

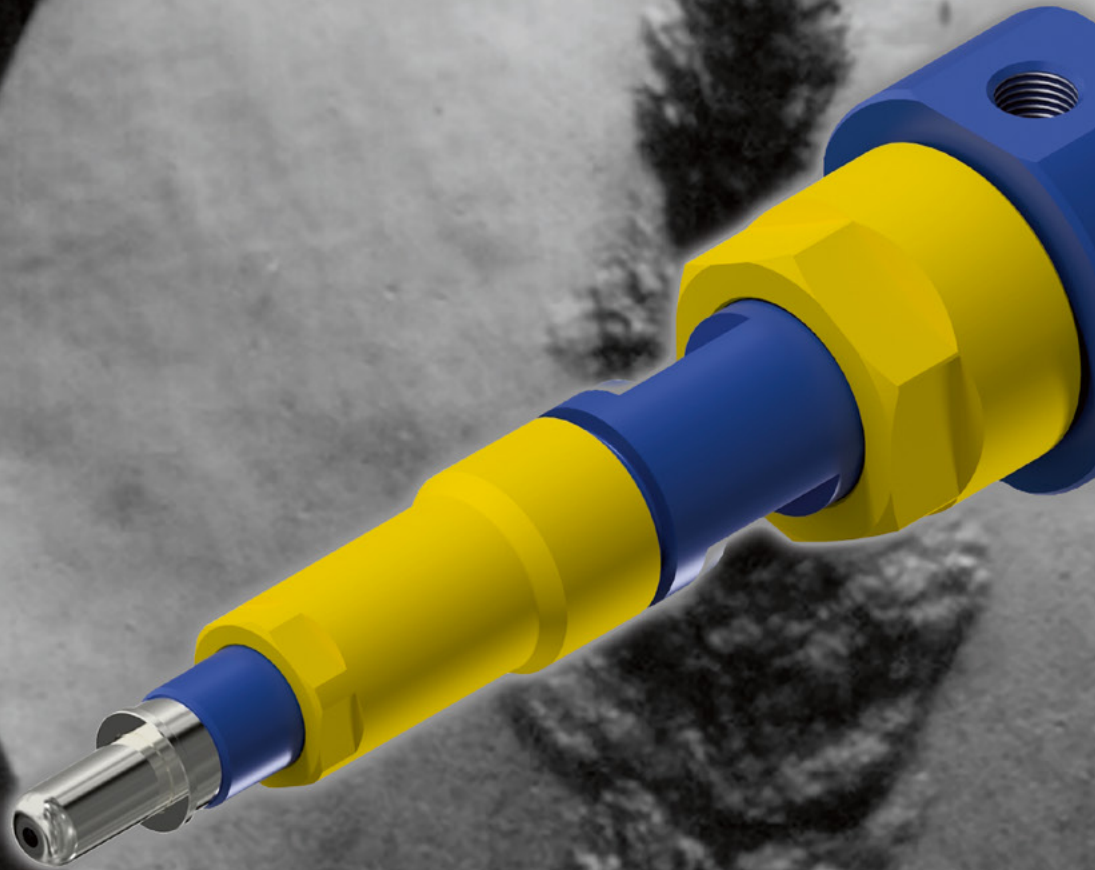
MTZ extra



**Injection Systems for
Conventional and new Fuels**

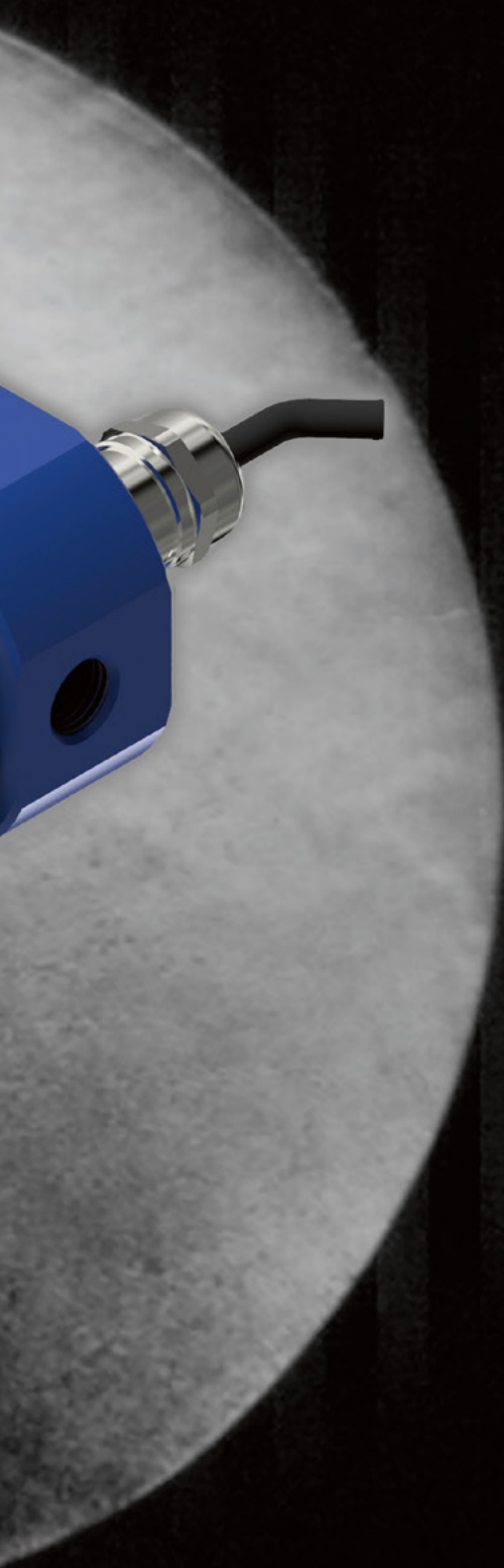
GANSER

COMMON RAIL SYSTEMS



Electro-hydraulically Actuated DI-injector for Alternative Fuels

To ensure engine compatibility with alternative fuels, the injection systems for example need to be adapted to the behavior, properties and peculiarities of each fuel. Ganser CRS has therefore developed an injector for the direct injection – initially of hydrogen – for a single-cylinder test engine to identify and address the core challenges of the new fuels.



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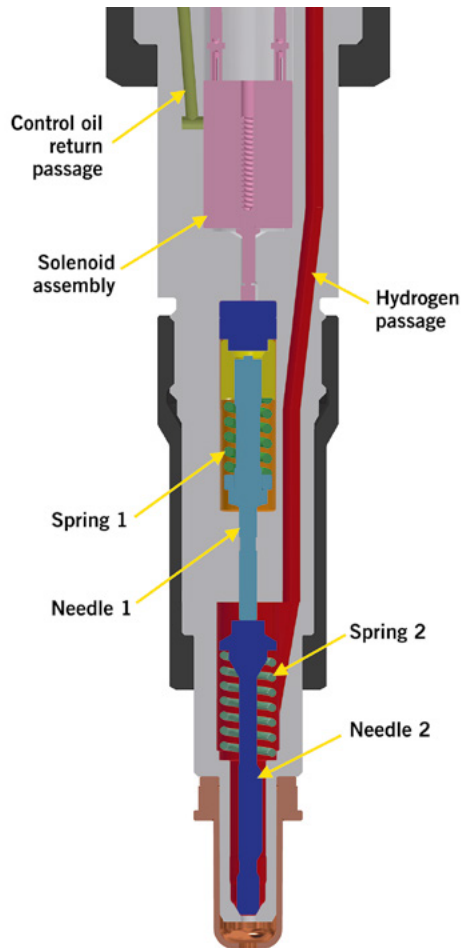
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■ The worldwide goal of greenhouse gases reduction, climate-neutral power generation and so-called green energy pushes many industries to rethink their technologies and processes. Among others, engine manufacturers aim to replace fossil fuels with alternative fuels which, in the future, shall be produced using green energy. The diesel common rail injector has been developed and refined over several decades [1, 2]. For alternative fuels, however, many questions still need to be answered, or even identified.

FIGURE 1 Internals of the injector (© Ganser)



Ganser CRS's approach with regard to the development of the injector consists of first studying injection systems on a small scale in order to determine and address the fundamental challenges of the new fuels, and subsequently move to larger engines and production scales with the acquired knowledge. The injector was primarily designed for the hydrogen injection on a single-cylinder test engine with roughly 1 l displacement. An injection quantity of approximately 24.5 mg was targeted. The injection duration depends on the injection pressure.

INJECTOR DESIGN

A direct-electrically actuated injector [3], that is where the solenoid is directly connected to the nozzle needle, is conceptually simpler as fewer components are needed and no other fluid than the

fuel is in use which could leak or mix with the fuel to be injected.

However, Ganser has opted for the electro-hydraulic actuation in this project to avoid the disadvantages of the directly actuated injector. The control oil serves both as a lubricant and, by the layout of the control hydraulics within the injector, as a damper for the movement of the needle, while in the directly actuated injector moving parts are not lubricated or their motion dampened, leading to additional wear.

Moreover, the pressure of the oil can be set several orders of magnitude higher than the hydrogen pressure, making the hydraulic forces the dominant forces in the injector. The pressure differences can be generated in the same way as in a diesel common rail injector in a relatively small space. Subsequently, the hydraulic forces can at the same time be used to seal

against hydrogen leakage and to quickly open the injector and start the hydrogen injection, all while keeping a compact design. In the directly actuated injector, the forces can only be increased by using a larger solenoid, leading to a bulky design and inefficient use of space.

Furthermore, for operation of engines in a power range above 1 MW and with the high compression ratios of a diesel cycle, often a micro-pilot diesel injector is used to ignite the main fuel charge [4]. The main charge can be hydrogen or another alternative fuel. In that case, diesel fuel can at the same time be used for pilot injection, and as control oil for the injector delivering the main charge of alternative fuel.

It is evident that, for a fuel differing from hydrogen (H_2), such as Methanol (CH_3OH) or Ammonia (NH_3), an injector with the same driving concept and the same outline dimensions can be designed. In some cases, for a given engine type, changing the injector's nozzle to be suitable for use with a different fuel will be the only major change in the injector. This characteristic allows the engine manufacturer to be more flexible, because the main fuel injector, having the same outline dimensions, will require the same space in the engine's cylinder head.

All connections are located at the top of the injector. From the inlet at the top, hydrogen flows directly to the tip of the injector, **FIGURE 1**. A removable cap is mounted on the nozzle, allowing the engine manufacturer to easily test different spray configurations.

The nozzle needle is made up of two pieces, the upper needle (needle 1) and the lower needle (needle 2). This facilitates the precise manufacturing and the assembly of the injector. A second needle spring (spring 2) is therefore needed as well. It will push the lower needle upwards when the upper needle is moving. Its force can be relatively small compared to the upper needle spring (spring 1) which closes the injector when no system pressure is present.

The control oil is pressurized to approximately 300 bar and fed into a chamber containing the top of the upper needle and the hydraulic actuation components, including Ganser's

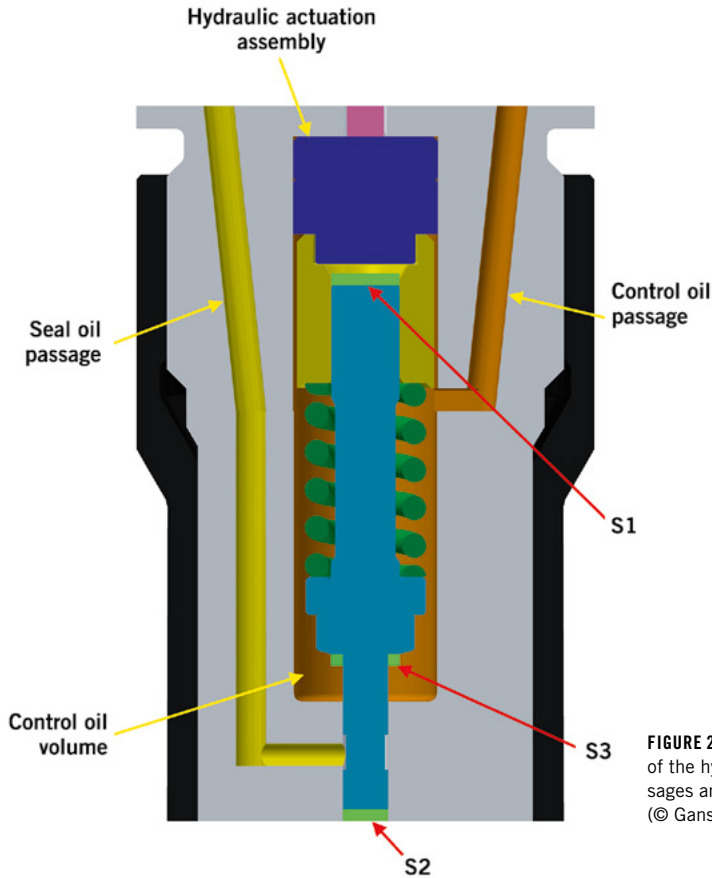


FIGURE 2 Detailed view of the hydraulic passages and components (© Gansner)

proprietary poppet valve [5], **FIGURE 2**. The solenoid is mounted above the actuation assembly. The actuation follows the principles used in Gansner's diesel common rail injectors.

The nozzle needle motion is governed mainly by the hydraulic forces on surfaces S1 and S3, **FIGURE 2**. Surface S3 is annular, with area

$$\text{Eq. 1 } A_3 = A_1 - A_2$$

where A_1 and A_2 are the areas S1 and S2, respectively. In the closed state, the control oil volume is at supply pressure p_s , acting on S1 and S3. Since A_1 is larger than A_3 , the net force pushes the needle downward.

When the solenoid opens, the pressure on S1 drops to a value p_r , which is considerably lower than p_s , while S3 remains at p_s . The force

$$\text{Eq. 2 } A_1 \times p_r$$

then becomes smaller than

$$\text{Eq. 3 } A_3 \times p_s$$

creating an upward net force that lifts the needle, initiating the injection. To end the injection, the solenoid closes and the pressure above S1 returns to p_s , restoring the initial balance and closing the needle.

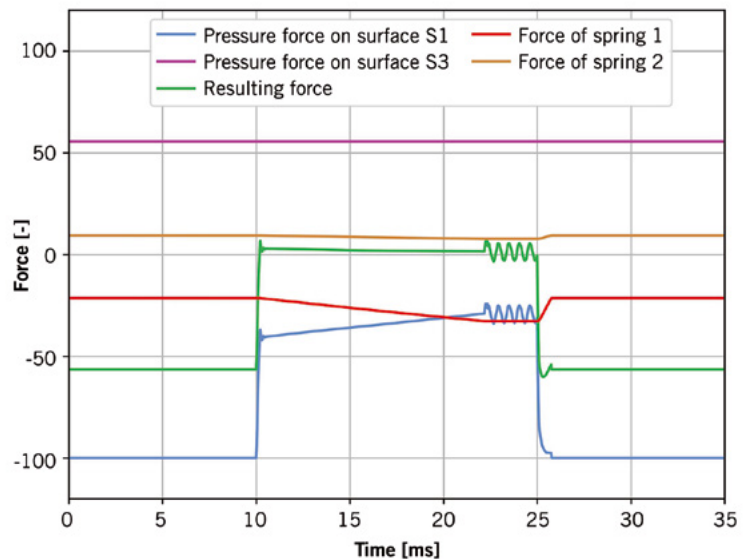
The springs exert nearly constant forces, mainly keeping components in place when the control oil circuit is depressurized. The force on surface S2 is negligible.

SIMULATIONS

To check the calculations and the injector concept, a model was set up with use of the 1D-multi-domain simulation software Siemens Simcenter Amesim. One of the major advantages of this software is that all aspects of the injector (pneumatic, hydraulic, electric and mechanical) can be integrated in one model.

The resulting forces exerted by the oil, the spring forces, as well as the resulting net force acting on the nozzle needle were normalized and are plotted over the duration of one injection, **FIGURE 3**. Negative forces push the needle downward, while positive forces push it upward. The plot shows that mainly the force on surface S1 changes, while the other forces remain comparatively constant.

FIGURE 3 Forces acting on the nozzle needle over one cycle and resulting net force on the needle (© Gansner)



Hydrogen pressure [bar]	Control oil pressure [bar]	Seal oil pressure [bar]	Hydrogen leakage [Nml/min]
10	15	15	0
10	300	15	0
20	25	25	21.4
20	300	25	3.2
30	35	35	49.2
30	300	35	7.9

TABLE 1 Measured hydrogen leakage at the tip of injector 2 (© Gansner)

The injected hydrogen mass was computed as well and the simulation was repeated for several pressures and pulse durations. The targeted injection mass of 24.5 mg could be met for a hydrogen pressure range between 10 and 30 bar. At 10 bar an injection duration of around 25 ms is necessary to reach the target quantity, which corresponds to 150 °CA at 1000 rpm.

TEST RESULTS

The injectors underwent several tests, and some of the results are presented in the following for two injectors. Since hydrogen is highly diffusive and requires careful handling, leakage tests

have been performed before engine operation. No leakage was detected on the first injector at any hydrogen pressure. However, small hydrogen leakage was detected at the nozzle tip of the second injector. This leakage has been measured at different hydrogen, control oil and seal oil pressures, TABLE 1. No leakage was detected at any other location on the second injector.

One of the advantages of the hydraulically actuated injector becomes apparent when looking at these test results: the force exerted by the control oil on the needle substantially reduces the hydrogen leakage or even prevents it completely.

The injector maps were recorded for different hydrogen pressures. With these, the engine operator has the certainty, that the injector delivers enough fuel for the engine to operate. Furthermore, they serve as verification of the simulations. Some discrepancies arose at 10 bar between the simulations and the tests. However, at 30 bar, the comparison shows an excellent match, FIGURE 4 and FIGURE 5.

The differences between both injectors may stem from minor differences in geometries coming from the manufacturing process. For example, small differences in the seat diameter of the nozzle needle can have an effect on the flow cross sections, which influence the flow behavior of the gas. Hence, precise manufacturing, especially of the smallest flow cross sections, are essential for consistent and repeatable injections across several injectors.

CONCLUSIONS AND OUTLOOK

The design, simulation, and testing of an electro-hydraulically actuated hydrogen injector for direct injection were described in this article. The working principle is based on the well-established diesel common rail injector concept. While the focus of this work was on hydrogen, the injector can be adapted for several alternative fuels with minimal modifications.

The use of high-pressure control oil generates forces of several hundred newtons on small surfaces. This allows for quick and stable injector dynamics while keeping the design compact with a comparatively small solenoid. Furthermore, the hydraulic oil and high forces help sealing against hydrogen leakage.

The simulation results accurately predicted the injector’s behavior in many scenarios. The injection tests confirmed these results and demonstrated that the target injection quantities could be reached for all pressures in the range of 10 to 30 bar. However, some discrepancies between the simulations and the tests still remain, highlighting some of the limitations of the current simulation methods.

Finally, it is worth emphasizing that the injector concept is scalable and can be adapted for larger applications, such as large-bore engines. In such cases,

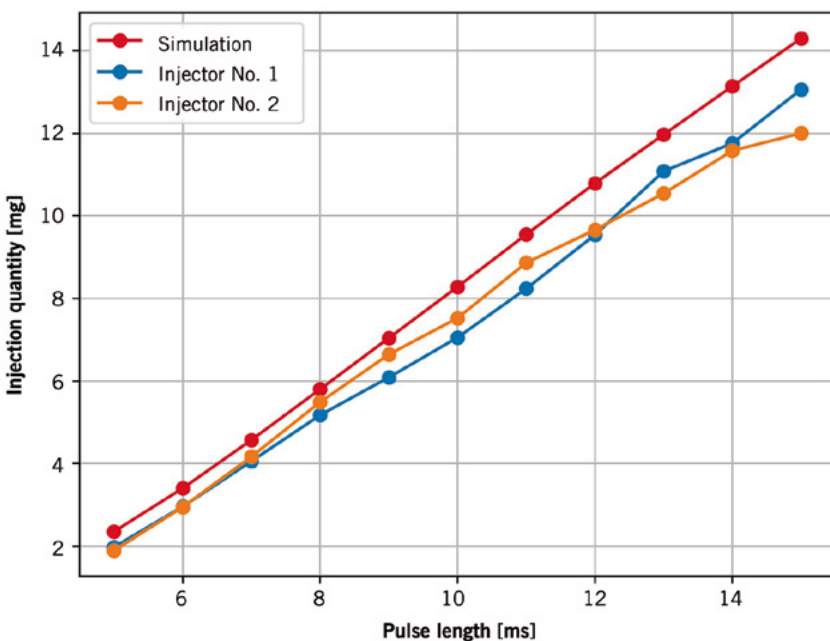


FIGURE 4 Injector map at 10 bar hydrogen pressure: comparison between simulation results and measurements for two injectors (© Gansner)

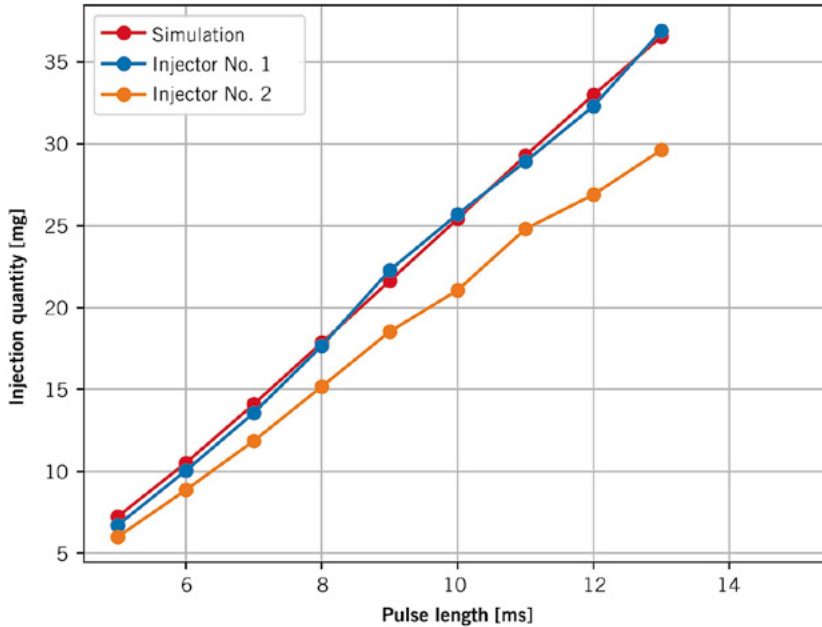


FIGURE 5 Injector map at 30 bar hydrogen pressure: comparison between simulation results and measurements for two injectors (© Ganser)

higher forces are required to open and close the nozzle needle and seal against hydrogen leakage. Thanks to the electrohydraulic actuation, this can be achieved

by increasing the control oil pressure or slightly enlarging the surface areas, allowing the injector to retain the original solenoid and a compact size.

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COMMON RAIL SYSTEMS

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