Technical Brochure

CR 2.2
2nd generation common rail system

Glossary

CR 1.6	Everllence first-generation common-rail system
CR 2.2	Everllence second-generation common-rail system
TBO	Time between overhauls
HFO	Heavy fuel oil according ISO 8217:2024
ISO	International Organization for Standardization
FIE	Fuel injection equipment

Table of contents

Introduction to Everllence

Everllence (formerly MAN Energy Solutions) is a leading provider of propulsion, decarbonization and efficiency solutions for shipping, the energy economy, and industry. True to our motto – 'Moving big things to zero' – we help key industries in the global economy to reduce hard-to-abate emissions. Our technologies have a measurable impact on the success of the global energy transition.

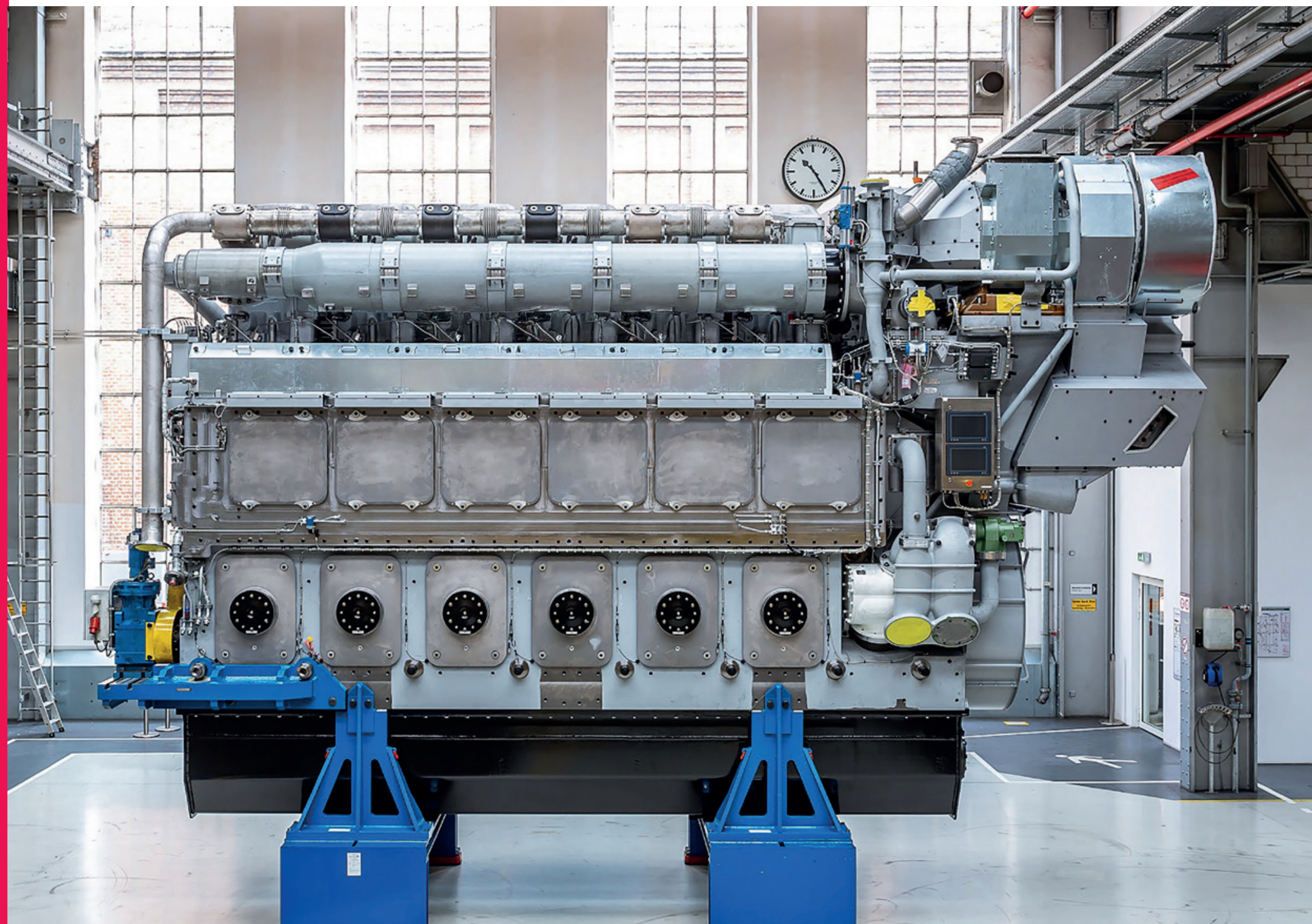
Everllence develops ship and power-plant engines, as well as retrofit solutions, that use climate-neutral fuels to reduce carbon emissions. Our large-scale heat pumps help decarbonize the heat supply for towns, cities, and industrial facilities across the globe, while our carbon capture and storage technologies ensure that unavoidable carbon emissions can be extracted from industrial processes safely. Through our subsidiary, Quest One, we manufacture electrolyzers for the production of green hydrogen and are part of the global hydrogen ramp-up.

Headquartered in Germany, Everllence employs some 15,000 people at over 140 sites globally. Our after-sales brand, Everllence PrimeServ, also supports our customers through its worldwide service center network.

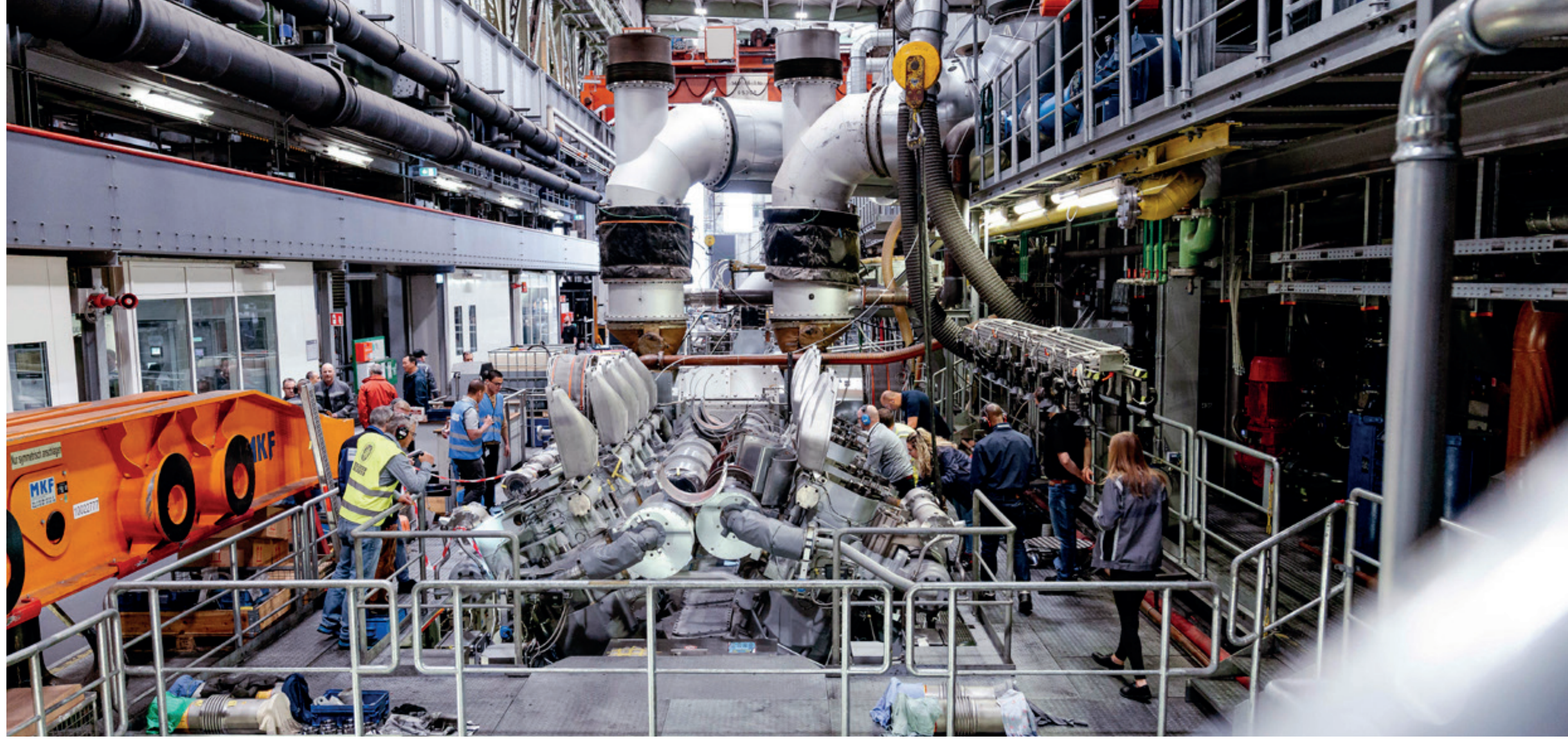
Why develop and release a new liquid fuel injection system?

Everllence is preparing its four-stroke engines for future fuels like methanol or ammonia. This requires new approaches in design, materials and testing. For the foreseeable future until these fuels are widely available the new engine releases require a next-level common-rail system. A new technology platform for multiple applications was developed.

Initially being introduced for the 49/60 engine family, this CR system provides state-of-the-art injection performance for currently available distillate fuels and future bio- and synthetic fuels like HVO and FAME, as an intermediate alternative to the future fuels mentioned above. It's the first step in establishing the technology in the market with best-in-class fuel consumption for current diesel and dual fuel engines.



Introduction to **CR 2.2 - the Everllence second-generation common-rail system**



Based on the experience of previous engine generations, Everllence developed a modular high-pressure system for medium speed engines, currently up to 1,300 kW per cylinder. The core components of the system are the solenoid-driven injector with an integrated accumulator, and the new high-pressure fuel pump.

This brochure highlights the design of the core components and the overall system layout. For example, the design enables multiple injections per cycle and shaping of the injection rate for each engine application. High-pressure generation is achieved with a cam-driven, unified high-pressure pump used across multiple engine types, designed to withstand the harshest environments and tested under heavy conditions.

The design kit described here is fundamental for upcoming injection equipment and paves the way for the alternative fuel future.

In the early 2010s Everllence started the first investigations which led to the development of a new common rail injection system for their medium-speed engines. It was decided that the design pressure of the system should be at 2,200 bar. A nomenclature was given to distinguish between the two common rail injection systems – CR 1.6 for the existing system and CR 2.2 for the new development – based on their respective design pressure.

CR 2.2 is a complete in house development. The CR 2.2 project was mainly driven by the following goals:

Technology kit instead of specific injection system
Having two individual CR 1.6 injection systems for 32/44CR and 48/60CR led to increased efforts in fleet and service maintenance of the field engines. In the CR 2.2 development project, a strong focus was placed on common parts to reduce complexity and validation efforts. Everllence succeeded in unifying pressure generation and all high-pressure valves as platform products.

Enabling multiple injections per cycle
The new injector changed the hydraulic layout of the system. With the arrangement of the high-pressure solenoid valve in the injector in the cylinder head, we eliminated hydraulic length between the actuator and the nozzle. The arrangement allows immediate injection after energyzing and gives a more precise control for more freedom to adopt the injection as well as multiple injections per cycle.

Eliminating cut-off fuel at injection end to improve efficiency
Inside the CR 2.2 injector, Everllence uses a different high-pressure valve concept. A single high pressure fuel valve replaced the previous combination of two interacting valve designs, which was applied in the valve group in the CR 1.6. The cut-off fuel of CR 1.6 was eliminated completely which significantly increases the hydraulic efficiency. No high-pressure fuel is lost at the end of injection. The control quantity of the high pressure fuel valve is negligible.

Suitability for ISO8217:2024 fuels including HVO and synthetic fuels
During the validation of the components a new revision of ISO 8217 - global standards for marine fuels - was released. To meet future requirements, Everllence conducted tests on a broad range of fuel qualities. The injection components are released for full scope of ISO 8217:2024.
On request, Everllence offers customers assistance in the use of non-ISO liquid fuels.

Simplification of the layout with fewer high-pressure connections
Based on customer feedback, Everllence designed a simplified hydraulic layout. With the introduction of an equal accumulator on each cylinder unit, we reduced the number of different high-pressure pipes, to reduce the number of high-pressure connections and to simplify the mounting procedure. The evaluation of multiple engine assemblies verified the improved tightness and the elimination of rework after maintenance. Mounting time is reduced, reliability is increased.

Increased system pressure up to 2,200 bar
Since the CR 2.2 has been designed as a technology kit with a lifespan of several years, the design pressure was raised to 2,200 bar for future engine requirements of atomization quality and better combustion efficiency. In relation to the parts size this needed effort to reach sufficient safety margins and the resulting design has been successful in balancing performance gains with material stress limits.

Increased target TBO of main components
With the decision to equip the 49/60 engine family with CR 2.2, the major maintenance intervals needed to be aligned. From multiples of 6,000 hours to multiples of 8,000 hours. This meant an increase in target TBO of 33% with additionally higher revolutions, making the increase even more challenging. Extensive testing is ongoing, to fulfill the TBO schedule as planned.

In summary, the new CR 2.2 is designed to be the future liquid fuel injection system for Everllence 4-stroke engines.

+38%
max. possible rail pressure

+33%
target TBO interval

-35%
high-pressure connections

System description and general overview

The system comprises three main component categories: high-pressure pump, injector and high-pressure valves.

Independent of the engine type, the layout is always seen per cylinder unit. In front of each cylinder is a high-pressure pump or accumulator unit. This allows standardized machining across different engine types, reducing the cost and complexity of the crank case. All pumps are connected with the same high-pressure pipe to create the common-rail system. From the pumps, the fuel is fed towards the injector via a high-pressure pipe and threaded piece. Each cylinder head houses an injector in the center of the exhaust and intake valves. Valve block with pressure-limiting valve and flushing valve complete the system.

The high-pressure pump creates the system pressure independent of engine speed and feeds the injectors between each injection. Just as in the CR 1.6 injection system, the injection is freely parameterizable for different engine types, either as pure diesel engine or dual fuel engine. A pressure limiting valve, flow limiters and flushing valve ensure safe engine operation and HFO capability. In terms of low-pressure fuel supply, all the pressure, flow and cleanliness requirements remain as for CR 1.6, meaning customer acceptance testing is no more demanding and ensuring a high degree of system approval.

The hydraulic path of the fuel flows from the engine inlet through the duplex filter and runs along the engine to the first high-pressure pump. At each high-pressure pump the fresh fuel flows around the inner pump element for thermal stability and leaves the pump on the opposite side. The fuel flow through the pumps is optimized for balancing the thermal load on these components. This helps keep the fuel temperature from rising excessively as it flows along the engine, consequentially reducing the risk of pump seizures in operation. From the supply, a smaller amount of fuel branches off to the injector for flushing. When running the engine on HFO, it is essential to heat up the fuel system before startup and maintain the temperature in operation or stand-by. The pneumatic controlled flushing valve allows the fuel to enter the high-pressure system on one side and circulate through, until the other side of the pump deck. This forced fuel flow requires a pressure difference over the engine and is realized with a spring-loaded valve. The required valves are grouped in a valve block at the first cylinder (see Figure 1 & 2).

In dual fuel operation with a gaseous fuel as the main energy source, the CR 2.2 injection system is pre-activated and ready for a quick change over to diesel operation, when needed.

The CR 2.2 system is equipped with the same sensors as the previous system. Two redundant rail pressure sensors meet maritime class society requirements for the rail pressure control. Solenoid driven control units regulate the fuel brought into the high-pressure system. Special sensors are used to detect break leakages within the double-walled leakage drain.

Based on full scale engine measurements, the necessary mechanical power needed to drive the 32/44CR2.2 injection system could be reduced by 48% compared to the 32/44CR predecessor system.

1 Injector
2 High-pressure pump*
3 Accumulator unit*
4 Flushing valve*
5 Pressure-limiting valve*
6 Non-return valve for flushing
7 High-pressure pipes
8 Pressure reducing valve for DF operation*

*Cross-platform

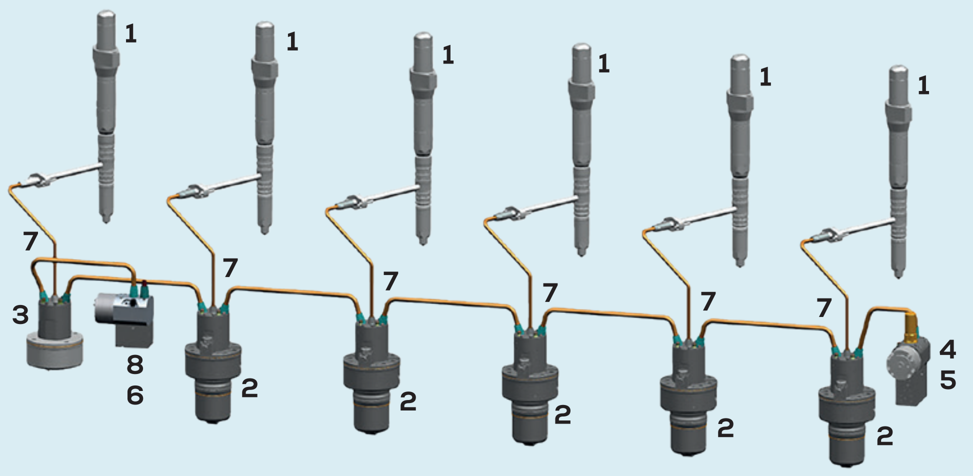


Figure 1: CR 2.2 injection system from 49/60DF

1 Injector
2 High-pressure pump*
3 Accumulator unit*
4 Flushing valve*
5 Pressure-limiting valve*
6 Non-return valve for flushing
7 High-pressure pipes

*Cross-platform

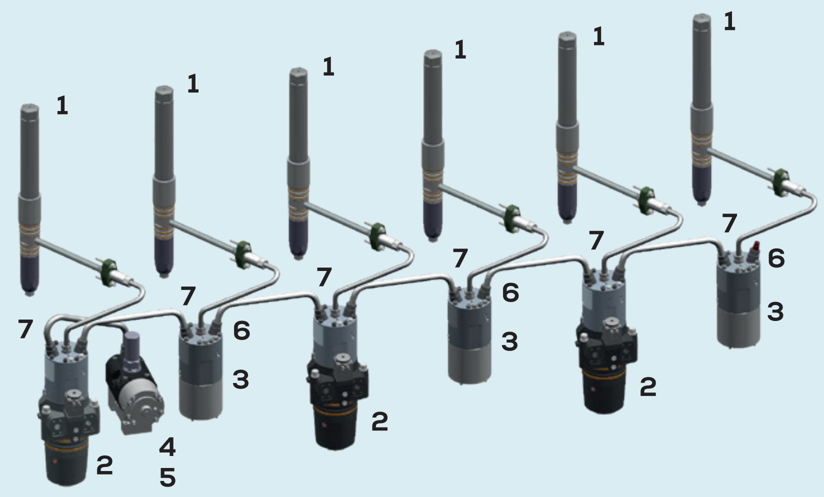


Figure 2: CR 2.2 injection system from 32/44CR

One high-pressure pump for 32/44 and 49/60

As a core component, the high-pressure pump was designed and manufactured in-house by Everllence. This allowed us to adapt the CR 1.6 high pressure pump to the new requirements. As the previous two-cylinder accumulator units from the CR 1.6 system were not continued in CR 2.2, a pressure reservoir for compressed fuel had to be attached to the pump. This resulted in design changes of the pump element itself and upwards to the high-pressure fuel delivery connection. The fuel flow path through the pump is optimized through several internal arrangement measures, resulting in better efficiency and improved tightness.

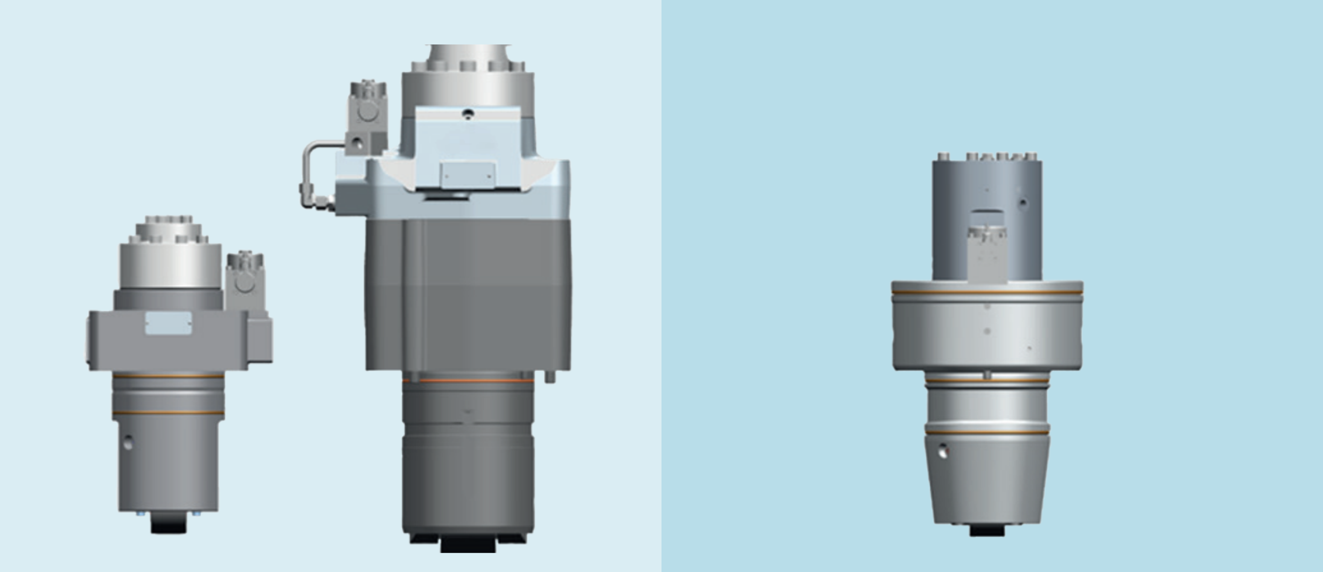


Figure 3: Comparison of high-pressure pumps CR 1.6 vs. CR 2.2

The pumps are still cam-driven adapted to the application to ensure to fulfil the demands of 3X & 4X. Also, on 4X engines there is no need for a separate pump drive anymore. The integration deep into the pump deck on the engine provides sturdy mounting without the need for an additional swing arm. In comparison to CR1.6 the pump element is unified. The piston design has been changed. Together with optimized design characteristics inside the cylinder, the efficiency increases enormously due to reduced internal leakages.

Based on the readings of the rail pressure sensors the solenoid-actuated suction valve controls the amount of fuel provided for compression. On top of the pump element assembly sits the accumulator, providing equal high-pressure connections on each cylinder and featuring the flow limiter towards the injector.

In comparison to 32/44 CR 1.6 the arrangement of suction and delivery valve in combination with the piston design results in a 13% higher hydraulic efficiency at 1,600 bar.

To be future proof, the high-pressure pump was tested with various fuels and loads. Besides endurance runs, Everllence conducted extreme condition tests with sharp load ramps combined with thermal stress. Even with heavily reduced inlet pressure or inlet flow, resulting in overheating of the pump element, excellent validation results were achieved. Experience to date validates the decision to use a standardized pump for both engine sizes.

Break leakages that can occur in the high-pressure circuit are caught via the double-walled high-pressure lines and returned to the leakage tank. This eliminates the risk before a spray can develop. The two detection screws in the accumulator help the engineer to narrow down the location of the leakage. This allows the affected component to be located more quickly without dismantling the whole system, and the leakage to be repaired.

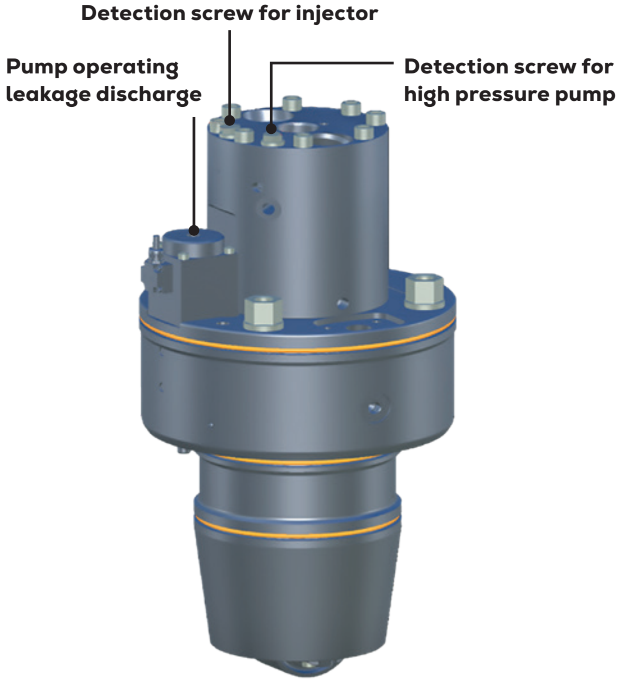


Figure 4: Leakage detection measures for the high-pressure pump

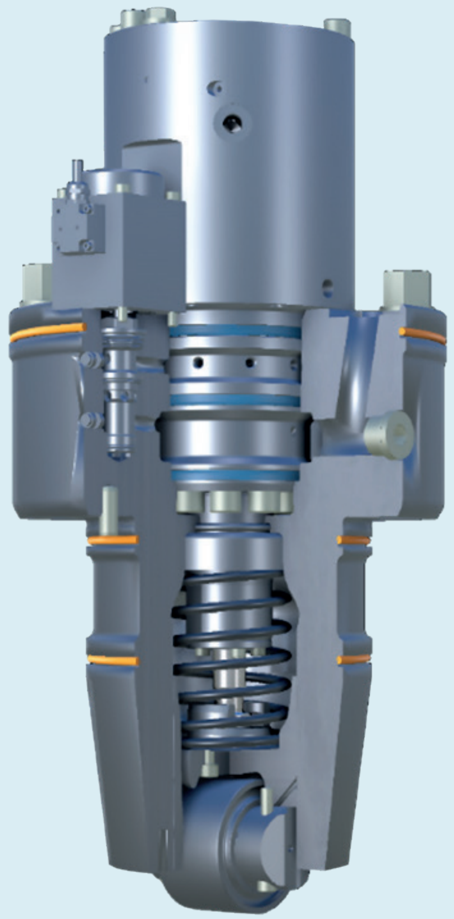


Figure 5: High-pressure pump cross-section

Injector with attached accumulator

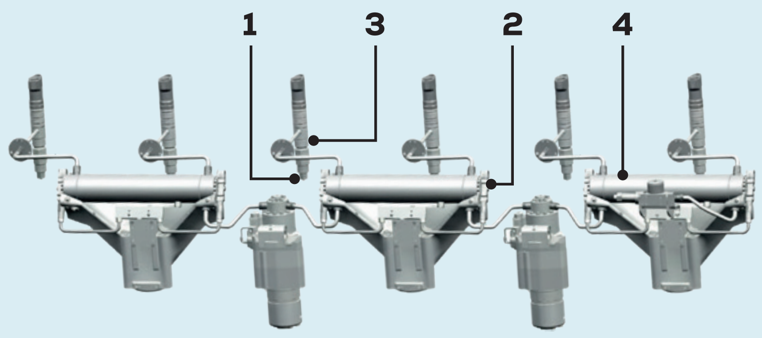
The most obvious new feature besides the high-pressure pump, is the Everllence injector. It's the essential component to realize improved injection stability and flexibility, and thus best engine performance. The injector combines several functions which were divided into different components in CR 1.6 – see figure 7. Firstly, the actuator, a solenoid-actuated high pressure fuel valve, was placed close to the nozzle for faster response time. Secondly, an accumulator was attached to the injector to stabilize the injection pressure during injection duration. These changes are key to overcome the CR 1.6 performance limits. The long hydraulic distance between CR 1.6 actuator and nozzle set boundaries for combustion development. Now, with the CR2.2-Injector, the injection pattern can be easily adapted to the needs of the engine including multiple injections per cycle.

Nozzle
Coming from a conventional spring-loaded injection valve in CR 1.6, the nozzle had to be re-designed. A major change is the presence of rail pressure up to the needle seat. That requires a different needle design to let the fuel pass. As always, the nozzle flow is determined by the needed power output of the engine.

Intermediate plate
Between the nozzle and the high-pressure fuel valve, an intermediate plate provides individual ratios of supply and return throttle diameter. Placing the throttles in a separate part simplifies the adaptation of the injection rate to each application. By varying the diameters, the slope of injection start or injection end can be manipulated. In most cases a steep injection end is preferable which results in lower soot emissions.

High pressure fuel valve
The fuel valve is a high pressure fuel valve downstream of the control chamber. When the valve is energized the anchor is lifted, enabling the valve seat to open. The solenoid valve is a high pressure valve downstream the accumulator. The needle moves as soon the valve is energized. At the end of each injection no cut-off fuel is wasted. Furthermore, the anchor of the valve is flushed with fuel. Firstly, for thermal stability and enabling HFO operation, secondly to return the control amount back into the fuel supply system.

48/60CR1.6
1 Nozzle with needle
2 Valve group
3 Support body
4 Accumulator



CR 2.2
1 Nozzle with needle
2 Solenoid valve
3 Support body
4 Accumulator

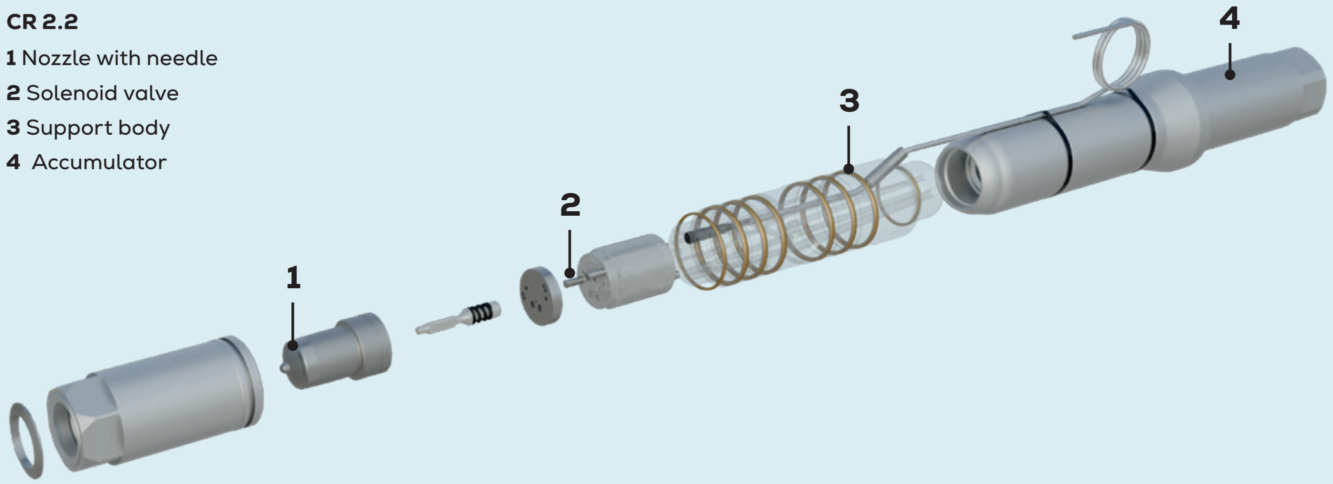
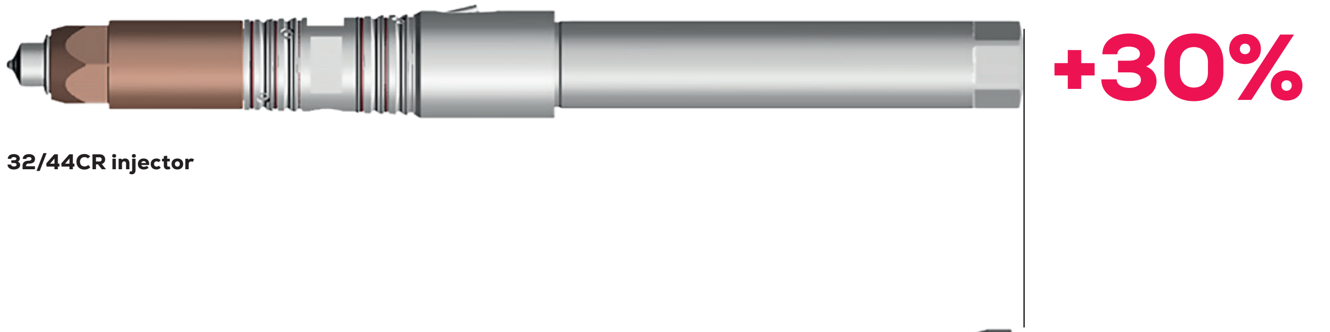


Figure 7: Comparison of the layout of the CR 1.6 and CR 2.2 main components



32/44CR injector

49/60DF injector

Figure 8: Size comparison of 32/44CR and 49/60DF injectors

High-pressure valves and safety functions

To ensure safe operation of the system and to fulfil all regulatory requirements, the system is equipped with high-pressure safety valves. The philosophy was taken over from CR 1.6 but adapted to the higher pressure level, with additional features incorporated where necessary.

As in CR 1.6 the pressure limiting valve and the flushing valve are located in a separate valve block. This block is connected with a high-pressure pipe and sits on top of a low-pressure connection block, enabling easier checking or changing of high-pressure components without the need to dismount low pressure connections. That principle is used on all engines equipped with CR 2.2.

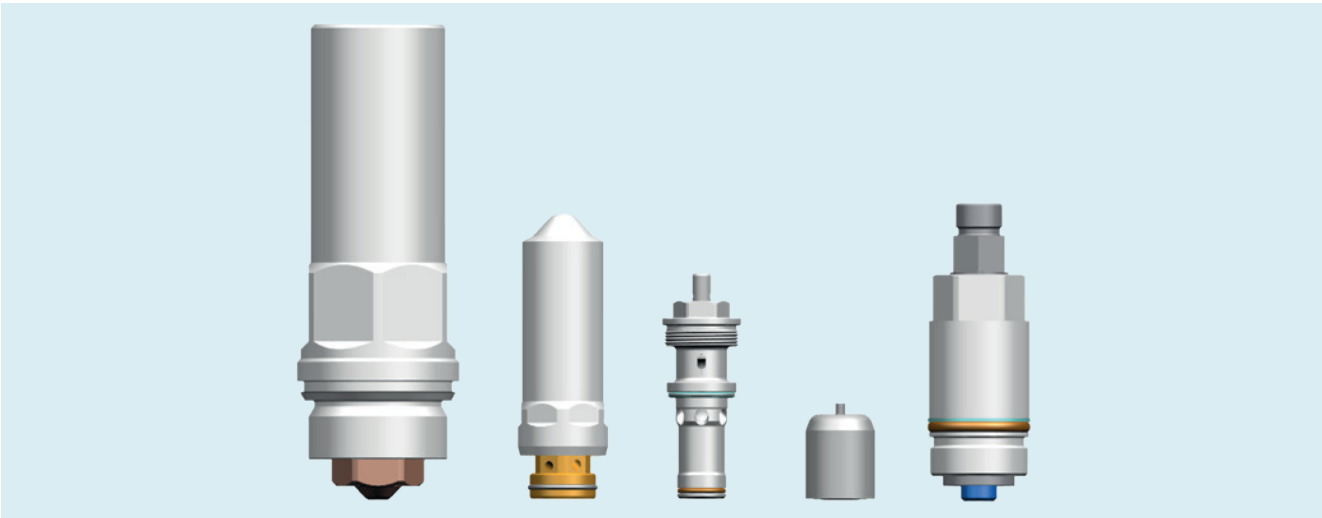


Figure 9: CR 2.2 high-pressure valves, from left to right pressure limiting valve, flow limiter, control valve, flushing valve and non-return valve

Pressure limiting valve (PLV)
The PLV is a spring-loaded safety valve. Its opening pressure is factory-set by shims to precisely increase/decrease the static opening pressure. For increased stability, the needle seat has a leakage discharge port to prevent small leakages causing an opening pressure reduction. Furthermore, the valve head is designed so that the spring chamber is flushed when the valves open. Also, there is no direct outlet on the valve itself, the discharged fuel is released back into the valve block.

Flow limiting valve (FLV)
As mentioned, the flow limiter is located in the accumulator on the high-pressure pump or accumulator unit. This setup is adopted from CR 1.6, a pressure-balanced integration in the flow path towards the injector. Since the rail pressure is present until the injector needle seat, additional safety features have been implemented.

Flushing valve (FV), pneumatic cylinder and non-return valve
The use of HFO requires the high-pressure system to be flushed in engine standstill. Either to preheat the FIE from cold engine condition or to maintain the fuel temperature in standby. It is a forced flushing process due to the differential pressure between engine inlet and outlet. Three components act together. The flushing valve seals the high-pressure system to the low-pressure side, where the rail pressure supports the tightness. This valve is actuated by the pneumatic cylinder. It is double-acting to have sufficient opening force even in aged condition or when air pressure is low. When the FV is pushed open, it releases the high pressure from the system to the low-pressure engine outlet. Since on the very other end of the system the non-return valve is connected to the higher supply pressure, this valve opens and fuel streams through the components on the pump deck.

An additional flushing is routed to the cylinder head towards the injector. The flushing supply fuel is brought from alongside the engine through the cylinder head to the central inner bore. Via ring grooves, the fuel is handed over to the injector. Inside the injector the fuel is routed through the solenoid valve to ensure a homogenous temperature distribution for stable spray characteristics and reduced wear.

Closed break leakage circuit
Since Everllence also serves the marine industry, special attention is paid to the safety of the injection equipment. This includes all lifetime periods of the engine. We make sure that the operation and maintenance can be conducted without danger. Part of this approach is that all components are connected to a closed and monitored break leakage circuit. This means that every single high-pressure connection has a discharge port to the break leakage system. Every high-pressure pipe is double walled. It is ensured that the discharge diameters are equal or bigger than the feed diameters. This effort is made so that in the unlikely case of a high-pressure leakage no pressure can be built up within the system and cause ruptures or fuel spills. At each bank of the engine a possible leakage is monitored with special sensors and alarms are raised at the engine control system. Together with the standard detection screws at each cylinder this means that a quick identification of the leakage point is possible. Based on several successful engine commissions, the simplified layout has proved to be sufficient for detection. The more complex detection screws of CR 1.6 are now obsolete. After the level switch, break-leakage joins the operational leakage and returns via one common line, enabling fuel reuse and a single engine–supply connection.

Break leakage supervision is also applicable to the pump deck itself, where any liquid leakage e.g. cooling water, lube oil or fuel is monitored by sensors. Such an external leakage is not suitable for reuse.

Service concept and operational changes

A service concept for injector and pump element assembly is in preparation. Everllence will provide a closed-loop exchange of exhausted components with its worldwide network of service hubs.

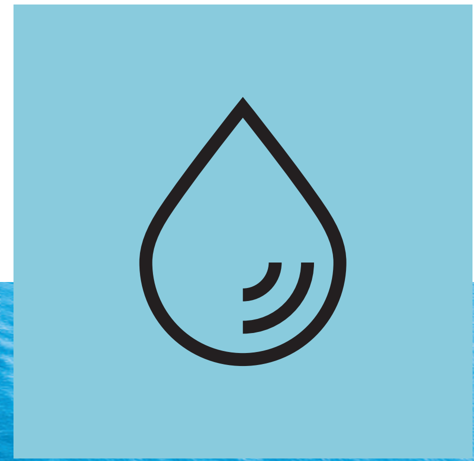
The benefit for customers is that the maintenance effort in onboard workshops is reduced. The plug & play exchange of an injector reduces engine downtime. On 49/60 engines the maintenance schedule for the injection systems requires less manpower and time.

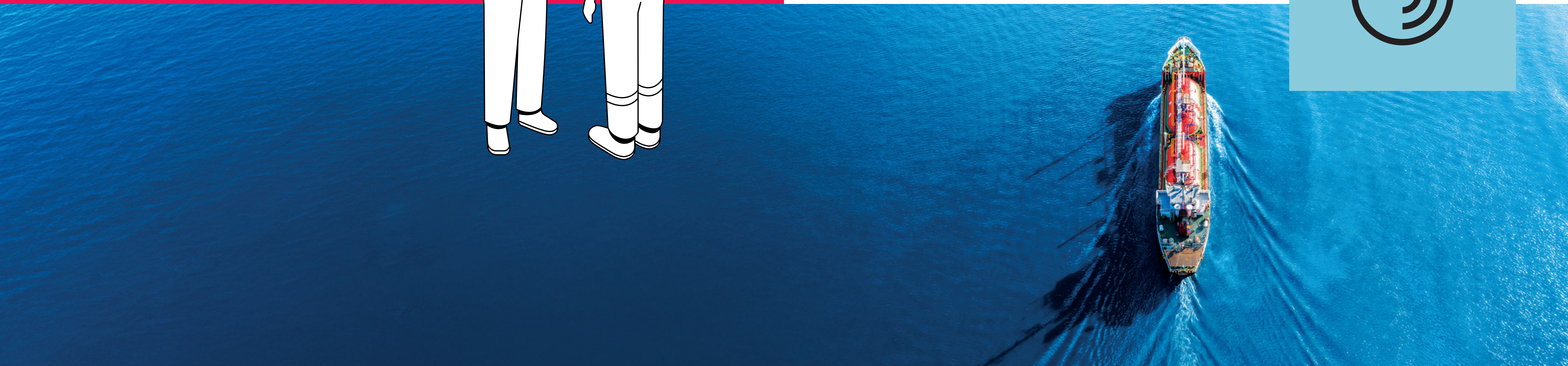
In the qualified service hub the injector is dismantled, cleaned and inspected for further use. Trained staff reassemble the injector with tested and approved components on a state-of-the-art assembly station. This process ensures the proper injection behavior and conformity of production.

Technology transfer to future fuel injection equipment

The medium-speed engine industry is heading towards new fuel types. In a fast-changing environment, there can be no certainty which fuel will dominate in 10 or 20 years. There are therefore various injection principles which may be required to meet upcoming combustion requirements.

The release of the CR 2.2 system enables state-of-the-art liquid injection performance for coming years. It provides key elements like nozzle design or solenoid technology. Design principles are applied to methanol or ammonia injectors, materials and manufacturing processes are pre-developed. All validation experience is transferred; the same validation strategy can be followed.





Figures

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