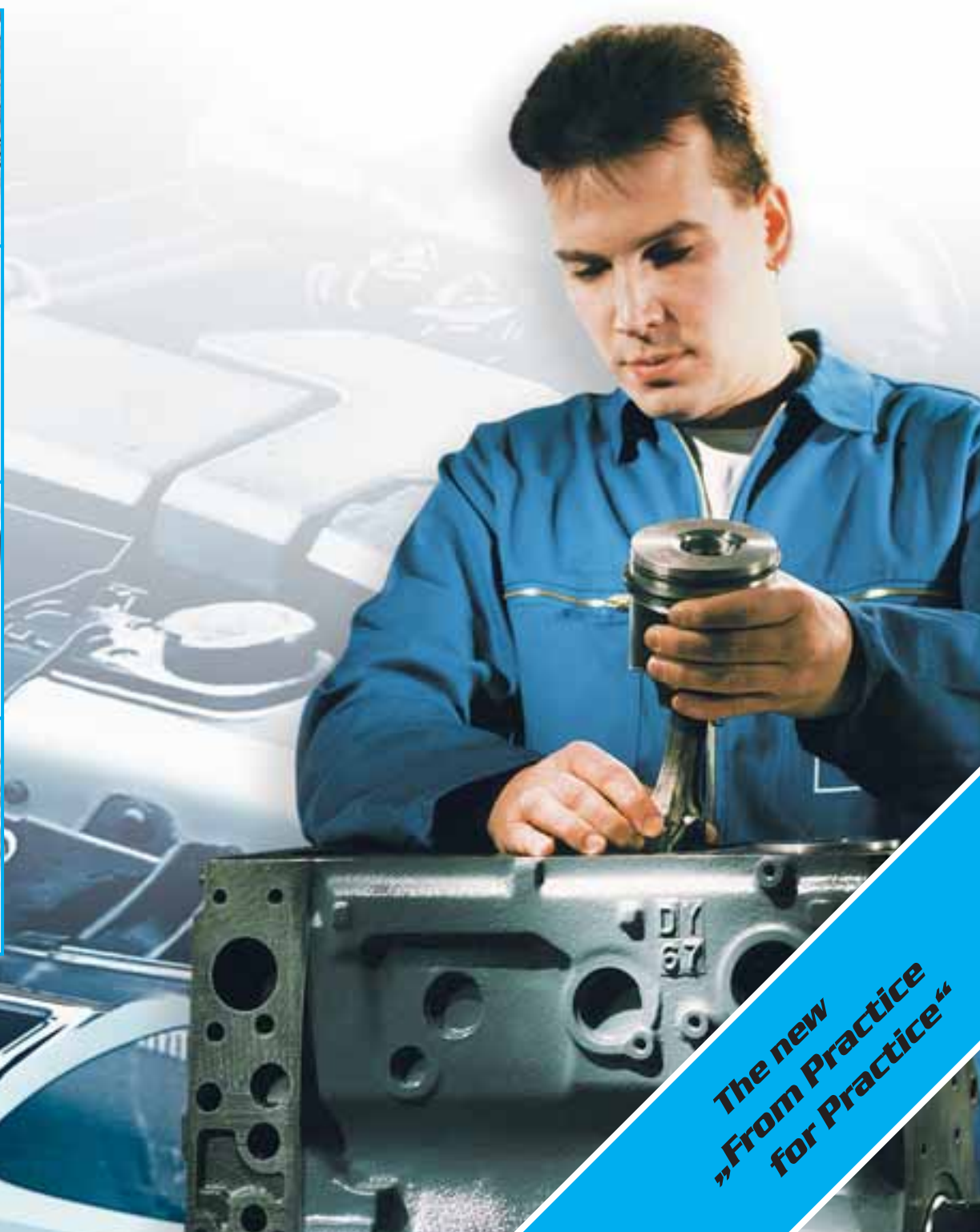




Piston damages

Recognising and rectifying



**The new
"From Practice
for Practice"**

Piston damages

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1 Introduction

1.1 Preface

The requirements placed on the internal combustion have continuously changed throughout the history of its development. Although modern car manufacturers try to attract buyers with the latest improvements in terms of power output per litre, output torque, low fuel consumption and compliance with the newest exhaust emission standards, the primary concern of engine manufacturers has always been the durability and service life of the engines.

Since the fuel crisis in the 1970s, awareness has risen for the need to improve fuel economy, driving developments to reduce fuel consumption. As a result, the first fuel-injected petrol vehicles were introduced into series production, reducing fuel consumption and improving engine performance in the process.

Concerns for the environment became paramount in the 1980s. It was during this time that the most fundamental changes were made to the mixture formation process and the exhaust emission treatment. The use of catalytic converters for emission control and exhaust emission treatment on petrol engines meant that the mixture formation process needed to be made much more accurate and controllable. Existing fuel-injection systems were modified in order to comply with the increasingly strict emissions regulations, and were then expanded to include lambda control systems. This finally meant the end of the road for carburettors, as there was no way that they could fulfil the more stringent regulations. Although in the past the mixture formation process on diesel engines mostly utilised indirect injection techniques with mechanical

fuel-injection pumps, today's diesel engines are equipped with direct injection systems with electronically controlled high-pressure fuel injection and turbocharging systems.

Another important development also dates back to the 1980s. With the increase in mobility and the associated increase in annual mileage covered by vehicles, it was inevitable that there would be a demand for longer service intervals. In order to ensure that the engines continued to operate safely and reliably between service intervals and to protect the sensitive catalytic converters against contamination with oil, it was necessary to reduce the engine's consumption of oil and to adapt the quality of the engine oil to meet the increased requirements.

As part of these developments, the internal workings of the engines have also been further developed and modified on a continuous basis. Production processes in engine construction have been optimised, and production tolerances and the weight of the components have been lowered, whilst the quality of materials has been steadily improved. The shapes of the combustion chambers and the paths through which the combustion gases flow have been optimised in order to minimise fuel consumption and emissions.

Despite such substantial changes to the design of the engine, the types of damage which can be observed on the pistons and cylinders have stayed remarkably similar. It is still the case that the main causes for engine damage are malfunctions, irregularities or excessive loads of a thermal or mechanical nature. The results are

damages to those parts of the engine which are subjected to the increased loads, in a particular the pistons.

The aim of this brochure is to provide the interested reader with an overview of the different types of damages that can be encountered in the innermost part of an internal combustion engine, as well as to provide a useful tool for specialists which will help to diagnose faults and determine their causes. The process of assessing engine damage is similar to a medical assessment in that it requires an all-encompassing approach to identify the cause(s) of a problem, which may not always be clear and obvious. It is not at all a rare occurrence for repairs to be carried out and then for the same damage to occur again and the same components to fail again because, although the damaged parts were replaced, nothing was done to eliminate the cause of the problem. For this reason a certain amount of "detective work" is always needed to track down the fault. In many cases the engineer is presented with just a faulty component, with no information about how long the component was in service before it failed, or what the extent of the damage is. Naturally this makes it difficult to retrace how the fault happened, and the resulting diagnosis invariably offers a general, non damage-specific conclusion.

All of the types of damages covered in this new, fully revised edition have been put together with the utmost care and brought right up to date. It should provide you with a comprehensive source of information which will assist you in either your work or your studies.

1.2 Notes on using this brochure

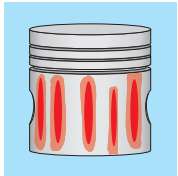


Fig. 1

Recognising damage is not always a straightforward task. In many cases the damage can be hard to make out in the photographs, or it may not be immediately obvious that any damage is present. This is why in addition to the photographs showing the damage you will also see damage pictograms like the one opposite (Fig. 1). These will help you to recognise and identify the damage on the photographs more easily. These pictograms do not show the damage on a 1:1 scale. The pictograms are merely intended to serve as examples, in some cases with useful additional information.

The quick diagnosis pages are also new in this brochure. The aim of these

pages is help you to locate and assign the damage quickly. Here you will also find the above-mentioned damage pictograms which can be used as the basis for assigning faults to their causes, or for making at least a preliminary decision about what type of damage might be present.

In some cases there are several different pictograms for the same damage. If for example damage has occurred and left behind characteristic traces on the piston and on the running surface of the liner, then there may be two pictograms for this damage with both of the relevant components and their characteristic damage patterns.

A glossary has been included as an appendix with this brochure. This contains the key specialist terms used in the brochure, together with appropriate explanations.

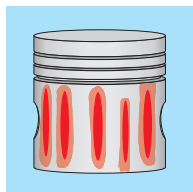
A list of the tools recommended by MSI Motor Service International GmbH and overviews of other available brochures and the MSI training programme completes this edition.

We hope that this brochure will provide you with valuable information and not only help you to determine the cause of existing damage, but also to prevent future damage.

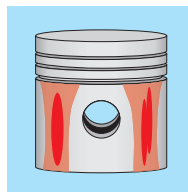
MSI Motor Service International GmbH



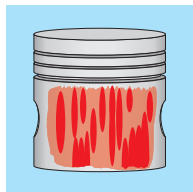
PISTON SKIRT SEIZING



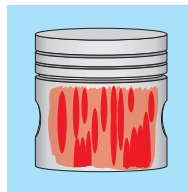
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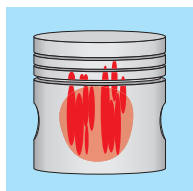
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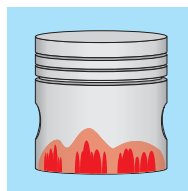
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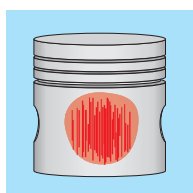
Seizure due to overheating centered around the piston skirt..... 26



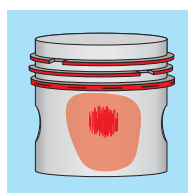
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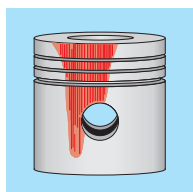
Dry running damage due to lack of lubrication caused by fuel flooding.... 20



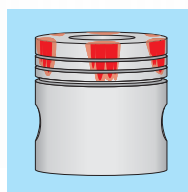
Wear on pistons, piston rings and cylinder running surfaces caused by fuel flooding (increased oil consumption) 80



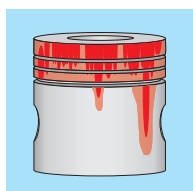
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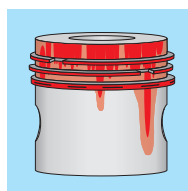
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Piston top land seizure due to the use of incorrect pistons (diesel engine) 42



Seizure due to overheating centered around the piston top land 25



Seizure due to lack of lubrication caused by scuffed piston rings..... 22

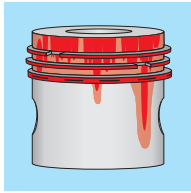




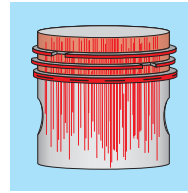
Piston damages

QUICK DIAGNOSIS

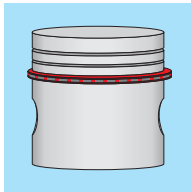
PISTON RING DAMAGES



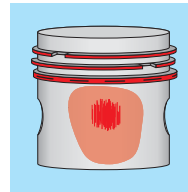
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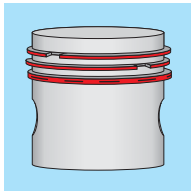
Wear on pistons, piston rings and cylinder running surfaces caused by the ingress of dirt (increased oil consumption) 78



Incorrectly installed oil scraper ring (increased oil consumption after engine repairs) 77



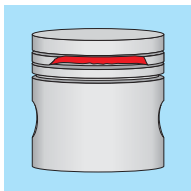
Wear on pistons, piston rings and cylinder running surfaces caused by fuel flooding (increased oil consumption) 80



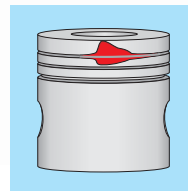
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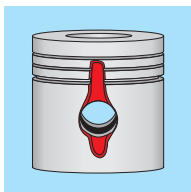
FURTHER DAMAGES IN THE RING AND SKIRT PANEL



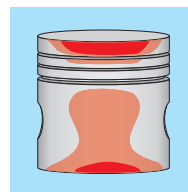
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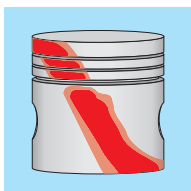
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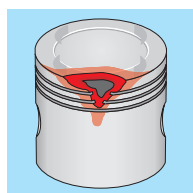
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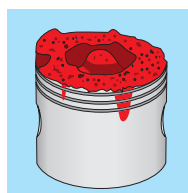
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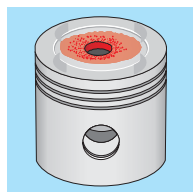
PISTON HEAD DAMAGES



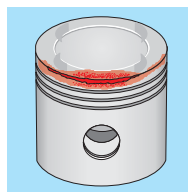
Removal of material by melting from the piston crown and ring zone (gasoline/petrol engine) 31



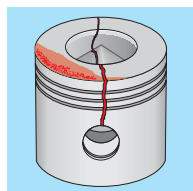
Material removal/fusion due to melting on the piston crown (diesel engine) 32



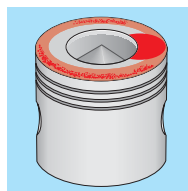
Hole in the piston crown (gasoline/petrol engine) 40



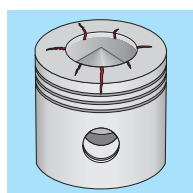
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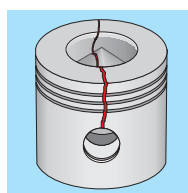
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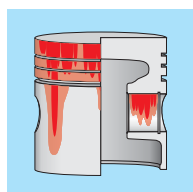


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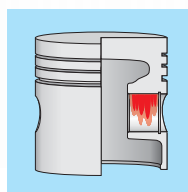


Piston fracture in the piston pin boss . 47

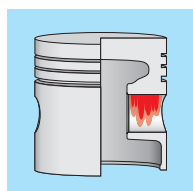
PISTON PIN SEIZING & PISTON PIN FRACTURES



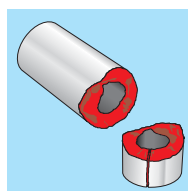
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Seizure in the piston pin bore (floating-fit piston pin) 59



Seizure in the piston pin bore (shrink-fit connecting rod) 60



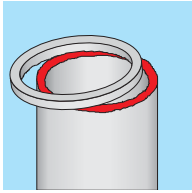
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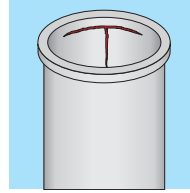
Piston damages

QUICK DIAGNOSIS

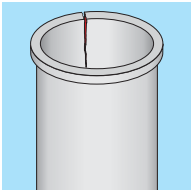
CYLINDER DAMAGES



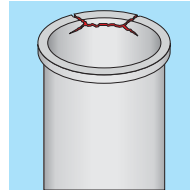
Torn off flange on the cylinder liner 66



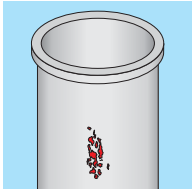
Torn off flange on the cylinder liner 66



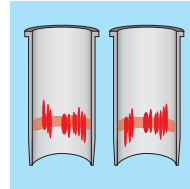
Longitudinal cylinder liner cracks 65



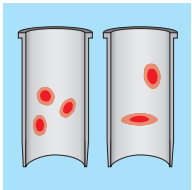
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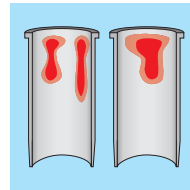
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Detailed descriptions of the different types of damages



3.1 Seizure due to insufficient clearances

3.1.0 General information about seizures due to insufficient clearances

In engine operation, the clearance between the piston and the cylinder may become reduced beyond permissible limits or even completely decimated as a result of incorrect dimensioning of the two sides, after cylinder distortion or after excessive thermal loads. In addition, the piston reaches much higher temperatures than the cylinder during engine operation, resulting in different thermal expansion behaviour of the piston and the cylinder. The thermal expansion of the piston is far greater than the cylinder which encloses it. In addition, the thermal expansion of aluminium materials is approximately twice that of grey cast iron, which needs to be taken into account accordingly at the design stage.

As the clearance between the piston and the cylinder starts to decrease, mixed friction occurs as a result of the oil film on the cylinder wall being forced away by the expanding piston. The initial result of this is that the load-bearing surfaces on the piston skirt are rubbed to a highly polished finish. The temperatures of the components increase further due to the mixed friction and the resulting frictional heat. In the process, the piston presses with increasing force against the cylinder wall and the oil film completely stops doing its job. The piston then starts to run dry in the cylinder, resulting in the first areas to show signs of wear due to rubbing, with dark discoloration on the surface.

In summary, seizure due to insufficient clearances is typified by the following main characteristics: highly polished pressure points which change gradually into darkly discoloured areas of wear due to rubbing. In the case of seizures due to insufficient clearances, the seizure points can be seen on both the pressure side and on the counterpressure side.



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

3.1.1 Seizure on the piston skirt due to insufficient clearance

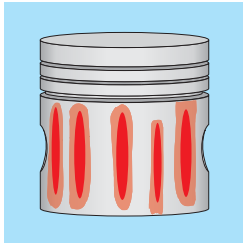


Fig. 1

Description of the damage

Around the skirt of the piston there are several different areas of seizure marks which are all identical in nature.

The seizure marks can be found on both the pressure side and on the counterpressure side, i.e. there are corresponding counter-seizure marks on one side of the piston to match the seizure marks on the other. The surface of the seizures gradually changes from highly polished pressure areas to darkly discoloured areas of wear caused by rubbing. The ring zone is undamaged.

Damage assessment

The clearance between the piston skirt and the running surface of the cylinder was either too narrow by design, or it was restricted beyond

acceptable limits by distortion which possibly did not occur until the engine was taken into normal operation.

Note:

In contrast to seizure caused by lack of lubrication, seizure due to insufficient clearances always occurs after a brief running-in period after an engine overhaul.

Possible causes for the damage

- Cylinder bore too small
- Cylinder head overtightened or tightened unevenly (cylinder head distortion)
- Uneven sealing surface on the cylinder or on the cylinder head
- Dirty or distorted threads in the threaded bores or on the cylinder head bolts
- Seized or insufficiently lubricated bolt head contact surfaces
- Use of incorrect or unsuitable cylinder head gaskets
- Cylinder head distortion caused by uneven heating due to deposits, dirt or other problems in the cooling system.

3.1.2 Seizure due to insufficient clearances next to the piston pin bores (45° seizure marks)

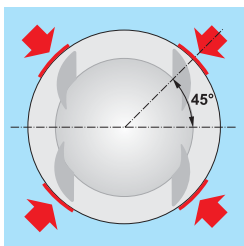
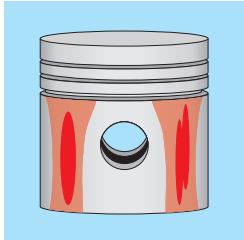


Fig. 1

Description of the damage

Seizure marks at an offset of approximately 45° to the piston pin axis which are found both on the pressure side and on the counterpressure side are characteristic of this type of damage. The surface at the seizures gradually changes from highly polished pressure areas to relatively smooth, darkly discoloured areas of wear caused by rubbing. The piston pin displays blue tempering colours; which indicates in this case that the piston pin bed must have become hot due to insufficient clearances or a lack of oil.



Fig. 2



Fig. 3



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Damage assessment

This damage is caused when the area around the piston pin heats up excessively. As this area of the piston is quite stiff, this causes an increased thermal expansion in the area and a restriction of the clearances be-

tween the piston and the cylinder running surface. The piston skirt is relatively thin-walled and therefore has a certain amount of flexibility which enables it to compensate for the increased thermal expansion.

However, at the transition to the more rigid piston pin bore the material then comes to bear with greater force on the cylinder wall, which ultimately causes the oil film to be forced out and the piston to rub.

Possible causes for the damage

- **Excessive load on the engine before it reaches operating temperature**

The piston can reach its full operating temperature after 20 seconds, whereas a cold cylinder can take a great deal longer. As a result of the different thermal expansion of the two components' material, the piston expands faster and further than the cylinder. The piston clearance is then significantly restricted and the damage described above occurs.

- **Excessively narrow fit of the piston pin in the small end of the connecting rod (shrink-fit connecting rod).**

An excessively tight fit of the piston pin in the connecting rod small end can cause the connecting rod small end and therefore also the piston pin to become out-of-round. The reason for this is the different wall thicknesses on the connecting rod small end. Whereas there is a lot more material and much thicker wall thickness in the direction of the big end rod, the wall thickness is much less at the top of the small end. The clearance in the piston pin boss becomes restricted if the piston pin is deformed. The resulting lack of clearance between the piston pin and the piston pin bore causes increased frictional heat and therefore greater thermal expansion in the affected area.

- **Seizure in the connecting rod small end due to insufficient lubrication when the engine was first taken into operation.**

The piston pin was either given insufficient lubrication or no lubrication at all when the engine was assembled. Before the oil can reach the bearing when the engine is first taken into operation, there is not enough lubrication and the piston pin bore surface seizes, causing additional heat to be generated in the process.

- **Incorrect assembly during the process of shrinking the piston pin (shrink-fit connecting rod)**

During the process of shrinking the piston pin into the connecting rod eye, it is also important that, in addition to the above-mentioned lubrication of the piston pin, piston pin and piston pin bore are not checked for freedom of movement immediately after installation by tipping the piston back and forth.

The temperatures are equalized immediately between the two components after the cool piston pin is inserted into the hot connecting rod. The piston pin can still become very hot as a result. It will then expand, and can become clamped in the piston pin bore, which in this stage is still cool. If the connection of the

two components is moved in this state, then it can cause initial rubbing marks or seizure marks which will cause subsequent stiffness of the bearing (and thus increased friction and heat generation) during operation. For this reason the assembled components should be allowed to cool off before checking that the bearing moves freely. ■

3.1.3 Seizure due to insufficient clearances at the lower end of the skirt

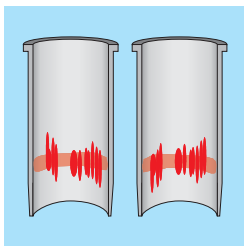
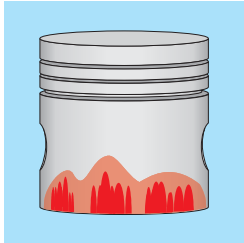


Fig. 1

Description of the damage

The piston displays typical seizure marks caused by insufficient clearances at the bottom end of the skirt, with pressure marks and counterpressure marks. The marks change from highly polished pressure points to smooth, darkly discoloured areas of wear caused by rubbing. (Fig. 1) There is nothing unusual about any of the remaining parts of the piston. The matching wet cylinder liner (Fig. 2) displays seizure marks of exactly the same nature in the lower part where the outer diameter is sealed with several sealing rings against water and oil in the crankcase.



Fig.2



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Damage assessment

As the seizure areas on both the piston and the cylinder liner display the characteristics of seizure caused by insufficient clearances, the clear-

ances in the lower area between the piston and the cylinder must have been restricted to such an extent by the distortion of the cylinder that the

oil film was forced out due to a lack of clearance.

Possible causes for the damage

- Incorrectly dimensioned or unsuitable liner sealing ring can distort a cylinder liner to the point of completely eliminating piston clearances. In order to ensure that there is enough space for the sealing rings to swell into, they should only take up approx. 70 % of the liner groove volume.
- Use of additional sealant with liner sealing ring.
One of the characteristics of the oil seals used for this purpose is that they swell up in operation following exposure to oil. This is an intended feature which is designed to ensure durable leak-tightness over longer periods of time. For this reason, no additional sealant must be used. This would cause the free space in the liner groove to become completely filled, and it would not be possible for the liner sealing ring to expand in operation.
- There were possibly leftovers from the old oil seals in the grooves for the sealing rings in the housing (see above).
- Sealing rings cannot offer a perfect seal if they twist the cylinder liner is inserted. Therefore they must always be coated with a sliding lubricant prior to installation of the cylinder liner.



3.2 Seizure due to lack of lubrication

3.2.0 General information about seizure due to lack of lubrication

Seizure due to lack of lubrication can occur generally, i.e. even if there is sufficient clearance between the cylinder and the piston. In the process the oil film breaks down (often only locally) because of the high temperatures

or because of flooding with fuel. In the areas affected in this way the surfaces of the piston, piston rings and cylinder running surface then run against each other without any lubrication, which in just a short time causes seizure

with a severely worn surface. A similar situation arises if there is a lack of oil, i.e. if there is no longer any lubricating film at all between the piston and the cylinder.

In summary, seizure due to lack of lubrication is typified by the following main characteristics:



a) If the oil film is destroyed altogether:

seamless areas of narrow seizure marks mainly on the piston skirt, showing a severely worn and darkly discoloured surface. In the early stages there are often no matching seizure marks on the opposite side of the piston.



b) If there is a lack of oil:

identical to the seizure marks due to lack of lubrication described above, apart from the discoloration of the surface. The surface of the seizure areas almost has a pure metallic finish, with no dark discoloration. As the lack of oil affects the entire surface of the cylinder, there are often seizure marks on both the pressure side and the counterpressure side, even in the early stages.



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

3.2.1 Seizure due to lack of lubrication on the piston skirt

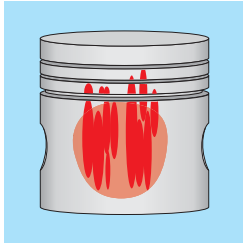


Fig. 1

Description of the damage

Seizure marks which in some cases extend into the ring zone are present in the running surface area where normally the wear pattern develops. Slight counter-seizure areas have occurred on the opposite side of the skirt. The surface of the seizure areas has no dark discoloration and almost has a pure metallic finish.

Damage assessment

There has been an acute lack of lubricant between the piston and the cylinder running surface. The fact that the surface of the seizure areas almost has a pure metallic finish indicates that the oil film was still present but significantly weakened at the time of

the seizure. Due to the limited extent of the damage, this may be evidence of a temporary lack of oil or the early stages of damage. The damage would have undoubtedly been even more serious if operation of the engine had continued with insufficient lubrication.

Note:

With this type of seizure due to lack of lubrication, the damage area on the piston is always located at the load-bearing points between the piston skirt and the cylinder, i.e. the points at which the normal wear pattern would have formed on an undamaged piston after running in.

Possible causes for the damage

- Lack of lubrication caused by lack of engine oil
- Oil pressure in the engine too low (oil pump, pressure relief valve etc.). As a result, not enough oil is available for lubrication. Not enough oil emerges at the crankshaft bearings.

This means that not enough lubricating oil is supplied to the running surfaces of the cylinder, which are primarily lubricated with splash oil and centrifugal oil from the crankshaft.



3.2.2 Piston skirt seizure on one side only without matching areas on the counterpressure side

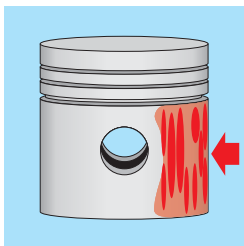
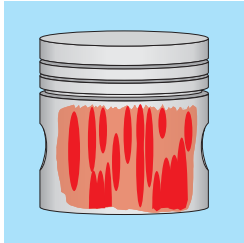


Fig. 1

Description of the damage

Darkly discoloured seizure areas with a severely worn surface are present on one side of the piston skirt. Due to the high temperatures on the piston (Fig. 1), large areas of piston material have been torn out from the surface of the piston skirt panel in the area of the seizure. The broken edge at the same height as the piston pin shows this clearly. In this scenario, it is completely typical for the side of the piston skirt opposite the seizure area to be completely free of damage, and the same applies in the early stages at least to the ring zone as well.



Fig. 2



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Damage assessment

This is a typical example of seizure due to lack of lubrication. This type of damage occurs when the lubricating film breaks down on just one half of the cylinder. The damage usually oc-

curs on the pressure side and is less common on the counterpressure side. It is caused either by a lack of lubrication within a locally confined area or by overheating of the affected side of

the cylinder. Lack of clearance can be excluded as the potential cause here as, despite the severity of the seizure marks, there are no marks on the opposing counterpressure side.

Possible causes for the damage

- Partial collapse of the cooling mechanism due to lack of coolant, air bubbles, dirt deposits or other malfunction of the cooling circuit.
- On ribbed cylinders, dirt deposits on the outside of the cylinder can lead to local overheating of the cylinder and therefore to a breakdown of the lubricating film.
- Defective, missing or incorrectly installed air baffles on air-cooled engines.
- On engines with a design in which oil is additionally splashed onto the cylinder pressure side under greater load by means of spray jets in the connecting rod, this type of damage can also be caused by a blocked spray jet or insufficient oil pressure.
- Dilution of the oil or use of an inappropriate oil grade for the purpose, leading to a lack of lubrication on the cylinder pressure side under greater load first. ■



3.2.3 Dry running damage due to lack of lubrication caused by fuel flooding

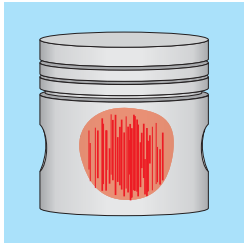


Fig. 1

Description of the damage

Instead of where you would normally find the piston wear pattern, there are narrow, sharply defined longitudinal friction marks on the running surface of the piston skirt.

Damage assessment

Unburned fuel which is wetting at the cylinder running surface has diluted or washed off the load-bearing oil film. As a result, the piston and cylinder run dry against each other. This results in long, narrow friction marks.

With this type of damage the ring zone remains undamaged, as here mostly just the piston rings are in contact with the cylinder running surface.

Note:

In the case of damage caused by unburned fuel, the damage always occurs at the areas on the skirt where the skirt bears against the cylinder. These are the points at which the normal wear pattern would have formed on an undamaged piston after running in.

Possible causes for the damage

- Over-rich operation of the engine and combustion problems caused by faults in the intake system, a blocked air filter, faults in the mixture preparation or in the ignition system.
- Insufficient compression and, as a result, incomplete combustion.
- Defective cold-starting device or excessive use of the choke (carburettor engines).
- Oil dilution caused by frequent short-distance driving or an overly rich mixture



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

3.2.4 Piston top land seizure on a piston from a diesel engine

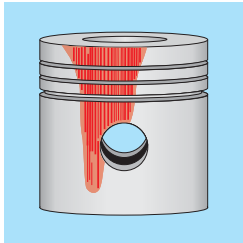


Fig. 1

Description of the damage

The piston crown has localised seizures which mainly focus on the piston top land. The surface of the seizure areas is rough and worn, in some cases larger pieces of material have already been torn out.

Damage assessment

Due to a fault on the injector, fuel which had not been atomized was able to reach the cylinder wall, where it diluted and reduced the strength of the oil film to the point where the

piston was running dry without any lubrication at all. In this area on the piston top land, the piston material has seized so much as a result of running with no lubrication that the

piston material has been virtually welded to the cylinder wall, causing smaller and larger chunks to be torn out of the piston top land.

Possible causes for the damage

- Injectors which are leaking, dripping after injection, clogged or of the wrong type.
- Blocked nozzle needle due to bent injector body (incorrect tightening torque).
- Incorrect injection timing (start of delivery).

3.2.5 Seizure due to lack of lubrication caused by scuffed piston rings

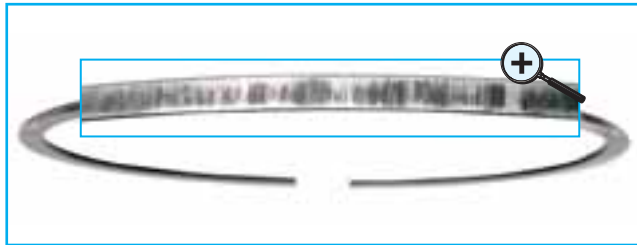
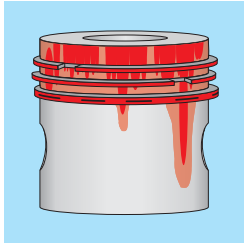


Fig. 1



Fig. 2

Description of the damage

Scratches caused by seizure and burned spots are present on the ring running surfaces. The cylinder bores (not shown in the picture) have longitudinal scratches. The first signs of wear due to rubbing can be seen on the left-hand piston (Fig. 3) at the top right on the piston top land. In a more advanced state (Fig. 4) the damaged areas have spread over the entire piston.



Fig. 3



Fig. 4



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Damage assessment

This type of damage primarily occurs during the running-in phase under heavy loads, when the piston rings are not yet run in and have hence not yet reached their full sealing capability (mostly on diesel pistons). The combustion gases which flow past the rings heat up the rings and the cylinder wall excessively and cause the

lubrication between the piston rings and the cylinder wall to break down. However, faults in the combustion process and increased temperatures or insufficient cooling of the piston and cylinder wall can also affect or even destroy the lubricating film. Initially this causes the piston rings to run dry without lubrication. This

is responsible for the so-called burn spots. The piston also has to slide over the non-lubricated parts of the cylinder, which initially causes wear due to rubbing on the piston top land and subsequently leads to seizures on the entire piston skirt (Fig. 4).

Possible causes for the damage

- Excessive engine loads during the running-in phase.
- The structure of the honed cylinder surface was not perfect for good adhesion of the engine oil (squashing of the graphite veins, peak folding, insufficient roughness and/or incorrect honing angle).

Note:

You can find more detailed information on the subject of honing in our brochures called “Honing of gray cast iron cylinder blocks” and “Oil consumption and loss of oil”. Both brochures are listed in the Appendix together with their order number.

- Unsuitable choice of lubricating oil (incorrect grade and viscosity).
- The temperature on the cylinder running surfaces was too high (malfunction in the cooling system or deposits in the cooling ducts surrounding the cylinder).
- Abnormal combustion and the resulting increased temperatures during combustion (lean mixture, glow ignition, injectors leaking or dripping after injection).

- Insufficient oil supply to the cylinder running surfaces due to insufficient quantities of splash oil and centrifugal oil from the connecting rod bearings and crankshaft bearings. ■



3.3 Seizures due to overheating

3.3.0 General information on seizures due to overheating



In the case of seizures due to overheating, the lubricating film breaks down as a result of excessively high temperatures. Initially this causes mixed friction with individual friction marks. As the damage progresses, the material heats up further and the piston loses all lubrication in the cylinder. The seizure areas have a dark discoloration and are badly broken up. Depending on the cause for the damage, seizure due to overheating will either start on the piston skirt or on the piston top land.



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

3.3.1 Seizure due to overheating centered around the piston top land

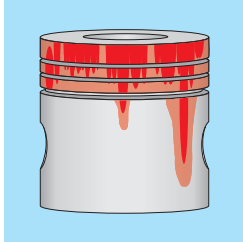


Fig. 1

Description of the damage

Severe seizure has occurred starting from the piston top land which lessens more and more towards the end of the skirt. The surface of the seizure areas has a dark discoloration with severe scoring marks, and has broken up in places. The seizure marks are distributed around the entire circumference of the piston.

The piston rings also show signs of seizure all around, whereby the seizure marks decrease in intensity toward the oil scraper ring.

Damage assessment

The piston crown has been heated up so much as a result of extreme thermal overload coming from the combustion chamber that, on the one hand, it has bridged the running clearances and, on the other hand, has destroyed the oil film to an increas-

ing extent. Ultimately this caused a combination of seizure marks due to insufficient clearances and seizure marks due to insufficient lubrication all around the circumference of the piston top land. A general lack of clearance due to insufficient piston

installation clearance can be excluded as the possible cause, because in this case the damage would start in the skirt area (see also point “3.1.1 Seizure on the piston skirt due to insufficient clearance”)

Possible causes for the damage

- Extended high loads on the engine before it has been fully run in.
- Overheating due to faults in the combustion process.
- Faults in the engine cooling system.
- Faults in the oil supply, i.e. pistons with oil cooling (jet nozzle type) with or without oil cooling gallery
- Bent or blocked oil splash nozzles which provide the piston with not enough or no cooling at all from underneath.

3.3.2 Seizure due to overheating centered around the piston skirt

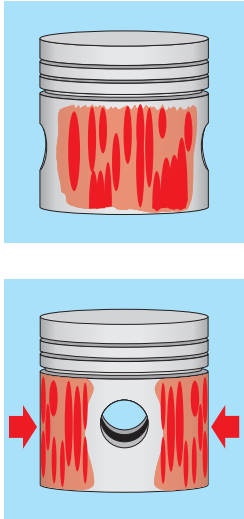


Fig. 1

Description of the damage

The piston skirt has seized nearly all the way round. The surface of the seizure marks has a dark discoloration and is rough and severely broken up. The ring zone has only suffered slight damage due to worn piston material which has been rubbed upwards.

Damage assessment

Severe overheating of the entire engine has caused the lubrication in the cylinder to completely break down. This has caused the characteris-

tic seizure marks due to insufficient lubrication with a heavily broken up surface. As there are no seizure marks on the piston top land and the dam-

age is centered on the skirt area it is possible to exclude a motive overload caused by abnormal combustion.

Possible causes for the damage

- Overheating of the engine due to faults in the cooling system (lack of coolant, dirt, faulty water pump, faulty thermostat, torn or slipping V-belt, inadequate or faulty breather systems for the cooling system).
- On air-cooled engines: Overheating due to dirt deposits on the exteriors of the cylinders, broken cooling ribs or failed or compromised cooling air ventilation.





Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

3.4 Damages due to abnormal combustions

3.4.0 General information about piston damage due to abnormal combustion

Abnormal combustion on gasoline/petrol engines

The normal combustion of the air-fuel mixture in the cylinder follows a precisely defined process. It is started by the spark from the spark plug shortly before top dead centre (TDC). The flame spreads from the spark plug with a circular flame front and crosses the combustion chamber with a steadily increasing combustion speed of 5–30 m/s. The pressure in the combustion chamber rises steeply

as a result and reaches a maximum shortly after TDC. In order to protect the engine components, the pressure increase per degree of the crankshaft must not exceed 3–5 bar. However, this normal combustion process can be disturbed by various factors which essentially can be reduced to three completely different cases of combustion faults:

- 1. Glow ignition**
causes a thermal overload of the piston
- 2. Knocking combustion:**
causes erosion of material and mechanical overloads on the piston and the crankshaft drive.
- 3. Fuel flooding:**
causes wear in conjunction with oil consumption and even piston seizure.

Fig. 1 shows the differences between a normal combustion process, a

knocking combustion and glow ignition.

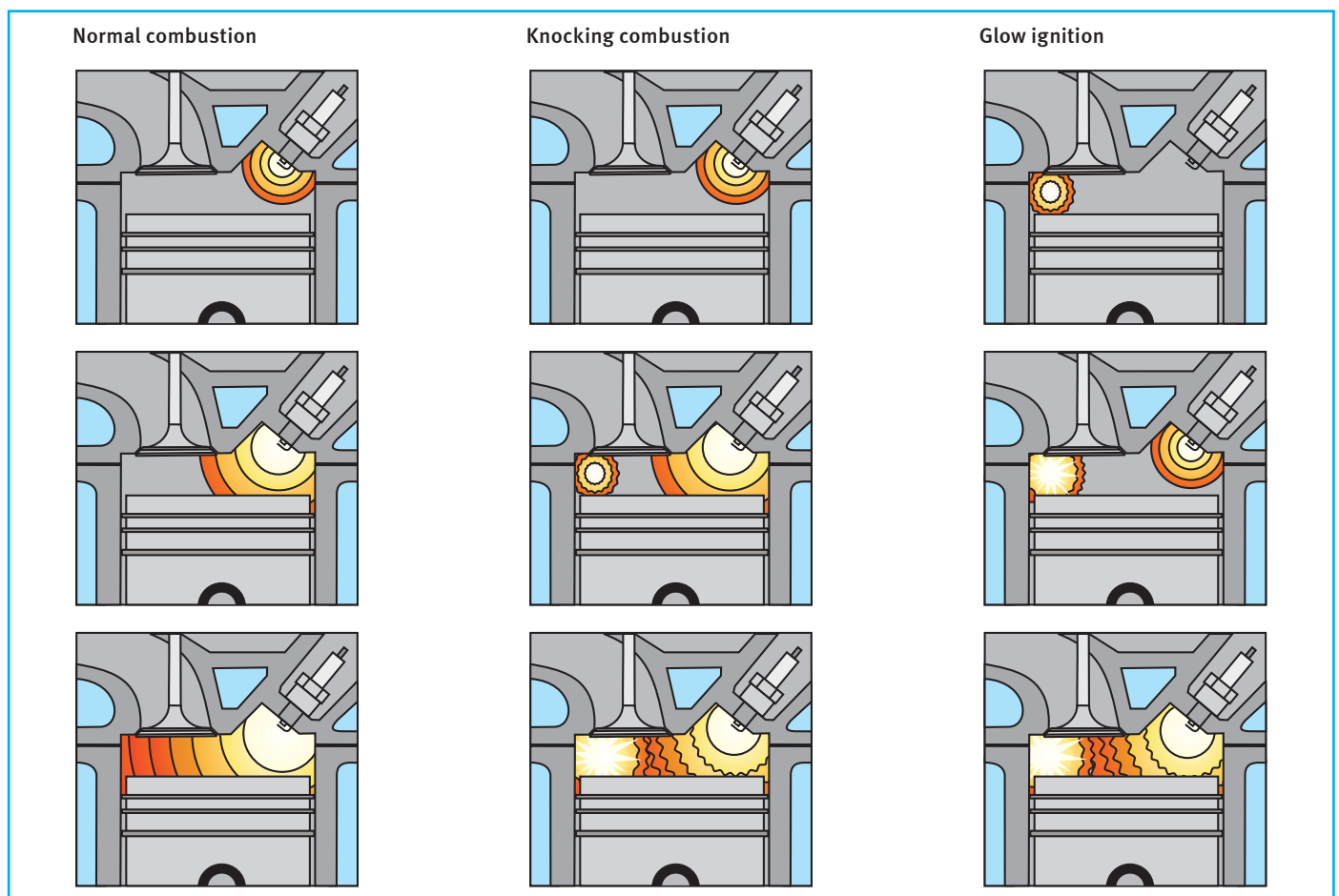


Fig. 1

Piston damages

DESCRIPTION – ASSESSMENT – CAUSES



Additional information for

1. Glow ignition:

In the case of glow ignition, a part which is glowing in the combustion chamber triggers combustion before the actual ignition point. Potential candidates are the hot exhaust valve, the spark plug, sealing parts and deposits on these parts and the surfaces which enclose the combustion chamber. In the case of glow ignition, the flame acts completely uncontrolled on the components, causing the temperature in the piston crown to increase sharply and reach the melting point of the piston material after just few seconds of uninterrupted glow ignition.

On engines with a for the most part hemispherical combustion chamber this causes holes in the piston crown which usually occur on an extension of the spark plug axis.

On combustion chambers with larger quenching areas between the piston crown and the cylinder head, the piston top land usually starts to melt at the point in the quenching area which is subjected to the greatest load. This often continues down to the oil scraper ring and into the interior of the piston.

Remarks:

The term quenching area describes the area on the piston crown which lies closest to the cylinder head when the piston is at TDC. On the upward stroke of the piston towards TDC the fresh gases are squashed from this narrow gap towards the centre of the combustion chamber, swirling the gases and hence improving combustion in the process.

Knocking combustion, which causes high surface temperatures on individual parts of the combustion chamber, can also lead to glow ignition.



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Additional information for

2. Knocking combustion:

When the combustion is knocking the ignition is triggered in the normal manner via the spark from the spark plug. The flame front expanding from the spark plug generates pressure waves which trigger critical reactions in the unburned gas. As a result, self-ignition takes place simultaneously at many points in the residual gas mixture. This in turn causes the combustion speed to increase by a factor of 10-15, and the pressure increase per degree of the crankshaft and the peak pressure also rise substantially. In addition, very high frequency pressure oscillations are set up in the expansion stroke. Furthermore, the temperature of the surfaces enclosing the combustion chamber increases a great deal. Combustion chambers which have been burned clean of any residue are an unmistakeable indication of combustion knocking.

Slight knocking with interruptions can be tolerated by most engines for longer periods of time without sustaining any damage.

More severe and longer lasting knocking causes piston material being to be eroded from the piston top land and the piston crown. The cylinder head and the cylinder head gasket can also sustain damage in a similar way. Parts in the combustion chamber (e.g. the spark plug) can heat up so much in the process that glow ignition (pre-ignition) can take place in conjunction with thermal overload of the piston (i.e. material is melted on or removed by melting).

Severe continuous knocking will cause fractures of the ring land and the skirt after just a short time. This usually occurs without any material being melted on or removed by melting and without seizure marks.

Fig. 1 shows a graphical representation of the pressure curve in the combustion chamber. The blue curve shows the pressure curve for normal combustion. The red curve shows a pressure curve for a knocking combustion with overlaid pressure peaks.

Additional information for

3. Fuel flooding:

An excessively rich mixture, gradual loss of compression pressure and ignition faults will generate an incomplete combustion with concurrent fuel flooding. The lubrication of the pistons, piston rings and cylinder running surfaces becomes less and less effective as a result. The consequence is mixed friction with wear and consumption of oil and seizure marks (please refer to the “Oil consumption” and “Piston seizure” sections as well).

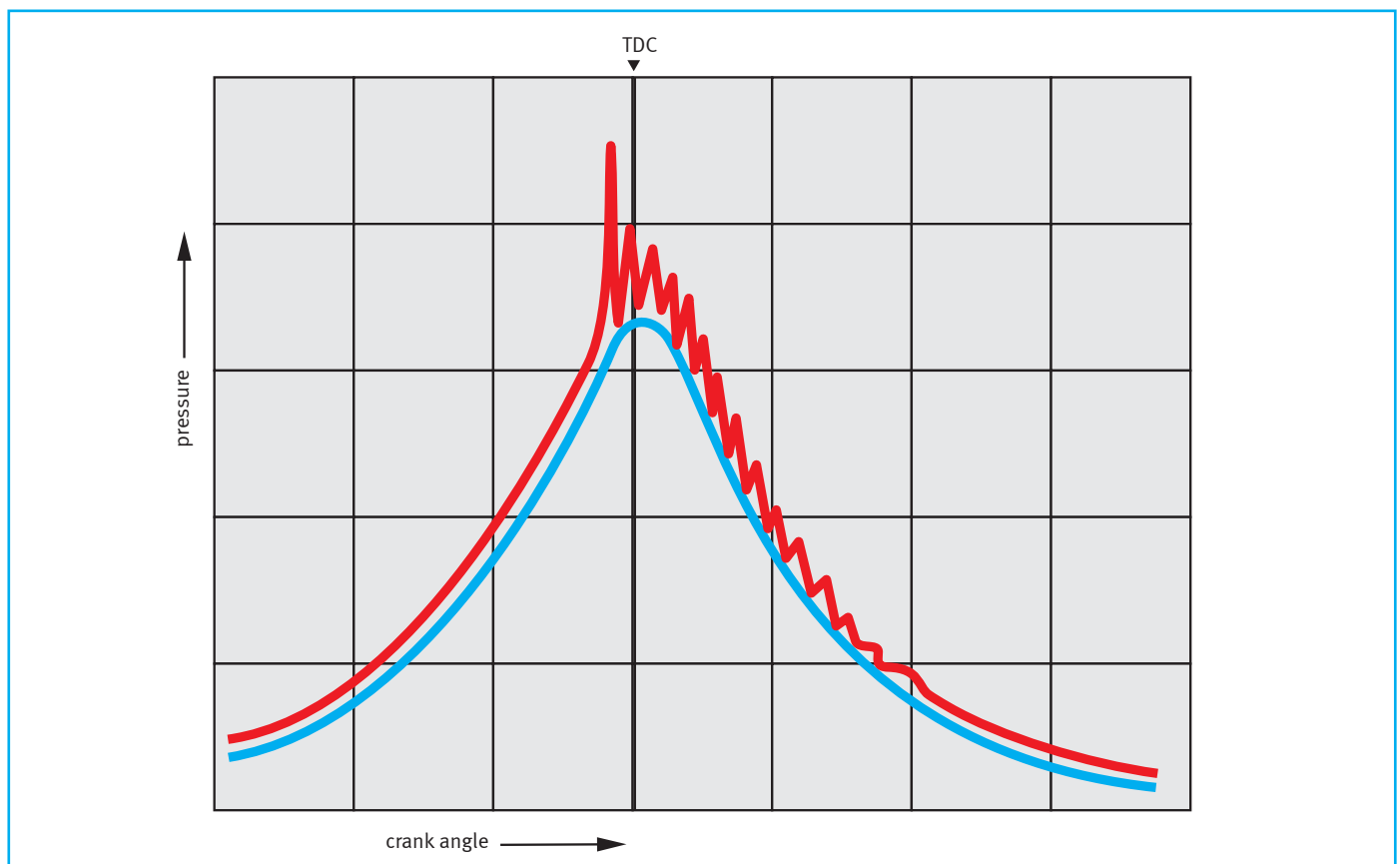


Fig. 1

Piston damages

DESCRIPTION – ASSESSMENT – CAUSES



Abnormal combustion on diesel engines

In addition to the basic requirement that the engine is mechanically in perfect working order, it is essential that a diesel engine has an injector with extremely fine fuel atomisation and precise delivery and correct start of injection in order to ensure that the combustion process is optimised. This is the only way to ensure that the injected fuel can ignite with a minimum ignition delay and, under normal pressure conditions, burn completely. However, various influences can disturb this normal combustion procedure. Fundamentally, there are three serious types of abnormal combustion:

- 1. Ignition delay**
- 2. Incomplete combustion**
- 3. Injectors dripping after injection**

Additional information for

1. Ignition delay:

The fuel injected at the start of delivery will ignite with a certain delay (ignition delay) if it is not atomised finely enough and if it does not reach the combustion chamber at the right time, or if the compression pressure is not yet high enough at the start of injection. The degree of atomisation depends on the condition of the injector. For example, an injector which demonstrates perfect fuel delivery during testing with an injector testing device can be jammed in such a way during installation that it no longer atomises the fuel properly.

The compression temperature depends on the compression pressure and therefore on the mechanical

condition of the engine. On a cold engine there is always a certain ignition delay. During compression, the cold cylinder walls absorb so much heat from the intake air - which is colder anyway - that the compression temperature present at the start of injection is not sufficient to immediately ignite the injected fuel. The required ignition temperature is not reached until the compression reaches a more advanced stage, at which point the fuel injected so far ignites suddenly. This causes a steep, explosive pressure increase which generates a noise and causes a sharp increase in the temperature of the piston crown. This can result in fractures in the power unit, for example in the ring land and the piston, as well as heat stress cracks on the piston crown.

Additional information for

2. Incomplete combustion:

If the fuel does not reach the combustion chamber at the right time, or if it is not properly atomised, then the short period of time available is not enough to ensure complete combustion. The same happens if there is not enough oxygen (i.e. intake air) in the cylinder. The causes for this could be a blocked air filter, intake valves not opening correctly, turbocharger faults or wear on the piston rings and the valves. Fuel which has been burned either incompletely or not at all will at least partly wetten on the cylinder walls, where it will adversely affect or even destroy the film of lubricant. Within a very short space of time this will result in severe wear or seizure on the running surfaces and edges of the piston rings, the edges of the piston grooves, the cylinder running surface

and, finally, also the piston skirt surfaces. This means that the engine will start to consume oil and lose power (please refer to the “Oil consumption” and “Seizure due to insufficient lubrication” sections for examples of possible damage scenarios).

Additional information to

3. Injectors dripping after injection

To prevent the injectors from opening again and post-injecting as a result of the pressure fluctuations in the system between the pressure valve of the fuel-injection pump, the fuel-injection lines and the injectors themselves, the pressure in the system is reduced by a certain amount by the pressure valve of the fuel-injection pump at the end of injection. If the injection pressure of the injectors is set too low or if it cannot be reliably maintained by the nozzle (mechanical nozzles), then it is possible that, despite this pressure reduction, the injectors could still open several times in sequence after the end of injection as a result of pressure fluctuations in the fuel-injection line. Nozzles which leak or drip after injection also cause an uncontrolled delivery of fuel into the combustion chamber. In both cases the injected fuel remains unburned due to the lack of oxygen and ends up unburned on the piston crown. There the fuel glows away under quite high temperatures and heats local areas of the piston material so much that parts of the piston can be torn away from the surface under the effects of gravity and erosion. This results in substantial amounts of material being carried away or washed away erosively on the piston crown.

3.4.1 Removal of material by melting from the piston crown and ring zone (gasoline/petrol engine)

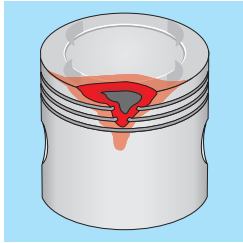


Fig. 1

Description of the damage

The material has melted away on the piston crown behind the piston rings. The piston skirt has not seized, instead piston material has been worn away off the damaged area to the piston skirt.

Damage assessment

The removal of material by melting from piston crowns on petrol engines is the result of glow ignition on pistons with mostly flat crowns and larger quenching areas. Glow ignition is triggered by glowing parts in the combustion chamber which are hotter than the self-ignition temperature of the air-gas

mixture. These are essentially the spark plug, the exhaust valve and any residue adhering to the combustion chamber walls. In the quenching area, the piston crown is heated up significantly due to the glow ignition. In the process, the temperatures reach values which make

the piston material go soft. Material is carried away as far as the oil scraper ring due to the combined effects of gravity and combustion gases entering the damage site.

Possible causes for the damage

- Heat range of the spark plugs too low.
- Mixture too lean, resulting in higher combustion temperatures.
- Damaged or leaking valves, or insufficient valve clearance, causing the valves to not close correctly. The combustion gases flowing past significantly increase the temperature of the valves, and the valves start to glow. This primarily affects the exhaust valves, as the intake valves are cooled by the fresh gases.
- Glowing combustion residue on the piston crowns, the cylinder head, the valves and the spark plugs.
- Unsuitable fuel with an octane rating which is too low. The fuel quality must correspond to the compression ratio of the engine, i.e. the octane rating of the fuel must cover the octane requirements of the engine under all operating conditions.
- Diesel fuel in the petrol, which lowers the octane rating of the fuel.
- High quantities of oil in the combustion chamber caused by high oil transfer rate on the piston rings or the valve guide.
- High engine or intake temperatures caused by inadequate ventilation of the engine compartment.
- General overheating.

3.4.2 Material removal/fusion due to melting on the piston crown (diesel engine)

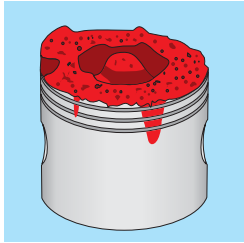


Fig. 1

Description of the damage

The crown area and the piston top land area have been completely destroyed (Fig. 1). The piston top land has melted away as far as the ring carrier. Melted-away piston material has been worn down on the piston skirt where it has also caused damage and seizure marks. The ring carrier of the first compression ring is now only partially intact on the left-hand side of the piston. The rest of the ring carrier has become detached from the piston during operation and caused further damage in the combustion chamber. The force of the parts flying around has transported them through the intake valve into the intake manifold and from there into the neighbouring cylinder, where they have caused further damage (impact marks).



Fig. 2

Additional information for Fig. 2:

Erosive-type removal of material due to melting has occurred on the piston crown and the edge of the piston top land in the injection direction of one or more nozzle jets. There are no seizure marks on the piston skirt or the piston ring zone.



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Damage assessment

This type of damage occurs particularly on direct-injection diesel engines. Prechamber engines are only affected if a prechamber is damaged and the prechamber engine therefore effectively becomes a direct-injection engine. If the injector of the affected cylinder cannot maintain its injection pressure after the end of the injection process and the pressure drops, oscillations in the fuel-injection line can cause the nozzle needle to lift again, causing

fuel to be injected into the combustion chamber again after the end of the injection process (mechanical nozzles). If the oxygen in the combustion chamber has been used up, then the individual fuel droplets will be distributed throughout the entire combustion chamber and end up further outside on the piston crown on its downward stroke. There they glow away under a shortage of oxygen, generating quite a lot of heat in the process. The mate-

rial in the localised area becomes soft in the process. The force of gravity and the erosion due to the combustion gases speeding past will tear out individual particles from the surface (Fig. 2) or carry away the entire piston crown, ultimately leading to the type of damage seen in Fig. 1.

Possible causes for the damage

- Leaking injector nozzles or stiff or jammed nozzle needles.
- Broken or worn nozzle springs.
- Faulty pressure relief valves in the fuel-injection pump.
- Injected fuel quantity and injection timing not set in accordance with the engine manufacturer's specifications.
- On prechamber engines: Prechamber defect, but only in conjunction with one of the above possible causes.
- Ignition delay due to insufficient compression caused by excessive gap dimensions (piston protrusion/overlap too low), incorrect valve timing or leaking valves.
- Excessive ignition delay caused by the use of diesel with a cetane rating which is too low (reluctant to ignite). ■



3.4.3 Cracks in the piston crown and combustion bowl recess (diesel engines)

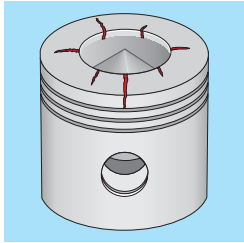


Fig. 1

Description of the damage

The piston crown displays a stress crack which extends on one side from the piston crown to the piston pin boss (Figs. 1 and 2). The hot combustion gases which have flown through the crack have burned a channel into the piston material which runs outward from the bowl to the cast bowl below the oil scraper ring.



Fig. 2



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Damage assessment

As a result of the high thermal overload, the piston material is heated up significantly in localised areas where the prechamber jets reach the piston (prechamber engine) or on the edge of the bowl (direct-injection engines). In the heated up areas the material expands much more than elsewhere. As the overheated areas are not surrounded by any cold surrounding materials, the material at the hot, thermally overloaded area is permanently deformed beyond its limit of elasticity. Exactly the opposite happens when it then cools down again.

In the areas where before the material was buckled and forced away, there is now suddenly a shortage of material. This results in tensile stresses in this area which ultimately cause stress cracks (see Figs. 3 and 4). If in addition to the stresses resulting from the thermal overload there are also superimposed stresses caused by warping of the piston pin, then in some cases the stress cracks can turn into a much larger major crack which causes complete breakage and failure of the piston.



Fig. 3



Fig. 4

Possible causes for the damage

- Faulty or incorrect injectors, faults in the fuel-injection pump, damage to the prechamber.
- High temperatures as a result of defects in the cooling system.
- Faults on the engine brake, or excessive use of the engine brake. This results in overheating.
- Insufficient piston cooling on pistons with a cooling oil gallery, caused for example by blocked or bent cooling oil nozzles.
- On engines which are subject to frequently changing loads, e.g. city buses, earth moving machinery etc., these factors can become particularly critical.
- Use of pistons with an incorrect specification, e.g. installation of pistons without a cooling oil gallery on an engine where the specifications require pistons with a cooling oil gallery, installation of pistons made by third-party manufacturers without fibre-reinforcement of the edge of the bowl.
- Installation of pistons with an incorrectly shaped piston bowl for the engine. See also point “3.4.7 Piston seizure due to the use of incorrect pistons”.

3.4.4 Ring land fractures

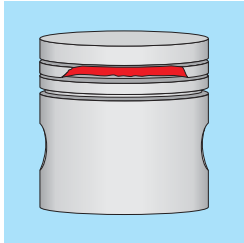


Fig. 1

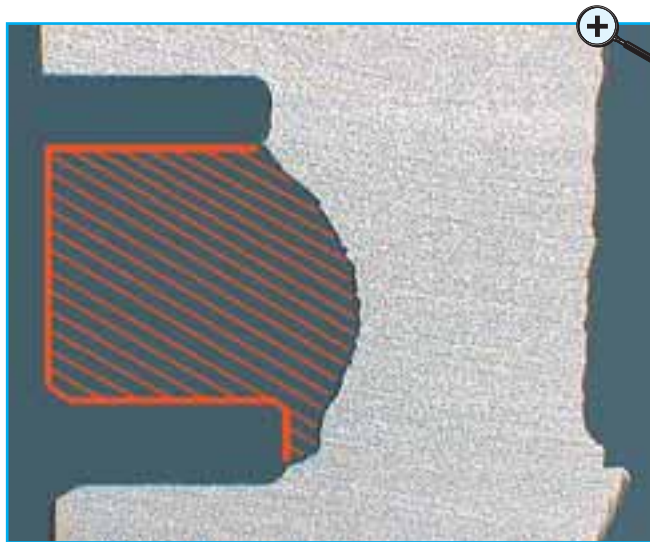


Fig. 2 cross section of ring land

Description of the damage

A ring land fracture is evident on one side of the piston between the first and second compression ring (Fig. 1). The fracture starts at the upper edge of the ring land in the base of the groove and runs at a diagonal angle into the piston material. Near the lower edge of the ring land the fracture then changes direction back outwards and emerges at the lower edge of the ring land or slightly underneath in the base of the groove. The longitudinal cracks in the ring lands which limit the lateral expansion of the fracture are extended downwards. There are no piston seizure marks or evidence of overheating.

Damage assessment

Material faults are not the reason for ring land fractures, even though they are often the suspected cause. This type of fracture always results from overstressing the material. A distinction can be made between 3 different causes for these symptoms of overstressing:

Knocking combustion:

This means that the octane rating of the fuel was not capable of covering the engine's needs under all operating and load conditions (see also point "3.4.0 General information about piston damage due to abnormal

combustion"). Ring land fractures caused by knocking combustion usually occur on the pressure side. On a diesel engine, knocking can only be caused by ignition delay.



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Hydraulic locks:

Liquid (water, coolant, oil or fuel) inadvertently enters the combustion chamber when the engine is stationary or running. As the liquid is incompressible, the piston and crankshaft drive are subjected to enormous stresses during the compression stroke. The unavoidable outcome is ring land fractures, hub fractures or connecting rod/crankshaft damage. Fig. 3 shows an example of the development of a fracture which occurs in response to knocking combustion and hydraulic locks. The fracture surfaces

extend further down as well, as the force which causes the fracture acts from above on the ring land.

Installation errors:

During installation, the piston was knocked in rather than being slid in, because the piston rings were not correctly compressed or unsuitable tools were used. In this case the ring lands fracture in the reverse direction as the pressure comes from below (Fig. 4), not from above as in the above case.

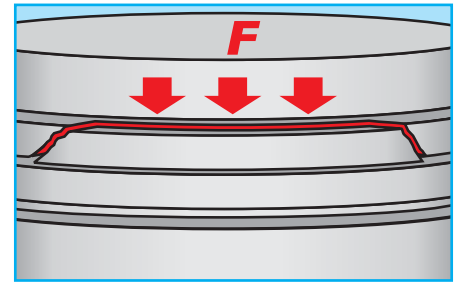


Fig. 3

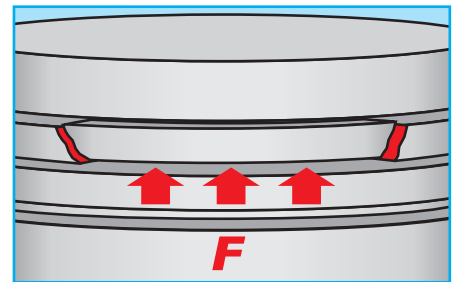


Fig. 4

Possible causes for the damage

Knocking combustion on gasoline/petrol engines

- Use of a fuel without suitable anti-knock properties. The fuel quality must correspond to the compression ratio of the engine, i.e. the octane rating of the fuel must cover the octane requirements of the engine under all operating conditions.
- Diesel fuel in the petrol, which lowers the octane rating of the fuel.
- Oil in the combustion chamber as a result of high oil consumption at the piston rings or valve guides lowers the antiknock properties of the fuel.
- Excessively high compression ratio caused by combustion residue on the piston crowns and cylinder head or excessive machining of the cylinder block surface and cylinder head surface for engine overhaul or tuning purposes.
- Ignition timing too advanced.
- Mixture too lean, resulting in higher combustion temperatures.

- Intake air temperatures too high, caused by inadequate ventilation of the engine compartment or exhaust gas backpressure. However, failure to switch over the intake air flap to summer operation or a faulty automatic switchover mechanism will lead also to a substantial increase in the intake air temperature (particularly on older carburettor engines).

Knocking combustion on diesel engines

- Injectors with poor atomisation or leaking injectors.
- Injection pressure of the injectors is too low.
- Compression pressure too low due to the use of an incorrect cylinder head gasket, insufficient piston protrusion, leaking valves or broken/worn piston rings.
- Defective cylinder head gasket.
- Damage to the prechamber.
- Improper or excessive use of starting aids (e.g. starting spray) during cold starts.

Hydraulic locks

- Accidental intake of water while driving through high water, puddles or low rivers/waters, or as a result of larger quantities of water being splashed up by passing vehicles or vehicles in front.
- Cylinder filling up with water while the engine is stationary due to leaks in the cylinder head gasket or due to cracks in components.
- Cylinder filling up with fuel while the engine is stationary due to leaking injectors (only applies to gasoline/petrol engines with fuel-injection). The residual pressure in the fuel injection system is dissipated through the leaking nozzle into the cylinder. In this case and the one above the described damage will occur when the engine is started.

3.4.5 Impact marks on the piston crown (diesel engine)

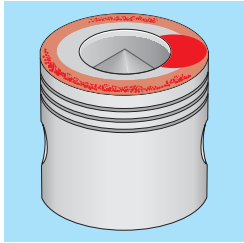


Fig. 1

Description of the damage

Severe impact marks can be seen on the piston crown (Fig. 1). Nearly all of the oil carbon deposits have been removed from this area due to metallic contact between the piston and the cylinder head. The oil carbon deposits have been pressed into the piston crown as a result of the impacts, leaving scarring in the process. The piston rings indicate signs of severe wear. The wear is evident even to the naked eye on the oil scraper ring in particular.

On the piston shown in Fig. 2, an imprint of the swirl chamber can be seen on the front edge of the crown, and a strong imprint of the valve can be seen on the right-hand side of the crown. This means that, as well as the swirl chamber, a valve has also made contact with the piston crown during operation, and the valve has gradually dug itself into the piston crown (see Fig 3). First indicators of rubbing marks due to a lack of lubrication are evident on the piston skirt (see Fig. 4).



Fig. 2



Fig. 3



Fig. 4



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Damage assessment

The pistons have struck against the cylinder head/swirl chamber and one of the valves during operation. There have been no fractures or breakages yet as a result of these violent impacts. However, the nature of the wear on the piston rings and the piston skirt indicates that one consequence of these impacts has been abnormal combustion due to fuel flooding. Mechanical contact between the piston crown and the cylinder head has resulted in vibration, with associated vibration being transferred through to the injector. As a consequence, the injector has been unable to hold the

pressure when closed. The increased injection of fuel into the cylinder causes fuel flooding. This in turn damages the oil film, which initially leads to a higher level of mixed friction and therefore increased wear in the piston ring area. Oil consumption increases as a consequence. The characteristic damage caused by unburned fuel does not arise until the oil film is destroyed by the fuel to such an extent that the piston is running without lubrication (see also point “3.2.3 Dry running damage due to lack of lubrication caused by fuel flooding”).

In the initial stages the piston skirt is affected to a lesser degree, as it is continuously supplied with new oil from the crankshaft drive which is still capable of providing lubrication. Once the abraded particles from the moving area of the pistons start to become more and more mixed with the lubricating oil and the lubricating oil starts to lose its load-bearing ability as a result of oil dilution, the wear will spread to all of the moving parts in the engine.

Possible causes for the damage

- Incorrect piston protrusion/over lap. The piston protrusion/over lap was not checked or corrected during an engine overhaul.
- Connecting rod small-end bush bored eccentrically during replacement of the small-end bushes.
- Eccentric regrinding of the crankshaft.
- Eccentric reworking of the bearing counter bore (when resinking the crankshaft bearing caps).
- Installation of a cylinder head gasket with insufficient thickness.
- Oil carbon deposits on the piston crown and resulting restriction or bridging of the gap.
- Incorrect valve timing caused by incorrect adjustment, chain stretching or a slipped belt.
- Excessive reworking of the cylinder head sealing surface and the resulting shift in the valve timing. (The distance between the driving pinion/sprocket and the driven pinion/sprocket changes. Depending on the design of the chain or belt adjustment mechanism, it may not be possible to correct this).
- New valve seat rings have been installed, but care was not taken to ensure that they are correctly positioned. If the valve recess is not positioned deeply enough in the cylinder head during machining, the valves will not be recessed enough into the cylinder head and will protrude too far as a result.
- Over-revving the engine. The valves no longer close in time due to the increased inertia forces and strike against the piston.
- Excessive clearances in the connecting rod bearings or a worn out connecting rod bearing, particularly in conjunction with over-revving during a hill descent.



3.4.6 Hole in the piston crown (petrol spark-ignition gasoline engine)

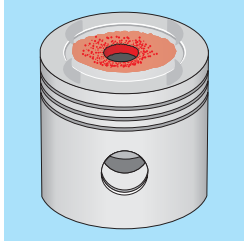


Fig. 1

Description of the damage

The piston crown has a hole which penetrates all the way through. The surface of the piston crown is covered by the solidified molten material. The skirt area has also been damaged as a result of the enormous intensity of the heat and the piston material which has been ground down and displays seizure marks.

Damage assessment

This type of damage is caused by glow ignition. Here, the self-ignition temperature of the air-gas mixture is exceeded by glowing parts in the combustion chamber. These are essentially the spark plug, the exhaust valve and any combustion residue present in the combustion chamber. As a result, the mixture ignites before it is due to be ignited by the spark plug. Combustion takes place so far in advance of the actual ignition point that the flame has much more time to act on the piston crown than in the normal combustion process. Within a short space of time the piston crown

heats up so much that the material there becomes soft. The softened material is then carried away as a result of the combination of the effects of gravity on the reciprocal movements of the piston and the fast-flowing combustion gases. Due to the lack of material strength no left in this area after the material has been softened and molten aluminium has migrated away from the piston crown, the combustion pressure can then force a hole in through the much weaker piston crown. In many cases there will not even be any seizure marks.

Note:

Such rapid heating of a localised area on the piston crown is only possible as a result of glow ignition.



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Possible causes for the damage

- Heat range of the spark plugs too low.
- Mixture too lean, resulting in higher combustion temperatures.
- Damaged or leaking valves, or insufficient valve clearance, causing the valves to not close correctly. The combustion gases flowing past significantly increase the temperature of the valves, and the valves start to glow. This primarily affects the exhaust valves, as the intake valves are cooled by the fresh gases.
- Glowing combustion residue on the piston crowns, the cylinder head, the valves and the spark plugs.
- Unsuitable fuel with an octane rating which is too low. The fuel quality must correspond to the compression ratio of the engine, i.e. the octane rating of the fuel must cover the octane requirements of the engine under all operating conditions.
- Gasoline contaminated by Diesel, which lowers the octane rating of the fuel.
- High quantities of oil in the combustion chamber caused by high oil transfer rate due to worn or damaged piston rings or valve guides, or a combination of both.
- High engine or intake temperatures caused by inadequate ventilation of the engine compartment.
- General overheating. ■

3.4.7 Piston top land seizure due to the use of incorrect pistons (diesel engine)

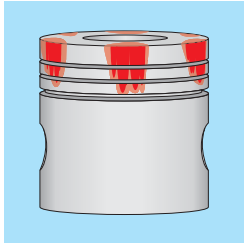


Fig. 1

Description of the damage

Clear localised scoring marks can be seen on the piston top land. These seizure marks go all around the circumference of the piston. The scoring marks are centered around the piston top land. They start at the edge of the piston crown and end at the second compression ring.

Damage assessment

Due to the nature of the symptoms, this damage has been clearly caused by an abnormal combustion. However, the fault lies in the use of an incorrect piston, not with the fuel-injection system as might initially be suspected. Within the framework of the legislation for reducing levels of pollutants in exhaust emissions, engines are now designed and built in accordance with the latest exhaust emission standards. Often the pistons for the different emission standards are barely any different to look at. In this example, pistons with different bowl diameters are used on the same range of engines to meet different exhaust emission standards.

One example not to be followed is: A piston for the Euro 1 emissions standard, which has a bowl diameter of 77 mm, has been replaced during engine repairs with a piston for the Euro 2 emissions standard with a bowl diameter of 75 mm. This caused increased heating at the edge of the bowl as, because of the smaller diameter of the bowl, the injector was spraying onto the edge of the bowl rather than the centre of the bowl. This caused localised overheating of the piston material where the fuel jets from the injector were reaching the piston, and therefore also increased thermal expansion which led to the localised seizure marks.

If the pistons which are used are not prescribed for the relevant engine type and the relevant emission standards, this can result in serious abnormal combustion during operation with completely unpredictable consequences. Apart from damage of the kind described above, failure to comply with the exhaust emission regulations would be just the start of the problems. Lack of engine performance, increased fuel consumption and subsequent installation of the correct pistons lead to significant follow-up costs.



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Possible causes for the damage

- Use of pistons with an incorrectly shaped bowl or an incorrect bowl depth or diameter.
 - Use of pistons which do not comply with the dimension specifications (compression height).
 - Use of the incorrect style of piston. For example, a piston with no cooling oil gallery must not be used if the engine manufacturer specifies a cooling oil gallery the particular application (e.g. for reaching a certain power output).
 - Use of the correct pistons, but use of other components which are unsuitable for the particular application (injectors, cylinder head gaskets, fuel-injection pumps or other components which affect the mixture formation or combustion process).
-

3.4.8 Erosion on the piston top land and on the piston crown (gasoline/petrol engine)

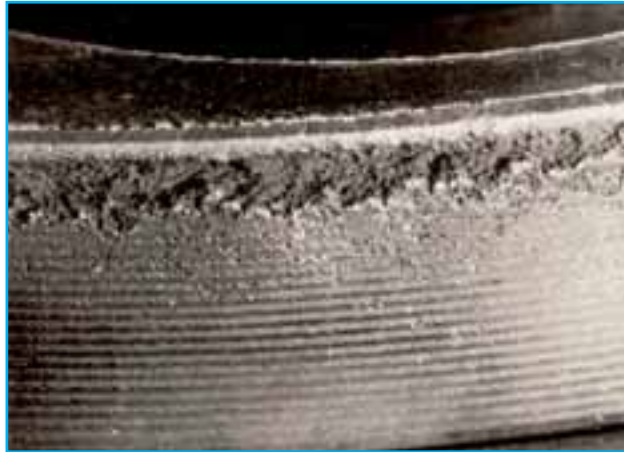
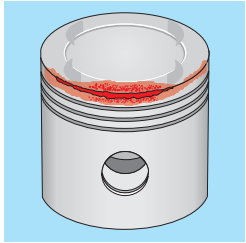


Fig. 1

Description of the damage

The piston top land shows areas where material has been carried away in an erosion-type process (see Fig. 1). This removal of material often continues on the surface of the piston crown (see Fig. 2). There are not necessarily any seizure marks or other damage to the piston.



Fig. 2



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Damage assessment

Erosion-type removal of material from the piston top land and from the piston crown always occurs as a result of extended periods of knocking combustion (medium severity). In the process, pressure waves are generated which spread in the combustion

chamber and run down between the piston top land and the cylinder wall as far as the first compression ring. At the reversal point of the pressure wave, the kinetic energy tears out tiniest particles from the surface of the piston. Gradually the area from which

material is carried away expands, particularly if glow ignition also occurs as a result of the knocking combustion. Material is often carried away in the damaged area behind the rings as far as the oil scraper ring.

Possible causes for the damage

- Use of a fuel without suitable anti-knock properties. The fuel quality must correspond to the compression ratio of the engine, i.e. the octane rating of the fuel must cover the octane requirements of the engine under all operating conditions.
- The gasoline/petrol has been contaminated with diesel. Accidental refuelling with the wrong type of fuel or shared use of tanks or canisters for both types of fuel can lead to this kind of contamination. Very small amounts of diesel are already enough to significantly lower the octane rating of the petrol.
- Large quantities of oil in the combustion chamber caused for example by worn piston rings, valve guides or the turbocharger (or other similar components) will reduce the antiknock properties of the fuel.
- Excessively high compression ratio caused by combustion residue on the piston crowns and cylinder head or excessive machining of the cylinder block surface and cylinder head surface for engine overhaul or tuning purposes.
- Ignition timing too advanced.
- Mixture too lean, resulting in higher combustion temperatures.
- Intake air temperatures too high, caused by inadequate ventilation of the engine compartment or exhaust gas backpressure. However, failure to switch over the intake air flap to summer operation or a faulty automatic switchover mechanism will lead also to a substantial increase in the intake air temperature (particularly on older carburettor engines). ■



3.5 Piston and piston ring fractures

3.5.0 General information about piston fractures

During operation of the engine, pistons can break as a result of an overload breakage or can suffer a fatigue fracture.



Fig. 1

An overload breakage (Fig. 1) is always caused by a foreign body which collides with the piston while the engine is running. This could be parts of the connecting rod, crankshaft or valves etc. which have been torn off. An overload breakage of the piston can also occur if water or fuel gets into the cylinder. The broken surfaces of an overload breakage appear grey.

They are not worn down and they display no nodal line markings. The piston breaks suddenly, with no development of a fracture.

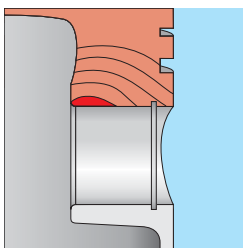
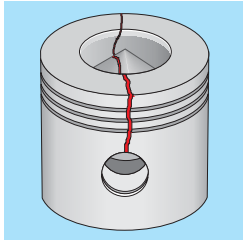


Fig. 2

In the case of a fatigue fracture (Fig. 2), nodal line markings form on the fracture surface which reveal the starting point and the gradual progress of the fracture. The fracture surfaces are often worn to the point of being shiny. The cause for a fatigue fracture is overstressing of the piston material. Overstressing can occur during knocking combustion,

severe shock vibrations of the piston, for example if the piston crown has mechanical contact with the cylinder head or excessive skirt clearance. Excessive deformation of the piston pin due to overstressing (warping and oval deformation) cause cracks in the pin boss. Furthermore, fatigue fractures can also stem from heat stress cracks on the piston crowns.

3.5.1 Piston fracture in the piston pin boss



Description of the damage

The early stages of a typical pin boss fatigue crack are evident in the centre axis of the piston pin bore (Fig. 2). The crack has spread in a semicircle around its starting point. A so-called cleavage fracture forms from the initial crack, which splits the piston up to the piston crown into two parts – as can be seen in Fig. 1 (the piston has been sawed



Fig. 1

open from the bottom for the purposes of investigation; the original crack extended from the piston pin bore to the piston crown).



Fig. 2 cross section of the piston pin boss

Damage assessment

Boss fractures arise as a consequence of excessive loads. This process can be accelerated if there is not a sufficient

oil supply. An incipient crack in the piston pin boss formed due to excessive loads will then spread even under

normal loads, and will ultimately cause the entire piston to split or break.

Possible causes for the damage

- Abnormal combustion, in particular spontaneous combustion caused by ignition delay.
- Excessive or inappropriate use of starting aids during cold starts.
- The cylinder has filled up with water, fuel or oil whilst stationary, resulting in a hydraulic lock.
- Performance enhancements (e.g. chip tuning) with continued use of the standard production piston.
- Use of incorrect or weight-reduced piston pins. The piston pin is deformed to an oval shape, placing excessive loads on the bearings in the process.

3.5.2 Piston fracture due to mechanical contact between the piston crown and the cylinder head

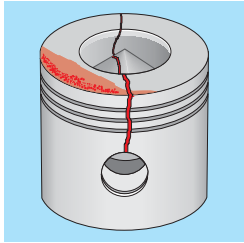


Fig. 1

Description of the damage

Impact marks can be seen on the piston crown in Fig. 1. The piston crown has mechanical contact damage, causing vibration. As a result of the shock vibrations and the effects of the violent impact during the pistons cyclic operation, a fracture has occurred in the direction of the piston pin.

On the piston in Fig. 2 the piston skirt has broken off in the lower oil scraper ring groove. The surfaces at the fracture display the characteristics of a fatigue fracture.



Fig. 2



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Damage assessment

Due to the exceptionally fast sequence of hard impacts as the piston crown strikes the cylinder head, the piston is subjected to such violent shock vibrations that cracks are generated. On pistons with a lower oil scraper

ring (like the one shown in Fig. 2), the skirt nearly always breaks in the area of the lower oil scraper ring groove. After striking the cylinder head, the piston no longer runs straight in the cylinder and subsequently strikes

the cylinder wall with its skirt. As the material thickness is less in the area of the lower ring groove than in e.g. the piston top land, this is where the piston breaks.

Possible causes for the damage

- The so-called gap dimension (this is the minimum distance between the piston crown and the cylinder head) was too small at TDC of the piston. The following scenarios may have caused this:

a) Installation of pistons with an incorrect compression height. During engine overhauls, the sealing surface of the cylinder block is often reworked. If pistons with the original compression height are then refitted after the engine block is resurfaced, then the piston protrusion/overlap may be too large. This is why pistons are available for repairs with a reduced compression height, enabling the piston protrusion to be kept within the tolerance specified by the engine manufacturer.*

b) Insufficient thickness of the cylinder head gasket. Many manufacturers provide cylinder head gaskets with different thicknesses for the same engine. On the one hand this is necessary to compensate for component tolerances during production, and on the other hand it also allows an adaptation for the piston protrusion during repairs. For this reason it is extremely important to ensure that a cylinder head gasket with the prescribed thickness is used during repairs. This is the only way to ensure that the specified gap dimension will be achieved after the repair. The thickness of the gasket must be redetermined depending on the piston protrusion in accordance with the manufacturer's specifications if the cylinder block is reworked or replaced.

Caution:

Checking the freedom of movement of the engine after an overhaul by turning the engine several times by hand with the engine being cold does not guarantee that the piston will not strike the cylinder head when the engine is at operating temperature. As the piston and connecting rod heat up, they also expand in terms of their length, which reduces the gap between the piston crown and the cylinder head. Particularly on larger engines in commercial vehicles with large compression heights, the differences can be significant and reduce the freedom of movement of the piston at TDC by several tenths of a millimetre.

- Excessive clearances in the connecting rod bearings or a worn out connecting rod bearing, particularly in conjunction with over-revving during a hill descent.

* MSI supply pistons with a reduced compression height for most heavy duty engines. Please refer to our current catalogue "Pistons/Cylinders/Kit Sets".



3.5.3 Material washout in the ring zone (ring fracture)

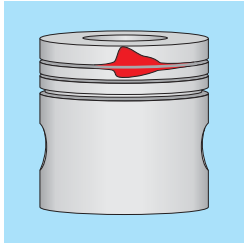


Fig. 1

Description of the damage

Severe material washout reaching as far as the piston crown is evident in the ring zone in the area of the first ring groove. The ring groove displays severe axial wear. Heavy imprints from broken fragments of the first ring can be seen on the piston crown. In some places the running pattern of the piston skirt has a matt, buffed appearance.



Fig. 2



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Damage assessment

Due to the severity of the axial wear on the grooves and on the first ring groove in particular, the damage shown here can only have been caused by ingress of contaminants or dirt into the combustion chamber. The contaminants were then also deposited in the ring groove, where they caused abrasive wear on the piston ring and the piston ring groove. The axial clearance of the

piston rings increased steadily as a result. In terms of its cross-section, the ring was then severely weakened, and it could ultimately no longer withstand the pressures of the combustion process and broke. Consequently, the broken off part of the ring had even greater freedom to move around in the rapidly enlarging groove, causing the washout shown in the picture as a re-

sult of continuous “hammering”. Once the washout finally reached the piston crown, the fragments of the piston ring were able to enter the space between the piston crown and the cylinder head, where they caused more damage to piston crown and cylinder head.

Possible causes for the damage

- Given the severity of the axial wear of the ring groove and the piston rings, the only possible explanation is the ingress of foreign bodies into the combustion chamber. Refer to section “3.11.2 Wear on the pistons, piston rings and cylinders caused by the ingress of dirt”.
- If there is severe radial wear to the piston rings without evidence of any axial wear then a likely cause is fuel flooding. Refer to section “3.11.3 Wear on the pistons, piston rings and cylinders caused by fuel flooding”.
- If there is no wear on the ring grooves or piston rings and the engine has only been run a short time after a major overhaul, then this type of damage can be caused by incorrect installation of the piston. It is possible for the piston rings to be broken when the piston is inserted into the cylinder if they have not been pressed far enough into the piston ring groove. This usually happens if the piston ring scuff band is not fitted and tightened correctly around the piston, or if an incorrect or damaged insertion tool is used during installation of the piston.
- Piston ring flutter caused by excessive axial ring clearance. This condition can arise if only a new set of piston rings is installed during repairs, even though the ring grooves in the piston are already worn. The excessive play causes the rings to flutter and possibly break. Another reason for excessive axial ring clearance may be the use of an incorrect set of piston rings. As a result, the height of the rings may be too small, so the clearance in the groove could already be excessive when the rings are installed.
- This type of damage could also be caused by using a piston which is unsuitable for the intended purpose. Pistons for diesel engines are subjected to greater loads and are expected to endure a longer service life, so they are equipped with a ring carrier which is made of cast iron alloyed with nickel. Pistons without a ring carrier are sometimes used on diesel engines for cost reasons, but only if the service life is expected to be shorter. This could be the case for example on agricultural machinery. If this type of piston without a ring carrier is used in engines which are intended to cover high mileage or survive a long service life, there is a chance that the resistance of the ring grooves to wear may not be sufficient for the length of service life to be endured. At some point the groove is widened so far as a result of natural wear that the piston rings start to flutter, and the ring(s) may break as a result.



3.6 Piston pin fractures

3.6.0 General information about piston pin fractures

Piston pin fractures can occur as a result of overloads caused by abnormal combustion, the effects of foreign bodies or material defects. In the case of a material defect, the crack usually originates from a slag line. This can be reliably verified by carrying out tests on the material in a laboratory.

Excessive or inappropriate use of starting aids during cold starts (e.g. starting spray) should be viewed in the same way as the effects of extreme abnormal combustion.

During operation, the piston pin is bent by the forces exerted from the combustion gases on the piston and deformed into an oval shape. As a result of this deformation into an oval shape, under excessive loads a longitudinal crack can initially form at the ends of the pin, with its starting point either at the outer or inner diameter of the pin. The crack then spreads as a fatigue fracture on towards the centre of the pin. In the area between the piston pin eye and the connecting rod eye which is subjected to the greatest

shear stresses and bending loads, the crack then changes direction and becomes a lateral crack. This then ultimately causes the entire pin to break right through.

In addition to the scenarios described here, fractures can also arise as a result of some other kind of damage to the pin or because of a hardness defect.



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

3.6.1 Fractured piston pin

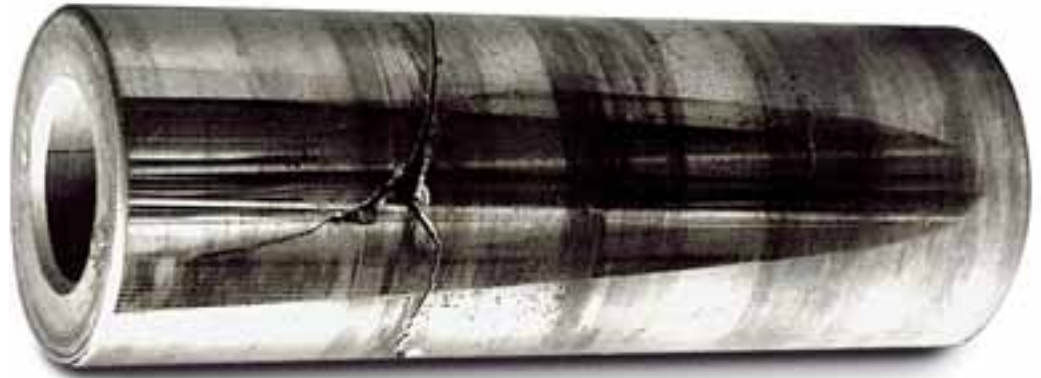
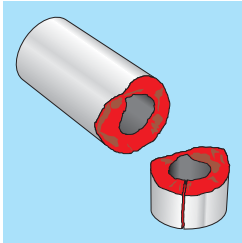


Fig. 1

Description of the damage

The piston pin in Fig. 1 has been completely broken due to a lateral crack at the transition between the connecting rod and the inner side of the piston pin boss.

The shorter fragment has been split along its length. The surfaces at the fracture displays the characteristics of a fatigue fracture.

Damage assessment

Provided there is no evidence of a material defect, piston pin fractures are always caused by excessive loads. Material defects can always be reliably identified by testing the material of the broken pin in laboratory tests.

Under excessive loads, the deformation of the piston pin to an oval shape in the piston pin bores initially causes a longitudinal crack at the ends of the pin. This crack can originate both in the outer surface and in the inner diameter. The crack then spreads as a fatigue fracture on towards the centre of the pin. In the area between the piston pin bore and the connecting rod small end which is subjected to the greatest shear stresses and bending loads, the crack

then changes direction and becomes a lateral crack. This then ultimately causes the entire pin to break right through.

Fig. 2 shows that an incipient crack can not only be caused by an excessive load, but also as a result of improper handling of the piston pin during installation. The end face of the broken piston pin clearly shows that the incipient fracture was caused by impact damage due to a blow, e.g. from a hammer. As can be seen from the above descriptions, even under normal load conditions any incipient fracture can develop as a fatigue fracture and ultimately lead to total breakage of the piston pin.



Fig.2

Possible causes for the damage

- Abnormal combustion on both petrol and diesel engines, in particular as a result of knocking combustion
- Hydraulic locks
- Improper handling of the piston pin during installation





3.7 Damage to the piston pin circlips

3.7.0 General information about damage to the piston pin circlips

Wire circlips or so-called Seeger-type circlips are used as retainers for the piston pins. It is possible for both types to break in operation or jump or be knocked out of the groove in the piston.

If the circlips fracture or their ends break off, this is always due to excessive loads or improper handling while inserting the circlips.

The circlips are only subjected to axial loads if the piston pin has an axial movement forced upon it. If the piston is misaligned or the connecting rod is

oscillating in an asymmetric fashion then this will cause the piston pin axis and the crankshaft axis to no longer be parallel, resulting in precisely this axial movement of the piston pin. The piston pin then strikes in a very rapidly alternating sequence against the piston pin circlips and gradually forces them out of the groove. They are then forced on as far as the cylinder running surface, where they are worn away. Ultimately the circlips will break up. Some fragments become trapped between the piston and the cylinder, while other parts are thrown back and forth under the forces of gravity in the

cutout of the piston pin bore, where they cause substantial material wash-out. It is also not uncommon for fragments to move through the inner bore in the piston pin right through to the other side of the piston, where they then also cause substantial amounts of damage.



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

3.7.1 Piston damage caused by broken piston pin circlips

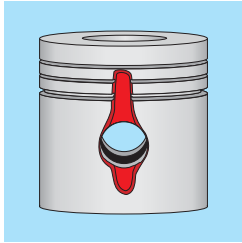


Fig. 1

Damage description I

On both sides of the piston, the end of the piston pin bore has suffered serious damage. In some places the damage reaches up as far as the ring zone (Fig. 1).

When the piston was removed there was no longer a circlip in the retaining groove. It had jumped out during operation and broken into fragments. Although the second circlip is damaged, it was still installed in its groove when the piston was removed. Due to the lack of retention, the piston pin has wandered outwards during operation towards the cylinder running surface. Clearly the front face of the pin has had prolonged contact with the cylinder running surface. As a result, the front face is worn to a convex shape (Fig. 3). The running pattern of the piston is formed very asymmetrically.

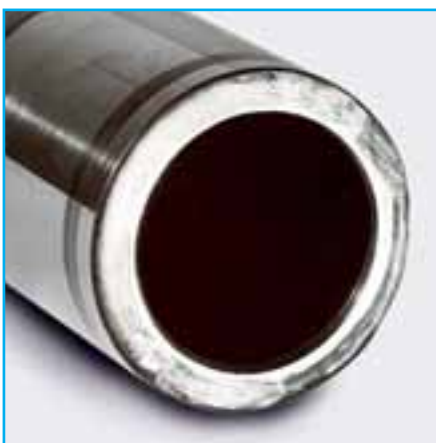


Fig. 3



Fig. 2

Piston damages

DESCRIPTION – ASSESSMENT – CAUSES



Fig. 4



Fig. 5



Fig. 6

Damage description II

In this case the piston has been running at an angle, which has also caused the piston pin circlip to be hammered out. As a result of the piston running at an angle in the cylinder and the one-sided load on the piston pin, the piston pin has broken (Fig. 6), and subsequently the piston has been broken as well (Fig. 5). The asymmetrical running pattern resulting from the piston running at an angle can be seen very clearly in Fig. 4 .



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Damage assessment

Whether as wire circlips or Seeger-type circlips, the piston pin circlip can only be forced out or hammered out in operation by means of an axial displacement of the piston pin. However, this is based on the requirement that the circlip has been correctly inserted and has not been damaged. Axial thrust in the piston pin always occurs when the piston pin axis is not parallel to the crankshaft axis during operation. This is most commonly

the case when a bent connecting rod leads to the piston running at an angle. The reciprocating movements of the piston result in an alternating axial thrust which effectively hammers out the circlip lying in the main pressure direction. Once the circlip has jumped out, it is then clamped between the piston pin moving in an outward direction, the piston and the cylinder running surface. There, it is worn away and finally breaks into several frag-

ments. Under their own inertia forces and the reciprocating movements of the piston, the fragments hammer into the piston material and break it down within a very short space of time, as can be seen in Fig. 2. Individual fragments also move through the hollow piston pin and cause corresponding destruction on the opposite side of the piston.

Possible causes for the damage

- Axial thrust of the piston pin during engine operation caused by:
 - Bending or twisting of the connecting rod
 - Axes of conrod small ends not bored parallel to crank shaft axis
 - Cylinder axis not rectangular (90°) to crank shaft axis
 - Excessive connecting rod big-end bearing clearance, particularly in conjunction with asymmetrical connecting rods
 - Use of old or damaged circlips
 - Improperly installed circlips





3.8 General information about seizures in the piston pin bore

3.8.0 Seizures in the piston pin bore can be a primary or secondary consequence of piston skirt seizures.

As the piston pin and the piston pin bores are not forcibly supplied with oil and only splash oil is available, seizures on the piston pin bed are nearly always typical dry seizures due to insufficient lubrication, with severely torn up surfaces and fusion of materials.

On floating-fit piston pins, primary seizures in the piston pin bores arise as a result of insufficient clearances or jamming if the piston is running at an angle.

This restricts the freedom of motion of the piston pin in the small-end bush. The pin is then forced to move back and forth in the piston pin bore. However, the clearance of a floating-fit piston pin in the piston pin bore is too small. Extreme build-up of heat and the resulting collapse of the lubrication system with dry running and seizures are then an unavoidable consequence.

Due to the high temperature increase, the piston also expands a great deal more on the skirt in the area of the piston pin bore. There, this can lead to a lack of clearances, as well as dry-running and seizures (see also point 3.1.2 Piston seizures next to the piston pin bore).

For piston pins which are shrunk into the connecting rod, the clearance in the piston pin bore is sufficiently dimensioned to ensure that a thick enough film of oil can form there at all times. When reusing used shrink-fit connecting rods it is important to ensure that the bore in the connecting rod has not become distorted or damaged in any other way. Otherwise, once the piston pin has been shrunk in place it could become deformed to such an extent that the clearance in the piston pin bores is no longer sufficient in places, as a result of which seizures could form very easily.

Always lubricate the piston pin and the piston pin bore when installing the pistons in the engine to ensure that enough lubrication is provided for the first few revolutions of the engine.

Note:

During the process of shrinking the piston pin into the connecting rod, it is also important that, in addition to the above-mentioned lubrication of the piston pin, the piston pin bed must not be checked for freedom of movement immediately after installation by tilting the piston back and forth. The temperatures are equalized immediately between the two components after the cool piston pin is inserted into the hot connecting rod. The piston pin can still become very hot as a result and expand so far that it seizes in the piston pin bore which is still cool. If the bearing is moved in this state then it can cause initial rubbing marks or seizure marks which will cause subsequent stiffness of the bearing (and thus increased friction and heat generation) during operation. For this reason the assembled components should be allowed to cool down first before checking them for freedom of movement.

Secondary seizures in the piston pin bores are triggered by severe piston skirt seizures. Here, the entire piston can be heated up to such an extent that the lubrication breaks down in the piston pin bores as well. In some cases, abraded material from the skirt seizures can also be washed into the piston pin bed.

3.8.1 Seizure in the piston pin bore (floating-fit piston pin)

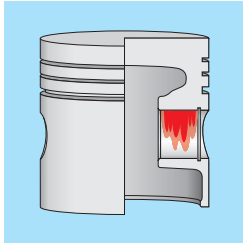


Fig. 1

Description of the damage

The piston pin has seized heavily in the piston pin bores. Piston material has been virtually “welded” onto the piston pin (Fig. 1). The piston pin displays a blue discoloration in the area of the connecting rod-small-end bush. There are no seizure marks on the piston skirt itself.

Damage assessment

The blue discoloration of the piston pin in the area of the connecting rod-small-end bush indicates that the clearance there was insufficient, and that as a result the piston pin was

only able to rotate in the small-end bush with increased difficulty or not at all. As a result, the only rotation of the piston pin took place in the piston pin bore. However, the clearance of a

floating-fit piston pin is too small for this. The increased friction caused excessive overheating in the bearing, as a result of which the oil film became ineffective and the piston pin seizure arose.

Possible causes for the damage

- The clearance between the small-end bush and the piston pin was not made large enough.
- Possibly the clearance in the small-end bush was reduced or even

eliminated by a misalignment of the connecting rod and the piston pin became seized as a result.

- The piston pin and piston pin bore was not lubricated during installation of the piston.

Note:

It is essential to lubricate the piston pin and the piston pin bore when installing the pistons to ensure that sufficient lubrication is present during the first few revolutions of the engine and to prevent rubbing marks from being formed straight away when the engine is started.

3.8.2 Seizure in the piston pin bore (shrink-fit connecting rod)

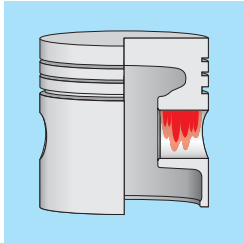


Fig. 1

Description of the damage

This piston has clearly only run for a short length of time. Neither a deposit on the crown nor any running marks can be seen. The piston pin has seized in both piston pin eyes on the upper side, i.e. the side under pressure load (Fig. 1). The surface at the seizures is clean bare metal. No traces of burned-in oil are evident.

Damage assessment

The piston has barely any running marks and can therefore only have been run for a short time. It can therefore be

assumed that the piston pin seized during the first revolutions of the engine. The clean bare metal seizures are a

clear indication of a lack of oil in the piston pin bed.

Possible causes for the damage

- It is possible that the piston pin and the piston pin bore were not lubricated before the piston pin was assembled in the engine.
- During the shrink-fitting process for inserting the piston pin into the connecting rod, the freedom of movement between the piston pin and the piston pin bore was checked immediately after inserting the piston pin by tilting the piston back and forth. The surfaces of the piston and the piston pin bore can suffer at this point as a result of the unusual temperature differences between the components which do not occur in normal operation.





Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

3.8.3 Seizure in the piston pin bore (with piston skirt seizure)

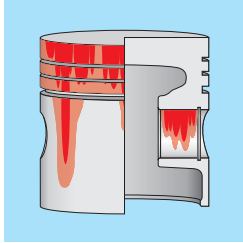


Fig. 1

Description of the damage

The piston has seized all around its circumference with the main focus on the piston top land (Fig. 1). The compression rings have become blocked in the ring grooves. Seizure marks are present in both piston pin bores.

Damage assessment

As the main focus of the seizures is on the piston top land, it is safe to assume that this is where the damage obviously originated as a result of abnormal combustion. Subsequently the

piston rings seized up, and the seizure marks spread increasingly down onto the skirt. The combustion gases which flew past the seized compression rings then heated up the piston

to such a point that eventually the oil film in the piston pin bed became ineffective, and seizures developed here as well.

Possible causes for the damage

- Abnormal combustion which lead to a seizure due to the combined effects of insufficient clearance and lack of lubrication on the piston top

land and skirt and subsequently also cause seizures in the piston pin bed.





3.9 Piston noises

3.9.0 General information about piston noises

Piston running noises can be caused by a wide variety of influences during operation of the engine.

- **Tilting of the pistons due to excessive clearance:**
The piston can tilt if the dimensions of the cylinder bore are too large or as a result of wear / material breakdown, stimulated by the pendulum motion of the connecting rod and the change of bearing surface of the piston in the cylinder, and the piston hits hard against the cylinder running surface (with the piston crown in particular) as a result.
- **Tilting of the piston caused by insufficient clearance in the piston pin bed:**
The clearance between the piston pin and the small-end bush can either be too small by design, or it may have been eliminated by jamming or warping in operation. This can happen particularly as a result of connecting rod misalignment (bending and/or twisting).
- **Piston striking in the direction of the piston pin:**
Any lateral striking of the cylinder bore by the piston mostly stems from the connecting rod. Due to misalignment of the connecting rod (bending or twisting in particular), the piston performs a pendulum movement during its upward/downward stroke in the longitudinal axis of the engine, as a result of which the piston strikes in an alternating sequence against the cylinder. Asymmetrical connecting rods or non-concentric support for the piston by the connecting rod have the same effect.
- **Piston pin striking alternately against the piston pin circlips:**
Axial thrust in the piston pin is always the result of an alignment error between the axis of the piston pin and the crankshaft axis. As described in the previous point, distortion or twisting of the connecting rod and asymmetry of the connecting rod are the most common causes for this type of fault. However, excessive big-end bearing clearances (big-end bearing journal on the crankshaft) can cause a lateral pendulum movement of the connecting rod, particularly at lower engine speeds. The piston pin is skewed as a result in the connecting small end rod and is pushed back and forth in the piston pin bore due to the pendulum motion of the piston. The piston pin strikes against the piston pin circlips as a consequence.
- **The correct installation direction of the piston was ignored:**
In order to smoothen the change of the contact surface of the piston before TDC and before the power stroke, the piston pin axis is offset by some tenth of a millimetre towards the piston pressure side. If the piston is inserted the wrong way round (i.e. rotated by 180°) and therefore the piston pin axis is offset to the wrong direction, then the piston changes bearing surface at the wrong time. The piston tilting is then much heavier and much noisier.



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

3.9.1 Radial impact points on the piston top land

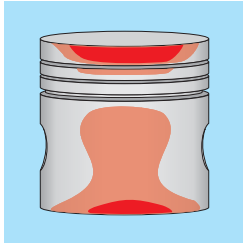


Fig. 1

Description of the damage

The piston top land has impact marks in the tilt direction (Fig. 1). The piston skirt displays a more pronounced running pattern to the top and bottom than in the middle of the skirt.

Damage assessment

One type of piston noise which is perceived as particularly annoying is caused by the piston crown striking

alternating sides of the cylinder running surface. Depending on the cause, the piston top land strikes either in

the tilt direction or in the oval plane (piston pin direction) against the cylinder wall.

Possible damage reasons for impact points in the tilt direction

- Excessive installation clearances and hence poor guidance of the piston due to excessively large bored or honed cylinders.
- The installation direction was not observed for pistons with a piston pin axis offset.
- Tight connection between piston and conrod: As a result of the lack of clearance, the piston top land strikes against the cylinder running surface in the so-called tilt direction.

Reasons for this are:

- Insufficient clearance in the connecting rod small end or in the piston pin bore.

- Excessively narrow fit of the piston pin in the small-end bush (shrink-fit connecting rod). If fit of the piston pin is too tight in the connecting rod small end, then the connecting rod small end is deformed in the direction of the narrowest wall thickness when the piston pin is shrunk and installed. The connecting rod small end and the piston pin take on an oval form in the process.
- On shrink-fit connecting rods: restriction of the clearance between the piston pin and the piston caused by distortion of the piston pin as a result of the bore in the connecting rod small end no longer being geometrically round.
- Seized piston pin

Possible damage reasons for impact points in the piston pin direction

- In case of misalignment of the connecting rod, particularly in the case of a twisted connecting rod or excessive big-end bearing clearances, the piston crown moves in a pendulum motion in the piston pin direction and strikes against the cylinder wall.
- Connecting rod alignment faults (distortion/twisting): This results in alternating axial thrust in the piston pin, as a result of which the piston pin strikes alternately against the circlips at either end.



3.10 Cylinders and cylinder liners





Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

3.10.1 Longitudinal cylinder liner cracks

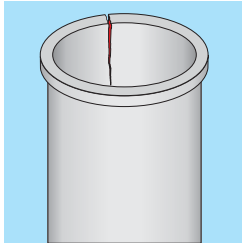


Fig. 1

Description of the damage

The crack is usually vertical and usually extends in a vertical direction from the liner flange. Dry liners can also be affected because of their relatively thin cylinder wall thickness.

Damage assessment

Cylinder liner cracks of this nature are frequently caused by careless handling (e.g. the results of impacts or blows). Even if the liner does not suffer visible damage straight away, a microscopic crack or notch can

generate a fracture during subsequent operation of the engine and therefore cause failure of the component. Similarly to the case described above, incorrect contact of the flange and dirt between the cylinder liner and the cyl-

inder block can also cause this type of damage. The longitudinal cracks often occur in conjunction with lateral cracks in cases of longitudinal cracks caused by faulty flange contact surfaces.

Possible causes for the damage

- Improper and careless handling of the cylinder liners during transport or repairs and associated damage due to cracks or notches.
- Hydraulic locks
- Foreign bodies underneath sealing surfaces.
- Faulty flange contact. (Refer also to point “3.10.2 Torn off flange on the cylinder liner”)



3.10.2 Torn off flange on the cylinder liner



Fig. 1

Description of the damage

The complete flange of the cylinder liner has been torn off (Fig. 1). The flange crack starts at the base of the lower edge of the liner flange and extends upwards under an angle of approx. 30°.

Damage assessment

This type of damage is caused by bending moments which arise as a result of improper installation (dirt / form defects). There are many reasons which can cause this type of fracture. In most cases, the cylinder liner flange is already pressed off when the cylinder head is tightened down. On the latest generations of engines for commercial vehicles with unit injectors or common rail fuel injection systems, the cylinder block is subjected to increasing loads as a result of the increasing combustion pressures. The use of very hard steel cylinder head gaskets on these two engine types can cause distortion of the crankcase in the area of the cylinder liner contact surface after the engine has been in operation for a long time. The distortion of the contact surface cannot be

detected by visual inspection alone unless the appropriate measuring aids are used.

One simple way to check for this distortion is the use of bearing ink. The ink is thinly applied around the contact surface of the liner flange on the cylinder block. The new liner is then inserted without gaskets and pressed onto the seat. The liner is then removed again. The contact surface on the liner should now be evenly coated with ink around the entire circumference. The liner seat needs to be reworked if any areas have not come into contact with ink. This reworking is best performed on a stationary horizontal boring machine or with a mobile liner flange lathe. This is the only way to ensure parallelism to the upper housing surface (Fig. 2).

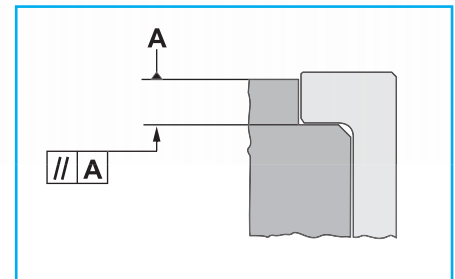


Fig. 2



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Possible causes for the damage

- Use of non-approved gaskets (in some cases the aftermarket gaskets have different shapes and diameters).
- Non-compliance with the engine manufacturer's recommended tightening torques and tightening angles.
- Failure to carefully clean any dirt off the liner seat in the cylinder block.
- Failure to ensure that the flange contact surface is perfectly rectangular and/or parallel (Figs. 2 and 5).
- Reworking of the flange seat without due care for the proper form. The form of the liner seat must correspond to the form of the cylinder liner.

The transition from the flange surface to the precision-fit seat diameter must have a bevelled edge of 0.5–1.0 mm X 45° to prevent the channel on the liner flange from making contact with the edge. If this is not ensured then it is very easy for the flange to be pressed off when the cylinder head is tightened down (Fig. 3).

Furthermore, it must also be ensured that the shape of the liner seat radius (D) in Fig. 4 is not chosen so large as to prevent the liner from bearing loads at the inner or outer edge on the liner flange.

- If the liner flange does not project by the prescribed dimension from the cylinder sealing surface, or if it is slightly recessed (Fig. 6), then the liner is not pressed onto the liner seat with enough force during installation. During operation, this can cause the liner to also adopt a pendulum motion as a result of the pendulum motion of the piston. The resulting forces acting on the liner flange can cause it to be torn off. If it is necessary to rework the liner flange contact surface during a major engine overhaul, it is possible to either insert steel adjustment shims underneath or use a liner with an oversized flange to provide the necessary protrusion of the liner over the cylinder surface. The solution involving a liner with oversized flange* is preferable to the option of inserting adjustment shims underneath, as it is technically the more sturdy solution.

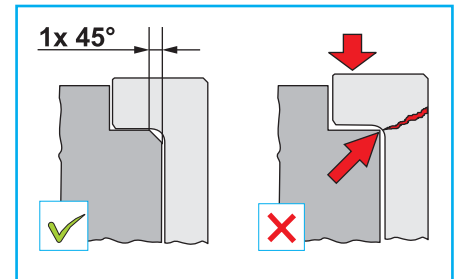


Fig. 3

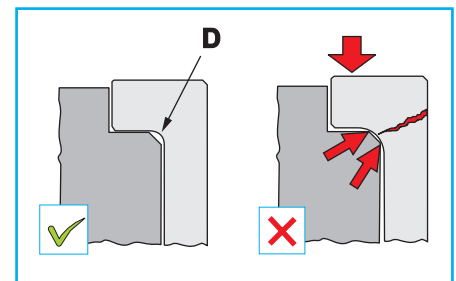


Fig. 4

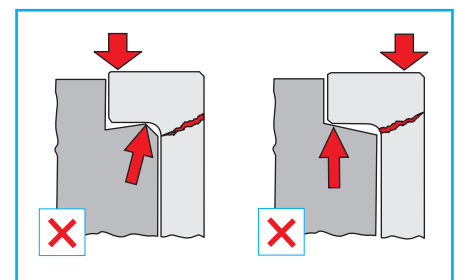


Fig. 5

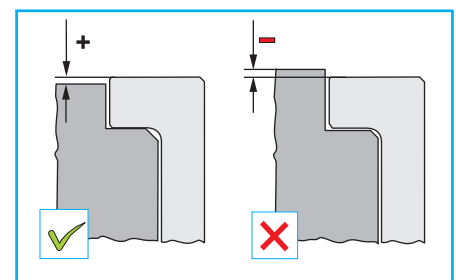
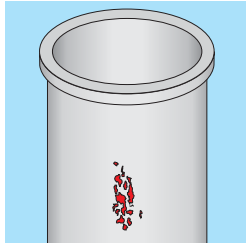


Fig. 6

* MSI supply cylinder liners with oversized flanges for most engines. Please refer to our current catalogue "Pistons, Cylinders and Kit Sets".

3.10.3 Cavitation on cylinder liners



Description of the damage

The wet cylinder liner displays severe cavitation in the area of the water jacket. The damage has progressed so far that there is already one hole into the inside of the cylinder.



Fig. 1



Fig. 2



Fig. 3 cross section of liner

Damage assessment

Cavitation is more likely to occur in the tilt direction of the piston (on the pressure or counterpressure side) and is triggered by vibrations of the cylinder wall. These high-frequency vibrations are caused by the combustion pressure, the lateral forces exerted by the pistons and the piston's change of bearing surfaces at TDC and BDC. If the cooling liquid is no longer capable of following the vibrations of the cylinder

wall, this results in temporary separation of the water film from the cylinder liner. Tiny vapour bubbles form in the resulting area of low pressure, and when the cylinder wall vibrates back at exceptionally high speed, these bubbles implode. The water displaced by the bubbles hits the surface of the cylinder very suddenly when the tiny bubbles implode. The impact energy generated in this way dissolves tiny

particles from the surface of the cylinder. With time, complete holes are torn out (washed out). A special feature of cavitation is the fact that the size of the holes increases further inside the material (Fig. 3), resulting in the cavities from which the name of this type of damage is taken.



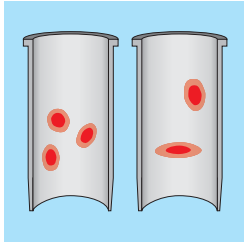
Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Possible causes for the damage

- Failure to comply with the correct piston clearance (re-installation of pistons which have already been used, or use of cylinders manufactured too large).
- Poor or inaccurate seating of the liner in the housing.
- The required permanent anti-freeze protection or corresponding additives in the cooling water are missing. The anti-corrosion protection agent contains inhibitors which prevent foaming. However, these inhibitors are gradually used up with time. Therefore it is necessary to change the anti-corrosion protection agent every 2 years and to use the correct mixture ratio.
- Use of unsuitable coolants such as salt water (sea water), aggressive or acidic water or other liquids.
- Lack of pre-pressure in the cooling system: The required radiator pre-pressure cannot be maintained as a result of using an unsuitable radiator cap (not enough pressure can be maintained due to a defective pressure relief valve) or because of a leak in the cooling system. If the pre-pressure in the cooling system is in accordance with the requirements, the boiling temperature of the coolant is higher than under atmospheric pressure. Although the pre-pressure in the cooling system cannot eliminate the cause for formation of the tiny vapour bubbles altogether, it can at least inhibit the formation of the bubbles.
- Engine operating temperature too low: If due to particular operating conditions or thermostat defects the engine does not reach its normal operating temperature, no excess pressure can build up in the cooling system because of the reduced thermal expansion of the coolant. The low operating temperature also means that the pistons do not expand in the required manner. As a result they run with increased piston clearance. Both cases assist the formation of the tiny bubbles and hence the effects of cavitation. ■

3.10.4 Uneven cylinder wear



Description of the damage

The cylinder bores display an uneven wear pattern with individual brightly polished areas (Fig. 2). No wear or rubbing marks are evident on the pistons. The engine was loosing oil at the sealing points, in particular the radial oil seals. Fig. 1 clearly shows the corrosion on the outer diameter of the cylinder liner which caused the out-of-roundness of the cylinder when it was installed.



Fig. 1



Fig. 2

Damage assessment

Highly polished irregular running patterns on the running surfaces in the cylinders always indicate cylinder distortion. Wet or dry cylinder liners in particular can already be distorted immediately after installation. If the cylinder is distorted the piston rings can neither provide a perfectly tight seal

for the oil nor the combustion gases. The oil escapes past the piston rings into the combustion chamber, where it is burned. The increasing quantities of combustion gases flowing past the piston causes the pressure in the crankcase to rise. This overpressure causes oil loss at various sealing

points around the engine, particularly at the radial oil seals. Furthermore, oil is forced through the valve guides into the intake and exhaust ducts, from where it is then sucked in by the engine and burned or eliminated.



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Possible causes for the damage

- Uneven or incorrect tightening of the cylinder head bolts.
- Uneven cylinder block and cylinder head sealing surfaces.
- Dirty or distorted threads on the cylinder head bolts.
- Unsuitable or incorrect cylinder head gaskets.
- Faulty flange contact in the housing, incorrect cylinder liner protrusion and distorted and/or a worn out lower liner guide can be the causes for substantial cylinder distortion.
- Liner seat too loose or too tight in the housing (on dry cylinder liners).
- Individual ribbed cylinders must lie exactly plane-parallel to the crankcase and the cylinder head. If several cylinders share a joint cylinder head then it is important that the ribbed cylinders have exactly the same height. The presence and arrangement of the air baffles is highly significant on this engine layout.
- With dry liners, significant unevenness is often caused during operation by contact corrosion in the counter bores in the housings (Fig. 1). In this case the cylinder counter bore should be cleaned carefully. If the process of cleaning alone does not promise good results, then the cylinder counter bores should be reworked, and afterwards a cylinder liner with external oversize* should be installed. The liners have very thin walls and must be able to make contact across their full length and width. If this is not the case then the liners will already become deformed on installation (and definitely during operation).
With dry cylinder liners, a distinction is made between press-fit and slip-fit types. Press-fit liners are

pressed into the cylinder block and still need to be bored and honed after being pressed in. Slip-fit liners are already finished off and only need to be slipped into the counter bore. Due to the clearance which remains between the liner and the cylinder counter bore on slip-fit liners, this type of liner has a greater tendency than the press-fit type to problems with distortion and corrosion.

- Distorted cylinder bores on cylinder blocks without cylinder liners. Certain engines have a tendency towards distortion during installation of the cylinder head. If these engines are bored and honed in the normal way then there can be distortion problems during subsequent operation of the engine.

Recommendation:

On cylinder blocks without cylinder liners where the cylinders are bored directly into the cylinder block, we recommend bolting a torque plate (also referred to as a honing mask) onto the sealing surfaces of the cylinder before machining the cylinder. This torque plate has the same openings as the cylinder block (apart from the water ducts) and is several centimetres thick. The act of bolting on this tool and tightening it to the specified tightening torque for the cylinder head bolts creates the same tension conditions as if the cylinder head were installed. Any distortion in the cylinder bores which could arise after tightening the cylinder head bolts is therefore deliberately simulated and is therefore taken into account during the machining of the cylinders. This ensures that the cylinder bore is (to

a great extent) round and cylindrical during subsequent operation of the engine (provided the machining is carried out properly).

It is recommended that when machining and inserting new cylinder liners into a cylinder block that has siamese bores, that the actual siamesed bores should all have new cylinder liners fitted i.e.: a four cylinder block that has a 2.2 cylinder formation (two cylinder space and then a further two cylinders) should have the two adjacent cylinders machined and fitted with new liners. The ideal situation is of course two always fit new cylinder liners in engine sets.

* MSI supply cylinder liners with oversize diameter.
Please refer to our current catalogue "Pistons, Cylinders and Assemblies".

Piston damages

DESCRIPTION – ASSESSMENT – CAUSES



3.10.5 Brightly polished areas in the upper part of the cylinder

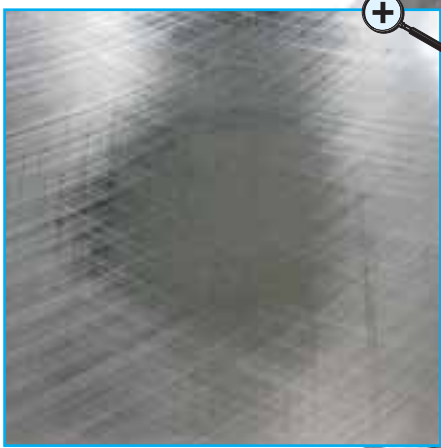
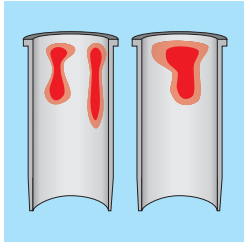


Fig. 2

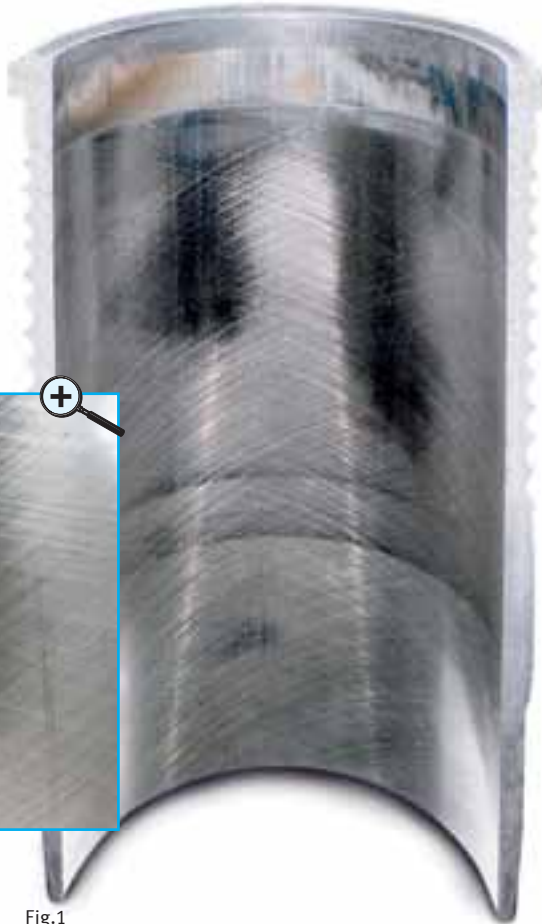


Fig.1

Description of the damage

In its upper area, the cylinder running surface has highly polished, bare areas in which the honing structure is completely unrecognisable (Fig. 1 and Fig 2). There are no significant signs of wear on the piston itself. The engine is consuming increased quantities of oil.



Fig. 3



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Damage assessment

This type of damage pattern occurs when a hard oil carbon deposit forms in operation on the piston top land as a result of burned oil and combustion residues (Fig. 3). This coating has abrasive properties which lead to increased wear in the upper part of the cylinder in operation due to the reciprocal motion and the change of bearing surfaces of the piston. The increased oil consumption is not caused by the polished areas themselves, as the polished areas do not cause a noticeable out-of-roundness of the

cylinder, and the piston rings can still continue to perform their sealing duties in the normal fashion. The lubrication of the cylinder is also unaffected, as it is still possible to retain enough oil in the open graphite veins of the cylinder surface despite the loss of the honing structure. When assessing this type of damage, it is important to note that, in this case, the polished areas all coincide with points in the cylinder which come into contact with the carbonised piston top land. If the polished areas are also present at

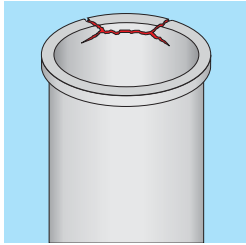
points which do not come into contact with the piston top land, then the cause for the damage is more likely to be found in distortion of the cylinder (point “3.10.4 Uneven cylinder wear”), fuel flooding (point “3.11.3 Wear on the pistons, piston rings and cylinders caused by fuel flooding”) or ingress of dirt or contaminants (point “3.11.2 Wear on the pistons, piston rings and cylinders caused by the ingress of dirt”).

Possible causes for the damage

- Excessively high ingress of engine oil into the combustion chamber due to a defective turbocharger, inadequate oil separation in the engine breather, defective valve stem seals etc.
- Excessive pressure in the crankcase due to increased emissions of blow-by gases or due to a faulty crankcase breather valve.
- Inadequate finishing of the cylinder, resulting in increased ingress of oil into the combustion chamber (see also point 3.11.4 Piston ring wear soon after a major engine overhaul).
- Use of non-approved engine oils or engine oils of a lower quality.



3.10.6 Cylinder liner fracture due to hydraulic lock



Description of the damage

The cylinder liner displays severe damage due to a crack in its upper area, together with seizure marks on the running surface (Figs. 1 and 2). The associated piston also displays seizure marks on the pressure and counterpressure side. A trough-shaped indentation in the piston crown has formed in the area where the seizure marks are present on the skirt (Fig. 3).



Fig. 1



Fig. 2



Fig. 3



Fig. 4



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Damage assessment

The cylinder has suffered a hydraulic lock in operation. The high pressure from the liquid has burst the cylinder liner and pressed an a dent the piston crown. As a result, the piston mate-

rial has been squashed outwards, causing a significant restriction of the clearance in this area and the seizure marks on both sides of the piston and the cylinder liner. It can no longer be

identified whether the hydraulic lock occurred while the engine was running or while it was being started.

Possible causes for the damage

- Accidental intake of water while driving through high water, puddles or low rivers/waters, or as a result of larger quantities of water being splashed up by passing vehicles or vehicles in front.
- Cylinder filling up with water while the engine is stationary due to leaks in the cylinder head gasket or due to cracks in components.
- Cylinder filling up with fuel due to leaking injectors while the engine is stationary. The residual pressure in the fuel injection system is dissipated through the leaking nozzle into the cylinder. In this case and the one above the described damage will occur when the engine is started.





3.11 Increased oil consumption

3.11.0 General information on oil consumption

The total amount of oil used by an engine is primarily made up of oil consumption (i.e. oil burned in the combustion chamber) and oil loss (i.e. leaks). In contrast to still prevailing and widely-held views, oil consumption due to oil passing the pistons and piston rings into the combustion chamber plays a far less important role today.

As a result of the continuous development of engines, the design of individual parts, material compositions and production processes have been improved and highly optimised. For this reason, the effects of wear on cylinders, pistons and piston rings and the resulting increase in oil consumption are among the more negligible concerns on a modern engine. This is underlined by the high mileages which can currently be achieved and the reduction of incidents of damage to the crankshaft drive.

Although the oil consumption due to oil which passes between the piston rings and the cylinder wall into the combustion chamber cannot be completely eliminated with technical means, it can however be minimised. The moving parts (piston, piston rings and cylinder running surface) require continuous lubrication to ensure frictionless and smooth operation. During the combustion stage the remaining oil film on the cylinder wall is subjected to the heat of the combustion. The quantity of oil which evaporates or burns here depends on the power output of the engine, the engine load and the temperature. Guide values for normal oil consumption are in the range from 0.2 to 1.5 g/kWh (max.).

In the majority of cases, wear on pistons, piston rings and cylinders and the resulting increased or excessive consumption of oil is not caused by

the components themselves. Instead, wear on these components can nearly always be explained as the result of an external event. Abnormal combustion due to incorrect mixture formation, dirt entering the engine from outside, inadequate engine cooling, lack of oil, incorrect oil grades and errors made during installation are the main reasons for premature wear and, subsequently, increased oil consumption. The following pages contain detailed descriptions of different types of damage which affects pistons, piston rings and cylinders.

Due to the complexity of the whole topic of oil consumption, a separate booklet entitled “Oil Consumption & Loss of Oil” has been published in the Service Tips & Information series. Ordering information can be found in the appendix attached to this document. The topics covered in the

booklet are:

- excessive bearing clearance in the turbocharger
- blocked oil return line on the turbocharger
- worn fuel injection pumps
- oil leaks into the intake system
- worn valve stem seams and valve guides
- errors made during installation of the cylinder head
- excess pressure in the crankcase
- excessively high oil levels
- abnormal combustion and fuel flooding
- incorrect piston protrusion
- irregular servicing / maintenance
- use of sub-quality mineral oils
- cylinder distortion
- machining faults during boring and honing
- graphite exposure rate too low
- twisted/distorted connecting rods
- broken/jammed/incorrectly installed piston rings



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

3.11.1 Incorrectly installed oil scraper ring (increased oil consumption after engine repairs)

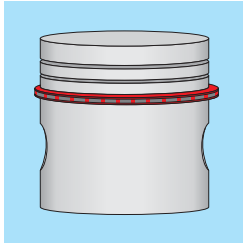


Fig. 1



Description of the damage

The rings do not display any visible or measurable wear. No signs of wear are evident on the pistons either (Fig. 1). In this case, the oil scraper ring is a 3 piece oil control ring comprising the expander spring and the two blade rings. Both of the ends of the expander spring should normally be flushed against each other. In this case the expander spring had been installed incorrectly, and the last segment overlapped at the joint (Fig. 2).

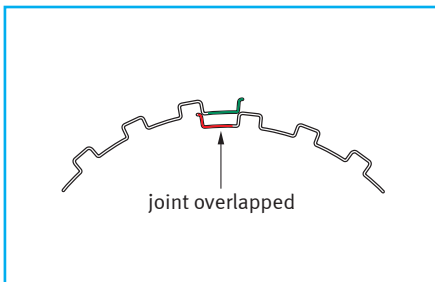


Fig. 2

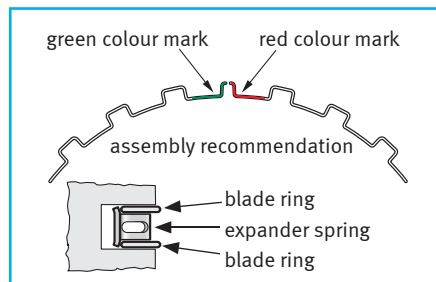


Fig. 3

Damage assessment

Due to the overlapping of the ends of the expander spring during installation, its circumferential length is shortened and the tension is lost for

the blade rings. The blade rings are then no longer pressed tightly against the cylinder wall, and as a result the oil scraper ring is no longer capable of

scraping off the oil. Oil can then enter the combustion chamber, where it is burned. Excessive oil consumption is a result.

Possible causes for the damage

The mistake was already made when the piston and piston rings were installed in the cylinder bore, as care was not taken to ensure correct installation of the expander spring. Usually,

the ends of the spring are colour-coded, for example green for the left end of the joint, and red for the right end of the joint.

Caution!

Both coloured parts of the expander spring must be visible after installation of the blade rings. These colour-coded marks should therefore *always* be checked (even on pre-assembled piston rings) before installation of the pistons in the cylinder bore (Fig. 3).

3.11.2 Wear on pistons, piston rings and cylinder running surfaces caused by the ingress of dirt (increased oil consumption)

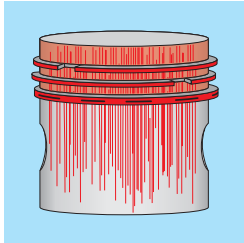


Fig. 1

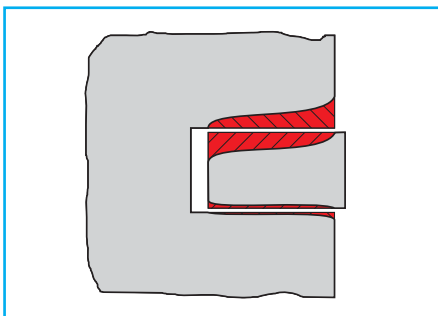


Fig. 2



Fig. 3

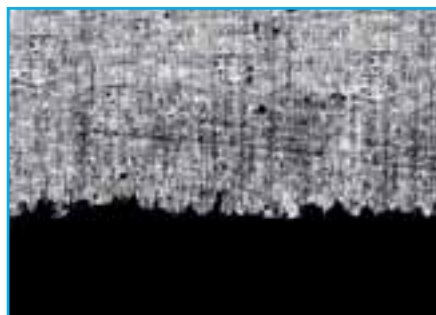


Fig. 4

Description of the damage

The piston skirt (Fig. 1) displays a milky-grey (buffed) wear pattern with fine, small longitudinal scratches on the piston top land and the piston skirt. The tool marks created during machining of the piston have been completely worn away from the skirt. Fig. 3 shows an enlarged section of the piston skirt on which this abrasive wear is clearly evident. The axial height of the piston rings has been substantially reduced because of the wear, and as a result the tangential tension has also been reduced. The edges of the compression rings (the first ring in particular) and the edges of the ring grooves are worn (Fig. 2). The sharp, oil-scraping edges of the piston rings have become frayed, leading to the formation of a burr (Fig. 4). In the microscopic enlargement, roll marks can be seen on the surfaces of the piston ring flanges. The cylinders have been worn into a bulged shape, with the largest diameter at approximately the centre of the ring running surface.

Damage assessment

Scratches on the piston and piston rings, a matt wear pattern on the piston skirt, roll marks on the ring flanges (Figs. 6 and 7) and a bulging cylinder wear (Fig. 5) are always the consequence of abrasive foreign bodies in the oil circuit. As the piston rings are worn on the running surfaces and edges, they can no longer seal the cylinder sufficiently and can therefore no longer prevent oil from passing into the combustion chamber. At the same time, the pressure in the crankcase increases as a result of combustion gases flowing past the cylinder. This excessive pressure can cause increased quantities of oil to escape through radial oil seals, valve stem seals and other sealing points.

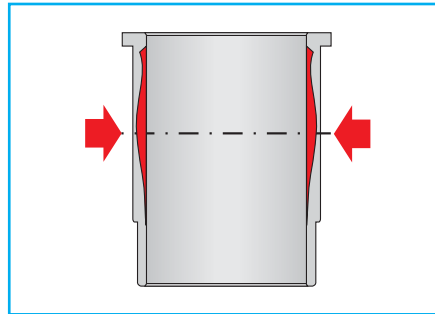


Fig. 5

Roll marks on the rings are caused by dirt particles which become lodged in the ring groove. As the piston ring rotates in the groove, it keeps running over the dirt particle and gradually creates the characteristic marks on the piston ring flanks.

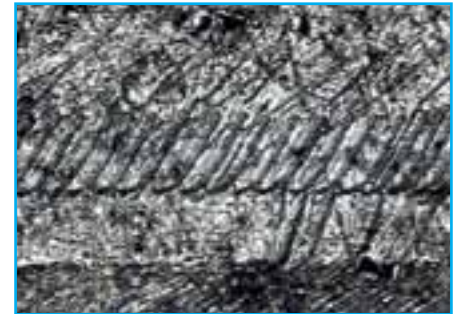


Fig. 6

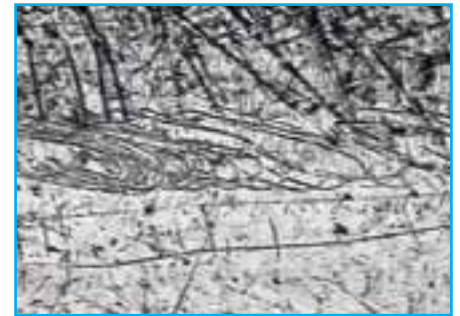


Fig. 7

Possible causes for the damage

- Abrasive dirt particles which enter the engine with the intake air due to inadequate filtration, including:
 - missing, defective, deformed or poorly maintained air filters
 - leaking points in the intake system, such as distorted flanges, missing gaskets or defective or porous hoses
- Particles of dirt which are not completely removed during an engine overhaul. Parts of the engine are often blasted with sand or glass beads during an overhaul in order to remove persistent deposits or combustion residues from the surfaces. If the blasting materials become deposited in the material and are not cleaned out properly then they may work their way loose when the

engine is running, thus causing abrasive wear. Figs. 8 and 9 show this type of damage due to dirt. The images were recorded with polarised light under a microscope in our laboratory. Glass fragments and even entire beads of the glass used for blasting can be clearly seen.

- If the first oil change is performed too late, the abraded particles which are generated when the engine is run in are then spread through the oil circuit to the other moving parts where they cause more damage. However, the sharp oil-scraping edges of the piston rings are particularly prone to damage.

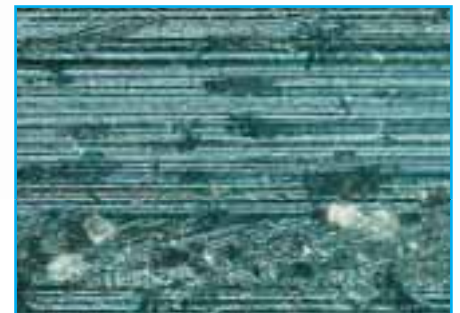


Fig. 8

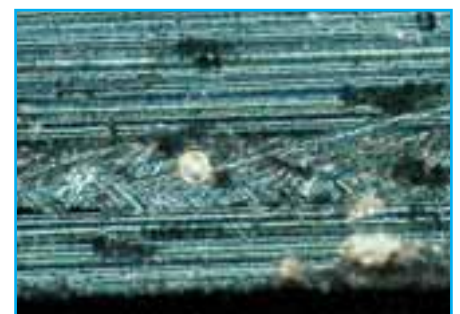


Fig. 9



3.11.3 Wear on pistons, piston rings and cylinder running surfaces caused by fuel flooding (increased oil consumption)

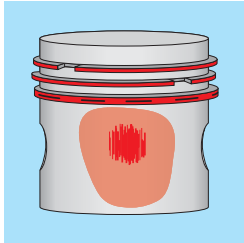


Fig. 1

Description of the damage

The piston displays signs of wear on the piston top land and the piston skirt. Rubbing marks can already be seen on the piston skirt which are characteristic for dry-running due to fuel flooding. The piston rings display very severe radial wear (Fig. 1). Both of the webs (support surfaces) on the oil scraper ring have been completely worn down, which also indicates significant wear (Fig. 2). By comparison, Fig. 3 shows the profile of a new and worn oil scraper ring (double bevelled spiral expander ring).



Fig. 2



Fig. 3



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Damage assessment

Fuel flooding due to abnormal combustion always damages the oil film. This initially leads to a higher level of mixed friction and therefore increased wear in the piston ring area. The characteristic damage caused by unburned fuel does not arise until the oil film is destroyed by the fuel to such an extent that the piston is running without lubrication (see also point “3.2.3 Dry running damage due to lack of lubrication

caused by fuel flooding”). However, the increasingly ineffective lubrication results in high levels of wear on the piston rings, piston ring grooves and cylinder running surfaces.

In the initial stages the piston skirt is affected to a lesser degree, as it is continuously supplied with new oil from the crankshaft drive which is still capable of providing lubrication. Once the abraded particles from the mov-

ing area of the pistons start to become more and more mixed with the lubricating oil and the lubricating oil starts to lose its load-bearing ability as a result of oil dilution, the wear will spread to all of the moving parts in the engine. This affects the crankshaft journals and piston pins in particular.

Possible causes for the damage

- Fuel flooding due to faults in the mixture formation stage (gasoline/petrol and diesel engines).
- Faults in the ignition system (gasoline/petrol engines).
- Insufficient compression pressure.

- Incorrect piston protrusion/overlap: The piston strikes against the cylinder head when the engine is running. On diesel engines with direct injection, the shocks and resulting vibrations cause uncontrolled injec-

tion of fuel from the injectors and thus fuel flooding in the cylinder (see also point “3.4.5 Impact marks on the piston crown”).



3.11.4 Piston ring wear (soon after a major engine overhaul) (increased oil consumption)

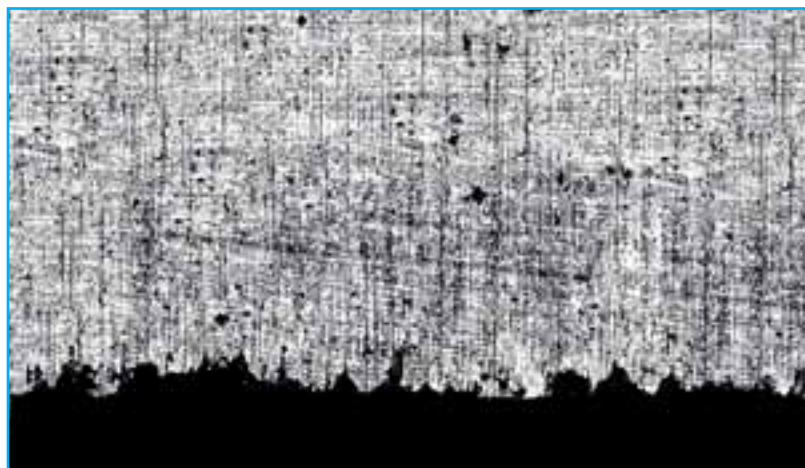
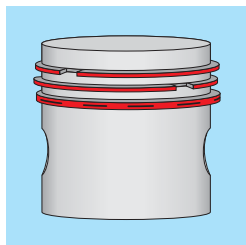


Fig. 1

Description of the damage

The pistons display no signs of wear. Superficial inspection of the piston rings initially reveals no visible or measurable wear. However, closer inspection of the rings reveals abnormal wear on the

oil-scraping ring edges, mostly on the bottom ring edge. A look at the enlarged image shows that the bottom ring edges have become almost frayed. Without resorting to an enlarged image, it is also

possible to detect this type of damage by touching the clearly sharp, burred edge of the ring (Fig. 1).

Damage assessment

High hydrodynamic forces arise between the running surfaces of the piston rings and the cylinder running surface as a result of the worn piston ring edges and the consequent formation of a so-called oil wedge (Fig. 2). The piston rings float on the oil film

during the upward/downward motion of the piston and are lifted slightly off the cylinder running surface. In this way, increased quantities of lubricating oil reach the combustion chamber where they are then burned.

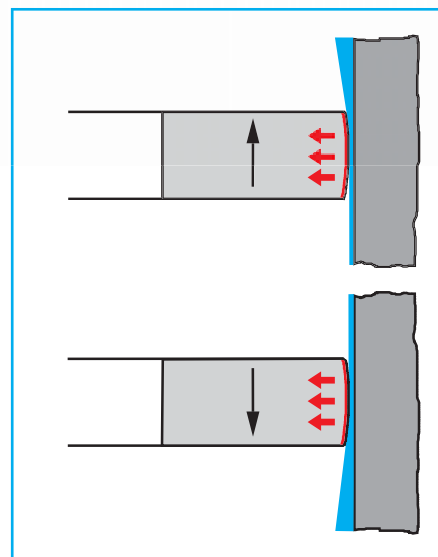


Fig. 2



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Possible causes for the damage

This type of burring is caused if the piston rings are refitted in less than ideal conditions after the engine overhaul. The main reasons are insufficient or inappropriate end finishing of the cylinder. If diamonds or blunt honing stones are used for finish honing, burrs and elevations which are folded over in the direction of machining form on the cylinder wall. This bending over of metal peaks is referred to as the so-called “peak folding formation” and causes increased friction during the running-in phase, preventing oil from becoming deposited in the fine graphite veins (Fig. 3).

If these burrs are not removed in a subsequent machining process referred to as plateau honing, then this will result in premature wear at the piston ring edges during the running-in phase. The rings then take on the undesired duty of wearing away the folded peaks and cleaning the graphite veins. However, this leads to wear on the piston ring edges and the burrs described above. Judging from experience, burrs created in this way on the piston ring edge can only be run off in operation with great difficulty, if at all. The only practical solution is to replace the damaged piston rings.

As the first set of piston rings will have removed most of the disadvantageous edge layer on the cylinder running surface (the so-called “peak folding formation”) through wear, a second set of rings installed as replacement rings will encounter much better – if not normal – operating conditions. The oil consumption will return to normal levels after installing new piston rings. In many cases this is incorrectly attributed to poor material quality of the first set of piston rings, which of course is not the case. Fig. 4 shows a microscopic enlargement through a section of the cylinder surface after honing the cylinder running surface. The bent-over peaks can be seen clearly. Fig. 5 shows the surface after plateau honing. The burrs and peaks have been mostly removed, and the graphite veins have been exposed. The piston rings will immediately encounter good conditions for running-in and should provide a long service life. Hone-brushing the surface to create the plateau finish delivers particularly good results. For further information on this topic, please refer to our booklet “Honing of gray cast iron cylinder blocks” (see appendix)



Fig. 3



Fig. 4

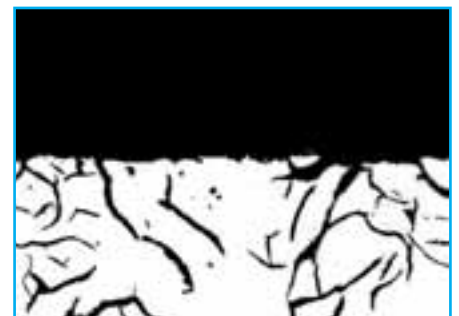


Fig. 5

Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

3.11.5 Asymmetric piston wear pattern (increased oil consumption)

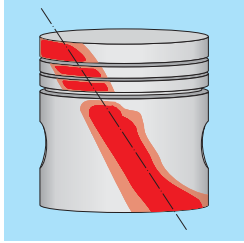


Fig. 1

Description of the damage

In Fig. 1, the wear pattern of the piston over the entire piston height is asymmetrical on both sides. The piston top land has been rubbed bare on the left-hand side of the piston above the piston pin bore (left-hand side of the picture), whereas stop marks are evident on the opposite side at the lower edge of the piston. The uppermost compression ring also displays an uneven wear pattern. Load-bearing, shiny surfaces alternate with darker, matt areas with a blue discoloration (tempering colours).

Fig. 2 also shows an example of a piston which has not run perfectly straight. However, in this case the main area which has been worn is on the lower right-hand edge of the piston around the cutout for the cooling oil nozzle, rather than around the piston top land.



Fig. 2



Piston damages

DESCRIPTION – ASSESSMENT – CAUSES

Damage assessment

This type of asymmetrical wear pattern indicates that the piston has not been running perfectly straight in the cylinder and that the piston pin axis and the crankshaft axis are not parallel to each other. As a result, the piston only bears against one side, and the piston rings cannot perform their sealing function properly due to the lack of proper con-

tact with the cylinder. The hot combustion gases blow through and heat up the piston rings and the cylinder wall excessively. This weakens the oil film, which may result in a dry seizure due to insufficient lubrication. As the piston is running skew in the cylinder, its reciprocating movement creates a pumping effect at the piston rings, which pumps

oil into the combustion chamber and thus increases oil consumption. Under certain conditions an axial thrust can be applied to the piston pin, which can lead to wear or fracturing of the piston pin circlips. See also point “3.7.1 Piston damage caused by broken piston pin circlips”

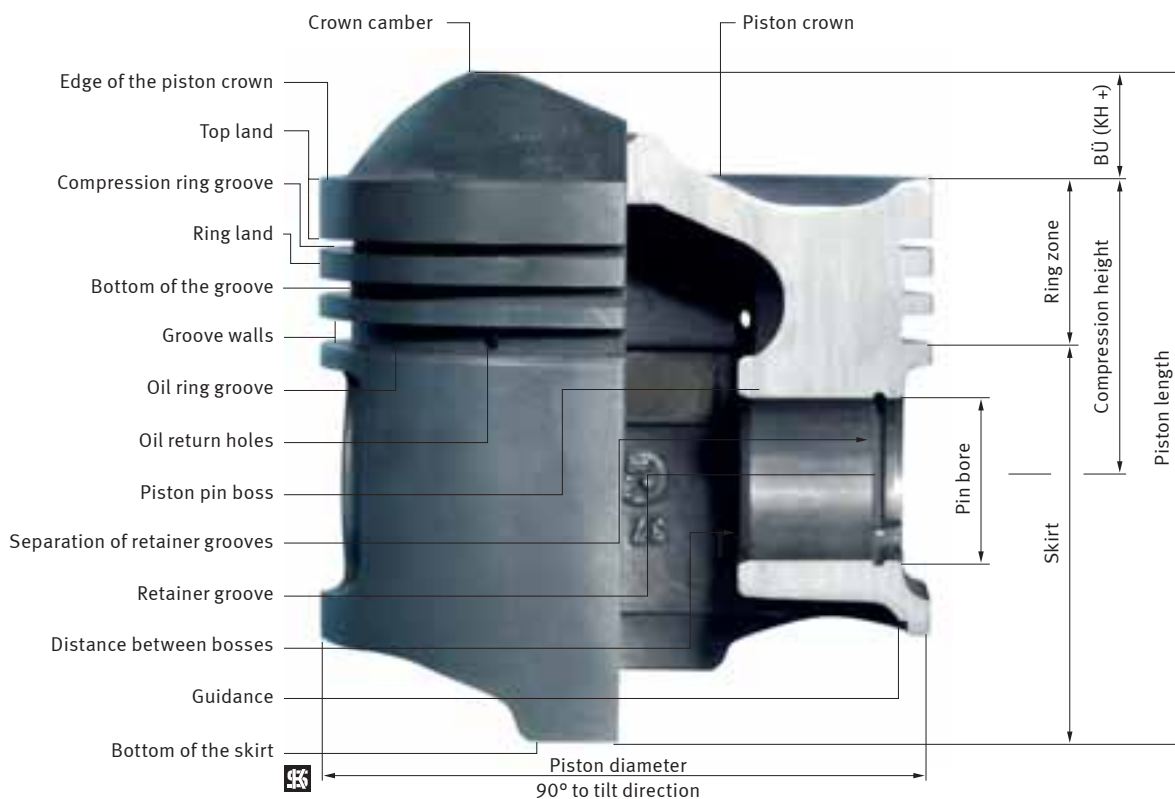
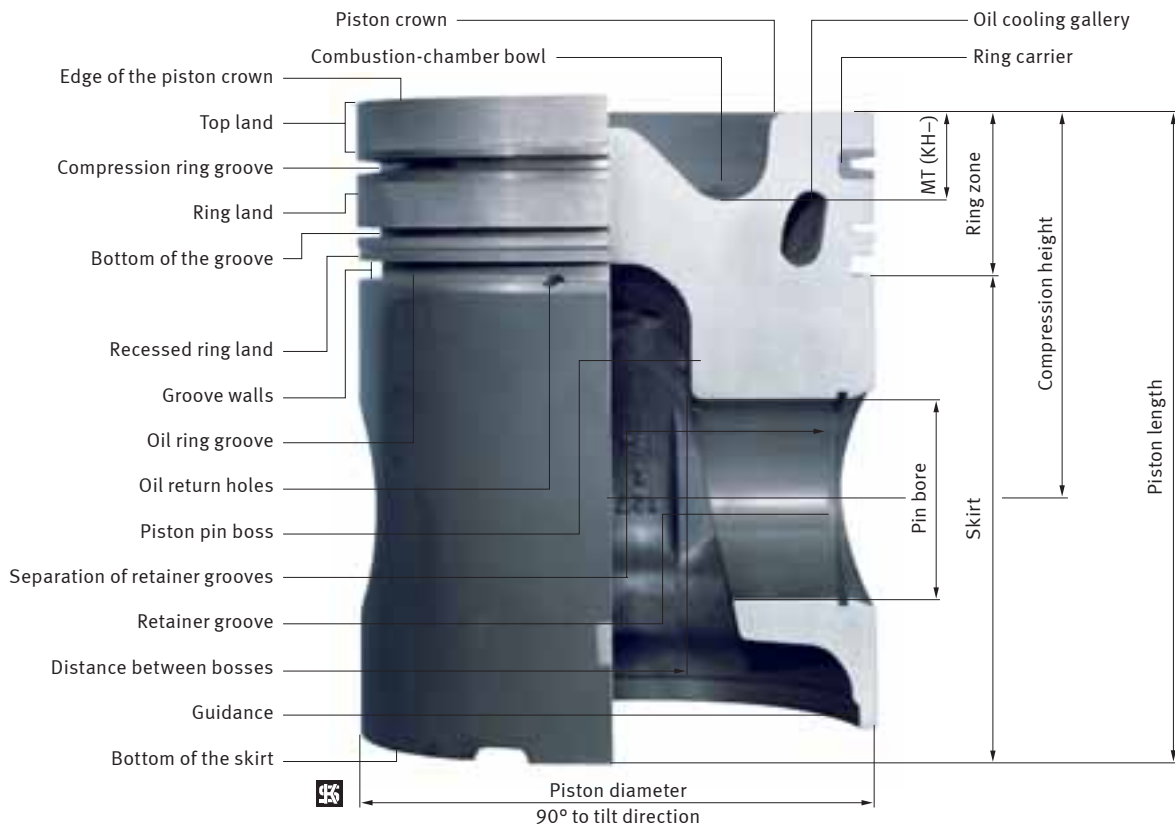
Possible causes for the damage

- Bent or twisted connecting rods
- Connecting rod small end bushing bored at an oblique angle
- Cylinder bores not rectangular
- Individual cylinders not installed straight (distorted during installation)
- Excessive big-end connecting rod clearance, particularly in conjunction with asymmetrical connecting rods

Appendix

4.1 Glossary

4.1.1 Technical terms and piston designations





4.1.2 Explanation of the technical terms used in this document

A	abrasive	Rubbing/grinding
	antiknock properties	Capability of the petrol fuel to resist self-ignition.
	assembly/kit set	Repair set containing the cylinder liner, piston rings, pin and pin retainers, sealing rings for wet liners
	asymmetric	Not symmetric
	axis offset	By design the piston pin axis is offset by some tenth of a millimetre towards the piston pressure side. As a result, the piston changes bearing surfaces at TDC before the actual combustion takes place. This makes the change of bearing surface quieter and less harsh than if the change of bearing surface took place due to the starting combustion under far greater loads. On diesel engines the offset of the piston pin axis may also be towards the counterpressure side for thermal reasons.
B	blow-by gases	Quantity of leakage gases which flow past the piston rings into the crankcase during combustion. The worse the sealing on the piston in the cylinder, the more blow-by gases can flow past.
C	cavitation	Hollowing-out of material which are situated in water or other liquids. If a vacuum is formed and a high temperature is present at the surface, vapour bubbles are formed (analogously to the process of boiling) which then collapse again immediately. As the bubbles collapse, the water column bounces back with high kinetic energy onto the material and tears out tiny particles from the surface of the material. The formation of these bubbles can be triggered by vibrations or a strong vacuum.
	centrifugal oil	Oil which emerges from the bearings of the crankshaft in a planned manner during operation of the engine and serves to coat and lubricate the cylinder running surfaces from underneath.
	cetane rating	Index which indicates the ignition qualities of diesel fuel. The higher the cetane rating, the higher the ignition quality.
	change of bearing surfaces	The changing of the piston from the counterpressure side to the pressure side in the cylinder or vice versa. During the upward stroke the piston bears against the counterpressure side of the cylinder and then changes to the pressure side around TDC.
	chip tuning	Method for modifying the software of an engine control unit in order to increase the power output of the engine.
	common rail	Name for the latest generation of diesel direct-injection systems. In this system, the electrically actuated injectors are supplied with highly pressurised fuel from a shared injection rail.
	connecting rod misalignment	Lack of parallelism between the crankshaft axis and the piston pin axis



D

continuous knocking	Knocking combustion which persists continuously while the engine is running.
counterpressure side	The side of the piston or cylinder upon which the piston moves upwards during the intake stroke and the power stroke. The counterpressure side always lies in the direction of rotation of the crankshaft.
dead centre	The point at which the reciprocating movement of the piston reverses direction. A distinction is made between top dead centre (TDC) and bottom dead centre (BDC).
direct-injection engine	Engine in which the fuel is injected directly into the combustion chamber.
downward piston stroke	Movement of the piston towards the crankshaft during the intake and power strokes (4-stroke engine)

E

erosion	The removal of material as a result of the effects of the kinetic energy of solids, liquids or gases acting on the surface.
exhaust emissions regulations	National or international legislation governing the limits for exhaust emissions from motor vehicles
expansion stroke	combustion stroke/power stroke

F

fatigue fracture	A fracture which develops with time, as opposed to a fracture which occurs suddenly due to overstressing of the material. During operation, the speed at which the fracture spreads can range from a few seconds to several hours all days. The fracture starts slowly from an incipient crack, a point of damage or as a result of vibrations, and does not develop suddenly. A characteristic feature of fatigue fractures is that the fracture surface is not evenly grey and matt, but instead has nodale line markings which document the gradual progress of the fracture.
fibre-reinforcement	Fibre-reinforcement of the edge of the combustion bowl on direct-injection diesel engines. Before casting, a fibre ring made of aluminium oxide is laid into the piston moulding. This ring is then penetrated by liquid aluminium during casting. As a result, the edge of the bowl is more resistant to the formation of cracks. Fibre-reinforcements are only possible for the process of diecasting under pressure, in which the aluminium is forced under high pressure (approx. 1000 bar) into the moulding.
peak folding formation (metal smearing)	Squashing of material at the cylinder running surface caused by blunt honing stones or excessive grinding pressure (honing)



G

fuel flooding	Excessive ingress of fuel into the combustion chamber. As a result of poor atomisation or an overly rich mixture, fuel is deposited on the components, from where it can dilute or wash off the oil film on the cylinder running surface, potentially leading to a lack of lubrication and rubbing marks or seizures.
gap/dimension width	<p>Remaining space between the piston crown and the cylinder head at TDC of the piston. When overhauling an engine, compliance with the manufacturer's specifications for the dimensions of this gap must be ensured at all times. (see also "piston protrusion" / "piston overlap")</p> <p>The gap is also referred to as the lead gap as it can be measured with lead wire. The lead wire is inserted in the cylinder during assembly, and the engine is then turned over once. The lead wire is squashed flat as a result and can then be remeasured. The size measured from the squashed wire is the lead gap.</p>
glow ignition	Self-ignition of the air/fuel mixture before the designated ignition by means of the spark plug takes place. In this process, the glow ignition takes place due to components which have started to glow (cylinder head gasket, spark plug, exhaust valve, oil carbon deposits etc.).
graphite exposure rate	The number of graphite veins exposed during hone-brushing. A usable value for the graphite exposure rate would exceed 20%.
graphite veins	Graphite deposits in the base material during lamellar graphite casting (grey cast iron). If the veins which become exposed during the end finishing of the cylinder are cleaned with honing brushes then oil can be deposited there for lubrication of the piston.

H

hone-brushing	The last stage of the honing process. The peaks and burrs are removed from the surface of the cylinder, and the graphite veins are exposed and cleaned. With hone brushing a graphite exposure rate up to 50% is possible.
honing	End-finishing of the cylinder by means of cross-grinding
honing structure	Characteristic grinding pattern (cross hatch) created during cross-grinding (honing)

I

initial rubbing marks	Pre-seizure stage occurring due to lack of lubricating oil or a starting restriction of clearances
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L

lack of lubrication	A lack of lubrication arises if the oil film is weakened to the point where it can no longer provide its full lubricating function. It is caused by not enough oil being present, the oil film breaking up or the oil film being diluted by fuel. It then results in mixed friction and, if allowed to continue, in rubbing marks or seizure of the components.
lambda control	Closed-loop control device used as part of the electronic engine management on a petrol engine for monitoring and controlling the mixture composition.
line markings	Lines which can be found on the fracture surfaces of fatigue fractures and which are caused by the spreading fracture (the speed of which may vary). The fracture occurs step-by-step. A new line is created every time a new piece becomes fractured.

M

material settling	Microstructural changes and resulting changes in shape to the piston skirt on a used piston (see piston installation clearance)
mixed friction	Mixed friction describes when the oil film is damaged between two moving parts which are mechanically separated by an oil film. Individual material elevations on one of the moving parts can then come into contact with the material peaks of the other, causing metallic friction.



O

octane rating	<p>The octane rating of a fuel (also referred to as the Research Octane Number, RON) indicates the number of seconds after which a to be tested fuel would change from normal combustion to knocking combustion in a specially developed test engine.</p> <p>The motor octane number (MON) indicates the research octane number (RON) at which a particular engine would change from normal combustion into knocking combustion.</p>
octane requirement	<p>The octane requirement of an engine is a function of its design characteristics. It increases with increasing compression ratio, engine temperature, advanced ignition timing, charge, engine load and disadvantageous combustion chamber design. The octane rating request of an engine should always be a few points below the octane rating of the available fuel to prevent engine knocking in all operating conditions.</p>
oil dilution	<p>Oil dilution describes the thinning of oil with fuel. This condition can arise if the vehicle is frequently driven for short journeys, if there are faults in the mixture formation stage or there is insufficient compression due to mechanical engine problems. Unburned fuel is then deposited on the cylinder wall where it is mixed with the oil and ultimately reaches the oil pan. The viscosity and lubricating capacity of the oil are reduced as a result, leading to increased wear and oil consumption.</p>
overload fracture	<p>A fracture which occurs within a fraction of a second as a result of overloading/overstressing a material, with no incipient crack beforehand. The fracture surfaces are matt, granular and not smeared.</p>



P

piston installation clearance

The clearance between the piston and the cylinder which ensures the freedom of movement of the new piston in the cylinder during installation and operation.

During the first hours of operation the new piston is still subject to permanent deformation (i.e. settling). This is caused on the one hand by the temperature rise and the resulting microstructural changes which still take place, and on the other hand by the mechanical loads. The maximum piston size (which always lies in the skirt area) is therefore subject to a certain amount of variation during the running-in phase. This variation will vary according to the design, material composition and specific loads. This is a completely normal response for aluminium pistons in operation and does not represent a cause for concern. Even in the event of piston damage caused by lack of lubrication, overheating or mechanical overloading, the piston skirt will be subject to plastic deformation, which can result in even greater deformation and dimensional changes.

In cases of damage, the piston installation clearance is often used to assess the wear, or installation clearances are incorrectly calculated afterwards even though the piston no longer has the original shape or dimensions that it had when it was new. In many cases the maximum piston size on the skirt is deemed to be too small, and wear is attributed to the piston even though the fine machining marks or the graphitizing/coating on the piston skirt are completely intact.

These piston dimensions measured on a used piston and the installation clearances calculated from them can neither be used to assess the quality of the engine repair work carried out nor the quality of materials and the dimensional accuracy of the piston when new.

If the installation clearance is too small then a seizure due to insufficient clearance(s) (see point 3.1.1 Seizure due to insufficient clearance) is the only potential consequence. If the installation clearance is too large then the engine will generate slightly more noise when cold as a result of increased piston tilting. Piston seizures, increased oil consumption or other forms of damage cannot occur as a result.

The installation clearance must not be confused with the running clearance of the piston. The running clearance is not established until the thermal expansion of the piston is complete, and cannot therefore be measured.

piston protrusion piston overlap

Protrusion of the diesel piston beyond the cylinder sealing surface at TDC. The protrusion is an important measurement which must be accurately checked and adjusted with when overhauling an engine to ensure that the compression ratio remains correct and the piston does not strike against the cylinder head during operation. Please refer to our current catalogue „Pistons, Cylinders and Kit Sets“.



piston tilting	The changing of the piston bearing surface from the pressure side to the counterpressure side and vice versa. The tilting of the pistons is the second loudest noise on a reciprocating piston internal combustion engine after the combustion noise itself.
piston running at an angle	A piston running skewed on the cylinder due to a twisted or bent connecting rod. Upon removal it reveals a characteristic asymmetrical wear pattern.
piston running clearance	The piston running clearance settles during operation once the thermal expansion of the components is complete. Due to its design characteristics and the different wall thicknesses, the piston changes shape as it is heated up. The piston expands more in areas where the wall thickness is greater, which is taken into account accordingly in the design.
piston wear pattern	The wear pattern on the piston skirt where the skirt lies against the cylinder.
piston with an oil gallery	Piston with a cooling oil gallery casted into the piston crown. During operation, oil is sprayed into this cooling oil gallery from underneath via cooling oil nozzles.
prechamber	Part of the combustion chamber on indirect-injection diesel engines. Fuel is injected into the prechamber where it then ignites. As the oxygen supply in the prechamber is limited, only a small part of the fuel is burned to start with. As a result of the excess pressure generated in the prechamber, the remainder of the fuel is forced into the cylinder where it then combusts with the rest of the oxygen supply.
press-fit	Type of dry cylinder liner which is pressed into the cylinder counter bore using a specially designated lubricant. With just a few exceptions these cylinder liners are semi-finished liners, i.e. the cylinder bore still needs to be end-finished afterwards by boring and honing. Advantage: The liner fits tightly with in the cylinder counter bore.
pressure side	The side of the piston or cylinder upon which the piston moves downwards during the intake stroke and the power stroke. The pressure side is always opposite to the direction of rotation of the crankshaft.



Q

quenching area	The part of the piston crown which gets very close to the cylinder head during operation. At the end of the compression stroke the mixture is squashed from the increasingly restricted edge area into the middle of the combustion chamber. This causes swirl and helps to provide better combustion.
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R

ribbed cylinder	Cylinders on engines cooled primarily with air cooling. The cylinders have cooling ribs on the outside for cooling of the engine.
ring carrier	A steel ring with a high nickel content which is casted into the aluminium piston. The first piston ring groove is cut into the ring carrier. As a result, the first (and sometimes the second) compression ring sits in a wear-proof groove, enabling operation with higher operating pressures and therefore higher loads. Ring carriers are always used on pistons for diesel engines.
roll marks	Wear marks on the piston ring flanks caused by the ingress of dust or dirt into the engine. The dirt particles become trapped in the piston ring groove, where they cause characteristic wear marks on the grooves and the flank of the piston ring. As the piston rings rotate during operation, the particle(s) of dirt scratch a regular pattern into the surface.
rubbing marks	The initial contact between two moving parts which is made when the lubricating oil film becomes damaged. In contrast to a seizure, rubbing changes the microstructure of the surface but does not particularly change its dimensions.

S

shrink-fit connecting rod	Connecting rod with a rigid link between the piston pin and the connecting rod. When the piston and connecting rod are assembled, the connecting rod small end is heated up whilst the temperature of the piston pin is significantly reduced. As a result of the shrinking of the pin and the expansion of the connecting rod small end, an air gap is generated which makes it possible to slide in the piston pin by hand. As the temperatures then equalize the clearance is eliminated and the piston pin is firmly clamped in the connecting rod. The piston does not need to be heated up when the piston pin is shrunk into the connecting rod small end.
slip-fit	A type of dry cylinder liner which can be inserted by hand into the cylinder block. Usually, this type of liner is already end-finished, so the cylinder bore does not need to be bored and honed afterwards. Dissadvantage: A remaining gap between the liner and the counter bore.
swirl chamber	Part of the combustion chamber on indirect-injection diesel engines. The difference to a prechamber is that the outlet opening of the chamber is larger and opens tangentially into the combustion chamber. During combustion, the shape of the combustion chamber imparts a substantial swirl on the air flowing into the chamber, which helps to improve the quality of the combustion process.



T	tangential tension	Force which presses the installed piston ring against the cylinder wall
	tilting direction	Direction of rotation around the piston pin axis. As rather than rotating around this axis the piston only tips back and forth in the cylinder, this is also referred to as the tilting direction.
U	unit injector (pump jet injector)	A special design used on direct-injection diesel engines whereby the injector and fuel pump form a unit which is installed directly in the cylinder head. The injection pressure is generated via a pump piston which is driven directly by the camshaft (in contrast to a distributor-type injection pump or an inline-type injection pump). The injectors are actuated electrically. The injection period and injected fuel quantity are controlled electronically by a control unit.
	upward piston stroke	Movement of the piston away from the crankshaft towards the cylinder head (during the compression and exhaust strokes, on a 4-stroke engine)



Piston damages

RECOMMENDED TOOLS & TESTING INSTRUMENTS



Part-No. **50 009 888**

4.2.1 Roughness tester T500

Roughness tester with independent power supply. Can be used for measurements on level surfaces, shafts and in bores. Especially suitable for mobile measurements.

Accuracy class 1. Smallest display value 0.01 μm . Surface measurement variables Ra, Rz, Rmax/R. Contents: Hommel tester T500, battery charger (230 V AC, 50 Hz), 2 rechargeable batteries, standard

roughness test sample RNDH (for calibration), prism incl. small hex screwdriver, operating instructions and sturdy case. Replacement 9.6V rechargeable battery Part-No. 50 009 905



Part-No. **50 009 889**

4.2.2 Printer for roughness tester T500

The delivery scope includes a printer, 2 rolls of paper and a mains adapter. (100–230 V AC, 50–60 Hz).



Part-No. **see table**

4.2.3 Cleaning set for valve guides

Often dirt is still deposited in the valve guides even after the cylinder head has been washed. These deposits must be removed before the valves are installed. The cleaning set includes a nylon brush for pre-cleaning and a felt brush for finishing off.

Part-No.	Description (\varnothing in mm)
50 009 901	Valve stem diameter \varnothing 5,0
50 009 902	Valve stem diameter \varnothing 6,0
50 009 895	Valve stem diameter \varnothing 7,0
50 009 896	Valve stem diameter \varnothing 8,0
50 009 897	Valve stem diameter \varnothing 9,0
50 009 898	Valve stem diameter \varnothing 10,0
50 009 899	Valve stem diameter \varnothing 11,0
50 009 900	Valve stem diameter \varnothing 12,0



Part-No. (car 4V) **50 009 904**
Part-No. (car) **50 009 893**
Part-No. (trucks) **50 009 894**

4.2.4 Assembly tool for valve stem seals

This tool allows very easy and straightforward assembly of valve stem seals.

Part-No. 50 009 904
(Set for passenger cars, 4V):
 \varnothing of valve stem: 5 mm
 \varnothing of valve stem: 6 mm
 \varnothing of valve stem: 7 mm

Part-No. 50 009 893
(Set for passenger cars):
 \varnothing of valve stem: 7 mm
 \varnothing of valve stem: 8 mm
 \varnothing of valve stem: 9 mm

Part-No. 50 009 894
(Set for trucks):
 \varnothing of valve stem: 10 mm
 \varnothing of valve stem: 11 mm
 \varnothing of valve stem: 12 mm



Part-No. 50 009 873

4.2.5 Honing angle test film

The honing angle can be measured without great difficulty using the test film. The honing angle should be between a minimum of 40° and a maximum of 80°.

For further technical information on the honing of cast iron cylinder blocks, refer to the KS brochure "Honing of gray cast iron cylinder blocks".



Part-No. (small) 50 009 882
Part-No. (large) 50 009 883
Part-No. (dial gauge) 50 009 884

4.2.6 Bracket for dial gauge (small/large) and dial gauge

Bracket for dial gauges. Example of application: to measure piston protrusion and cylinder liner protrusion. The scope of delivery does not include a dial gauge.

Art. no. 50 009 882 (small)
Total length: 75 mm
8 mm location hole

Part-No. 50 009 884
matching dial gauge
Measuring range: 0–10mm
Smallest measuring unit: 0.01mm

Art. no. 50 009 883 (large)
Total length: 90 mm
8 mm location hole



Part-No. see Table

4.2.7 Assembly sleeves

The assembly sleeve ensures easy, safe and quick assembly of pistons. Assembly sleeves are available for 13 different cylinder diameters.

Part-No.	Description (Ø in mm)
50 009 865	Assembly sleeve for Ø 86,0
50 009 877	Assembly sleeve for Ø 94,4
50 009 878	Assembly sleeve for Ø 94,8
50 009 866	Assembly sleeve for Ø 97,0
50 009 903	Assembly sleeve for Ø 97,5
50 009 874	Assembly sleeve for Ø 100,0
50 009 875	Assembly sleeve for Ø 102,0
50 009 867	Assembly sleeve for Ø 121,0
50 009 868	Assembly sleeve for Ø 125,0
50 009 869	Assembly sleeve for Ø 127,0
50 009 870	Assembly sleeve for Ø 128,0
50 009 876	Assembly sleeve for Ø 130,0
50 009 906	Assembly sleeve for Ø 130,2



Part-No. (car) 50 009 816
Part-No. (truck) 50 009 828

4.2.8 Piston ring scuff band with tightener

Infinitely variable adjustment.

Part-No. 50 009 816
(Set for passenger cars):
Tightening range
Ø 57–125 mm

Part-No. 50 009 828
(Set for trucks):
Tightening range
Ø 90–175 mm



Piston damages

RECOMMENDED TOOLS & TESTING INSTRUMENTS



Part-No. 50 009 817

4.2.9 Liner flange seat facing attachment

Precision-type facing tool for machining liner flange seats in cylinder blocks. May even be used with the engine installed. Refacing by hand. The device is locked by an electric

magnet (230 V, 50 Hz connection required). The delivery scope includes a facing tool, a sturdy wooden case and detailed operating instructions (turning tool not included).

For further technical information refer to Service Information SI 02/2002 "Liner flange fracture".



Part-No. (car) 50 009 815
Part-No. (truck) 50 009 829

4.2.10 Piston ring pliers

For installation and removal of piston rings. Sturdy workshop quality. Bright nickel-plated.

Part-No. 50 009 815
For piston rings in cars
Ø 50–125 mm

Part-No. 50 009 829
For piston rings in trucks
Ø 60–160 mm



Part-No. 50 009 864

4.2.11 Honing brushes for plateau honing

Honing accessories for cast iron cylinder blocks for plateau honing to reduce oil consumption and to facilitate the running in of pistons, piston rings and cylinders.

The set of accessories contains two honing brushes which consist of nylon

fibres with silicon crystals. A minimum of 10 strokes should be carried out using honing oil. In doing so, the bore is cleaned and the peaks are removed.

Brushing does not cause any further dimensional changes.

For further information on honing cast iron cylinder blocks, refer to the KS brochure "Honing of gray cast iron cylinder blocks" (refer to the Appendix for the order number).



4.2.12 Honing accessories for aluminium cylinder blocks (Alusil®/Silumal®)

Part-No.	Description
50 009 860	Honing stone set (2 roughing stones)
50 009 861	Honing stone set (2 roughing stones)
50 009 862	Honing stone set (2 polishing stones)
50 009 863	Felt pad set (2 felt pads)
50 009 859	Silicon paste

For further information on honing aluminium engines, refer to the KS brochure "Reconditioning of aluminium engines" (refer to the Appendix for the order number).



Product Manual – Engine components

Basic technical information on all KS product groups

Part-No.	Language	Part-No.	Language
50 003 734	German	50 003 731	Spanish
50 003 733	English	50 003 580	Russian
50 003 732	French		



Piston damages

Recognising and rectifying

Part-No.	Language	Part-No.	Language
50 003 973-01	German	50 003 973-04	Spanish
50 003 973-02	English	50 003 973-09	Russian
50 003 973-03	French	Additional languages upon request.	



Honing of Gray Cast Iron Cylinder Blocks

Part-No.	Language	Part-No.	Language
50 003 823	German	50 003 818	Arabic
50 003 822	English	50 003 817	Portuguese
50 003 821	French	50 003 816	Turkish
50 003 820	Spanish	50 003 815	Russian
50 003 819	Italian	50 003 814	Czech



Reconditioning of Aluminium Engines

Brochure

Part-No.	Language	Part-No.	Language
50 003 813	German	50 003 808	Arabic
50 003 812	English	50 003 807	Portuguese
50 003 811	French	50 003 806	Turkish
50 003 810	Spanish	50 003 805	Russian
50 003 809	Italian	50 003 804	Czech



Valve Seat Inserts

Technical information and assembly instructions

Part-No.	Language	Part-No.	Language
50 003 728	German	50 003 725	Spanish
50 003 727	English	50 003 724	Italian
50 003 726	French	50 003 700	Russian



Piston damages TECHNICAL BROCHURES



Oil Consumption and Loss of Oil

Part-No.	Language	Part-No.	Language
50 003 605-01	German	50 003 605-04	Spanish
50 003 605-02	English	50 003 605-09	Russian
50 003 605-03	French		



Technical Filter Booklet

Part-No.	Language	Part-No.	Language
50 003 596-01	German	50 003 596-04	Spanish
50 003 596-02	English	50 003 596-09	Russian
50 003 596-03	French		



Interior Compartment Filter

Part-No.	Language	Part-No.	Language
50 003 939-01	German	50 003 939-04	Spanish
50 003 939-02	English	50 003 939-09	Russian
50 003 939-03	French		



Tools & Testing Instruments

Part-No.	Language	Part-No.	Language
50 003 931-01	German	50 003 931-04	Spanish
50 003 931-02	English	50 003 931-09	Russian
50 003 931-03	French		



Installation of Pistons / Rings / Bearings

Pane, 70 x 100 cm, with attachment eyes

Language	Pistons	Rings	Bearings
German	50 003 842	50 003 717	50 003 999
French	50 003 840	50 003 715	50 003 996
Spanish	50 003 839	50 003 714	50 003 997
Italian	50 003 834	50 003 708	50 003 843
Arabic	50 003 838	50 003 712	50 003 995
Portuguese	50 003 837	50 003 713	50 003 846
Russian	50 003 835	50 003 710	50 003 844
English	50 003 841	50 003 716	50 003 998



4.4 For engine reconditioners

• Courses (include a practical part)

Engine repair, trucks

- Short block and cylinder head machining

Engine repair, passenger cars

- Short block and cylinder head machining

Special course 1 : Engine reconditioning, trucks (Mercedes Benz)

- Actros, engine types OM 500
- Short block and cylinder head machining

Special course 2 : Engine reconditioning, trucks (Mercedes Benz)

- Atego, engine types OM 900
- Short block and cylinder head machining

Operator training course on precision machining instruments

- Machine training course for short block and cylinder head repair

Special courses

- Crankshaft surface welding and grinding
- Other subjects, contents and key topics to be agreed on an individual basis

• Seminars (without practical part)

Machining

- Drilling, honing and hone-brushing of cast iron cylinder blocks
- Reconditioning of aluminium cylinder blocks: General
- Reconditioning of aluminium cylinder blocks: Alusil machining

Product training

- Product training on the construction and function of the relevant KS product groups such as pistons, piston rings, plain bearings, cylinder liners, valves, valve guides, valve seat rings and filters

Assembly training

- Basic seminars on the assembly of the relevant KS product groups such as pistons, piston rings, plain bearings, cylinder liners, valves, valve guides and valve seat rings

From Practice for Practice

- Training on actual engine defects and their causes in relation to pistons, cylinder liners, plain bearings, piston rings and valves

Other seminars

- Running in engines
- New engine designs - petrol / diesel
- Oil consumption (in preparation)
- Other subjects, contents and key topics to be agreed on an individual basis



4.5 For workshops

• Courses (include a practical part)

On-board diagnosis (OBD, EOBD), vehicle integrated engine monitoring and diagnosis

- Layout, function, execution and technical details
- Reading out faults and interpreting fault codes
- Experiences so far
- Fault diagnosis on the engine and ancillary equipment

AU courses* (in line with the latest legislation for vehicles up to 7.5 t gross vehicle weight)

- Introduction course
- Refresher course

Special courses

- Subjects, contents and key topics to be agreed on an individual basis
- *) Only for employees of Pierburg Services

• Seminars (without practical part)

Module 1: OBD, EOBD, vehicle integrated engine monitoring and diagnosis

- Scope and function, execution and technical details, fault codes and test modes
- OBD-monitored Pierburg products

Module 2: Fuel supply and service

- Layout and function of modern fuel systems, fuel pumps, pressure regulators and valves
- Possible faults, causes and remedies
- Checking the system on fuel injected engines using the fuel pressure tester

Module 3: Vacuum supply

- Vacuum pumps are safety relevant components
- Types, application, special features and service
- Testing vacuum pumps with the vacuum pump tester
- Identifying and rectifying potential faults and their causes

Module 4: Reduction of harmful pollutants

- Exhaust gas recirculation and secondary air systems - layout of the system.
- Components in the system, EGR valves, secondary air pumps, function and actuation.
- Possible faults, checking components and their functions.
- How much help can OBD offer? Interpreting fault codes correctly

All MSI training courses (for workshops and engine reconditioners) are available from our customer services training centre in Dormagen and in Neckarsulm, as well as on-site at the customer. Technical seminars can also be offered

on request for owners, purchasers, internal and external sales employees. For more information on our training courses, please refer to our training programme or send us your queries to the following e-mail address: training@msi-motor-service.com



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