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Foreword

All the manuals from the Bosch "Technical Instruction" publication range dealing with diesel technology were combined to form this reference book. It is intended to satisfy the thirst for knowledge of a large circle of readers.

The diesel engine and the diesel fuel-injection system form an inseparable unit, that is, one is unthinkable without the other. It was fuel-injection technology which first put the diesel engine on the road and enabled it to achieve its present-day significance as an indispensable power unit for vehicles and stationary units – from the subcompact-car engine, up to the large stationary diesel engine. The excellent interaction between the diesel engine and its injection system determines the engine's torque, power output, emissions, and noise.

Following its introduction, the diesel engine operated for many years without any form of electrical device or add-on unit. But on the diesel engine too, without electronics state-of-the-art injection techniques are inconceivable, and it would be impossible to comply with the increasingly stringent demands for low pollutant emissions and improved fuel economy. The innovative VR radial-piston distributor injection pump, and the "Common Rail" accumulator injection system, are examples of the latest developments in diesel fuel-injection technology.

This reference book provides comprehensive information on the state-of-the-art in diesel injection technology. It provides the reader who is interested in automotive-engineering technology with a wide range of easily understood descriptions of the most important components on and around the diesel engine.

The editorial staff

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Injection timing

Assignment

If the start of injection is left constant, the faster the engine turns the greater is the crank angle between start of injection and start of combustion. This means that the start of combustion can no longer take place at the correct instant in time (referred to the engine-piston setting).

The diesel engine features its most efficient combustion and delivers its maximum power at one specific position of the crankshaft (or pistons). As engine speed increases, it is the job of the injection timing to advance the pump's start of delivery with reference to the crankshaft. The injection timing comprises an angle-of-rotation sensor, timing device, and timing-device solenoid valve. By compensating for the time lag resulting from the injection and combustion delays, it optimally adapts the instant of injection to

the engine's operating status (Fig. 1). Examples of working-stroke characteristics are shown in Figs. 2 to 4:

The start of delivery (FB) starts after the high-pressure solenoid valve has closed. High fuel pressure builds up in the high-pressure delivery lines. This nozzle-side line pressure p_D (Fig. 3) opens the nozzle needle upon reaching the nozzle-opening pressure, and injection starts (SB).

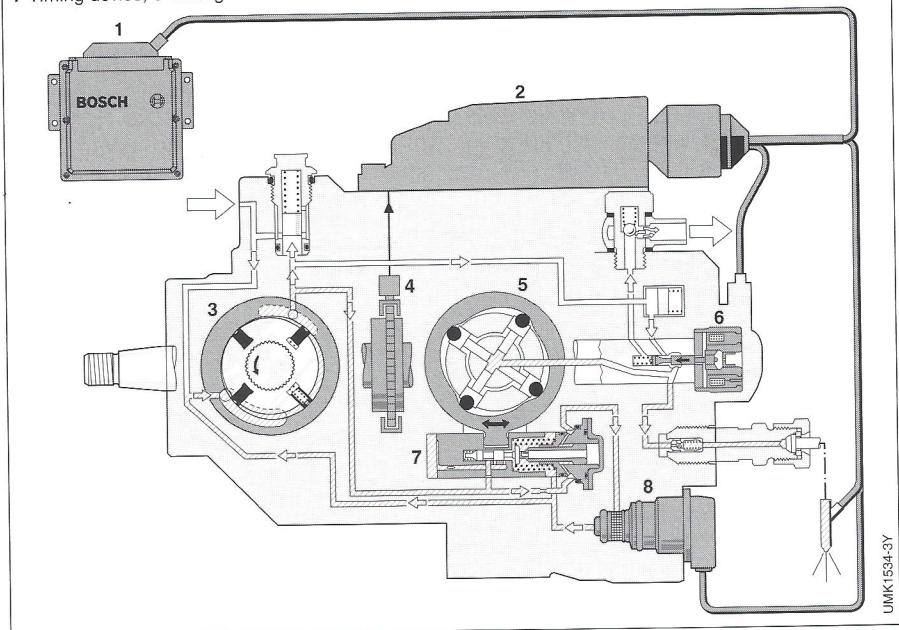
The time between start of delivery and start of injection is referred to as the injection lag (SV). Combustion (VB) starts when the pressure in the combustion chamber (Fig. 2) climbs further. This time interval between start of injection and combustion is known as the ignition lag (ZV).

As soon as the high-pressure solenoid valve opens again, the fuel high pressure collapses (end of delivery) and the nozzle needle closes (end of injection, SE).

Fig. 1

Injection timing in the radial-piston distributor pump

To facilitate ease of understanding, a number of components have been turned with respect to their real position. 1 Engine ECU, 2 Pump ECU, 3 Vane-type supply pump (turned through 90°), 4 Angle-of-rotation sensor, 5 Cam ring (turned through 90°), 6 High-pressure solenoid valve, 7 Timing device, 8 Timing-device solenoid valve.



This is followed by the end of combustion (VE). During the injection pump's delivery process, the injection nozzle is opened by a pressure wave travelling at the speed of sound in the high-pressure delivery line. The pressure wave's propagation time is defined by the length of the line and the speed of sound in diesel fuel which is approx. 1500 m/s. The propagation time is the time between the start of delivery and the start of injection, and is therefore also known as the injection lag (SV).

Basically, the injection lag is independent of the engine speed. The crank angle between start of delivery and start of injection, though, increases along with rising engine speed. This leads to the nozzle opening later and later (referred to the engine-piston position).

Following the injection into the cylinder, the diesel fuel needs a certain time to convert to the gaseous state and form an ignitable mixture with the air. The required period of time between start of injection and start of combustion is independent of engine speed, and on the diesel engine is referred to as the ignition lag.

The ignition lag is defined by the following parameters:

- The diesel fuel's ignition quality (given by means of the Cetane number),
- The compression ratio,
- The air temperature, and
- The fuel atomization.

As a rule, the ignition lag lasts about 1 millisecond.

Fig. 3

Characteristic of the nozzle-end line pressure p_0 at WOT and high engine speeds

FB Start of delivery,
SB Start of injection,
SE End of injection,
OT Top Dead Center (TDC),
 p_0 Nozzle opening pressure.

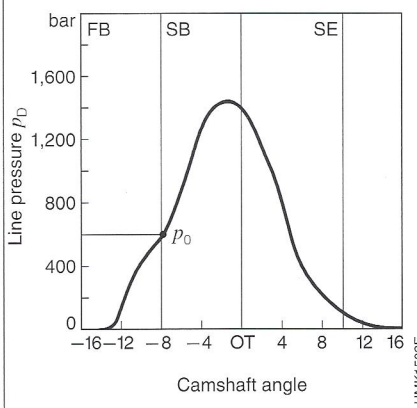


Fig. 2

Characteristic of a working stroke at WOT and high engine speeds (not true-to-scale)

FB Start of delivery, SB Start of injection, SV Injection lag, VB Start of combustion, ZV Ignition lag, SE End of injection, VE End of combustion. ① Combustion pressure ② Compression pressure, UT Bottom Dead Center (BDC), OT Top Dead Center (TDC).

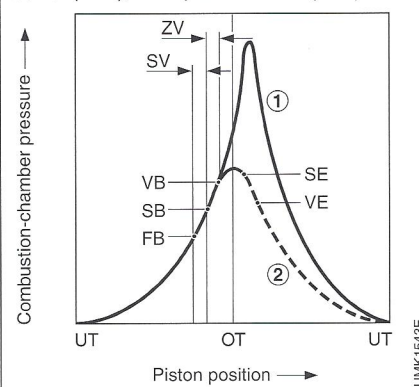
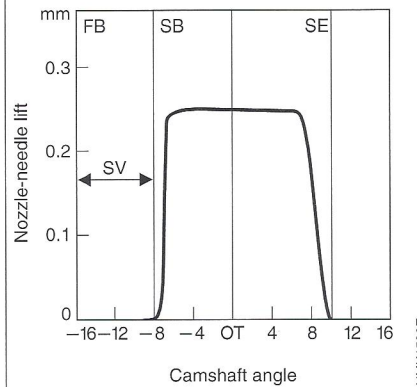


Fig. 4

Characteristic of the nozzle-needle lift at WOT and high engine speeds

FB Start of delivery, SB Start of injection, SV Injection lag, SE End of injection, OT Top Dead Center (TDC).



Design and construction

The hydraulically controlled timing device is installed in the bottom of the radial-piston distributor pump's housing, at right angles to the pump's longitudinal axis (Fig. 5). Through a ball pivot (2), the cam ring (1) engages with a transverse passage in the timing-device piston (3). This means that axial movement of the timing-device piston is converted to rotational movement of the cam ring. Located in the center of the timing-device piston, is a control collar (5) which opens and closes

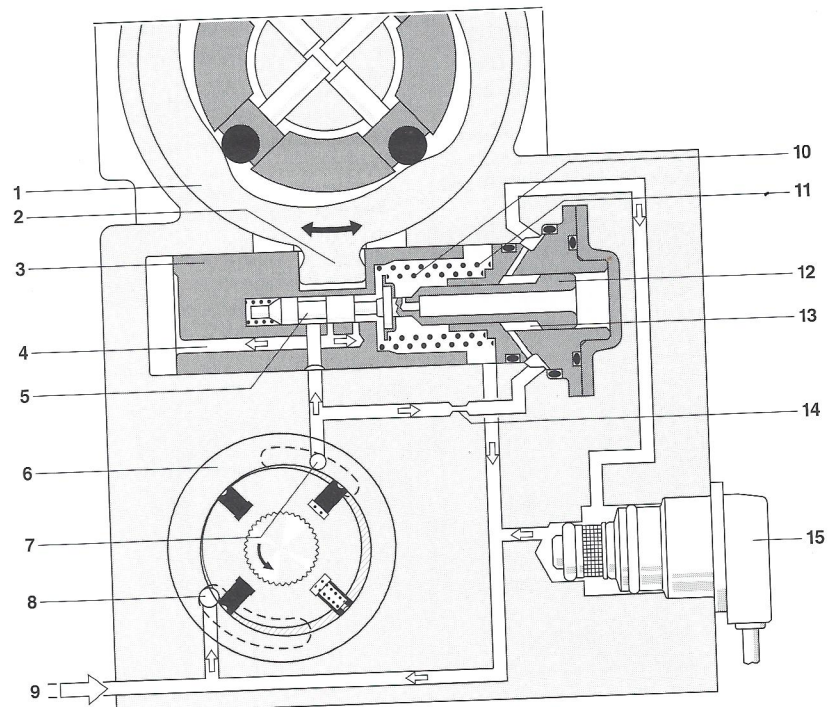
the spill ports in the piston. A spring-loaded hydraulic control plunger (12) is located along the same axis, and serves to define the control collar's set position:

The timing-device solenoid valve is arranged at right angles to the timing-device plunger axis. It is shown as Item 15 in the schematic diagram Fig. 5, in which it has been pivoted into the timing-device plane. When triggered by the pump ECU, it influences the pressure at the control plunger.

Fig. 5

Fig. 5: Timing device with solenoid valve
(shown schematically in one plane).

- | | |
|---------------------------------|--|
| 1 Cam ring, | 9 Input from fuel tank, |
| 2 Ball pivot, | 10 Control plunger spring, |
| 3 Timing-device piston, | 11 Return spring, |
| 4 Inlet passage/outlet passage, | 12 Control plunger, |
| 5 Control collar, | 13 Ring chamber of the hydraulic stop, |
| 6 Vane-type supply pump, | 14 Throttle, |
| 7 Pump outlet (pressure side), | 15 Timing-device solenoid valve. |
| 8 Pump inlet (suction side), | |



Method of operation

Start-of-injection control

Depending upon the engine's operating status (load, engine speed, engine temperature), the engine ECU accesses the start-of-injection map and selects a start of injection which it stipulates as the setpoint value. The start-of-injection controller in the pump ECU continually compares the actual start of injection with the setpoint figure and, in case of deviation, triggers the solenoid with an appropriate on-off ratio. The signal from an angle-of-rotation sensor, or from a needle-motion sensor in the nozzle holder, provides the information on the actual start-of-injection value.

Injection timing in the "advance" direction

The timing-device piston (3) is held in its neutral position ("retard setting") by a return spring (11). During operation, the fuel pressure inside the pump is regulated by the pressure-control valve as a function of pump speed. This fuel pressure is applied as control pressure (through a throttle) to the ring chamber of the hydraulic stop (13), and with the timing-device solenoid valve (15) closed, shifts the control plunger (12) in the "advance" direction against the force of the spring (to the right in Fig. 5). This causes the control collar to shift in the "advance" direction as well so that the inlet passage in the timing-device piston is opened and fuel can flow into the space behind the timing-device piston and shift the piston to the right in the "advance" direction. The ball pivot (2) converts the piston's axial shift to a rotational movement at the high-pressure pump's cam ring (1). In the case of injection-timing shift in the "advance" direction, rotating the cam ring relative to the direction of rotation of the pump driveshaft leads to the rollers reaching the cam lobes sooner so that start of injection takes place earlier. Maximum injection advance is 20° camshaft (corresponding to 40° crankshaft).

Injection timing in the "retard" direction

The timing-device solenoid valve (15) opens upon receiving time-pulsed signals from the pump ECU, and the pressure in the ring chamber of the hydraulic stop (13) sinks as a result. The spring force shifts the control plunger (12) in the "retard" direction (to the left in Fig. 5). Initially, the timing-device piston (3) remains where it is. The control collar (5) must open the spill port for the control passage before the fuel can leave the space behind the timing-device piston. The spring (11) can now shift the piston in the "retard" direction and into its neutral position.

Control of the control pressure

The timing-device solenoid valve acts as a variable throttle when its needle is opened and closed rapidly. It can continuously vary the control pressure so that the control plunger can be shifted to any position required between advance and retard. The pump ECU is responsible for defining the valve needle's on/off ratio, that is, the ratio of the open time to the total duration of a working cycle.

If, for instance, the control plunger is to be adjusted further in the "advance" direction, the on/off ratio is changed by the pump ECU so that the proportion of time that the valve remains open is reduced. Less fuel flows via the timing-device solenoid valve, and the piston is free to move towards "advance".

Injection timing