MAHLE

Engine components

Damage scenarios: Causes, remedies, and avoidance

Preface

MAHLE is one of the most important development partners and manufacturers of engine components and systems in the automotive industry.

The engineers at MAHLE develop products of the highest quality throughout the world in conjunction with engine and vehicle manufacturers.

For info, visit:

www.mahle-aftermarket.com

The same high-quality guidelines are also applied to spare parts for the aftermarket.

Numerous checks during and after production ensure the consistently high quality of MAHLE products. If, however, unexpected failures occur in practical operation, the causes are usually to be found in the engine environment. Operating or assembly errors, or unsuitable operating media, may also be causes of failure.

This brochure summarizes typical damage scenarios, describes their causes, and provides tips for avoiding similar damage in the future. The aim is to make it easier to identify potential causes of damage. The advice provided in the brochure helps to ensure that our products continue to function reliably in the long term, thus prolonging engine service life.

Our experts are also confronted with complex damage scenarios that go beyond the scope of this brochure. In cases where damage to our products cannot be readily diagnosed, we are more than willing to examine them at our premises and put together an expert damage report for you. Please contact your local sales partner.

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1.1 Wear caused by contamination

Fig. 1: Wear on the piston caused by contamination—deep longitudinal grooves

Fig. 2: Axial wear on the piston rings

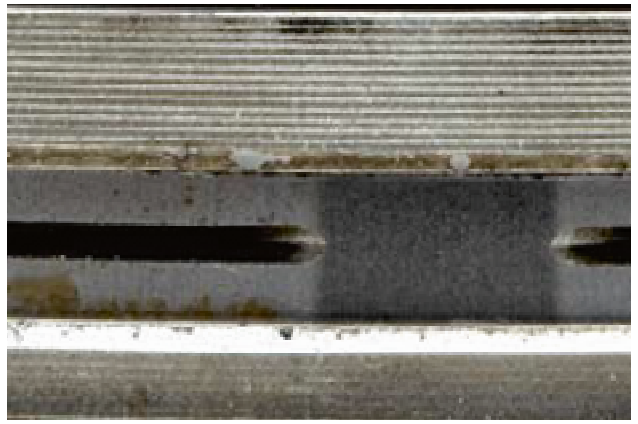


Fig. 3: Severely worn oil control ring

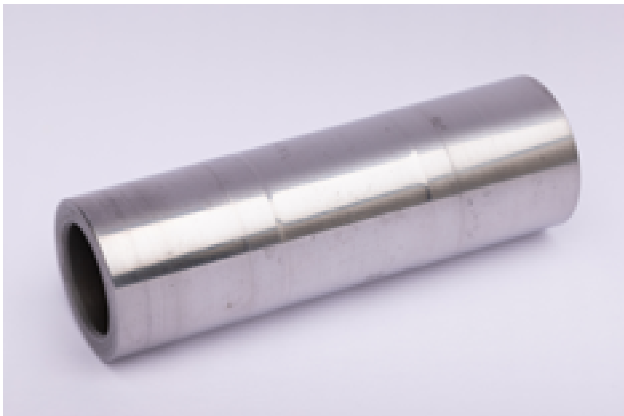


Fig. 4: Worn piston pin

Findings:

- Engine wear caused by contamination is usually indicated by increased oil consumption. Examination of the components reveals different damage scenarios:
- The piston skirt has a broad, matte wear pattern on the thrust and antithrust sides (Fig. 1).
- The machining profile on the piston skirt (Fig. 2) and on the running surface (cylinder surface) has been removed (Fig. 3).
- The piston skirt, piston rings, and cylinder surface exhibit fine score marks in the running direction.
- Vertical wear on piston rings and groove flanks (Fig. 4).
- The piston rings exhibit increased gap clearance. The edges of the rings may be razor-sharp.
- The oil control ring lands have been worn away (Fig. 3).
- There are longitudinal score marks with a wave-shaped profile on the piston pin (Fig. 4 & 5).
- Wear caused by contamination can also be found on other components, e.g., on a valve stem.

Cause(s):

When it comes to damage resulting from wear caused by contamination, we can differentiate between several scenarios based on the number of damaged cylinders and the state of wear on the piston rings:

If only one cylinder is damaged ... and the first piston ring is significantly more worn than the third, then the contamination has entered the combustion chamber via the intake system of one cylinder, i.e., from above. This is caused by either a leak or debris that was not removed before fitting.

If several or all cylinders are damaged ... and the first piston ring is significantly more worn than the third, then the contamination has entered the combustion chamber via the common intake system shared by all the cylinders. This is due to either leaks and/or a damaged or missing air filter.

... and the third piston ring is significantly more worn than the first, then we can assume that the engine oil is contaminated.

The engine oil could have been contaminated by dirt remaining in the engine after fitting. Changing the engine oil and oil filter too often can also be the cause.

Remedies/avoidance:

- Check the intake system for leaks.
- Check the air filter and replace it if necessary.
- Remove any dirt from the crankcase and the intake pipes before installation.
- Take care to maintain cleanliness during installation.

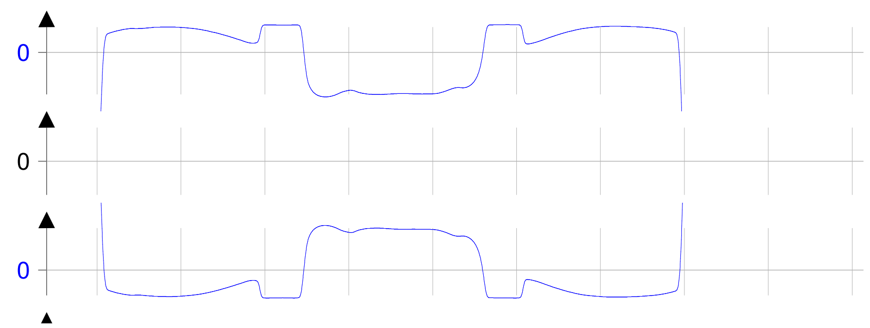


Fig. 5 Mantle lines on a piston pin

1.2 Fuel flooding

Fig. 1: Pitting in the pin bore due to diluted engine oil

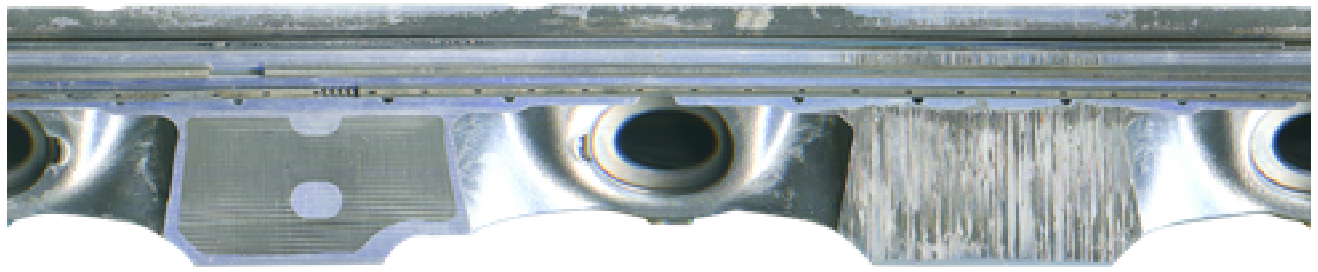


Fig. 2: Seizure marks on one side (panorama)

Findings:

- A matte—in places, dark-colored—wear pattern can be seen on the piston skirt, with localized seizure marks and grooves (Fig. 2).
- There are grooves on the piston rings, possibly also scuff marks on the ring surface.
- The honing in the cylinder liner or cylinder surface is heavily worn.
- Significant signs of wear can be seen on the piston pin. Pitting is visible in the pin bore (Fig. 1).

Cause(s):

An excessive amount of fuel in the oil has diluted the oil film, drastically reducing its load-carrying capacity and resulting in increased wear on the engine components. This kind of damage may have the following causes:

- The fuel injection system is set incorrectly.
- Cold start enrichment is too rich.
- The injection nozzles are not working properly.
- Frequent short-distance journeys mean that the diesel particulate filter's (DPF) regeneration cycle is often interrupted. This causes unburned fuel to accumulate in the engine oil.
- Insufficient gap width means that the piston can strike against the cylinder head, leading to uncontrolled fuel injection from the nozzles.
- The compression pressure is too low. This may have the following causes:
  - A valve is leaking.
  - The cylinder head gasket is leaking.
  - The valve timing is not set correctly.
  - The gap width is too large.
  - One or several piston rings are defective.
  - A fault has occurred in the ignition system, e.g., a defective spark plug.

Remedies/avoidance:

- Set the injection system correctly (cold start enrichment, etc.).
- Check the injection nozzles.
- Adhere to the installation dimensions.
- Replace the fuel filter at the specified interval and reduce the interval as necessary in extreme conditions.
- Check the spark plugs and replace them if necessary.
- Diesel vehicles in particular should be driven longer distances regularly so that the regeneration of the DPF can be completed. Take care to maintain cleanliness during installation.

1.3 Hydraulic lock

Fig. 1: Piston in a commercial vehicle shattered due to hydraulic lock

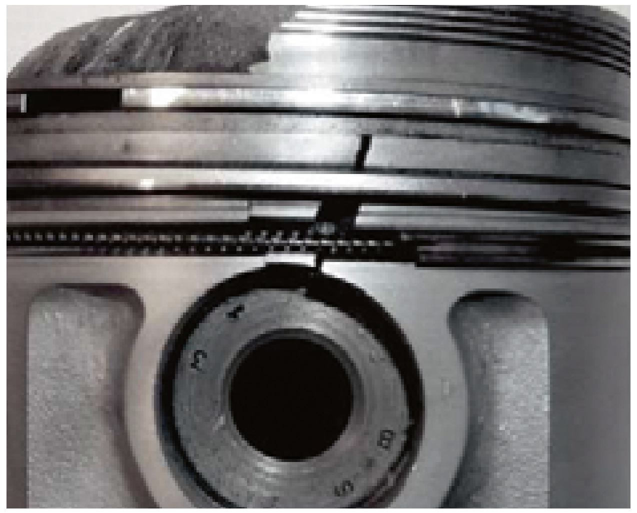


Fig. 2a: Forced fracture from the top of the piston to the pin bore

Fig. 2b: Close-up of a forced fracture

Findings:

Hydraulic lock releases extreme forces, which can affect several components:

- The piston is broken or deformed (Fig. 1).
- The connecting rod is bent or broken (Fig. 3).
- One or both pin bosses exhibit a crack or fracture that runs upward, sometimes through the entire upper part of the piston (Fig. 2a & b).
- The piston pin is broken.

Cause(s):

This damage is caused by liquid, water, or fuel entering the combustion chamber. Since neither water nor fuel can be compressed, hydraulic lock places an abrupt load on the piston, the piston pin, the connecting rod, the cylinder head, the crankcase, the bearings, and the crankshaft. Too much liquid may enter the combustion chamber for the following reasons:

- Water has found its way into the combustion chamber via the intake system (e.g., while driving through water).
- Coolant has leaked into the combustion chamber due to defective seals.
- Too much fuel has entered the combustion chamber due to a defective injection nozzle.

Remedies/avoidance:

- Always use undamaged seals when overhauling an engine. Defective seals must be replaced.
- Check injection nozzles and replace them if in any doubt.

1.4 Increased oil consumption

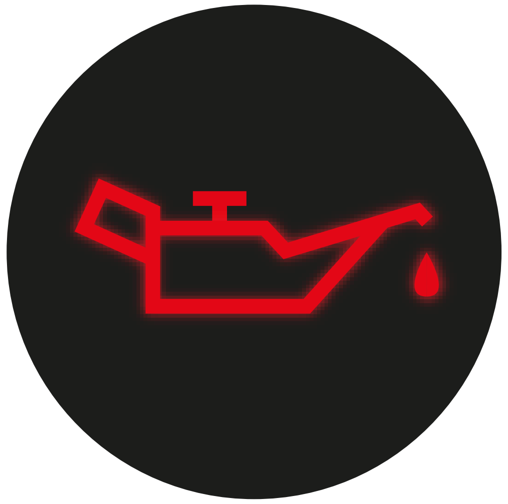


Fig. 1: Turn off the engine immediately if this light comes on!

Fig. 2: Clogged oil ring

Findings:

It is normal for the engine to consume a certain amount of oil. Oil consumption varies depending on engine type and load. If oil consumption is higher than indicated by the manufacturer, this is known as increased oil consumption—in contrast to oil loss, which is caused by leaks, etc.

Cause(s):

- Oil has entered the combustion chamber via the intake section due to leaks in the turbocharger, e.g., worn bearings.
- The oil return line on the turbocharger is blocked or coked. The resulting rising pressure in the oil circuit has forced oil out of the turbocharger into the intake section and the exhaust system.
- Oil has entered the combustion chamber together with the fuel, e.g., through a worn injection pump, which is usually lubricated via the engine's oil circuit.
- A leaky intake system has allowed dirt particles into the combustion chamber, increasing wear in the chamber (see also section "1.1 Engine wear caused by contamination," page 6).
- Incorrect piston protrusion can cause the piston to strike against the cylinder head. The resulting vibrations affect the injection nozzle. This may result in the nozzle no longer closing fully, allowing too much fuel to enter the combustion chamber and causing fuel flooding (see also section "1.2 Fuel flooding," page 8).
- The engine oil is in poor condition, because, for example,
  - the oil is too old due to overextended oil change intervals or
  - because low-grade, unapproved oils have been used.
- This results in the formation of excessive oil carbon and soot. These suspended particles in the oil can block the piston rings and clog the oil return bores in the oil control rings (Fig. 2).
- Bent or twisted connecting rods cause the piston to travel at an angle, as a result of which the combustion chamber is no longer adequately sealed (see also section "2.2.4 Asymmetrical wear pattern on the piston skirt," page 44). In the worst case, the piston may act as a pump, actively feeding the oil into the combustion chamber.
- If piston rings are broken, jammed, or fitted incorrectly, this can lead to an inadequate seal between the combustion chamber and the crankcase, allowing oil to leak into the combustion chamber.
- The cylinder head bolts have been tightened incorrectly. This may result in distortion and thus leaks in the oil circuit.
- Worn pistons, piston rings, and cylinder bores increase the level of blowby gases, resulting in overpressure in the crankcase. If the pressure is too high, oil mist can be pushed into the combustion chambers via the crankcase ventilation system.
- If the oil level is too high, the crankshaft will be submerged in the engine oil in the oil pan, leading to the formation of oil mist. In addition, old or low-grade oil can cause the oil to foam. The oil mist or foam then travels with the blowby gases through the engine ventilation into the intake section and from there into the combustion chambers.
- Fuel flooding can occur as a result of malfunctions in the combustion process. If the oil becomes diluted with fuel, wear on the piston, piston rings, and cylinder surface increases dramatically (see also section "1.2 Fuel flooding," page 8).
- Low-grade oils often have a lower load-carrying capacity and can therefore lead to increased wear.

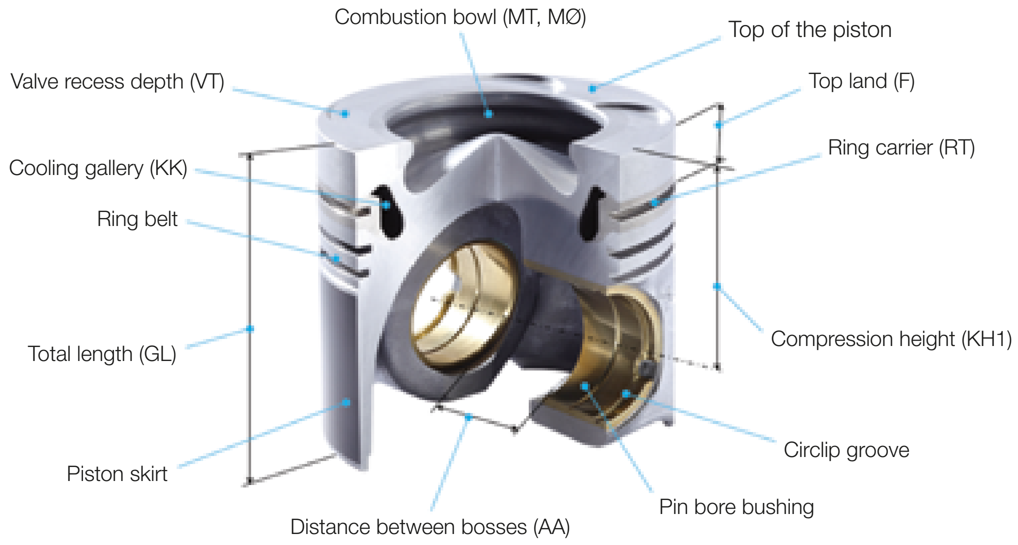
- Cylinder distortion, caused, for example, by old and/or incorrectly tightened cylinder head bolts, can prevent the piston rings from providing an adequate seal between the combustion chamber and the crankcase. This can allow oil mist to leak into the combustion chamber. Extreme distortion can even cause the piston to act as a pump, effectively pumping oil into the combustion chamber.
- A poorly honed cylinder surface resulting from inadequate machining of the cylinder prevents sufficient oil from being absorbed. This greatly increases the wear on the running surfaces, such as pistons, piston rings, and cylinder surface, leading to inadequate sealing of the crankcase. If honing stones are blocked or clogged, they will not cut cleanly, but rather crush and tear, leaving a smeared metal layer behind. The lamellar graphite becomes coated with this material and can no longer do its job. In addition, the smeared metal layer (flakes of metal) is worn away by the piston rings. The metallic particles that become detached in the process lead to scoring and wear.
- In compressors designed for pneumatic systems, a leaky valve plate can cause condensation to form in the cylinder. This condensation dilutes the lubricating oil, resulting in increased wear on the piston, piston rings, and cylinder surface. The oil also enters the compressed-air system, causing damage to other components (see also Filters damage brochure).

Fig. 2: Smoky tailpipe

2. Pistons

MAHLE Original repair pistons are ready for installation, complete with piston rings. The major dimensions and characteristics of the pistons are indicated in the catalog. Piston diameter, mounting clearance, and, where applicable, installation direction are marked on the top of the piston. The stated piston diameter added to the corresponding mounting clearance gives the cylinder diameter.

When installing the piston, it is important to take note of the installation direction. The gaps on the individual piston rings should be evenly distributed around the circumference. The circlip must be fitted so that the gap faces upward or downward. The cylinder bore or the pistons and the rings must be oiled. To avoid damage when installing the piston in the cylinder bore, a suitable tool must be used (e.g., ring sleeve).



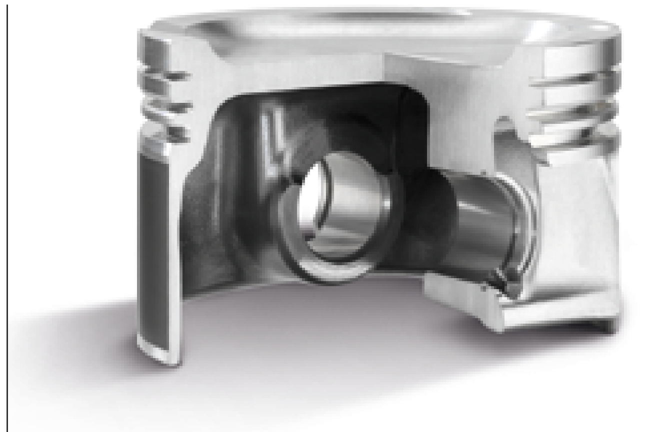
Types

As the largest piston manufacturer worldwide, we offer a variety of product and material choices.

Our product portfolio comprises cast and electron beam-welded aluminum pistons, as well as composite pistons with aluminum, nodular cast iron, and steel skirts. Composite pistons are bolted to piston crowns made of forged steel—a material that has been tried and tested with outstanding results. Not only are steel pistons delivered as bolted variants, they are also available as friction-welded or high-temperature brazed versions. The MAHLE piston range for large engines includes products with diameters of up to 580 mm.

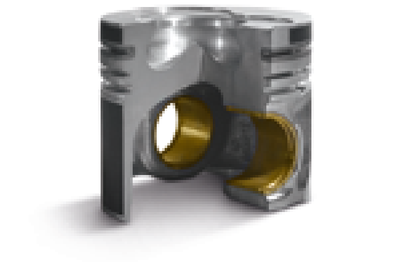
Areas of application for large-bore pistons

- Railroad vehicles
- Special vehicles
- Marine technology
- Oil and gas
- Industrial engines



ECOFORM® pistons with pivoted side cores

Weight-optimized pistons for passenger car gasoline engines. Thanks to a special casting technology, these pistons offer low weight with high structural rigidity.

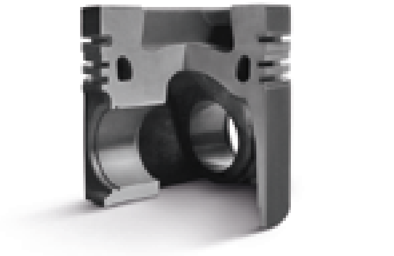


Ring carrier pistons with pin bore bushings

The ring carrier in each of these pistons for diesel engines is made of special cast iron and metallically bonded to the piston material. This increases wear resistance in diesel engines, particularly in the first groove. Pin bore bushings made of a special material raise the pin bore's load capacity.

MONOTHERM® pistons

These single-piece, forged steel pistons for passenger cars and commercial vehicles have an extremely high structural rigidity and were developed for modern combustion chambers operating at pressures of 220 bar and above. In the variant with an open skirt and combined with a short piston pin, its weight is comparable to that of an aluminum piston.



Ring carrier pistons with cooling gallery and top reinforcement

These pistons are used in highly loaded diesel engines. For added protection and to prevent cracks in the bowl rim and the top, these pistons have a special hard-anodized layer (HA layer) on the top of the piston.

AUTOTHERMATIK®/ HYDROTHERMATIK® pistons

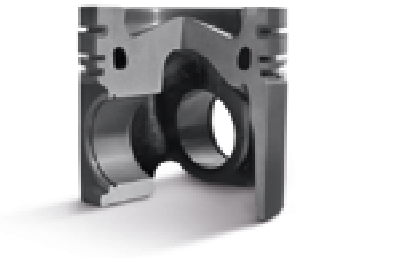
These pistons are mainly used in passenger car gasoline and diesel engines subject to high loads. They have cast-in steel strips but are not slotted. This means each piston consists of a single body, offering greater strength.

AUTOTHERMIK®/ HYDROTHERMIK® pistons

These smooth-running pistons are chiefly used in passenger car engines. They have cast-in steel strips and are slotted at the transition from the ring belt to the skirt area.

Pistons with cooled ring carriers

In these pistons, the ring carrier and cooling gallery are combined to form one system in a special manufacturing process. This gives the pistons significantly improved heat transfer properties, especially at the first ring groove.

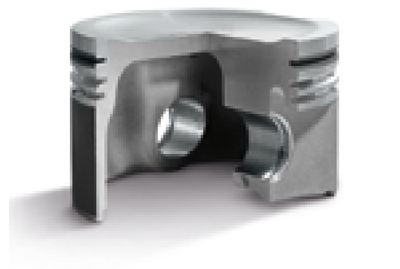


Ring carrier pistons with cooling gallery

Ring carrier pistons with a cooling gallery are used wherever operating temperatures are particularly high. Oil circulating in the cooling gallery produces an intensive cooling effect to reduce the elevated temperatures in the top of the piston and ring belt.

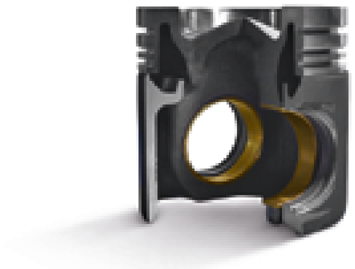
Cast solid-skirt pistons

The top of the piston, ring belt, and skirt form a robust unit. Cast solid-skirt pistons have a long service life and are used in gasoline and diesel engines. Their range of application extends from model engines to large engines.



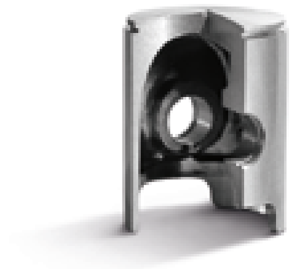
Forged solid-skirt pistons

These pistons are predominantly fitted in highly loaded series production and motorsports engines. The manufacturing process gives these pistons increased strength, enabling reduced wall cross sections and lower piston weight.



FERROTHERM® pistons

These pistons comprise a steel piston crown and an aluminum piston skirt, which are flexibly connected via the piston pin. Due to their high strength and low wear rate, these pistons make it possible for diesel engines subjected to particularly high loads to comply with low exhaust and emissions limits.



Two-stroke pistons

Pistons made of special aluminum alloys that can withstand the high mechanical and thermal loads in two-stroke engines.

MonoWeld® pistons for commercial vehicles

These friction-welded steel pistons are impressive thanks to their ability to withstand high thermal loads, making peak cylinder pressures over 230 bar possible. Their enclosed, rigid structure allows for improved cooling of the bowl rim because the walls can be thinner. The bonded skirt provides improved lateral support, thereby reducing cavitation propensity.

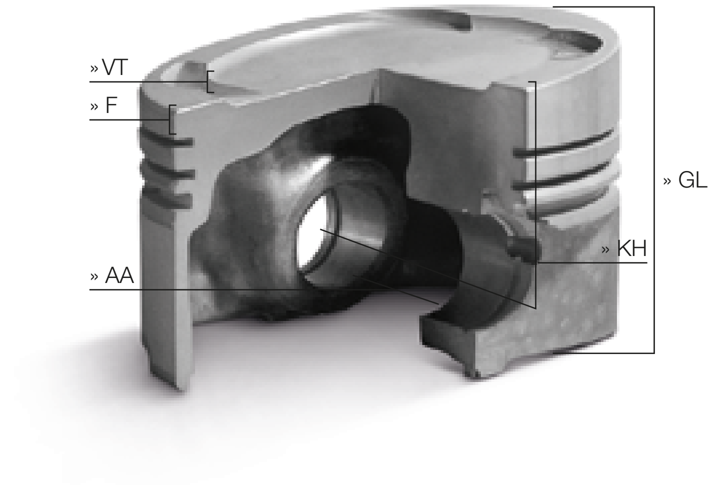
Technical terms

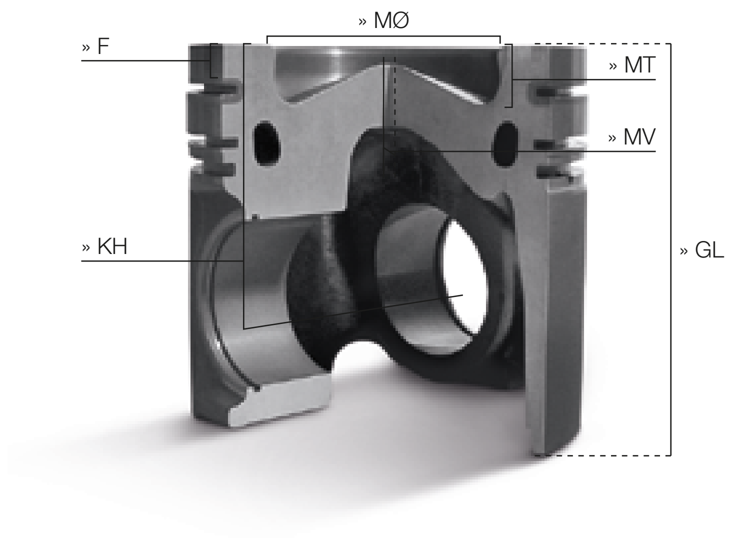
Types of raw piston

F	= Squeeze-cast piston
KB	= FERROTHERM® piston
L	= Solid-skirt piston
MT	= MONOTHERM® piston
P	= Forged piston
V	= AUTO-/HYDROTHERMIK® piston/ AUTO-/HYDROTHERMATIK® piston

AK	= Recess for cooling oil injection nozzle
DRT	= Double ring carrier
KK	= Cooling gallery
RT	= Ring carrier
GRT	= Cooled ring carrier
Fe	= Iron-coated
HA	= Hard anodizing
C	= Graphite-coated

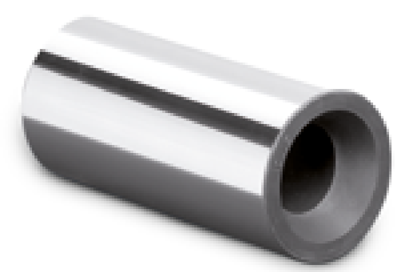
Technical terms





Pistons (dimensions)

» AA	= Distance between bosses
» F	= Top land width
» GL	= Total length
» KH	= Compression height
» MØ	= Combustion bowl diameter
» MT	= Combustion bowl depth
» MV	= Combustion bowl offset
» ÜH	= Dome height
» VT	= Valve recess depth



Piston pins

Pin dimensions:
Outer diameter of pin × total length

FB	= Profiled piston pin
NB	= Pin bore bushing
S	= Shrink-fit/fixed-pin connecting rod
T	= Keystone connecting rod
ST	= Stepped connecting rod

Fitting recommendations

MAHLE repair pistons are ready for installation, complete with piston rings. Piston diameter, mounting clearance, and installation direction are marked on the top of the piston. The stated piston diameter added to the corresponding mounting clearance gives the cylinder diameter. For pistons with a graphite-coated skirt, the nominal diameter stamped on the piston is calculated by deducting another 0.015–0.020 mm from the measured piston diameter to allow for the thickness of the coating.

Example

Measured diameter on graphite layer	90.00 mm
Diameter marked on the top of the piston	– 89.96 mm
Thickness of the graphite coating	0.04 mm

The piston rings are fitted with the greatest of care. Any unnecessary removal and refitting of the piston rings involving excessive stretching causes permanent deformation, which in turn impairs running behavior. The piston pins are packed in such a way that they are protected from corrosion and are enclosed with the piston, as are the circlips (if required). The piston pins are selected for the appropriate fit and are interchangeable within the same piston type. However, some pistons and pins are color-coded. These parts must not be exchanged for others under any circumstances.

Assembly of pistons and connecting rods

Prior to assembly, the connecting rods are checked to ensure that their bores are on parallel axes (no bending or distortion) and replaced if necessary. It is important to make sure that the components are adequately lubricated on assembly. Pistons and connecting rods must always be assembled in the specified installation direction.

Shrink fit

The assembly of pistons and pins with shrink fit in the connecting rod has to be done very carefully. It is vital that the piston and pin can move freely after assembly.

Floating pin

For pistons with floating pins, the enclosed circlips serve to secure the piston into place in the pin bore.

The circlips must be fitted using a suitable tool. The circlips must be fully seated in the grooves provided for that purpose with the gap always positioned in the stroke direction of the piston. Never reuse circlips and avoid squeezing them together too much, as this can cause permanent deformation.

Installing a piston

When installing a piston, it is important to take note of the installation direction. The gaps on the individual piston rings should be evenly distributed around the circumference. The circlip must be fitted so that the gap faces upward or downward. The cylinder bore or the pistons and the rings must be oiled.

To avoid damage when installing the piston in the cylinder bore, a suitable tool must be used (e.g., ring sleeve).

In diesel engines, the gap width must be measured and the relevant instructions from the engine manufacturer must be followed.

In pistons with a hard-anodized top, the top of the piston should not be machined.

Only cylinder head gaskets and air, fuel, and oil filters approved by the engine manufacturer should be used.

The components (cylinder block, crankshaft, connecting rod, and oil pan) must be cleaned carefully before assembly to remove machining remainders and deposits.

Markings

Information on the top of the piston

1. Company/brand logo: these markings signify MAHLE quality.

2. The installation direction specified by the respective engine manufacturer is marked on the top of the piston. This must be followed during installation. Other markings used include a crankshaft symbol, a cast-in notch, or terms such as “vorn” (meaning front), “Front,” or “Abluft” (meaning exhaust air). It may be necessary to install the piston in a certain direction because the design of the top of the piston is asymmetrical or because a pin bore has been offset to change noise levels. In addition to the greatest piston diameter, pistons for engines with cylinder dimensions in inches are marked “Std.” or, for oversize dimensions, “.020,” etc.

3. The mounting clearance in millimeters corresponds to the required difference in diameter between the cylinder bore and the piston skirt.

4. The largest piston diameter is specified in millimeters. Small pistons are usually only stamped with their defining group and nominal diameter. Additional diameter information and the mounting clearance may be specified on the packaging.

Further markings on the top of the piston may include:

A = Exhaust
E = Intake
1 = Cylinder 1
1/2 = Cylinders 1 and 2

How to calculate the nominal dimension for the cylinder bore using the example of the piston shown below:

Piston diameter (4)	83.93 mm
+ clearance (3)	0.07 mm
Cylinder diameter	84.00 mm

2.1.1 Hole burned through the top of the piston

in gasoline and diesel engines

Fig. 1: Hole in the top of the piston caused by using spark plugs with the wrong heat rating

Findings:

- There is a hole in the top of the piston (Fig. 1).
- The surface surrounding the hole is coated with melted piston material.
- The top land has melted (Fig. 2).
- The top of the piston has melted and the ring belt has partially burned through (Fig. 3 & 4).

Cause(s):

The cause of the damage is localized overheating. In this case, we must differentiate between gasoline and diesel engines.

Gasoline engines:

- The heat rating of the spark plug is too low.
- An overheated spark plug has caused surface ignition (see also section 2.1.2, page 28).

Diesel engines:

The piston crown has overheated, but the combustion bowl is not damaged. A good spray pattern can be seen on the top of the piston. The excessive temperature at the piston crown may be caused by the following:

- The cooling oil nozzle has been bent, snapped off, or not fitted (assembly error).
- The oil change interval has been exceeded. In this case, there is a risk of polymerization of the engine oil, particularly when using biofuels such as rapeseed and soybean oil, which can cause the cooling oil nozzles to clog.
- Foreign objects such as gasket residue are obstructing vital circulation in the oil circuit (see also section 2.1.3, page 30).

Remedies/avoidance:

Gasoline engines:

- Only use fuel with the specified octane rating.
- Set the fuel injection system, carburetor, and ignition correctly.
- Only use spark plugs that meet manufacturer specifications.
- Check the intake system for leaktightness.

Diesel engines:

- Set the injection quantity and timing in accordance with manufacturer specifications.
- Check the leaktightness, spray pressure, and spray pattern of the injection nozzles.
- When fitting the cooling oil nozzles, ensure they face the right direction.
- Drastically reduce the oil change intervals when the engine is run on biofuels.
- Thoroughly clean the oil channels in the engine block, crankshaft, and cylinder head.
- Check that the pressure-regulating valve is functioning correctly.

Fig. 2: Melted top land on a gasoline engine piston

Fig. 3: Hole burned through a diesel engine piston

Fig. 4: Melted top land on a diesel engine piston

2.1.2 Melting on the top of the piston and top land

in gasoline engines

Fig. 1: Signs of erosion on a gasoline engine piston

Fig. 2: Engine knocking

Findings:

The damage scenario described here covers several stages from melting to holes in the top of the piston:

- There is localized erosion-like wear on the surface of the top of the piston and/or top land (Fig. 1).
- The piston ring land is broken (Fig. 3).
- Melted areas can be seen on the piston crown (Fig. 2)—sometimes the top of the piston has completely melted away and the piston ring land is fractured (Fig. 3).
- There is a hole in the piston.

Cause(s):

This damage can be attributed to a malfunction in the combustion process. This may have several causes:

- Combustion is taking place with an air–fuel mixture that is too lean, which may be due to the following issues:
  - Excess air is being sucked in.
  - There is an engine management problem, e.g., with the fuel delivery rate.
  - The carburetor is set incorrectly.
  - A sensor is defective (air mass flow meter, lambda sensor, TDC sensor, etc.).
- The wrong fuel has been used (insufficient octane rating, diesel instead of gasoline).
- The heat rating of the spark plug is too low.
- The ignition timing is set incorrectly.
- The boost pressure is too high (e.g., due to tuning).
- Individual components or the entire engine are overheated. Possible causes include:
  - Insufficient valve clearance, resulting in overheating of the valve disk.
  - Excessively high intake air temperature.
  - A malfunction in the coolant circuit, e.g., insufficient fluid, a loose V-belt, or a defective thermostat.

Remedies/avoidance:

- Only use fuel with the specified octane rating.
- Set the fuel injection system, carburetor, and ignition correctly.
- Only use spark plugs that meet manufacturer specifications.
- Check the intake system for leaks.
- Fit a thicker gasket if the cylinder head has been reworked, and ensure that the compression height is reduced in oversize pistons.
- Check that the boost pressure is correct in turbocharged engines.

Fig. 3: Fractured ring land

2.1.3 Melting on the top of the piston and top land

in diesel engines

Fig. 1: Melted piston crown on a diesel engine piston

Fig. 2: Melting on the top land and seizure marks on the skirt

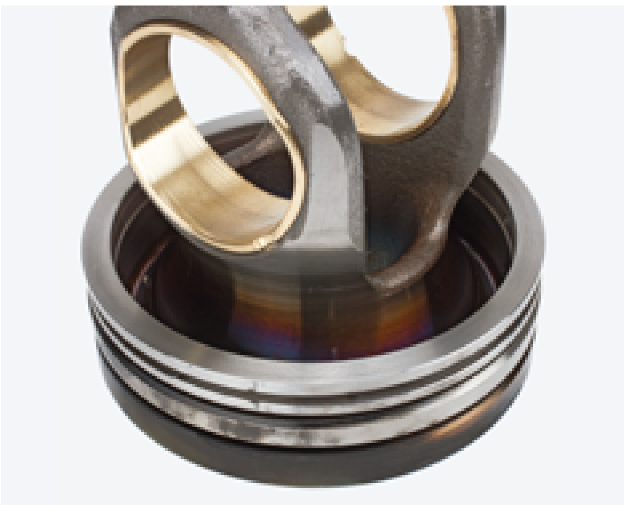


Fig. 3: Discoloration on a FERROTHERM® piston caused by overheating

Fig. 4: Broken cooling oil nozzle

Findings:

The damage scenario described here covers several stages from minor piston damage to serious engine damage:

- There are signs of erosion on the piston crown.
- Melted areas can be seen on the piston crown—sometimes the top of the piston has completely melted away (Fig. 1).
- In extreme cases, there are seizure marks all along and around the piston.
- There is a hole in the top of the piston.

Cause(s):

This damage is due to thermal overload of the piston. There are two possible causes for this, which have different symptoms:

1. Malfunction in the combustion process:

This problem can be diagnosed on the following characteristics:

- The bowl rim has been “gnawed” and there is localized melting of material.
- The injection nozzles are producing a poor spray pattern.
- The injection pressure and delivery rate from the injection nozzles are set incorrectly.
- A malfunction in the combustion process may have several causes:
- Air–fuel mixture is too rich, which may be caused by the following:
  - The air supply is reduced, e.g., the air filter is clogged.
  - The fuel delivery rate is set incorrectly.
  - The start of fuel delivery is set incorrectly.
  - The nozzle needle is jammed or moves with difficulty.
  - The exhaust system is blocked.
- There is ignition delay and misfiring, which may have the following causes:
  - The wrong fuel or fuel with an insufficient cetane rating has been used, or there is gasoline in the diesel.
  - The valves are leaking, resulting in compression loss.
  - The gap width is too large, causing insufficient compression.
  - The air intake preheater is defective (especially at very low outside temperatures).

2. Overheating of the piston crown:

This can be identified based on the following details:

- The combustion bowl is not damaged.
- A good spray pattern can be seen on the top of the piston (Fig. 2). In steel pistons: discoloration on the inside toward the top of the piston (Fig. 3).

The excessive temperature at the piston crown may be caused by the following:

- The cooling oil nozzle has been bent, snapped off, or not fitted (assembly error, Fig. 4).
- The oil change interval has been exceeded. In this case, there is a risk of polymerization of the engine oil, particularly when using biofuels such as rapeseed and soybean oil, which can cause the cooling oil nozzles to clog.
- Foreign objects such as gasket residue are obstructing vital circulation in the oil circuit.

Remedies/avoidance:

- Set the injection quantity and timing in accordance with manufacturer specifications.
- Check the leaktightness, spray pressure, and spray pattern of the injection nozzles.
- When fitting the cooling oil nozzles, ensure they face the right direction.
- It is advisable to remove the cooling oil nozzles before disassembling the pistons. This prevents the connecting rod from bending the cooling oil nozzle when the pistons are removed.
- Thoroughly clean the oil channels in the engine block, crankshaft, and cylinder head.
- Check that the pressure-regulating valve is functioning correctly.
- When the engine is run on biofuels, it is important to use a suitable engine oil and follow the oil change intervals specified for this situation.

2.1.4 Broken piston ring lands

Fig. 1: Broken piston ring lands due to a malfunction in the combustion process

Fig. 2: Forced fracture in the top land

Fig. 3: Fracture running from bottom to top

Findings:

- In broken piston ring lands, we need to differentiate between two fracture directions: from top to bottom (Fig. 1) and from bottom to top (Fig. 2 & 3).
- Erosion can usually be seen on the top of the piston, the top land, and the groove flanks.

Cause(s):

These damage scenarios are caused by mechanical overloading of the piston ring lands, due to either an abnormal combustion process or an assembly error.

1. Malfunction in the combustion process:

After ignition is triggered by the ignition spark, autoignition occurs at other points in the combustion chamber, causing the combustion velocity to increase approximately tenfold. This leads to an excessively steep rise in pressure of up to 300 bar per crank angle degree (standard value: 3–5 bar per crank angle degree) as well as to ultrasound-like vibrations and overheating due to irregular combustion behavior. The consequences are cracks or fractures in the piston ring lands and piston skirt that run from top to bottom. This malfunction in the combustion process is also known as engine knocking.

Causes of knocking may include:

Gasoline engines:

- The ignition timing is incorrect (advanced ignition).
- The air–fuel mixture is too lean.
- Diesel was used instead of gasoline (even a small amount mixed into the gasoline is a major problem).
- The intake air is too hot.
- The compression ratio is too high.

Diesel engines:

Here, an excessive ignition delay leads—as with knocking in gasoline engines—to uncontrolled combustion with high pressure peaks and to mechanical overloading of the piston ring lands. This may be due to the following factors:

- The compression pressure is too low.
- The injection pressure of the nozzles is too low.
- Starting aids, e.g., starting aid spray, have been used incorrectly.
- The injection nozzles are not leaktight.
- Too much fuel is being injected.
- Gasoline has been used instead of diesel.

2. Assembly errors:

- When piston rings have been fitted without using a compressor tool, they are often not seated properly in their grooves. When the piston is subsequently tapped into position, the rings protrude slightly, blocking the front face of the bore. This results in a typical bottom-to-top fracture in the piston ring lands (Fig. 2 & 3).
- In the case of an assembly error in a two-stroke engine, on the other hand, the fracture runs from top to bottom, as the piston is pushed into the cylinder from below.

Remedies/avoidance:

- Only use fuel with the specified octane rating.
- Set the fuel injection system, carburetor, and ignition correctly.
- Only use spark plugs that meet manufacturer specifications.
- Check the intake system for leaks.
- Fit a thicker gasket if the cylinder head has been reworked, and ensure that the compression height is reduced in oversize pistons.
- Check that the boost pressure is correct in turbocharged engines.
- Always use undamaged seals when overhauling an engine, and remember to replace relevant seals.
- Check injection nozzles and replace them if in any doubt.

2.1.5 Valve impacting on the top of the piston and piston striking against the cylinder head

Fig. 1: Top of the piston with valve impact mark

Fig. 2: Piston that has struck the cylinder head

Fig. 3: Piston broken off at a right angle in line with the piston pin axis

Findings:

- Valve impact or contact marks can be seen on the top of the piston due to collisions with the cylinder head (Fig. 1 & 2).
- The piston has been snapped off at a right angle to the pin bore (Fig. 3), associated with extreme impacts on the top of the piston.

Cause(s):

The damage scenario described above results from collision damage to the piston. It may have collided with:

One or more valves:

The causes of the collision may include:

- As a result of overspeed, the valve springs are no longer able to retract the valve in time and the piston collides with the valve(s).
- The valve timing is off due to incorrect setting after engine assembly or due to faulty assembly chain tension adjusters, e.g., owing to incorrectly set valve timing or insufficient tension on the timing belt/chain.
- A valve has snapped off.
- The timing chain is stretched (as a result of overextended oil change intervals).
- The timing chain has jumped (backward rotation of the engine).
- The bearing clearance has become too great due to spun connecting rod bearings or loose connecting rod bolts.
- The specified valve depth was not maintained after machining of the cylinder head.

The cylinder head:

The causes of the collision may include:

- The bearing clearance has become too great due to spun connecting rod bearings or loose connecting rod bolts.
- In a diesel engine, if the compression height of the piston is too great or a cylinder head gasket is too thin after machining of the cylinder head, the gap width will be too large.

Foreign objects:

This may be due to the following:

- Small parts, e.g., nuts or bolts, entered the combustion chamber during assembly.
- As a result of oil consumption (see also section "1.4 Increased oil consumption," page 12), oil carbon has built up in the combustion chamber, reducing the gap width.

In extreme cases, any of these causes of collision can damage the piston so badly that it breaks off at a right angle to the pin bore (horizontally).

Remedies/avoidance:

- Set the valve timing correctly during installation.
- When installing the connecting rod bearings, check the clearance between the bearing journal and the big end bore.
- Fit the connecting rod bearing bolts in accordance with the vehicle manufacturer's instructions (replace, following tightening torque specifications).
- Check the gap width on all cylinders during installation.
- If loud running noises can be heard, switch off the engine to prevent consequential damage and investigate the cause.

2.1.6 Cracks in the top of the piston

Fig. 1: Cracks in the bowl rim

Fig. 2: Piston fractured right into the pin bore

Fig. 3a: Cracks in the bowl rim

Fig. 3b: Close-up

Findings:

- There are cracks in the top of the piston (Fig. 1).
- The piston is broken in the piston pin axis (Fig. 2).
- There are cracks in the bowl rim (Fig. 3a & b).

Cause(s):

These cracks result from mechanical or thermal overload of the piston.

Mechanical overload:

Mechanical overload of the piston is often caused by tuning.

- Excessively increasing engine performance (tuning) leads to piston overload, especially in the piston pin axis. This can result in a crack in the pin bore or a cleavage fracture lengthways through the piston in the piston pin axis.
- Engine tuning with significantly increased peak cylinder pressures or subsequent machining of the geometry of the piston pin (weight saving) can cause mechanical overload of the piston pin. The peak cylinder pressure causes the piston pin to become oval, which can lead to high stresses in the pin bore and to the piston cracking along the pin axis.
- By reducing the weight of the piston at a later stage, the forces that are generated can no longer be absorbed, causing the material to crack.

Thermal overload:

Fuel injection system malfunctions, engine performance increases (tuning), or starting aids in diesel engines can result in an excessive amount of fuel in the combustion chamber, which in turn leads to extreme variations in the thermal loads on the piston. This can cause cracks in the bowl rim, especially in diesel engines (Fig. 3a & b).

Remedies/avoidance:

- Tuning and associated modifications to the engine should only be carried out by the engine manufacturer or by engine-tuning experts.
- Set the injection system in accordance with manufacturer specifications.

2.2.1 Piston seizure on thrust and antithrust sides

only in piston skirt area

Fig. 1: Seizure marks on a FERROTHERM® piston, thermal discoloration on a cylinder liner

Fig. 2: Seizure marks on the piston skirt, caused by lack of clearance

Findings:

- The piston skirt has seizure marks and grooves on both the thrust and antithrust sides (Fig. 1).
- The seizure points are very glossy in some areas, as if polished (Fig. 2).
- The seizure marks are concentrated toward the skirt end.
- The piston rings and the piston ring belt are in good condition.
- In two-piece pistons (FERROTHERM®): significant seizure marks can be seen all over the piston skirt. Light scoring in the ring zone of the steel crown.

Cause(s):

The cause of the damage is localized overheating. Since the piston crown and the top of the piston are undamaged, a malfunction in the combustion process can be ruled out. That leaves two possible causes:

Seizure due to lack of clearance (overheating):

The engine may overheat for the following reasons:

- The coolant level is too low.
- Coolant is not circulating sufficiently, e.g., due to a defective coolant pump, a loose or torn V-belt, a defective thermostat, a damaged Visco® clutch, or a defective fan.
- The engine has not been bled correctly.
- The cross-sections in the radiator have become constricted because radiator sealant has been used.

Since heat causes the aluminum in the piston to expand twice as much as the gray cast iron in the cylinder, an excessively high thermal load (cold engine, hot piston) can lead to piston seizure.

Seizure due to lack of clearance (machining defect):

The cylinder bore has not been machined to the correct dimensions (piston diameter plus mounting clearance). The damage occurs immediately upon initial operation as soon as the engine reaches operating temperature.

Remedies/avoidance:

- It is essential that the cylinder dimensions are correct. Calculate the figure using the values indicated on the piston (piston diameter plus mounting clearance).
- Check the coolant circuit, specifically:
  - Coolant level
  - Coolant pump (V-belt)
  - Thermostat
  - Fan
- Bleed the cooling system, including the heating circuit, EGR cooler, transmission cooler, and oil cooler.
- The use of a vacuum-venting device is recommended to bleed the cooling system.

2.2.2 Piston seizure on one side of the piston skirt

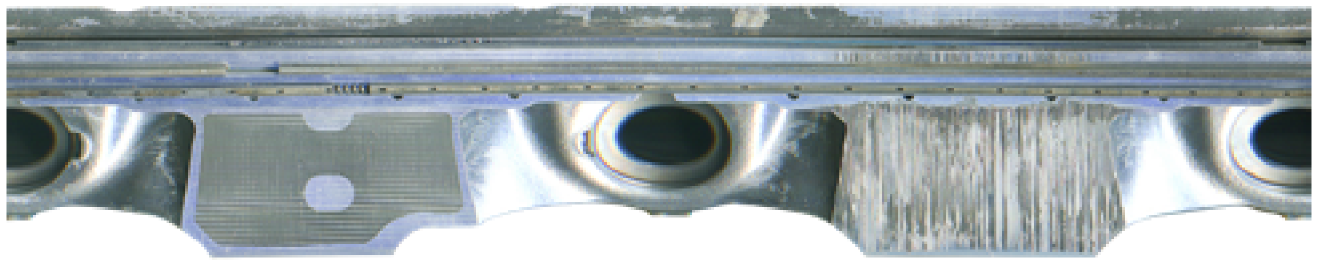


Fig. 1: Seizure marks on one side

Fig. 2: Piston rings with scoring and scuff marks

Findings:

- Piston seizure marks are only present on the thrust side of the piston skirt (Fig. 1).
- There is a discreet wear pattern on the antithrust side.
- The piston rings are scuffed in places (Fig. 2).

Cause(s):

Since the thrust side of the piston is subjected to significantly higher loads during the power stroke than the antithrust side, inadequate lubrication becomes apparent on the thrust side first. This may be the result of the following:

High fuel content in the oil:

- Fuel injection system set incorrectly.
- Cold start enrichment too rich.
- Defective injection nozzles.
- Frequent short-distance journeys.

Lack of oil on the cylinder wall:

- Oil level too low.
- Clogged oil feeder bore in the connecting rod.
- Defective cooling oil nozzle.
- Engine not properly broken in after repair .
- Load-carrying capacity of the oil too low.
- Oil diluted by fuel or water condensation (see also section “1.2 Fuel flooding,” page 8).

Remedies/avoidance:

- Ensure that the oil supply is maintained—and check that the oil feeder bores in the connecting rod are not clogged.
- Only use oils approved by the engine manufacturer.
- Operate the engine at moderate rotational speeds and loads immediately after assembly.
- Checking the oil level regularly is essential. If necessary, add more oil.
- Check the oil pressure. Insufficient oil pressure may be due to a worn oil pump, contamination of the filter, a defective pressure-relief valve in the oil pump, or diluted oil.
- Check the cooling system. A leaky oil cooler is responsible for coolant in the oil and for oil in the coolant.

2.2.3 Diagonal piston seizure marks next to the pin bore

Fig. 1: Diagonal seizure marks next to the pin bore

Fig. 2: Lateral piston seizure marks next to the pin bore

Fig. 3: Pin bore with seizure marks

Findings:

- Seizure marks can only be seen running diagonally next to the pin bore (Fig. 1).
- There are usually no seizure marks on the piston skirt in the thrust and antithrust directions (Fig. 2).
- In addition to the seizure marks, some areas appear highly polished.
- It is difficult to move the connecting rod around the piston pin axis.
- There are seizure marks in the pin bore (Fig. 3).

Cause(s):

Damage occurs when the load-carrying capacity of the oil film between the piston skirt and the cylinder surface is no longer sufficient in the area diagonally adjacent to the pin bores.

This causes the lubricating film to be partially pushed through. The resulting localized contact between the piston skirt and the cylinder surface leads to seizure at certain points.

This may be due to the following:

- The fixed-pin connecting rod has been installed incorrectly, e.g., if the piston and the connecting rod have been moved immediately after shrinking in. Temperature compensation can cause the piston pin to become very warm, expand accordingly, and seize in the pin bore.
- Cylinder distortions can severely restrict the running clearance. Since the area around the pin boss is the most rigid, the piston can give only slightly here.
- If the piston pin has not been sufficiently oiled before engine assembly, there may be inadequate lubrication between the piston pin and the piston when starting up the overhauled engine. This causes seizure in the pin boss, which raises the temperature in the vicinity of the pin bore.
- The warm-up phase at excessively low rotational speeds has been too long. Air guide plates or clogged cooling fins are overheating at certain points.

Remedies/avoidance:

- Immediately before assembling the engine, apply sufficient oil to the connecting rod, piston pin, and pin boss and ensure that the parts can move easily.
- It is recommended that some of the new engine oil is added to rebuilt engines under pressure, e.g., via the oil pressure switch connection. This means that there is already engine oil in the oil filter housing and the oil cooler as well as in the oil channels, oil lines, and bearings when the engine is started up for the first time.
- Operate the engine at moderate rotational speeds and loads immediately after assembly.

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2.2.4 Asymmetrical wear pattern on the piston skirt

Fig. 1: Asymmetrical wear pattern (slanting) on the piston skirt

Findings:

- There is an asymmetrical wear pattern on the piston skirt (Fig. 1).
- The top land is brightly polished on one side in the direction of the pin axis and blackened by combustion deposits on the opposite side.

Cause(s):

Geometric deviations in the piston guidance cause the piston to move at an angle in the cylinder. This means that one side of the piston is in contact with the cylinder, while a large gap is created on the opposite side through which the hot exhaust gases (blowby gases) blow, burning the oil film. The piston rings, which also travel at an angle, flutter, causing a pumping motion that leads to increased oil consumption (see also section “1.4 Increased oil consumption,” page 12). The piston may travel at an angle due to the following causes:

- The bores in the small end and big end bores of the connecting rod are not parallel. Alignment deviations arise
  - because the connecting rod is bent or twisted or
  - because the connecting rod bore has been drilled at an angle.
- The main bearing gallery is slanted, which can be caused by spun bearing bushings, for example.
- The cylinder head bolts have been tightened incorrectly (incorrect sequence or incorrect tightening torque). Caution: Air-cooled finned cylinders are particularly susceptible to this.
- There is soiling on the cylinder base of the finned cylinder. As a result, the finned cylinder sits crookedly on the crankcase, causing the piston to travel at an angle in the cylinder bore (slanting).

Remedies/avoidance:

- Align the main bearing gallery, crankshaft, and connecting rod properly (concentrically) during machining and installation.
- Make sure that the connecting rod is at the correct angle.
- Tighten the cylinder head bolts in accordance with manufacturer specifications.
- Take care to ensure absolute cleanliness when assembling the engine, e.g., remove all gasket residue.

2.2.5 Piston seizure only in the lower piston skirt area

Fig. 1: Seizure marks on the piston skirt due to constriction of the cylinder liner

Fig. 2: Shiny line running around the circumference of the cylinder bore

Findings:

- There is a sharply defined seizure mark in the lower piston skirt area (Fig. 1).
- A shiny mark runs around the inside of the cylinder bore (Fig. 2).

Cause(s):

These marks are caused by a localized lack of clearance between the piston and the cylinder bore, which may in turn be due to the following:

If there is not enough space in the seal groove, the cylinder liner will become constricted in this area. This can be attributed to:

- the use of an incorrect (too thick) gasket,
- the use of additional sealants,
- a slipped gasket, or
- remnants of the old gasket that have not been removed.

If the cylinder head bolts are tightened at the wrong torque and/or unevenly, there is a higher risk of cylinder distortion—especially in the case of finned cylinders.

An incorrectly set honing machine, e.g., with insufficient projection of the honing stones, can result in the bore diameter at the cylinder end being too small.

Remedies/avoidance:

- Tighten the cylinder head bolts in accordance with the tightening torque specifications.
- To prevent a lack of clearance or cylinder distortion, fit wet cylinder liners without gaskets first. This way, a lack of clearance can be detected in good time. Only then should you fit the cylinder liner complete with the gaskets.
- Only use the gaskets supplied.
- Make sure that the gaskets are positioned correctly in the grooves provided for this purpose.
- Set the honing machine correctly. Measure the cylinder bores in several planes and positions during and after honing.

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2.2.6 Heavy wear on the piston skirt with a rough, matte surface

Fig. 1: Wear on the piston skirt caused by contamination

Findings:

- The engine is consuming an increased amount of oil (see also section “1.4 Increased oil consumption,” page 12).
- High gas leakage (blowby), unsatisfactory starting behavior, especially at low outside temperatures.
- There is a broad, matte wear pattern on both sides of the piston skirt (Fig. 1).
- The machining profile is partially worn away.
- There are individual, narrow score marks on the piston skirt.
- The piston rings exhibit a large gap clearance and radial wear.
- The oil control ring lands are heavily worn or even stripped away.
- Axial wear can be seen on the groove flanks.

Cause(s):

This damage results from wear caused by contamination. We can differentiate between several scenarios based on the number of damaged cylinders and the state of wear on the piston rings:

If only one cylinder is damaged

... and the first piston ring is significantly more worn than the third, then the contamination has entered the combustion chamber via the intake system of one cylinder, i.e., from above. This is caused by either a leak or debris that was not removed before fitting.

If several or all cylinders are damaged

... and the first piston ring is significantly more worn than the third, then the contamination has entered the combustion chamber via the common intake system shared by all the cylinders. This is due to either leaks and/or a destroyed or missing air filter.

... and the third piston ring is significantly more worn than the first, then we can assume that the engine oil is contaminated. The engine oil could have been contaminated with dirt while it was being added to the system.

Dirt remaining in the crankcase after assembly.

Remedies/avoidance:

- Check the intake system for leaks.
- Check the air filter and replace it if necessary.
- Remove any dirt from the crankcase and the intake pipes before installation.
- Take care to maintain cleanliness during installation.
- Store measuring jugs and funnels for engine oil in the workshop in such a way that they do not become dirty.

2.3.1 Seizure marks in the pin bore

Fig. 1: Seizure marks in the pin bore

Findings:

- The piston exhibits seizure marks in the pin bore, especially in the upper section (Fig. 1).

Cause(s):

- The piston pin was not sufficiently oiled before assembly (see also section "2.2.3 Diagonal piston seizure marks next to the pin bore," page 42).
- The load-carrying capacity of the oil film has been severely reduced due to dilution with fuel (see also section "1.2 Fuel flooding," page 8).
- The connecting rod bushing has not been machined to the specified dimension and the diameter is too small. As a result, the piston pin can only move freely in the piston.
- The oil supply is restricted due to incorrectly fitted bearings (main bearing/connecting rod bearing/connecting rod bushing) (see also section "6.8 Seizure marks on bearings," page 128).
- Low-grade oil has been used that does not satisfy the specified requirements.
- The oil film in the pin bore has been destroyed by forces, heat, and abrasion resulting from piston seizure.
- This damage scenario is a precursor to the damage described in section "2.2.3 Diagonal piston seizure marks next to the pin bore" (page 42).

Remedies/avoidance:

- During assembly, ensure there is sufficient clearance between the piston pin and the connecting rod bushing.
- Apply sufficient oil to the piston pin before engine assembly.
- Fit the bearings in the correct installation direction (oil feeder bore, oil grooves).
- Only use engine oil approved by the vehicle manufacturer.

2.3.2 Cratered piston wall near the pin boss

Fig. 1a: Cratered piston wall caused by a loose piston pin circlip or foreign matter in the bore of the piston pin

Fig. 1b: Close-up surface view of softer piston material and harder piston ring material that are worn to the same extent

Findings:

- The piston is cratered in the area around the pin bosses (Fig. 1a).
- The damage extends up into the ring belt.
- The surface has been scoured until shiny and smooth (Fig. 1b).
- The piston rings may also be damaged.
- There is cratering on both sides of the piston.

Cause(s):

This damage scenario is caused by loose parts in the region of the pin bore, e.g., due to foreign objects or a piston pin circlip that has jumped out as a result of overspeed or an assembly error.

Foreign objects and fragments can also migrate through the bore in the piston pin to the other side of the piston. That is why there is usually cratering on both sides of the piston, even if the circlip has only jumped out on one side.

Overspeed:

Overspeeds can trigger resonance vibrations at both ends of the piston pin circlip, causing them to work loose from the circlip groove.

Assembly errors:

- Foreign objects are migrating through the bore in the piston pin to the other side. That is why there is often cratering on both sides, even though the trigger (e.g., a circlip that has jumped out) was only on one side.
- A circlip has been inserted crookedly.
- There is no circlip in the groove or it is broken.
- Old circlips have been reused.
- A forced fracture occurred in the circlip groove area during installation of the piston pin.
- The connecting rod is not straight (see also section "2.2.4 Asymmetrical wear pattern on the piston skirt," page 44).

Remedies/avoidance:

- When fitting the circlips, make sure that the gap in the circlips faces 6 o'clock or 12 o'clock.
- Always use new circlips that are not deformed.
- Never use force to fit the piston pin, e.g., by hitting it with a hammer.
- Check that the bores are parallel before fitting the connecting rod (straighten the connecting rod).

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3. Piston rings

The MAHLE "N" ring set corresponds to the rings used in original equipment. This ring set can be used for both new pistons and those that have already been broken in. The MAHLE "V" and "G" ring sets provide a cost-effective solution for normalizing oil consumption and reducing compression loss in broken-in pistons.

Piston rings must be mounted with the markings (e.g., "top" or "m") pointing upward (toward the top of the piston).

Types and technical terms

The piston rings are fitted with the greatest of care. Any unnecessary removal and refitting of the piston rings involving excessive stretching causes permanent deformation, which in turn impairs running behavior.

Designs

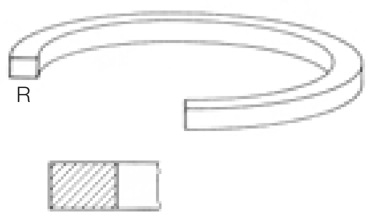
Cr = Chromium
CrC = Chromium multilayer
CrK = Chromium-ceramic
Fe = Ferrous oxide
Mo = Molybdenum
P = Phosphate
N = Nitrided
PVD = Plasma-coated
IF = Internal bevel (top)
IFU = Internal bevel (bottom)
IW = Interior angle (top)
IWU = Interior angle (bottom)

Conversion from millimeters to inches

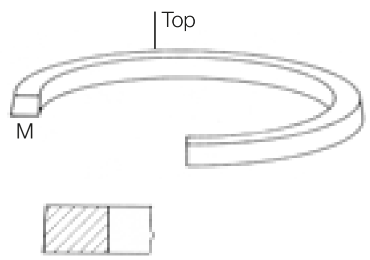
Millimeters	Inches
1.600	1/16
1.990	5/64
2.385	3/32
3.160	1/8
3.947	5/32
4.747	3/16
6.335	1/4

Compression rings

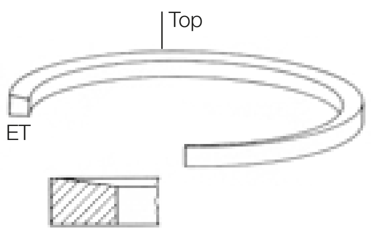
Rectangular ring



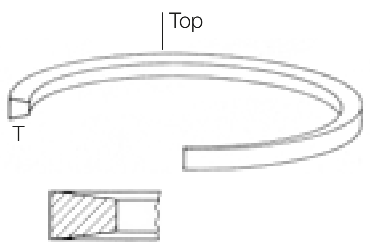
Taper-face ring



Half keystone ring

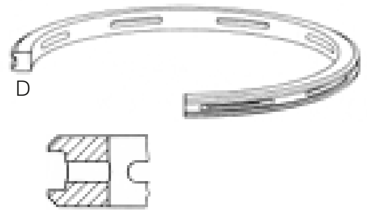


Keystone ring

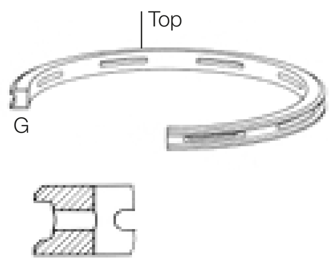


Oil control rings

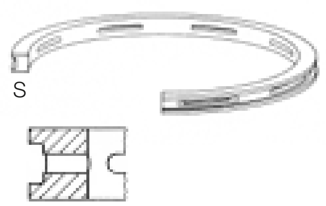
Beveled ring



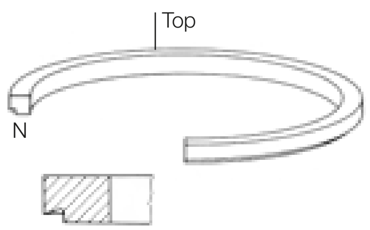
Double-beveled oil control ring



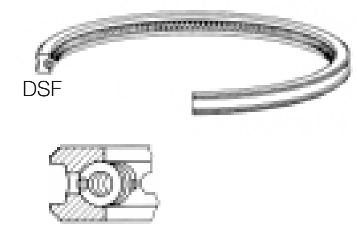
Slotted oil control ring



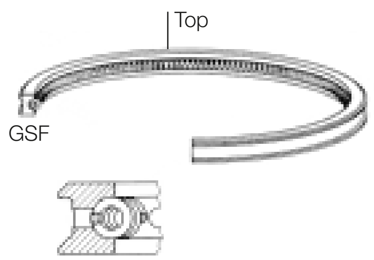
Napier ring



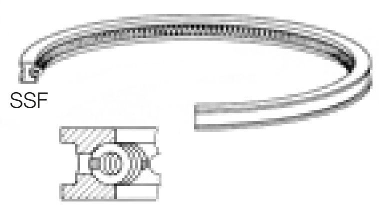
Beveled ring with coil spring



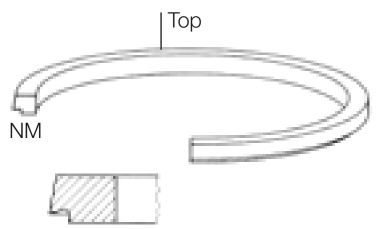
Double-beveled with coil spring



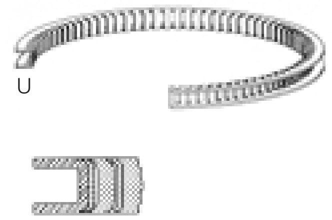
Slotted oil control ring with coil spring



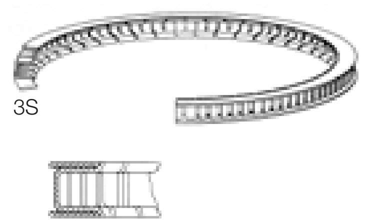
Taper-faced Napier ring



U-flex ring (multipiece)



Oil control ring (multipiece)



Fitting recommendations

The ring grooves must be cleaned thoroughly before the rings are fitted. It is essential to make sure that neither the groove flanks nor the radii in the groove root are damaged.

Fit the rings using suitable piston ring pliers, starting with the bottom ring. Avoid overstretching the rings as they can become deformed and unable to provide a good seal.

Always pay attention to the “top” marking. Rings with a “top” marking must be fitted with the marking facing upward toward the top of the piston.

In the case of coil-supported spring lock washers, the spring joint (the butt end with connector wire) must be positioned at 180° to the ring gap. If the coil spring has a Teflon coil cover, this cover must be positioned at the ring gap.

Special care is required when fitting steel rail rings (3S rings). After the spring has been loaded, the rails should be fitted with the rail gaps pointing toward the pin bore. When fitting the upper rail, the ends of the spring must be held together to prevent overlapping (refer to the color marking). The lower rail can then be fitted.

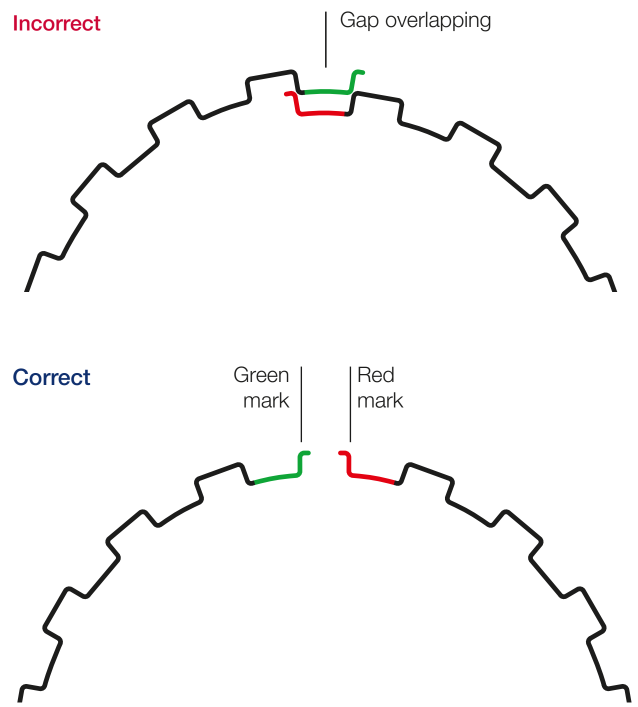
In the case of pistons with rotation stops in the ring grooves, care must be taken to ensure that the ring gaps are positioned alongside the safety dowel pins.

After the rings have been fitted, the ring gaps must be evenly distributed around the circumference (e.g., at 120° for a 3-ring piston).

The side clearance must be checked after the rings have been fitted. Clearances of up to 0.100 mm are acceptable, but if the clearance is greater, the piston must be replaced.

The ring sets allow for a certain amount of wear on the cylinder surface. This should not exceed a value of approx. 0.100 mm (in relation to the cylinder diameter). In the event of greater wear, a new cylinder liner must be used or the cylinder bore must be rebored and equipped with a suitable oversize piston.

Chrome-plated piston rings must not be used on chrome-plated cylinder surfaces.



3.1 Piston rings with scuffing and seizure marks on the piston skirt

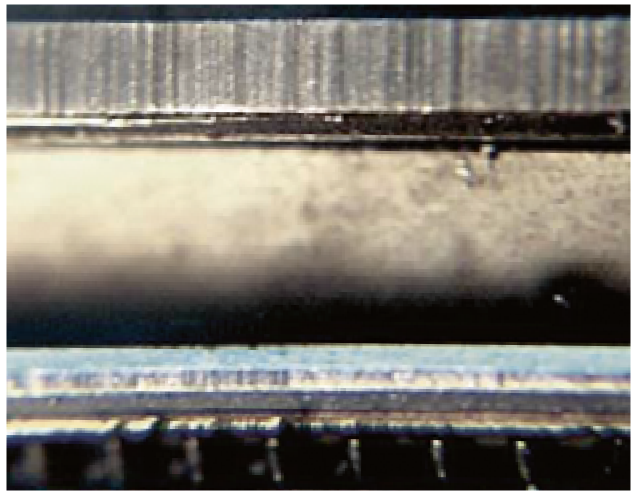


Fig. 1: Piston rings with scoring and scuff marks

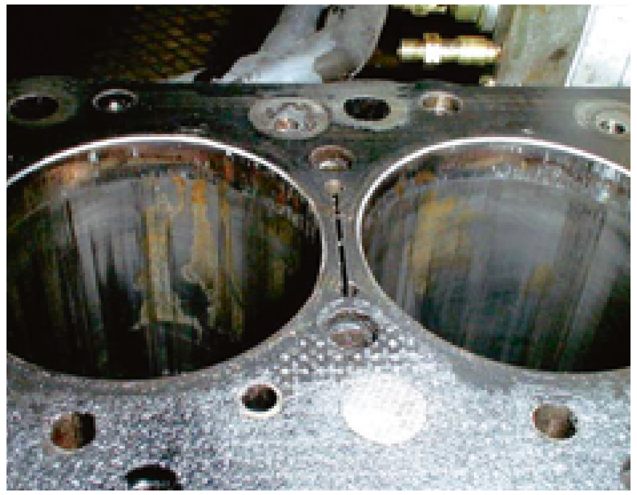


Fig. 2: Cylinder bore with longitudinal score marks

Findings:

- There are seizure grooves and scuff marks around the entire circumference of the piston rings (Fig. 1).
- Seizure marks are visible on the piston skirt.
- Longitudinal score marks can be seen in the cylinder bore (Fig. 2).

Cause(s):

Scuffed piston rings represent a damage scenario that usually occurs in conjunction with other piston or cylinder damage. Scuffing on piston rings is due to a lack of lubrication as a result of the following factors:

- The engine has been subjected to high loads in the break-in phase. Since the piston rings have not yet reached their full sealing effect in this phase, the hot combustion gases can blow past the piston (blowby) and burn off the lubricating oil film. Piston seizure can be another consequence in addition to piston ring seizure.
- The honing is unsatisfactory, resulting in insufficient engine oil adhering to the cylinder wall.
- The lubricating oil film has been diluted due to fuel flooding (see also section “1.2 Fuel flooding,” page 8).
- There is abrasion on the piston rings caused by the piston traveling at an angle (see section “2.2.4 Asymmetrical wear pattern on the piston skirt,” page 44).
- The piston is overheating due to malfunctions in the combustion process, and engine oil has coked in the ring grooves, restricting the movement of the piston rings.

Remedies/avoidance:

Avoid high rotational speeds or high loads at low rotational speeds during the engine break-in phase.

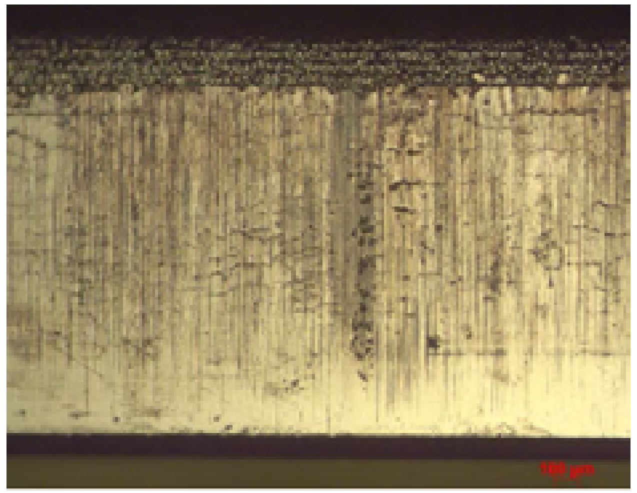


Fig. 3: Piston ring with seizure marks in the stroke direction

3.2 Damage to the ring belt due to broken piston rings

Fig. 1: Damage to the top of the piston due to individual ring carrier fragments

Fig. 2a: Piston ring fracture caused by knocking

Findings:

- Depressions have been worn into the piston ring lands and/or the top land (Fig. 1).
- The surfaces of the worn areas are shiny and smooth.
- As the damage progresses, marks from ring fragments impacting on the top of the piston can be seen.
- The piston ring in the worn groove is broken.

Cause(s):

The damage is caused by a fracture in a piston ring or by piston ring flutter. Possible reasons include:

Assembly error:

The piston ring was not fully inserted into the piston ring groove during assembly and broke when it was pushed into the cylinder.

Knocking:

A piston ring has fractured due to pressure peaks during knocking (Fig. 2a & b).

Piston ring vertical clearance:

- The piston ring grooves are worn.
- The piston ring is worn.
- Thermal overload of the engine has reduced the material strength and the grooves have failed.

Remedies/avoidance:

- Use a compressor tool when fitting piston rings.
- Check the piston ring grooves for wear before assembly. Use a new piston if the piston ring grooves are heavily worn.

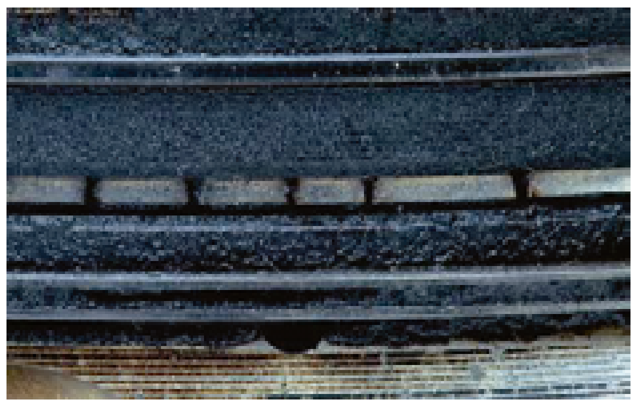


Fig. 2b: Close-up of a piston ring fracture

3.3 Heavy wear on the piston ring grooves and piston rings

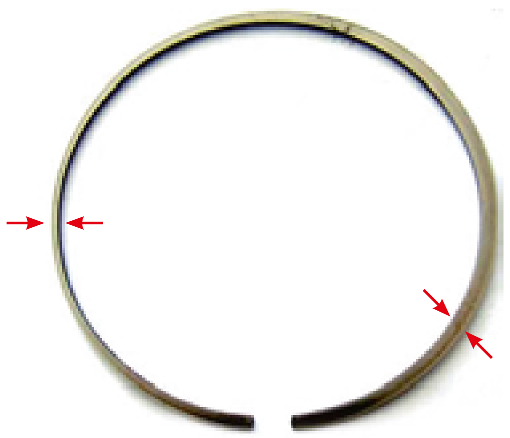


Fig. 1: Piston ring with severe radial wear

Fig. 2: Heavy axial wear, especially on the first piston ring

Findings:

- There is severe radial wear on the piston rings (Fig. 1), which can increase the gap clearance to several millimeters.
- Heavy axial wear can be seen on the piston rings and groove flanks (Fig. 2 & 3).
- The engine is consuming an increased amount of oil (see section “1.4 Increased oil consumption,” page 12) combined with power loss.

Cause(s):

This damage results from wear caused by contamination. We can differentiate between several scenarios based on the number of damaged cylinders and the state of wear on the piston rings:

If only one cylinder is damaged

... and the first piston ring is significantly more worn than the third, then the contamination has entered the combustion chamber via the intake system of one cylinder, i.e., from above. This is caused by either a leak or debris that was not removed before fitting.

If several or all cylinders are damaged

... and the first piston ring is significantly more worn than the third, then the contamination has entered the combustion chamber via the common intake system shared by all the cylinders. This is due to either leaks and/or a destroyed or missing air filter.

... and the third piston ring is significantly more worn than the first, then we can assume that the engine oil is contaminated. The oil is contaminated by either an uncleaned crankcase and/or a dirty oil mist separator.

Remedies/avoidance:

- Check the intake system for leaks.
- Check the air filter and replace it if necessary.
- Remove any dirt from the crankcase and the intake pipes before installation.
- Take care to maintain cleanliness during installation.
- Check and clean or replace the oil mist separator.

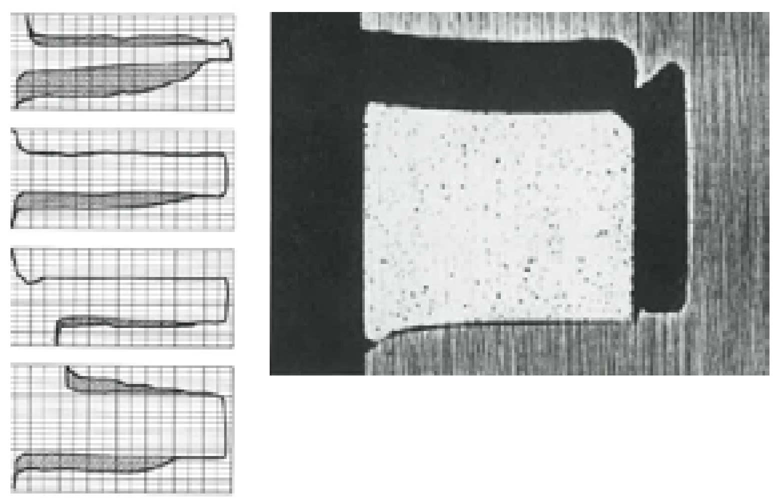


Fig. 3: Groove wear

3.4 Heavy radial wear on the piston rings

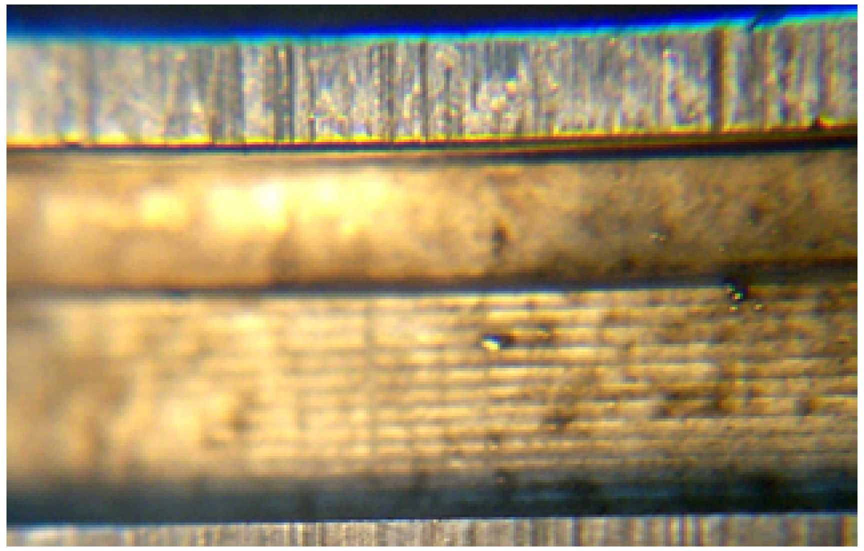


Fig. 1: Heavy radial wear with relatively low axial wear

Fig. 2: Scoring and scuff marks on the piston rings

Findings:

- There is severe radial wear on the piston rings (Fig. 1).
- Score marks can be seen around the entire circumference of the running surfaces of the piston rings in the running direction.
- The running surfaces of the piston rings are partly scuffed (Fig. 2).
- Axial wear on the piston rings is minimal.
- Axial wear on the groove flanks is also minimal.
- The oil control ring lands may have been worn away (Fig. 2).
- There are deep grooves on the piston skirt, possibly combined with friction or seizure marks.

Cause(s):

An excessive amount of fuel in the oil has diluted the oil film, drastically reducing its load-carrying capacity and resulting in increased wear on the engine components. This kind of damage may have the following causes:

- The fuel injection system is set incorrectly.
- Cold start enrichment is too rich.
- The injection nozzles are not working properly.
- Insufficient gap width means that the piston strikes against the cylinder head, causing uncontrolled injection from the nozzles.
- The compression pressure is too low, which can lead to misfiring. This may have the following causes:
  - A valve is leaking.
  - The cylinder head gasket is leaking.
  - The valve timing is not set correctly.
  - The gap width is too large.
  - One or several piston rings are defective.
  - A fault has occurred in the ignition system, e.g., a defective spark plug.

Remedies/avoidance:

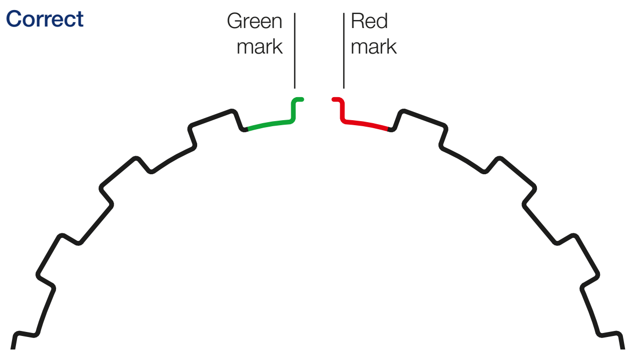
- Set the injection system correctly (cold start enrichment, etc.).
- Check the injection nozzles.
- Adhere to the installation dimensions.
- Check the spark plugs and replace them if necessary. Use the settings specified by the manufacturer.

3.5 Increased oil consumption after changing the piston rings

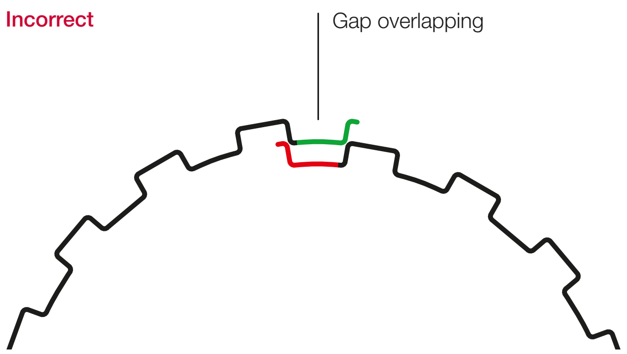
Fig. 1: Correctly inserted expander spring (both color markings visible)

Fig. 2: Oil return

Correct



Incorrect



Findings:

- After installing new piston ring sets with a three-piece oil control ring (type 3S), the engine is producing blue smoke and oil consumption has increased.
- Oil consumption is often only increased on individual pistons in the engine.
- The spark plug and combustion chamber of the affected cylinder are oily or/and sooty.

Cause(s):

When fitting the three-piece oil ring, the expander spring was positioned so that there was overlapping. As a result, the contact pressure of the spring on the two steel rails is too low.

When handling the piston, for example when fitting the connecting rod, the expander spring has jumped, causing the two butt ends to overlap.

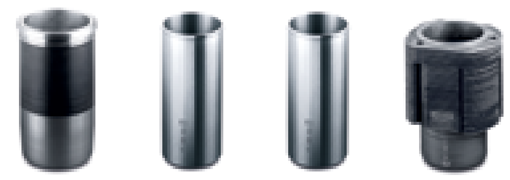
The gap in the lower rail of the 3S ring is in the wrong position (close to the oil return).

Remedies/avoidance:

- Insert the expander spring so that the butt ends do not overlap.
- Insert the lower and upper rails 120° to the left or right of the expander spring gap.
- Do not locate the gap in the rail close to the oil return.
- Before installing the piston in the cylinder bore, check the expander spring gap again. Both color markings on the butt ends must be visible (Fig. 1). If only one color marking is visible, remove the oil control ring and fit it again correctly.
- Do not locate the gap in the rail close to the oil return (Fig. 2). Otherwise, there is a risk that the rail will spring out of the groove.
- Check and clean or replace the oil mist separator.

4. Cylinder liners

In accordance with the engine manufacturer's design requirements, MAHLE cylinder liners (WN/LW & WT/LD) and finned cylinders (WR/LF) have a finished (honed) or semifinished cylinder bore (WV/LP). The major dimensions and characteristics of the cylinders are indicated in the catalog.



Wet cylinder liners (WN/LW)

The location holes and particularly the seat surfaces on the cylinder block must be cleaned thoroughly and free of damage. Corroded surfaces must be reworked (use collar and outer diameter oversize liners), ensuring that the liners are correctly positioned (projecting length of the liner in accordance with the engine manufacturer's specification). After the liner has been fitted with the corresponding sealing rings (use lubricant), the cylinder diameter must be checked—particularly in the region of the sealing rings—to determine whether any deformation has been caused by pinched sealing rings. Using incorrect gaskets (diameter or material) can lead to a narrowing of the cylinder, leading to engine damage. That is why we recommend using MAHLE cylinders with the corresponding MAHLE gasket sets.

Dry cylinder liners (WT/LD)

Before the cylinder liner is fitted, the location hole in the cylinder block must be cleaned thoroughly and checked for dimensional accuracy and any distortion. It is important that the location hole is circular and cylindrical, as this determines the geometrical inner shape of the press-fit, thin-walled liner.

As a rule, no oil or grease should be used when press-fitting the liners, as it will coke and hinder heat transfer. Special lubricants such as molybdenum sulfide are more suitable.

Semifinished cylinder liners (WV/LP)

The collar seat surface must be perpendicular to the location hole as well as sufficiently and evenly beveled. If the liner collar is unevenly supported, it can break off.

The bore of this cylinder is only semifinished. After the cylinder has been fitted, the cylinder bore is precision bored then finished and honed to the nominal dimension.

The end surface of the liner must be flush with the sealing surface of the cylinder block. If necessary, the block surface and cylinder liner must be finished by surface grinding.

Finned cylinders (WR/LF)

Gray cast iron or light-alloy cylinders are used in accordance with the engine manufacturer's requirements.

Light-alloy cylinders (e.g., with running surfaces made of NIKASIL®, SILUMAL®, or Cromal®) are classified into several groups due to the small mounting clearances in some cylinder types. The chosen piston must be compatible with the defining group. We recommend using a complete assembly (cylinder plus piston) as the parts are paired for compatibility in the MAHLE plant.

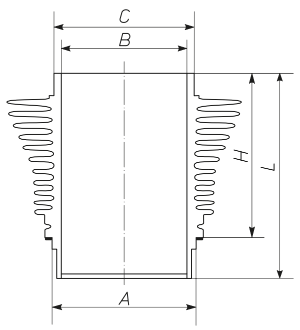
Types and technical terms

Major dimensions

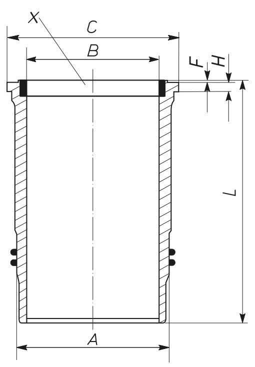
A = Register diameter
B = Maximum permissible finished diameter for semifinished liners
C = Collar diameter
F = Fire protection rim height
H = Collar height
L = Total height
R = Height of pin bore relief
X = Cylinder liner ring

MAHLE cylinders and liners are optimally matched in terms of tribology to the sliding partners: the pistons and piston rings.

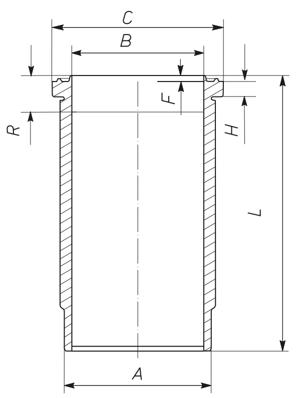
Finned cylinder



Wet liner



Dry liner



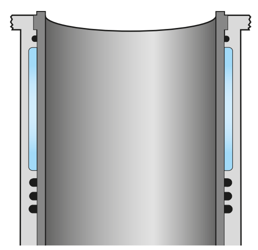
Fitting recommendations for finned cylinders and cylinder liners

In accordance with the engine manufacturer's requirements, MAHLE finned cylinders and cylinder liners have a finished (honed) or semi-finished cylinder bore.

If the engine manufacturer has specified subdivided defining groups (e.g., color coding or letters), the corresponding markings have been retained for the assemblies.

Wet cylinder liners (WN/LW)

The location holes and particularly the seat surfaces on the cylinder block must be cleaned thoroughly and free of damage. Corroded surfaces must be reworked (use collar and outer diameter oversize liners), ensuring that the liners move easily and are correctly positioned (projecting length of the liner in accordance with the engine manufacturer's specification). After the liner has been fitted with the corresponding sealing rings (use lubricant), the cylinder diameter must be checked—particularly in the region of the sealing rings—to determine whether any deformation has been caused by pinched sealing rings. Using incorrect gaskets (diameter or material) can lead to a narrowing of the cylinder, leading to engine damage. The cooling system should be pressure-tested after the liners have been fitted to find out if there are any leaks before the engine is started.



Dry cylinder liners

Before the cylinder liner is fitted, the location hole in the cylinder block must be cleaned thoroughly and checked for dimensional accuracy and any distortion.

Out-of-round or damaged location holes can be reworked to allow fitting of oversize liners. It is important here that the location hole is circular and cylindrical, as this determines the geometrical inner shape of the press-fit, thin-walled liner.

Semifinished cylinder liners (WV/LP)

The collar seat surface must be perpendicular to the location hole as well as sufficiently and evenly beveled. If the liner collar is unevenly supported, it can break off.

After the cylinder liner has been fitted—the inner diameter of which is only semifinished—the cylinder bore is precision bored, then finished and honed to the nominal dimension. Precision-bored liners are only finished and honed (tolerance in accordance with DIN/ISO H5).

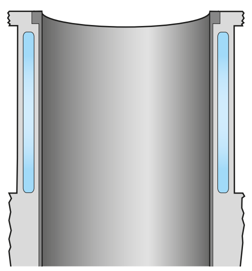
The end surface of the liner must be flush with the sealing surface of the cylinder block. If necessary, the block surface and cylinder liner must be finished by surface grinding.

Finished and honed cylinder liners (WT/LD)

These cylinder liners either fit exactly into the bore of the cylinder block or have a slight overlap. The location hole in the block must be measured precisely before the liner is fitted.

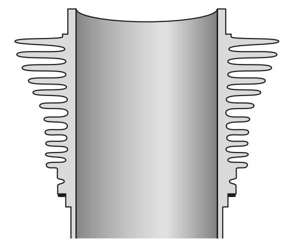
As a rule, no oil or grease should be used when press-fitting the liners, as it will coke and hinder heat transfer. Special lubricants such as molybdenum sulfide are more suitable.

Once the liner has been press-fitted, the cylinder diameter must be measured crosswise in several planes (at the top and bottom as a minimum).



Finned cylinders (WR/LF)

Gray cast iron or light-alloy cylinders are used in accordance with the engine manufacturer's requirements. Light-alloy cylinders (e.g., with running surfaces made of NIKASIL®, SILUMAL®, or Cromal®) are classified into several groups due to the small mounting clearances in the standard cylinder dimensions.



The following example for three defining groups illustrates the classification for a standard dimension.

Piston 503 81 00	Cylinder 503 WR 27	Assembly 503 81 92
Defining group identifier: diameter (mm)		Piston/cylinder combinations
A 94.919–94.923	A 95.000	A–A
AB 94.923–94.933		AB–A and AB–B
B 94.933–94.937	B 95.013	B–B

Gaskets for cylinder liners and finned cylinders

Gasket sets (SK)

Corresponding gasket sets are available for our most common cylinder liners and finned cylinders and can be ordered under separate part numbers (Fig. 1).

Gasket materials

Ke = Keltan/EPDM
Pa = Paper gasket
Pe = Perbunan/NBR
Si = Silicone/VMQ/MVQ
T = Tombac ring
Vi = Viton/FKM/FPM
We = Soft iron gasket/shim

Material properties of gaskets

For engines subjected to heavy loads, we offer gaskets made of peroxide cross-linked material in accordance with OE specifications. These seals have been marked "perox" in the catalog.

perox = peroxide cross-linked material

Fig. 1: Gasket set for wet cylinder liner

4.1 Grains on the outer wall of cylinder liners (cavitation)

Fig. 1a: Cylinder liner with cavitation damage

Findings:

Recesses or holes can be seen on the outside of wet cylinder liners in the water jacket area (cavitation, Fig. 1a & b). However, these holes are usually only visible on the thrust and antithrust sides in the vicinity of the top or bottom dead center of the piston.

Cause(s):

Cavitation damage is caused by vibrations in the cylinder liner. These vibrations can occur in the cylinder wall due to contact alternation at top and bottom dead center and can be transmitted to the surrounding water jacket. As the cylinder wall retracts during a vibration cycle, a temporary vacuum is created, causing vapor bubbles to form in the coolant. When the cylinder wall moves back, the vapor bubbles implode and the impact of the coolant crashing back against the cylinder liner causes the material to erode. The following factors promote cavitation:

- There is not enough antifreeze in the coolant to reduce the formation of bubbles.
- There is a leak in the cooling system, e.g., at the radiator cap. This prevents pressure from building up in the cooling system and promotes the formation of bubbles.
- The cylinder liner has too much clearance in the crankcase. This means that the vibrations caused by contact alternation are no longer sufficiently absorbed.
- The wrong coolant (acidic water, etc.) has been used.
- The engine temperature is too low. As a result, the coolant pressure level is too low, which promotes the formation of bubbles. It also prevents the piston from reaching its operating temperature, increases the clearance, and causes excessively violent contact alternation. The temperature may be too low for the following reasons:
  - The thermostat or thermal switch is defective.
  - The fan wheel's Visco® clutch is defective, i.e., the fan wheel is running continuously.

Remedies/avoidance:

- Always check the cooling system (radiator cap, hoses, clamps) for leaks.
- Check the opening pressure of the valve in the radiator cap/expansion tank cap. Replace the cap if necessary.
- Ensure that there is enough antifreeze with corrosion protection in the system.
- Check that the cooling system (thermostat, fan, thermal switch) is working properly.

Fig. 1b: Close-up of the cylinder liner with sharp edges and holes that become larger toward the inside

4.2 Collar torn off cylinder liner

Fig. 1: Broken-off cylinder liner collar

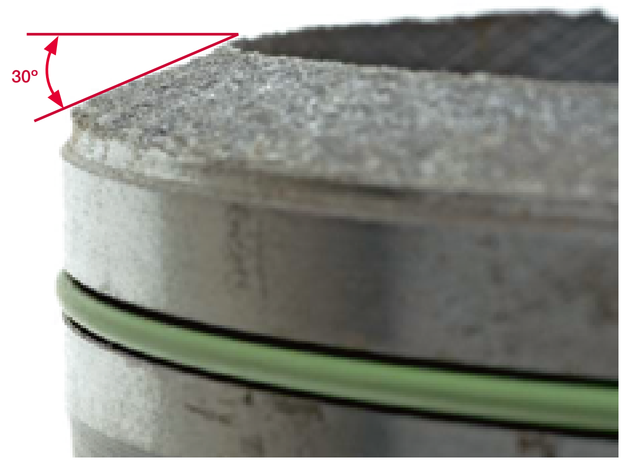


Fig. 2: Fracture with a coarse-grained structure, at an angle of approx. 30°

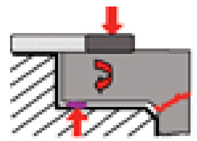
Findings:

- The cylinder liner has been torn off below the collar (Fig. 1).
- The fracture runs at an angle of approx. 30° (Fig. 2).
- The fracture has a coarse-grained structure (Fig. 2).

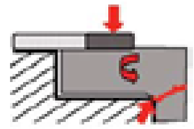
Cause(s):

This forced fracture has been caused by a bending moment in the collar seat. This bending moment may have the following causes:

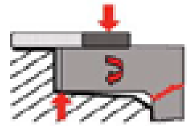
There are foreign objects (e.g., dirt, gasket residue, chips) between the cylinder liner and the collar seat.



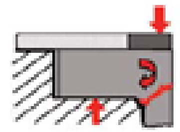
The collar seat has not been beveled.



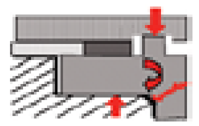
The collar seat has been machined at an angle.



The wrong cylinder head gasket has been used and the diameter of the combustion chamber bezel is too small.



The seat of the fire protection rim in the cylinder head has not been cleaned or reworked following surface grinding of the cylinder head.



The cylinder liner is recessed too deeply in the block, causing the cylinder liner to wobble in the seat, resulting in large impact loads.

Remedies/avoidance:

- Ensure that the collar mount in the engine block is machined cleanly.
- Check that the cylinder liner seat in the engine block is flat and perpendicular.
- Bevel the collar after machining.
- Only use cylinder head gaskets intended for the engine.

4.3 Longitudinal cracks in cylinder liners

Findings:

There is a longitudinal crack in the cylinder liner (Fig. 1 & 2).

Cause(s):

Longitudinal crack starting from the upper or lower end of the cylinder liner:

The cylinder liner has been damaged during handling or transportation, possibly as a result of a violent axial impact, e.g., falling onto a hard floor. The resulting stresses in the cylinder liner material can lead to the damage scenario described above.

Longitudinal crack in the piston running surface:

Hydraulic lock (see also section "1.3 Hydraulic lock," page 10) generates enormous forces in the combustion chamber. Since water cannot be compressed, the adjacent components, including the cylinder liner, must absorb the resulting forces. This can cause the cylinder liner to crack.

Fig. 1: Longitudinal crack in a cylinder liner

Fig. 2: Longitudinal crack in the lower end of a cylinder liner

Remedies/avoidance:

- Transport cylinder liners carefully and always in an upright position.
- Before fitting, carry out a tap test on the cylinder liner and perform a visual inspection of the cylinder liner surface.

4.4 Seizure marks on the outside and inside of a semifinished cylinder liner (WN/LS)

Fig. 1: Seizure marks on the piston skirt

Fig. 2a & b: Seizure marks on the outside of the cylinder liner (around the entire circumference)

Findings:

- Piston seizure occurs approx. 1,000 km after an engine overhaul (Fig. 1).
- Severe seizure marks are evident around the entire circumference of the cylinder bore.
- There are deep longitudinal grooves on the outside of the cylinder liner and material has been scraped off around its entire circumference (Fig. 2a & b).
- All of the engine's cylinders exhibit similar damage.

Cause(s):

The location holes in the engine block for the semifinished cylinder liners were drilled too small, Consequently, the overlap between the cylinder liner and the engine block was too large. This resulted in the grooves on the outside of the cylinder liner and very high stresses in the cylinder liner during press-fitting. Even after the cylinder surface was machined to the intended dimensions by drilling and honing, the stresses were still present. The operating temperatures during the first approx. 1,000 km slowly relieved the stresses in the cylinder liner, leading to a wave-shaped distortion of the cylinder liner in its installed state. Due to the wave-shaped distortion, the clearance between the cylinder bore and the piston was continually compromised, which led to piston seizure.

Remedies/avoidance:

Press fit semifinished cylinder liners with the overlap specified by the engine manufacturer. In passenger car engines, this is usually 0.04–0.06 mm (reference values for a gray cast iron block and gray cast iron cylinder). Press-fitting usually requires forces of 5,000–15,000 N (equivalent to 500–1,500 kg).

If 40,000–50,000 N (equivalent to 4–5 t) are needed to press fit the cylinder, this is a clear indication that the overlap is too large! Stop the process as soon as such high forces are indicated on the press, then measure and rehone the location hole.

5. Valves

Types and technical terms

Monometallic valves

These valves are manufactured efficiently in a hot extrusion or stamping process.

Bimetallic valves

Bimetallic valves use an ideal combination of materials for both the stem and the head.

Hollow valves

These valves serve to reduce both weight and temperature. With a stem filled with sodium (melting point 97.5°C), heat can be transported away from the valve head into the valve stem owing to the shaker effect of liquid sodium, achieving temperature reductions of between 80°C and 150°C.

Materials

S = High-alloy CrSi steel for intake valves subjected to high loads and exhaust valves subjected to low loads. Also used as a stem material in bimetallic valves.

X = CrMoV steel with outstanding wear resistance and sliding properties, used for intake valves subjected to relatively high loads.

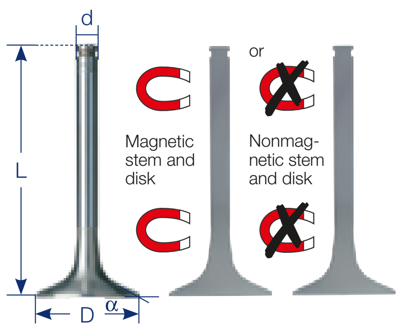
T = Austenitic CrMnNi steel with added nitrogen for intake and exhaust valves subjected to the most severe mechanical and thermal stresses in gasoline and diesel engines. Also used as a material for the heads of bimetallic valves.

PT = Austenitic CrMnNiNb steel with excellent strength at elevated temperatures and wear resistance. Standard valve for trucks with and without seat reinforcement. Also used for turbocharged diesel passenger cars.

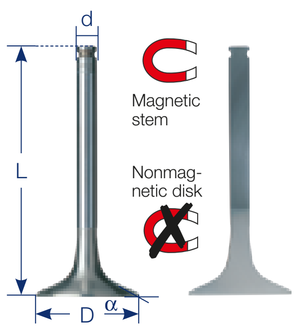
I2 = Low iron–nickel alloy with good corrosion resistance and high strength at elevated temperatures. Used as a material for the heads of bimetallic valves mainly in commercial vehicles.

I = Nickel superalloy (Nimonic 80A©) for exhaust valves subjected to the most severe loads.

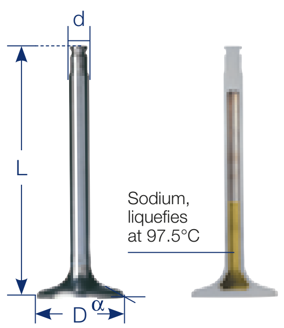
Monometallic valve



Bimetallic valve



Sodium-filled hollow valve



Fitting recommendations

Valves are among the engine components that are subjected to the greatest thermal and mechanical loads. Correct installation is critical to their service life—and ultimately the service life of the engine.

MAHLE valves are supplied ready for installation and packed individually.

Before installation, check the valves for damage (e.g., caused by dropping). Never install damaged or bent valves. Make sure that the valves are the right ones for your engine.

MAHLE valves are only to be used for the application for which they were designed. They must not be mechanically reworked or modified under any circumstances.

Before installing a valve, check the inner cone of the valve spring retainer to see if it is worn or damaged. Also check that the valve spring force is still within the values specified by the engine manufacturer.

Always use new valve collets and valve stem seals when installing a valve.

Ensure that the valve stem is sufficiently lubricated with clean engine oil before inserting it into the valve guide.

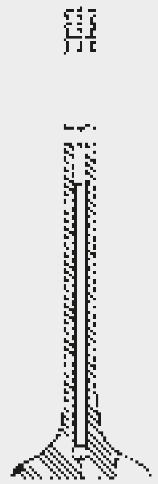
Always follow the information and installation guidelines provided by the engine manufacturer.

After inserting the valves, slide the mounting sleeve for the stem seals over the valve base. This prevents the sealing lips of the valve stem seal from being damaged by the valve grooves.

Materials
Austenitic steels
Martensitic steels

Design
Monometallic valves
Bimetallic valves

Valve seat design
Plasma powder hard-facing
Induction hardening



Valve base induction hardening
Profile hardening
Full hardening
Base surface hardening

Hollow valves
Stem diameter: >6 mm

Bore sealing:
- Laser welding
- Friction welding
- Sodium-filled

Fillet profile
Turned, ground
Contour-forged

Valve disk surface
Machined
Forged
With or without calotte

Valve base geometry
1–3 grooves
Special design

Valve length
80–210 mm

Valve disk diameter
18–65 mm

Valve stem diameter
5–12 mm

Surface treatment
Salt bath-nitrided, hard chrome-plated
(coating thickness: 3–35 μm)

Our valves are optimized for a wide variety of applications in order to withstand extreme mechanical, chemical, and thermal loads and to dissipate heat as effectively as possible.

Valve guides

Technical terms

Valve guides center the valve on the valve seat insert and compensate for the lateral forces acting on the valve stem. They also transfer heat away from the valve head to the cylinder head via the valve stem. Generally, a distinction is made between dedicated intake or exhaust valve guides and valve guides that are used on both the intake and exhaust sides.

Materials

Valve guides are made of gray cast iron, brass, and sintered materials. Special alloying constituents are used to optimize their sliding, thermal, and wear properties. The following materials are used:

B = CuZnAl alloy with good wear resistance as well as good fatigue and corrosion resistance. For applications subjected to medium loads.

B1 = CuSn alloy with added phosphorus for increased wear resistance. Suitable for applications subjected to high loads.

G1 = Gray cast iron alloy with a pearlitic microstructure offering good wear resistance. For normal loads.

G2 = Gray cast iron alloy with a pearlitic microstructure and an increased phosphorus content. The interconnected lamellar arrangement in the material matrix provides increased wear resistance and enhanced boundary lubrication properties. Suitable for high loads.

CN = CuNi alloy exhibiting increased hardness and thermal conductivity as well as wear and abrasion resistance. For high strength even under difficult operating conditions.

SM = Sintered metal alloy with high mechanical stability even at extremely high temperatures. Developed for high-performance engines.

Fitting recommendations

After the valve guides have been fitted (shrunk in/press-fitted), the inside of the valve guides must be reamed to the specified dimensions. This applies both to semifinished valve guides and to valve guides that have already been machined to nominal dimensions.

This is due to deformation of the new valve guides, which can occur during installation in the cylinder head.

We recommend using a hand reamer and some thread-cutting oil for reaming.

The valve stem diameter only provides the clearance specified by the vehicle manufacturer in conjunction with the reamed valve guide.

Prior to assembly, clean all parts and lubricate them well.

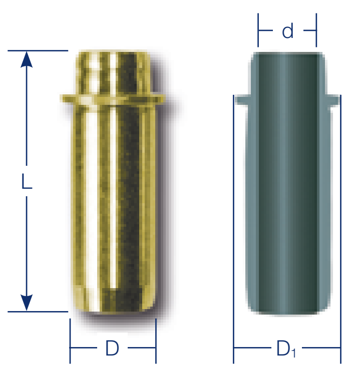
To prevent damage to the sealing lips, always use a mounting device to fit new valve stem seals.

Reference values for reaming valve guides

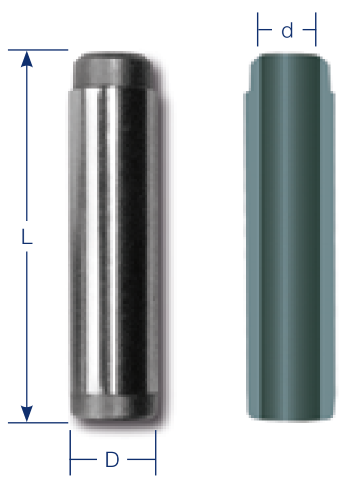
Valve stem diameter	Intake valve	Exhaust valve
6–7 mm	10–40 µm	25–55 µm
8–9 mm	20–50 µm	35–65 µm
10–12 mm	40–70 µm	55–85 µm

Reference values for the clearance between valve stem and valve guide

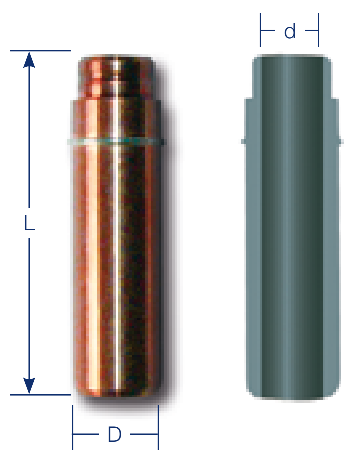
Valve guide made of nonferrous metal



Valve guide made of gray cast iron



Valve guide made of copper



Valve seat inserts

Technical terms

In aluminum cylinder heads, valve seat inserts play a central role in the overall valve train concept. Along with the valves, their main function is to seal the combustion chamber and transfer the heat generated to the cylinder head. As the material properties of the aluminum cylinder head and its alloys are not adequate for the tasks of a valve seat, the highly resilient valve seat inserts prevent the valves from striking the soft cylinder head material.

Valve seat inserts are precisely engineered to cope with the loads placed on them and able to perform their functions thanks to their materials and their machinability.

Materials

To meet the increased demands of modern engines, MAHLE offers highly resilient sintered metals in addition to various gray cast iron steels and cast steels.

ST = Cobalt-based material with a high chromium and tungsten content. Valve seat inserts made from these extremely wear- and corrosion-resistant alloys are mostly used in engines powered by alternative fuels, such as CNG, biogas, and landfill gas.

GG1 = Readily machinable gray cast iron alloy with a high carbon content. This material, valued for its high compressive strength and wear resistance, is used in the intake area of gasoline and turbocharged diesel engines.

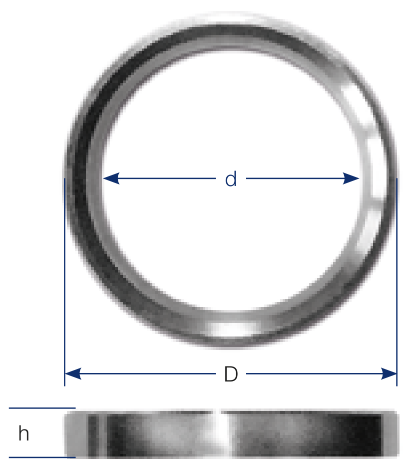
SG1 = High temperature-resistant cast steel with a high chromium (>10%) and molybdenum content. In addition to their strength at elevated temperatures, these valve seat inserts are noted for their good creep resistance and excellent corrosion resistance. They are used in diesel and gasoline engines.

SG2 = High-performance cast steel with a very high chromium content (>30%), which—in combination with molybdenum—is extremely resistant to corrosion and heat. It is mainly used in diesel and gasoline engines.

SG3 = High-alloy cast steel material with a high molybdenum and vanadium content. It is used for highly wear-resistant valve seat inserts in turbocharged diesel and gasoline engines and in combination with alternative fuels such as CNG and LPG.

SM1 = Extremely high-grade and high-performance sintered material for intake and exhaust valve seat inserts with extreme wear resistance. Developed for high-performance naturally aspirated and turbocharged engines fueled with gasoline, diesel, or gas.

Valve seat insert



Major dimensions of a valve seat insert
D = Outer diameter
d = Inner diameter
h = Height

Fitting recommendations

MAHLE valve seat inserts are ready for installation, i.e., no finish machining of the seat is necessary.

To secure the valve seat insert in the cylinder head, the correct interference fit (overlap) is needed between the valve seat insert and the seat in the cylinder head. If the overlap is too large, the severe deformation of the aluminum caused by press-fitting the valve seat insert can lead to plastic deformation in the cylinder head. Stress cracks can also occur on the lands between the valve seat inserts.

The interference table provides information about the correct dimensions for location holes in cylinder heads.

After oiling the location hole with a pressure-resistant oil (transmission oil), MAHLE valve seat inserts made of sintered metal are press-fitted into the cylinder head at room temperature, allowing for the appropriate overlap.

The following methods can be used to install cast valve seat inserts:

- Press fit the valve seat insert into the location hole in the cylinder head at room temperature.
- Press fit the room-temperature valve seat insert into the preheated cylinder head.
- Cool the insert in liquid nitrogen then insert it into the room-temperature cylinder head.
- Heat the cylinder head and cool the valve seat insert—this is the optimum method for virtually force-free assembly.

Reference values for the location hole

Outer diameter of seat insert	Overlap in cylinder heads made of gray cast iron	Overlap in cylinder heads made of aluminum
20–30 mm	0.050–0.090 mm	0.040–0.080 mm
30–40 mm	0.060–0.100 mm	0.050–0.090 mm
40–50 mm	0.070–0.110 mm	0.060–0.100 mm
50–60 mm	0.080–0.120 mm	0.070–0.110 mm
60–70 mm	0.090–0.130 mm	0.080–0.120 mm

5.1 Seizure marks on valve stem

Fig. 1a: Valve stem has seized in the guide

Fig. 1b: Seizure marks and grooves on valve stem

Findings:

There are seizure or friction marks on the valve stem (Fig. 1a & b).

Cause(s):

There are generally two causes:

Geometric deviations:

- The valve guide and the valve seat are not aligned. This can be due to either inadequate machining or dirt in the valve guide and/or valve seat.
- The valve is crooked or bent, which can be caused by valve impact, for example. Even a barely visible bend can lead to the valve running out of round.
- A loose valve seat insert results in misalignment with the valve guide.
- The inner diameter of the valve guide is too large or too small, leading to the clearance between the valve and valve guide being too large or too small.
- Old or worn valve collets have been used.
- Distortion of the cylinder head can lead to geometric deviations in the location hole for the valve guide. These are then transferred to the valve guide.

Overspeed:

- Overspeed can cause the tribological system to collapse. The film of lubricating oil between the valve guide and the valve can no longer withstand the rapid movement, and there is metallic contact between the valve and the valve guide.
- Valve impacts occur due to excessive rotational speeds (see “Geometric deviations,” above).

Remedies/avoidance:

- Align the valve guide and valve seat correctly.
- When reworking used valves, take great care to keep the valve stem straight.
- Install valve seat inserts in accordance with manufacturer specifications.
- Always use new valve collets. Old collets are usually unevenly worn, which means that the valves can no longer rotate freely.
- Always ream valve guides (both semifinished and fully finished) to the correct dimensions and geometry after press-fitting them into the cylinder head. Refer to manufacturer specifications.
- After the engine has been run at overspeeds, it is advisable to inspect the entire valve train system and the top of the piston for damage.

5.2 Deformation of the valve stem

Fig. 1: Bent valve stem

Fig. 2b: Vibration fracture with fracture surface on the valve stem

Findings:

- The valve stem is slightly crooked or bent (Fig. 1).
- The valve disk has snapped off (Fig. 2a & b).

Cause(s):

Deformations of the valve stem are due to mechanical overloading. This may have the following causes:

- An incorrect valve setting can lead to the valve impacting on the piston.
- At engine overspeeds, the return speed of the valve springs is not fast enough and the piston and valve collide.
- The valve timing is set incorrectly, i.e., the markings have not been followed, with the result that the valve train and piston movements are no longer synchronized correctly, which can lead to valve impacts.
- The timing belt or chain has jumped due to a defective clamping device.
- Backward rotation of the engine has caused the chain to jump.
- The timing belt or chain has broken.
- The valve depth is too shallow.

Remedies/avoidance:

- Set the valve clearance correctly.
- Avoid running the engine at overspeeds.
- Set the valve timing precisely.
- Never reverse the direction of the engine.
- When replacing timing belts or chains, replace the clamping device as well.
- Check the valve depth after machining the cylinder head.
- Always apply the handbrake when parking manual transmission vehicles.

5.3 Fracture in the valve groove

Fig. 1: Severely deformed valve

Fig. 2: Valve base broken at the groove (forced fracture/bending stress)

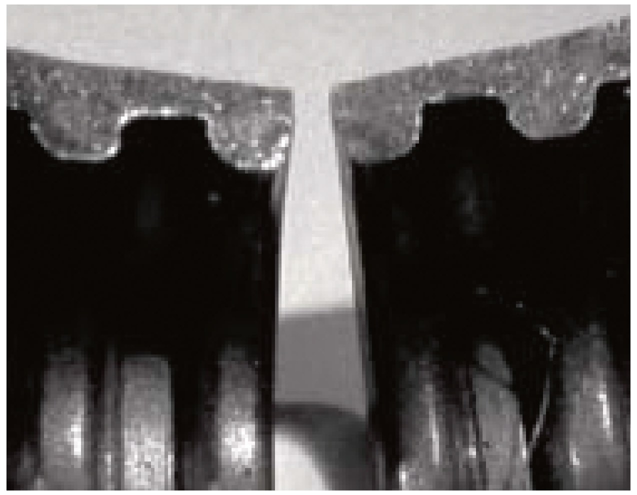


Fig. 3: Deformation of the valve collets along the reinforcing ribs

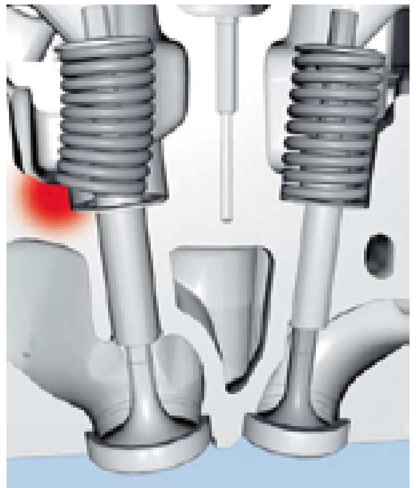


Fig. 4: Spring, fitted at an angle, jamming on one side

Findings:

- The valve has broken or snapped off at a groove (Fig. 1 & 2). The valve collets are deformed (Fig. 3).

Cause(s):

This damage scenario can only be caused by mechanical overloading of the valve. There are two possible reasons for this:

Coarse-grained fracture structure—assembly error:

- A forced fracture has occurred, characterized by a coarse-grained fracture structure. This is due to an assembly error and occurs shortly after the engine has been repaired. If the valve spring is fitted at an angle, it will jam on one side when compressed. This creates a large bending moment on the valve spring retainer. This bending moment can cause the valve to fracture or snap off (Fig. 4 & 5).

Fine-grained fracture structure—geometry defect:

- A fatigue fracture has occurred, characterized by a fine-grained fracture structure. This fatigue fracture is caused by a geometry defect in the valve train system. For example, if the valve disk no longer sits at a right angle to the valve stem due to slight contact between the valve and the piston, a bending moment will occur at the point where the valve disk connects with the valve stem when the valve makes contact with the seat. Over an extended period of operation, this can lead to material fatigue and ultimately to the valve snapping.
- Slanted rocker arms or reusing valve collets can also cause a slight bending moment on the valve. Over an extended period of operation, this can lead to the valve snapping.

Remedies/avoidance:

- Ensure that the valve spring is correctly seated during installation.
- Check the valve train system.
- Always use new valve collets. Old valve collets are usually unevenly worn, which means that the valves can no longer rotate freely, causing bending stresses to build up on the valve stem.

Fig. 5: Marks on the cylinder head caused by a valve spring installed at an angle

5.4 Fracture in the valve disk area

Fig. 1: Valve disk broken off and hammered into the piston

Fig. 2: Valve impact marks on the top of the piston

Findings:

- The valve has broken off and/or bent in the valve disk area (Fig. 1).

Cause(s):

This damage scenario is caused by mechanical overloading of the valve. There are three different types of overload:

Coarse-grained fracture structure—forced fracture:

- This is the result of a brief, sudden, very high force peak, such as the impact of a valve on a piston (see also section “2.1.5 Valve impacting on the top of the piston and piston striking against the cylinder head,” page 34). This is caused by incorrectly set valve timing, incorrect valve depth, or the engine being run at overspeeds.

Fine-grained fracture structure—fatigue fracture:

- A slight deformation of the valve in the area where the valve disk connects with the valve stem means that the valve bends each time it closes. This leads to material fatigue, causing the valve disk to snap off.

Thermal overload:

- Especially in high-alloy valve steels, thermal overload can cause material damage in the metal matrix (hot gas corrosion). This microstructural wedge-shaped spalling is not visible from the outside.

Remedies/avoidance:

- Set the valve timing precisely during assembly.
- When repairing a cylinder head, check the valve depth carefully.
- Avoid running the engine at overspeeds.
- When reusing valves, always check their dimensional accuracy.
- Machine the valve seat carefully to ensure that the valve guide and the valve seat align.
- It is the responsibility of the workshop to decide whether reworking old valves is worthwhile or whether fitting new valves is the better choice.
- Fitting new valves is always highly recommended in the case of valves made of high-alloy steels, as material damage resulting from hot gas corrosion can only be detected after a valve has snapped off.

5.5 Valve seat wear

Fig. 1: Heavy wear on the sealing surface

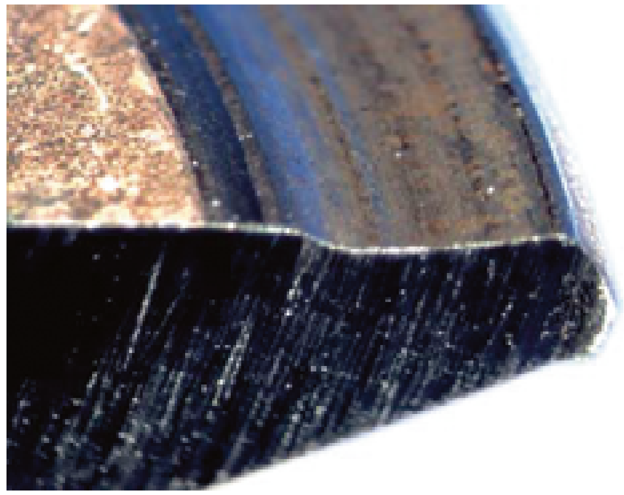


Fig. 2: Close-up of the sealing surface

Fig. 3: Severely worn sealing surface (with Stellite hard-facing)

Findings:

- The sealing surface on the valve disk is severely worn (Fig. 1–3).
- The valve collets are deformed.

Cause(s):

The valve seat is worn due to excessive part loading. This loading can be caused by the following:

- The valve guide and valve seat exhibit a geometric deviation, i.e., they are not aligned.
- The temperature is too high, e.g., due to
  - incorrectly set mixture,
  - malfunctions in the combustion process,
  - insufficient valve clearance,
  - knocking, or tuning.
- The valve seat is subjected to excessive mechanical loads, e.g., reinforced valve springs or sharp camshafts.
- When an engine has been converted for use with gas, the resulting lack of evaporation cooling or lack of lubricating effect provided by the fuel means that the valve becomes hotter and is exposed to greater loads.

Remedies/avoidance:

- Ensure that the valve guide and the valve seat are aligned.
- Set the valve clearance in accordance with the specifications.
- Only use parts (springs, camshafts, etc.) specified by the manufacturer.
- Use valves and valve seat inserts that are suitable for use with gas.

5.6 Deformation of the valve disk

Fig. 1: Deformed valve disk (tulip shape)

Fig. 2: For comparison: valve disk without deformations

Fig. 3: Linear contact marks on a deformed valve disk

Findings:

- The valve disk is deformed and/or broken (Fig. 1).
- Deformation of the valve disk means it is only in linear contact with the sealing surface (Fig. 3).

Cause(s):

The valve disk is deformed due to either thermal or mechanical overloading. This overloading may have the following causes:

Thermal overload:

- The valve clearance is insufficient.
- Malfunctions have occurred in the combustion process.
- Tuning work has been carried out.

Mechanical overload:

- A foreign object is trapped between the valve and the valve seat.

Remedies/avoidance:

- Set the valve clearance correctly.
- Check the injection system.
- During engine assembly, remove any small parts that may be left in the combustion chamber or intake section.

5.7 Hole burned through the valve disk

Fig. 1: Hole burned through a valve

Fig. 2: Cracks and melting damage at various stages

Findings:

- A wedge-shaped piece of the valve disk has melted away (Fig. 1).
- Cracks or melting damage can be seen on the valve disk (Fig. 2).

Cause(s):

Leaky valve:

The valve no longer seals properly due to a poorly reworked valve seat, incorrectly set valve clearance, a small crack in the valve disk, or other geometry defects. A lack of clearance between the valve guide and the valve stem can also obstruct valve rotation. The turbocharger was replaced after mechanical damage, but the charge air path was not cleaned and the charge air cooler was not replaced. Foreign objects from the previous damage enter the combustion chambers and some settle on the valve disks. If contact between the valve disk and the valve seat insert in the cylinder head is too brief or no longer occurs, the valve can no longer dissipate the heat. This causes heat to build up on the valve disk, leading to cracks forming during extended periods of operation and then to the valve disk melting.

Restricted valve rotation:

Three-grooved valves need to rotate. If old valve collets are reused during assembly, there is a risk that the valves will no longer be able to rotate. This can cause heat to accumulate, leading the valve to burn through during extended use.

Remedies/avoidance:

- When reworking the valve seat, ensure that the valve guide and seat are at right angles to each other.
- Always use new valve collets. Old collets are usually unevenly worn, which means that the valves can no longer rotate freely.
- Ream the valve guide to the specified dimensions using a reamer.
- After mechanical turbocharger damage, clean the charge air path thoroughly (including the air filter housing) and replace the charge air cooler.

Resilient and robust— for every engine type

6. Bearings

Fitting recommendations

When disassembling the engine, mark the parts that belong together. Examples include the connecting rod and its bearing cap. Thoroughly clean the removed parts.

Before installing the bearings, measure the dimensions and geometries of the location holes and bearing journals.

Ensure that the bearings are well lubricated on installation. Some bearing halves must be installed in a specific direction. The backs of these bearings are marked “upper” or “lower.”

Most connecting rod bolts and bolts for main bearing caps are antifatigue bolts that may only be used once. They must be replaced.

During assembly, test whether the crankshaft can be turned easily and without jerking.

Always refer to the specifications and data provided by the relevant engine manufacturer.

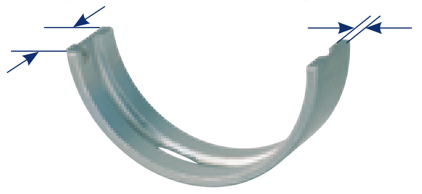
In addition to all conventional technologies, MAHLE also supplies various polymer-coated bearings and polymer-coated thrust washers.

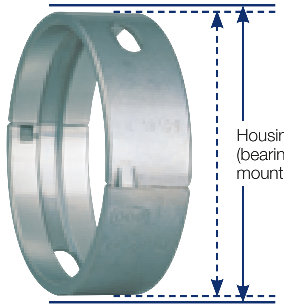
Bearing types

Bearing bushings

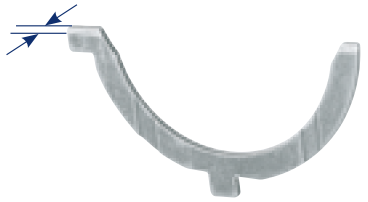
HL Main bearing

PL Connecting rod bearing

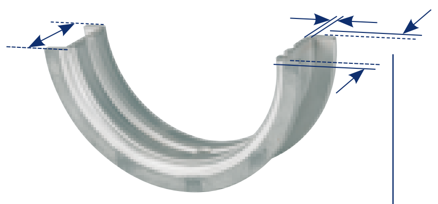


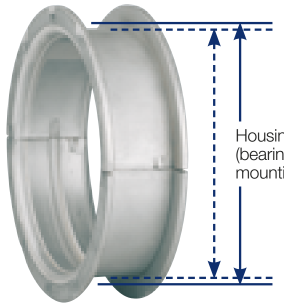


AL Thrust washer



FL Thrust bearing





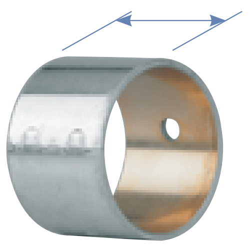
Bushings

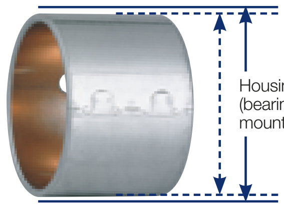
BB Piston pin bushing

KB Valve rocker bushing

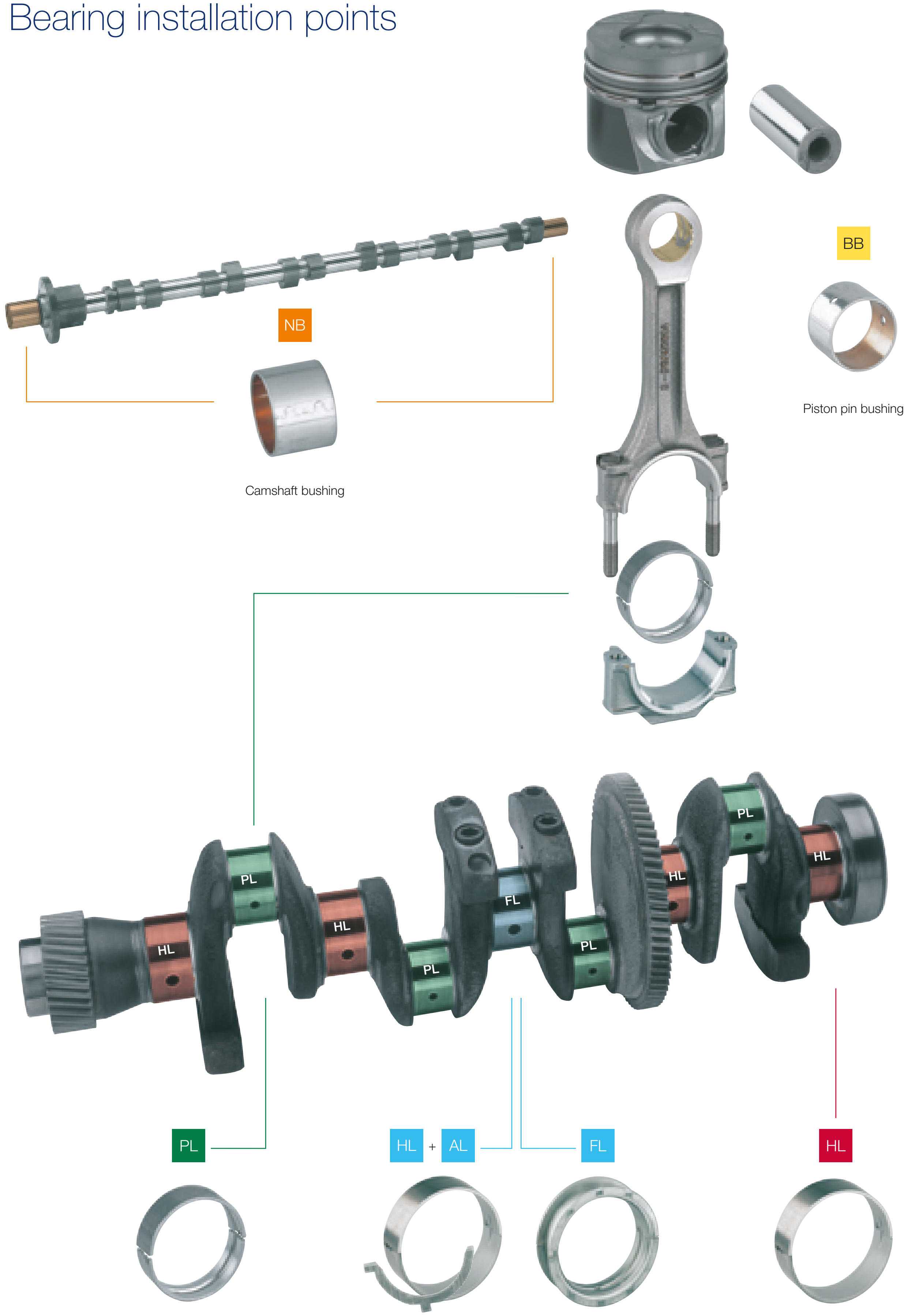
LB Bushing

NB Camshaft bushing





Bearing installation points



Types and materials

Types

Solid bearings consist entirely of bearing material. Special bronze alloys are frequently used. The majority of solid bearings are bushings.

Two-component bearings consist of a steel support shell, an intermediate layer, and a layer of bearing material. Aluminum alloys are the main bearing materials used. Two-component bearings are used in low-load to medium-load gasoline and naturally aspirated diesel engines in passenger cars.

Three-component bearings consist of a steel support shell, a bearing layer, a barrier layer, and a bearing overlay. Three-component bearings are predominantly used in high-performance engines.

Sputter bearings are three-component bearings. Thanks to a special production process (sputtering), these bearings exhibit significantly greater hardness and wear resistance. These properties make sputter bearings ideal for turbocharged engines with charge air cooling. Sputter bearings are not only used in commercial vehicle engines but also increasingly in passenger car diesel engines.

In most cases, all bearing types feature additional protection from corrosion in the form of a galvanically applied layer of tin.

Solid bearing

Two-component bearing

Three-component bearing

Materials

Depending on the application, MAHLE bearings consist of a high-strength steel support shell that is coated with several different bearing materials. The bearing materials are selected to ensure that the positive properties of the various materials complement each other and are optimal for the application in question.

Material development plays a key role in making sure that present and future demands on bearings can be met. Thanks to its many years of experience and development work, MAHLE has a wide range of high-quality bearing alloys at its disposal, including alloys containing aluminum and bronze.

	Metals in %							
Material	Cu	Al	Si	Pb	Sn	Sb	Other	Bearing overlay
M1	3				89	8		
M5	80			10	10			
M7	73			23	4			
M10	88			1	10		1	
M11	0.5			74	10	15	0.5	
M23			1	82	1	15	1	
M30	70			30				
M31	70			30				P77
M83	1	91	1	1			6	P77
M100	80			10	10			
M114	78			20	2			P77, P80, P94
M157	1	79			20			
M172	2	81			17			
M183	2	91	2				5	P77, P80
M215	2	83	4		11			
M218	2	83	4		11			
M221	85			2	11.5		1.5	
M222	83			7	7		3	

Types and materials

	Metals in %							
Material	**Cu**	**Al**	**Si**	**Pb**	**Sn**	**Sb**	**Other**	**Bearing overlay**
M250	73			23	4			
M330	78			20	2			AlSn sputter
M331	75			23	2			AlSn 40Cu sputter
M770	74			25	1			
M780	78			20	2			P77
M790	72			23	3.5		1.5	
M800	74			20	2		4	P77
M810	0.8	87	3		9		0.2	
M817	1	80.3		1.7	17			
M900	75			23	2			Q1
M901	75			23	2			P77, P78, P80
M902				83	6	10	1	
M916	1	78.7			20		0.3	
M920	1	90	2		6		1	

Fitting recommendations

1. When disassembling the engine, mark the parts that belong together.

2. Take care not to damage any parts when removing the crankshaft. Thoroughly clean the removed parts. Contamination is the most common cause of damage to bearings, so clean all of the parts making up the oil circuit carefully, particularly the oil channels for the engine block and crankshaft.

3. Inspect the parts. Check the dimensions, roundness, hardness, roughness, and cylindricity of the blind bores and crank pins (surface, radii, and oil outlet bores). Inspect the parts for damage, too.

   Check the connecting rods to make sure they are not bent or distorted.

   Always refer to the relevant specifications and data provided by the engine manufacturer.

4. The shape of the housing bore has a significant influence on the service life of the bearings. That's why the housing bore may be machined only after the bolts have been tightened—in line with the engine manufacturer's tightening torque specifications.

   Before final installation—carry out a test installation, if necessary—clean the blind bores and remove the protective coating on the new bearings. To prevent damage caused by a dry start-up, lubricate the running surfaces with clean engine oil when installing the bearings.

   When using bearing pairs made of different materials, ensure that they are installed correctly. The markings "upper" or "lower" can be seen on the backs of these bearings. The bearing half marked "upper" must be installed at the top of the housing; the half marked "lower" must be fitted on the cap at the bottom.

   Once the bearings have been correctly positioned, tighten the cap bolts in accordance with the specification. The bearing bore diameters must then be measured precisely in three measuring planes, one of which must be in the load direction.

5. Before installing the thrust bearing, check the difference in dimensions between the width of the crankshaft side wall and the overall width of the thrust bearing.

   During assembly, test whether the crankshaft can be turned easily and without jerking. Check the axial movement of the crankshaft, too.

   When checking the axial clearance of the connecting rod, ensure that the connecting rod can be moved easily.

   Always refer to the specifications and data provided by the relevant engine manufacturer.

6.1 Score marks and foreign objects in the running surface of bearings

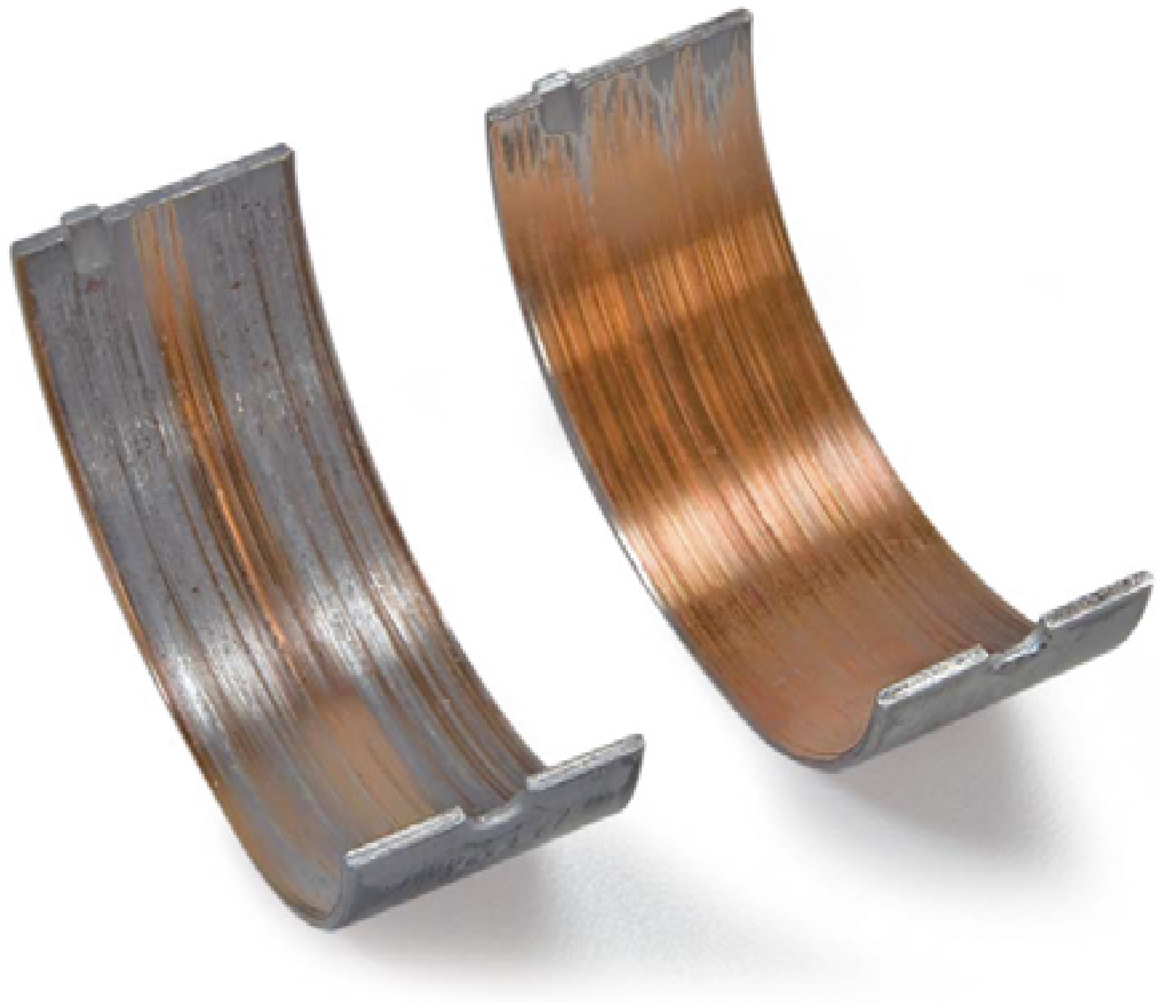


Fig. 1: Deep circumferential score marks

Findings:

There are circumferential score marks in the running surface of the bearings and foreign objects are embedded in the bearing material (Fig. 1).

Cause(s):

This damage scenario is caused by foreign objects in the oil. These objects may have entered the oil circuit for the following reasons:

- Foreign objects have entered the engine as work was done on the vehicle.
- Contaminants have penetrated via the intake system or the crankcase ventilation.
- Other engine components have produced abrasion particles or chips.
- The vehicle has been inadequately maintained, e.g., poor quality filters and/or oil have been used or inspection intervals have been too long.
- Frequent short-distance journeys mean that the diesel particulate filter's (DPF) regeneration cycle is often interrupted. This causes unburned fuel to accumulate in the engine oil. Fuel is diluting the oil, reducing its carrying capacity and lubricity.

Remedies/avoidance:

- Take care to ensure cleanliness when repairing or assembling the engine.
- Only use high-quality filters.
- Clean or replace the oil mist separator.
- Carry out vehicle maintenance at regular intervals and in accordance with manufacturer specifications.
- Diesel vehicles in particular should be driven longer distances regularly so that the regeneration of the DPF can be completed.

6.2 Localized wear on the running surface of bearings

Fig. 1: Signs of wear in the center of a bearing

Fig. 2: Impression of a foreign object on the outer surface of a bearing

Findings:

- There are localized signs of wear on the running surface of the bearing (Fig. 1).
- There may also be impressions on the outer surface of the bearing (Fig. 2).

Cause(s):

- There are foreign objects or dirt between the bearing and the bearing seat.
- The machining is inadequate or the oil feeder bores on the crankshaft have not been deburred properly.

Remedies/avoidance:

- Take care to ensure cleanliness when mounting bearings. Clean bearings with a leather cloth before installation.
- Always carefully deburr the oil feeder bores after grinding the crank journals.

6.3 Significant signs of wear around the joint face of bearings

Fig. 1a: Wear on the running surface near the joint face of the bearing

Fig. 1b: Close-up

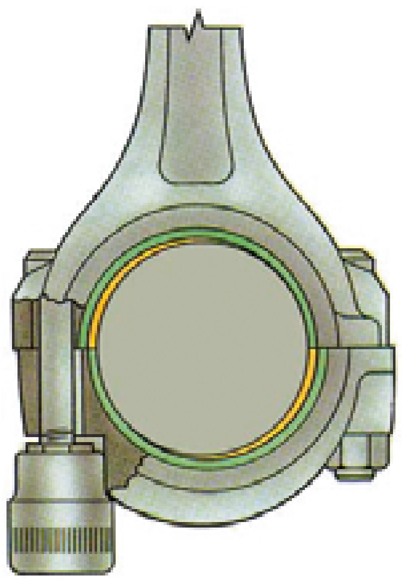


Fig. 2: Misaligned bearing cap

Findings:

There are significant signs of wear in the area around the joint face of the bearing (Fig. 1a & b).

Cause(s):

The following assembly errors are responsible for this wear:

- The bearing cap is out of alignment (Fig. 2). This can happen if, for example, the diameter of the wrench socket used for tightening is too large. It is also possible that incorrect fitting sleeves/adjusting pins have been used, the bearing bolts have been tightened with the wrong tightening torque, or the bolts have been overstretched.
- The bearing cap has been reversed or twisted, and the cap and cylinder may not have been paired correctly.
- When reworking the bearing caps, the bore diameters were machined too small.
- A used connecting rod with an oval end bore has been installed without the necessary rework being carried out on the big end bore.

Remedies/avoidance:

- Only tighten bolts with appropriate tools. A socket with an excessively large outer diameter will push the bearing cap to the side, causing the location hole for the bearing to become out-of-round.
- Apply the correct tightening torque to the bearing bolts.
- Replace antifatigue bolts in accordance with manufacturer specifications.
- Ensure that the bearing cap and cylinder are paired correctly.
- Check the bearing gallery and rework it if necessary.

6.4 Polished areas, run marks, or corrosion on the outer surface of bearings

Fig. 1: Polished areas on the outer surface of bearings

Findings:

- On the outer surface of the bearing, there are polished areas and/or run marks around the circumference and/or corrosion grains (Fig. 1).

Cause(s):

- Dirt is trapped in the joint face of the bearing seat, which means that the bearing bushings have too much play.
- The bearing cap bolts have not been sufficiently tightened.

Remedies/avoidance:

- Take care to ensure cleanliness when mounting bearings. Clean the bearings and the joint face of the bearing seat with a leather cloth before installation.
- Check the bearing cap bolts in accordance with manufacturer specifications and replace them if necessary.
- Tighten the bearing cap bolts in accordance with manufacturer specifications (tightening torque, angle of rotation).
- In the event of a fracture-split connecting rod and a cracked main bearing cap, clean the fracture surfaces thoroughly before assembly. If there are any foreign objects or oil in the fracture structure, it will not be possible to tighten the bearing cap properly.

6.5 Abrasion or damage to the outer edges of bearings

Fig. 1: Worn outer edges of bearings

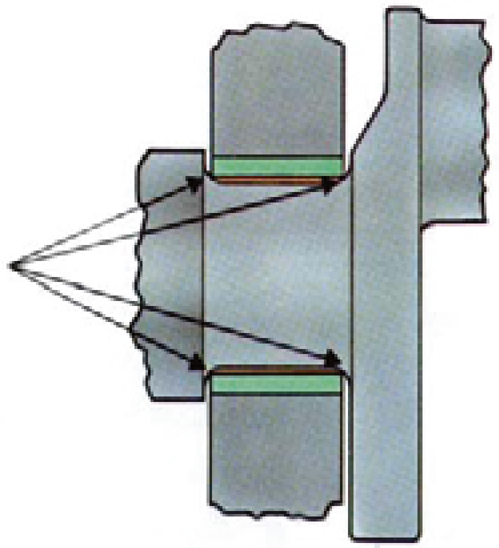


Fig. 2: Excessive radius on the bearing journals

Findings:

The outer edges of the bearings are severely worn (Fig. 1).

Cause(s):

This damage scenario is caused by a machining defect in the crankshaft. The corner radius of the bearing journals on the crankshaft is too large. The outer edges of the bearing bushings suffer wear on this radius (Fig. 2).

Remedies/avoidance:

- Rework the bearing journals to the dimensions specified by the manufacturer.
- During installation, make sure that the bearing bushings are seated correctly.
- To grind the bearing journals, the grinding wheel of the crankshaft grinding machine must be honed at regular intervals using a diamond tool.

6.6 Heavy wear on all main bearing bushings

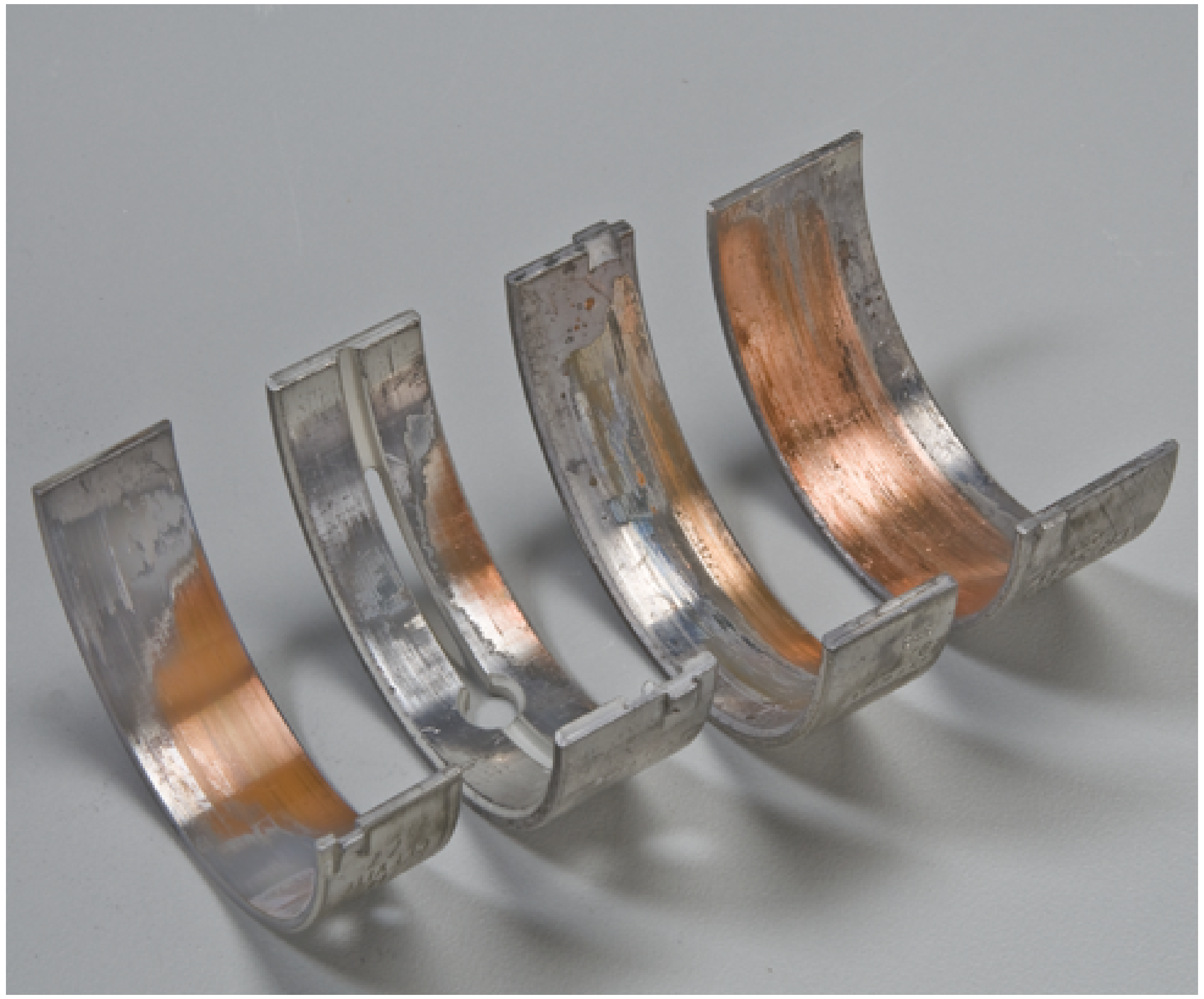


Fig. 1: Deep circumferential score marks

Findings:

There are clear signs of wear on all main bearings (Fig. 1).

Cause(s):

This damage scenario is due to a geometry defect originating in either the main bearing gallery or a bent crankshaft. These geometry defects mean that the bearings are subjected to forces for which they are not designed. This results in increased wear on all main bearing bushings. The geometry defects may have the following causes:

Geometry defects in the main bearing gallery:

- An excessively high engine temperature, e.g., due to insufficient coolant, can cause permanent distortion in the crankcase, leading to distortions in the main bearing gallery (see also section "2.2.1 Piston seizure on thrust and antithrust sides," page 38).
- Distortion can also be due to tightening cylinder head bolts or bearing bolts using the incorrect torque.

Bent crankshaft:

- The crankshaft has been aligned incorrectly prior to reassembly.
- A mechanical overload has occurred, e.g., piston seizure.
- The torque loading on the crankshaft was too great.

Remedies/avoidance:

- Ensure that the engine is cooled sufficiently (coolant, oil, cooling oil nozzles, thermostat, fan).
- Check or replace bolts in accordance with manufacturer specifications.
- Tighten all bolts in accordance with manufacturer specifications. Follow the recommended sequence.
- Check that the crankshaft is precisely aligned or replaced before installation.

6.7 Uneven wear pattern on bearings

Fig. 1: Uneven wear on the bearing bushings, bearing layer partially removed

Fig. 2: Uneven wear on the bearing bushings

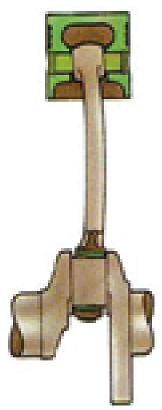


Fig. 3: Bent connecting rod

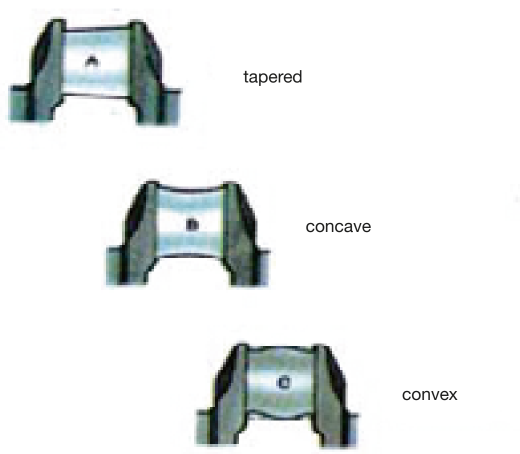


Fig. 4: Irregularly shaped bearing journals

Findings:

Uneven wear patterns can be seen on one or multiple bearings—either only on the edge or only in the center of the bearing bushing (Fig. 1 & 2).

Cause(s):

This damage scenario is due to geometric deviations in the connecting rod and/or the crank pins. These deviations create high surface pressures, either in the center of the bearing or on the outer edges, leading to an uneven wear pattern on the bearing bushings. This may be the result of the following:

- The connecting rod has bent due to hydraulic lock (Fig. 3; see also section “1.3 Hydraulic lock,” page 10).
- The connecting rod has not been angled correctly before installation.
- The bearing journals have not been reworked properly, i.e., the surfaces are either convex, tapered, or concave (Fig. 4).

Remedies/avoidance:

- Before installation, always check that the connecting rods are at the correct angle and align them if necessary.
- Grind the bearing journals cylindrically.

6.8 Seizure marks on bearings

Fig. 1: Glossy spots on the running surfaces of the bearing bushings

Fig. 2: Severely worn and spun bearing

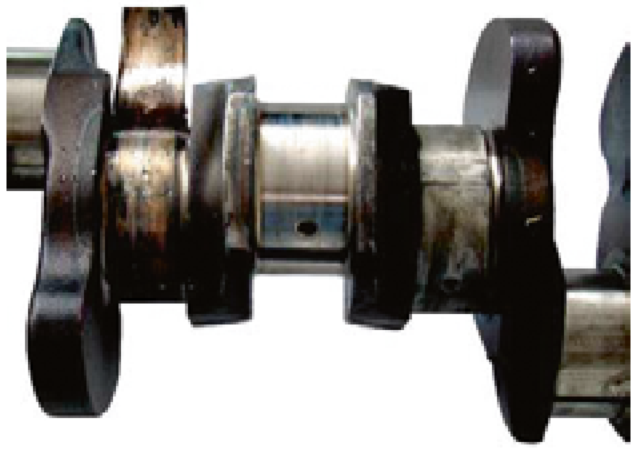


Fig. 3: Bearings welded to the crankshaft

Fig. 4: Incorrectly installed bearing—impressions of the oil feeder bores on the outer surface

Findings:

There are various stages to this form of bearing damage:

- The first signs are very shiny areas on the bearing (Fig. 1).
- During sustained operation with inadequate lubrication, the bearings take on a bluish tinge, then turn black (Fig. 2).
- In extreme cases, the bearing overlay can melt (Fig. 3) and the bearing can weld to the bearing journal.

Cause(s):

The bearing damage described here is due to inadequate lubrication. In this damage scenario, it is important to determine whether just one bearing or all of them are damaged.

One bearing is damaged:

- One half of the bearing has oil feeder bores, the other does not. If these bearing bushings are installed the wrong way round, the oil feeder bore (Fig. 4) in the bearing seat will be blocked and no oil will be able to get into the bearing.
- If the main bearing is inserted the wrong way round, the connecting rod bearing, which should be supplied with oil from this connecting rod bearing, will be affected by the lack of lubrication first.
- Blocked oil feeder bores lead to inadequate lubrication. Especially when using biofuels, there is a risk of the oil gelling and clogging the oil feeder bores.
- The bolts were not tightened correctly (not tight enough) at one of the bearing points. The resulting increase in play leads to overloading of the oil film.

All bearings are damaged:

- If all the bearings have seized, there must be a general lack of oil (see also section "1.4 Increased oil consumption," page 12). This has many possible causes, e.g.,
  - a defective or leaky oil pump or a fault in the pressure control valve,
  - a leak in the oil line system,
  - insufficient oil,
  - the vehicle is inclined at too great an angle, or
  - the oil has been diluted by fuel or coolant.

Remedies/avoidance:

- Install the bearings in accordance with the specifications. Ensure that the oil feeder bores in the bearing and the oil feeder bores in the engine are correctly aligned.
- Change the oil and filters regularly in accordance with the manufacturer specifications—especially when using biofuels, as much shorter intervals are needed.
- Check the oil level and add more if necessary.
- Antifatigue bolts on the connecting rod and main bearing caps may only be used once and must be replaced. Refer to manufacturer specifications.
- Diesel vehicles in particular should be driven longer distances regularly so that the regeneration of the DPF can be completed and unburned fuel does not accumulate in the oil.
- If there is coolant in the oil, drain the cooling system and check the head gasket and oil cooler.

6.9 Pitting of material from the bearing layer of bearings

Fig. 1: Pitting of material caused by mechanical overload or an oil film with insufficient load-carrying capacity

Findings:

Pitting of material can be seen in some areas of the bearing layer of the bearing (Fig. 1).

Cause(s):

This pitting of material is caused by material fatigue in the bearing material, which can in turn result from the following factors:

- The connecting rod has not been angled correctly before installation.
- The bearing journals have not been reworked properly, i.e., the surfaces are either convex, tapered, or concave.
- The bearing has been overloaded due to tuning.
- The lubricity of the engine oil has been reduced due to contamination with fuel or coolant (see also section "2.2.2 Piston seizure on one side," page 40).
- Low-grade engine oil or oil with insufficient viscosity has been used.

Remedies/avoidance:

- Before installation, always check that the connecting rods are at the correct angle and align them if necessary.
- Grind the bearing journals cylindrically.
- If the oil is diluted, perform an oil change immediately and identify and rectify the cause.
- Use engine oils approved by the vehicle manufacturer.

6.10 Porous bearing layer on bearings

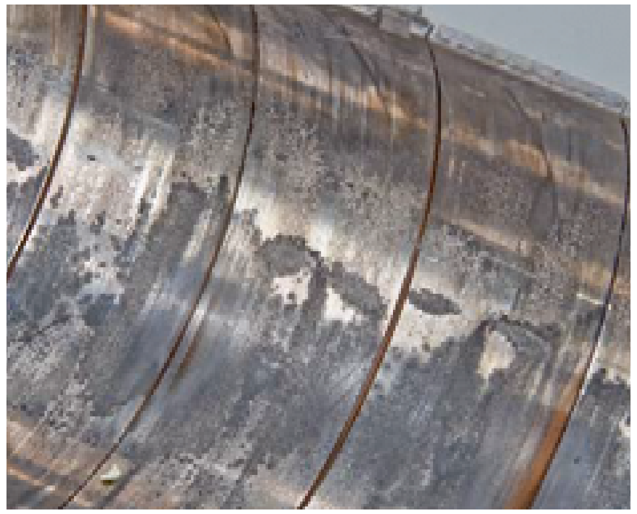


Fig. 1a: Bearing layer burned by chemically aggressive substances in the oil

Fig. 1b: The eroded bearing material is clearly visible in this close-up

Fig. 2: Damaged connecting rod bushing

Findings:

The bearing layer of the bearing is dark in color and has porous patches (Fig. 1 & 2).

Cause(s):

The damage described here can be attributed to chemical burns, which may result from the following circumstances:

- Above a certain concentration, chemical constituents in the engine oil, such as sulfur from low-grade fuels, can be aggressive.
- The engine oil has been acidified due to use with gas.
- The oil change intervals have been significantly exceeded.
- There are coolant residues in the engine oil.

Remedies/avoidance:

- Always perform oil changes in accordance with the manufacturer specifications.
- Check the cooling system regularly for leaks or coolant loss.
- If the presence of coolant in the engine oil is detected in good time, the cause (e.g., leaky oil cooler) must be rectified. Afterward, replace the filters and change the oil several times in quick succession to remove all traces of coolant from the oil circuit.
- Noting the correct oil change intervals and oil quality is especially important in engines fueled with gas.

Glossary

Term	Explanation
air compressor	Engine-driven compressor that produces compressed air for pneumatic systems in commercial vehicles.
air mass flow meter	Sensor in the air intake system that measures the intake air necessary for setting the optimum air–fuel mixture.
airflow rate	The quantity of air (unit of measurement: liters per hour) that flows through a medium (filters or lines).
angle of rotation	Angle at which antifatigue bolts are tightened in addition to a specific torque.
antifreeze	Coolant additive that changes the physical properties of the coolant, preventing the coolant from freezing and raising its boiling point. It also lubricates the coolant pump bearings and protects the engine from corrosion.
antithrust side	The side of the piston that is subjected to less load during the power stroke.
biodiesel	Unlike conventional diesel fuel, biodiesel is not derived from crude oil but from vegetable oils or animal fats.
biofuel	Fuel produced from biomass.
blowby gas	Combustion gas that leaks past the pistons and enters the crankcase.
boost pressure	Pressure downstream of the compressor/turbocharger. As boost pressure increases, so does the air mass supplied to the engine and with it the engine torque or engine performance, while the air–fuel mixture remains constant.
cetane rating	A measure of the ignition characteristics of diesel fuels. The higher the cetane rating, the more readily the fuel ignites.
circlip	Ring made of spring steel used to hold the piston pin in the pin bore.
cold start enrichment	Enrichment of the air–fuel mixture with fuel. Cold engines require a richer air–fuel mixture to run smoothly.
contact alternation (pistons)	When the piston switches from the thrust side to the antithrust side and vice versa at top dead center and bottom dead center.
cooling oil nozzle	Curved tube that ensures that the permissible temperature level is maintained by selectively injecting engine oil from the oil circuit into the interior of the piston. In pistons with a cooling gallery, engine oil is injected into the annular channel for improved cooling of the piston.
dead center	Position of the piston in the cylinder: highest position = top dead center (TDC), lowest position = bottom dead center (BDC).
erosion	Damage to component surfaces caused by liquids or hot gases.
excess air	Air that enters the system where there is a leak.
fan	Propeller that blows fresh air at the radiator. The fan is driven mechanically by the engine via a Visco® clutch or via a separate electric motor.
fatigue fracture	A fracture in a component caused by stress due to cyclic loading.
fixed-pin connecting rod	Connecting rod used to clamp the piston pin in the small end bore. This means that no circlips are required to fix the piston pin in the piston.
forced fracture	Fracture in a component caused by a single violent overload event.
fuel delivery rate	Amount of fuel injected in diesel engines.
gap clearance	Gap between the ends of a piston ring when installed.
gap width	Measurement between the top of the piston (piston at top dead center) and cylinder head.
gelling (engine oil)	When molecule chains in engine oil bond together, causing it to suddenly become viscous. This can happen if the oil change intervals are not adjusted when a diesel engine is run on vegetable oils.

Glossary

Term	Explanation
granules	Small hygroscopic beads in an air drier that remove moisture from the air.
heat rating	The heat rating of a spark plug indicates its thermal load capacity.
honing	Process of machining cylinders by combining the rotary and axial motions of a grinding tool. The resulting cross-hatch finish improves the tribological properties of the cylinder surface.
honing stones	Grinding tool (abrasive strips) used to execute the honing process.
ignition timing	Position of the crankshaft at which the air–fuel mixture in a gasoline engine is ignited by the spark plug.
lambda sensor	Sensor in the exhaust system of an internal combustion engine fitted with a catalytic converter. It is used to measure the proportion of residual oxygen in the exhaust gas in order to determine the rate of combustion of the air–fuel mixture.
load-carrying capacity	Stability of the oil film.
machining profile	Piston skirt profile precisely engineered to optimize tribological conditions.
material fatigue	Damage to the material due to prolonged mechanical overload.
mounting clearance	Dimensional difference between the largest piston diameter and cylinder diameter at 20°C. Any graphite coating on the piston is not taken into account.
octane rating	A measure of a gasoline fuel's knock resistance (tendency to autoignite). The higher the octane rating, the higher the knock resistance of the gasoline fuel.
overspeed	Rotational speed above the permissible range. Overspeed can occur, for example, when engaging the clutch after shifting into a gear that is too low.
piston protrusion/recess	Describes the position of the piston relative to the cylinder block sealing surface at top dead center. If the piston sits proud of the block sealing surface, this is known as protrusion. If the piston is set back from the block sealing surface, this is known as recess.
piston seizure	Damage caused by the piston and cylinder rubbing against each other for too long without lubrication or with excessive contact pressure.
pitting	Particles detached from the piston material, which reattach to and coat the piston elsewhere.
polymerization	When molecule chains in engine oil bond together, causing it to suddenly become viscous.
pressure control valve (oil pump)	Valve that prevents pressure peaks or general overpressure in the oil circuit by returning oil from the oil pump directly to the oil pan.
regeneration phase	The phase in which the granules in the air drier are dehumidified with a backflow of dry air from the compressed air tank into the air drier. The regeneration phase is initiated by control valves.
removal tool	Tool for unscrewing spin-on filters or oil filter covers. MAHLE identification code: OCS. The tool may only be used for removing filters, not for screwing them on (risk of damaging the corrosion protection).
seizure, seizure mark	Damage caused by two moving metal parts rubbing against each other for too long without lubrication or with excessive contact pressure.
smeared metal layer	Compressed material produced during honing due to worn or clogged honing stones, which can lead to increased oil consumption.
start of fuel delivery	Start of fuel injection at a specified crank angle before top dead center of the piston in diesel engines.
sulfurous fuel	Diesel fuel containing more than 0.5% sulfur. When sulfur burns, aggressive compounds form and accumulate in the engine oil, causing damage to components. As a result, oil change intervals must be shortened accordingly.
TDC sensor	Sensor for determining the position of the piston in the engine. The data from this sensor is required by the electronic control unit.

Glossary

Term	Explanation
thermostat	Control valve in the coolant circuit. During the warm-up phase, the coolant only circulates in the engine. In a warm engine, all the coolant circulates through the radiator.
thrust side	Contact side of the piston during the power stroke.
tightening torque specifications	The engine manufacturers specify the sequence, torque, and angle of rotation that must be used when tightening antifatigue bolts.
tribological system	Friction and lubrication ratio in the engine.
tuning	Method of increasing engine performance.
use with gas	When an internal combustion engine runs primarily on gas (usually LPG, natural gas, or fermentation gases).
valve collet	Collet required to secure valves.
valve depth	Distance between the end face of the cylinder head and the valves.
valve timing	Synchronization between the valve train and the crankshaft position.
Visco® clutch	The fan speed of the Visco® clutch regulates engine cooling. The fan speed varies depending on the engine load.

Our product portfolio

Engine components
Quality built to last—precise fit and long life

- Pistons
- Piston rings
- Cylinder liners
- Bearings
- Valve train components
- Assemblies
- Turbochargers
- Controlled oil pumps
- Intake modules with flap control
- Oil mist separators

Gaskets
Gasket range available worldwide for over one million applications

- Oil seals
- Cylinder head bolts
- Sealants

Filters
Our filter range—a clean solution

- Air filters
- Oil filters
- Oil filter modules
- Fuel filters
- Cabin filters
- Air drier cartridges
- Transmission oil filters
- Urea filters
- CleanLine filters

Engine cooling & air conditioning
Comfort you can feel—now and in the future

- Radiators, charge air coolers
- Fans & clutches, condenser/radiator fans
- Expansion tanks, cabin heat exchangers
- Exhaust gas recirculation coolers, oil coolers
- E-water pumps
- Thermostats, thermal switches
- A/C compressors, A/C compressor oils
- A/C condensers, filter-driers, and accumulators
- Evaporators, expansion valves, and orifice tubes
- Interior blowers, A/C switches
- A/C blower control units and resistors, electric controls for blending flaps
- Sensors

Starter motors & alternators
Powerful and efficient—for the perfect start

- Starter motors
- Alternators

E-mobility & electronics
Innovative solutions—for the mobility of the future

- Actuators & switches
- High-performance electronics
- Various sensors
- Electric drive systems

Workshop equipment & diagnostics
Efficient solutions—for maintenance and service

- TechPRO® **diagnostics**
- **TechPRO**® Digital ADAS
- ArcticPRO® **A/C service**
- FluidPRO® **automatic transmission flushing**
- NitroPRO® **nitrogen tire inflation**
- **EmissionPRO**® emissions testing measuring instrument
- **LogiqPRO**® software tool
- **OzonePRO**® cleaning system
- **RemotePRO**® remote diagnostics
- **BatteryPRO**® electric vehicle battery diagnostics

Our information services

- **Technical Messenger**
  Valuable technical information and the latest tips on all aspects of the maintenance and repair of MAHLE products (see under “Services” on our website)
- **Technical posters**
- **Damage brochures**
- **Installation videos and animations**
- **Refrigerant and A/C compressor oil filling quantities manual**
  mahle-aftermarket.com/filling-quantities/
- **Training portal**
  training.mahle.com
- **TechTool**
  techtool.mahle.com
- **MAHLE Insider newsletter**
  mahle-aftermarket.com/mahle-insider

Do you have technical questions? We’re happy to help:

Technical Hotline: +49 1806 115599*
E-mail: product.support@mahle.com
Monday to Friday, 08:00–12:30 and 13:00–17:00

*From Germany: EUR 0.20 per call from a landline, max EUR 0.60 per call from a cell phone (charges from other countries may vary)

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