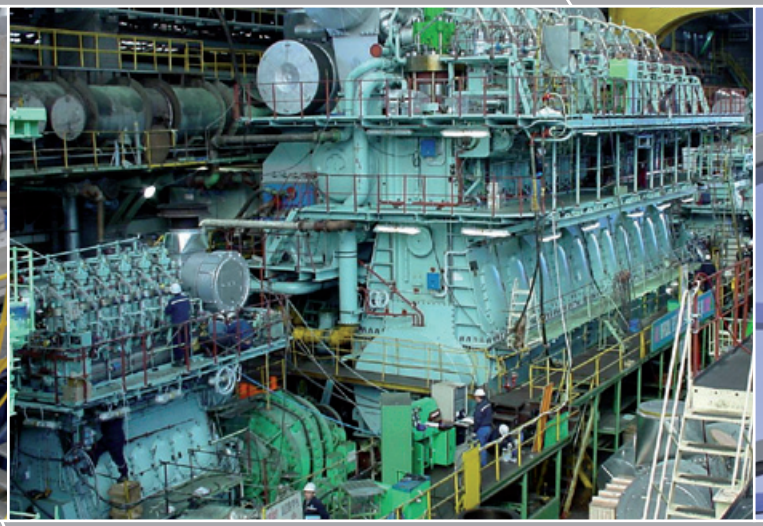
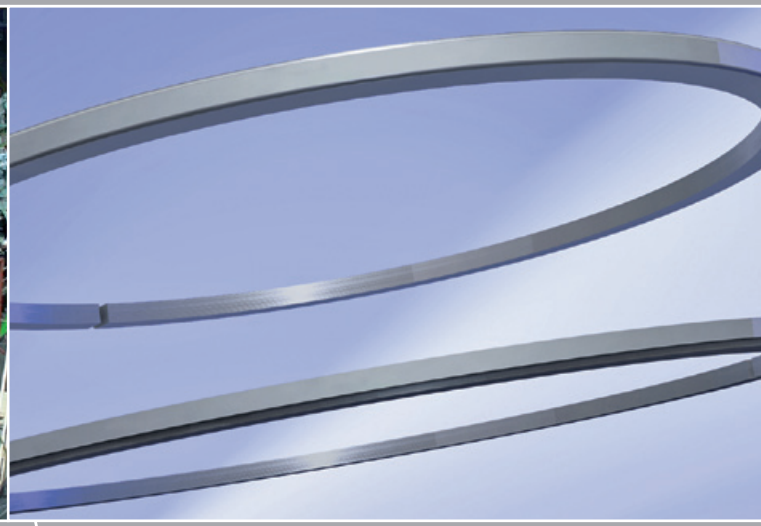
FEDERAL MOGUL

GOETZE

DAROS

Piston rings for large bore engines





FEDERAL MOGUL

GOETZE

DARROS

Today, more than 90,000 ships with greater than 100 gross register tons are crossing the oceans, transporting more than 90 % of commercial goods worldwide. The large majority are powered by diesel engines while a small number by steam and gas turbines.

Over the past decades, the dominant position of the diesel engine in shipbuilding has increased rapidly. However, this was not always the case. If we look back to 1903 we will search in vain for a ship powered by diesel. Almost six years had passed since the market launch of the new combustion engine – in 1897.
Rudolf Diesel remarked as early as 1892 that his engine could be used to power ships, but it was not until 1903 that two ships were outfitted for diesel power within a short space of time: the transport ship VANDAL which travelled the Volga and the small french canal boat PETIT PIERRE.

Now let us imagine that Rudolf Diesel had gone to a gasket manufacturer in 1897 with the following request: to provide a dynamic seal for a piston oscillating at a speed of approximately 10 m/sec for an explosive mixture at a pressure of around 250 bar pressure and a temperature of around 400 °C and using a few drops of oil as lubrication – and all with a service life of several thousand hours.

This task would have been declared simply impossible to implement.

Today piston rings remain an essential part of the service life of many engines. The object of this article is to give an overview of the fascinating and essential technology behind piston rings in large bore engines. In addition to the current status of the technology, a brief summary is given of future developments to be expected in this field.

The name Federal-Mogul and the brand GOETZE have been a fixed concept in the world of piston rings and associated motor components for decades. Rings and coatings by Federal-Mogul have marked repeated progress in the efficiency of large bore engines. This know-how has grown with the large bore engine industry, and continues to grow: the latest development was the acquisition of DAROS Industrial Rings, a company specialising in the production of piston rings in small and medium production series.

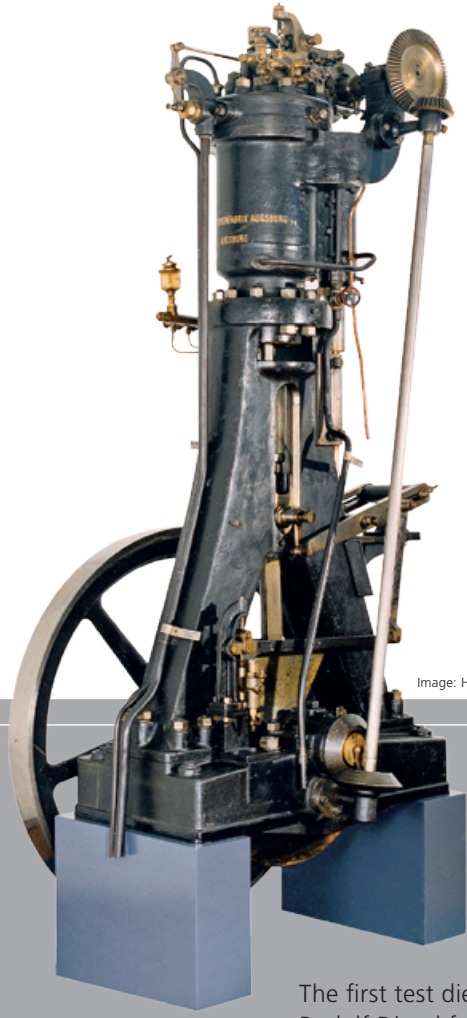


Image: Historic archive manroland AG/MAN AG

Piston rings for large bore engines

The first test diesel engine developed by Rudolf Diesel from 1893 to 1895

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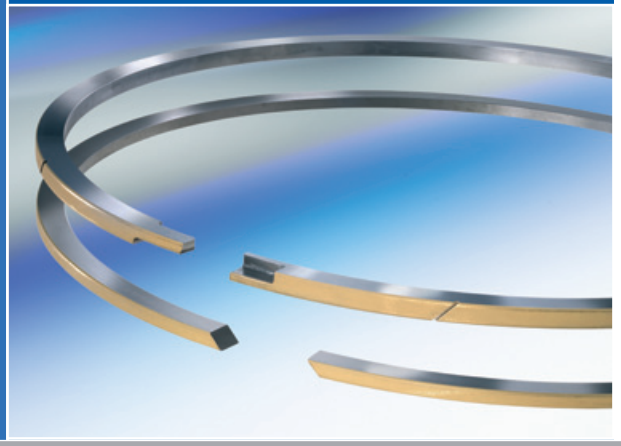
Introduction



The general direction of the ongoing development of engines largely mirrors economic and competitive factors that demand a reduction in costs over the whole service life of an engine. Legislation around the globe, together with increasing environmental awareness, has contributed to placing exhaust gas emissions at the centre of attention. The increasing availability of natural gas as a fuel has also created diversification into new markets. Therefore, we can place the following aspects at the forefront of the agenda in the field of engine development:

- Service life
- Specific performance
- Fuel consumption lubricating
- Oil consumption
- Exhaust emissions

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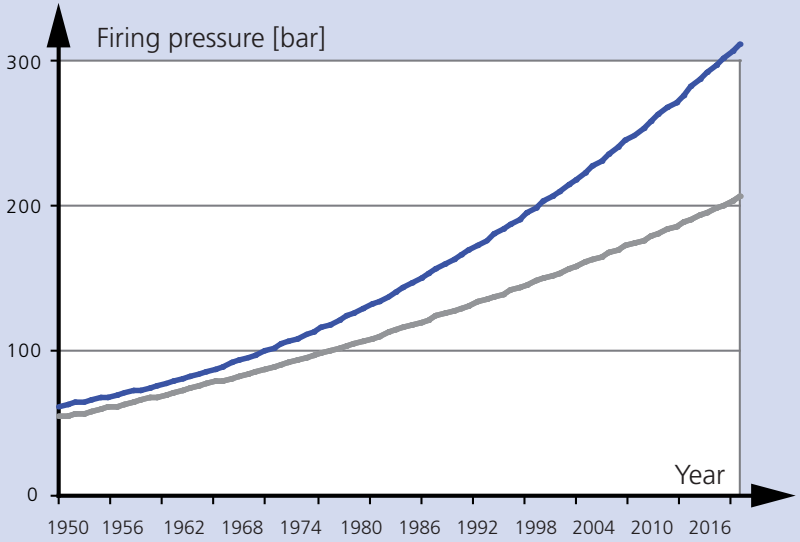
This long list of targets means great challenges for engine development. Driven by the wish to achieve greater specific performance, maximum cylinder pressures are increasing, as shown in the diagramm. In the meantime, the first 4-stroke engine with 250 bar firing pressure is now going into serial production; on the test bench this engine has been operated up to 270 bar without any problem.

Development of peak firing pressures



As a direct consequence the thermal and mechanical loads for piston rings are rising, while the quality of fuels is deteriorating continuously. This is particularly noticeable with abrasive matter which increases the wear on sliding contact surfaces piston ring, piston groove and cylinder running surface.

How is it possible under these circumstances to satisfy service life requirements? This question is dealt with below. After some basic technical explanations the specific piston ring technology for 4- and 2-stroke diesel applications is explained in detail.

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Role of piston rings

Piston rings seal the combustion chamber from the cylinder crankcase in order to prevent combustion gases (or blow-by) penetrating the crankcase and to prevent the lubricating oil being sprayed around in the crankcase from penetrating the combustion chamber.

In addition, the piston rings dissipate the heat from the piston to the cylinder and ensure the lubricating film is evenly distributed. Therefore the main requirements for piston rings are high resistance to wear and corrosion and a low drop in elasticity at high temperatures.

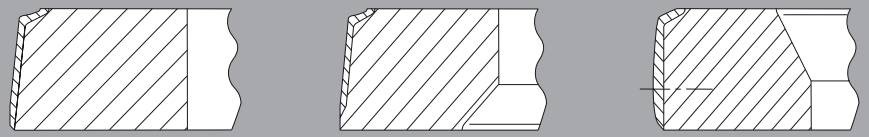
Today all modern trunk piston engines have two compression rings and one oil control ring which perform different functions, as shown below.

In order to satisfy the high requirements for piston rings, the basic material used in Federal-Mogul piston rings comprises high-quality lamellar or spherolithic cast materials. The basic material is selected from a wide range according to application and fuel quality.

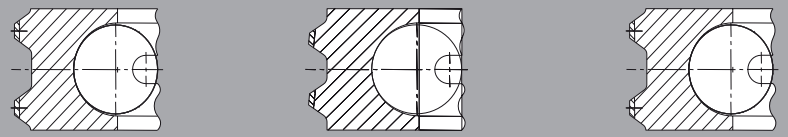
Materials of piston rings for large bore engines

Material designation	Material type	Min. bending strenght	Modulus of elasticity	Diameter range
STD **LP7**	Unalloyed flake cast iron	350 MPa 420 MPa	85 - 115 GPa 90 - 120 GPa	700 mm
IKA **F14**	Alloyed tempered flake cast iron	500 MPa 650 MPa	100 - 130 GPa 130 - 160 GPa	700 mm
KV1 **KV4**	Unalloyed hardened and tempered ductile iron	1300 MPa	min. 150 GPa	600 mm 1000 mm
VP6	Vermicular graphite cast iron	900 MPa	min. 140 GPa	1000 mm
LP8	Alloyed lamellar cast iron	700 MPa	110 - 140 GPa	1000 mm
1.4112 **1.4028**	Stainless steel		230 GPa 220 GPa	260 mm

Examples of compression rings



Examples for oil control rings



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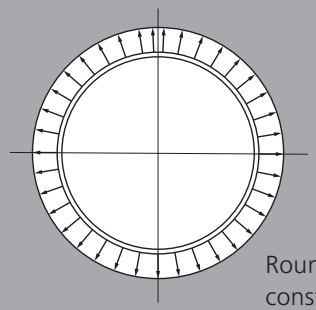
In a few applications in the diameter range up to 230 mm, which also require a very high fracture resistance, steel is also used. The basic material is a steel wire which is wound on a specially developed machine.

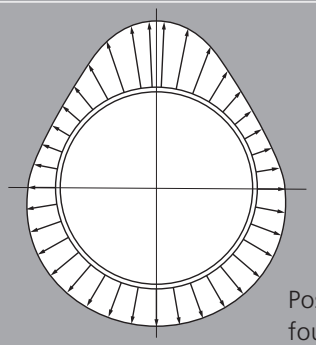
Piston ring shapes

One common feature of all piston rings is a slot and that they are manufactured to be non-circular. This non-circular form is necessary so that the piston ring exerts an exactly defined pressure over the whole ring circumference when inserted in the circular cylinder. This pressure can be distributed evenly over the circumference; however, a negative oval form is generally aimed for. This means that the pressure in the area of the slot is lower than on the remaining circumference which avoids increased pressure on the slot during operation of the engine.

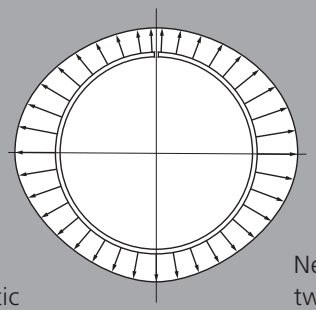
Radial pressure distribution



Round –
constant characeristic



Positive ovality –
four-stroke characeristic



Negative ovality –
two-stroke characeristic

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Forms of running surfaces

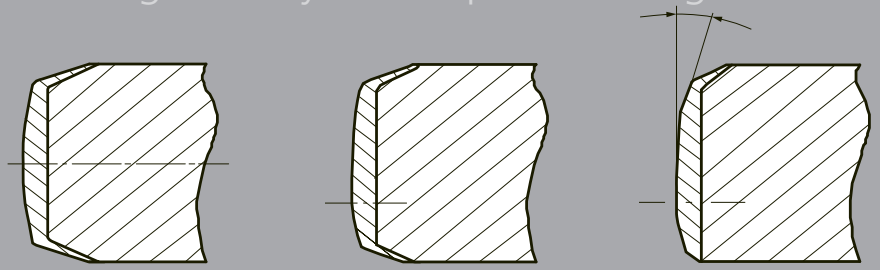
In order to secure a good oil film between ring and cylinder, rectangular rings with a symmetrical or asymmetrical barrelled running surface are used as pressure rings in the first groove, as shown below. The running surface is the contour of the ring facing the cylinder surface. The objective of this running surface profile is to create a lubrication slot with a hydrodynamic film which the piston ring can slide on without touching the other surface.

An optimised asymmetrical-barrelled running surface ensures low lubricant consumption even after a very long running time. The additional angle on the running surface prevents the upper edge of the ring touching the cylinder and transporting oil upwards into the combustion chamber, as the figure below shows.

Piston ring coatings

In order to improve the wear resistance and tribological properties of the rings, different coatings have been used on running surfaces for many years. Galvanic coatings, thermal coatings and PVD coatings are used.

Profile geometry of compression rings



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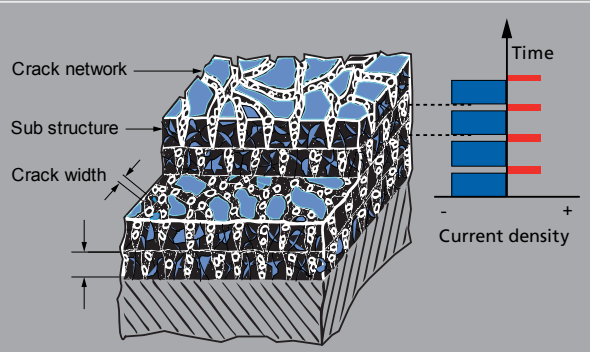
Galvanic coatings – Chrome ceramic coating

In 95 % of new developments you will find a chrome ceramic coating (CKS®) developed by Federal-Mogul (see figure below). This coating has very good wear-resistance and good scuff-resistance.

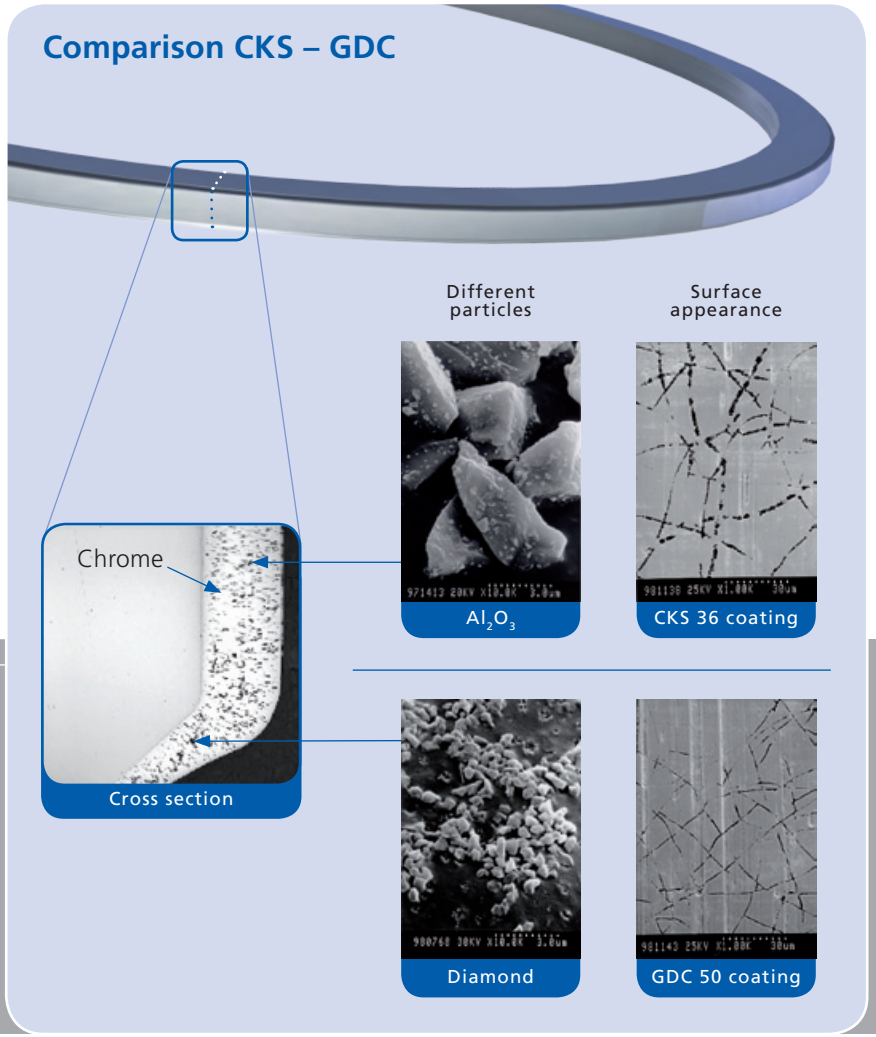
As a refinement of the chrome ceramic coating, the Goetze Diamond Coating (GDC® 50) has proved its excellent wear-resistance in large bore engines. Instead of aluminium oxide particles which are embedded in the micro fissure network of the CKS layer, small diamond particles are used (see comparison CKS - GDC).

These diamond particles have both higher wear-resistance and offer the advantage that they turn into carbon at high local temperature peaks. This produces a self-lubricating effect (like graphite inclusions) and hence gives the coating higher scuff resistance.

Design of the CKS coating



Comparison CKS – GDC



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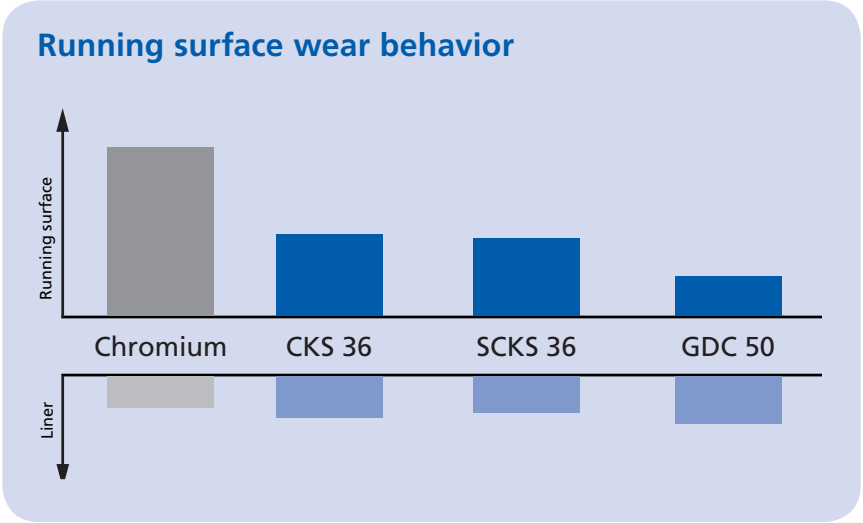
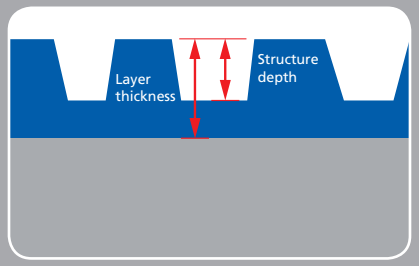
Galvanic coatings – Structured chrome coatings

A further development based on CKS® and GDC® technology resulted in structured chrome coatings (SCKS and SGDC). These coating systems have the characteristic that structures within the coatings can be mapped in a highly targeted manner, see figures below. These structures (≈ depressions or grooves) have a depth of up to 50 µm and can store lubricant during operation; this lowers friction and hence reduces oil consumption even further. These coating systems are being tested by various customers and have largely fulfilled expectations.

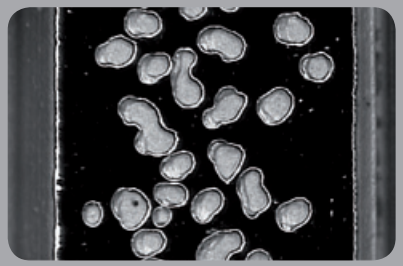
The diagram below shows the wear of the various galvanic coatings for the running surface and the liner.

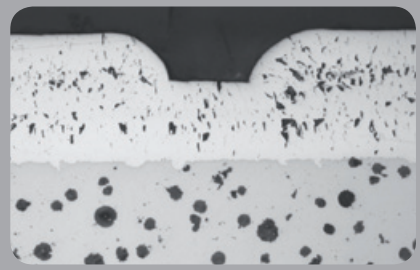


Structured chrome coatings



Properties
Hardness: 800 to 1200 HV
Crack density: > 100/mm
Structure Characteristics
Width: intense Varity
Length: intense Varity
Depths: depending on coating thickness
Advantages
Reduction of friction
Reduced lube oil consumption





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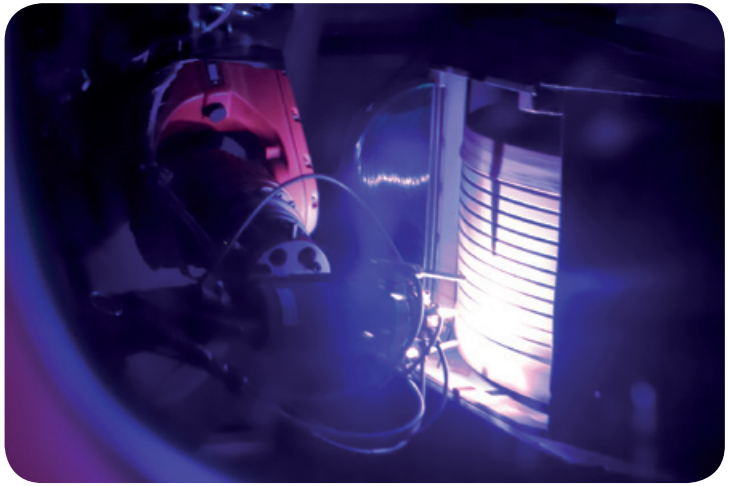
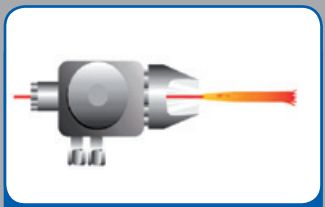
Thermal coatings

Even the high scuff resistance of chrome ceramic coatings is not sufficient for some applications, which means another coating system must be used. All types of thermal spray coatings have a significantly improved anti-seizing property. The HVOF coating (High Velocity Oxygen Fuel) developed by Federal-Mogul has delivered very good results.

In the course of many engine tests a coating variation called MKJET has come to the forefront; this coating is based on chrome carbides with other alloy components and provides similarly good wear resistance results as with the CKS® coatings – but with a significantly higher anti-seizing property under extreme operating conditions. Due to its high performance, the increased intrinsic wear of these coatings is a factor when weighing the characteristics required for specific applications.

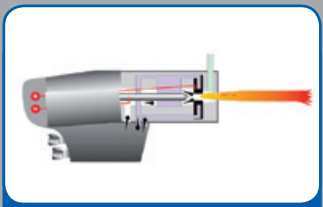


Thermical coating technoligies



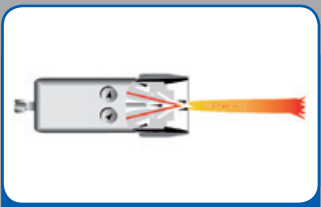
Wire-flame

Coatings
- Mo



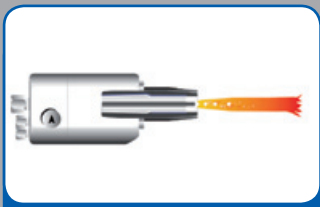
Plasma

Coatings
- MP 43
- MKP 81 A
- MKP 110
- MKP 200



Arc

Coatings
- Al
- AlSI12
- St08



HVOF

Coatings
- MKJet 502
- MKJet526

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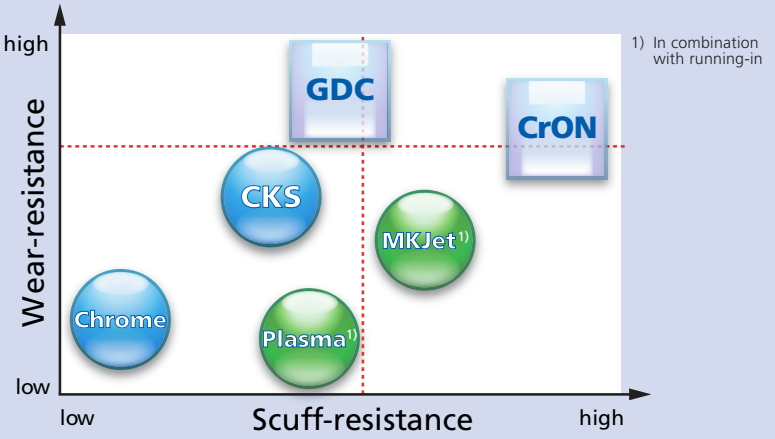
PVD coatings

Modern PVD coatings (physical vapour deposition) offer very high scuff-resistance. However, due to the very complex manufacturing process involved, for most applications it is too expensive (see figure PVD coating technique). In addition the limited coating thickness of up to around 50 µm is not sufficient for diesel operation in order to satisfy current requirements for the service life of rings

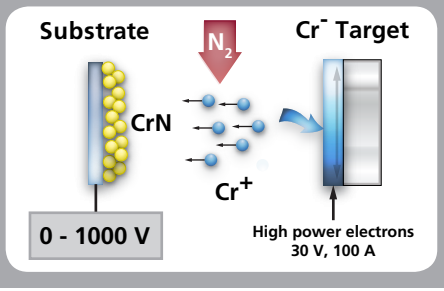
However, some gas engines are already running with a PVD coating on the running surface of the first compression ring because thermal loads in a gas engine are higher, but yet the wear on the running surface is so small that a correspondingly long service life can be expected.

The diagram below shows a comparison of all coatings described here regarding their scuff- and their wear-resistance.

Scuff- and wear-resistance



PVD coating technique



Specifics
- High process complexity
- Atomic formation of coatings
- Extensive equipments
- Applied for serial production

PVD coating system

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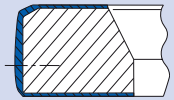
4-stroke diesel and gas engines

With the introduction of chrome ceramic coatings, modern 4-stroke engines have achieved a high level of reliability. Damages to the cylinder, such as scuff marks or ring fractures, are very seldom.

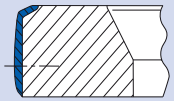
The figure to the right shows a typical ring set for modern engines. The rings are, of course, adapted in geometry and dimensions to the specific engine requirements.

It is worth noting that today around 95 % of engines with piston diameters between approximately 150 mm and up to 640 mm are fitted with piston rings with running surfaces coated with CKS® and hence run smoothly up to the 270 bar firing pressure mentioned above.

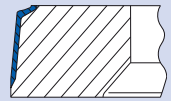
Ring set for 4-stroke engines



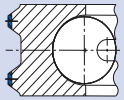
Asymmetrically barreled
CKS 36 coated
Top ring



Asymmetrically barreled
Chromium coated
2nd ring - Diesel



Asymmetrically barreled
Chromium coated
2nd ring - Gas



Oil control
Chromium coated
3rd ring

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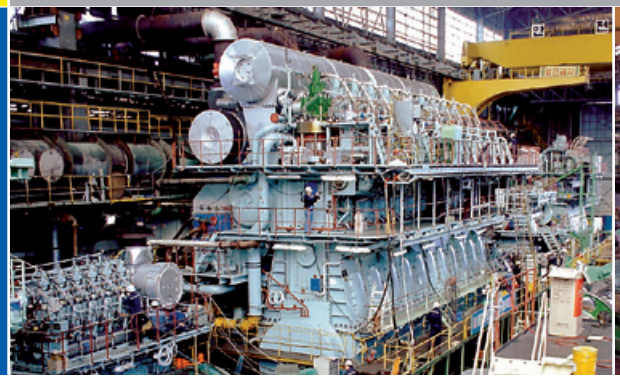
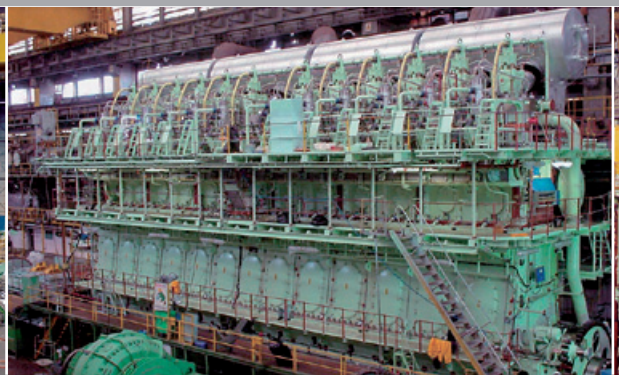
CKS® 36 applications

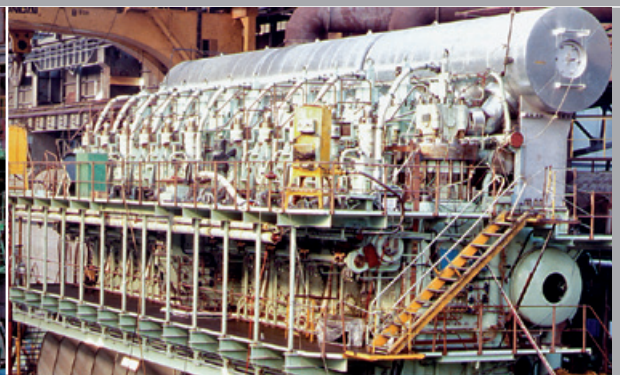
Today, using CKS® 36, running times of around 20,000 operating hours using heavy fuel oil, up to 30,000 operating hours using diesel and up to 50,000 operating hours using gas can be achieved. These running times correspond to a specific running surface wear of around 10 µm using heavy fuel oil, around 5 µm when using diesel and around 1.3 µm for gas.

Lubricating oil consumption for diesel and heavy fuel oil operation is between 0.3 g and 0.8 g per kWh, while oil consumption in a gas engine is between 0.15 g and 0.3 g per kWh.

However, wear on the running surface is not the only factor which determines the service life. The side faces of the rings are also exposed to wear which can impact the operation of the ring system in engines running on heavy fuel oil.







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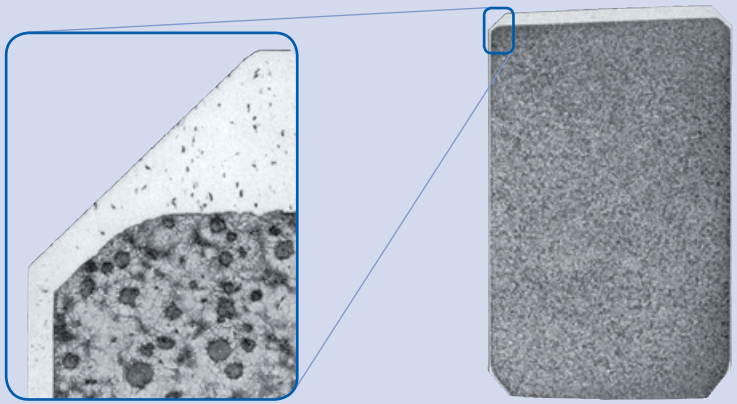
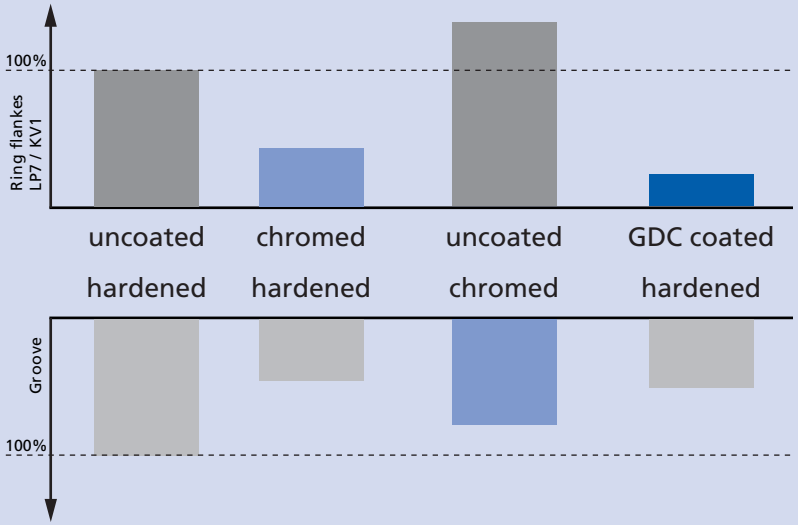
When the wear between the lower piston groove side face and the piston ring side face of the first groove reaches critical values, this can be a criterion for early failure.
In collaboration with leading engine manufacturers, the combination of a ring with chrome plated side faces together with a hardened groove has proven the best combination.

Ring with chrome plated side face



In the meantime, Federal-Mogul has taken the protective measures a step further: the GDC 50 coating is used as wear protection for the ring side face. The diagram shows the combined effect of individual coatings on wear of ring side face and piston groove.

Wear behaviour on side face and groove coatings



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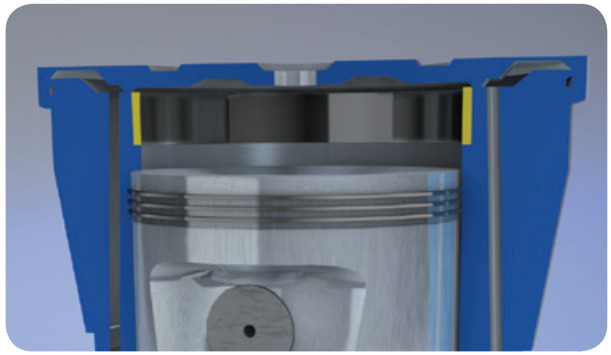
Today most cylinder liners made of untreated cast iron are used as the counter running surface to the piston ring. For final machining of the running surface, clean plateau honing, also recommended by Federal-Mogul, has long since become the norm. Nitrided or laser hardened cylinder sleeves are therefore being used less frequently. Cylinder sleeves today have a service life of around 100,000 operating hours; the sleeve must be honed twice during this period.

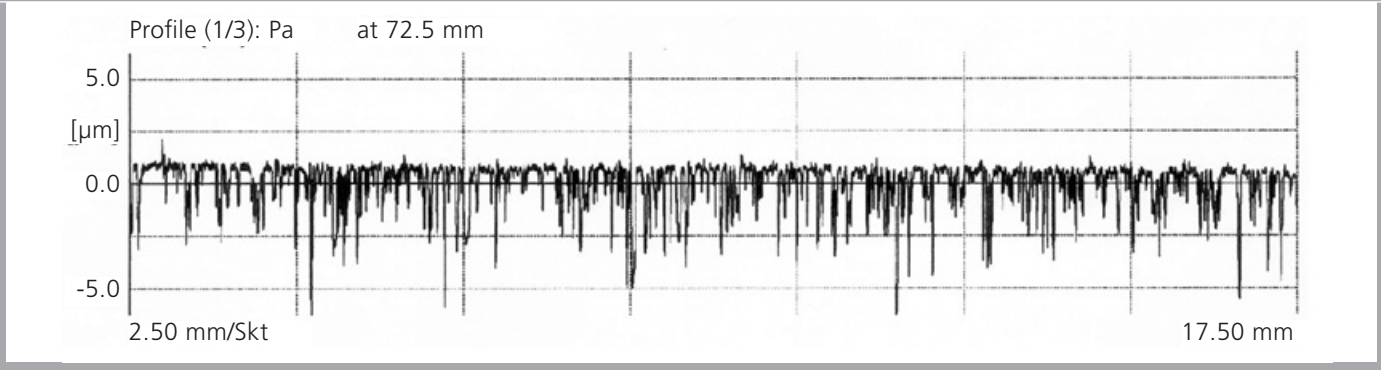
In summary we can say that the introduction of the chrome ceramic coating in combination with the antipolishing ring marked a milestone in the development of the module piston ring and cylinder sleeve. The anti-polishing ring (also called fireband) is a ring inserted in the upper end of the cylinder sleeve in order to prevent carbon deposits forming on the piston above the top compression ring.

Rpk < 0.3 µm
Rk = 0.5..1.3 µm
Rvk = 1.0..3.0
(acc.ISO 13565)

Anti-polishing ring



Plateau honing



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2-stroke diesel engines

The current market for 2-stroke diesel engines is dominated by two manufacturers who use different ring systems. These are a temper-hardened casting with inclusions of vermicular graphite is used in the first groove, while in the lower grooves, a non-hardened alloyed casting with lamellar graphite.

Both manufacturers use wear-resistant coatings on the running surfaces, with the difference that MAN uses thermal spray coatings while Wärtsilä uses a galvanic coating which was developed for use in 2-stroke engines. Both manufacturers use asymmetric convex running surface profiles and achieve ring operating times of around 30,000 operating hours.

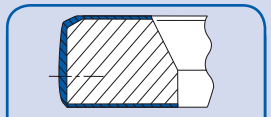
However, it should be noted that these values fluctuate widely depending on operating conditions and that large ring diameters are more critical.

With regard to cylinder machining no one process can be definitively identified as dominant. Both classic wave-cut machining and a type of plateau honing are used.

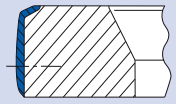
In oil consumption modern 2-stroke engines nearly achieve the low level of 4-stroke engines. Today 2-stroke diesel engines are being used with an oil consumption of 0.8 g/kWh.

Ring set for 2-stroke engines

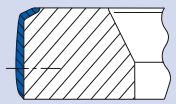
Piston ring set for MAN 2-stroke engines



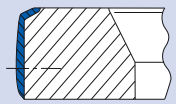
Asymmetrically barreled
Twin layer coated
Side face chromium coated
Top ring



Asymmetrically barreled
Running-in coated
3rd ring

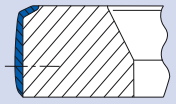


Asymmetrically barreled
Running-in coated
Side face chromium coated
2nd ring

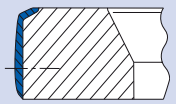


Asymmetrically barreled
Twin layer coated
4th ring

Piston ring set for Wärtsilä 2-stroke engines



Asymmetrically barreled
Chrome ceramic coated
Top ring



Asymmetrically barreled
Chrome ceramic coated
Lower rings

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Outlook on the future

Millions of combustion engines have been in use for over 100 years. No other form of drive is so multi-faceted and can be operated with varying types of fuel for such widely differing applications.

At the same time, environmental protection targets are in the public's eye around the world, meaning that the requirements for exhaust gas emission of engines will become more stringent. The challenge now is to lower pollutant emissions and fuel consumption even further, also for large bore engines, using current and future technologies while maintaining a balanced cost-benefit ratio.

Federal-Mogul has been a driving force for decades in the ongoing development of materials, coatings and shaping of piston rings and key components for efficient, long-life engines.

Federal-Mogul is applying its expertise to future challenges in order to optimise piston rings for increasingly stringent operating conditions. This includes a complete value added chain throughout the whole product life cycle from development to foundry technology to coating and service.

This established expertise is being expanded in specific areas with targeted strategic measures, such as the recent acquisition of the piston ring specialist DAROS Industrial Rings.

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Federal-Mogul, your worldwide specialist for large bore engine piston rings

Annotation

This catalogue sets out to the description of our products.

The information it contains is not designed as a statement of warranties, warranted characteristics or any warranty for fitness in regard to definite or assumed applications. The catalogue shall not be considered as a guarantee in whatever way. The wear performance of piston rings for large bore engines are governed by the prevailing peripheral influences, and all calculations can only ever be approximate. The products must always be individually tested by the user in the envisaged application. We reserve the right to undertake technical changes and improvements at any time without notice and to adapt our products to changing standards and guidelines. The contractual agreements which are entered into, especially the agreed specifications, drawings and other data are binding only and shall prevail.

Any liability deriving from the contents of this catalogue is hereby excluded.

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