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Diesel Engine Management

Systems and Components

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Konrad Reif
Editor

Diesel Engine Management

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Foreword

This reference book provides a comprehensive insight into today´s diesel injection systems and electronic control. It focusses on minimizing emissions and exhaust-gas treatment. Innovations by Bosch in the field of diesel-injection technology have made a significant contribution to the diesel boom. Calls for lower fuel consumption, reduced exhaust-gas emissions and quiet engines are making greater demands on the engine and fuel-injection systems.

Complex technology of modern motor vehicles and increasing functions need a reliable source of information to understand the components or systems. The rapid and secure access to these informations in the field of Automotive Electrics and Electronics provides the book in the series "Bosch Professional Automotive Information" which contains necessary fundamentals, data and explanations clearly, systematically, currently and application-oriented. The series is intended for automotive professionals in practice and study which need to understand issues in their area of work. It provides simultaneously the theoretical tools for understanding as well as the applications.

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Basics

History of the diesel engine

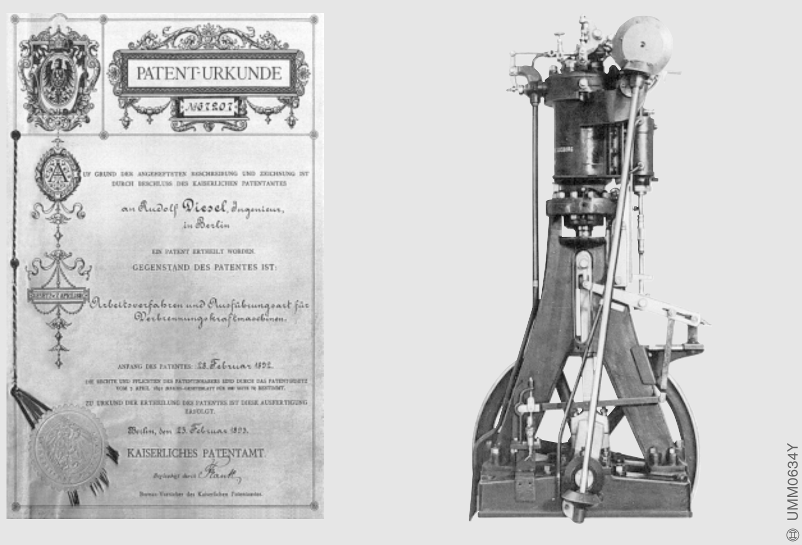
As early as 1863, the Frenchman Etienne Lenoir had test-driven a vehicle which was powered by a gas engine which he had developed. However, this drive plant proved to be unsuitable for installing in and driving vehicles. It was not until Nikolaus August Otto's four-stroke engine with magneto ignition that operation with liquid fuel and thereby mobile application were made possible. But the efficiency of these engines was low. Rudolf Diesel's achievement was to theoretically develop an engine with comparatively much higher efficiency and to pursue his idea through to readiness for series production.

In 1897, in cooperation with Maschinenfabrik Augsburg-Nürnberg (MAN), Rudolf Diesel built the first working prototype of a combustion engine to be run on inexpensive heavy fuel oil. However, this first diesel engine weighed approximately 4.5 tonnes and was three meters high. For this reason, this engine was not yet considered for use in land vehicles.

"It is my firm conviction that the automobile engine will come, and then I will consider my life's work complete." (Quotation by Rudolf Diesel shortly before his death)

However, with further improvements in fuel injection and mixture formation, Diesel's invention soon caught on and there were no longer any viable alternatives for marine and fixed-installation engines.

2 Rudolf Diesel



1 Patent document for the diesel engine and its first design from 1894

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Rudolf Diesel

Rudolf Diesel (1858–1913), born in Paris, decided at 14 that he wanted to become an engineer. He passed his final examinations at Munich Polytechnic with the best grades achieved up to that point.

Idea for a new engine

Diesel's idea was to design an engine with significantly greater efficiency than the steam engine, which was popular at the time. An engine based on the isothermal cycle should, according to the theory of the French physicist Sadi Carnot, be able to be operated with a high level of efficiency of over 90%.

Diesel developed his engine initially on paper, based on Carnot's models. His aim was to design a powerful engine with comparatively small dimensions. Diesel was absolutely convinced by the function and power of his engine.

Diesel's patent

Diesel completed his theoretical studies in 1890 and on 27 February 1892 applied to the Imperial Patent Office in Berlin for a patent on "New rational thermal engines". On 23 February 1893, he received patent document DRP 67207 entitled "Operating Process and Type of Construction for Combustion Engines", dated 28 February 1892.

This new engine initially only existed on paper. The accuracy of Diesel's calculations had been verified repeatedly, but the engine manufacturers remained skeptical about the engine's technical feasibility.

Realizing the engine

The companies experienced in engine building, such as Gasmotoren-Fabrik Deutz AG, shied away from the Diesel project. The required compression pressures of 250 bar were beyond what appeared to be technically feasible. In 1893, after many months of endeavor, Diesel finally succeeded in reaching an agreement to work with Maschinenfabrik Augsburg-Nürnberg (MAN). However, the agreement contained concessions by Diesel in respect of the ideal engine. The maximum pressure was reduced from 250 to 90 bar, and then later to 30 bar. This lowering of the pressure, required for mechanical reasons, naturally had a disadvantageous effect on combustibility. Diesel's initial plans to use coal dust as the fuel were rejected.

Finally, in Spring 1893, MAN began to build the first, uncooled test engine. Kerosene was initially envisaged as the fuel, but what came to be used was gasoline, because it was thought (erroneously) that this fuel would auto-ignite more easily. The principle of auto-ignition – i.e. injection of the fuel into the highly compressed and heated combustion air during compression – was confirmed in this engine.

In the second test engine, the fuel was not injected and atomized directly, but with the aid of compressed air. The engine was also provided with a water-cooling system.

It was not until the third test engine – a new design with a single-stage air pump for compressed-air injection – that the breakthrough made. On 17 February 1897, Professor Moritz Schröder of Munich Technical University carried out the acceptance tests. The test results confirmed what was then for a combustion engine a high level of efficiency of 26.2%.

Patent disputes and arguments with the Diesel consortium with regard to development strategy and failures took their toll, both mentally and physically, on the brilliant inventor. He is thought to have fallen overboard on a Channel crossing to England on 29 September 1913.

Mixture formation in the first diesel engines

Compressed-air injection

Rudolf Diesel did not have the opportunity to compress the fuel to the pressures required for spray dispersion, spray disintegration and droplet formation. The first diesel engine from 1897 therefore worked with compressed-air injection, whereby the fuel was introduced into the cylinder with the aid of compressed air. This process was later used by Daimler in its diesel engines for trucks.

The fuel injector had a port for the compressed-air feed (Fig. 1, 1) and a port for the fuel feed (2). A compressor generated the compressed air, which flowed into the valve. When the nozzle (3) was open, the air blasting into the combustion chamber also swept the fuel in and in this two-phase flow generated the fine droplets required for fast droplet vaporization and thus for auto-ignition.

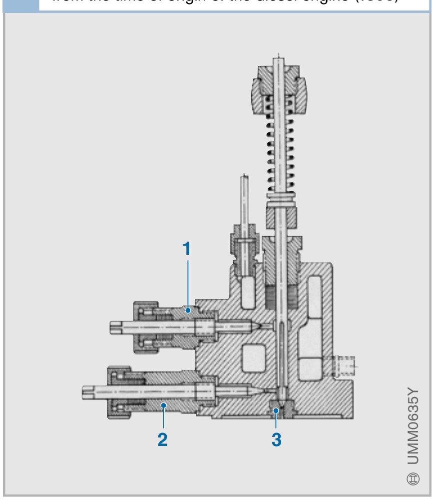
A cam ensured that the nozzle was actuated in synchronization with the crankshaft. The amount of fuel to be injected as controlled by the fuel pressure. Since the injection pressure was generated by the compressed air, a low fuel pressure was sufficient to ensure the efficacy of the process.

The problem with this process was – on account of the low pressure at the nozzle – the low penetration depth of the air/fuel mixture into the combustion chamber. This type of mixture formation was therefore not suitable for higher injected fuel quantities (higher engine loads) and engine speeds. The limited spray dispersion prevented the amount of air utilization required to increase power and, with increasing injected fuel quantity, resulted in local over-enrichment with a drastic increase in the levels of smoke. Furthermore, the vaporization time of the relatively large fuel droplets did not permit any significant increase in engine speed. Another disadvantage of this engine was the enormous amount of space taken up by the compressor. Nevertheless, this principle was used in trucks at that time.

Precombustion-chamber engine

The Benz diesel was a precombustion-chamber engine. Prosper L'Orange had already applied for a patent on this process in 1909. Thanks to the precombustion-chamber principle, it was possible to dispense with the complicated and expensive system of air injection. Mixture formation in the main combustion chamber of this process, which is still

1 Fuel injector for compressed-air injection from the time of origin of the diesel engine (1895)



2 Principle of the precombustion-chamber engine

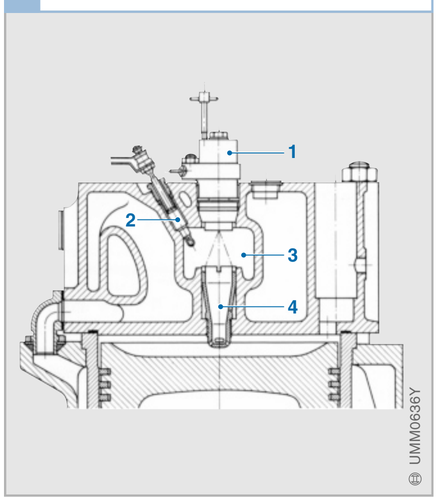


Fig. 1
1 Compressed-air feed
2 Fuel feed
3 Nozzle

Fig. 2
(Picture source: DaimlerChrysler)
1 Fuel valve
2 Glow filament for heating precombustion chamber
3 Precombustion chamber
4 Ignition insert

used to this day, is ensured by partial combustion in the precombustion chamber. The precombustion-chamber engine has a specially shaped combustion chamber with a hemispherical head. The precombustion chamber and combustion chamber are interconnected by small bores. The volume of the precombustion chamber is roughly one fifth of the compression chamber.

The entire quantity of fuel is injected at approximately 230 to 250 bar into the precombustion chamber. Because of the limited amount of air in the precombustion chamber, only a small amount of the fuel is able to combust. As a result of the pressure increase in the precombustion chamber caused by the partial combustion, the unburned or partially cracked fuel is forced into the main combustion chamber, where it mixes with the air in the main combustion chamber, ignites and burns.

The function of the precombustion chamber here is to form the mixture. This process – also known as indirect injection – finally caught on and remained the predominant process until developments in fuel injection were able to deliver the injection pressures required to form the mixture in the main combustion chamber.

Direct injection

The first MAN diesel engine operated with direct injection, whereby the fuel was forced directly into the combustion chamber via a nozzle. This engine used as its fuel a very light oil, which was injected by a compressor into the combustion chamber. The compressor determined the huge dimensions of the engine.

In the commercial-vehicle sector, direct-injection engines resurfaced in the 1960s and gradually superseded precombustion-chamber engines. Passenger cars continued to use precombustion-chamber engines because of their lower combustion-noise levels until the 1990s, when they were swiftly superseded by direct-injection engines.

Use of the first vehicle diesel engines

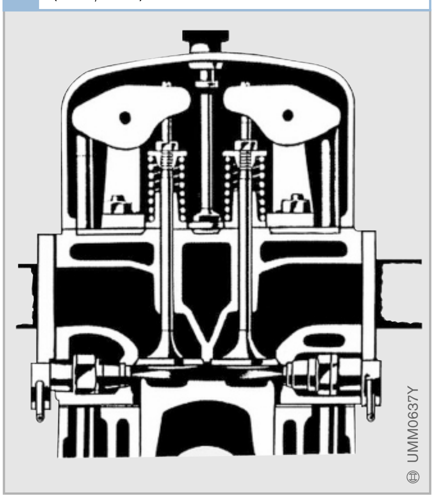
Diesel engines in commercial vehicles

Because of their high cylinder pressures, the first diesel engines were large and heavy and therefore wholly unsuitable for mobile applications in vehicles. It was not until the beginning of the 1920s that the first diesel engines were able to be deployed in commercial vehicles.

Uninterrupted by the First World War, Prosper L'Orange – a member of the executive board of Benz & Cie – continued his development work on the diesel engine. In 1923 the first diesel engines for road vehicles were installed in five-tonne trucks. These four-cylinder precombustion-chamber engines with a piston displacement of 8.8 *l* delivered 45...50 bhp. The first test drive of the Benz truck took place on 10 September with brown-coal tar oil serving as the fuel. Fuel consumption was 25% lower than benzene engines. Furthermore, operating fluids such as brown-coal tar oil cost much less than benzene, which was highly taxed.

The company Daimler was already involved in the development of the diesel engine prior to

3 First vehicle diesel with direct injection (MAN, 1924)



4 The most powerful diesel truck in the world from 1926 from MAN with 150 bhp (110 kW) for a payload of 10 t

the First World War. After the end of the war, the company was working on diesel engines for commercial vehicles. The first test drive was conducted on 23 August 1923 – at virtually the same time as the Benz truck. At the end of September 1923, a further test drive was conducted from the Daimler plant in Berlin to Stuttgart and back.

The first truck production models with diesel engines were exhibited at the Berlin Motor Show in 1924. Three manufacturers were represented, each with different systems, having driven development of the diesel forward with their own ideas:

- The Daimler diesel engine with compressed-air injection
- The Benz diesel with precombustion chamber
- The MAN diesel engine with direct injection

Diesel engines became increasingly powerful with time. The first types were four-cylinder units with a power output of 40 bhp. By 1928, engine power-output figures of more than 60 bhp were no longer unusual. Finally, even more powerful engines with six and eight cylinders were being produced for heavy commercial vehicles. By 1932, the power range stretched up to 140 bhp.

The diesel engine's breakthrough came in 1932 with a range of trucks offered by the company Daimler-Benz, which came into being in 1926 with the merger of the automobile manufacturers Daimler and Benz. This range was led by the Lo2000 model with a payload of 2 t and a permissible total weight of almost 5 t. It housed the OM59 four-cylinder engine with a displacement of 3.8 *l* and 55 bhp. The range extended up to the L5000 (payload 5 t, permissible total weight 10.8 t). All the vehicles were also available with gasoline engines of identical power output, but these engines proved unsuccessful when up against the economical diesel engines.

To this day, the diesel engine has maintained its dominant position in the commercial-vehicle sector on account of its economic efficiency. Virtually all heavy goods vehicles are driven by diesel engines. In Japan, large-displacement conventionally aspirated engines are used almost exclusively. In the USA and Europe, however, turbocharged engines with charge-air cooling are favored.

Diesel engines in passenger cars

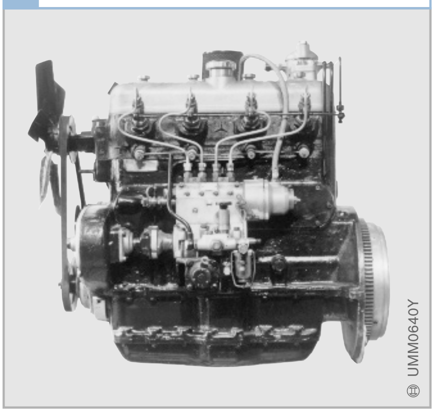
A few more years were to pass before the diesel engine made its debut in a passenger car. 1936 was the year, when the Mercedes 260D appeared with a four-cylinder diesel engine and a power output of 45 bhp.

The diesel engine as the power plant for passenger cars was long relegated to a fringe existence. It was too sluggish when compared with the gasoline engine. Its image was to change only in the 1990s. With exhaust-gas turbocharging and new high-pressure fuel-injection systems, the diesel engine is now on an equal footing with its gasoline counterpart. Power output and environmental performance are comparable. Because the diesel engine, unlike its gasoline counterpart, does not knock, it can also be turbocharged in the lower speed range, which results in high torque and very good driving performance. Another advantage of the diesel engine is, naturally, its excellent efficiency. This has led to it becoming increasingly accepted among car drivers – in Europe, roughly every second newly registered car is a diesel.

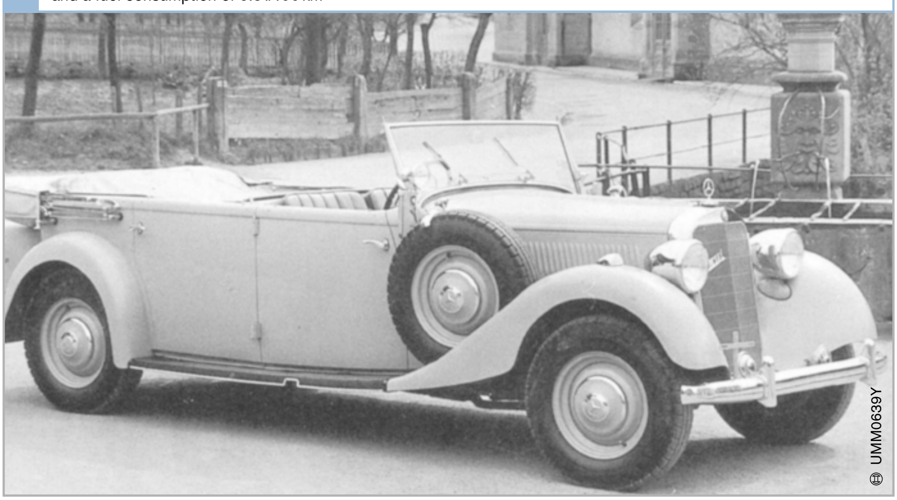
Further areas of application

When the era of steam and sailing ships crossing the oceans came to an end at the beginning of the 20th century, the diesel engine also emerged as the drive source for this mode of transport. The first ship to be fitted with a 25-bhp diesel engine was launched in 1903. The first locomotive to be driven by a diesel engine started service in 1913. The engine power output in this case was 1,000 bhp. Even the pioneers of aviation showed interest in the diesel engine. Diesel engines provided the propulsion on board the Graf Zeppelin airship.

6 Bosch in-line fuel-injection pump on the engine of the Mercedes 260D

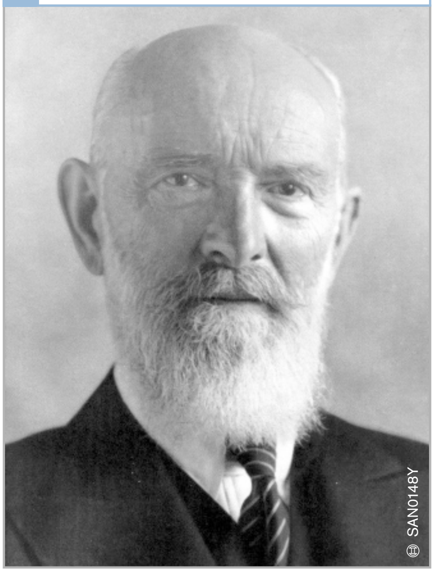


5 First diesel car: Mercedes-Benz 260D from 1936 with an engine power output of 45 bhp (33 kW) and a fuel consumption of 9.5 l/100 km



Bosch diesel fuel injection

1 Robert Bosch



Bosch's emergence onto the diesel-technology stage

In 1886, Robert Bosch (1861–1942) opened a "workshop for light and electrical engineering" in Stuttgart. He employed one other mechanic and an apprentice. At the beginning, his field of work lay in installing and repairing telephones, telegraphs, lightning conductors, and other light-engineering jobs.

The low-voltage magneto-ignition system developed by Bosch had provided reliable ignition in gasoline engines since 1897. This product was the launching board for the rapid expansion of Robert Bosch's business. The high-voltage magneto ignition system with spark plug followed in 1902. The armature of this ignition system is still to this day incorporated in the logo of Robert Bosch GmbH.

In 1922, Robert Bosch turned his attention to the diesel engine. He believed that certain accessory parts for these engines could similarly make suitable objects for Bosch high-volume precision production like magnetos and spark plugs. The accessory parts in question for diesel engines were fuel-injection pumps and nozzles.

Even Rudolf Diesel had wanted to inject the fuel directly, but was unable to do this because the fuel-injection pumps and nozzles needed to achieve this were not available. These pumps, in contrast to the fuel pumps used in compressed-air injection, had to be suitable for back-pressure reactions of up to several hundred atmospheres. The nozzles had to have quite fine outlet openings because now the task fell upon the pump and the nozzle alone to meter and atomize the fuel.

The injection pumps which Bosch wanted to develop should match not only the requirements of all the heavy-oil low-power engines with direct fuel injection which existed at the time but also future motor-vehicle diesel engines. On 28 December 1922, the decision was taken to embark on this development.

Demands on the fuel-injection pumps

The fuel-injection pump to be developed should be capable of injecting even small amounts of fuel with only quite small differences in the individual pump elements. This would facilitate smoother and more uniform engine operation even at low idle speeds. For full-load requirements, the delivery quantity would have to be increased by a factor of four or five. The required injection pressures were at that time already over 100 bar. Bosch demanded that these pump properties be guaranteed over 2,000 operating hours.

These were exacting demands for the then state-of-the-art technology. Not only did some feats of fluid engineering have to be achieved, but also this requirement represented a challenge in terms of production engineering and materials application technology.

Development of the fuel-injection pump
Firstly, different pump designs were tried out. Some pumps were spool-controlled, while others were valve-controlled. The injected fuel quantity was regulated by altering the plunger lift. By the end of 1924, a pump design was available which, in terms of its delivery rate, its durability and its low space requirement, satisfied the demands both of the Benz precombustion-chamber engine presented at the Berlin Motor Show and of the MAN direct-injection engine.

In March 1925, Bosch concluded contracts with Acro AG to utilize the Acro patents on a diesel-engine system with air chamber and the associated injection pump and nozzle. The Acro pump, developed by Franz Lang in Munich, was a unique fuel-injection pump. It had a special valve spool with helix, which was rotated to regulate the delivery quantity. Lang later moved this helix to the pump plunger.

The delivery properties of the Acro injection pump did not match what Bosch's own test pumps had offered. However, with the Acro engine, Bosch wanted to come into contact with a diesel engine which was particularly suitable for small cylinder units and high speeds and in this way gain a firm foothold for developing injection pumps and nozzles. At the same time, Bosch was led by the idea of granting licenses in the Acro patents to engine factories to promote the spread of the vehicle diesel engine and thereby contribute to the motorization of traffic.

After Lang's departure from the company in October 1926, the focus of activity at Bosch was again directed toward pump development. The first Bosch diesel fuel-injection pump ready for series production appeared soon afterwards.

2 Design of a Bosch fuel-injection pump from 1923/1924

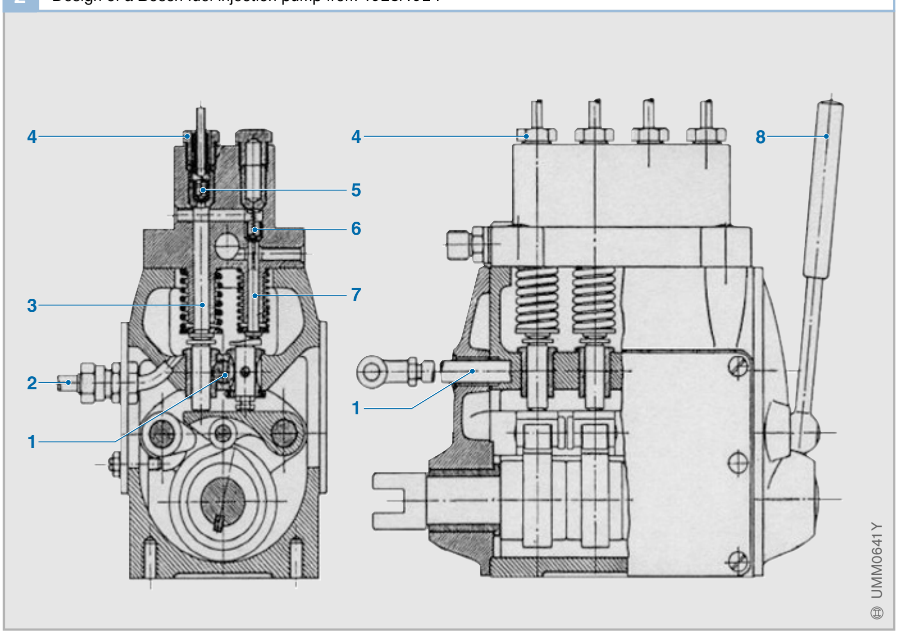


Fig. 2
1 Control rack
2 Inlet port
3 Pump plunger
4 Pressure-line port
5 Delivery valve
6 Suction valve
7 Valve tappet
8 Shutdown and pumping lever