The historic development of hydraulic valve lash adjustment components can be traced back to the early 1930s, when the idea was born and patents were first registered in the USA. By the end of the 1950s, hydraulic valve lash adjustment components were already a standard feature in 80% of American passenger cars.

For economic reasons, during this same period European manufacturers concentrated on high-speed engines with relatively small displacement. 1971 saw the SOP for hydraulic valve lash adjustment components in the Federal Republic of Germany. By 1987 a large number of German, British, Swedish, Spanish and Japanese vehicle types were already fitted with hydraulic valve lash adjustment components. Their market share is steadily increasing, and since 1989, French and Italian cars have also offered this advanced technology. Engineers and technicians involved in designing new engines are faced with continuously tighter requirements and growing demands, especially in terms of:

- environmental friendliness
- noise emissions
- reliability
- cost-efficiency
- ease of maintenance, and
- performance

Each of these requirements has an impact on the rating of the valve timing and the corresponding system components, regardless of what engine type is used (OHV or OHC). Whatever concept is realized, it is essential to rule out valve lash and keep engine performance characteristics stable throughout the service life.

In systems with mechanical valve timing, thermal expansion together with wear and tear in the valve train components are the main causes of uncontrolled variations in working clearance, the result being that the valve timing deviates from the ideal specification for the engine.

Hydraulic valve lash adjustment components by RUVILLE are designed to meet the requirements made of timing systems in modern engines.

They make engines...

- low-pollutant
  Thanks to optimized design, engine timing – and consequently exhaust emission – remains practically constant throughout the entire service life and during all operating conditions of the engine.

- quiet
  The engine noise level is reduced by avoiding noisy valve lash.

- durable
  Constant frictional contact between the components minimizes wear and tear, thus ensuring consistently low valve seating velocities.

- cost-efficient
  No adjustment of valve lash during initial assembly.

- maintenance-free
  No adjustment of valve lash throughout the entire engine service life.

- speed-tolerant
  RUVILLE’s specific lightweight design allows for permanently high engine speeds.
2. THE VALVE TRAIN

Internal combustion engines require a cyclic supply of fresh air, with corresponding removal of the exhaust gases produced during combustion. In a 4-stroke combustion engine, the intake of fresh air and removal of exhaust air is called a charge cycle. In the course of several charge 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 cross-section
- quickly perform opening and closing processes
- have a streamlined design to minimize pressure loss
- ensure effective sealing when closed, and
- offer excellent endurance.

2.1 Requirements

The valve train is subjected to high acceleration and deceleration rates. 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 conditions, valve train components must satisfy a number of requirements, such as:

- offering high strength characteristics (over the entire service life of the engine);
- functioning without friction;
- ensuring sufficient and efficient heat removal from the valves (particularly from the exhaust valves).

Furthermore, it is important to ensure that no impulses are induced into the system by the valve train components, and that there is no loss of contact between the frictionally coupled components.

2.2 Designs

There are different types of valve train designs. Their common feature is that they are all driven by the camshaft. Valve trains differ in terms of:

- the number of valves driven and
- the number and position of camshafts driving the valve train.

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

### OHV valve train

**Figure detail (1):** The camshafts are mounted below the separating line of cylinder head and engine block. The valve train in this kind of engine is called an overhead valve (OHV) valve train.

**Figure detail (2):** The camshafts are mounted above the separating line of cylinder head and engine block. If there is only one camshaft, it is called an overhead camshaft (OHC) valve train.

**Figure detail (3):** If there are two camshafts, it is called a double overhead camshaft (DOHC) valve train.

**Figure detail (4):** The finger follower system is the most rigid construction form of a lever-type valve train.

**Figure detail (5):** OHC valve trains with valves directly operated by bucket tappets are suitable for very high engine speeds. Neither rocker arms nor finger followers are required.

All types of valve timing systems (details (1) to (5)) are used today in mass produced engines. Engineers have to weigh up the benefits and drawbacks of the respective system depending on the construction priorities such as performance, torque, capacity, packaging, manufacturing costs etc., and opt for a corresponding design. Consequently, all valve train systems have their own justification, from pushrod systems through to compact OHC valve trains with directly operated valves.

2.3 Valve lash

When the valve is closed, a valve train system must have a precisely defined clearance, the so-called “valve lash”. Valve clearance (lash) compensates for changes in length and dimensions of the valve train components that are caused by wear and tear and temperature fluctuations, for example:

- temperature fluctuations between the various engine components (e.g. in the cylinder head)
- use of different materials with differing thermal expansion coefficients
- wear and tear in the contact surfaces between camshaft and valve
- wear and tear in the contact surfaces between valve and valve seat.

Valve clearance (lash) is defined as the difference between the valve seat and valve stem, and is called the “valve seat clearance” or “valve clearance”. Valve clearance is a precisely defined clearance, which is defined for each type of engine. Valve clearance can be adjusted by means of a valve clearance adjuster, which is a hollow pin with a spring in the valve train.

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2.4 Valve lash adjustment

With mechanical valve train systems, valve lash used to be, and still has to be, set manually during initial installation and readjusted at regular maintenance intervals by means of adjusting screws and shims. Alongside mechanical solutions, automatically controlled hydraulic valve lash adjustment solutions have also 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.

Insufficient valve lash

Valve opens earlier and closes later
- The shorter closing time means that heat cannot dissipate rapidly enough from the valve head to the valve seat.
- The valve head of the exhaust valve heats up; if it gets too hot, the valve breaks.
  
- Engine damage or failure!

Valve does not close properly
- There is a risk that the exhaust valve or intake valve does not close properly 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.
  
- Poorer emission values
- The constant leakage of hot exhaust gases overheats the valves, burning the valve head and valve seats.

Valve subjected to high mechanical stress
- Noise in the valve train.
- Distortion of the valve neck.
  
- Engine damage or failure

The consequences of insufficient or excessive valve lash range from noise emission in the valve train to engine damage or failure. Another important point is the poorer emission values that place a greater burden on the environment. The following summary indicates the possible effects of insufficient or excessive valve lash.

Excessive valve lash

Valve opens later and closes earlier
- This results in shorter opening times and smaller opening cross-sections.
- The amount of fuel mixture in the cylinder is too low, causing a decrease in engine performance.
- Poorer emission values

Valve subjected to high mechanical stress
- Noise in the valve train.
- Distortion of the valve neck.
- Engine damage or failure

More information about valve lash adjustment using bucket tappets, finger followers and rocker arms is provided below in Section 3 “Structure and functions of valve train components”.

3.1 Bucket tappet

In bucket tappet valve trains, valves are actuated directly. There is no transmission mechanism 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 with their high rigidity and small moving masses. They therefore also ensure good performance at high speeds. Bucket tappets are actuated by sliding contact, causing friction losses between tappet bottom and cam. Suitable material pairing can minimize these losses. Further reduction in wear and tear is achieved with bevelled cams mounted opposite the tappet in lateral misalignment, rotating the tappet through a certain angle at each stroke.

3.1.1 Mechanical bucket tappet

Features of the mechanical bucket tappet:
- Steel body
- Directly actuated valve
- Mechanically adjusted valve lash

Features
- The adjusting shim is:  
  - closely inserted in the tappet body; supplied in various thicknesses;  
  - material and heat treatment can be selected as required;  
  - valve lash is adjusted by means of the shim thickness (a).

Bucket tappet valve train

1. Lifting groove
2. Adjusting shim
3. Tappet body
4. Tappet outer surface
5. Tappet body
6. Adjusting shim
7. Tappet body

Mechanical bucket tappet with top adjusting shim

Mechanical bucket tappet with bottom adjusting shim

Mechanical bucket tappet with graded bottom thickness

Features
- Defined lash (b) between cam base circle and tappet body outer surface based on the adjusting shim thickness  
- Very low mass of the bucket tappet, reducing valve spring forces and frictional power  
- Large contact surface for cam  
- Can be produced at very low cost
3.1.2 Hydraulic bucket tappet

Features
- directly actuated valve
- very high valve train rigidity
- automatic valve lash adjustment
- maintenance-free throughout the whole service life
- very quiet valve train
- consistently low exhaust emissions throughout the whole service life

A. Anti-drain bucket tappet
   Oil cannot drain out of the outer reservoir while the engine is switched off – improved operating behaviour during multiple engine start-ups.

B. Bottom drain bucket tappet
   Oil reservoir volume can be used more effectively – improved operating behaviour during multiple engine start-ups.

C. Labyrinth bucket tappet
   Combination of anti-drain and bottom drain – considerably improved operating behaviour during multiple engine start-ups.

D. 3CF bucket tappet (3CF = cylindrical cam contact face)
   - 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, therefore.
   - extremely low tappet mass,
   - very high rigidity, and
   - reduced friction power.

Bucket tappet is put under load by the engine valve spring force and mass inertia forces.

The distance between piston and inner housing is reduced so that a small amount of oil is forced from the high pressure chamber through the leakage gap (a) and returned to the oil reservoir (b).

There is a small valve lash at the end of the sink down phase.

A small quantity of oil/air is forced out through the inlet hole and/or guidance gap (c).

1. Outer housing
2. Piston
3. Inner housing
4. Valve ball
5. Valve spring
6. Valve cap
7. Return spring
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 hole
3.2 Finger follower with pivot element

Finger followers are preferably made from sheet metal. Contact between the cam and finger follower is frequently ensured by a rolling bearing cam roller (roller-type finger follower). Finger followers can also be made from precision cast steel. Compared to bucket tappets, short levers create smaller mass moments of inertia. This allows for designs with reduced masses on the valve side. However, in terms of rigidity, roller-type finger followers are significantly inferior to bucket tappets.

Each valve train design 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 and concave flanks, generating a smaller cam lift depending on the transmission ratio.

The camshaft is located above the roller, which is preferably mounted centrally between the valve and the pivot element. This arrangement makes finger followers suitable particularly for four-valve diesel engines. Here the valves are positioned either in parallel or at a slight angle to each other so that finger followers are needed to ensure sufficient distance between the camshafts.

Features of the finger follower
- contact between finger follower and cam preferably by rolling bearing cam roller
- very low valve train friction
- very simple assembly of cylinder head
- very easy oil supply to the cylinder head
- takes up very little installation space

Hydraulic valve lash adjustment with finger follower

The hydraulic pivot element (b) is put under load by the valve spring force and mass inertia forces, reducing the distance between piston (5) and housing (6). A small quantity of oil is forced out of the high pressure chamber through the leakage gap and then returned via the leakage oil collecting groove and the intake hole to the oil reservoir. At the end of the sink down phase, there is a small lash in the valve train. A small quantity of oil/air is forced out through the ventilation hole (8) and the leakage gap.

The return spring pushes the piston (5) and housing (6) apart until the valve lash is adjusted. The check valve opens due to the difference in pressure between the high pressure chamber and the oil reservoir. Oil flows out of the reservoir via the check valve into the high pressure chamber. The check valve closes; frictional contact in the valve train is restored again.

- Cam roller
- Oil injection nozzle (optional)
- Retaining clip (optional)
- Guiding tab
- Piston
- Housing
- Retaining ring (polygon ring)
- Ventilation hole/pressure relief hole
- Sheet steel finger follower
- Pivot element
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 loss, needle bearing cam rollers are used in modern rocker arms. Either a hydraulic valve lash adjustment component (e.g. hydraulic insert element) or an adjusting screw for mechanical valve lash adjustment is 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 pivoting movement of the rocker arm, the contact surface between insert element and valve actuating element must be slightly curved (or spherical). This results in a very small contact area, so that comparatively large surface pressure is applied to the valve stem end.

Insert elements with a contact pad are used for very high exhaust gas emissions throughout the entire service life.

- Very quiet
- Constantly low exhaust gas emissions
- Small installation space
- Very cost-effective

The hydraulic insert element (b) is put under load by the valve spring force and mass inertia forces, thus reducing the distance between piston (4) and housing (5). A small quantity of oil is forced out of the high pressure chamber through the leakage gap and then returned via the leakage oil collecting groove and the intake hole to the oil reservoir. At the end of the sink down phase, there is a small lash in the valve train. A small quantity of oil/air is forced out through the ventilation hole and the leakage gap.

The return spring pushes the piston (4) and housing (5) apart until the valve lash is adjusted. The ball check valve opens due to the difference in pressure between the high pressure chamber and the oil reservoir. Oil flows out of the reservoir via the ball check valve and into the high pressure chamber. The ball check valve closes; frictional contact in the valve train is restored again.

- Cam roller
- Oil channel
- Support shim
- Piston
- Housing
- Retaining cage made of sheet metal or plastic
- Contact pad
  a. Rocker arm
  b. Insert element

**General features of hydraulic insert elements**
- Automatic valve lash adjustment
- Maintenance-free
- Very quiet
- Constantly low exhaust gas emissions throughout the entire service life

**Features**
- The main body (a) of the rocker arm is preferably made from aluminium. It is fitted with:
  - A needle bearing cam roller (1)
  - A hydraulic pivot element (b)

**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.**

**Features**
- Supported with a swivel mechanism on the insert element consisting of a ball-and-socket joint
- The contact pad (c) is made of hardened steel
- Very low surface pressure in the valve contact area

**Features**
- Small installation space
- Low weight (low moving masses)
- Very cost-effective

**General features of hydraulic insert elements**
- Automatic valve lash adjustment
- Maintenance-free
- Very quiet
- Constantly low exhaust gas emissions throughout the entire service life

**Features**
- The hydraulic insert element (b) is put under load by the valve spring force and mass inertia forces, thus reducing the distance between piston (4) and housing (5). A small quantity of oil is forced out of the high pressure chamber through the leakage gap and then returned via the leakage oil collecting groove and the intake hole to the oil reservoir. At the end of the sink down phase, there is a small lash in the valve train. A small quantity of oil/air is forced out through the ventilation hole and the leakage gap.

**Adjustment phase (base circle)**

**Sink down phase (cam lift)**

**Image 162x139 to 292x269**

**Image 304x258 to 433x373**

**Image 304x519 to 433x659**

**Image 899x189 to 1163x404**

**Image 899x391 to 1163x659**
3.4 Pivot rocker arm with insert element

In end pivot rocker arm valve trains, the camshaft is positioned above the rocker arm and operates several valves at the same time. This is carried out by two cams which act on two or three insert elements by means of two rollers (roller-type end pivot rocker arm). The design with two insert elements is also referred to as dual end pivot rocker arm, while the version with three insert elements is called a triple end pivot rocker arm. This type of valve train is used in multi-valve diesel engines. Even if these have an inversely mounted valve arrangement, the system allows all valves to be operated by a single camshaft while leaving sufficient installation space for the injection nozzles.

Features of the end pivot rocker arm

The main body of the rocker arm is preferably made of aluminium. 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 entire service life
- In addition, it is extremely speed-tolerant and has low friction power.

Hydraulic valve lash adjustment with end pivot rocker arm

The hydraulic insert element is put under load by the valve spring force and the mass inertia forces, thus reducing the distance between the piston and the housing. A small quantity of oil is forced out of the high pressure chamber through the leakage gap and then returned to the oil reservoir via the leakage oil collecting groove and intake hole. At the end of the sink down phase, there is a small lash in the valve train. A small quantity of oil/air is forced out through the ventilation hole and the leakage gap.

The return spring pushes the piston and the housing apart until the valve lash is adjusted. The ball check valve opens as a result of the difference in pressure between the high pressure chamber and the oil reservoir. Oil flows out of the reservoir through the ball check valve into the high pressure chamber. The ball check valve closes; frictional contact in the valve train is restored again.

1. Cam roller
2. Oil channel
3. Piston of the insert element
4. Housing of the insert element
5. Contact pad of the insert element
a. Triple end pivot rocker arm
b. Insert element
3.5 OHV valve train

Engines with a lower camshaft have a relatively large distance between cam and lever. A pushrod transmits the reciprocating movement to the lever. Pushrods are used in combination with special types of cam followers and/or tappets. They connect to the cam by means of a sliding contact (flat-base or mushroom tappets) or by roller contact (roller-type tappets) and are also responsible for guiding the pushrod.

3.6 Switching valve lash adjustment elements

Since the beginning of the 20th century, engine designers and thermodynamics engineers have been trying to transmit variable lift curves to a valve, as manifested by the large number of patents. Stricter standards for exhaust emissions and demands for reduced fuel consumption together with demands for more driving pleasure in terms of performance, torque and responsiveness call for greater flexibility in the valve train. Today, variable valve timing systems are available with corresponding cam followers such as switching rocker arms, finger followers or bucket tappets. Variable valve timing is used to make different valve lift curves possible depending on the operating point, thus allowing for the optimum setting of the respective valve lift at all times. For each alternative valve lift, such a system requires a corresponding cam as the stroke-giving element, unless the alternative is zero lift, when the valve is deactivated. The element engaged in the valve is supported at the base circle cam.

Cylinder or valve deactivation is used mainly in large displacement multi-cylinder engines (for example 8, 10 or 12 cylinders), aiming at reducing charge cycle losses (pump or throttle losses) and/or shifting the operating point. Due to the equidistant (uniform) firing sequences, common V8 and V12 engine transmission units can be “switched” to straight-four or straight-six engines. Tests on a stationary operating V6 engine have proven that the use of cylinder deactivation allows for fuel savings between 8% and 15% during normal driving cycles. Valve deactivation is achieved by abandoning the second eccentric cam for each cam follower. This decouples the cam lift transmitting component from the valve. The motion of the transmitting element is therefore idle, which is also referred to as “lost motion”. Since there is no longer any connection to the valve spring, the respective mass moments of inertia must be sustained by an additional spring, also called “lost motion” spring. Those parts of the valve train which are not deactivated continue to perform the reciprocating movement. On the deactivated cylinders, the cam shaft only works against lost motion spring forces, which are lower than the respective valve spring forces by a factor of 4 to 5, which minimizes friction losses.
Functioning of the switching bucket tappet

Base circle phase (switching phase)
- The support spring (7) pushes the outer tappet (6) against the end stop of the inner tappet (5).
- The inner tappet (5) is in contact with the inner cam (2); there is small lash between the outer cam (1) and the outer tappet (6).
- Under reduced engine oil pressure, the spring-loaded locking piston (4) links the outer tappet (6) with the inner tappet (5).
- If the engine oil pressure exceeds the switching oil pressure, the operating piston (3) pushes the locking piston (4) back into the outer tappet (6), thus disengaging the outer tappet (6) from the inner tappet (5).
- The hydraulic adjusting element (8) in the inner tappet (5) adjusts the valve lash.

Cam lift phase, decoupled (zero or partial lift)
- The pair of outer cams (1) moves the outer tappet (6) down against the support spring (7).
- The engine valve follows the outline of the inner cam (2).
- If all engine valves of a cylinder are deactivated (outer tappet (6) decoupled), the cylinder can be deactivated, thus considerably reducing fuel consumption.

Cam lift phase, locked (full lift)
- The pair of outer cams (1) moves the coupled outer (6) and inner tappet (5) down and opens the engine valve.
- The hydraulic adjusting element (8) is put under load.
- A small quantity of oil is forced out of the high pressure chamber through the leakage gap.
- On reaching the base circle phase, valve lash is set to zero.

Switching phases of a switching mechanical bucket tappet

1. Outer cam
2. Inner cam
3. Operating piston
4. Locking piston
5. Inner tappet
6. Outer tappet
7. Support spring
8. Adjusting element
9. Support plate
10. Guiding groove
11. Antirotation device

1. Piston
2. Guide
3. Return spring
4. Locking piston
5. Inner tappet
6. Outer tappet
7. Support spring (lost motion spring)
4. CAMSHAFT PHASING SYSTEMS

4.1 General information

The purpose of camshaft phasing is to vary the gas exchange valve timing in a combustion engine. There are systems for variable intake and exhaust phasing, as well as a combination of the two. Adjusting the camshaft phasing can reduce exhaust emissions and fuel consumption. Typical adjustment angles range from 20° to 30° at the camshaft and 40° to 60° at the crankshaft. Camshaft phasing systems are available for both belt drive and chain drive engines. Various compact designs solutions meet individual installation space requirements.

4.2 Summary of camshaft phasing concepts

<table>
<thead>
<tr>
<th>Concept</th>
<th>Advantages</th>
<th>Gas exchange valve lift curves</th>
</tr>
</thead>
</table>
| Intake camshaft phasing | ■ Reduced emissions  
 ■ Reduced fuel consumption  
 ■ Improved comfort (decreased idling speed)  
 ■ Optimized torque and performance | ![Intake Camshaft Phasing Lift Curves] |
| Exhaust camshaft phasing | ■ Reduced emissions  
 ■ Reduced fuel consumption  
 ■ Improved comfort (decreased idling speed) | ![Exhaust Camshaft Phasing Lift Curves] |
| Independent phasing of intake and exhaust camshaft (DOHC) | ■ Reduced emissions  
 ■ Reduced fuel consumption  
 ■ Improved comfort (decreased idling speed)  
 ■ Optimized torque and performance | ![Independent Phasing Lift Curves] |
| Synchronous phasing of intake and exhaust camshaft (DOHC/SOHC) | ■ Reduced emissions  
 ■ Reduced fuel consumption | ![Synchronous Phasing Lift Curves] |

Each adjuster concept offers different advantages:
- Adjuster in advanced timing position
- Adjuster in retarded timing position
- Controlled position (adjuster held at a fixed angle position)

4.3 Camshaft phasing components and how they work

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 timing angle for the inlet and exhaust valves, depending on load condition, temperature and engine rpm, is retrieved from a characteristic map stored in the engine control unit (3).
- The engine control unit (3) calculates the actual timing angle of the inlet and exhaust valves read by the sensors at the camshaft (4) and crankshaft (5) and compares it with the desired angle.
- If the actual angle differs from the desired angle, the power supply to the control valve (2) is modified so that oil from the engine oil circuit flows to the oil chamber in the phasing unit (1), increasing it in size, to reduce it in size, oil from the oil chamber flows 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, so that the gas exchange valve timing is shifted to either advanced or retarded opening and closing position.
- The engine control unit (3) permanently calculates the deviation of the actual angle from the desired angle 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

1. Camshaft phasing units  
2. Control valve  
3. Engine control unit  
4. Trigger disk and sensor, camshaft  
5. Trigger disk and sensor, crankshaft

- Chamber connected to engine oil pressure  
- Chamber decoupled / oil return
4.4 Camshaft phasing units

Two types of camshaft phasing units are currently in use: axial piston camshaft adjusters and vane-type camshaft adjusters.

4.4.1 Axial piston camshaft adjusters

Features

- 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:
  - Sealing rings (steel or plastic rings) are frequently used on the camshaft (in the camshaft bearing area).
  - Alternatively, oil can be fed to the camshaft via simple grooves in the plain bearing.
- The axial piston adjuster 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 robust design, minimized oil leakage and high control precision.

Function of an axial piston camshaft adjuster

- Depending on the requirements, applying current to the solenoid (7) activates the hydraulic slider (8) integrated in the hydraulic section (6) of the control valve to regulate the oil flow in one of the two oil chambers of the adjuster.
- Impeller (1) and drive hub (3) are connected in pairs by means of a helical spline.
- Axial displacement of the adjustment piston (2), which serves as link between the impeller (1) and the drive hub (3), 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 (2), which serves to maintain a constant angle position, is hydraulically locked in the controlled mode (8), with oil pressure applied from both ends.
4.4.3 Differences between phasing units in the chain drive and belt drive

- The belt drive camshaft phasing unit (B) must be absolutely oil-tight. This does not apply to the chain drive camshaft phasing unit as the chain drive itself is protected by a cover.
- Sealing of the belt drive phasing unit is ensured by sealing elements in the adjuster, by the rear cover which serves as contact surface to the shaft sealing ring, and by the front protective cover which seals the adjuster towards the front after the central screw is fixed.
- Various running surface shapes suit the requirements of different timing chain or toothed belt designs.

4.4.2 Vane-type camshaft adjuster

Features
- Vane-type adjusters are available for both chain drive (A) and belt drive timing systems (B).
- The stator (1) is linked to the crankshaft via the timing drive, and the rotor (2) is connected to the camshaft by means of the central screw.
- The rotor (2) is radially mounted between two end stops in the stator (1).
- Typical adjustment ranges are between 20° and 30° cam angle and 40° and 60° crank angle.
- The spring-supported vanes (3) slotted into the rotor and the stator (1) segments link up to build oil chamber pairs and are filled completely with oil during operation.
- Torque transmission from the stator (1) to the rotor (2) is ensured via the hydraulically locked vanes (3).
- There are usually 3-5 vanes, depending on the required adjusting time and the overall load applied on the system.
- The locking device (4) provides secure a mechanical connection between the drive and output during engine start-up. It is hydraulically released as soon as the phasing unit is moved from its basic position.
4.4.4 Differences between intake and exhaust phasing

**Intake phasing by means of vane-type camshaft adjuster in the chain drive**
- Adjuster in basic position (A)
  - Valve timing is in “retarded” position.
  - The locking device (4) is engaged.
  - At the same time, oil in the oil chamber puts the vanes under one-sided pressure, thereby keeping them at the end stop.
  - The control valve is not energized.

- Adjuster in controlled mode (B)
  - Current is applied to the control valve.
  - Oil flows into the second chamber (A).
  - The oil unlocks the locking element (4) and turns the rotor (2).
  - This shifts the camshaft to “advanced” position.

To hold the phasing unit in an intermediate position, the control valve is switched to the control position. The oil chambers are then almost completely closed, compensating only for any oil leakage that may occur.

**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 spring (7) moment is higher than the friction moment of the camshaft.
  - The spiral spring (7) is fitted in the cover (8) and connected in the centre to the rotor (2) by means of a support sheet (9) as part of the central screw clamp-type joint.

- Adjuster in controlled mode (B)
  - Current is applied to the control valve.
  - Oil flows into the second chamber (A).
  - The oil unlocks the locking element and turns the rotor (2).
  - This moves the camshaft to “retarded” position.
4.5 Control valve

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

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

Features

- The valve is compact but modular in design and can be modified to suit the particular application. Flexible selection is possible of 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 sealing between “wet” hydraulic section and “dry” plug-in section.
- There are two types of plug-in control valve:
  - integrated directly in 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 hole with connections to the oil feed, working chambers of the camshaft phasing unit and the oil return.
- The slider is axially loaded by spring force in the basic position, and directed against this spring force when current flows through the solenoid.
- The oil flow to and from both chambers varies
- In the control position, the oil flow is practically stopped, resulting in rigid clamping of the rotor in the camshaft phasing unit.

Function of a plug-in valve

When current is applied to the solenoid (1), it moves the internal control slider (2) against a spring force in the hydraulic section of the valve and thus switches the oil pressure between the working chambers (A) and (B). The working chamber which is decoupled from oil pressure is connected to the return (T). In order to fix a timing position, the valve is held in the central position, where it is almost entirely decoupled from all connections.

A. Basic position
B. Control position
C. Cam angle
1. Solenoid
2. Control slider
3. Oil chamber inlet
4. Return (T)
5. Engine control unit
6. Connection the crankshaft sensor
7. Connection the camshaft sensor
I. Chamber connected to engine oil pressure
II. Chamber relieved/oil return
4.5.2 Central valve

The central valve is a proportional valve with five connections, each with a connection to the:
- Oil pump P
- Return T
- Working chamber A of the camshaft phasing unit
- Working chamber B of the camshaft phasing unit

**Features**
- 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 firmly connected to the camshaft (welded).
- Short oil flow distances between central valve and camshaft phasing unit allow for reduced oil pressure loss and high adjustment speeds.

**Function**
When current is applied to the coaxially mounted solenoid (2), it presses 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 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.
5. REPAIRS AND SERVICE

Important:
- To prevent malfunctions caused by contamination with foreign matter, CLEANLINESS is imperative.
- Even the slightest soiling can impair the functioning of the components and cause total engine failure.
- Make sure the parts are installed correctly (recess on ball head and valve contact surface on valve stem).
- Since rocker arms vary in construction and design, ensure that the rocker arm is in the correct mounting position (offset).
- Due to the precision of the hydraulic valve lash adjustment components, they may not be disassembled.
- Only engine oils approved by the manufacturer may be used.

5.1 Replacing mechanical bucket tappets

During initial assembly, manufacturing tolerances between cam base circle and valve seating are compensated for by 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 differences in length of the valve train resulting from:
  - thermal expansion,
  - the settling process and/or
  - wear and tear.

If the setting dimensions differ from the manufacturer’s specifications (excessive or insufficient valve lash), the adjusting shim has to be replaced (camshaft does not have to be removed!).

If the setting dimensions differ from the manufacturer’s specifications (excessive or insufficient valve lash), the adjusting shim has to be replaced (in this case, the camshaft and bucket tappet must be removed).

5.2 Replacing hydraulic bucket tappets

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

5.3 Replacing finger followers with hydraulic pivot element

In order to avoid repeated repairs and subsequent additional costs for the customer, we strongly recommend replacing the complete finger follower set. If a new pivot element is mounted on a used finger follower, it will result in poor contact between the recess of the finger follower and the head of the pivot element, causing excessive wear.

Important: The main difference between the various hydraulic pivot elements is the sink down time. Mounting the wrong finger follower to a hydraulic pivot element can lead to serious malfunctions in the valve train— even total engine failure.

5.4 Replacing rocker arms with hydraulic insert element

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

These general instructions must be observed when repair or maintenance work is being performed on the valve train. At the same time, always comply with the manufacturer’s specifications and instructions.

Replace after every 120,000 km
When overhauling an engine with mileage exceeding 120,000 kilometres, always 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 as a set
If one or more hydraulic valve lash adjustment components are damaged, the whole set of components should be replaced. If only single components are replaced, uniform valve lift is no longer ensured for all parts due to different amounts of oil released through the leakage oil gap. This may result in a faulty valve closing, and eventually in a burnt valve seating. In order to avoid repeated repairs and subseuent 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, using new and worn parts together will result in a short service life of the components.

Selection of hydraulic components
The main criteria for selecting the suitable hydraulic component are always the actual assembly length (may differ from overall length of the hydraulic element), outer diameter as well as the dimension and arrangement of the oil grooves. As a rule, only use the hydraulic elements included in parts lists and catalogues. Caution: never install standard-size hydraulic bucket tappets in oversize bores on the cylinder head!

Filling hydraulic components
Valve lash adjustment elements for the aftermarket are sometimes offered as elements already pre-filled with the required amount of oil or at least with an amount sufficient for the running-in phase. Partly filled valve lash adjustment elements ensure that the hydraulic piston is automatically in the right position during start-up of the overhauled engine. During this brief period, the hydraulic elements are automatically vented, however, in contrast to filled adjustment elements, this causes rattling noises in the cylinder head area until the engine oil circuit has replenished the required amount of oil. Since hydraulic elements are shipped in transport position, they do not settle to their individual installation position until they have been mounted and loaded by the camshaft. Do not rotate the camshaft during this period. The sink down phase normally takes 2-10 minutes at ambient temperature, after which the camshaft can be rotated and the engine started.

General installation instructions
- Drain the engine oil
- Clean the oil system, in particular the oil channels leading to the hydraulic components, disassemble and clean the engine sump and oil strainer 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 Recommendations for venting hydraulic valve lash adjustment elements in the engine

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

- Keep the engine running at a constant speed of approx. 2500 rpm or at variable speeds in the 2000 to 3000 rpm range for at least 4 minutes.
- Then keep the engine idling for approx. 30 seconds.
- If noise can no longer be heard, the system has been vented. If valve train noise persists, repeat steps 1 and 2.

5.7 Recommendations for replacing camshaft phasing units

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 the phasing unit from lifting. Failure to do so can cause malfunctions and inaccurate guiding of the belt or chain.

Camshaft seal
When replacing the camshaft phasing unit, we also strongly recommend replacing the camshaft seal, which protects the connection between camshaft and cylinder head.

Central screw (a)
When replacing the camshaft phasing unit, the central screw connecting the phasing unit to the camshaft should also be replaced, because the screw becomes plastically deformed when the specified tightening torque is applied; the tightening torque varies depending on the vehicle manufacturer and must be observed at all times. Reusing the screw is therefore not advisable.

Screw plug (b)
When replacing the camshaft phasing unit, we also recommend replacing the screw plug, which seals the phasing unit towards the outside. It is fitted with a sealing ring, which can be damaged during the unscrewing process.
6. FAILURE DIAGNOSIS/ DAMAGE ASSESSMENT

6.1 General damage assessment

Mixed friction conditions can result in abrasive and adhesive wear between metallic friction partners. Total failure of the friction partners is often caused by both types of wear, together with fatigue wear which leads to pitting formation at the surface. 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 influence wear:

- Materials (material pairing, heat treatment, coating)
- Contact geometry (macro/micro geometry, moulding accuracy, roughness, percentage contact area)
- Load (forces, moments, torques, Hertzian pressure)
- Kinematic parameters (relative velocity, hydrodynamic velocity, surface pressure)
- Lubrication (oil, viscosity, amount, additives, contamination, ageing)

6.1.1 Noise emitted during the warm-up phase

In most cases, noise during engine warm-up is not grounds for concern. 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. Compression of the air cushion generated in the open hydraulic element causes temporary rattling noises.

6.1.2 Noise emitted by warm engine

Insufficient oil supply is frequently the root cause of noise emitted by a warm engine. Possible reasons include:

- Hydraulic piston seized due to oil contamination
- Oil foaming due to too much or too little engine oil
- Leakage on the oil pump intake side
- Insufficient oil pressure due to leaks in the oil lines

6.1.3 Noise emitted by “inflation”

Possible causes:

- Defective, fatigued or wrong valve spring (wrong parts mounted together);
- Defective valve guide or valve stem;
- Over-revving the engine.

This causes separation of the valve train components at the contact surfaces which in turn generates disproportionate piston lift. Consequently, not enough oil can be displaced in this short period of time.

Results: 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 contaminants in the engine oil. Apart from increased wear of the moving parts, dirt particles in the hydraulic valve lash adjustment components also cause rattling noises.

6.2 Residual dirt

The inspection of returned defective parts frequently reveals large quantities of residual dirt particles. These foreign particles, e.g. aluminium, are left behind after machining the cylinder head.

6.3 Damage assessment of valve train components

Important:

When inspecting damage to hydraulic components, the manufacturer’s instructions must be followed at all times. The methods described in this section generally apply to all types of valves.

Visual inspection

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 tappet bottom; its contact surface is subject to the highest load in the engine. In new condition, phosphated VW tappets have a spherical bottom. The coating wears off during the running-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 bottom. If the contact surface has become concave, all bucket tappets must be replaced together with the camshaft.

Manual inspection

A simple yet effective method for checking hydraulic valve lash adjustment components in the repair shop consists in their ability to be compressed by hand. A filled component cannot be easily or quickly compressed by hand. This test must be performed with great caution, to ensure that oil is not squeezed out of the leakage oil gap. If the filled element can be compressed quickly without applying much force, it must be replaced. Thorough function tests of hydraulic elements, including, e.g., measurement of the sink-down time, can only be performed using extensive testing procedures and equipment. Such tests can only be conducted on-site at the manufacturer’s facilities.
6.3.1 Damage assessment: bucket tappets

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 concern.

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

Increased wear
- Heavily worn bucket bottom.
- Such a running surface profile indicates heavy abrasion of the tappet bottom.

Remedy:
Bucket tappet and camshaft must be replaced.

Heavy wear
Adhesive-abrasive wear causing complete failure.

Remedy:
The bucket tappet must be replaced. Thorough inspection of the camshaft position is also necessary.

Scoring on the bucket tappet housing and guiding hole

Cause: Too much residual dirt in the engine oil.
Result: Bucket tappet seized in the locating hole.
Remedy:
- Clean (scavenge) the engine.
- Pay attention to cleanliness when installing the new bucket tappet.

6.3.2 Damage assessment: finger followers

Wear and tear in the finger follower and pivot element

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

Remedy:
The hydraulic pivot element and the respective finger follower must be replaced.

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:
- No remedial measure required – the surface is in good working condition.
Wear of the valve contact face of the finger follower

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 and over the service life.

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 indicate that wear depth is in the range of several tenths.
- Continued operation involves the risk of lever fracture.

Remedy: The hydraulic pivot element and the respective 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 worn. The circular marks result from minute foreign particles trapped between cam roller and cam.
- Normal wear and tear as occurring during operation and over the service life.

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 the respective finger follower must be replaced. The position of the respective camshaft must be checked.

Wear of the finger follower roller shaft

To check the radial play, the rocker is simply moved up and down in a radial direction. Radial play in the range of several tenths indicates that the load zone of the roller shaft is worn: the finger follower must be replaced.

Remedy: The hydraulic pivot element and corresponding finger follower must be replaced.

Malfunction in the pivot element

Cause: Contamination by foreign particles that have washed into the valve lash adjustment component via the engine oil.

Result: The check valve no longer works properly.

Caution! The manufacturer’s warranty expires if the parts are disassembled at the repair shop 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.
6.3.3 Damage assessment: camshaft phasing

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

Cause:
- Excessive locking play

Remedy:
- The phasing unit must be replaced

Limited or no function of the phasing unit

Cause:
- Sludged or soiled engine oil

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

Control valve does not work

Cause:
- Dirt particles in the engine oil can impair the functioning of the control valve piston, the piston seizes up.
- Intermittent contact at the control valve electrical connection

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

Note: If the control valve piston does not reach the required end positions, the engine control unit generates a corresponding error message (“Target angle not reached”).