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1 History

The beginning of hydraulic valve lash adjustment components dates back to the early 1930s, when the idea was born and patents were first registered in the USA. By the 1950s, hydraulic valve lash adjustment components were already a standard feature in 80 % of US passenger car engines.

and since 1989 French and Italian car builders have also been using this innovative technology.

When designing new engines, engineers and technicians are confronted with ever-growing demands, especially in terms of:

- Environmental friendliness
- Noise emission
- Reliability
- Economy
- Ease of maintenance
- Performance

Each of these requirements has an impact on the setting of the valve timing and the design of the system components, no matter what engine type is used (OHV or OHC). Whatever concept is realized, it is essential to rule out valve play and to keep engine output characteristics stable throughout its service life.

In systems with mechanical valve timing, thermal expansion and wear of the valve train components lead to unintentional variations of the valve clearance resulting in the valve timing deviating from the optimal setting.

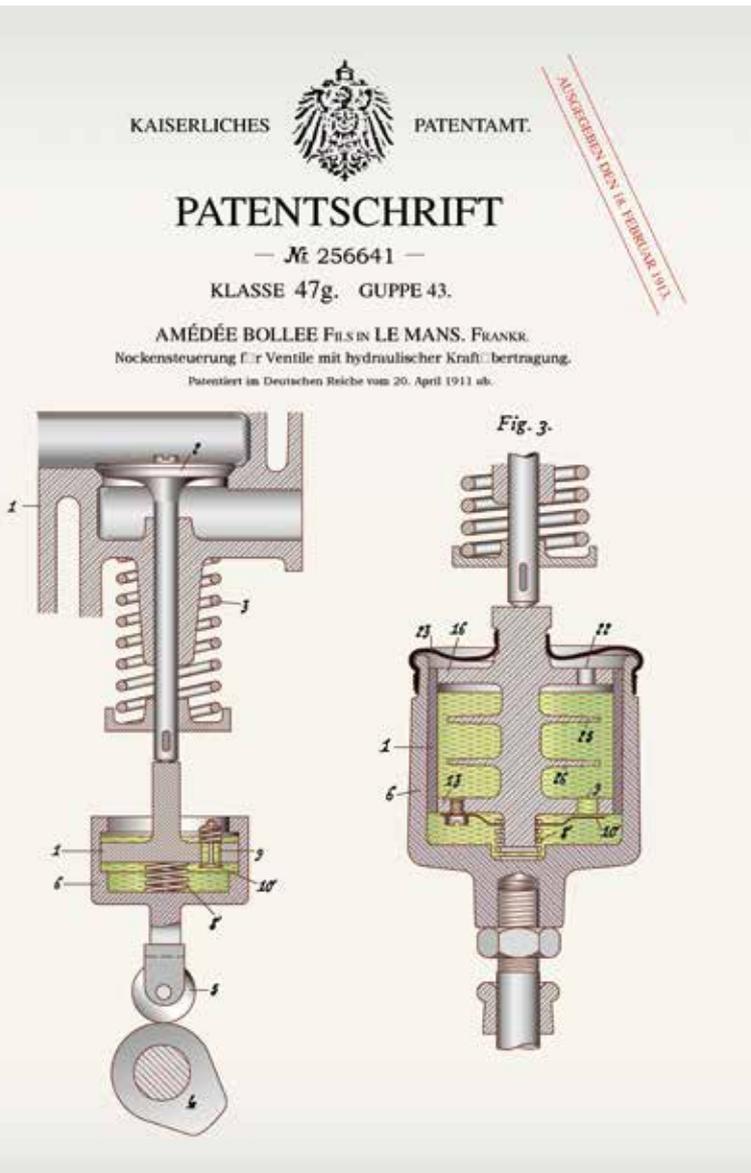
INA hydraulic valve lash adjustment components are designed to meet the requirements of state-of-the-art engine timing systems.

They make engines:

- **Low-pollutant**
By optimizing its design, engine timing – and thus exhaust emissions – remains practically constant throughout the entire engine service life and under all operating conditions.
- **Quiet-running**
The engine noise level is reduced as excessive valve clearance is eliminated.
- **Durable**
Wear is minimized, as the valve train components are always frictionally engaged, thereby ensuring consistently low valve seating velocity.
- **Economic**
No valve clearance setting is required during initial assembly.
- **Maintenance-free**
No re-adjusting of the valve clearance throughout the entire engine service life.
- **Speed-tolerant**
The unique INA lightweight design allows for permanently high engine speeds.

For economic reasons, European manufacturers at the time designed high-revving engines with relatively small capacity.

In 1971, volume production of hydraulic valve lash adjustment components was launched in the Federal Republic of Germany. In 1987 a large number of German, English, Swedish, Spanish and Japanese vehicle models were already fitted with hydraulic valve lash adjustment components. Their market share is steadily increasing



2 Valve train

Internal combustion engines require a cyclic supply of fresh air and the exhaust air produced during combustion must be removed. In a 4-stroke combustion engine, the intake of fresh air and removal of exhaust air is called charge exchange. In the course of several charge exchange cycles, the cylinder control devices (inlet and outlet ports) are periodically opened and closed by shut-off devices (intake and exhaust valves). Shut-off devices fulfill special tasks.

They have to:

- Clear the largest possible opening diameter
- Perform opening and closing processes rapidly
- Have a streamlined design to minimize pressure loss
- Ensure effective sealing when closed
- Provide advanced durability characteristics

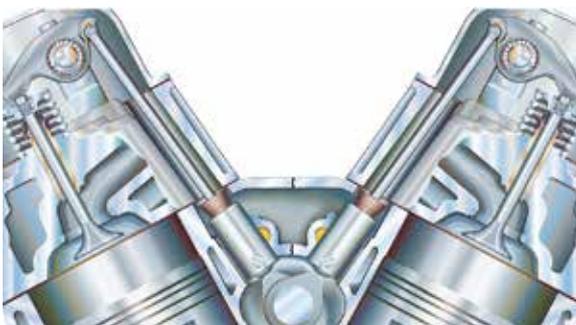
2.1 Requirements

The valve train is subjected to high acceleration speeds in alternation with deceleration periods. As the engine speed accelerates, the resulting inertia forces also increase and apply high stress on the structure. In addition, the exhaust valve must be designed to withstand high temperatures resulting from hot exhaust gases. In order to operate reliably under these extreme conditions, valve train components must satisfy a number of requirements, such as:

- Providing advanced resistance characteristics (over the entire service life of the engine)
- Ensuring friction-free operation
- Providing good heat removal capacity of the valves (particularly of the exhaust valves)

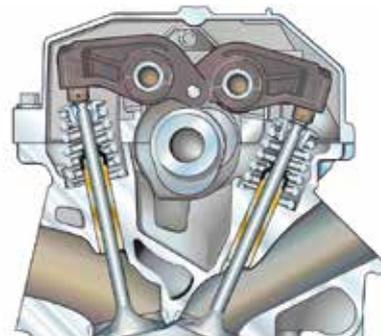
Furthermore, it is essential that the valve train components do not induce an impulse into the system and that the non-positive coupling between the valve train components is disconnected.

Overhead Valves



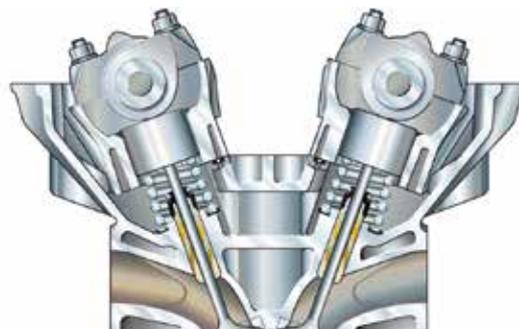
The lower camshaft is mounted below the separation line of cylinder head and engine block. This design is called overhead valve (OHV).

Overhead Camshaft



The upper camshaft is mounted above the separating line of cylinder head and engine block. With only one camshaft, this set-up is called overhead camshaft (OHC).

Double Overhead Camshaft



If two camshafts are mounted, the arrangement is called double overhead camshaft (DOHC).

2.2 Designs

There are different types of valve train designs. Their common feature is that they are all driven by the camshaft. These can be distinguished according to:

- The number of valves driven

OHV control system

Figure 1:

This shows the OHV control system with valve pushrod and lower camshaft. This design requires many transmission components in order to transmit the cam stroke to the valve: plunger, pushrod, rocker arm, rocker arm bearing.

The further refinement of car engines always entailed increased engine rpm in order to make them more powerful, compact and less heavy. The pushrod-type OHV construction was soon at its speed limits owing to its poor overall stiffness. The logical consequence was to reduce the number of moving parts in the valve train.

Figure 2:

The camshaft is now located in the cylinder head, making the pushrod redundant.

OHC control system

Figure 3:

In OHC control systems no lifter is required and the camshaft is mounted at a much higher position, thus allowing for the direct transmission of the cam stroke via rocker arms or finger followers.

Figure 4:

This rocker arm-type control system represents the stiffest construction of a lever-type valve timing system.

Figure 5:

OHC control systems with directly operated valves via bucket tappets are able to transmit even the highest engine speeds. In this design, rocker arms or finger followers are not required.

All of the above construction principles (figures 1 to 5) can be found on high-volume production engines. Depending on the construction priorities – performance, torque, capacity, packaging, manufacturing costs etc. – engineers have to carefully weight up the benefits and drawbacks of the respective design. Any of the described valve timing systems, from pushrod design to compact OHC control systems with directly operated valves, can therefore be the ideal solution for state-of-the-art engines.

- The number and position of camshafts driving the valve train

Camshafts can be mounted in the engine in two ways; accordingly, they are referred to as the upper and lower camshaft.

Types of valve timing systems

Figure 1

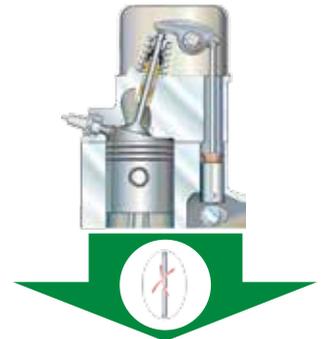


Figure 2

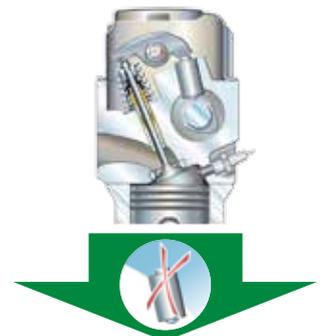


Figure 3

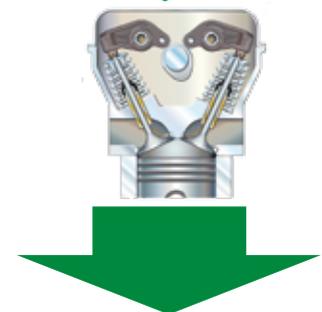


Figure 4

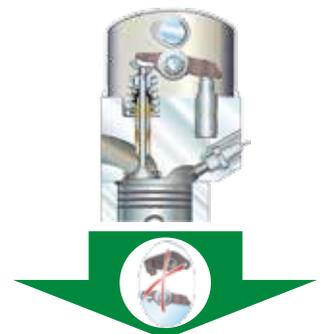


Figure 5



2.3 Valve lash

With the valve closed, a valve control system must have a precisely defined clearance, the so-called valve lash or valve play. The valve clearance is required to compensate for changes in length and dimension of the valve train components, caused by wear and tear and thermal fluctuations and occurring as a result of:

- Temperature differential between the various engine components (e.g. in the cylinder head)
- Different coefficients of thermal expansion of the materials used
- Wear of contact surface between camshaft and valve

2.4 Valve lash adjustment

With mechanical valve lash adjustment components, valve play has to be set manually during initial installation and re-adjusted at regular intervals by means of adjusting screws and shims. In parallel with mechanical solutions, automatically controlled hydraulic valve lash adjustment mechanisms have been developed, where overlap variation of the lift curves is reduced for all operating conditions of the engine over its entire service life, thereby ensuring consistently low exhaust emissions.

The consequences of insufficient or excessive valve clearance range from noise emission in the valve train to a total engine failure. No less important are the detrimental effects on the environment due to poor exhaust emission behavior.

The following summary gives an outline of potential damage caused by insufficient or excessive valve lash.

Insufficient valve lash

Valve opens earlier and closes later

- Because of the shorter closing time, heat cannot dissipate from the valve head to the valve seat rapidly enough.
- Valve head and exhaust valve stem heat up until, in extreme cases, the valve breaks.
→ Engine failure!

Valve does not close properly

- This involves the risk of improper closing of the exhaust valve or intake valve when the engine is warm.
- The exhaust valve sucks in exhaust gas and flames fire back into the intake tract through the intake valve.
- Losses in gas and performance reduce the engine output.
→ Poor emission behavior!
- The constant leakage of hot exhaust gases overheats the valves and burns the valve seats.

Valve subjected to high mechanical stress

- Noise in the valve train.

Excessive valve lash

Valve opens later and closes earlier

- This results in shorter opening times and smaller opening diameters.
- The amount of fuel mixture in the cylinder is insufficient, engine output decreases.
→ Poor emission behavior!

High mechanical stress applied on the valve

- Noise in the valve train.
- Distortion of the valve neck.
→ Engine failure!

Further information on valve lash adjustment by means of bucket tappets, finger followers and rocker arms is provided in the following chapter 3, “**Design and Operating Principle of Valve Lash Adjustment Components**”.

3 Design and operating principle of valve lash adjustment components

3.1 Bucket tappet

In bucket-tappet valve trains, valves are actuated directly. No transmission mechanism is required between valve and camshaft. The cam stroke is transmitted directly to the valve via the bottom of the bucket tappet.

Systems with direct valve actuation stand out by their high rigidity and small moving masses. Owing to these characteristics, they ensure excellent performance at high engine speeds.

Bucket tappets are actuated by sliding contact, causing friction losses between tappet crown and cam lobe.

Matching appropriate materials can help to minimize these losses. In order to further reduce normal wear and tear, beveled cam lobes are mounted opposite the tappet

in lateral misalignment, making the tappet rotate by several degrees at each stroke.

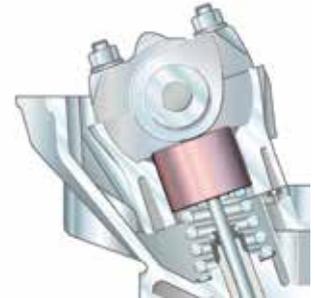


Figure:
Bucket tappet valve train

Mechanical bucket tappet

Characteristics

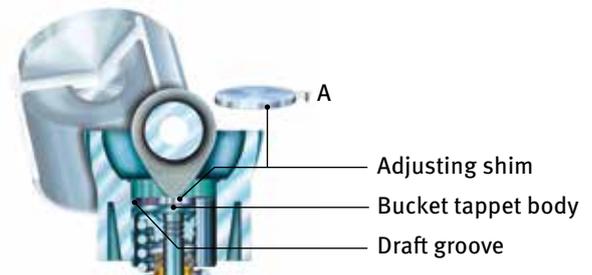
- Steel body
- Direct valve actuation
- Mechanical valve lash adjustment

Mechanical bucket tappet with top adjusting shim

Characteristics

The adjusting shim is:

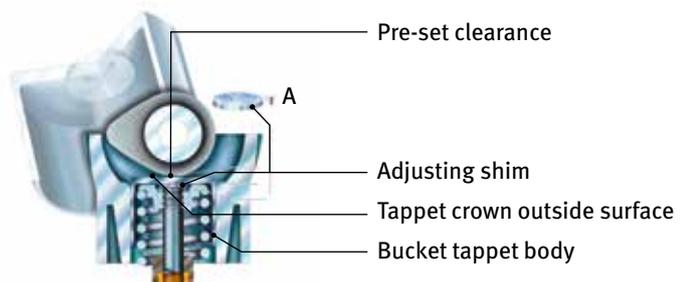
- Loosely inserted in the tappet body
- Supplied in various thicknesses
- Individually selectable according to the material and heat treatment requirements
- Responsible for maintaining the pre-set valve clearance "A" by means of its thickness



Mechanical bucket tappet with bottom adjusting shim

Characteristics

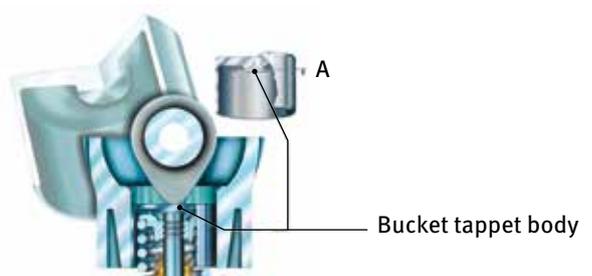
- Pre-set clearance between cam base circle and tappet crown outside surface by means of adjusting shim thickness
- Very low mass of the bucket tappet reduces valve spring forces and thus friction losses
- Increased contact area to cam lobe



Mechanical bucket tappet with graded bottom thickness

Characteristics

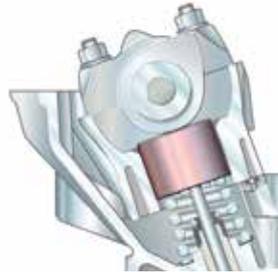
- Valve lash adjustment by means of graded tappet crown thickness "A"
- Bucket tappet design with lowest mass
- Reduced valve spring forces and thus less friction loss
- Increased contact area to cam lobe
- Very cost-effective production



Hydraulic bucket tappet

Characteristics

- Direct valve actuation
- Very high valve train rigidity
- Automatic valve lash adjustment
- Maintenance-free for life
- Very quiet valve train
- Consistently low exhaust emissions for life of the engine



Anti-drain bucket tappet

Characteristics

- Oil cannot drain out of the outer reservoir while the engine is switched off – improved operating behavior during multiple engine start-ups



Bottom drain bucket tappet

Characteristics

- Oil reservoir volume can be used more effectively – improved operating behavior during multiple engine start-ups



Labyrinth-type bucket tappet

Characteristics

- Combines anti-drain and bottom drain mechanisms
- Considerably improved operating behavior during multiple engine start-up



3CF-bucket tappet

(3CF = cylindrical cam contact face)

Characteristics

- With cylindrical cam contact face – anti-rotation mechanism
- Easy oil supply
- Accelerated opening and closing velocity
- 80% reduction in oil throughput by means of plunger guidance
- Low surface pressures in cam contact area
- Enhanced valve lift characteristics possible with smaller plunger diameter, allowing for:
 - Very low tappet mass
 - Very high rigidity
 - Minimized friction losses



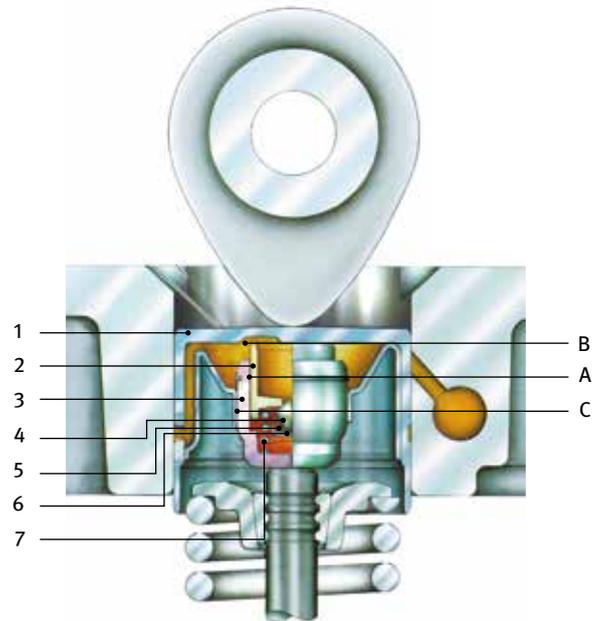
3.1 Bucket tappet

Hydraulic valve lash adjustment by means of bucket tappet

Sink-down phase (cam lift)

- The bucket tappet is loaded by the engine valve spring force and inertia forces.
- The distance between piston and inner housing is reduced, thereby forcing small amounts of oil from the high pressure chamber through the leakage gap "A", which are then returned to the oil reservoir "B".
- At the end of the sink-down phase a small valve clearance is generated.
- Small amounts of oil-gas mixture are forced out via the intake bore and/or the guiding gap "C".

- 1 Outer housing
- 2 Piston
- 3 Inner housing
- 4 Valve ball
- 5 Valve spring
- 6 Valve cap
- 7 Return spring

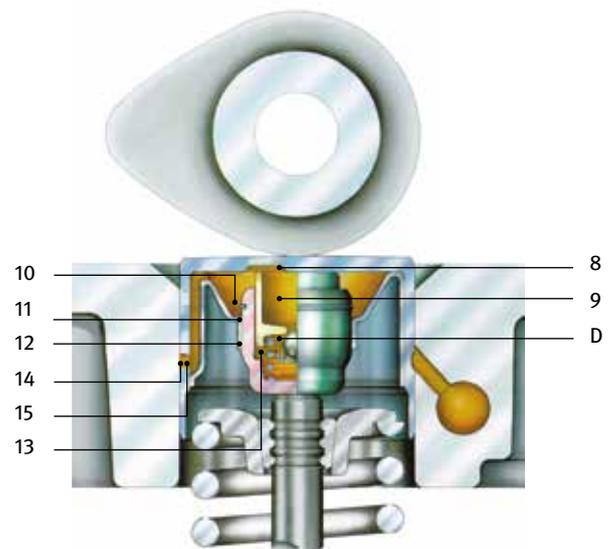


- Oil under engine oil pressure
- Oil under high pressure

Adjustment phase (base circle)

- The return spring separates the piston from the inner housing until valve clearance is adjusted.
- The ball-type non-return valve opens as a result of the pressure differential between the high-pressure chamber and oil reservoir (piston).
- Oil flows from the reservoir "10" via the oil overflow, oil reservoir "9" and ball-type non-return valve into the high-pressure chamber "D".
- The ball-type non-return valve closes; non-positive engagement in the valve train is re-established.

- 8 Oil overflow
- 9 Oil reservoir (piston)
- 10 Oil reservoir (outer housing)
- 11 Leakage gap
- 12 Guiding gap
- 13 High-pressure chamber
- 14 Oil feed groove
- 15 Intake bore

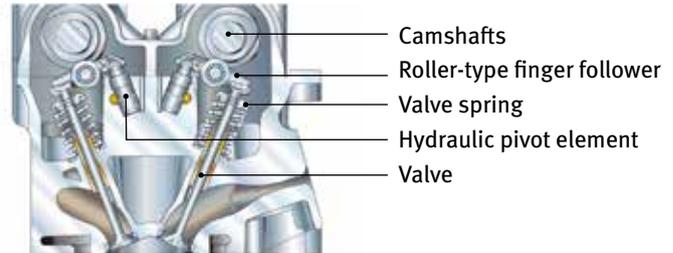


- Oil under engine oil pressure

3.2 Finger follower with pivot element

Finger followers are preferably made from sheet metal. Contact between the cam and finger follower is typically ensured by means of a roller-type finger follower. Additionally, finger followers made from precision-cast steel are available. Compared to bucket tappets, short levers create a lower mass moment of inertia. This allows for designs with reduced masses on the valve side. In terms of stiffness, roller-type finger followers significantly fall short of bucket tappets. Each design of valve train requires differently shaped cams. When compared to the cams used in a bucket tappet valve train, those used on roller-type finger followers have a larger lobe radius, concave flanks and, depending on the transmission ratio, smaller cam lift. The camshaft is located above the roller, which is preferably mounted centrally between the valve and pivot element. Owing to this design, finger followers are particularly well suited for four-valve diesel engines. In this type of engine, the valves are positioned either in parallel or slightly at an angle to each other, requiring

the use of finger followers to ensure sufficient distance between the camshafts.



Characteristics of finger followers:

- Contact between finger follower and cam preferably by means of rolling bearing cam roller
- Very low valve train friction
- Very simple assembly of cylinder head
- Very easy oil supply to the cylinder head
- Very little installation space required

Sheet steel finger follower

Characteristics

- Formed from sheet steel
- Height of guiding tab on valve freely selectable
- Optionally with oil feed hole
- Optionally with retaining clip for simplified cylinder head assembly
- Very large load-bearing surfaces in the recess area and valve contact surface
- Very cost-effective



Cast finger follower

Characteristics

- Complex lever geometry possible
- High load-carrying capacity
- High stiffness, depending on design
- Low mass moment of inertia, depending on design



Hydraulic pivot element

Characteristics

- Anti-split protection by means of polygon ring
- Reliable support of high transverse forces

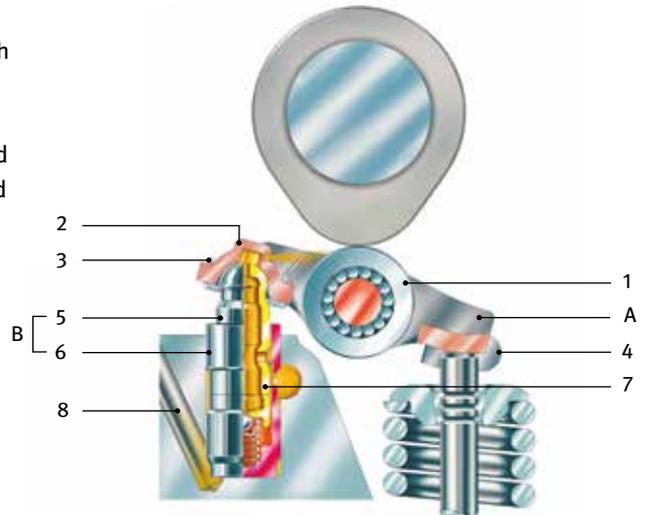


3.2 Finger follower with pivot element

Hydraulic valve lash adjustment by means of finger follower

Sink-down phase (cam lift)

The hydraulic pivot element is loaded by the engine valve spring force and inertia forces, as a result of which the distance between piston and housing is reduced. Small amounts of oil are forced from the high-pressure chamber through the leakage gap and are then returned to the oil reservoir via the leakage collecting groove and intake bore. At the end of the sink-down phase a small valve clearance is generated. Small amounts of oil-gas mixture are forced out through the intake bore and/or leakage gap.

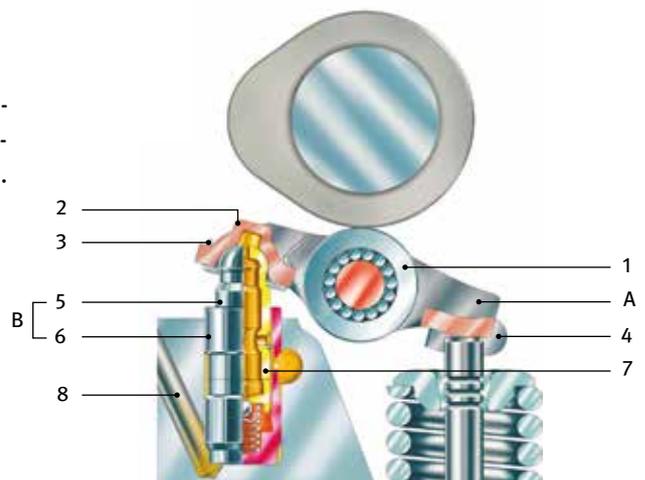


— Oil under engine oil pressure
 — Oil under high pressure

- | | |
|-----------------------------|---|
| 1 Cam roller | 7 Retaining ring (polygon ring) |
| 2 Oil feed hole | 8 Ventilation hole/pressure relief hole |
| 3 Retaining clip (optional) | |
| 4 Guiding tab | |
| 5 Piston | A Sheet steel finger follower |
| 6 Housing | B Pivot element |

Adjustment phase (base circle)

The return spring separates the piston from the housing until valve clearance is adjusted. The non-return valve opens as a result of the pressure differential between the high-pressure chamber and oil reservoir. Oil flows from the reservoir via the non-return valve into the high-pressure chamber. The non-return valve closes and non-positive engagement in the valve train is re-established.



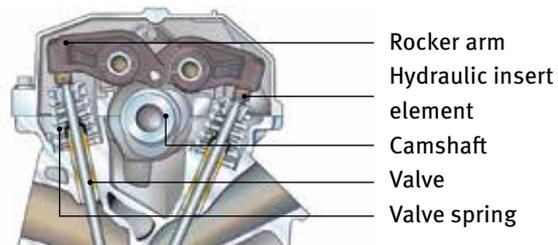
— Oil under engine oil pressure

3.3 Rocker arm with insert element

In rocker-arm valve trains the camshaft is positioned below the rocker arm at one of its ends. The cam stroke is transmitted to the lever either by means of sliding contact or by a roller (roller-type rocker arm). In order to minimize friction losses, modern rocker arms use needle bearing cam rollers. Either a hydraulic valve lash adjustment component (e.g. hydraulic insert element) or an adjusting screw for mechanical valve clearance adjustment are attached to the other end of the rocker arm. This part of the rocker arm operates the intake and/or exhaust valves.

The point of contact between adjusting element (insert element) and valve must always be located at the end of the valve stem. Due to the reciprocation movements of the rocker arm, the contact surface between insert element and valve actuating element must be shaped in a slight curve (or spherical). This reduces the contact area and, consequently, the surface pressures applied to the valve stem end. In the event of excessive surface pressure, insert elements with contact pad are used. The contact pad is attached to the insert element using a ball/socket joint, thus ensuring even contact on the

valve stem end. The contact surface is increased, thus reducing the contact pressure on the valve stem end.



Characteristics of hydraulic insert elements

- Automatic valve lash adjustment
- Maintenance-free
- Very quiet
- Consistently low exhaust gas emissions throughout the entire service life
- Oil supply of the insert element is provided via the rocker arm shaft by oil feed holes leading from the rocker arm to the insert elements

Hydraulic insert element without contact pad

Characteristics

- Little installation space
- Low weight (low moving masses)
- Very cost-effective



Hydraulic insert element with contact pad

Characteristics

- Supported with a swivel facility on the insert element using a ball/socket joint
- Contact pad made from hardened steel
- Very low surface pressure in the valve contact area



Contact pad

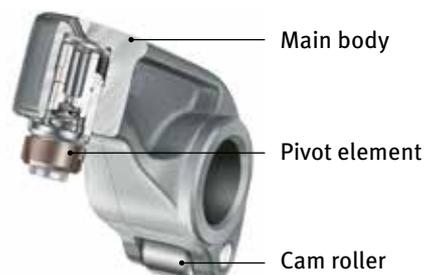
Rocker arm

Characteristics

The main body of the rocker arm is preferably made from aluminum. It accommodates:

- A needle bearing cam roller
- A hydraulic pivot element

Rocker-arm valve trains operate at very low friction levels. In addition, they require little installation space, as all valves can be actuated by a single camshaft.

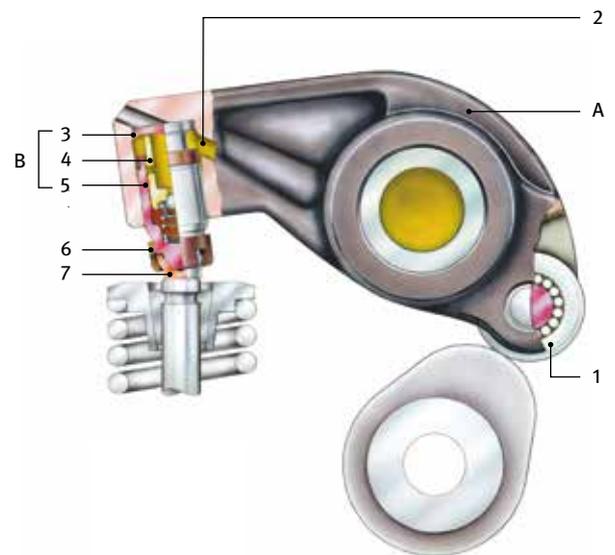


3.3 Rocker arm with insert element

Hydraulic valve lash adjustment by means of rocker arm

Sink-down phase (cam lift)

The hydraulic pivot element is loaded by the engine valve spring force and inertia forces, as a result of which the distance between piston and housing is reduced. Small amounts of oil are forced from the high-pressure chamber through the leakage gap and are then returned to the oil reservoir via the oil collection groove and intake bore. At the end of the sink-down phase a small valve clearance is generated. Small amounts of oil-gas mixture are forced out through the ventilation hole and/or leakage gap.

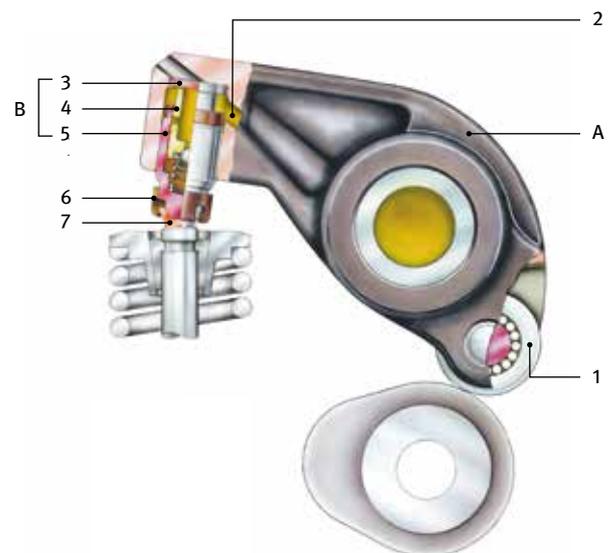


— Oil under engine oil pressure
 — Oil under high pressure

- | | |
|----------------|--|
| 1 Cam roller | 6 Retaining cage
(sheet metal or plastic) |
| 2 Oil channel | 7 Contact pad |
| 3 Support shim | A Rocker arm |
| 4 Piston | B Insert element |
| 5 Housing | |

Adjustment phase (base circle)

The return spring separates the piston from the housing until valve clearance is adjusted. The ball-type non-return valve opens as a result of the pressure differential between high-pressure chamber and oil reservoir. Oil flows from the reservoir via the ball-type non-return valve into the high-pressure chamber. The ball-type non-return valve closes and non-positive engagement in the valve train is re-established.



— Oil under engine oil pressure

3.4 End pivot rocker arm with insert element

End pivot rocker arm valve train

In end pivot rocker arm valve trains, the camshaft is positioned above the valves and operates several lifters simultaneously using two cams which, by means of two rollers (roller-type end pivot rocker arm) mounted in the lever, act on two or three insert elements. The design with two insert elements is also referred to as dual end pivot rocker arm, with three insert elements as triple end pivot rocker arm. This type of valve train is typically used on multi-valve diesel engines.

Although in this case the valves are mounted inversely, the system allows all valves to be operated by a single camshaft while leaving sufficient installation space to accommodate the injection nozzles.



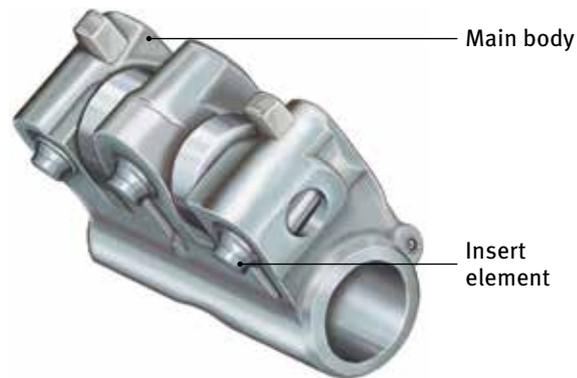
End pivot rocker arm characteristics

The main body of the end pivot rocker arm is preferably made from aluminum. It accommodates:

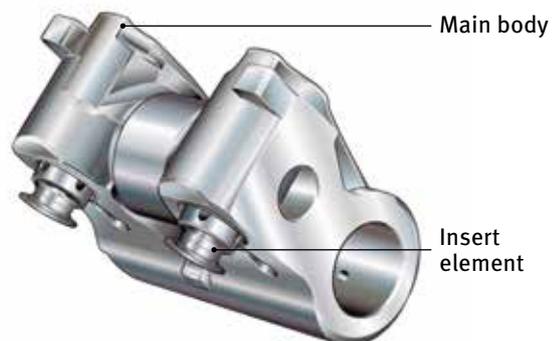
- Needle bearing cam roller
- Hydraulic insert elements:
 - One per valve
 - Automatic valve lash adjustment
 - Maintenance-free
 - Very quiet
 - Consistently low exhaust gas emissions throughout the entire service life

It is also extremely speed-tolerant and minimizes friction loss.

Triple end pivot rocker arm



Dual end pivot rocker arm

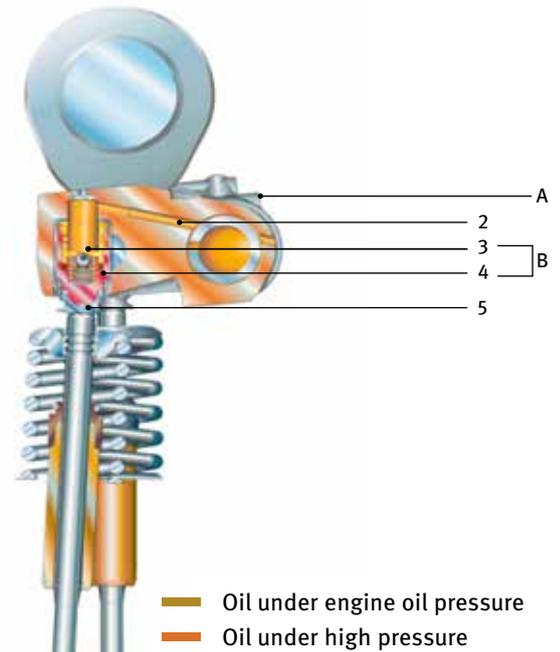


3.4 End pivot rocker arm with insert element

Hydraulic valve lash adjustment by means of end pivot rocker arm

Cam lift phase (front view)

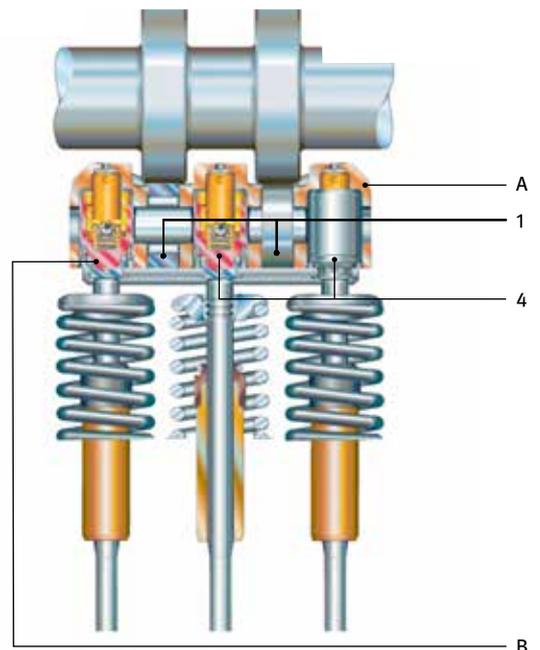
The hydraulic insert element is loaded by the valve spring force and inertia forces, as a result of which the distance between piston and housing is reduced. Small amounts of oil are forced from the high-pressure chamber through the leakage gap and are then returned to the oil reservoir via the oil collection groove and intake bore. At the end of the sink-down phase small valve clearance is generated. Small amounts of oil-gas mixture are forced out through the ventilation hole and/or leakage gap.



- | | |
|---------------------------------|-------------------------------------|
| 1 Cam roller | 5 Contact pad of the insert element |
| 2 Oil channel | |
| 3 Piston of the insert element | A Triple end pivot rocker arm |
| 4 Housing of the insert element | B Insert element |

Base circle phase (side view)

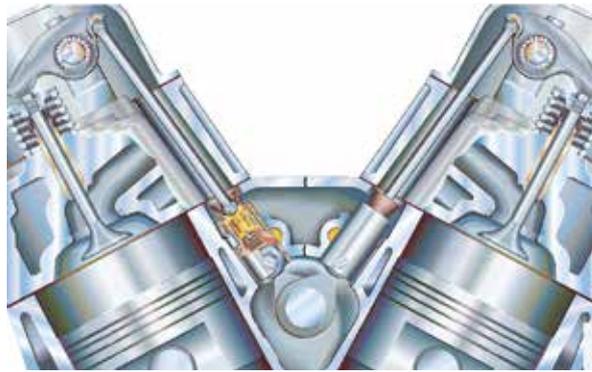
The return spring separates the piston from the housing until valve clearance is adjusted. The ball-type non-return valve opens as a result of the pressure differential between high-pressure chamber and oil reservoir. Oil flows from the reservoir via the ball-type non-return valve into the high-pressure chamber. The ball-type non-return valve closes and non-positive engagement in the valve train is re-established.



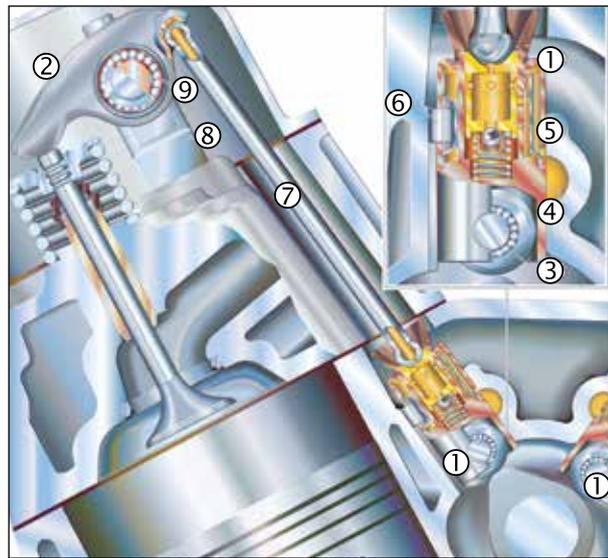
3.5 OHV control system

OHV control system

In engines with a lower camshaft the distance between cam and lever is relatively large, requiring a pushrod to transmit the cam lift to the lever. Pushrods are used in combination with special types of cam followers and/or valve lifters. The latter connect to the cam by means of sliding contact (flat-base or mushroom tappets) or by roller contact (roller-type tappets) and perform the task of guiding the pushrod.



- 1 Hydraulic roller tappet
- 2 Rocker arm
- 3 Cam roller
- 4 Housing
- 5 Piston
- 6 Anti-rotation element
- 7 Pushrod
- 8 Rocker arm bearing mounting
- 9 Needle bearing



Hydraulic roller tappet

Characteristics

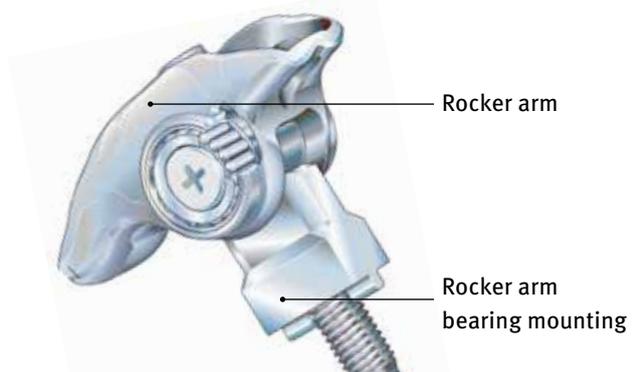
- Designed with unique internal oil circulation system (labyrinth design)
- Improves dry-running properties in the event of insufficient pressure oil supply
- Automatically adjusts valve lash
- Maintenance-free
- Very quiet
- Consistently low exhaust gas emissions throughout the entire engine service life



Rocker arm with rocker arm bearing mounting

Characteristics

- Supplied as ready-to-fit lever/lever bearing unit
- Pivoted rocker arm mounting
- Rocker arm supported by needle roller bearing on rocker arm bearing mounting
- Low-friction motion



3.6 Switching valve lash adjustment components

Since the beginning of the 20th century, engine designers and thermodynamics engineers have been searching for mechanisms to transmit variable lift curves to the valve – the great number of filed patents gives evidence of this.

Pressure to meet strict exhaust emission and fuel consumption standards, and demands for increased driving comfort in terms of performance, torque and responsiveness call for more flexibility in the valve train.

Today, volume production of variable valve timing systems, including cam followers such as rocker arms, finger followers or bucket tappets, is a reality. Variable valve timing is used to make different valve lift curves possible depending on the operating point, thus allowing for the optimal setting of the respective valve lift at all times. For each alternative valve lift such a system requires a corresponding cam to be the stroke-giving element, except if the alternative is zero lift, meaning deactivation of the valve. The element engaged in the valve is supported at the base circle cam.

Cylinder or valve deactivation systems are predominantly used in high-capacity multi-cylinder engines (for example 8, 10 or 12 cylinders) aiming at reducing charge exchange losses (pump or throttle losses) and/or shifting the operating point. Due to the equidistant firing sequences, common V8 and V12 engine/transmission units can be “switched” to straight-four or straight-six engines. Tests on a stationary operating V8 engine have proved that the use of a cylinder deactivation system allows for fuel economy improvements between 8 % and 15 % during normal driving cycles. Valve deactivation is achieved by abandoning the second cam lobe driving the cam follower.

Thus, the cam lift transmitting component is disconnected from the valve. The motion of the transmitting element is therefore idle, which is also referred to as “lost motion”. Since the connection to the valve spring is interrupted, the respective mass moments of inertia must be sustained by an additional spring, also called a “lost-motion” spring. The reciprocating movement continues to be performed by those parts of the valve train which are not deactivated. On the deactivated cylinders, the camshaft is only working against lost-motion spring forces, which are lower than the respective valve spring forces by a factor of 4 to 5. This minimizes friction losses.

Switching mechanical bucket tappet



Switching pivot element



Switching roller tappet



Operating principle of the switching bucket tappet

Base circle phase (switching phase)

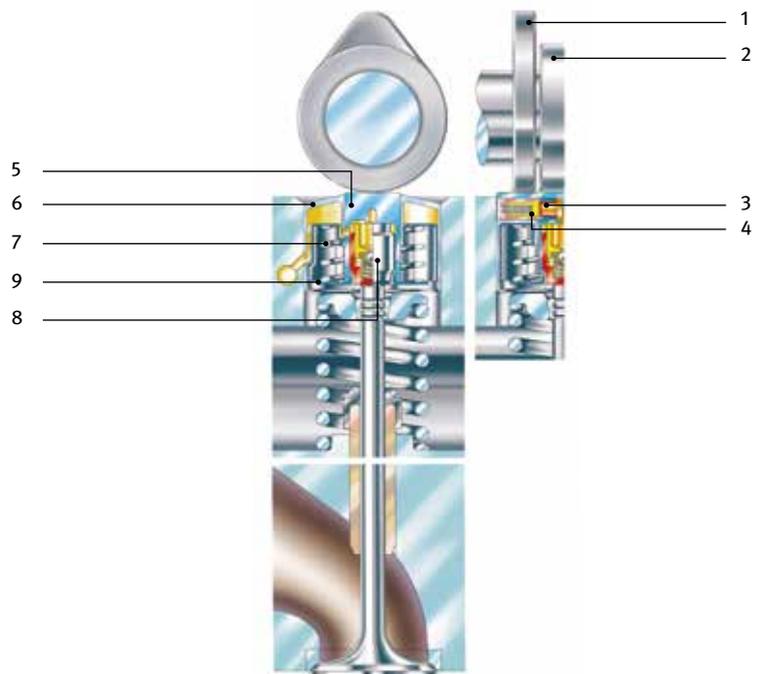
- The support spring pushes the outer lifter against the end stop of the inner lifter.
- The inner lifter touches the inner cam; a small clearance is generated between the outer cam and the outer lifter.
- At reduced engine oil pressure, the outer and inner lifters are linked via the spring-loaded locking piston.
- As the engine oil pressure exceeds the switching oil pressure, the locking piston is pushed back into the outer lifter by the operating piston.
- The hydraulic adjusting element positioned in the inner lifter adjusts valve clearance.

Cam lift phase, decoupled (zero or partial lift)

- The pair of outer cams directs the outer lifter downward against the support spring.
- The movement of the engine valve follows the outline of the inner cam.
- If all engine valves of a cylinder are deactivated (outer lifter decoupled), the cylinder will be deactivated, which allows for considerable fuel economies.

Cam lift phase, locked (full lift)

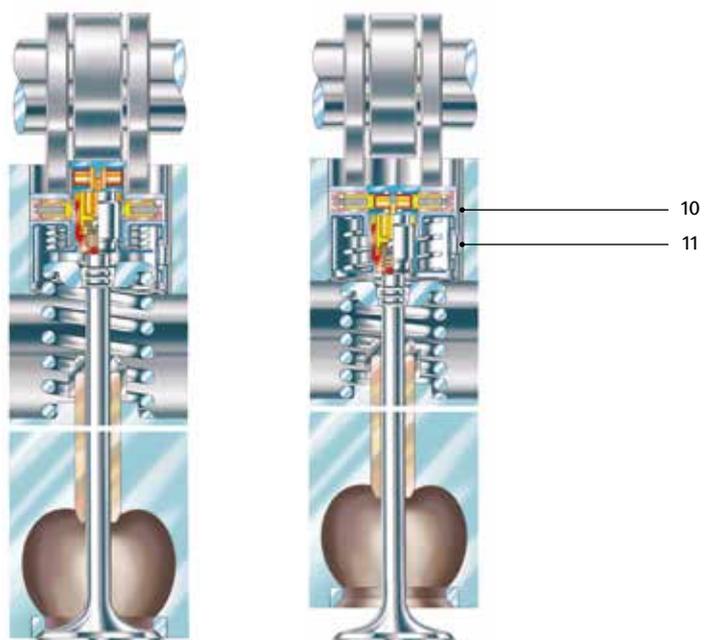
- The pair of outer cams directs the outer and inner lifters, which are coupled to each other, downward, and opens the engine valve.
- The hydraulic adjusting component is put under load.
- Small amounts of oil are forced from the high-pressure chamber through the leakage gap.
- Having reached the base circle phase, valve clearance is set to zero.



- | | |
|--------------------|---------------------------------|
| 1 Outer cam | 8 Adjusting element |
| 2 Inner cam | 9 Support plate |
| 3 Operating piston | 10 Guiding groove |
| 4 Locking piston | 11 Anti-rotation device |
| 5 Inner lifter | — Throttled engine oil pressure |
| 6 Outer lifter | — Oil under engine oil pressure |
| 7 Support spring | — Oil under high pressure |

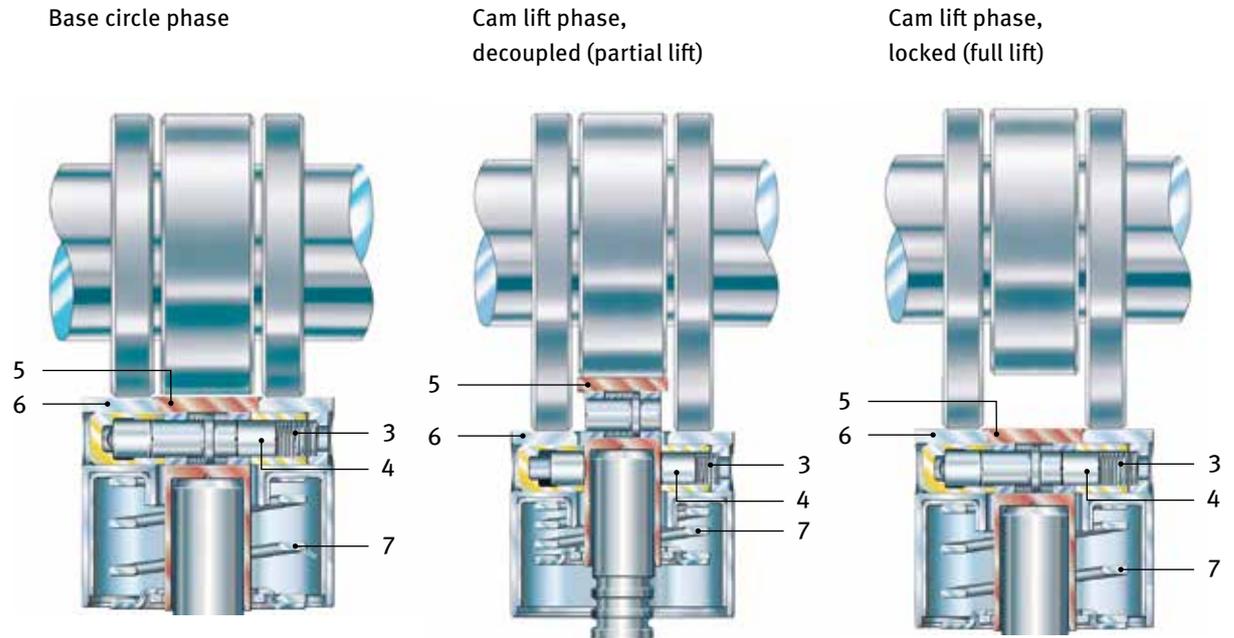
Decoupled

Locked



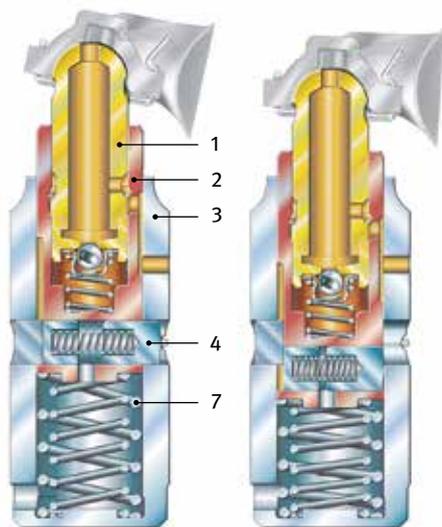
3.6 Switching valve lash adjustment components

Switching phases of a switching mechanical bucket tappet



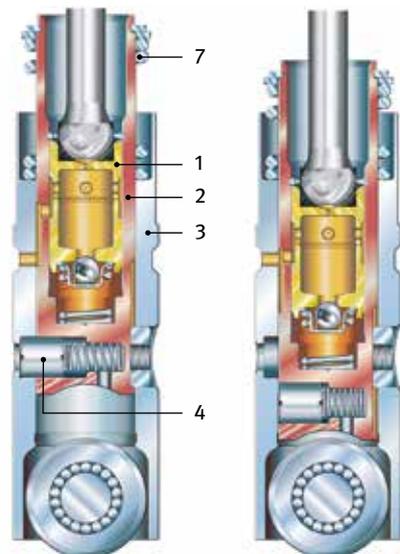
- | | | | |
|--------------|------------------|----------------|--|
| 1 Piston | 3 Return spring | 5 Inner lifter | 7 Support spring
(lost motion spring) |
| 2 Cam roller | 4 Locking piston | 6 Outer lifter | |

Switching pivot element



Locked (full lift) Decoupled (zero lift)

Switching roller tappet

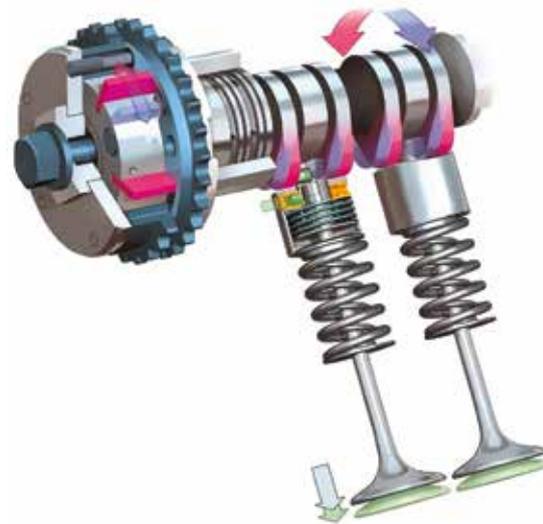


Locked (full lift) Decoupled (zero lift)

4 Camshaft phasing systems

4.1 General information

The purpose of camshaft phasing systems is the variation of the gas exchange valve timing in an internal combustion engine. There are systems for variable intake and exhaust phasing, and also a combination of the two. By adjusting camshaft phasing, exhaust emissions and fuel consumption can be reduced. Typically, adjustment angles range from 20° to 30° at the camshaft and 40° to 60° at the crankshaft. Camshaft phasing systems are available for both the belt drive and the chain drive. And there are various compact design solutions to match individual installation space requirements.



4.2 Summary of camshaft phasing systems

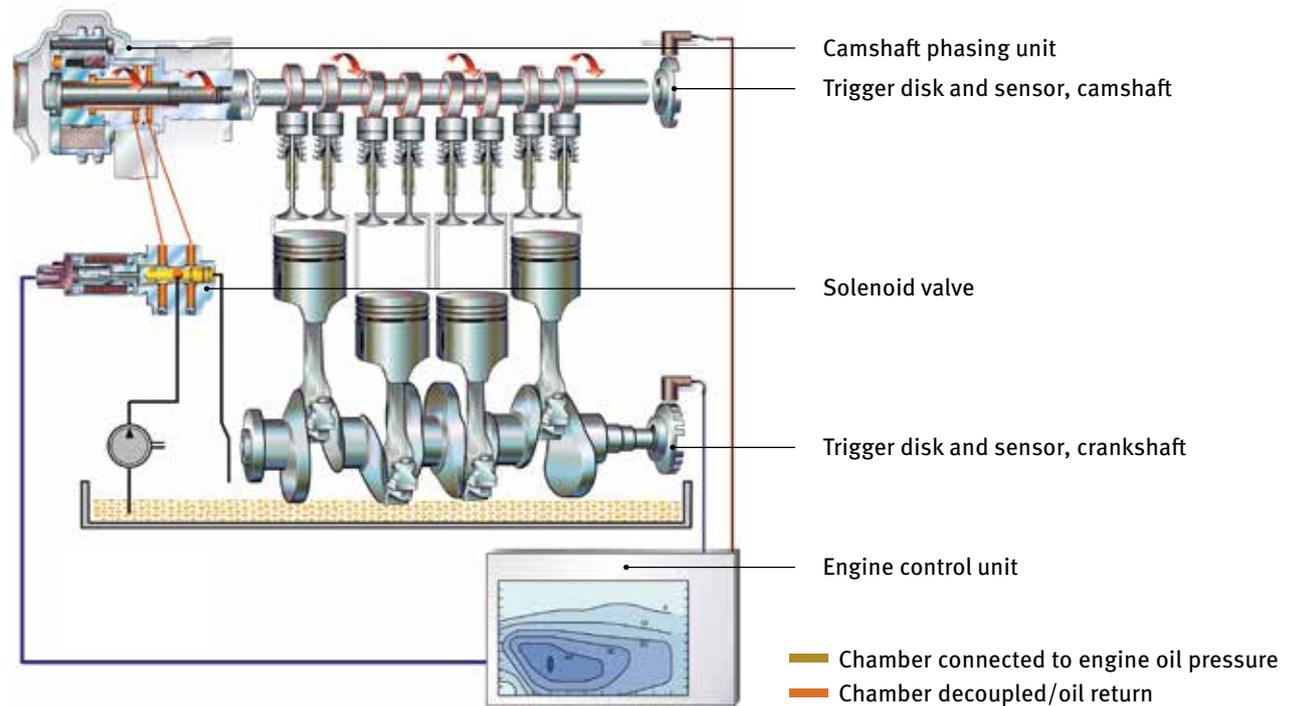
Each phasing concept has its benefits:

Concept	Advantages	Gas exchange valve lift curves
Intake phasing	<ul style="list-style-type: none"> • Reduced emissions • Reduced fuel consumption • Improved driving comfort (decreased idling speed) • Optimized engine torque and output 	
Exhaust phasing	<ul style="list-style-type: none"> • Reduced emissions • Reduced fuel consumption • Improved driving comfort (decreased idling speed) 	
Independent phasing of intake and exhaust camshaft (DOHC)	<ul style="list-style-type: none"> • Reduced emissions • Reduced fuel consumption • Improved driving comfort (decreased idling speed) • Optimized engine torque and output 	
Synchronous phasing of intake and exhaust camshaft (DOHC/SOHC)	<ul style="list-style-type: none"> • Reduced emissions • Reduced fuel consumption 	

..... Unit in retarded timing position
 - - - - - Unit in advanced timing position
 ——— Unit in controlled position
 (with fixed adjustment angle)

EO → Exhaust open
 EC → Exhaust closed
 IO → Intake open
 IC → Intake closed

4.3 Camshaft phasing components and their operating principle



Camshaft phasing – control loop

The camshaft is continuously adjusted in a closed control loop. The control system is driven by engine oil pressure.

→ The desired adjustment angle of the inlet and exhaust valves, which depends on the load condition, temperature and engine rpm, is retrieved from a data map stored in the engine control unit.

→ The engine control unit calculates the actual adjustment angle of the inlet and exhaust valves read by the sensors at the camshaft and crankshaft, and compares it against the desired angle.

→ If the actual angle differs from the desired angle, the power supply of the solenoid valve is modified such that oil from the engine oil circuit flows to the oil chamber in the phasing unit, increasing it in size, and oil from the oil chamber to reduce it in size goes back to the engine sump.

→ Depending on the oil volume flow, a more or less rapid rotation of the camshaft relative to the crankshaft is initiated, i.e. the shifting of the gas exchange valve timing to either advanced or retarded opening and closing position.

→ In the engine control unit the deviation of the actual angle from the desired angle is calculated constantly at high frequency.

Advantages of the control loop:

- Deviation from the desired angle is almost immediately adjusted
- The desired angle is maintained with high angle precision

4.4 Camshaft phasing units

There are currently two types of camshaft phasing units used in volume production: axial piston camshaft adjusters and vane-type camshaft adjusters.

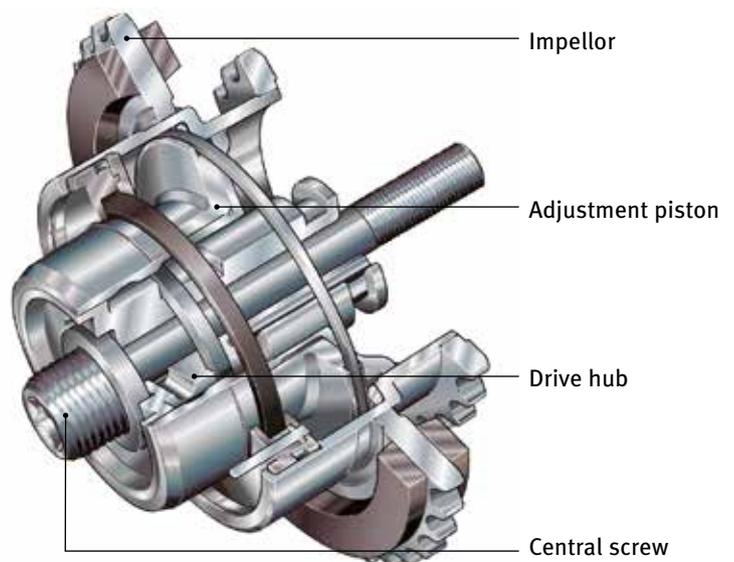


Axial piston camshaft adjuster

Core components of an axial-piston camshaft adjuster

Characteristics

- Axial piston camshaft adjusters are available for both chain-drive and belt-drive timing systems.
- Depending on the function and installation space requirements, the lines feeding the oil to the phasing unit chambers have different degrees of sealing ability:
 - Seal rings (steel or plastic rings) on the camshaft (in the camshaft bearing area) are frequently used.
 - Alternatively, oil can be fed to the camshaft via simple grooves in the plain bearing.
- The axial piston phasing unit is mounted on the camshaft by means of a central screw.
- Oil is delivered via the first camshaft bearing and the camshaft.
- This type of phasing unit is characterized by its robust design, minimized oil leakage and advanced control precision.



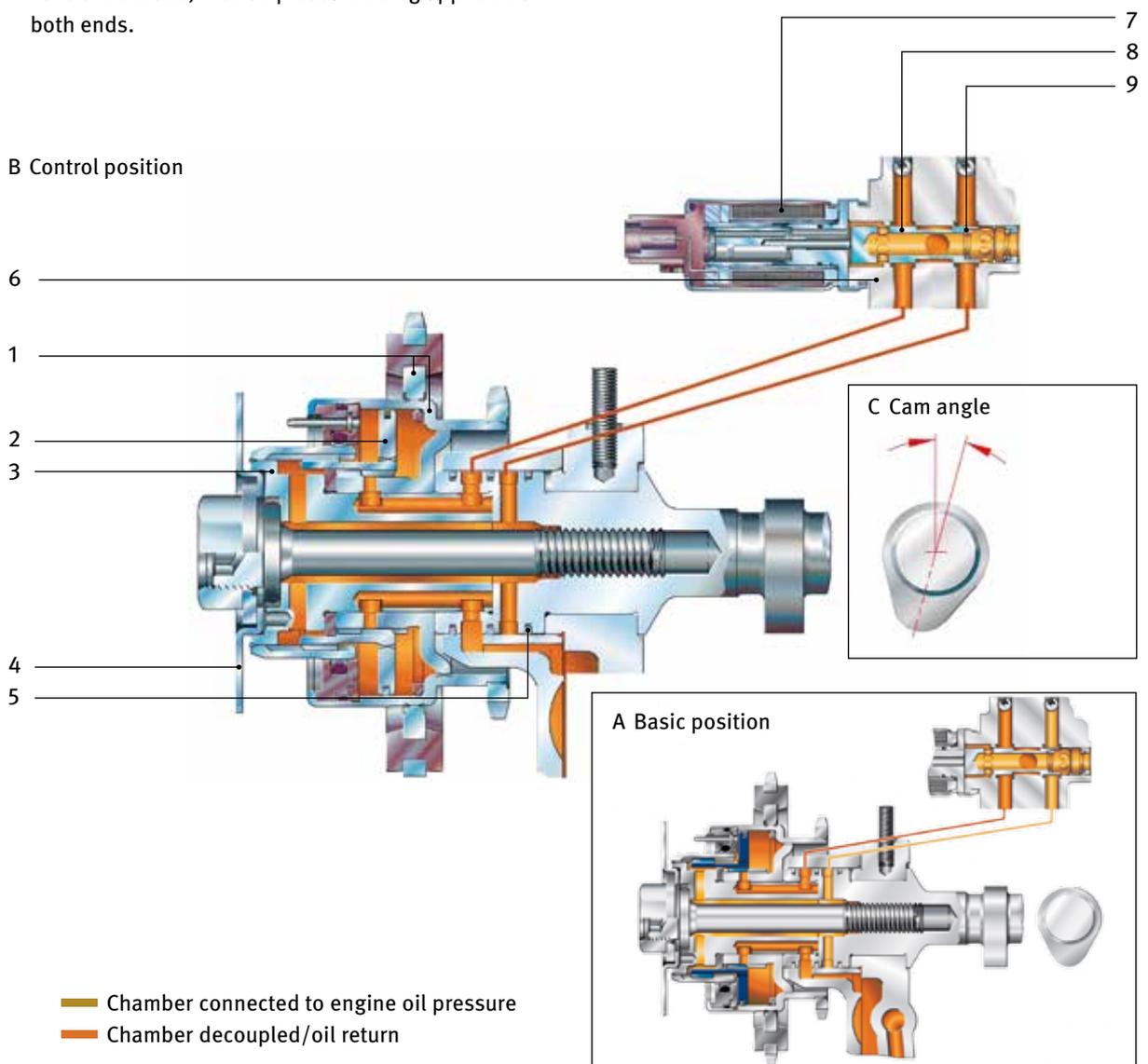
4.4 Camshaft phasing units

Axial piston camshaft adjuster

Operating principle of an axial piston camshaft adjuster

- Depending on the requirements, applying current to the solenoid activates the hydraulic slider integrated into the hydraulic section of the solenoid valve to regulate the oil flow in one of the two oil chambers of the phasing unit.
- Impellor and drive hub are connected to each other in pairs by means of a helical spline.
- Axial displacement of the adjustment piston, which serves as linking element between the impellor and the drive hub, enables relative rotation between camshaft and crankshaft.
- Typical adjustment ranges are between 20° and 30° cam angle, and 40° and 60° crank angle.
- The adjustment piston, which holds a permanent angle position, is hydraulically locked in the controlled mode, with oil pressure being applied from both ends.

- 1 Impellor
- 2 Adjustment piston
- 3 Drive hub
- 4 Camshaft trigger disk
- 5 Seal ring
- 6 Solenoid valve, hydraulic section
- 7 Solenoid valve, solenoid
- 8 Hydraulic slider
- 9 Spring



Vane-Type camshaft adjuster

Vane-type camshaft adjuster for the chain drive

Characteristics

- Vane-type adjusters are available for both chain-drive and belt-drive timing systems.
- The stator is linked to the crankshaft via the timing drive, and the rotor is connected to the camshaft by means of the central screw.
- The rotor is radially mounted between two end stops in the stator.
- Typical adjustment ranges are between 20° and 30° cam angle, or 40° and 60° crank angle.
- The spring-supported slot-in vanes and the stator segments link up to form oil chamber pairs, which are fully filled with oil during operation.

Chain drive



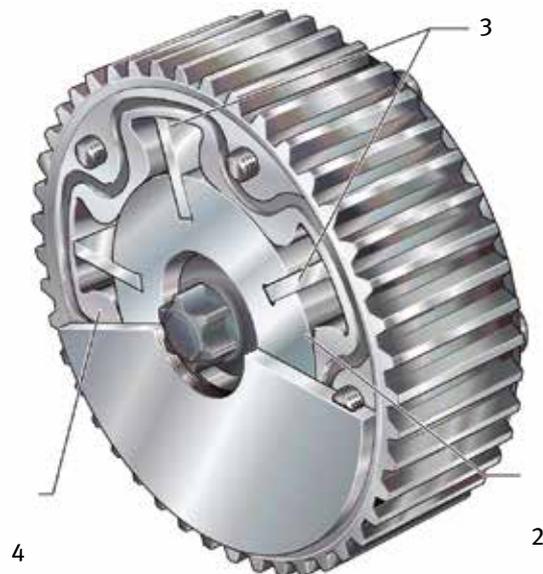
- 1 Stator (impellor)
- 2 Rotor (drive hub)
- 3 Vane
- 4 Locking device

Vane-type camshaft adjuster for the belt drive

Belt drive

Characteristics

- Torque transmission from the stator to the rotor is ensured via the hydraulically locked vanes.
- The typical amount of vanes is 3-5, depending on the required adjusting time and the overall load applied to the system.
- The locking device provides a secure mechanical connection between the drive and output during engine start-up. It is hydraulically released as soon as the phasing unit starts to move from its basic position.



4.4 Camshaft phasing units

Distinctions between Camshaft Phasing Units in the chain drive and belt drive

Chain drive phasing unit

- Camshaft phasing units in the belt drive must provide absolute oil-tightness. This is not required for chain drive camshaft units, as the chain drive itself is protected by a cover.

Chain drive



Belt drive phasing unit

- Sealing of the belt drive phasing unit is ensured by seal elements in the adjuster, by the rear cover which serves as contact surface to the shaft seal ring, and by the front protective cover which seals the adjuster towards the front after the central screw is fixed.

Belt drive



Distinctions between Intake and exhaust phasing

Intake phasing by means of a vane-type camshaft adjuster in the chain drive

Adjuster in basic position "A"

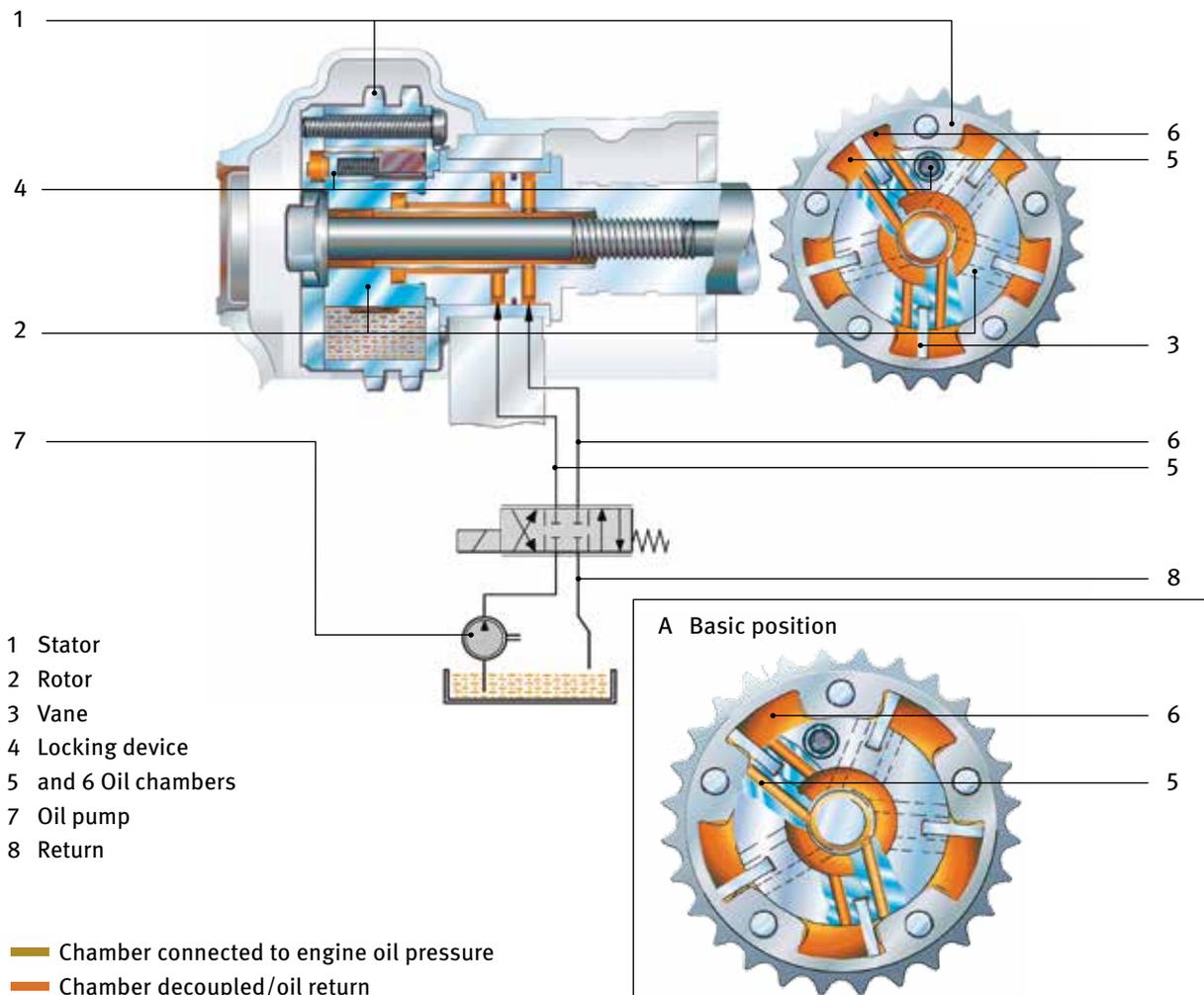
- Valve timing is in "retarded" position.
- The locking device is engaged.
- At the same time, oil in the oil chamber puts the vanes under single-sided pressure, thereby keeping them at the end stop.
- The solenoid valve is not energized.

Adjuster in controlled mode "B"

- Current is applied to the solenoid valve.
- Oil flows into the second chamber "A".
- The oil unlocks the locking element and turns the rotor.
- This shifts the camshaft to "advanced" position.

To arrest the phasing unit in an intermediate position the solenoid valve is switched to control position. The oil chambers are then almost completely closed, compensating only for oil leakage.

B Control position



4.4 Camshaft phasing units

Distinctions between Intake and exhaust phasing

Exhaust phasing by means of vane-type camshaft adjuster in the belt drive

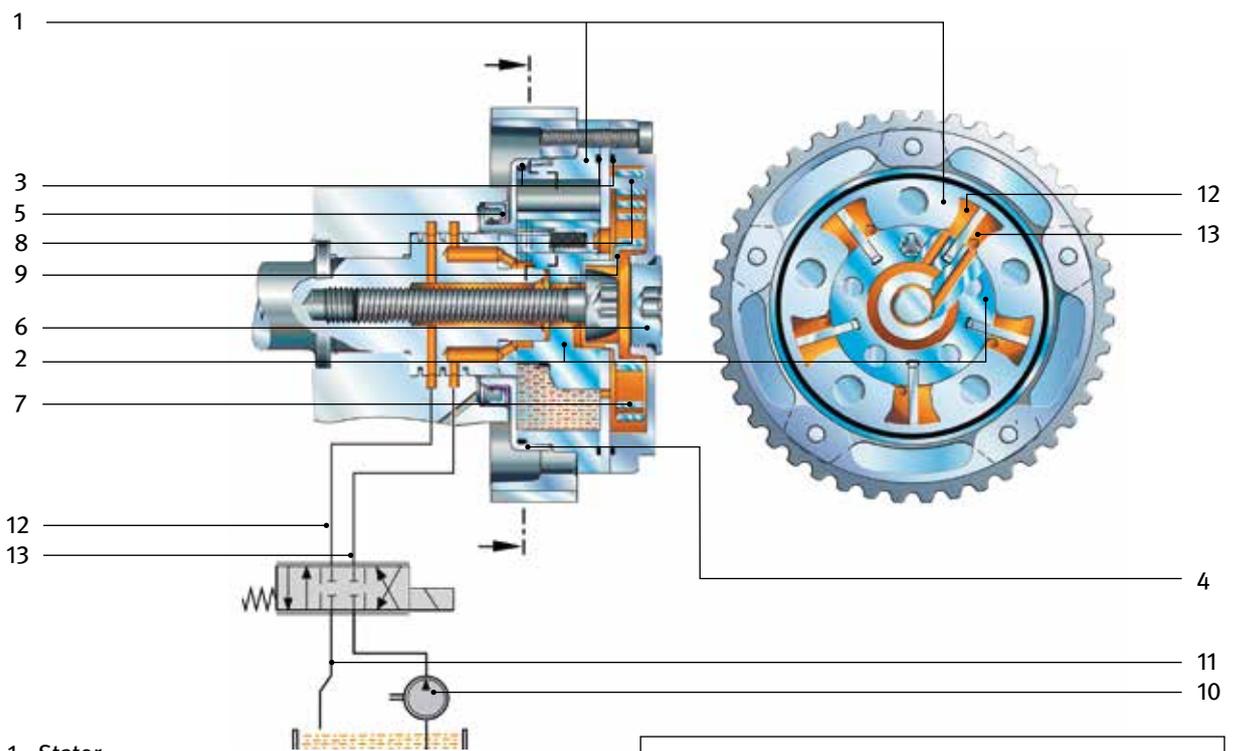
Adjuster in basic position "A"

- Valve timing is in "advanced" or "retarded" position.
- The locking device is engaged.
- The dragging friction at the camshaft has a decelerating impact towards the "retarded" position.
- The spiral-coiled spring moment is higher than the friction moment of the camshaft.
- The spiral-coiled spring is attached to the cover and connected in the center to the rotor by means of a support sheet as part of the central screw clamp-type joint.

Adjuster in controlled mode "B"

- Current is applied to the solenoid valve.
- Oil flows into the second chamber.
- The oil unlocks the locking element and turns the rotor.
- This moves the camshaft to "retarded" position.

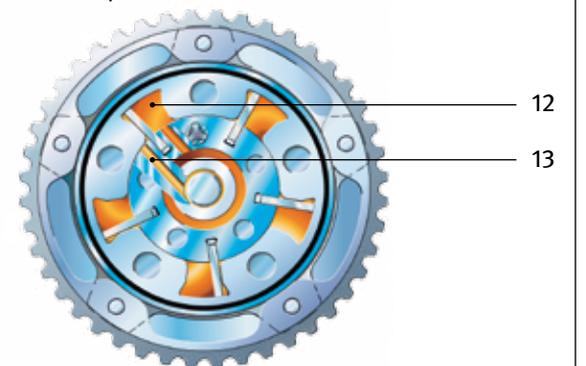
B Control position



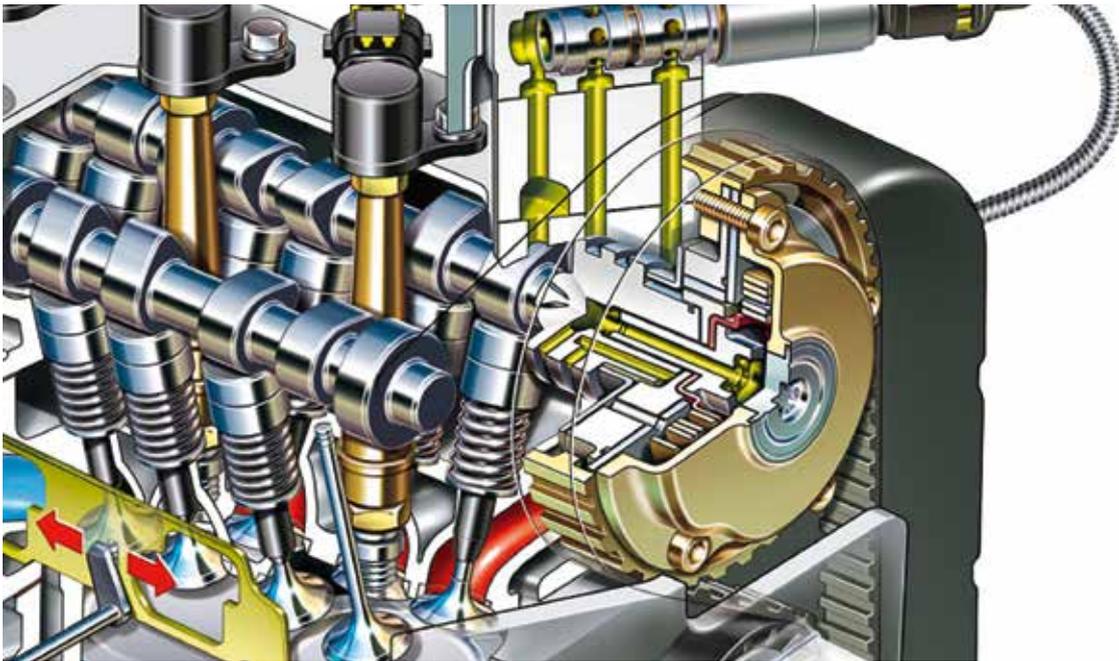
- 1 Stator
- 2 Rotor
- 3 Seal elements
- 4 Rear cover
- 5 Shaft seal ring
- 6 Front protective cover
- 7 Spring
- 8 Cover
- 9 Support sheet
- 10 Oil pump
- 11 Return
- 12 and 13 Oil chambers

- Chamber connected to engine oil pressure
- Chamber decoupled/ oil return

A Basic position



4.5 Solenoid valve

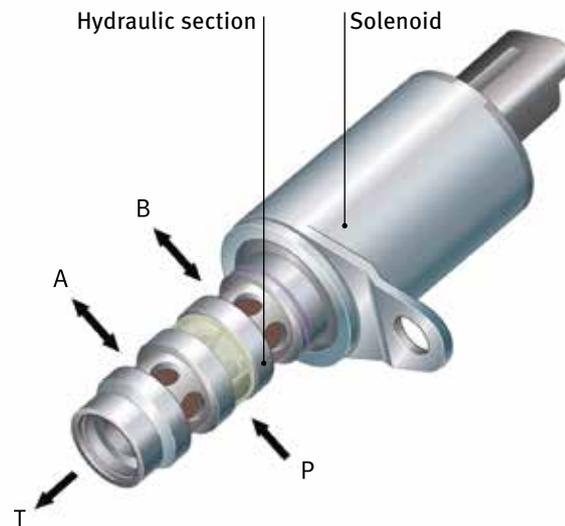


Plug-In valve

Core components of a plug-in valve

Characteristics

- The valve is compact but of a modular design and permits modification to match the particular application. The position and type of the plug and the bolting flange, the type of oil feed (lateral or end face) and the position of the seal between “wet” hydraulic section and “dry” plug-in section are flexibly selectable.
- There are two variants of plug-in solenoid valves:
 - Integrated directly into the cylinder head
 - Connected via an intermediate housing
- The valve is electrically connected to the engine control unit.
- The hydraulic slider is located in a bore providing connection to the oil feed, working chambers of the camshaft phasing unit and the oil return.
- The control slider is axially loaded by spring force in the basic position, and directed against this spring force when current flows through the solenoid:
 - Oil flow to and from both chambers varies
 - In control position the oil flow is practically interrupted, so that the rotor is stiffly locked in the camshaft phasing unit



The control valve is a proportional valve with four connections, with one connection each to the:

- Oil pump “P”
- Return “T”
- Working chamber “A” of the camshaft phasing unit
- Working chamber “B” of the camshaft phasing unit

4.5 Solenoid valve

Plug-In valve

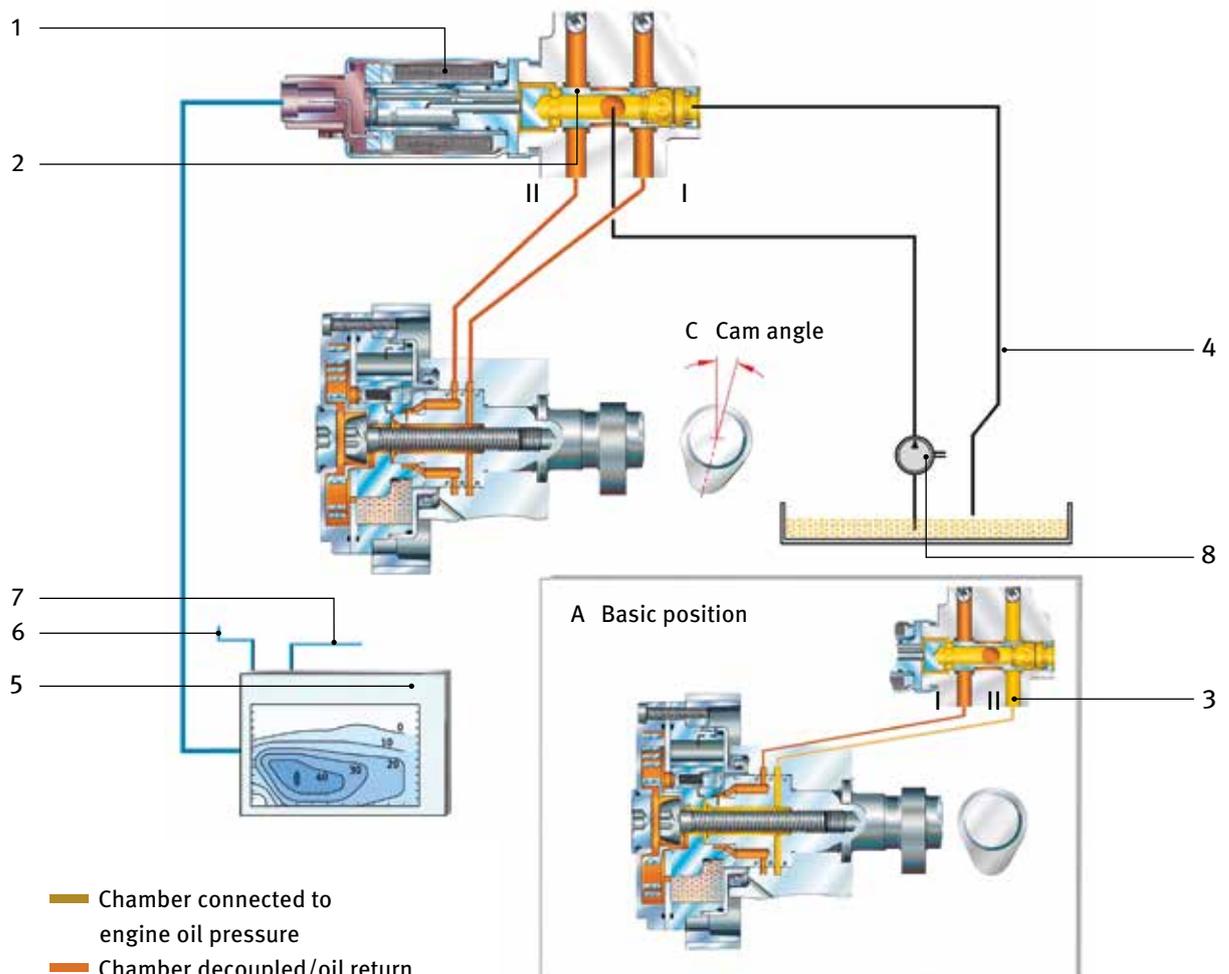
Operating principle of a plug-in valve

When current is applied to the solenoid, this directs the internal control slider against a spring force in the hydraulic section and thus switches the oil pressure between the working chambers I and II.

The working chamber, which is decoupled from oil pressure after a predetermined period of time, is connected to the return. In order to fix a timing position, the valve is held in the central position, where it is almost entirely decoupled from all connections.

- 1 Solenoid
- 2 Control slider
- 3 Oil chamber inlet
- 4 Return "T"
- 5 Engine control unit
- 6 Connection to the crankshaft sensor
- 7 Connection to the camshaft sensor
- 8 Oil pump

B Control position



Central valve

Core components of a central valve

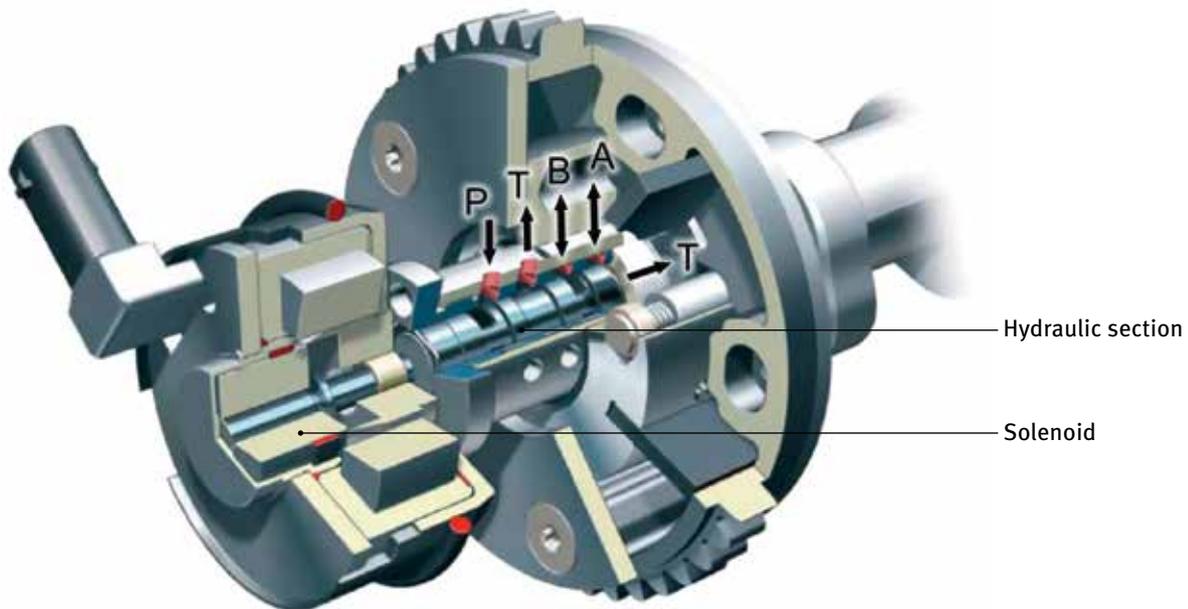
Characteristics

- The separate central magnet is coaxially positioned in front of the central valve.
- The central valve is screwed into the camshaft.
- The camshaft phasing unit is solidly connected to the camshaft (by welding).
- Short oil flow distances between central valve and camshaft phasing unit allow for reduced oil pressure loss and high adjustment velocity.

Operating principle

When current is applied to the coaxially mounted electromagnet, this directs the internal control slider against a spring force in the hydraulic section and thus switches the oil pressure between the working chambers. The working chamber, which is decoupled from oil pressure after a predetermined period of time, is connected to the return.

In order to fix a timing position, the valve is held in a central position, where it is almost entirely decoupled from all connections.



The central valve is a proportional valve with five connections, with one connection each to the:

- Oil pump "P"
- Return "T" (2x)
- Working chamber "A" of the camshaft phasing unit
- Working chamber "B" of the camshaft phasing unit

5 Maintenance and service

Important:

- To avoid malfunction resulting from contamination with foreign matter, CLEANLINESS is imperative!
- Even the slightest contamination can impair the functioning of the components and eventually cause total engine failure!
- Make sure the parts are installed correctly (mount recess on ball head and valve contact surface on valve stem).
- Ensure that the rocker arm is in the correct mounting position (offset). This varies according to the individual design.
- Hydraulic valve lash adjustment components must not be disassembled, to avoid impairment of the high-precision mechanism.
- Only engine oils authorized by the manufacturer must be used.

5.1 Replacement of mechanical bucket tappets

During initial assembly, manufacturing tolerances between cam base circle and valve seating are adjusted using adjusting shims of different thicknesses.

Important:

With the correct setting there is still a defined basic clearance between base cam circle and adjusting shim. This basic clearance serves to compensate for length differences in the valve train as a result of:

- Thermal expansion
- Compression set
- Wear and tear

Mechanical bucket tappet with top adjusting shim

If the setting dimensions differ from the manufacturer's specifications (excessive or insufficient valve clearance), the adjusting shim has to be replaced (removal of the camshaft is not necessary!).



Mechanical bucket tappet with bottom adjusting shim

If the setting dimensions differ from the manufacturer's specifications (excessive or insufficient valve clearance), the adjusting shim and the bucket have to be replaced (in this case, removal of the camshaft is required!).



Mechanical bucket tappet with graded bottom thickness

If the setting dimensions differ from the manufacturer's specifications (excessive or insufficient valve clearance), the bucket has to be replaced (in this case, removal of the camshaft is required!).



5.2 Replacement of hydraulic bucket tappets

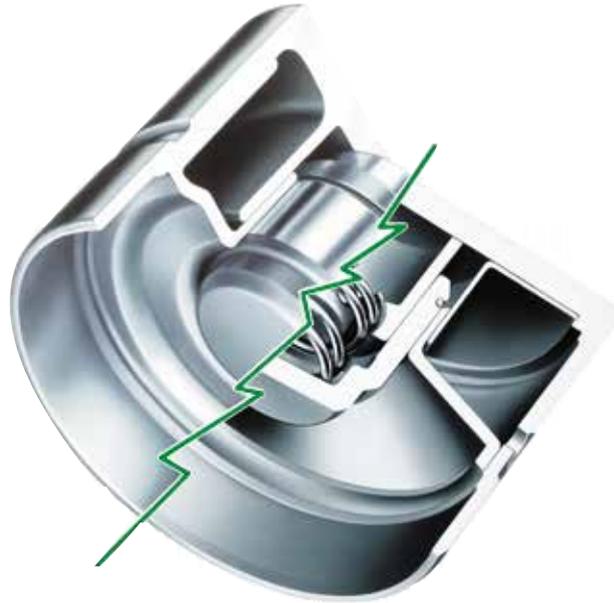
Important:

When replacing hydraulic components, the manufacturer's specifications must be followed at all times. The methods described in this section generally apply to all types of bucket tappets.

All hydraulic bucket tappets are different! Even if some types look identical from the outside, they differ significantly on the inside. So remember that hydraulic bucket tappets are not automatically interchangeable.

The reasons are:

- Different sink-down times of the hydraulic element
- Different oil consumption
- Different oil specifications
- Different finishing of the cup bottom (e.g. case hardened or nitrated)
- Different oil pressure
- Different tappet design (labyrinth-type, with anti-drain protection or with internal return)
- Different spring forces of the non-return valve
- Different valve lift (in mm)



5.3 Replacement of finger followers with hydraulic pivot element

In order to avoid repeated repairs and subsequent additional costs for the customer, it is strongly recommended to replace the complete finger follower set.

If a new pivot element is mounted on a used finger follower, the head of the pivot element will not fit properly in the recess of the finger follower, which causes excessive wear and premature failure.

Important:

The most important difference between the various hydraulic pivot elements is in their sink-down time. Matching the wrong hydraulic pivot element and finger follower can entail serious malfunction in the valve train – even complete engine failure.



5.4 Replacement of rocker arms with hydraulic insert element

Defective rocker arms must always be replaced together with the hydraulic insert element!

The reasons are:

- The fit size of the mounting bore for the rocker arm precisely matches the outer diameter of the hydraulic insert element (toleranced dimensions).
- To extract the hydraulic insert element from the rocker arm, force must be applied by a tool (e.g. pliers), which causes “pinching”, and thus damage, to the locating bore of the hydraulic insert element.
- If the oil feed holes and channels are clogged with old oil deposits, the oil supply of the hydraulic insert elements is no longer guaranteed.
- The cam roller (needle bearing) of the rocker arm is subjected to constant wear generated at the contact surface of the cam lobe.

Important:

The most important difference between the various hydraulic pivot elements is in their sink-down time. Matching the wrong hydraulic insert element and rocker arm can lead to total engine breakdown.



5.5 General repair and maintenance guidelines

Note:

These general guidelines must be observed when repair or maintenance work is being performed on the valve train. Adhere to the manufacturer's specifications at all times.

Replacement every 120,000 km

When overhauling engines with more than 120,000 driven kilometers, be sure to replace the hydraulic valve lash adjustment components. Due to the narrow system tolerances, hydraulic components have then generally reached or even exceeded their wear limit.

Always replace in a set

If one or more hydraulic valve lash adjustment component(s) is damaged, the whole set of components should be replaced. If only single components are replaced, the valve lift may not be equal for all parts due to different amounts of oil released through the leakage gap. This may result in faulty valve closure, and eventually in a burnt valve seating. In order to avoid repeated repairs and

subsequent additional costs for the customer, we strongly recommend replacing the complete finger follower set.

New camshaft – new hydraulic bucket tappet

When replacing hydraulic bucket tappets, the camshaft must always be replaced as well and vice versa. Due to the wear pattern on the bucket tappet bottom and cam track, matching new and worn parts will result in short service life of the components.

Choice of hydraulic components

The main criteria for the choice of a suitable hydraulic component must be actual assembly length (may differ from overall length of the hydraulic element), outer diameter as well as dimension and arrangement of the oil grooves. Always only use the hydraulic elements included in parts lists and catalogs.

Please be sure to never install standard-size hydraulic bucket tappets in over-sized bores of the cylinder head.

Filling of hydraulic components

Some manufacturers offer valve lash adjustment components for the aftermarket, which are already pre-filled with the required amount of oil or contain at least an amount sufficient for the running-in phase. Partly filled valve lash adjustment components ensure that the hydraulic piston is automatically in the right position during start-up of the overhauled engine. In this short period of time the hydraulic elements auto-air bleed, unlike initially filled components, emitting a ticking noise in the cylinder head area until the part is filled to the required oil level by the engine oil circuit. Since hydraulic elements are shipped in transport position, they do not settle to their individual installation position until they have been mounted and loaded in the camshaft.

Do not rotate the camshaft during this period. The sink-down phase normally requires 2-10 minutes at ambient temperature, after which the camshaft can be rotated and the engine started.

General fitting instructions

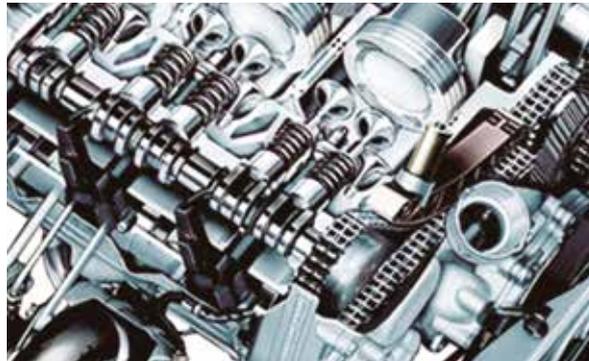
- Drain the engine oil
- Purify the oil system, in particular the oil channels leading to the hydraulic components, disassemble and purify the engine sump and oil screen, if necessary
- Mount a new oil filter
- Check the oil level and oil supply
- Assemble the cylinder head
- Wait for the hydraulic components to sink down before rotating the camshaft and starting the engine

5.6 Air bleeding of hydraulic valve lash adjustment components – recommendations

Valve train noise can occur under certain operating conditions (multiple start-ups, cold start, engine initial assembly). Observe the following instructions to ensure rapid bleeding of the high-pressure chamber and reservoir of the hydraulic element:

- Keep the engine running at a constant speed of approx. 2,500 rpm or at variable speeds in the 2,000 to 3,000 rpm range for at least 4 minutes.
- Then keep the engine idling for approx. 30 seconds.
- The system is bled if no more noise is audible. If valve train noise persists, repeat steps 1 and 2.

In 90 % of cases, valve train noise is eliminated after the first air bleeding cycle. In very few cases, it may be necessary to repeat the procedure up to 5 or 6 times. If valve train noise is still perceptible after the fifth bleeding cycle, it is recommend to replace the relevant parts and perform additional tests.



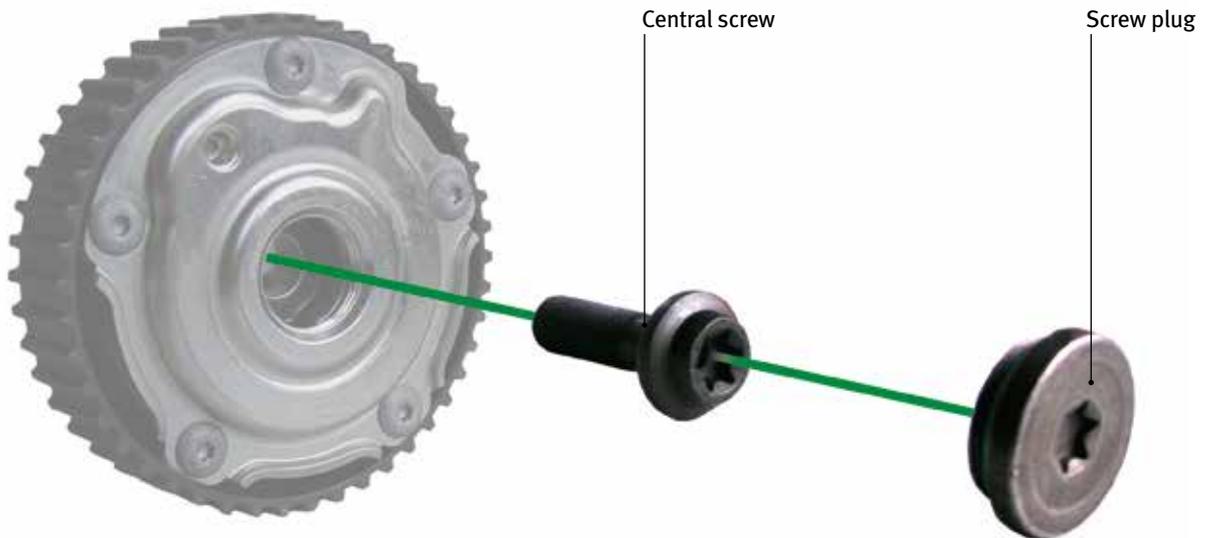
5.7 Replacement of camshaft phasing units – recommendations

Timing pin

Some types of camshaft phasing units are equipped with a timing pin. When installing these, ensure that the pin is precisely aligned to the hole in the camshaft to prevent tilting of the phasing unit. Failure to do so results in malfunction and inaccurate guiding of the belt or chain.

Camshaft seal

When replacing the camshaft phasing unit, it is also strongly recommended to replace the camshaft seal which protects the connection between camshaft and cylinder head.



Central screw

When replacing the camshaft phasing unit, the central screw, which connects the phasing unit to the camshaft, should also be replaced, as the screw is plastically deformed when the specified tightening torque is applied, which varies depending on the vehicle manufacturer and must be observed at all times. Therefore, re-using the screw is not advisable.

Screw plug

When replacing the camshaft phasing unit, it is also recommended to replace the screw plug, which seals the phasing unit towards the outside. It is fitted with a seal ring, which may be damaged by unscrewing.

6 Failure diagnosis and damage assessment

6.1 General information on damage assessment

Under mixed friction conditions abrasive and adhesive wear occurs between metallic friction partners. Both types of wear including fatigue wear, which leads to pitting formation at the surface, often result in the total failure of the friction partners. Wear can also be the result of different kinds of corrosion.

- Abrasion generally describes rubbing or scraping processes.
- Adhesion occurs where main body and counter body are in direct contact with each other.

Several parameters can influence wear:

- Materials (combination of materials, heat treatment, coating)
- Contact geometries (macro/micro geometries, molding accuracy, roughness, percentage contact area)
- Load (forces, moments, Hertzian pressure)
- Kinematic parameters (relative velocity, hydrodynamic velocity, surface pressure)
- Lubrication (oil, viscosity, amount, additivity, contamination, ageing)

Noise emission during warm-up phase

In the majority of cases, noise during engine warm-up is not grounds for complaint. When the engine is turned off, some valves can remain in the opened position where valve spring force is applied to adjust valve lash. As a result, oil is forced out of the high-pressure chamber, which is then gradually refilled during engine warm-up.

The air cushion generated in the open hydraulic element is being compressed, which is the source of the ticking noise.

Noise emitted by warm engine

Frequently, the root cause of noise emitted by a warm engine is insufficient oil supply. Possible causes are:

- Hydraulic piston seized resulting from oil contamination
- Oil foaming caused by engine oil level being too high or too low
- Leakage on the oil pump intake side
- Insufficient oil pressure due to oil line leak

Noise emission caused by “inflation”

Possible causes:

- Defective, fatigued or wrong valve spring (wrong parts mounted together)
- Defective valve guide or valve stem
- Engine overrev

As a result of this the valve train components are separated at the contact surfaces, which in turn generates disproportionate piston lift. Consequently, only an insufficient amount of oil can be displaced in this short period of time.

Result:

The valve does not close properly, causing performance loss and even burning of the valve. In addition, valves hitting the piston crown can cause severe engine damage.

Owing to the narrow system tolerances, valve lash adjustment components are very sensitive to engine oil contamination. In addition, dirt particles do not only lead to increased wear of the moving parts, but also cause ticking noise in hydraulic valve lash adjustment components.

6.2 Residual dirt

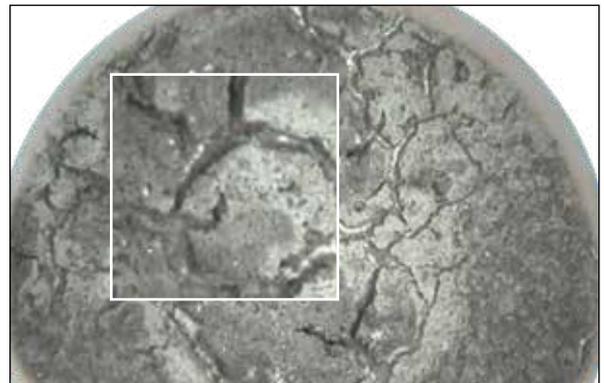
Aluminum residues from cylinder head machining

Large quantities of residual dirt particles are frequently found when examining returned defective parts. These foreign particles, e.g. aluminum, result from cylinder head machining.



Combustion deposits in diesel engines

Lint from cleaning cloths or combustion deposits from diesel engines may be found in the engine oil.



6.3 Failure diagnosis of valve train components

Important:

When examining and assessing damage to hydraulic components, the manufacturer's instructions must be observed at all times. The methods described in this section generally apply to all types of valves.

Visual examination

Always replace hydraulic components showing external damage, such as scoring, scratching or seizing marks. Also examine the mating surface in the valve train.

Pay particular attention to the bucket tappet bottom. Its contact surface is the highest-loaded area in the engine.

In new condition, the phosphated crown of VW tappets is spherical. The coating wears off during the break-in period. The criterion for damage assessment on a bucket tappet is therefore not the pattern on the coating, but the outline of the tappet crown. If the contact surface has become concave, the bucket tappets and the camshaft have to be replaced.

Manual examination

A simple yet effective examination method of hydraulic valve lash adjustment components under workshop conditions is their ability to be compressed.

A filled component should be difficult to compress by hand. This test must be performed with great caution, so as not to press oil out of the leakage gap.

If the filled element can be compressed quickly without applying much force, it must be replaced. Thorough function tests of hydraulic elements are only possible using extensive testing procedures, including, for example, measurement of the sink-down time, which can only be carried out at the manufacturer's facilities.

Damage assessment – bucket tappets

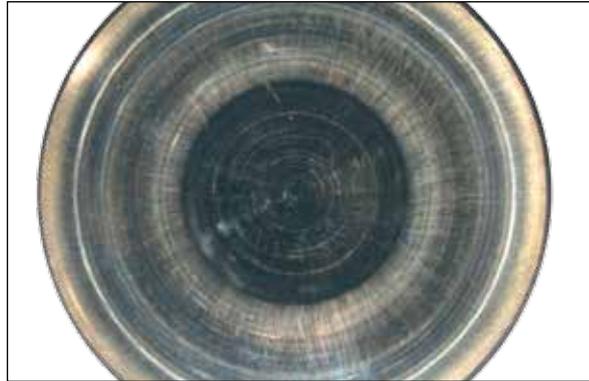
Wear to the bucket crown

Normal wear and tear

- Normal running surface profile of a bucket tappet.
- The circular marks are caused by the rotation of the tappet and are not grounds for complaint.

Remedy

- No remedial measure required – the surface is in good working condition.



Increased wear

- Heavily worn bucket crown.
- Such a running surface profile implies heavy abrasion of the bucket tappet crown.

Remedy

- Bucket tappet and camshaft must be replaced.



Heavy wear

- Adhesive-abrasive wear causing complete failure.

Remedy

- The bucket tappet must be replaced. Additionally, thorough inspection of the camshaft position is required.



Scoring on the bucket tappet housing and guiding bore

Cause

- Engine oil contaminated by excessive residual dirt.

Result

- Bucket tappet seized in the locating bore.

Remedy

- Clean (scavenge) the engine.
- Pay attention to cleanliness when installing the new bucket tappet.

Bucket tappet

Guiding bore



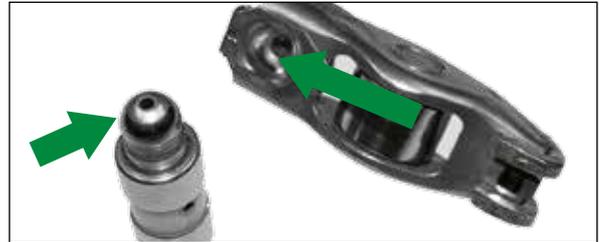
6.3 Failure diagnosis of valve train components

Damage assessment – finger followers

Wear to the finger follower and pivot element

Note:

Direction of view in the figures 1 to 4.



Normal wear and tear

- Smoothing marks in the contact area of the rocker arm recess.
- Normal wear and tear as occurring during operation.
- Smoothing marks in the contact area of the ball head.

Remedy

- No remedial measure required – the surface is in good working condition.



Increased wear

- Critical degree of highly abrasive wear of the ball head resulting in distorted ball head geometries.
- Critical degree of highly abrasive wear of the recess resulting in distorted recess geometries.

Remedy

- The hydraulic pivot element and its finger follower must be replaced.



Wear to the valve contact face of the finger follower

Note:

Direction of view in the figures 1 to 4.



Normal wear and tear

- Minor smoothing marks on the valve contact face resulting from the relative movement between finger follower and valve.
- Normal wear and tear as occurring during operation.

Remedy

- No remedial measure required – the surface is in good working condition.



Heavy wear

- Highly abrasive wear of the valve contact face.
- Clearly visible edges at the outer contact face imply that wear depth is several tenths of a millimeter.
- Continued operation involves the risk of lever fracture.

Remedy

- The hydraulic pivot element and its finger follower must be replaced. The valve stem must be checked.



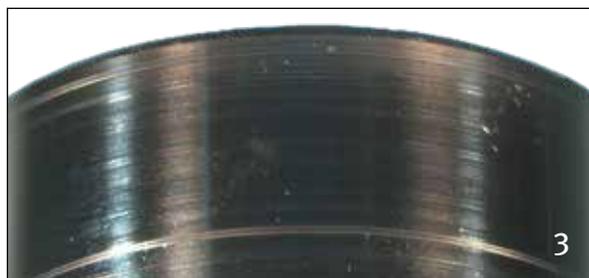
Wear of the outer ring of the cam roller

Normal wear and tear

- Outer diameter of the cam roller is not visibly damaged. The circular marks result from minute foreign particles trapped between cam roller and cam.
- Normal wear and tear as occurring during operation.

Remedy

- No remedial measure required – the surface is in good working condition.



Heavy wear

- Heavy wear of the outer diameter of the cam roller including significantly deformed geometries of the cam roller.

Remedy

- The hydraulic pivot element and its finger follower must be replaced. The position of the relevant camshaft must be checked.



6.3 Failure diagnosis of valve train components

Damage assessment – finger followers

Wear to the finger follower roller shaft

Examination of the radial play of the roller bolt

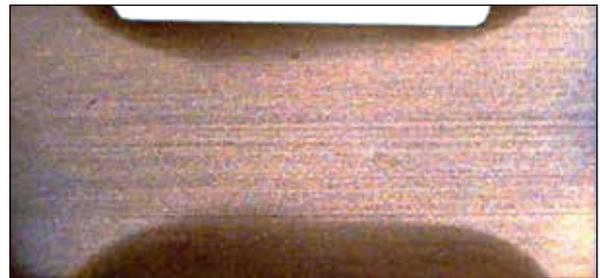
To check the radial play the rocker is simply moved up and down in a radial direction.

If the radial play is several tenths of a millimeter, the load zone of the roller shaft is worn and the part must be replaced.



Heavy wear

- The load zone of the roller shaft is heavily worn.



Final stage of wear:

- The needles in the roller shaft have become loose.

Remedy

- The hydraulic pivot element and its finger follower must be replaced.



Improper functioning of the pivot element

Non-return valve of the pivot element

Cause

- Contamination with foreign particles washed into the valve lash adjustment component by engine oil.

Result

- Improper functioning of the non-return valve.

Caution!

The manufacturer's warranty expires if the parts are disassembled at the garage during the warranty period. In order to ensure proper functioning of the high-precision adjustment mechanism of hydraulic pivot elements, parts which have been disassembled must not be re-installed as this is detrimental to the system's overall operational reliability.



Damage assessment – camshaft phasing

Rattling noise in the phasing unit area at engine start-up

Cause

- Excessive locking play.

Remedy

- The phasing unit needs to be replaced.
- Limited or no function of the phasing unit.

Cause

- Oil sludge build-up or oil contamination.

Remedy

- Clean (scavenge) the engine and change oil.
- Replace phasing unit.



Solenoid valve for camshaft phasing

Solenoid valve does not work

Cause

- Dirt particles in the engine oil impair the function of the control valve piston, the piston is seized.
- Intermittent contact at the control valve electrical connection.

Remedy

- The solenoid valve needs to be replaced.
- The electrical connection must be examined and repaired, if necessary.

Note:

If the solenoid valve piston does not reach the required end positions, the engine control unit generates a corresponding error message (“Failure to reach desired angle”).



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