

BEARINGS



EVERY BEARING YOU NEED



BEARINGS
TECHNICAL
MANUAL



BEARINGS
TECHNICAL
MANUAL



GLYCO[®]

Glyco is a trademark of Federal-Mogul Corporation

[i] INTRODUCTION	4
> OE QUALITY TOTAL CONFIDENCE	
> GLYCO HISTORY	
> Federal-Mogul RESEARCH AND DEVELOPMENT	
> Federal-Mogul RACING ACTIVITIES	
> STAY ON TOP OF THE LATEST DEVELOPMENTS	
[1] FUNDAMENTALS	8
> INSTALLATION OF BEARINGS	
> TYPES OF BEARINGS	
> STRENGTHS & WEAKNESSES OF ENGINE BEARINGS	
[2] DESIGN FEATURES OF A SLIDING BEARING SHELL	10
> BASIC MEASUREMENTS & TERMINOLOGY	
> LOCATING LUG	
> CRUSH HEIGHT	
> FREE SPREAD DIAMETER	
> CRUSH RELIEF	
> WALL THICKNESS	
> UNDERSIZE BEARINGS	
[3] BUSHES & THRUST WASHERS	14
> JOBS	
> DESIGN	
> STRESSES	
[4] CRANK PINS	16
> AXIAL SHAPE ERROR	
> RADIAL SHAPE ERROR	
> SURFACE ROUGHNESS	
> NCI CRANKSHAFTS	
[5] BEARING CLEARANCE	18
> FACTORS INFLUENCING BEARING CLEARANCE	
> SIZE AND TOLERANCES OF BEARING CLEARANCE	
> CONSEQUENCES OF BEARING CLEARANCE FOR THE ENGINE	
> THE INFLUENCE OF OIL TEMPERATURE ON BEARING CLEARANCE	
[6] OIL FILM	20
> FUNCTIONS OF THE OIL FILM	
> LUBRICATING THE ENGINE'S BEARINGS	
> THE PHYSICS OF LUBRICATION	
> HYDRODYNAMIC LUBRICATION	
> HYDROSTATIC DAMPING	
> DIRT PROBLEMS	
[7] MATERIALS FOR SLIDING BEARINGS	24
> REQUIREMENTS FOR BEARING MATERIALS	
> STRUCTURE OF BEARING MATERIALS	
> TYPES OF BEARING MATERIALS	
[8] Federal-Mogul TECHNOLOGIES IN BEARING MATERIALS	26
> GLYCO-199 TECHNOLOGY: GLYCO SPUTTER BEARINGS [®]	
THE PROCESS	
REPAIR & RUNNING TIPS GLYCO SPUTTER BEARINGS [®]	
> LEAD-FREE BUSHES & BEARINGS	
NEW LEGISLATION REQUIREMENTS	
LEAD-FREE MATERIALS	
GLYCO LEAD-FREE TECHNOLOGY: A370 [®] & CS-4	
> GLYCO-188 TECHNOLOGY	
PRINCIPLES & ADVANTAGES	
RESULTS	
CONCLUSION	31

TABLE OF
CONTENTS

INTRODUCTION



OE QUALITY TOTAL CONFIDENCE

Rebuilding an engine requires tremendous skill and hard work. To protect this investment, professional rebuilders rely on the Expert Brands. Federal-Mogul's industry-leading range of OE-quality replacement engine parts includes not only Glyco® bearings and bushings, but also the globally respected and proven AE® brand of valvetrain, camtrain; belts and related components; Goetze® for piston rings and cylinder liners; the Nüral® brand of pistons and cylinder assembly kits; and Payen® branded gaskets, oil seals and headbolts. This exclusive portfolio of "Expert Brands" provides the OE quality and total confidence preferred by today's engine rebuilding community.

WIDEST RANGE

Glyco is the world's largest bearing manufacturer with a range of over 2,450 parts, covering more than 5,000 engines. Glyco bearings, established in Germany in 1897, have become a top choice in the industry through a combination of leading technology and product reliability. Our Aftermarket parts are manufactured to the same exact quality specifications as our OE products. Federal-Mogul is a renowned pioneer in the development of advanced materials and designs that help ensure superior engine performance and reliability.



MARKET LEADER IN TECHNOLOGY

Our bearings are able to meet extreme demands in terms of withstanding loads and providing long life. The durability of Glyco Sputter Bearings® (Glyco-199) means twice the service life than that of conventional bearings. Glyco G-188 is the first "intelligent" bearing material – soft during the running-in phase, and hard throughout the rest of its life-time. Glyco was also the first to create fully lead-free materials like Glyco A370® and is 100% ready for the EU End of Life Directive (2000/53/EC) – well ahead of its foreseen implementation in 2011.

OE SUPPLIER FOR OVER 70 VEHICLE & ENGINE MANUFACTURERS

Glyco bearings and bushings are engineered in Germany and each year installed as OE components in more than 10 million new automotive, maritime and stationary engines, as well as in agricultural and construction equipment.



OE QUALITY AND TOTAL CONFIDENCE:
THE ULTIMATE COMPETITIVE ADVANTAGE AVAILABLE THROUGH EVERY ENGINE BRAND AND PRODUCT LINE FROM Federal-Mogul.

GLYCO HISTORY

- 2009 Glyco® becomes the unique brand for bearings with the widest range as Federal-Mogul merges AE® bearings range with Glyco®. New visual identity and packaging with a market leader message: **EVERY BEARING YOU NEED**
- 2008 Glyco® introduces the RVD® process, Rapid Vapor Deposition Lead- free Sputter® Technology
Glyco® achieves the goal to be 100% ready for the EU End of Life Directive (2000/53/EC), well ahead of its foreseen implementation in 2011
- 2005 Glyco® introduces lead-free bearing technology
- 2003 Introduction of the G-188 "intelligent material" – soft during run-in phase, hard for the rest of its life-time
- 2000 Federal-Mogul Wiesbaden is certified under VDA 6.1, in addition to QS 9000 and ISO 9001
- 1990 Federal-Mogul Corporation acquires Glyco® and becomes the world's largest manufacturer of engine bearings
- 1984 Construction of the first production plant for Glyco Sputter® bearings;
1981 successful engine tests at MAN and Mercedes-Benz
- 1978 Patent issued for the Physical Vapor Deposition (PVD) process for manufacturing Glyco Sputterlager®
- 1974 Glyco® becomes the largest supplier of bearing shells in Europe
- 1970 Glyco® starts research into Sputter coatings
- 1968 Introduction of GLYCODUR® sliding bearings
- 1966 Initial co-operation scheme between Federal-Mogul in Southfield (USA) and Glyco®
- 1937 Glyco® becomes the biggest supplier of bearing shells in Germany
- 1936 Development of replaceable engine bearings – a crucial contribution toward the serial production of engines
- 1915 Felix Daelen and Wilhelm Loos acquire Glyco-Metallgesellschaft for 100,000 Gold Marks and assume its management
- 1901 Patent issued by the "Imperial Patent Office" for "bearing shells made of a combination of resistant metal and soft metal"
- 1897 Dr. John Edward Stead (England) coins the trade name Glyco® for lead-containing bearing metal.
Max Wagner sets up Glyco Metallgesellschaft GmbH, Wiesbaden-Schierstein, on 24th October

Federal-Mogul RESEARCH AND DEVELOPMENT

NUMBER OF TEST BEDS: 19	Fully automatic engine testing with different test procedures during total test run including data recording and limit control Operation: 24 hours a day, 7 days a week and about 50 weeks a year
MAXIMUM BRAKE POWER: 700 Kw – MAXIMUM TORQUE: 4,000 NM	Range: 10,000 rpm / 230 Kw – 7,500 rpm / 400 Kw – 4,000 rpm / 700 Kw
ROAD-LOAD SIMULATION	Range: 8,000 rpm / 335 Kw
OIL CONSUMPTION, FUEL CONSUMPTION, BLOW-BY MEASUREMENT	Oil consumption continuously, automatic drain and weight Fuel consumption highest quality 0,1% Blow-by different measuring methods
EMISSION MEASUREMENT	Gaseous FTIR and FID Particulates (Soluble/Insoluble) within Gaschromatography
WEAR TESTING UNDER SPECIAL CONDITIONS	Temperatures, fuel and lubricant qualities, liner surfaces
CYLINDER HEAD GASKET TESTING	Special test procedures, field and material related

FEDERAL-MOGUL ENGINEERS SIMULATE THE WHOLE ENGINE IN DETAIL

The bearings and bushes are simulated together with the con rod and the Federal-Mogul pistons, rings, liners and gaskets in the engine block and the cylinder head.



DEFORMATION OF, AND STRESSES IN THE CON ROD



TESTING A BEARING UNDER REAL CONDITIONS IN AN ENGINE WOULD TAKE YEARS.



Federal-Mogul RACING ACTIVITIES

MOTOR SPORTS, THE ULTIMATE TESTING GROUND FOR INNOVATION

What better way to test Federal-Mogul products than to place them in the extreme conditions found on the track? The use of motor sports as a testing ground is further evidence of Federal-Mogul's commitment to developing the road products of tomorrow. The world top manufacturers and motor sports champions alike insist on Federal-Mogul products.

Federal-Mogul's WORLDWIDE PRESENCE

Federal-Mogul is a world-class player par excellence. Unlike many Aftermarket suppliers, the vast majority of the products it distributes are manufactured in-house. Federal-Mogul prides itself on its manufacturing and quality excellence, making its other additional brands such as Champion®, Ferodo®, Moog® – some of the most sought after names among the distributors and resellers whose job it is to channel parts to their installer customer base.

Federal-Mogul works closely with automotive manufacturers to design new products, and develop product and engineering solutions to meet customer requirements. Many of these innovations and technologies are driven by the specific needs of its OE customers, and a great many more by the needs of the Aftermarket. Proof of this lies in the number of patents for new technology for which Federal-Mogul files each year. The company's global network of research and development facilities is a testimony to its commitment to innovation and technology and ensures that Federal-Mogul will remain at the technological forefront of the market sectors it serves.



STAY ON TOP OF THE LATEST DEVELOPMENTS

The Technical Training Institute (tti) in Burscheid, Germany, was established to make sure that market skills and knowledge keep pace with the development of the products themselves, the manufacturing processes behind them, the support needed to service these products and our customers' growing needs. We do this by providing training to all Federal-Mogul staff as well as our customers, either at the institute or at satellite training facilities throughout Europe. No matter what your level of expertise, there will always be a course available to benefit your working practice. Each completed course will be acknowledged with an approved accreditation from Federal-Mogul.



FUNDAMENTALS

INSTALLATION OF BEARINGS

In an internal combustion engine there are certain sites where components move against each other. At these sites friction can lead to wear and damage of the components involved. To avoid these effects bearings are employed.

A bearing has the job of transmitting power, of reducing friction and of preventing wear on expensive engine parts. On top of this, bearings should be both economical and quick and easy to replace in case of damage.

TYPES OF BEARINGS

In an engine, the most important bearing sites are found at the crankshaft and camshaft.

The crankshaft is held in the crankcase by the main bearings (Figure 1). At one end, the connecting rods are linked by bearings of the crankshaft. At the other end the connecting rods are linked by the connecting rod bush to the piston pins (Figure 2). The crankshaft is held in either the crankcase or the cylinder head by camshaft half bearings or camshaft bushes.

Engineers distinguish between different kinds of bearings in various ways. On one hand, we can divide them up, on the basis of the nature of the power transmitted. In this case, we distinguish between radial and axial bearings. On the other hand, we may distinguish on their design. Then we distinguish between anti-friction bearings (e.g. ball or roller bearings) and sliding bearings.

In four stroke engines, predominantly sliding bearings are used as radial bearings. Radial bearings are produced either in form of divisible half shells or as bushes. The axial bedding of the crankshaft and the camshaft is done by trust washers or flanged bearings.

STRENGTHS & WEAKNESSES OF ENGINE BEARINGS

For internal combustion engines, sliding engine bearings offer a number of advantages over anti-friction bearings. One principle advantage of sliding bearings is that it can be divided in half shells. For this reason, a sliding bearing can, in contrast to a roller bearing, be mounted on a crankshaft.

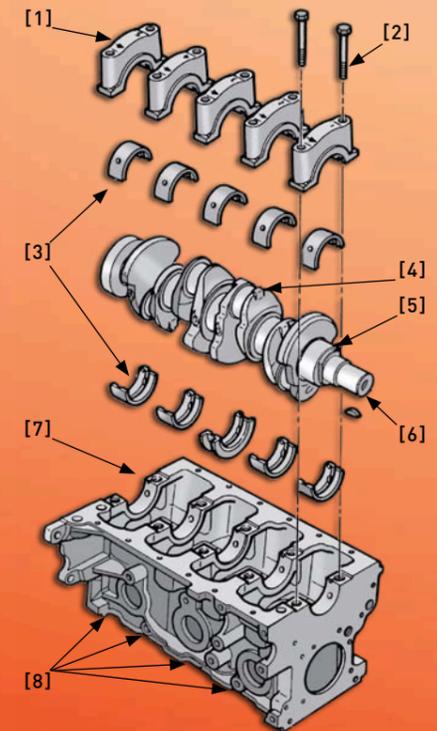
Sliding bearings of the same dimensions as anti-friction bearings can bear higher loads. Additionally, they are less sensitive to shock loads. As a consequence, sliding bearings have a longer lifetime and they generate less noise.

In comparison to roller bearings, sliding bearings have a smaller volume and less mass. Therefore, their production is more economical.

A disadvantage of sliding engine bearings is that they produce greater friction than anti-friction bearings at low revs. This drawback is most significant when starting up an engine, when sliding engine bearings cause both boundary friction and mixed friction, leading to greater wear to components than they suffer when the engine is running.

[FIG.1] ENGINE ELEMENTS CONNECTED WITH THE BEARINGS

- [1] MAIN BEARING CAP
- [2] MAIN CAP BEARING BOLTS
- [3] MAIN BEARINGS
- [4] CON ROD BEARING CRANK PIN
- [5] MAIN BEARING CRANK PIN
- [6] CRANKSHAFT
- [7] ENGINE BLOCK
- [8] CYLINDER BORES

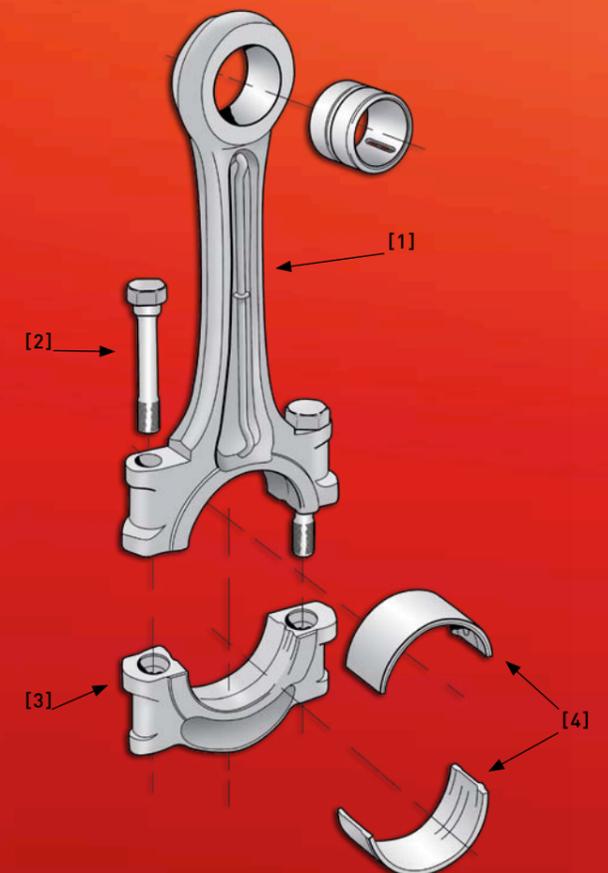


[1]



[FIG.2] ELEMENTS OF A CONNECTING ROD

- [1] CONNECTING ROD
- [2] CON ROD BOLT
- [3] CON ROD CAP
- [4] CON ROD BEARINGS



DESIGN FEATURES OF A SLIDING BEARING SHELL

FOR HOLDING THE CRANKSHAFT AND THE CONNECTING RODS, SLIDING BEARINGS, CONSISTING OF TWO HALF SHELLS ARE USED. AXIALLY, CRANKSHAFT AND CAMSHAFT ARE HELD IN PLACE BY FLANGED BEARINGS OR TRUST WASHERS. CON ROD BEARINGS ARE GUIDED BY THE CRANK WEBS.

BASIC MEASUREMENTS & TERMINOLOGY

The main external dimensions of smooth and flanged bearing shells are shown in Figures 3-5, which also show the drilled oil ways and grooves. These design features are discussed in greater detail in the chapter on the lubrication. Apart from this dimensions, there are further features characteristics of the bearing half shell.

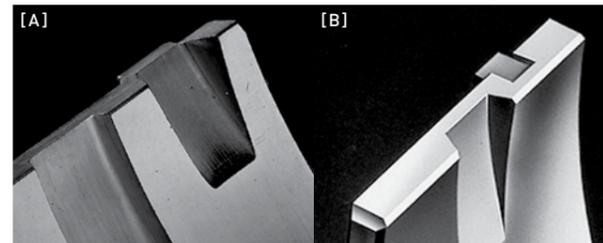
LOCATING LUG

The locating lug is the most apparent of these features. It ensures that the bearing shell is installed in its correct position within the case (Figure 6). Ensuring the correct positioning of the bearing in the housing is the only function of the locating lug. Specifically, it does not safeguard the bearing shell against torsion/twisting inside the case. This is prevented by interference fit, as a result of the 'crush height', which is discussed below.

The locating lug may be designed either as a conventional locating lug or a coined locating lug (Figure 7). Today, both variants are employed in mass production by many reputable manufacturers.

Unlike the conventional lug, the coined lug leaves the sliding surface unaltered. This offers a small advantage with diagonally-arranged connecting rod bearings, since with this arrangement a coined lug does not disrupt the oil flow.

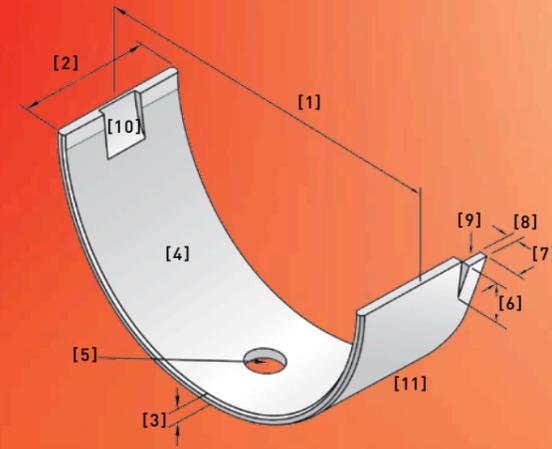
Bearings in more modern engines often do not have a locating lug any more. This requires special care while positioning the bearing inside the housing. The locating lug is not used because it is expensive. The case needs a recess to put in the locating lug. It is more cost effective to produce the case without the recess. Apart from its dimensions and the locating lug, the bearing shell has three further construction features which are not apparent to the naked eye: the excess length, the free spread diameter and crush relief.



[FIG.7]

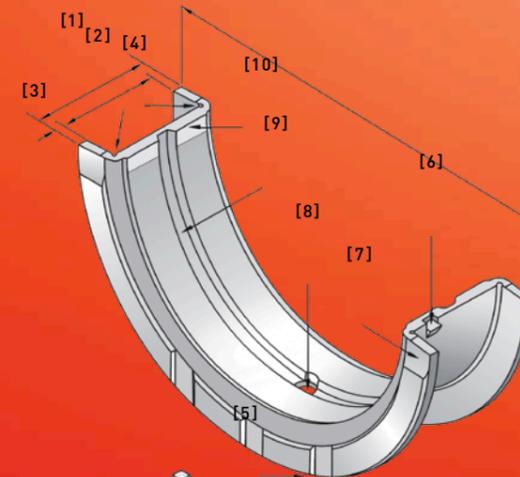
[A] THE CONVENTIONAL LOCATING LUG IS PRODUCED BY PUNCHING AND IN SOME CASES MILLING OF THE INNER SHAPE OF THE LOCATING LUG.

[B] A COINED LOCATING LUG IS PRODUCED BY MEANS OF AN UPSETTING IN ONE SINGLE PASS. THIS TYPE OF A LOCATING LUG IS USED BY MOST OF THE IMPORTANT OE MANUFACTURERS TODAY.



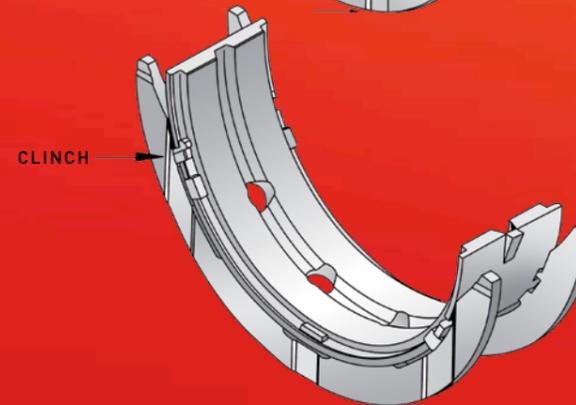
[FIG.3] DIMENSIONS AND CHARACTERISTICS OF AN ENGINE BEARING

- [1] OUTER DIAMETER
- [2] BEARING LENGTH
- [3] WALL THICKNESS
- [4] SLIDING SURFACE
- [5] OIL BORE
- [6] LENGTH OF LOCATING LUG
- [7] WIDTH OF LOCATING LUG
- [8] DEPTH OF LOCATING LUG
- [9] LUG RELIEF
- [10] PARTIAL OIL GROOVE
- [11] BEARING BACK



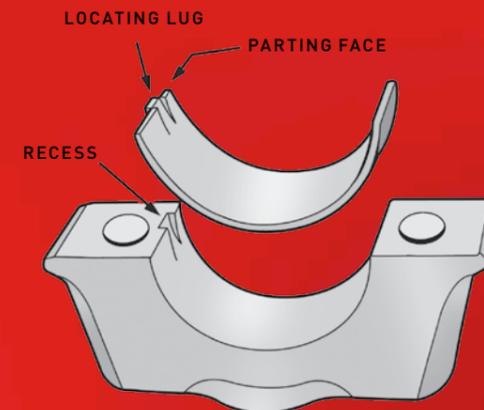
[FIG.4] CHARACTERISTICS OF AN ASSEMBLED FLANGE BEARING

- [1] LENGTH
- [2] FLANGE DISTANCE
- [3] FLANGE WALL THICKNESS
- [4] STRESS REDUCTION RELIEVES
- [5] JOINT RELIEF OF THRUST FACE
- [6] LOCATING LUG
- [7] JOINT RELIEF OF THRUST FACE
- [8] OIL BORE
- [9] OIL GROOVE
- [10] JOINT RELIEF OF SLIDING SURFACE



[FIG.5]

CHARACTERISTICS OF AN ASSEMBLED FLANGE BEARING. FOR DIMENSIONS SEE FIG. 4.



[FIG.6]

THE ONLY PURPOSE OF THE LOCATING LUG OF A BEARING IS TO AVOID THE BEARING BEING ASSEMBLED IN AN INCORRECT POSITION INTO THE HOUSING. THE HOUSING BORE HAS A RECESS IN WHICH THE LOCATING LUG FITS. THE LOCATING LUG DOES NOT PREVENT THE BEARING FROM TURNING IN THE HOUSING.

[2]



CRUSH HEIGHT

The external circumference of a half shell is longer than the internal circumference of the closed housing bore. This difference is called the crush height (Figure 8). When the con rod bolts or the main cap bolts are tightened, the bearings are compressed elastically. By this means, the bearings adapt to the inner diameter of the much less elastic housing bore. The elastic compression creates a pressfit between bearing and housing bore that keeps the bearing in its position while the engine works.

FREE SPREAD DIAMETER

The free spread diameter (Figure 9) is the difference between the external distance between the two ends of the bearing shell (i.e., the parting faces) and the inner diameter of the housing bore. The free spread diameter is between 0.5 and 1.5 mm for passenger car and truck bearings. It causes that the bearing shell remains in contact with the case wall around its entire circumference. Said contact must be ensured as otherwise the crank pins and the bearing shell could come into contact in the region of the parting faces. This contact would take off the oil film and lead to wear and bearing damage.

The contact between the bearing and case must be ensured for a second reason. When the oil flows through the lubrication gap, the friction between the oil molecules heats the oil. The heat is partially transferred through the bearing shell into the case. A good contact between the bearing shell and the case is necessary for sufficient heat transfer. A helpful side effect of the free spread diameter is that it retains the bearing shell in its housing during assembly.

CRUSH RELIEF

During the assembly of a bearing there may be misalignment between the bearing cover and the case, and in some cases this misalignment may cause the bearing shell and crank pins to come into contact, leading to wear and bearing damage (Figure 10, see also "crush height"). To avoid this harmful effect the bearing shell's wall is thinner underneath the area of the parting faces (Figure 11). This area, with a reduced wall thickness, is known as the crush relief.

WALL THICKNESS

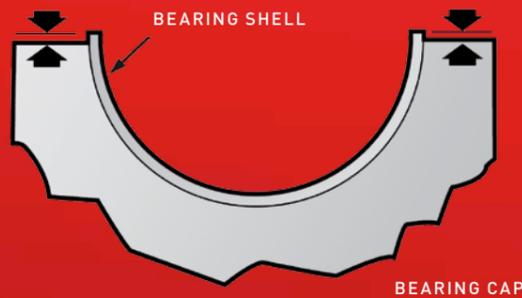
The wall thickness is measured in the crown of the bearing. It is constant in case of a cylindrical bearing, with the exception of the crush relief. The tolerance for fluctuations of the wall thickness is very little. It amounts to about 3 μm in axial direction and about 6 μm in circumferential direction.

In case of eccentric bearings, the wall thickness is also measured in the crown of the bearing. The wall thickness is reduced from the crown towards the parting faces, up to the start of the crush relief area, normally by up to 20 μm . The extent of this tapering depends on the construction of the housing bore.

UNDERSIZE BEARINGS

For an overhaul of the engine, there are several undersizes with wall thicknesses increased to suit the reduced diameter of the crankshaft journal. The external diameter of an undersize bearing is the same as that of a bearing of standard dimensions. As the crankshaft diameter is reduced, the wall thickness will be greater. The dimensions of the undersize bearing are related to the reduced diameter of the crankshaft.

For instance, undersize 0.50 mm means that the bearing shells' wall thickness is 0.25 mm greater than in a standard bearing.



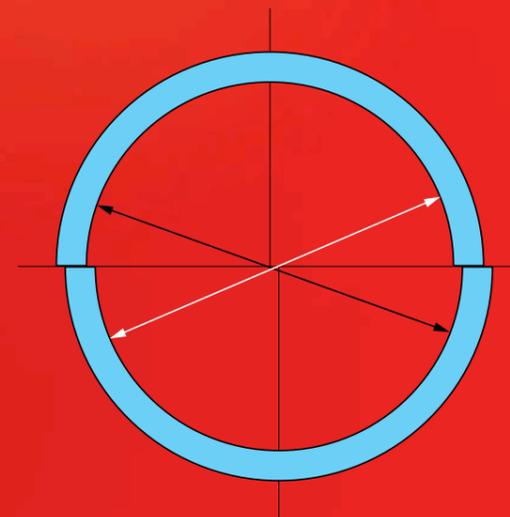
[FIG.8]

THE CRUSH HEIGHT INCREASES THE OUTER DIAMETER OF THE BEARING PAIR SO THAT IT IS LARGER THAN THE INNER DIAMETER OF THE HOUSING BORE. THE CRUSH HEIGHT IS COMPRESSED BY THE CON ROD BOLTS OR THE MAIN BEARING CAP BOLT. THIS COMPRESSION OF THE BEARING CREATES A PRESSFIT WHICH PREVENTS THE BEARING PAIR FROM TURNING AND MOVING INSIDE THE HOUSING BORE.



[FIG.9]

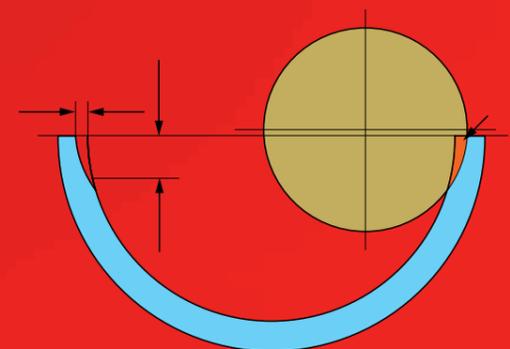
LARGE AREAS OF THE SURFACES OF THE BEARING BACK AND THE HOUSING BORE HAVE TO BE IN CONTACT FOR TWO REASONS. ON THE ONE HAND, A GOOD CONTACT GUARANTEES A GOOD TRANSPORT OF HEAT CREATED BY THE FRICTION INSIDE THE BEARING. ON THE OTHER HAND, A GOOD CONTACT MINIMISES THE RISK OF A DIRECT CONTACT BETWEEN THE SURFACES OF THE BEARING AND THE CRANKSHAFT JOURNAL. THE DISTANCE BETWEEN THE TWO PARTING LINES IS LARGER THAN THE INNER DIAMETER OF THE HOUSING BORE. A CONSEQUENCE OF THIS DIMENSIONAL DIFFERENCE IS A GOOD CONTACT BETWEEN THE TWO SURFACES OF BEARING BACK AND HOUSING BORE.



[FIG.10]

WHEN UPPER AND LOWER SHELLS OF A BEARING PAIR ARE MISALIGNED, THE INNER DIAMETER OF THE BEARING IS PARTIALLY TOO SMALL. THIS MEANS THAT ALSO THE BEARING CLEARANCE IS PARTIALLY TOO SMALL. IN EXTREME CASES, THE SURFACES OF BEARING AND CRANKSHAFT JOURNAL TOUCH. THIS LEADS TO A FAILURE OF THE BEARING AFTER A SHORT RUNNING TIME.

MISALIGNMENT OF BEARING SHELLS
— DIAMETER TOO SMALL
— DIAMETER TOO LARGE



[FIG.11]

COMBUSTION AND INERTIA FORCES DEFORM THE BIG CON ROD EYES CYCLICALLY TO AN OVAL SHAPE. DUE TO THE OVAL SHAPE THE CLEARANCE BETWEEN BEARING AND CRANKSHAFT JOURNAL IS DECREASED IN THE AREA OF THE PARTING LINES. A SMALLER CLEARANCE INCREASES THE RISK OF A CONTACT BETWEEN THE SURFACES OF THESE TWO ELEMENTS. TO AVOID A DIRECT CONTACT, SOME BEARINGS HAVE A THINNER WALL IN THE AREA OF THE PARTING LINES (CRUSH RELIEF).

BUSHES & THRUST WASHERS

APART FROM (HALF) SHELLS, TWO OTHER FORMS OF ENGINE BEARINGS EMPLOYED IN INTERNAL COMBUSTION ENGINES ARE THE BUSH AND THE THRUST WASHER.

JOB

Bushes are used in the small con rod eye, with camshafts and in some cases at the ends of the crankshaft. Thrust washers are used to control the crankshaft float in the engine block in the axial direction.

DESIGN

Solid & Clip on flanged bearings are also used instead of thrust washers. This is basically a combination of a plain shell with the thrust washer attached (clip on) or, a solid shell where the plain bearing and flange is formed from one piece of material.

A bush's external diameter is greater than the internal diameter of the case boring. Similar to the excess length of a bearing shell, this difference generates a force fit, which retains the bush in the boring.

STRESSES

Connecting rod bushes used to be cylindrical. During power transmission between the piston and the piston pins, this design leads to high pressures on the area of the piston boss. The stress resulting from these pressures can cause cracks. To reduce these stresses the bearing surface between the piston and piston pin is enlarged and accordingly the small connecting rod eye and connecting rod bush are today often tapered in design (Figure 14).

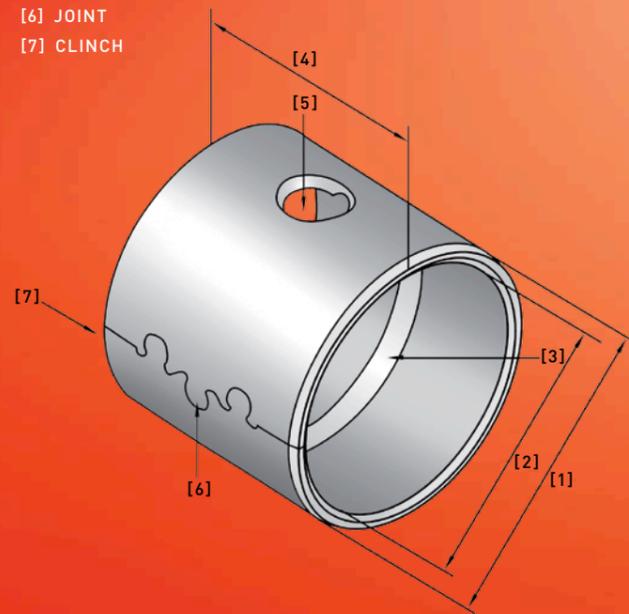
The specific stresses are considerably greater in a connecting rod bush than in the connecting rod bearing. To counteract these greater stresses the connecting rod bush and the piston pins must have less play than the connecting rod bearing. Accordingly, the internal diameter of connecting rod bushes is bored down to the desired dimensions only after pressing into the connecting rod eye.

[3]



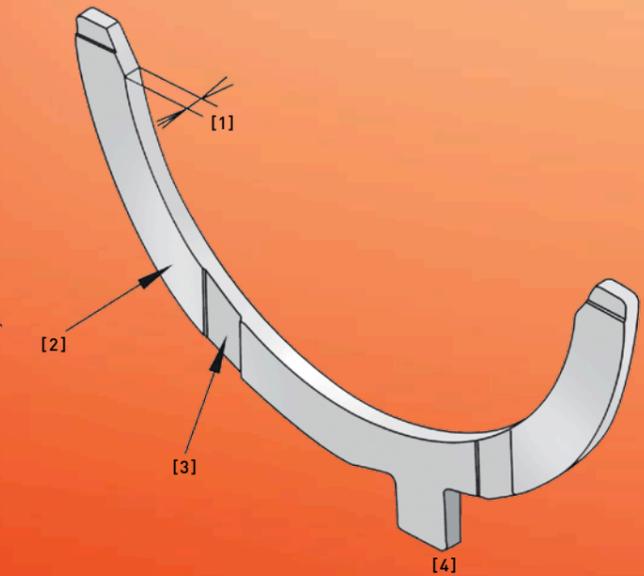
[FIG.12] DIMENSIONS AND CHARACTERISTICS OF A SMALL END BUSH

- [1] OUTER DIAMETER
- [2] INNER DIAMETER
- [3] OIL GROOVE
- [4] LENGTH
- [5] OIL BORE
- [6] JOINT
- [7] CLINCH



[FIG.13] DIMENSIONS AND CHARACTERISTICS OF A THRUST WASHER

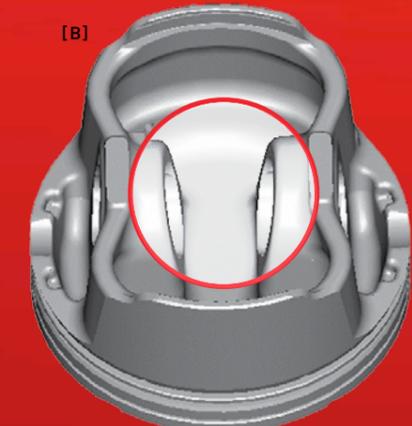
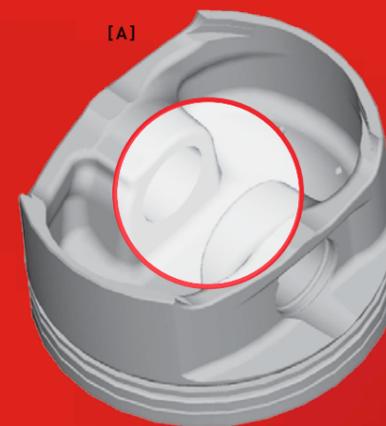
- [1] WALL THICKNESS
- [2] SLIDING SURFACE
- [3] LUBRICATING GROOVE
- [4] LOCATING LUG



[FIG.14]

[A] THE SMALL CON ROD EYE FOR THIS PISTON HAS A CYLINDRICAL SHAPE WHICH IS THE TRADITIONAL SHAPE FOR PISTON AND CON ROD.

[B] THE SMALL CON ROD EYE FOR THIS PISTON HAS A CONICAL SHAPE. THE CONICAL SHAPE INCREASES THE LOAD CARRYING SURFACE OF THE CON ROD BUSH AND THE PISTON PIN. AT THE SAME TIME, THE RIGIDITY OF THE PISTON IS STRENGTHENED. DUE TO THE LARGER LOAD CARRYING SURFACE THERE IS LESS PRESSURE ON CON ROD BUSH AND PISTON PIN.



CRANK PINS

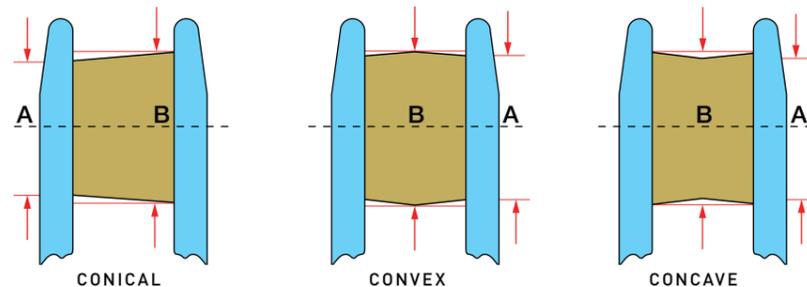
CONSTRUCTING AN EFFICIENT AND DURABLE BEARING IS NOT JUST A MATTER OF OPTIMALLY DESIGNED BEARING SHELLS. THE CRANK PINS ALSO PLAY A VITAL ROLE, SINCE ANY DEPARTURE FROM THE PERMISSIBLE GEOMETRY CAN LEAD TO BEARING DAMAGE.

AXIAL SHAPE ERROR

Axial shape error in crank pins may involve either conical, convex or concave deviations (Figure 15). Degrees of permissible shape deviation fall within preset limits which depend on the diameter and width of the crank pin. Table 1 shows an example involving a pin with a nominal diameter of 50 mm.

[TABLE 1]

DIAMETER TOLERANCE CLASS: H6	EXAMPLE FOR D=50 MM:	
	DMIN = 49.984	
	DMAX = 50.000	
CONICITY: (TAPER SHAPE)	LENGTH OF CRANK PIN	MAX. TAPERSHAPE B-A (SEE FIG.15) IN μM
	< 25 MM	3 μM
	25 TO 50 MM	5 μM
	> 50 MM	5 μM
CONVEX/CONCAVE DEVIATION TOLERANCE:	MAX. 50% OF ALLOWED TAPER SHAPE	
ROUNDNESS ERROR:	MAX. 25% OF ALLOWED TAPER SHAPE (ROUNDNESS ERROR OF 1ST ORDER ONLY)	

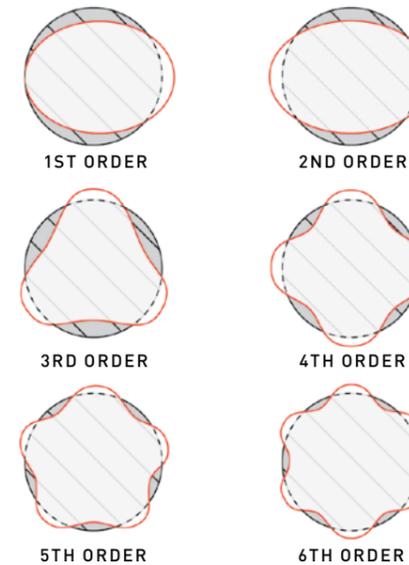


[FIG.15]

FORM ERRORS OF THE CRANKSHAFT JOURNAL IN AXIAL DIRECTION AS CONICAL, CONVEX AND CONCAVE DEVIATIONS FROM THE IDEAL CYLINDRICAL SHAPE. PRACTICALLY ALL CRANKSHAFT JOURNALS DEVIATE FROM THE IDEAL CYLINDRICAL SHAPE. THE DECISIVE QUESTION IS THE DIFFERENCE BETWEEN THE LARGEST AND THE SMALLEST DIAMETER A AND B. EXAMPLES FOR MAXIMUM ADMISSIBLE FORM ERRORS ARE GIVEN IN TABLE 1.

RADIAL SHAPE ERROR

Radial shape error occurs when there is vibration between the tool and the crank pin during its working. Figure 16 shows examples of possible radial shape errors. Degrees of permissible shape deviation depend on the type of deviation involved and also the minimum oil film thickness. The minimum oil film thickness depends on the load carry on the bearing.



[FIG.16]

TYPICAL FORM ERRORS OF CRANKSHAFT JOURNALS IN RADIAL DIRECTION FROM THE IDEAL ROUND SHAPE. THE ILLUSTRATION SHOWS DEVIATIONS FROM FIRST TO SIXTH ORDER. SUCH FORM ERRORS ARE CREATED WHEN IT COMES TO HARMONIC VIBRATIONS BETWEEN THE GRINDING WHEEL AND THE TURNING CRANKSHAFT.

SURFACE ROUGHNESS

Alongside axial and radial shape errors, surface quality is a further important property of a crank pin. High surface quality leads to minimal wear to the pin and its bearing. Table 2 shows some guidelines for surface roughness parameters Ra and Rz.

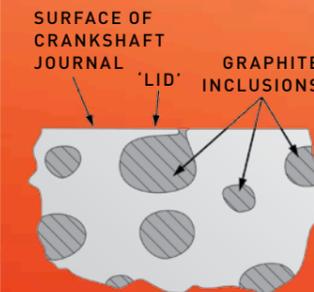
[TABLE 2]

A) HEAVY LOAD BEARINGS (ESPECIALLY DIESEL ENGINES) ($> 45 \frac{\text{N}}{\text{MM}^2}$)	
RA	MAX. 0.2 μM
RZ	MAX. 0.8 μM
B) STANDARD LOAD BEARINGS ($< 45 \frac{\text{N}}{\text{MM}^2}$)	
RA	MAX. 0.4 μM
RZ	MAX. 1.5 μM

NCI CRANKSHAFTS

Today crankshafts are manufactured either of steel or nodular cast iron (NCI). NCI contains graphite inclusions (so-called graphite nodules) which improve the material's elasticity. When working NCI pins one special characteristic must be taken into account.

When a nodular cast iron pin is reground you will cut into the graphite inserts, and 'smearing' of the material during the cutting process leads to the formation of 'lids' which cover the graphite inserts. Thus, although the surface has a smooth external appearance, stresses on the lids while the engine is running can cause them to break off, leading to bearing damage (see Figures 17 & 18). The formation of lids must be avoided at all costs. This can be done in two ways. Firstly, the formation of lids can be minimised by the use of CBN (cubic crystalline boron nitride) strips. Secondly, after grinding the shaft can be gas nitrated and polished. Gas nitrated lids are more brittle and snap off more readily during polishing. It should be noted that grinding and polishing should be done in opposing directions, with polishing taking place in the engine's direction of rotation.



[FIG.17] SURFACE OF CRANKSHAFT 'LID' GRAPHITE INCLUSIONS

SKETCH OF A MAGNIFIED CROSS SECTIONAL VIEW OF A CRANKSHAFT JOURNAL MADE OF NODULAR GRAPHITE IRON. THE HATCHED AREAS REPRESENT INCLUSIONS OF GRAPHITE IN THE IRON MATRIX. GRAPHITE INCLUSIONS ARE CUT WHEN THE CRANKSHAFT JOURNAL IS REGROUNDED. THE CUTTING TOOL SMEARS IRON OVER THE INCLUSION SO THAT THE INCLUSION IS COVERED PARTIALLY OR TOTALLY BY A LID. SUCH LIDS CAN BE DANGEROUS FOR THE ENGINE. THE CYCLIC LOAD ON THE BEARING CAN MAKE THE LIDS VIBRATE AND BREAK. IF THE LIDS BREAK, THEY CAN DAMAGE THE BEARING AS DIRT PARTICLES.



[FIG.18]

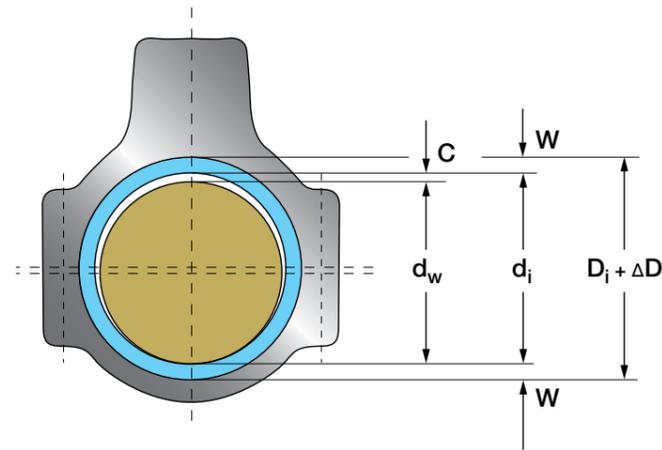
300 TIMES MAGNIFIED VIEW OF THE SURFACE OF A CRANKSHAFT JOURNAL MADE OF NODULAR GRAPHITE IRON AFTER GRINDING. ONE CAN CLEARLY SEE THE LIDS EXPLAINED IN FIGURE 17.

[4]



BEARING CLEARANCE

BEARING CLEARANCE IS DEFINED AS THE DIFFERENCE BETWEEN THE EXTERNAL DIAMETER OF THE CRANKSHAFT AND THE INTERNAL DIAMETER OF THE INSTALLED BEARING (FIGURE 19).



[FIG.19]

THE BEARING CLEARANCE IS THE DIFFERENCE BETWEEN THE INNER DIA-METER OF THE BEARING ASSEMBLED INTO THE HOUSING AND THE OUTER DIAMETER OF THE CRANKSHAFT JOURNAL. THE DIAMETERS OF HOUSINGBORE AND CRANKSHAFT JOURNAL AS WELL AS THE WALL THICKNESS OF THE BEARING HAVE TO BE WITHIN CERTAIN TOLERANCES. THESE TOLERANCES ARE INDICATED ON THE DRAWINGS OF THESE COMPONENTS. THE TOTAL OF THE MAXIMUM PERMITTED TOLERANCES RESULTS IN THE MAXIMUM OF THE BEARING CLEARANCE. FOR EXAMPLE, MINIMUM WALL THICKNESS COMBINED WITH LARGEST HOUSING BORE AND SMALLEST CRANKSHAFT JOURNAL DIAMETER RESULT IN THE MAXIMUM BEARING CLEARANCE. MAXIMUM WALL THICKNESS COMBINED WITH SMALLEST HOUSING BORE AND LARGEST CRANKSHAFT JOURNAL RESULT IN THE MINIMUM BEARING CLEARANCE. THE NORMAL MINIMUM BEARING CLEARANCE IS 20 μM FOR CON ROD BEARINGS AND 25 μM FOR MAIN BEARINGS.

$$\text{CLEARANCE: } C = D_i + \Delta D - 2W - d_w$$

$$\text{TOLERANCE: } \text{TOL. } C = \text{TOL. } D_i + 2 \times \text{TOL. } W + \text{TOL. } d_w$$

[5]

FACTORS INFLUENCING BEARING CLEARANCE

The bearing clearance depends upon three factors: the component's dimensional tolerance, the wear to the bearing during operation and the properties of the materials making up the component.

The materials of crankshaft, bearings and housing have different coefficients of thermal expansion. These different coefficients can influence significantly the bearing clearance at high and low temperatures. The pressfit of a bearing normally also results in a minor widening of the housing bore.

SIZE AND TOLERANCES OF BEARING CLEARANCE

The bearing clearance tolerance is determined from the sum of the tolerances of the individual parts. Typical values for the tolerances in the case of a car engine are 19 μm for the case boring, 19 μm for the crankshaft diameter and 10 μm for the bearing wall thickness. In a car the minimum clearance of 20 μm for the connecting rod bearing and 25 μm for the main bearing must also be allowed for.

This yields clearance of between 20 and 78 μm for the connecting rod bearing and 25 – 83 μm for the main bearing. Figure 20 compares the minimum clearance for a car connecting rod bearing with the width of a human hair. This brings home the point that even very fine particles of dirt in an engine bearing can cause damage.

CONSEQUENCES OF BEARING CLEARANCE FOR THE ENGINE

The amount of bearing clearance has consequences for the engine's operation. If the clearance is minimal there is good conformability between the bearing and crankshaft journal. This conformability is a result of material that is worn in some parts of the bearing in the order of magnitude of μms. This process leads to less local stress on the sliding layer, a better absorption of shock loads and less wear. The smaller clearance also reduces the engine noise.

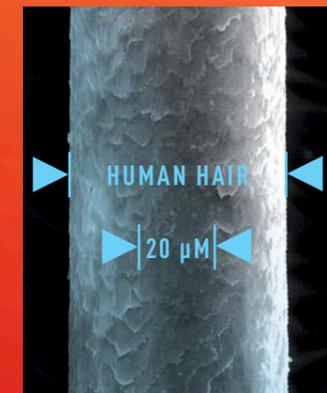
A disadvantage of having little bearing clearance is that less oil can flow through the smaller lubrication gap. This means that bearing cooling is poorer than when the clearance is greater.

To improve cooling of the bearings, larger clearances are used. An example is motor sports engines. Their larger clearances lead to significantly shorter lifetimes. This is less of an issue as motor sports engines are overhauled after each race.

THE INFLUENCE OF OIL TEMPERATURE ON BEARING CLEARANCE

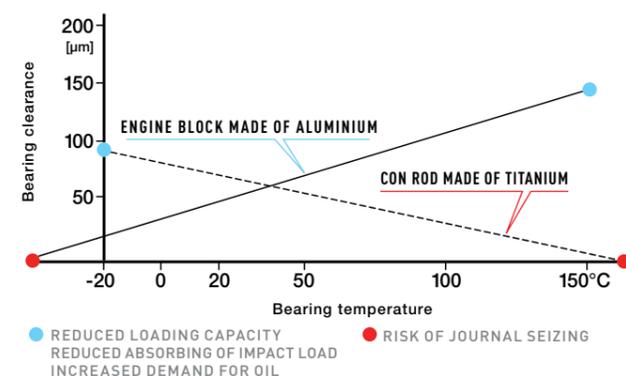
If the case and the shaft are made of the same material, components will expand evenly as the oil temperature rises. In this case bearing clearance remains unaltered as the oil temperature rises. However, the situation is different if, for example, the case is made of aluminium and the shaft of steel (Figure 21). Aluminium expands more than steel with increasing temperature, so in this case the clearance will rise as temperature increases. Furthermore, the pressfit will decrease. This effect can be compensated by an increased crush height, which has already to be considered during the development of the engine.

At extremely low temperatures the clearance may even fall to zero, making it impossible to start the engine.



[FIG.20]

COMPARISON BETWEEN A HUMAN HAIR AND THE MINIMUM PERMITTED CLEARANCE OF A CON ROD BEARING OF 20 μM.



[FIG.21]

THE BEARING CLEARANCE IS CONSTANT WITH RISING OIL TEMPERATURE IF HOUSING AND CRANKSHAFT ARE MADE OF THE SAME MATERIAL. THE SITUATION CHANGES WHEN DIFFERENT MATERIALS ARE USED. THE REASON IS THAT DIFFERENT MATERIALS HAVE DIFFERENT THERMAL EXPANSION COEFFICIENTS. THE DIAGRAM SHOWS TWO EXAMPLES FOR CRANKSHAFTS MADE OF STEEL. IF THE ENGINE BLOCK IS MADE OF ALUMINIUM, THE CLEARANCE INCREASES WITH RISING OIL TEMPERATURES (CONTINUOUS LINE). IF THE CON ROD IS MADE OF TITANIUM (E.G. IN RACE ENGINES), THE CLEARANCE DECREASES WITH RISING OIL TEMPERATURE (BROKEN LINE).

OIL FILM

FUNCTIONS OF THE OIL FILM

While the engine is running, an oil film develops and is maintained between the bearings and the crank pins. This oil film has two functions.

The oil film's principal function is to separate the bearing from the crank pins. This reduces friction and avoids wear on expensive parts. The thickness of the lubricating film is determined by four factors: the load on the bearing, the sliding speed, the lubricant oil's viscosity and the bearing play.

The oil film's second function is to cool the bearing and the crank pins. As they flow through the narrow lubrication gap, the oil molecules rub against each other, and this friction heats the oil, the bearings and the crank pins. Most of the heat generated must then be drawn off by the oil film itself. The rest of the heat generated is conducted through the crankshaft and through the bearing shell into the engine case or the con rod. The heat generated must then be drawn off by the oil film itself. In modern engines the bulk of the oil flow is required for bearing cooling, relatively little oil would be needed for actual lubrication.

LUBRICATING THE ENGINE'S BEARINGS

To supply the various bearings with oil, an engine is equipped with a widely branched oil pipe system. First the oil is sucked out of the oil sump and pumped through an oil filter. Then it passes through borings in the engine block via the boring and grooves in the main bearing's upper shell to the main bearing crankshaft journal.

The oil pressure in the main bearing transports a lot of this oil through borings in the crankshaft further to the con rod bearing (Figure 22). In engines with high loads, the oil pressure in the con rod bearing pumps a part of this oil through a boring in the con rod to the small con rod eye (Figure 23). The small con rod eye may also be lubricated by oil dripping down from the pistons. In this case the oil passes through a boring on the upper side of the con rod eye to the con rod bush/piston pin bearing.

Apart from the oil borings, the bearing shells and bushes are often also fitted with oil grooves. These oil grooves should help to ensure that the lubricant oil is distributed evenly over the bearing. They also help to transport the oil through borings in the crankshaft journal to further lubricating points.

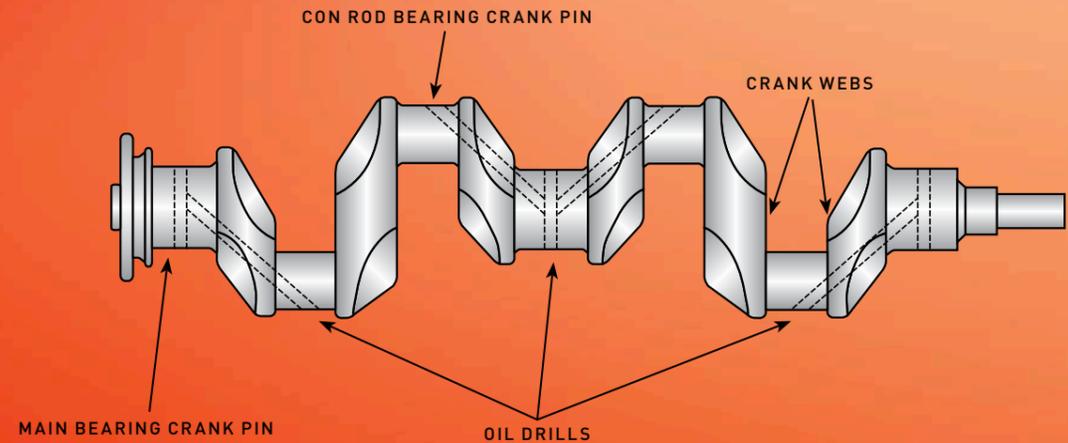
The con rod bushes and piston pins perform a pendulum motion relative to each other, and this motion does not promote the oil distribution as much as the rotating movement in the main and con rod bearings. Accordingly, to improve lubricant oil distribution con rod bushes may be fitted with oil grooves of generous proportions.

[6]



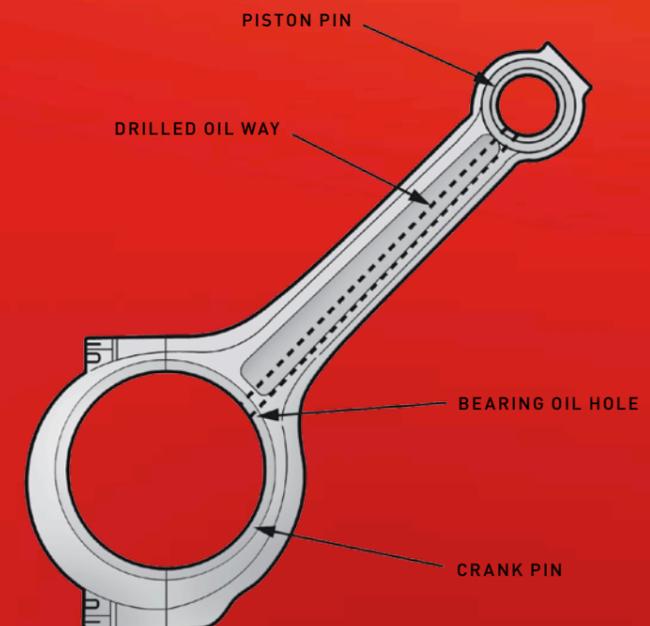
[FIG. 22]

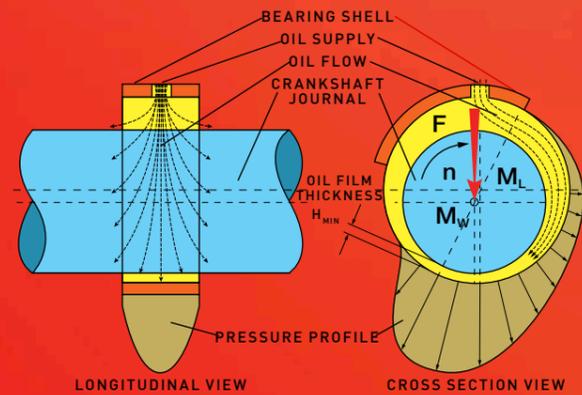
CRANKSHAFT JOURNAL WITH OIL PIPES SHOWN IN BROKEN LINES. THE OIL PRESSURE IN THE MAIN BEARINGS PUMPS THE OIL THROUGH THESE OIL PIPES TO THE CON ROD BEARINGS.



[FIG. 23]

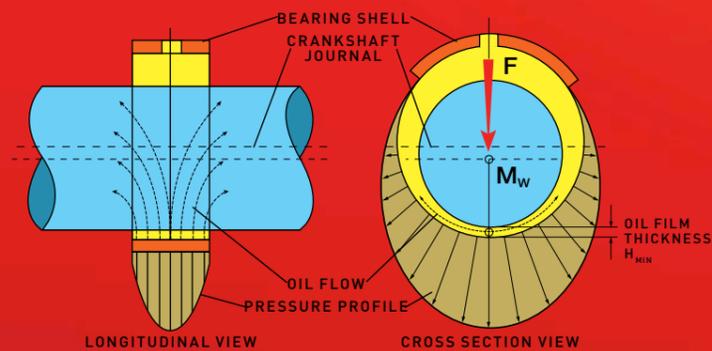
THIS ILLUSTRATION SHOWS THE OIL PIPE IN A CON ROD IN A BROKEN LINE. THE OIL PRESSURE IN THE CON ROD BEARING PUMPS THE OIL THROUGH THIS PIPE TO THE PISTON PIN BUSH IN THE SMALL CON ROD EYE.





[FIG.24] HYDRODYNAMIC LUBRICATION

PRINCIPLE OF THE HYDRODYNAMIC LUBRICATION: THE CRANKSHAFT JOURNAL IS SHOWN IN BLUE, THE BEARING IN RED AND THE BEARING CLEARANCE IN YELLOW. WE ASSUME THAT THE CRANKSHAFT JOURNAL IS LOADED WITH A CONSTANT FORCE F. THERE IS FRICTION BETWEEN THE SURFACE AND THE OIL AND FRICTION INSIDE THE OIL. DUE TO THE FRICTION, THE TURNING CRANKSHAFT TEARS OIL IN BETWEEN THE SURFACES OF BEARING AND CRANKSHAFT. BY MEANS OF THIS EFFECT AN OIL FILM IS CREATED. THE OIL FILM SEPARATES THE SURFACES OF BEARING AND CRANKSHAFT JOURNAL. THE OIL FILM BECOMES THICKER WHEN A) THE CRANKSHAFT TURNS FASTER, B) THE CLEARANCE IS REDUCED, C) AN OIL WITH HIGHER VISCOSITY IS USED AND D) THE LOAD ON THE BEARING IS REDUCED.



[FIG.25] HYDROSTATIC DAMPING

PRINCIPLE OF THE HYDROSTATIC DAMPING: WE ASSUME THAT THE CRANKSHAFT STANDS STILL AND THAT THERE IS AN OIL FILM BETWEEN CRANKSHAFT JOURNAL AND BEARING. WE ALSO ASSUME THAT THE CRANKSHAFT JOURNAL IS LOADED WITH A FORCE F FOR A SHORT PERIOD OF TIME. THIS FORCE F MOVES THE CRANKSHAFT JOURNAL TOWARDS THE BEARING. THE VISCOSITY OF THE OIL CREATES A RESISTANCE TO THIS MOVEMENT. THE OIL BETWEEN JOURNAL AND BEARING IS DISPLACED. THE RESISTANCE INCREASES WHEN THE OIL FILM BECOMES THINNER. FOR EXAMPLE, IF THE INITIAL OIL FILM THICKNESS IS HALVED, THE RESISTANCE INCREASES BY THE FACTOR 8. THIS MEANS THAT EVEN VERY THIN OIL FILMS CREATE A SUFFICIENT RESISTANCE AGAINST SHOCK FORCES. SUCH SHOCK FORCES APPEAR WHEN THE FUEL IN THE COMBUSTION CHAMBER IS IGNITED.

THE PHYSICS OF LUBRICATION

One of the oil film's functions is to separate the bearings from the crank pins. When discussing lubrication we distinguish between two physical effects: hydrodynamic lubrication, which is caused by rotation and hydrostatic damping, which cushions shock load. In an internal combustion engine the two effects overlap.

HYDRODYNAMIC LUBRICATION

Figure 24 explains the principle of hydrodynamic lubrication. A shaft on which a force is acting is rotating in its bearing. The bearing is supplied with oil from above via the oil borings. Through friction the shaft draws oil through the lubrication gap and creates the oil film. The oil film produces an even distribution of pressure that separates the shaft from the bearing. However, the oil is not only drawn through the lubrication gap but also flows laterally out of the bearing.

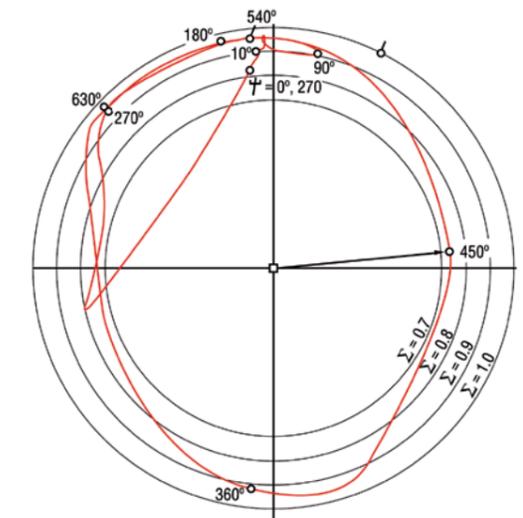
HYDROSTATIC DAMPING

The principle of hydrostatic damping is illustrated in Figure 25. In the case shown, the shaft and pins are separated from each other by the oil film. A periodic load is suddenly imposed from above, for instance via the ignition of the combustion of the fuel-air mix in the combustion chamber. This periodic force displaces the oil, driving it in all directions out of the lubrication gap between shaft and bearing. The greater the oil's viscosity, the greater the resistance to this displacement process, and resistance to it increases greatly as the thickness of the lubricant film decreases. The oil's resistance to displacement thus prevents the shaft and bearing from coming into contact during the imposition of a periodic load of brief duration.

Both combustion forces and inertial forces are acting on the shaft. These forces ensure that the crank pins describe a complex displacement path within the bearing (Figure 26). The minimum lubrication film thickness, i.e., the smallest gap between crank pins and bearings, occurs during the combustion process. Calculations have shown that this gap can be less than one micrometer.

[FIG.26]

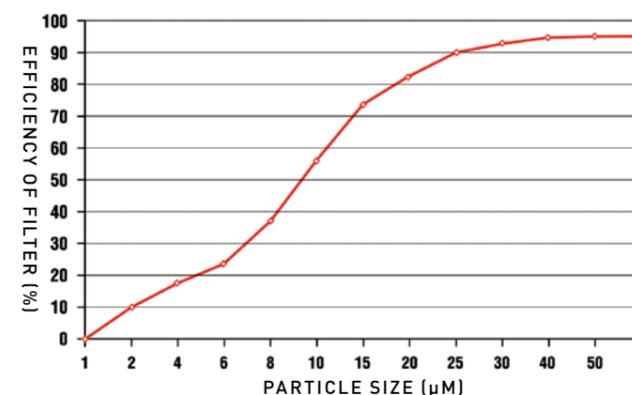
COMBUSTION AND INERTIA FORCES MOVE THE CRANKSHAFT JOURNAL INSIDE THE BEARING. THE ILLUSTRATION SHOWS A TYPICAL JOURNAL ORBIT OF A CRANKSHAFT JOURNAL IN A CON ROD BEARING (BEARING-FIXED VIEW). THE DISTANCE BETWEEN THE SURFACES OF BEARING AND CRANKSHAFT JOURNAL IS INDICATED AS Σ AT $\Sigma = 0$, THE CRANKSHAFT JOURNAL IS IN THE MIDDLE OF THE BEARING, AT $\Sigma = 1$, CRANKSHAFT JOURNAL AND BEARING TOUCH EACH OTHER. AS CAN BE SEEN, THE SMALLEST DISTANCES APPEAR IN THE UPPER SHELL OF THE BEARING FOR A RELATIVELY LONG WAY OF THE JOURNAL ORBIT. THIS EXPLAINS WHY THE WEAR IS HIGHER IN THE UPPER SHELL THAN IN THE LOWER SHELL OF A CON ROD BEARING.



DIRT PROBLEMS

The effectiveness of a typical paper oil filter is charted in Figure 27. Contaminant particles with diameters greater than 25 μm will be filtered out of the oil with a high probability of passing the oil filter once. However, the smaller the contaminant particle, the lower the probability that it will be intercepted by the oil filter, and in our example a particle 5 μm in diameter will only be intercepted in a relatively low number of all cases.

Thus most of the smallest contaminant particles will not be stopped by the oil filter. However, they are capable of damaging bearings and crank pins. This consideration makes clear the importance of ensuring absolute cleanliness when overhauling an engine.



[FIG.27]

EFFICIENCY OF A TYPICAL PAPER OIL FILTER DEPENDING OF THE SIZE OF THE DIRT PARTICLES IN THE OIL WHEN THE OIL PASSES THE FILTER ONCE.

MATERIALS FOR SLIDING BEARINGS

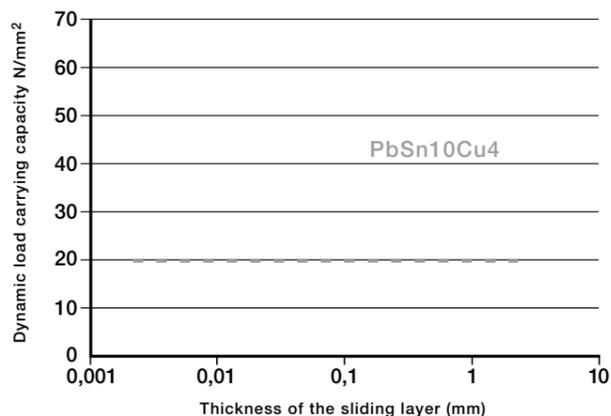
REQUIREMENTS FOR BEARING MATERIALS

A wide variety of demands are placed on engine bearings, and the materials they are made of must combine the properties of hard and soft materials. Wear caused by metallic friction can occur when starting up an engine, when coasting and also under high operating load. During running, the bearing must withstand cyclic loads imposed by combustion and inertial forces. The continual exertion and releasing of the load can lead to fatigue in the bearing materials.

Accordingly, materials for engine bearings should have high resistance to wear and fatigue, properties provided best by hard materials.

However, after installation the bearing must adapt to the unevenness of the crank pin surface. The material should be able to bed in any contaminant particles that were not eliminated by the oil filter. Furthermore, the material should not be corrosive and must have good emergency running properties, and all these properties are offered best by soft materials.

Apart from these features, a bearing material must also be highly resistant to corrosive components in the oil and must permit economic production.



[FIG.28]

PBSN10CU4 IS A TYPICAL MATERIAL FOR THE SLIDING LAYER OF A COPPER-LEAD BEARING. THE DIAGRAM SHOWS THAT THE LOAD CARRYING CAPABILITY OF THIS MATERIAL DEPENDS OF THE THICKNESS OF THE LAYER. THE LOAD CARRYING CAPABILITY INCREASES WHEN THE LAYER BECOMES THINNER. THE LOAD CARRYING CAPABILITY IS A RATE FOR THE RESISTANCE AGAINST FATIGUE. THE COMBUSTION AND INERTIA FORCES PRESS THE CRANKSHAFT JOURNAL CYCLICALLY AGAINST THE BEARING. THE LOAD ON THE BEARING INCREASES AND DECREASES CYCLICALLY. IF THE CYCLICAL LOAD IS TOO HIGH, THE MATERIAL TIRES AND BREAKS AFTER A CERTAIN TIME. THE LOAD CARRYING CAPABILITY IS THE MAXIMUM CYCLICAL LOAD THAT A MATERIAL CAN STAND PERMANENTLY.

STRUCTURE OF BEARING MATERIALS

Composite materials offer the best chance of combining this range of contradictory requirements.

Current composite materials generally have a steel spine as a basis. This basis gives the bearing shell or the bushing the necessary durability. During the production of the strip, this steel spine is coated with a layer of comparatively thin and soft bearing materials.

This layer gives the bearing the necessary capability to carry high loads, increases the emergency running properties and enables the bedding-in of dirt particles.

A further layer can increase the adaptation, embedding and emergency running properties more. This layer is produced after the bearing shell has been formed out of the strip. Means are electroplating or other processes (e.g. PVC Sputtering).

Figure 28 shows how the fatigue resistance of a bearing's layer depends on the thickness of the layer, increasing as the layer becomes thinner. By applying thin layers, the fatigue resistance of soft materials can be increased.

TYPES OF BEARING MATERIALS

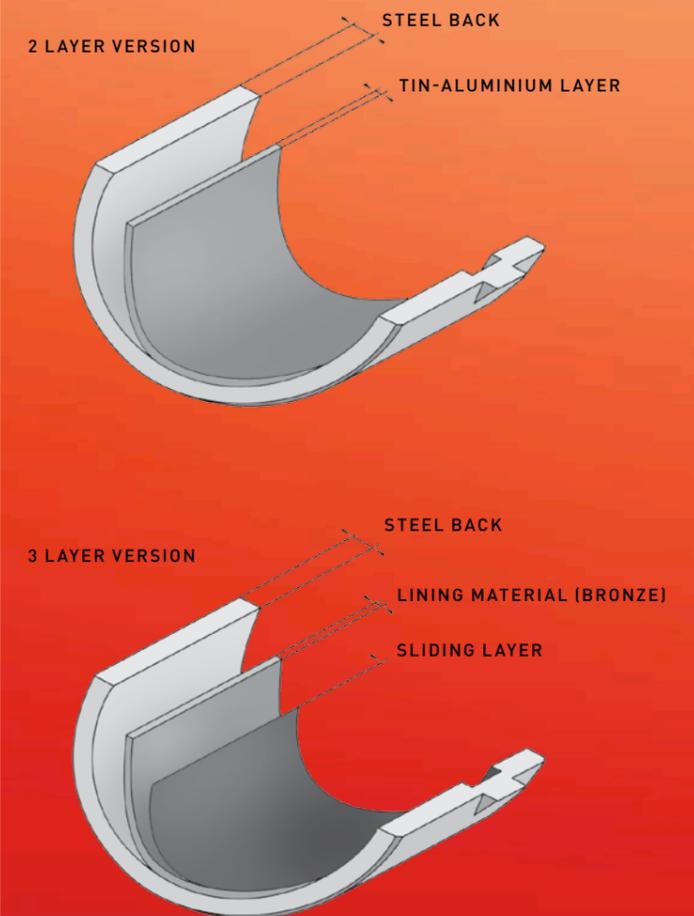
In the early days of sliding bearing development, white metals were used for bearings. They contained lead and tin as base materials as well as cadmium or antimony as alloy materials.

Today, however, two different types of materials are used most often. Composite materials of two and three layers have established themselves through practical experience (Figure 29).

A two-layer (bi-metal) bearing is composed of a steel back and a bearing metal layer. This layer of bearing metal in modern bearings is a combination of aluminium, tin and some alloy materials like copper, antimony or nickel. In the market, there are also combinations of aluminium with lead and tin. To achieve the desired material properties, various materials are combined and treated chemically or thermally.

A three-layer or tri-metal bearing also uses a supporting steel back plus a bearing metal layer. This layer of bearing metal is generally made of leaded bronze. Like the tin and aluminium layer, it is between 0.2 and 0.3 mm thick. Higher performance bearings are made from either cast or sintered copper lead/leaded bronze. High to ultra high performances are catered for by varying the combination of elements that go into the materials, and by applying different overlay compositions as follows. This leaded bronze layer is then coated with an additional sliding layer made of a material still softer than leaded bronze and between 10 and 30 µm thick.

In some cases the sliding layer and the bearing material are separated from each other by an intervening layer whose purpose is to prevent atoms from the bearing metal diffusing into the sliding layer. Diffusion processes can detract from the properties of the sliding layer.



[FIG.29]

CONVENTIONAL BEARINGS ARE COMPOSED OF TWO OR THREE LAYERS. THE BASIS IS ALWAYS A BACK OF STEEL. EITHER A LAYER OF TIN AND ALUMINIUM OR A LAYER OF LEAD-BRONZE IS BONDED ONTO THE STEEL BACK. THE LEAD-BRONZE LAYER IS PLATED WITH ANOTHER LAYER. IN THE CASE OF CONVENTIONAL BEARINGS, THIS TOP LAYER IS MAINLY COMPOSED OF LEAD AND TIN.

[7]



Federal-Mogul TECHNOLOGIES IN BEARING MATERIALS

[8]



GLYCO-199 TECHNOLOGY: GLYCO SPUTTER BEARINGS®

In recent years engine technology has achieved major increases in performance. This is evident in the development of diesel engines for cars and commercial vehicles, where over the past ten years the average performance per litre of cubic capacity has increased from 34 kW/l to 63 kW/l, leading to increased loads on engine bearings. One of the main requirements of a sliding engine bearing is that it has sufficient load-bearing capacity. This is calculated from the mean combustion pressure, the piston's cross-sectional area and the cross-sectional area of the bearing shell.

There is an increase in the specific loads on main and con rod bearings for car and commercial vehicle engines from 1965 to 2000. In some cases the specific load-withstanding capacity has more than doubled during the period in question.

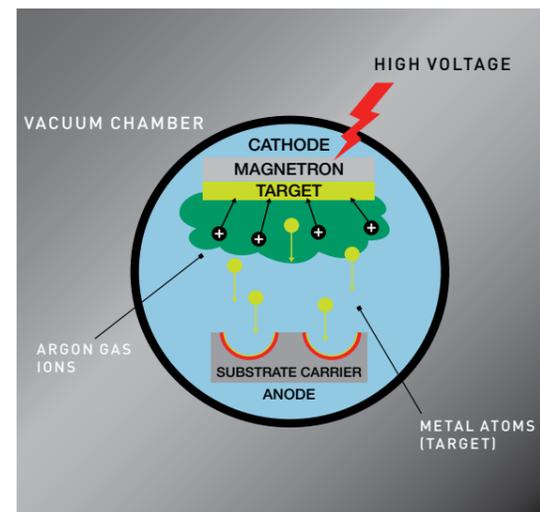
Only Glyco Sputter Bearings® Glyco-199 are able to meet the extreme demands imposed by these engines, in terms of withstanding loads and providing long life.

Dirt and geometric inaccuracies in the crankshaft cause boundary friction, which in turn leads to local heating and bearing damage. Thus the bearing's specific load-withstanding capacity falls with increasing sliding speed (i.e., increasing engine rpm). Conversely, the lubricant film thickness (and with it the bearing's load-withstanding capacity) falls with decreasing sliding speed. If the lubricant film thickness is about the same as the height of roughness peaks, mixed friction will result, and the consequent frictional heat also reduces the bearing's load-withstanding capacity and lifetime.

THE PROCESS

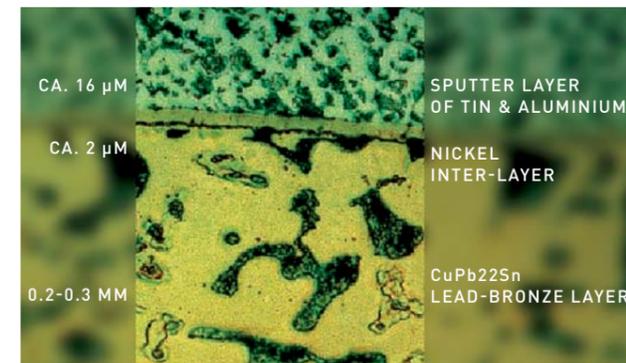
In response to the ever-increasing demands placed by the engine on engine bearing technology, Glyco factories were breaking new ground as early as 1970. A new production process was developed by Glyco following years of research work. This process made possible to combine the high wear-resistance of an aluminium-tin sliding layer with the extremely high load-withstanding capacity of a cast copper lead bearing metal layer. Glyco created the most durable material for engine bearings known today!

A modified cathode Sputtering process of Physical Vapor Deposition (PVD) provided the coating technology needed to make the desired combinations of layers possible (Figure 30).



[FIG.30] GLYCO-199 SPUTTERING PHYSICAL PRINCIPLE

In Sputtering, a dispenser cathode of an aluminium-tin alloy is bombarded by argon plasma, causing the aluminium and tin atoms to deposit as lining on the specially prepared engine bearings. The Physical Vapor Deposition (PVD) process produces an exceptionally even alloy matrix, offering outstanding resistance to wear and to very high loads. The structure of Glyco Sputter Bearings® makes the reasons for their high performance clear. The bond between the die-cast leaded bronze bearing metal layer and the sliding surface is strengthened by an intermediate layer of pure nickel, which is circa 2 µm thick (Figure 31).



[FIG.31]

NICKEL PREVENTS THE DIFFUSION OF ATOMS BETWEEN THE LEAD-BRONZE AND THE SPUTTER

Commercial vehicle engines fitted with Glyco Sputter Bearings® achieve lifetimes of one million km, and engine manufacturers are now working to increase this to one million miles.

Computer-controlled processes incorporating high cleanliness and precision standards lead to uniform high quality in mass production. Under extreme loads, even minimal discrepancies can be detrimental to the bearing's reliable functioning – therefore 100% fault-free production is essential.

REPAIR AND RUNNING TIPS FOR GLYCO SPUTTER BEARINGS®

The hardness of the Sputter layer gives the bearing extremely high wear resistance and high fatigue resistance. The Sputtered AlSn20 layer is sensitive to the contamination of the lubricant oil with particles, water or alkaline elements, the last of which can get into the engine oil via anti-freeze in the coolant water.

To ensure that engine repairs are carried out correctly, these Glyco Sputter Bearings® characteristics must be taken into account. Under high loads the oil film thickness decreases, so that even very small contaminant particles can penetrate it. On the other hand, the hard Sputter layer's high wear resistance means that it adapts more slowly to the unevenness of the crankshaft's surface.

As a consequence, the crankpins and the housing bores must be in optimum condition in terms of geometry and surface roughness. During running the loads can cause the housing bore to deform. The original bearing can adapt to this deformation during running, but when new bearings are installed the reduced play in the deformation zones can lead to the destruction of the lubrication film. For these reasons the housing bores must also be carefully finished.

In comparison to conventional surfaces, the increased surface hardness of the layers of the Glyco Sputter Bearings® reduces the capacity to bed-in contaminant particles. Accordingly, Glyco Sputter Bearings® are, as a rule, composed of a bearing shell with a Sputter layer plus a bearing shell with a softer running surface. The Sputter shell is fitted in areas exposed to high loads, while the softer shell is used in the vicinity of the engine bearing, which is subject to lower load. The softer half of the bearing shell is more able than the Sputter layer to absorb the contaminant particles contained in the oil.

This engineering solution has proved best in practice. Nevertheless, the careful cleaning of all engine parts and the lubrication system and also the utmost cleanliness when repairing and assembling the engine are vital prerequisites for successful maintenance. Any residual dirt must be removed by rinsing the stationary engine before the engine is started for the first time.

Where the maximum permissible engine rpm is n_{MAX} , the following running-in programme has been established:

STEP	MIN	FRACTION	MAX
STEP 1	1 MIN	1/3	n_{MAX}
STEP 2	1 MIN	1/4	n_{MAX}
STEP 3	1 MIN	1/2	n_{MAX}
STEP 4	1 MIN	1/3	n_{MAX}

During running-in, the engine performance should not exceed 15 to 20% of maximum load.

LEAD-FREE BUSHES & BEARINGS NEW LEGISLATION REQUIREMENTS

Every year, end of life vehicles generate between 8 and 9 million tones of waste in the European Union which should be managed correctly. In 1997, the European Commission adopted a Proposal for a Directive which aims at making vehicle dismantling and recycling more environmentally friendly, sets clear quantified targets for reuse, recycling and recovery of vehicles and their components and pushes producers to manufacture new vehicles also with a view to their recyclability.

The legislation covering the use of lead was officially adopted in September 2000 and thousands of automotive businesses – from vehicle manufacturers to engine rebuilders – are impacted by the European Union's End of Life Directive (2000/53/EC) that bans lead. The law, which came into effect on 1st July 2003, initially provided an indefinite exemption of bearings used in engine, transmission and drive train systems. This exemption was later amended and is now expected to end in 2011.

Federal-Mogul COMMITMENT TO THE ENVIRONMENT

Thanks to the special efforts of our Research & Development departments, Federal-Mogul already is the most advanced lead-free company in 2008. Federal-Mogul is ready to provide reliable and performing lead-free materials to fulfill the EU directive and achieve the required engine performance demanded by today's automotive industry. This clearly shows our commitment to innovation and to the environment. Federal-Mogul's leadership is once more proven, and we continue to be first in the market with the best available bearing materials.

Although leaded replacement bearings for old vehicles (but not for new ones) can be supplied after the next legislation deadline, Federal-Mogul is independently committed to environmentally friendly manufacturing. Whenever technically possible, we will go further than new legislation and we have made it our goal to eliminate lead from the manufacture of all bearings and bushes.

LEAD-FREE MATERIALS

Through world-class expertise in design, metallurgy and manufacturing, Federal-Mogul works with OE customers to develop materials to meet the requirements of new legislation, while allowing engines to deliver maximum performance, lower pollution and use less harmful materials.

Now, Federal-Mogul Research & Development has created lead-free bushes and bearings. The several new patented technologies are already used by many OE manufactures and will be the base to allow compliance to new EU directives and to achieve the required modern engine outputs produced today and in the future. Examples of some of these new patented technologies:

- LF-4, LF-5, LF-8 and RC-9 bronze bushings materials
- G-444 and G-488 lead-free overlays (unique Federal-Mogul MSA bath technology)
- New G-499 Sputter and new RVD G-469 (Rapid Vapor Deposition)
- Innovative aluminium bearing technology: A-273, A-370, A-480, and A-590 bearing materials
- Advanced manufacturing concepts
- New boring technology
- Laser welding

For over 100 years, Glyco has been the leading supplier of engine bearings. Thanks to our advanced material developments and manufacturing mastery, our leadership continues in this new lead-free era. Glyco has set new standards and has become the benchmark on new bearing materials. This is why Glyco is the supplier of choice for most OE manufacturers.

GLYCO LEAD-FREE TECHNOLOGY: A-370® & CS-4

Federal-Mogul has become leader with its exclusive new Glyco A-370 lead-free patented material as it provides the highest performance with very high resistance to fatigue and good adaptability. Furthermore, we have developed the bearing bronze alloy CS-4, a lead-free alloy that is not compromised by impurities. CS-4 is used as a substrate to make the new G-444 and G-488 overlay materials, created with a new and unique Federal-Mogul bath technology. CS-4 is also used in the newest generation of Glyco Sputter Bearings®, now developed into lead-free innovate ones, called G-469 and G-499.

Normally, copper alloys contain lead. While developing and re-searching lead-free solutions, Federal-Mogul has worked hard on creating lead-free bronze alloys. This is why: without the presence of lead, copper alloys tend to harden. When impurities like metal powder are mixed in, bearings made of such an alloy will not change shape, and foreign matter may get into the bearing. By improving materials and fabrication methods, the hardness of the bronze CS-4 alloy is very close to that of a lead-copper alloy.



[FIG.32]
CROSS-SECTIONAL CUT THROUGH A BEARING SHELL MADE OF A370®. THE PURE ALUMINIUM INTER-LAYER BONDS THE TIN-ALUMINIUM ONTO THE STEEL BACK.

MACHINING SPECIFICATIONS FOR THE NEW Federal-Mogul SEMI-FINISHED BUSHES OF ALUMINIUM ALLOYS

Boring of AlSn20 alloy materials

Machining parameter recommendation
Cutting speed: $vc = 500 \text{ m/min}$
Infeed: $\approx 0,1 \text{ mm/revolution}$
Expected roughness: $\approx Rz 4 - 5 \mu\text{m}$

PCD* cutting inserts recommendation

- Basic shape: 55°
Relief angle: 7°
Corner radius: $0,4 \text{ mm}$
Max. tip temperature: 600°C
- Use PCD cutting insert according to alike geometry.
 - Geometry may vary due to individual machining equipment.
 - 1-2 drops of low viscosity oil per piece will improve machining.
 - Overheating of tip temperature will destroy PCD-structure immediately.



* PCD - Poly Crystalline Diamond

GLYCO-188 TECHNOLOGY PRINCIPLES AND ADVANTAGES

In recent years, the requirements on engine bearing materials have increased in two ways: firstly, the elimination of lead (in addition to other white metals) will become more and more a future legal requirement. Secondly, the performance specifications of modern cars continue to increase.

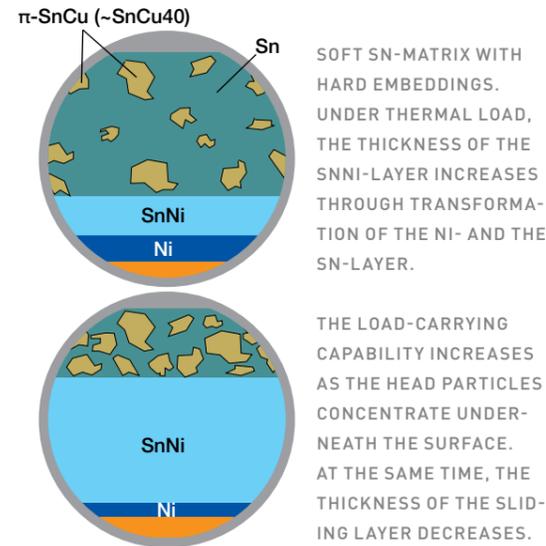
The development of modern initial combustion engines has led to performance increases. At the same time, engine dimensions, masses and parts are reducing. The smaller dimensions of sliding engine bearings increase the loads on them. Lightweight engine parts result in greater deformation of the con rod and engine block and this, in turn, puts further loading on the bearings. Consequently conventional tin-aluminium or leaded bronze bearings have often not continued to be developed.

The famous Glyco Sputter Bearings® are a solution developed by Federal-Mogul. These bearings are capable of withstanding even the highest loads, however their disadvantage is the high production costs involved with the technology. **The durability of Glyco Sputter Bearings® (technical term: Glyco-199) is twice as long as a conventional bearing.** Federal-Mogul's development centre in Wiesbaden consequently worked on closing this gap, the result being the new sliding bearings material Glyco-188.

The layer structure of this material (Figure 34): a bronze and a tin-nickel layer are applied to a steel spine. An intervening nickel layer between the other two layers avoids the diffusion of tin atoms into the bronze layer.

As a result of new production methods, it is now possible to add a further layer to the material consisting of tin and copper. Thanks to the copper, the otherwise relatively soft Sn-matrix becomes hardened.

The tin-copper layer is still relatively soft during the engine's initial running-in phase and adapts itself well to the surface structure of the crankshaft. The diffusion process is strengthened by thermal demands encountered during the running of the engine. Over time, the diffusion of nickel atoms from the nickel intervening layer and the tin atoms from the tin-copper layer result in the growth of the tin-nickel layer (Figure 33). This layer becomes durable and fatigue resistant as a result of the copper deposit of



[FIG.34] GLYCO-188 PROCESS OF CHANGING

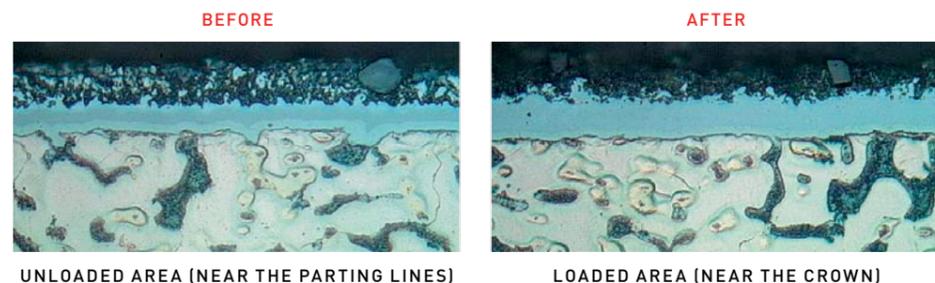
the tin-copper layer concentrating itself on the tin-copper layer that had thinned.

GLYCO-188 IS THE FIRST "INTELLIGENT" BEARING MATERIAL
SOFT DURING THE RUNNING-IN PHASE
HARD THROUGHOUT THE REST OF ITS LIFE-TIME

RESULTS

With Glyco-188, Federal-Mogul has developed a bearing material, which is capable of resisting very high loads. This new material offers good adaptability and bedding-in properties, whilst meeting the need to be lead-free. The problems of high loads generating greater deformations are optimally and safely controlled through the hardening process which occurs naturally during the running of the engine.

[FIG.33] CHANGE OF THE LAYER SYSTEM OF GLYCO-188: DIFFUSION OF ATOMS INCREASES THE THICKNESS OF THE TIN-NICKEL LAYER.



UNLOADED AREA (NEAR THE PARTING LINES)

LOADED AREA (NEAR THE CROWN)

CONCLUSION

ENGINE BEARINGS OPERATE IN A BRUTAL ENVIRONMENT. WITH A BROAD RANGE OF ENGINE OPERATING SPEEDS, TEMPERATURES AND OTHER PARAMETERS, THESE VITAL COMPONENTS ARE CALLED ON TO PROTECT THE CRANKSHAFT AND ENGINE BLOCK FROM PREMATURE WEAR AND CATASTROPHIC DAMAGE.

TO WEAR IS, IN FACT, WHAT BEARINGS ARE EXPECTED TO DO, VERY GRADUALLY, OVER MILLIONS OF ENGINE REVOLUTIONS AND THOUSANDS OF MILES. BUT PROTECTING THE BEARINGS THEMSELVES FROM ACCELERATED WEAR IS THE JOB OF THE ENGINE REBUILDER, WHO MUST ENSURE THAT THE ENGINE IS FREE OF DIRT AND DEBRIS AND THAT ALL APPROPRIATE INTERNAL TOLERANCES ARE MAINTAINED.

DIRT IS THE ENGINE BEARING'S MOST COMMON ENEMY. IN FACT, MOST PREMATURE BEARING WEAR CAN BE TRACED TO DIRT PARTICLES IN THE LUBRICATING OIL. THAT'S WHY THE REMOVAL OF CONTAMINATION THROUGHOUT THE ENGINE REPAIR PROCESS IS CRITICAL.

A QUALITY REBUILDING JOB ALSO REQUIRES STRICT ATTENTION TO INTERNAL OPERATING TOLERANCES. DIMENSIONAL AND SHAPE VARIANCES IN THE CRANKSHAFT JOURNALS, MATING SURFACES AND HOUSING BORES CAN CAUSE IMMEDIATE AND SEVERE DAMAGE TO A REBUILT ENGINE.

TO ENSURE THE QUALITY OF ANY REBUILD, THE TECHNICIAN ALSO SHOULD CAREFULLY DOCUMENT IN WRITING EACH STEP OF THE REPAIR. IF A SUBSEQUENT QUESTION OR RELIABILITY ISSUE ARISES, THIS RECORD OF THE REPAIR PROCESS CAN SERVE AS AN INVALUABLE GUIDE IN IDENTIFYING AND ELIMINATING ANY PROBLEM.

Important: Claims for damages, of any form whatsoever, resulting from details made in this brochure or from incorrect use, application, storage or handling, are explicitly excluded. This brochure is not an operating manual for the use and installation of the bearings. It does not contain any advice in a legal sense. The brochure neither replaces the constantly applicable technical regulations – particularly for tolerances – nor the installation and maintenance stipulations of the individual engine manufacturer. Also, it is not possible to forego the expertise of those carrying out the installation and application. The individual references made in this brochure for the installation and the application of the bearings are instructions solely for the technically qualified specialists and are to be checked and verified by him for their suitability in each case. Federal-Mogul/GLYCO accepts no responsibility for application decisions.

Reproduction of this brochure of parts hereof is only allowed with our explicit permission in writing. Pictorial representations and design are copyrighted. The right is retained to correct errors and alterations.

Federal-Mogul ADVANCED ANTI-COUNTERFEIT PROGRAMME

The following features on all NEW ENGINE packaging prove that the parts inside are Original Quality.

CHECK THE UNIQUE CODE ONLINE AT www.fmecat.eu

Each Federal-Mogul part has a unique code which is displayed on the labels in an alphanumeric and Data Matrix format. A Data Matrix code is a 2-dimensional (2-D) matrix barcode. The Unique Code can be verified in 3 different ways:

- Typing in the Unique Code
- Reading the 2-D code with a 2-D scanner
- Reading the 2-D code with a mobile phone which is supported by NeoReader™ (www.neoreader.com)

For further details please check www.fmecat.eu



LOOK FOR THE HOLOSPOT®

The Holospot® label features a 4-digit alphanumeric code.

Please check it to make sure that:

- The 4-digit code appears in rainbow colours using the light of the magnifier and is different on each pack
- The Federal-Mogul logo also appears in the Holospot®. The last 4 digits of the alphanumeric code have to be the same as the ones in the Holospot®



PROTECTION

Special label design means any attempt to remove or swap the label will result in tearing



PERMANENT SELF-ADHESIVE LABEL

Seals the box with label detail on the front



CRASH LOCK BOX BOTTOM

Prevents any attempt to remove or exchange items as it is impossible to reseal once opened



Verify the Unique Code online at www.fmecat.eu