keeps the engine 'footprint' small so that the engines can be located far aft in ships with fine afterbodies.

The supply unit is naturally at the location of the gear drive: at the driving end for five- to seven-cylinder

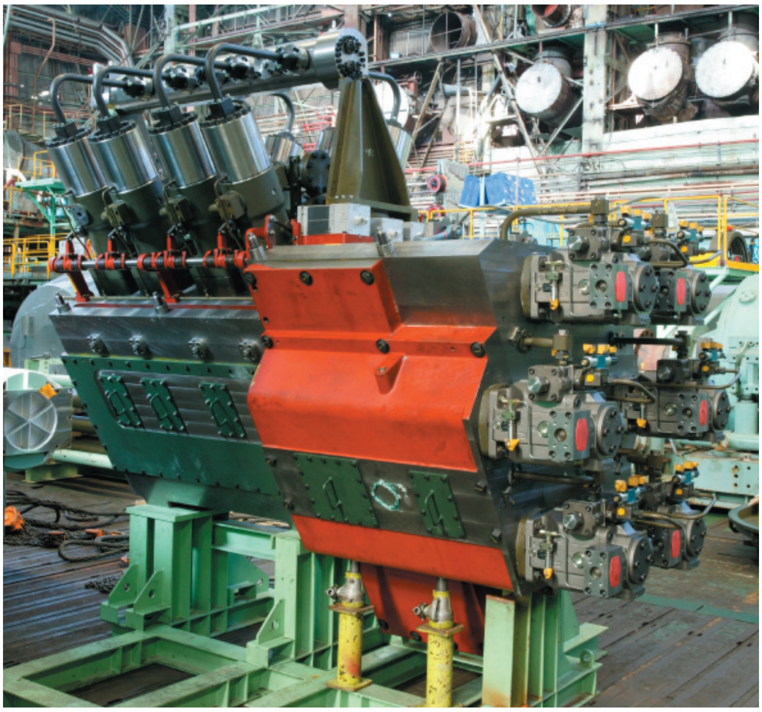


Fig. 3: Supply unit for a Sulzer 12RT-flex96C engine with the fuel pumps in a Vee-form arrangement on the left and servo oil pumps on the right-hand face of the central gear drive. The fuel pumps all deliver into the collector seen above the fuel pumps. [04#074]

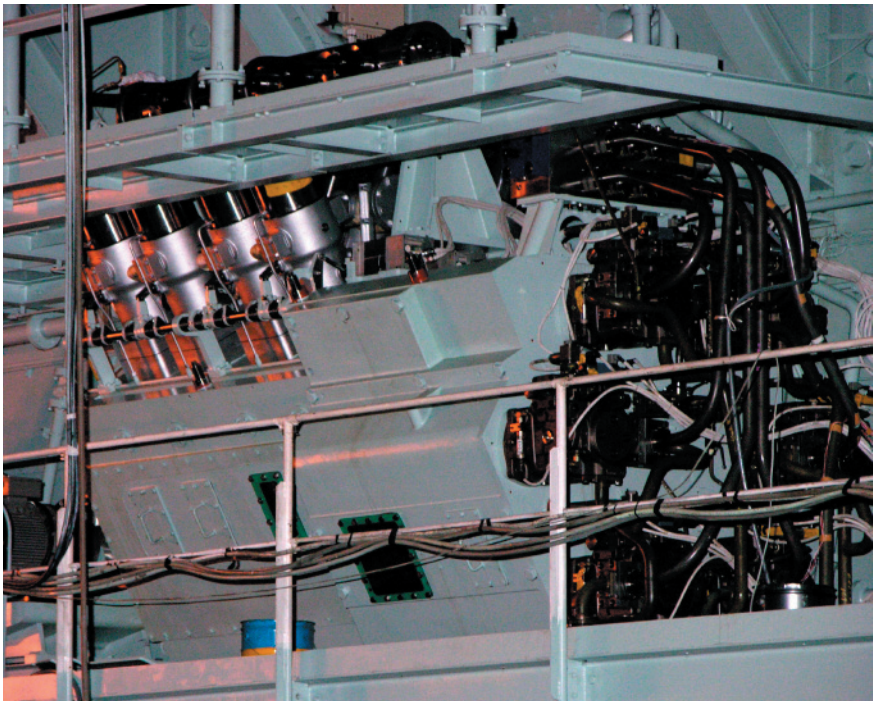


Fig. 4 above: Supply unit on a Sulzer 12RT-flex96C engine with the fuel pumps in a Vee-form arrangement on the left and servo oil pumps on the right-hand face of the central gear drive. [04#111]

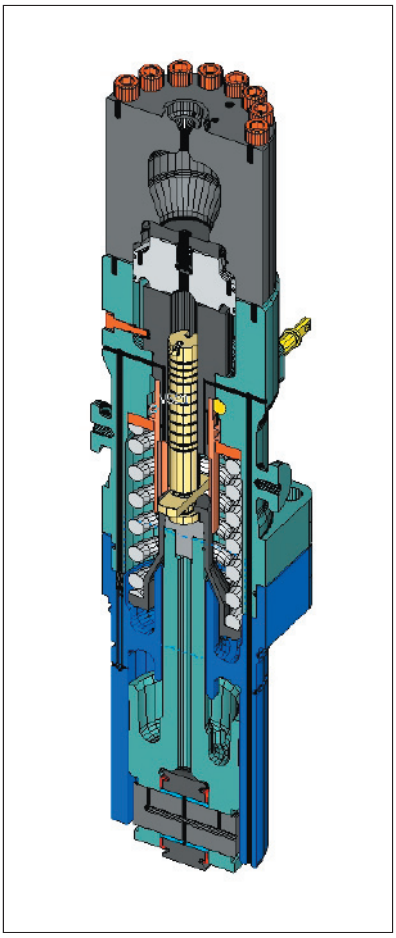
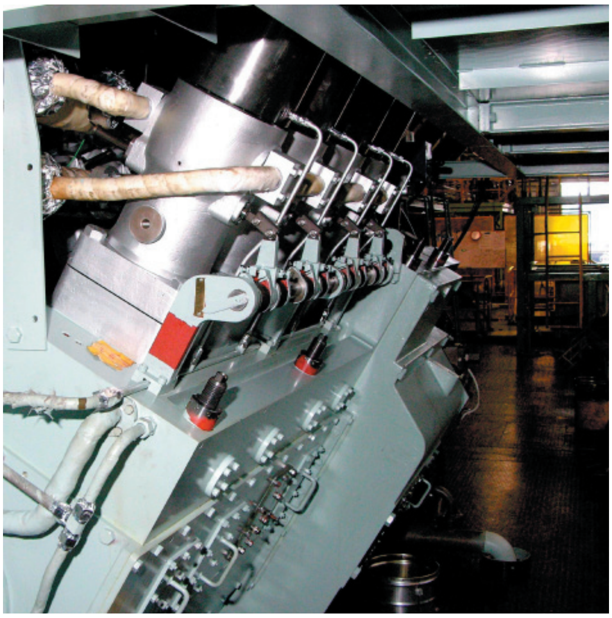


Fig. 5 right: Cutaway drawing of the fuel supply pump element for RT-flex96C engines. [04#017]

engines, and at the mid gear drive for greater cylinder numbers.

The supply unit has a rigid housing of GGG-grade nodular cast iron. The fuel supply pumps are arranged on one side of the drive gear and the hydraulic servo-oil pumps are on the other side. This pump arrangement allows a very short, compact supply unit with reasonable service access. The numbers, size and arrangement of pumps are adapted to the engine type and the number of engine cylinders.

Fig. 6: Close view of the fuel supply pumps in figure 4 showing the regulating linkage. [04#112]



For RT-flex Sizes I and IV, the supply unit is equipped with between four and eight fuel supply pumps arranged in Vee-form. The Size 0 supply unit, however, has just two or three supply pumps in-line.

Two sizes of fuel pumps are employed for all RT-flex engines, both based on the well-proven injection pumps used in Sulzer Z-type medium-speed four-stroke engines though with some adaptations to suit their function as supply pumps and to raise their volumetric efficiency up to a very high degree. For Sizes 0 and I, the fuel pump elements are based on the injection pumps of Sulzer ZA40S engines, while the Size IV pumps are based on the injection pumps of the Sulzer ZA50S engine type.

The fuel supply pumps are driven through a camshaft with three-lobe cams. This camshaft cannot be compared with the traditional engine camshaft. It is very short and of much smaller diameter, and is quite differently loaded. There is no sudden, jerk action as in fuel injection pumps but rather the pump plungers have a steady reciprocating motion. With tri-lobe cams and the speed-increasing gear drive, each fuel supply pump makes several strokes during each crankshaft revolution. The result is a compact supply unit.

Two designs of camshaft are employed. For Size I it is manufactured in one piece. For Size IV, the camshaft is assembled from a straight shaft on to which the tri-lobe cams are hydraulically press fitted. This latter form of

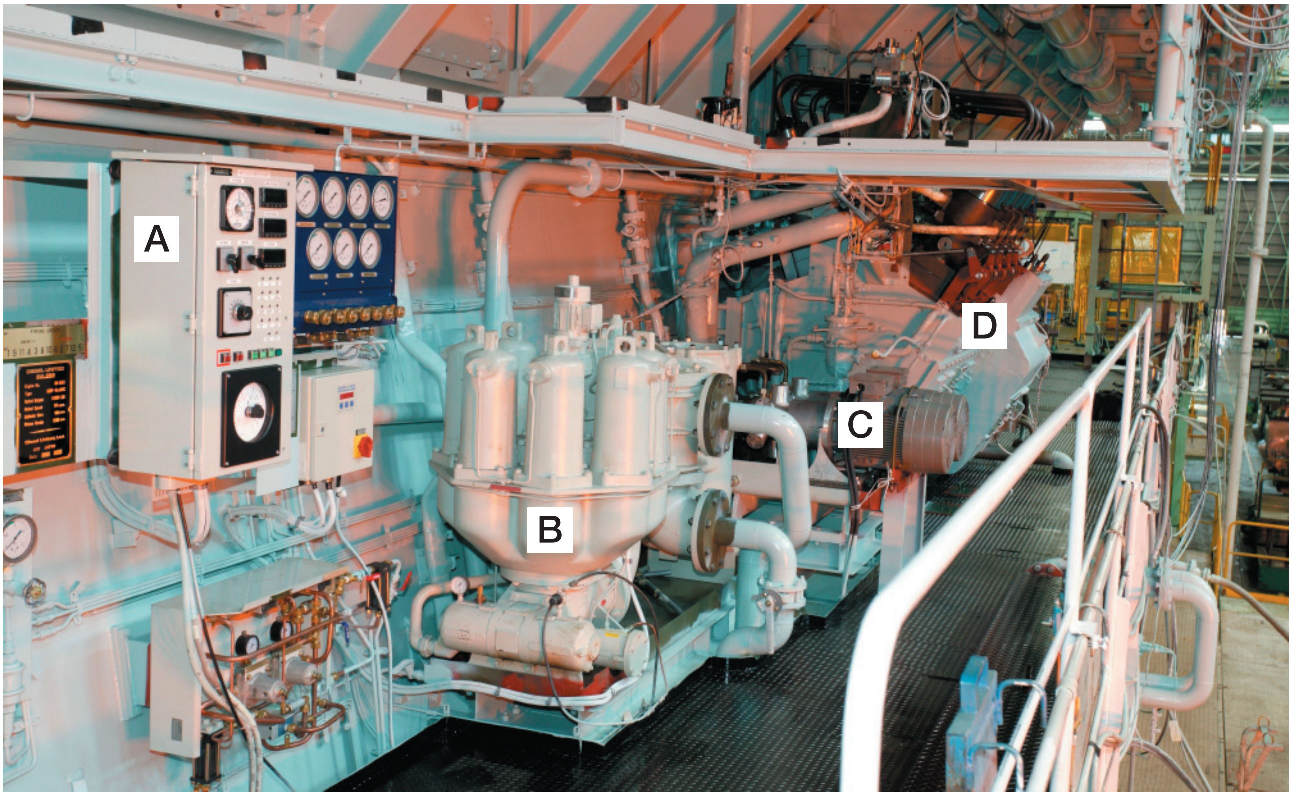


Fig. 7: Various RT-flex equipment on the half-platform of a 12RT-flex96C engine. From left to right, these include (A) the local engine control panel, (B) the automatic fine filter for servo and control oil, (C) the two electrically-driven control oil pumps and (D) the supply unit.
[04#113]

construction has been used for decades in Sulzer Z-type engines. It is extremely service friendly and minimises maintenance cost. The camshaft bearings have an aluminium running layer.

The fuel delivery volume and rail pressure are regulated according to engine requirements through suction control with helix-controlled filling volume regulation of the fuel supply pumps. Suction control was selected for its low power consumption as no excess fuel is pressurised.

The roller guide pistons contain the floating-bush bearings for the rollers as they are used on all Sulzer RTA- and Z-type engines. Owing to the moderate accelerations given by the tri-lobe cam shape, the specific loads of roller bearings and pins as well as the Hertzian pressure between cam and roller are less than for the original pumps in ZA40S and ZA50S engines.

For every individual fuel pump element of the supply unit, the roller can be lifted off the cam, blocked and manually taken out of service in case of difficulties.

The fuel pumps deliver the pressurised fuel to an adjacent collector from which two independent, double-walled delivery pipes lead upwards to the fuel rail. Each delivery pipe is dimensioned for full fuel flow. The collector is equipped with a safety relief valve set to 1250 bar.

An equivalent arrangement of a collector and duplicated independent, double-walled delivery pipes is employed for the servo oil supply.

Servo oil

Servo oil is used for exhaust valve actuation and control. It is supplied by a number of swashplate-type axial-piston hydraulic pumps mounted on the supply unit. The pumps are of standard proprietary design and are driven at a suitable speed through a step-up gear. The working pressure is controllable to allow the pump power consumption to be reduced. The nominal operating pressure is up to 200 bar. The number and size of servo oil pumps on the supply unit depend on the engine output or number of engine cylinders. There are between three and six servo oil pumps.

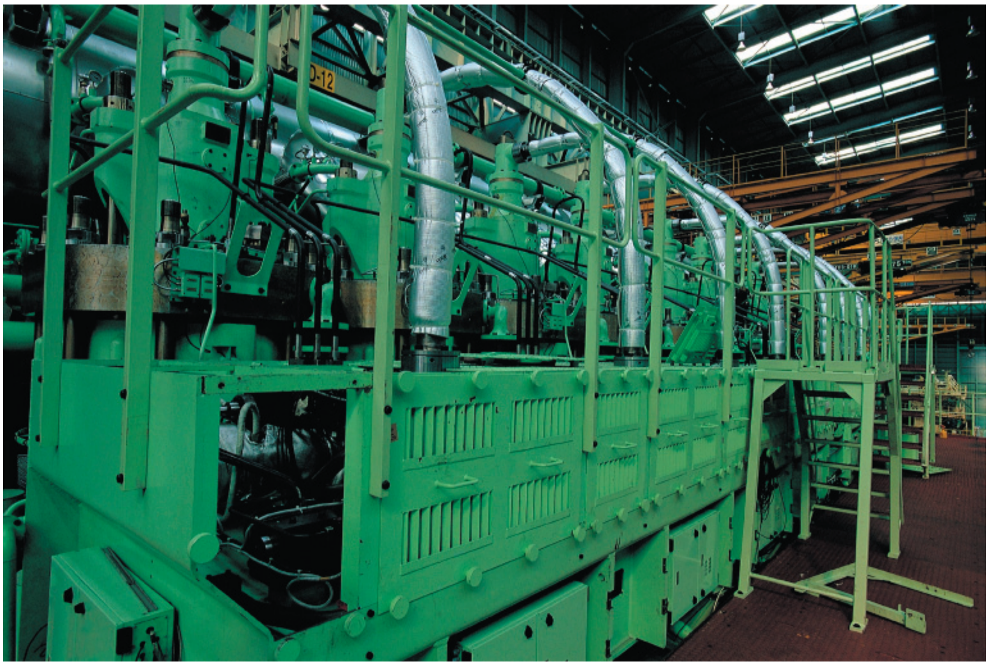
The oil used in both the servo and control oil systems is standard engine system lubricating oil, and is simply taken from the delivery to the engine lubrication system. The oil is drawn through a six-micron automatic self-cleaning fine filter to minimise wear in the servo oil pumps and to prolong component life.

After the fine filter, the oil flow is divided, one branch to the servo oil pumps and the other to the control oil pumps.

Control oil

Control oil is supplied at a constant 200 bar pressure at all engine speeds by two electrically-driven oil pumps, one active and the other on standby. Each pump has its own pressure-regulating valve and safety valve attached.

The control oil system involves only a small flow



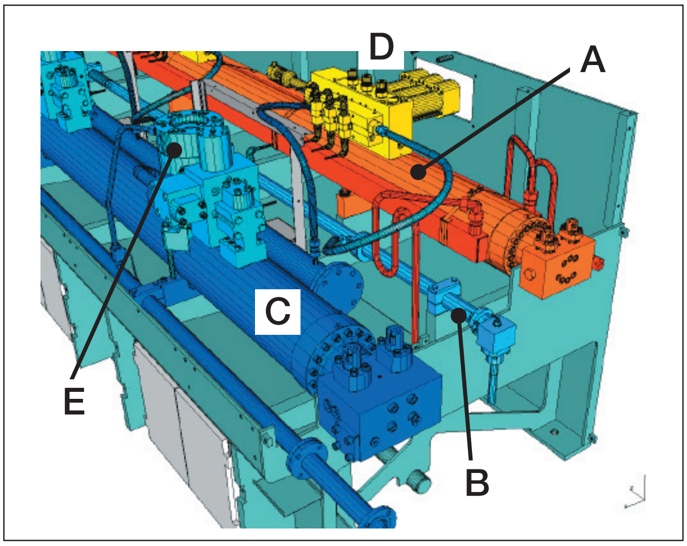
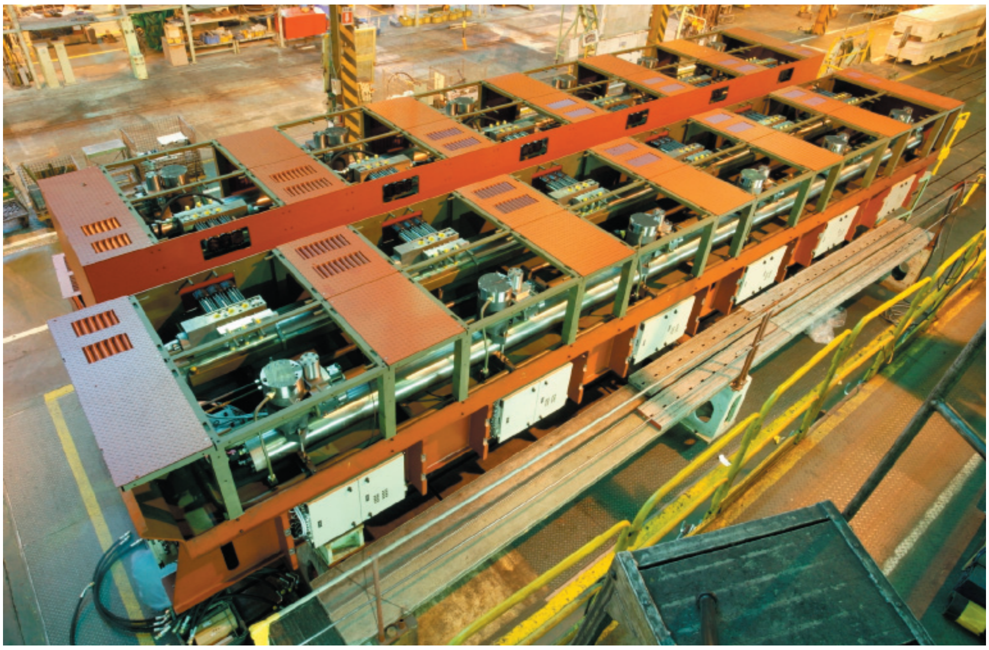


Fig. 8 above: Cylinder tops and rail unit of a Sulzer 8RT-flex96C engine. The electronic control units are mounted on the front below the rail unit.
[04#034]

Fig. 9 left: Three-dimensional drawing of the inside of a rail unit for an RT-flex96C engine, showing the fuel rail (A), the control oil rail (B) and the servo oil rail (C) with the control units for injection (D) and exhaust valve actuation (E) on top of their respective rails. Other manifold pipes are provided for oil return, fuel leakage return, and the system oil supply for the exhaust valve drives.
[04#023]

Fig. 10 below: The two sections of rail unit for a 12-cylinder RT-flex96C engine during the course of assembly.
[04#076]



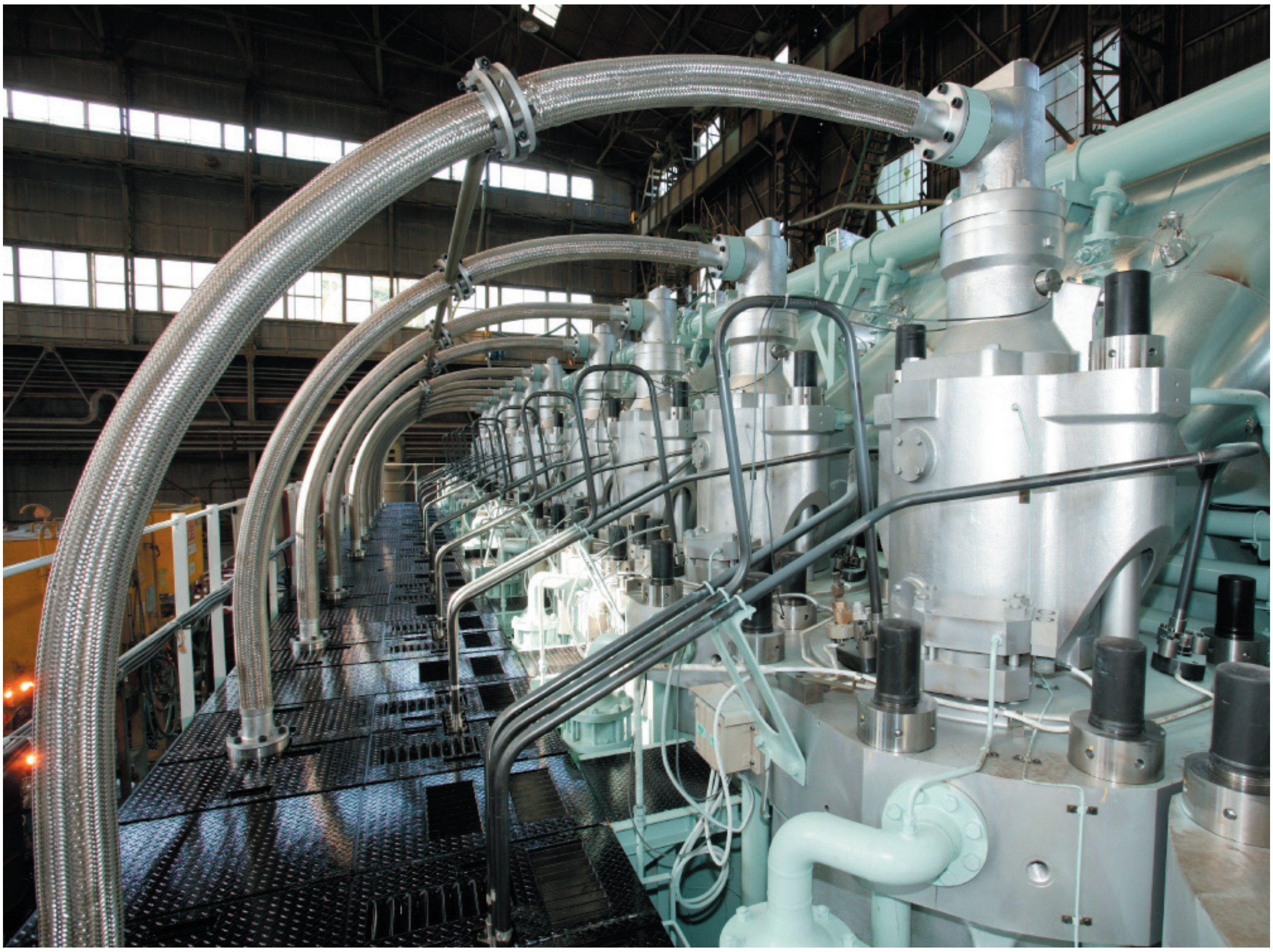


Fig. 11: Cylinder tops of a 12-cylinder RT-flex96C engine with the rail unit under the platform on the left. The hydraulic pipes for the exhaust valve drives arch up from the exhaust valve actuators on the servo oil rail, and the sets of triple high-pressure fuel injection pipes rise up from the injection control units on the fuel rail.
[04#091]

quantity of the fine filtered oil. The control oil serves as the working medium for all rail valves of the injection control units (ICU). The working pressure of the control oil is maintained constant to ensure precise timing in the ICU. It is also used to prime the servo oil rail at standstill thereby enabling a rapid starting of the engine.

Rail unit

The rail unit is located at the engine's top platform level, just below cylinder cover level. It extends over the length of the engine. It is fully enclosed but has good maintenance access from above and from the front. The rail unit contains the rail pipes and associated equipment for the fuel, servo oil and control oil systems. The starting air system is not included in the rail unit.

For engines with up to eight cylinders, the rail unit is assembled as a single unit. With greater numbers of cylinders, the engines have a mid gear drive and the rail unit is in two sections according to the position of the mid gear drive in the engine.

The fuel common rail provides storage volume for the fuel oil, and has provision for damping pressure waves. There is no need for energy storage under gas pressure. The volume of the common-rail system and the supply rate from the fuel supply pumps are such that the rail pressure is very stable with negligible pressure drop after each injection.

In the RT-flex Size I, the high-pressure pipe for the fuel rail is modular with sections for each cylinder and flanged to the individual injection control units for each cylinder.

With the Size IV, the high-pressure fuel rail was changed to a single-piece rail pipe to shorten assembly time and to simplify manufacture. A single length of rail pipe is installed in each section of the rail unit. The only high-pressure pipe flanges on the Size IV pipe are the end covers.

The common rail system is designed with very high safety margins against material fatigue. The fuel rail pipe for instance has a very special inner shape to keep the stress amplitude in cross-bored drillings remarkably low. The fact that, by definition, common rails have almost constant pressure levels further increases the safety against high cycle fatigue cracking compared to conventional injection and actuator systems with high pressure cycles.

The high-pressure rail is trace heated from the ship's heating system, using either steam or thermal oil.
The simplification of the fuel rail for Size IV, without intermediate flanges, compared with that for Size I

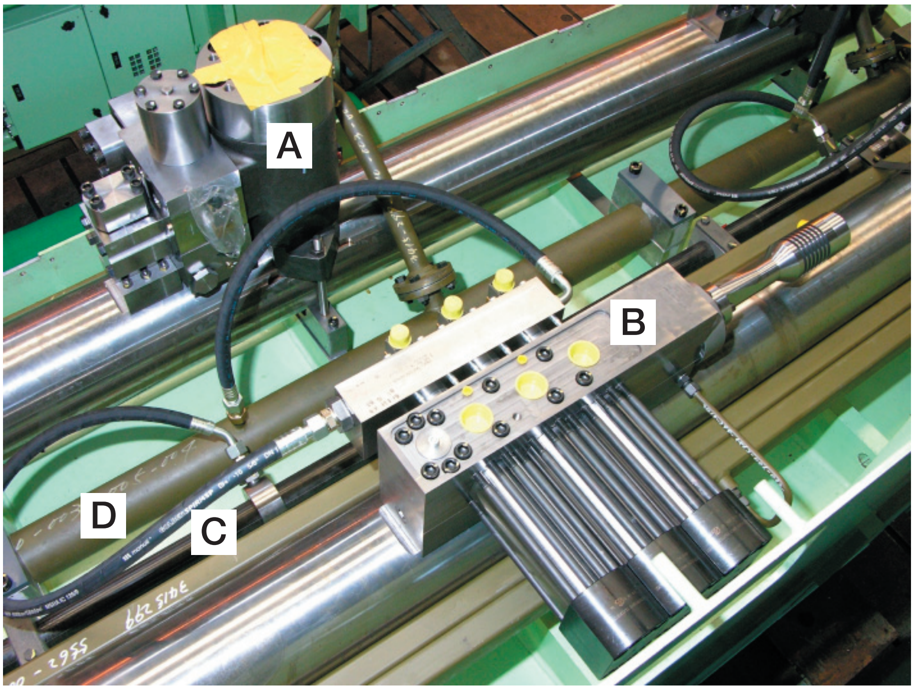


Fig. 12: Inside a Size IV rail unit during assembly. The exhaust valve actuator (A) is mounted on the servo oil rail and the injection control unit (B) is on the fuel rail. Next to the fuel rail is the smaller control oil rail (C) and the return pipe for servo and control oil (D).
[04#114]

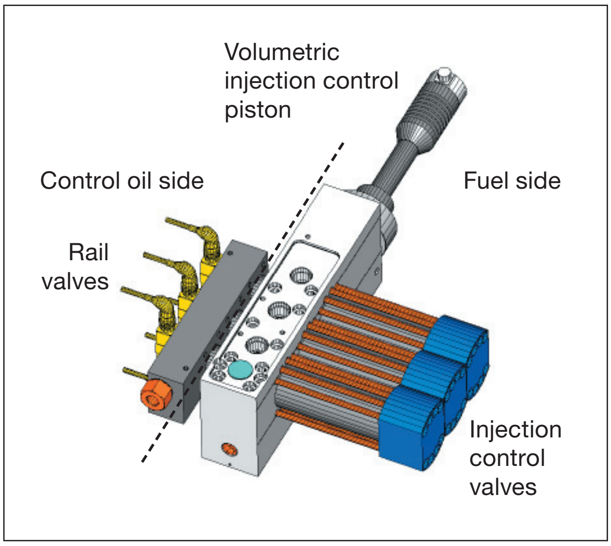


Fig. 13: Injection control unit (ICU) for the three fuel injection valves of one cylinder. The dashed line marks the separation between the control oil and the fuel oil sides.
[04#015]

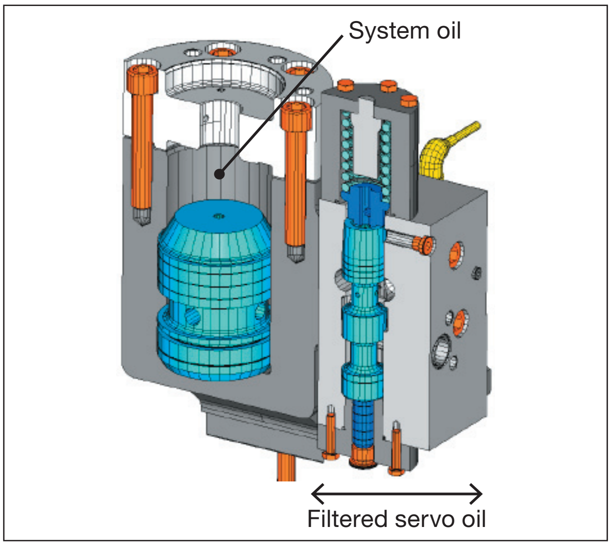


Fig. 14: The exhaust valve actuator with the large-diameter actuator piston on the left and the hydraulic control slide on the right.
[04#108]

allowed the trace heating piping also to be simplified. The trace heating piping and the insulation are both slimmer, allowing easier service access inside the rail unit.

Injection control unit (ICU)

Fuel is delivered from the common rail to the injection valves through a separate ICU for each engine cylinder. The ICU regulates precisely the timing of fuel injection, accurately controls the volume of fuel injected, and sets the shape of the injection pattern. The ICU has an injection control valve and a Sulzer electro-hydraulic rail valve for each fuel injection valve. The rail valves receive control signals for the beginning and end of injection from the respective electronic unit of the WECS (Wärtsilä Engine Control System).

There are three fuel injection valves in each engine cylinder except for the RT-flex50 which has two. The fuel injection valves are the same as those already employed in RTA engines, and are hydraulically-operated in the usual way by the high-pressure fuel oil. Each fuel injection valve in a cylinder cover is independently controlled by the ICU for the respective cylinder so that, although all the injection valves in an individual cylinder normally act in unison, they can also be programmed to operate separately as necessary.

For Size I, the individual ICU are arranged between the sections of rail pipe but for Size IV the individual ICU are mounted directly on the rail pipe. The ICU for Size IV was adapted from that in Size I with the same function principles for integral injection volume flow but to suit the greater flow volumes involved.

The common-rail system is purpose-built for operation on just the same grades of heavy fuel oil as are already standard for Sulzer RTA-series engines. For this reason, the RT-flex system incorporates certain design features not seen in other common-rail engines using middle-distillate diesel oils. The key point is that, in the ICU, the heated heavy fuel oil is isolated from the precision rail valves.

The Sulzer rail valves are bi-stable solenoid valves with an extremely fast actuation time. To achieve the longest possible lifetime, the rail valves are not energised for more than 4 ms. This time is sampled, monitored and limited by the WECS. The valves' bi-stability allows their position and status to be reliably controlled.

Exhaust valve control

The exhaust valves are operated by a hydraulic 'push rod', being opened by hydraulic oil pressure and closed by an air spring, as in the Sulzer RTA engines with mechanical camshafts. But for RT-flex engines the actuating energy now comes from the servo oil rail. There is one exhaust valve actuator (also known as the partition device) for each cylinder.

In the exhaust valve actuator, fine-filtered servo oil acts on the underside of a free-moving actuator piston, with normal system oil above the actuator piston for valve actuation. The adjacent hydraulic control slide is precisely activated by a Sulzer rail valve and controls the flow of servo oil to the actuator piston so that the exhaust valve opens and closes at precisely the correct time with appropriate damping. The exhaust valve actuator employs the same Sulzer rail valves as are used for the ICU.

The exhaust valve drive on top of the valve spindle is equipped with two analogue position sensors to provide a feedback on valve operation to the WECS.

The electronically-controlled actuating unit for each cylinder gives full flexibility for exhaust valve opening and closing patterns. At the same time, the actuating unit provides a clear separation of the clean servo oil and the normal system oil. Thus the exhaust valve hydraulics can be serviced without disturbing the clean servo oil circuit.

Operating pressures and system energy

The normal operating pressure for the fuel rail ranges up to 1000 bar. It is lowered for the best compromise between BSFC (brake specific fuel consumption) and NO_X emissions according to the respective engine load and to keep the parasitic energy demand low.

It was determined years ago in engine tests in Winterthur that, under steady load conditions, the influence of fuel injection pressure on specific fuel consumption in low-speed engines diminishes with increasing injection pressure. Thus, higher fuel injection pressures than are presently used in large two- stroke low-speed engines have no real benefit. Should an increase become necessary in the future, for instance in combination with other measures to reduce NO_X emissions, the RT-flex system is ideal to cope with it. The additional, parasitic system energy would be very limited indeed, as the increase is about proportional to the pressure increase.

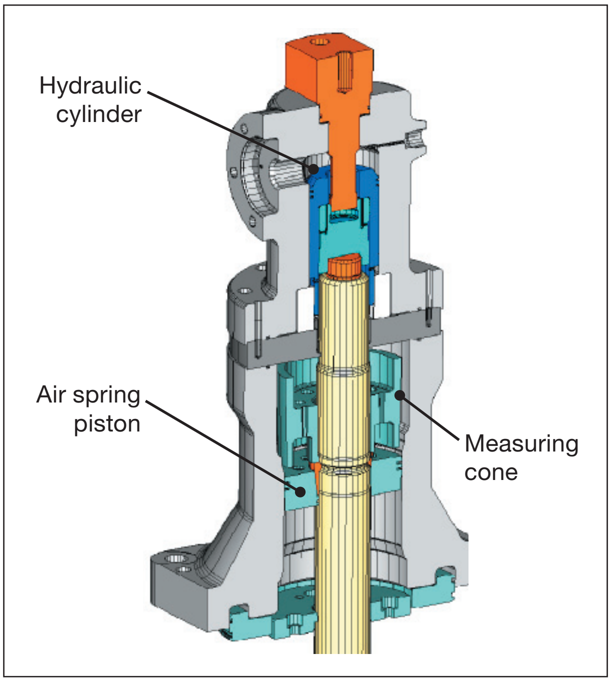


Fig. 15: The exhaust valve drive on top of the exhaust valve spindle with the hydraulic cylinder and the air spring. The two position sensors (not visible in this view) measure the radial distance to the cone to determine the spindle's vertical position. [04#109]

Exhaust valve actuation requires a high volume flow of oil. With an appropriately stepped hydraulic piston diameter on the valve spindle both proper valve movement and low parasitic power could be achieved at the same time. Additionally, the servo oil pressure of 200 bar nominal is variably adapted to the minimum requirement over engine load to ensure a proper function and minimal power demand.

Starting air system

The starting air system of RT-flex engines is very similar to that in Sulzer RTA engines, except that its control is incorporated into the WECS. The starting air system, however, is installed outside the rail unit to facilitate overhaul access.

Electronic control

All functions in the Sulzer RT-flex system are controlled and monitored through the Wärtsilä Engine Control System (WECS). This is a modular electronic system with separate microprocessor control units for each cylinder, and overall control and supervision by duplicated microprocessor control units. The latter provide the usual interface for the electronic governor and the shipboard remote control and alarm systems. The microprocessor control units, or electronic control units, are mounted directly on the engine, either on the front of the rail unit or adjacent to it..

An essential input signal for WECS is the engine crank angle. This is measured very accurately by two sensors driven from a stub shaft on the free end of the crankshaft. The two sensors are driven by toothed belts

Fig. 16: Electronic control units beneath the front of the rail unit of a Sulzer RT-flex96C engine. [04#115]

so that axial and radial movements of the crankshaft are not passed to the sensors. The sensors are able to give the absolute crank angle position immediately that electrical power is applied.

At present RT-flex engines are being equipped with the WECS-9500 control system. However, this will be superseded in 2005 by the WECS-9520 control system. The new system provides simpler communication with the ship automation system and easier wiring for the shipbuilder. Only one electronic module is used throughout the new system, and there are fewer equipment boxes which are also of simple, standard design. The functionality of WECS-9520 is the same as that of the WECS-9500 system.

Sulzer RTA and RT-flex engines have standardised interfaces (DENIS) for remote control and safety systems. The remote control and safety systems are supplied to the ship by a variety of approved manufacturers and DENIS (Diesel Engine Interface Specification) defines the interface between the engine-mounted equipment and the shipboard remote control and safety system.

With RT-flex engines, the remote control sends engine manoeuvring commands to the WECS. The remote control processes speed signals from the engine order telegraph according to a defined engine load program and fuelling limitations, and generates a fuel reference signal for the WECS according to DENIS.

The safety system function in RT-flex engines is basically the same as in conventional RTA engines, except that it has additional inputs for WECS slowdown and WECS shutdown signals, and some outputs to the WECS system.

Reliability and redundancy

Reliability and safety has the utmost priority in the RT-flex system. Although particular attention is given to the reliability of individual items of equipment in the RT-flex system, the common-rail concept allows for increased reliability and safety through its inherent redundancy.

High-pressure fuel and servo-oil delivery pipes, the

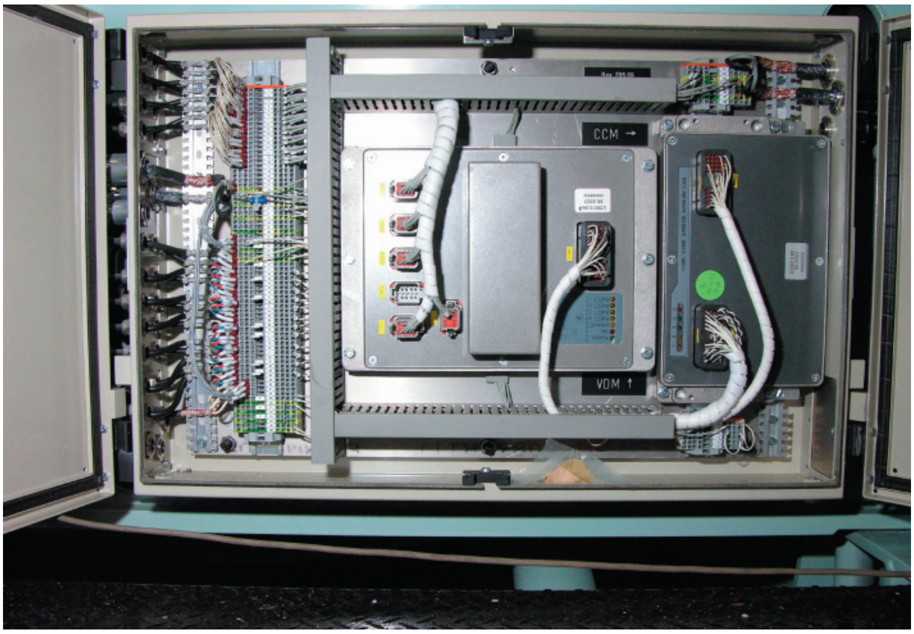


Fig. 17: Inside one of the electronic control units shown in figure 16. [04#116]

electrically-driven control oil pumps, and essential parts of the electronic systems are duplicated for redundancy. The duplicated high-pressure delivery pipes have stop cocks at both ends to isolate any failed pipe. Each single pipe is adequate for the full delivery. All high pressure pipes are double-walled for safety.

With a more traditional injection arrangement of one fuel high-pressure pump to each cylinder, a failure of one pump leads to the loss of that cylinder and the imbalance in engine torque requires a drastic power cut. In contrast, with the RT-flex system in which all high-pressure supply pumps are grouped together and deliver in common to all cylinders, the loss of any pumps has much less effect. Indeed with larger RT-flex engines having several fuel pumps and several servo oil pumps there can be adequate redundancy for the engine to deliver full power with at least one fuel pump and one servo oil pump out of action. Should further pumps be out of action, there would be only a proportional reduction in power.

Every injection nozzle is independently monitored and controlled by the WECS. In case of difficulties, such as a broken high pressure line or a malfunctioning injector, the affected injection valve can be cut out individually without losing the entire cylinder.

The injection control unit ICU hydraulically excludes the injection of an uncontrolled amount of fuel. During the entire working cycle of the metering cylinder, there is never a direct hydraulic connection between fuel rail and the injectors. The maximum injection quantity is limited to the content of the metering cylinder as the travel of the metering piston is monitored. If the travel of the metering piston should be measured as out of range, the subsequent injections of that ICU will be suppressed and an engine slow-down activated.

The ICU also serves as a flow fuse: if the metering piston should travel to its physical limit, it cannot return hydraulically and no further injection would be possible until it is reset.

If the stroke measuring sensor fails, the WECS system switches the ICU to a pure time control and triggers the signal based on the timing of the neighbouring cylinders.

Two redundant crank angle sensors measure the absolute crank angle position which is evaluated through WECS. WECS is able to decide which sensor to follow in case of a discrepancy.

The WECS main controller and all essential communication interfaces such as CAN-bus cablings are duplicated for redundancy. WECS monitors the momentary position of each rail valve for proper function of each cycle before starting the next.

Operation and maintenance

Sulzer RT-flex engines are designed to be user friendly, without requiring ships' engineers to have any special additional skills. Indeed the knowledge for operating and maintenance of RT-flex engines can be given in the same form as Wärtsilä's usual one-week courses for Sulzer RTA-series engines given to ships' engineers and owners' and operators' shore staff. The training time usually given to the camshaft system, fuel pumps, valve actuating pumps and reversing servomotors is simply given instead to the RT-flex common-rail system.

It has been seen from shipboard operation of the RT-flex engines that the ships' engineers quickly become comfortable operating the engines.

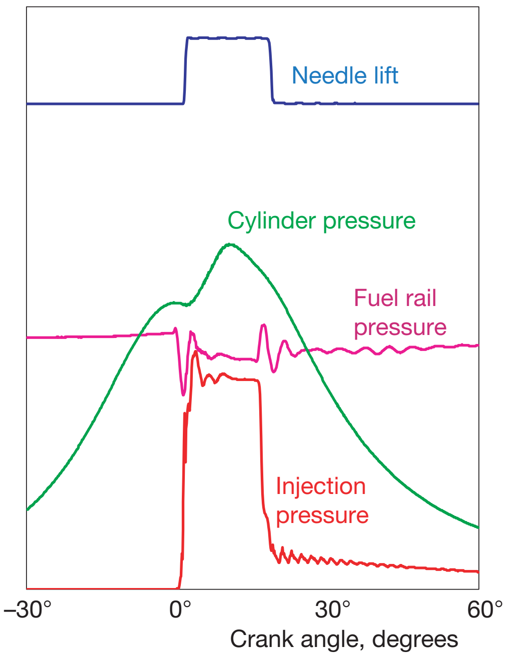


Fig. 18: Typical injection pattern of Sulzer RT-flex engines with all injection nozzles acting in unison showing needle lift, fuel rail pressure, injection pressure and cylinder pressure when all injection nozzles are operating simultaneously. Note the sharp beginning and ending of injection, the lack of a significant pressure drop in the common rail during injection, and the small rail pressure fluctuations. [04#107]

Key features of the Sulzer RT-flex system

The key features of the Sulzer common-rail system can be summarised as:

- Precise volumetric control of fuel injection, with integrated flow-out security
- Variable injection rate shaping and variable injection pressure
- Possibility for independent action and shutting off of individual fuel injection valves
- Ideally suited for heavy fuel oil
- Well-proven standard fuel injection valves
- Proven, high-efficiency common-rail pumps
- Lower levels of vibration and internal forces and moments
- Steady operation at very low running speeds with precise speed regulation
- Smokeless operation at all speeds.

Benefits from the Sulzer RT-flex system

At its heart, the Sulzer RT-flex engine is the same reliable, basic engine as the existing Sulzer RTA engine series. The power ranges, speeds, layout fields and full-power fuel consumptions are the same for both engine versions.

For shipowners, the principal benefits of Sulzer RT-flex engines with their electronically-controlled common rail systems are:

- Reduced part-load fuel consumption
- Smokeless operation at all running speeds
- Very low, stable running speeds at about ten per cent nominal speed
- 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.

Comments below are made on just the first three of the above points as these are the ones which have so far been definitely quantified.

Low exhaust emissions

A clearly visible benefit of Sulzer RT-flex engines is their smokeless operation at all ship speeds. It helps give a 'green' image.

This was well demonstrated in the testing of the first RT-flex engine and during the sea trials of the *Gypsum Centennial*.

The superior combustion performance with the common-rail system 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 precision and flexibility in engine setting given by the RT-flex system facilitates compliance with the NO_X regulation of Annex VI of the MARPOL 73/78 convention, usually referred to IMO NO_X regulation.

The flexibility of the RT-flex engines will also allow a lowering of NO_X emissions if the corresponding increase in BSFC is acceptable. With common-rail injection, a wide variety of injection patterns can be generated. The injected quantity of fuel can be divided, for pre-injection, triple injection, etc. The Sulzer RT-flex engine, with its individual fuel valve control, also has the unique ability to vary individually the injection timing and sequence between the three fuel injectors in each cylinder and thus to generate a tailor-made heat release.

In engine tests, this degree of flexibility has proved useful to reach NO_X emissions of 20 per cent below the IMO NO_X limit with a moderate BSFC increase of 2.3 per cent.

Very slow running

Sulzer RT-flex engines have also demonstrated their ability to run stably at very low speeds, lower than engines with mechanically-controlled injection. They can run without smoking at about ten per cent nominal speed. This makes for easy ship handling when manoeuvring or in river and canal passages.

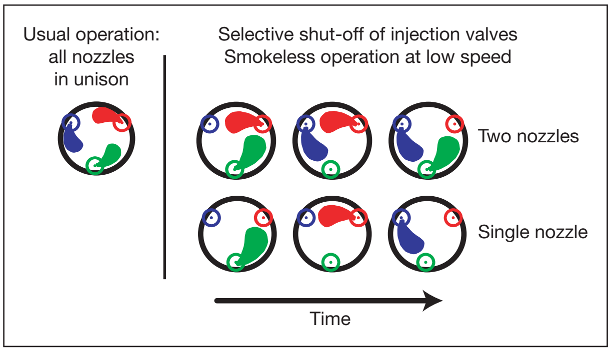


Fig. 19: Sulzer RT-flex engines have the unique ability to shut off individual fuel injectors, here shown schematically. This feature is used to assure clean combustion for smokeless, stable running at very low speeds.
[03#118]

Such slow running was well confirmed in service in the *Gypsum Centennial*. Slow running was taken to a new 'low' during the testing in May/June 2004 of the first 12-cylinder RT-flex96C engine. Owing to its number of cylinders, it could run steadily at just seven revolutions per minute.

The very slow running is made possible by the precise control of injection, together with the higher injection pressures achieved at low speed, and shutting off injectors at low speeds. Reducing the number of injection valves in operation makes injection of the reduced fuel quantities more efficient, especially as the injection pressure is kept up to a higher value than in a mechanically-injected engine at the same speeds.

Shutting off injectors provides more stable operation with better distribution of engine load and thermal loads than if very slow running was to be achieved by cutting out whole cylinders.

Shutting off injectors is enabled by the separate control of individual fuel injection valves. This feature is unique to Sulzer RT-flex engines. Usually the injection valves operate in unison but, as the engine speed is reduced, one injection valve can be shut off and at a lower speed a second injection valve can be shut off. Thus at minimum speed, the engine runs on all cylinders but with just one injection valve in each cylinder.

If the RT-flex engine then runs for a period in single-injector operation, the electronic control system switches between the three injection valves in a cylinder so that the thermal load is equalised around the combustion chamber.

Fuel consumption flexibility

Sulzer RTA engines have always been highly competitive in fuel consumption right across the load range owing to the use of variable injection timing (VIT). Variable exhaust valve closing (VEC) was also added in RTA84T engines in 1991 to reduce further the part-load BSFC. These benefits have already been carried over to the

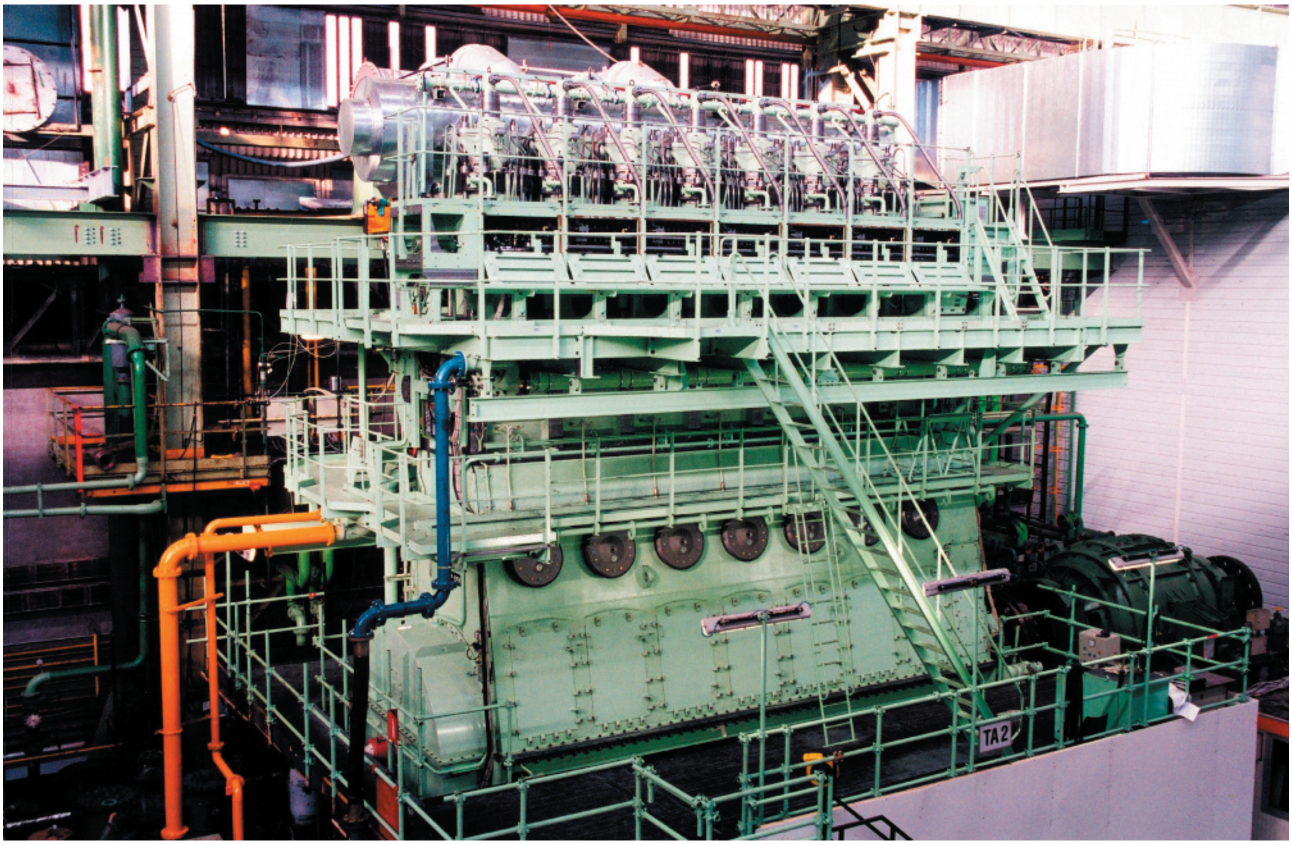


Fig. 20: Sulzer 7RT-flex60C engine in Wärtsilä's Trieste factory in October 2002. It develops 16,520 kW at 114 rpm, and measures about 11.4 m long by 10.5 m high. Above the top platform, the rail unit covers can be seen open. [03#023]

electronically-controlled common-rail systems of the RT-flex engines.

At the first stage of development of RT-flex engines, however, the main objective has been to achieve the same performance standards as are achieved in the mechanical-camshaft engines, particularly with respect to power, speed, fuel consumption, exhaust emissions, cylinder pressures, etc. Thus the curves of brake specific fuel consumption (BSFC) of the first RT-flex engines have been the same as with corresponding RTA engines, or perhaps slightly lower in the part-load region. As the fuel injection pressure at part-load is kept higher with the common-rail injection system, combustion is sufficiently better to have a beneficial effect on fuel consumption in part-load operation.

Recently an alternative fuel consumption curve was introduced with Delta Tuning to provide even lower BSFC at loads less than 90 per cent full load. For both the original (Standard) and Delta Tuning curves, the RT-flex engines comply with the IMO NO_X regulation.

The question, of course, arises as to why the BSFC could not be lowered at all engine loads and speeds. It is technically possible to do so. With RT-flex engines all the relevant parameters can be continuously varied so that the engine can follow any specified BSFC curve as engine load and speed are varied. Yet there is a limitation because of the need to comply with the IMO NO_X regulation and the inevitable trade-off between lower fuel consumption and greater NO_X emissions. This explains the shape of the new BSFC curve given by Delta Tuning. The BSFC is lowered in the mid- and low-load range, thereby increasing the NO_X emission levels at those load points, but then has to be increased at high engine loads (90–100 per cent load) for a compensating reduction in NO_X levels.

Delta Tuning was first applied in the first Sulzer 8RT-flex96C engine which completed its official shop test on 9 April 2004.

Conclusion

Common rail is now an industrial standard for diesel engines. It has been proven to be an tremendous step forward for all sizes of diesel engines from automotive engines up to the largest low-speed two-stroke engines.

In this environment, Sulzer RT-flex engines have become well accepted by shipowners. Shipowners' confidence is being encouraged by the good operating experience with the growing number of RT-flex engines in service.

The combination of common-rail concepts and fully-integrated electronic control applied in Sulzer RT-flex engines clearly has excellent potential for future development. It gives the large degree of flexibility in engine setting and operation, together with reliability and safety, which are required to meet the challenges in future marine engine applications in terms of emissions control, optimised fuel consumption, insensitivity to fuel quality, ease of use, operational flexibility, etc.

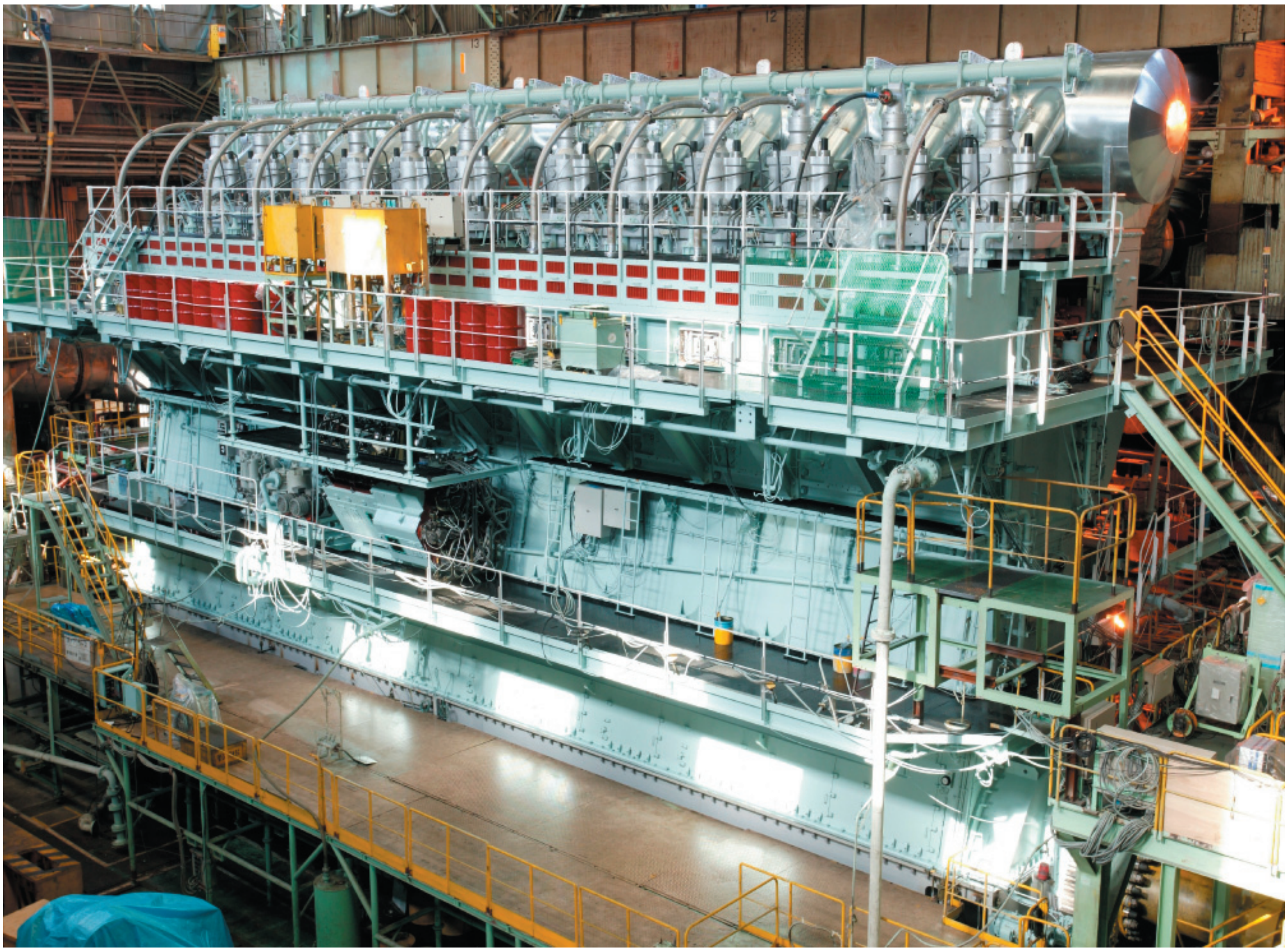


Fig. 21: The world's most powerful common-rail engine, the Sulzer 12RT-flex96C engine develops 68,640 kW at 102 rpm, and measures about 24 m long by 13.5 m high. It passed its official shop test in June 2004. The supply unit shown in figure 4 can be seen at the middle of the engine.
[04#090]

Chronology for Sulzer RT-flex engines

1981:	First tests with electronically-controlled fuel injection on a Sulzer low-speed engine, using individual, hydraulically-operated fuel injection pumps.
1990 Mar:	World's first multi-cylinder electronically-controlled uniflow two-stroke engine is started on the Winterthur test bed. Tested until 1995.
1993:	Project started to develop the Sulzer RT-flex common-rail system.
1996:	Component testing began for the Sulzer RT-flex common-rail system.
1998 Jun:	Starting of the first Sulzer RT-flex full-scale engine on the Winterthur test bed. Sulzer 4RTA58T-B research engine.
2000 Feb:	Order for the first series-built Sulzer RT-flex engine.
2001 Jan:	Official shop test of the first series-built Sulzer RT-flex engine, the 6RT-flex58T-B at Hyundai H.I. in Korea.
2001 Sep:	First RT-flex engine entered service. Sea trials of the bulk carrier *Gypsum Centennial* with a Sulzer 6RT-flex58T-B engine, of 11,275 kW.
2002 Oct:	Official shop test of the first Sulzer RT-flex60C engine, at Wärtsilä's Trieste factory in Italy.
2003 Jan:	Official shop test of Sulzer 7RT-flex60C at Hyundai H.I. in Korea.
2003 Jan:	Sulzer RT-flex96C and RT-flex84T-D engine types announced.
2003 Mar:	Sulzer RT-flex50 engine type announced.
2003 Mar:	Official shop test of first Japanese-built RT-flex engine, a Sulzer 6RT-flex58T-B at Diesel United Ltd.
2003 Aug:	Aframax tanker *Sea Lady* entered service in Japan with Sulzer 6RT-flex58T-B
2003 Nov:	Multi-purpose carrier *Wladyslaw Orkan* entered service in China with Sulzer 7RT-flex60C.
2003 Nov:	Reefer *Carmel Ecofresh* entered service in

Portugal with Sulzer 7RT-flex60C.
2004 Jan: Sulzer RT-flex68T-B engine type announced.
2004 Feb: Multi-purpose carrier *Chipolbrok Sun* entered service in China with Sulzer 7RT-flex60C.
2004 Feb: Reefer *Carmel Bio-Top* entered service in Portugal with Sulzer 7RT-flex60C.
2004 Mar: Confirmed orders for RT-flex engines reach 100.
2004 Apr: Official shop test of first RT-flex96C engine, an 8RT-flex96C at HSD Engine Co Ltd in Korea.
2004 May: Multi-purpose carrier *Chipolbrok Moon* entered service in China with Sulzer 7RT-flex60C.
2004 May: Containership *Safmarine Cameroun* entered service in Germany with Sulzer 9RT-flex60C.
2004 Jun: Official shop test of world's largest common-rail engine, a Sulzer 12RT-flex96C engine of 68,640 kW at Diesel United Ltd in Japan.

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