Smooth operators

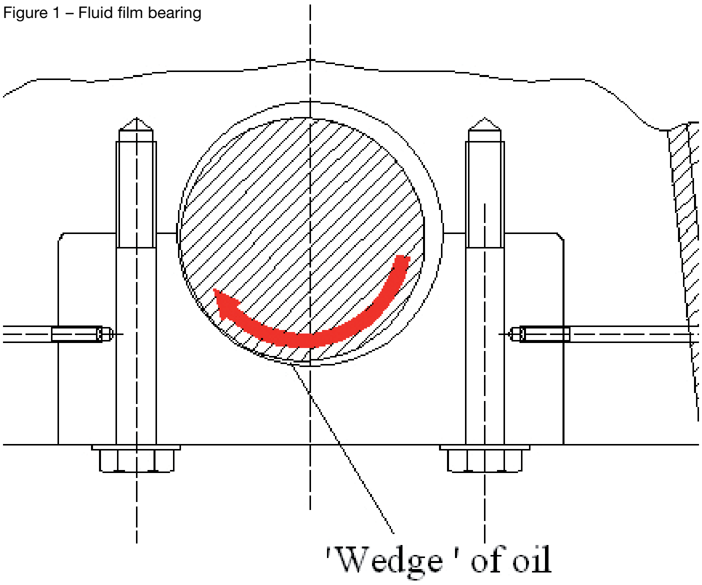
John Coxon explains the technology underlying the different types of bearing design, and gives some pointers to future developments

That bastion of meanings and definitions, the Oxford English Dictionary, describes a bearing as, "a device in a machine that allows two parts to rotate or move in contact with each other with reduced friction". But in the simplicity of its definition, the complexity of bearing design is very much understated. The key words here are 'rotate' and 'friction', as one inevitably leads to the other and so the whole design philosophy behind any bearing system is to enable the former with the minimum of the latter.

Bearing technology can be generally classified into four broad categories – rolling element, dry, semi-lubricated and fluid film. In an engine, semi- or splash lubrication might be relevant to the piston pins or the cam lobes, but most bearing development over the past 100 years has gone into rolling element and fluid-film designs for the main and big-end bearings on the crankshaft. Rolling element bearings have been used successfully in the past and are still common in many small two-stroke engines, but for the vast majority of reciprocating units used for racing the fluid film, in the form of the shell bearing, pretty much reigns supreme at the moment.

This has not always been the case though. In many engines, particularly high-performance units in the early 20th century, roller bearing technology was uppermost. The first four-valve engine of note, the Peugeot L3 back in 1913, used ball races for the main bearing assemblies on its crankshaft, yet still used plain fluid-film units for the big end. Since then, and as fluid-film designs became more durable, ball or roller-bearing assemblies have been progressively phased out.

Figure 1 – Fluid film bearing



Even so, as late as the mid-1950s, Mercedes-Benz was still using roller bearings in its 2.5 litre M196 Grand Prix engine on both main and big-end bearings, using a fabricated crankshaft and a method of crankshaft assembly known as the 'Hirth' concept. Nowadays, fluid-film bearing technology has come so far that modern designs can withstand 150,000 miles of the most arduous stop-start driving conditions using low viscosity oils which, less than 30 years ago, would have worn them out after only a few thousand miles.

The fluid-film bearing

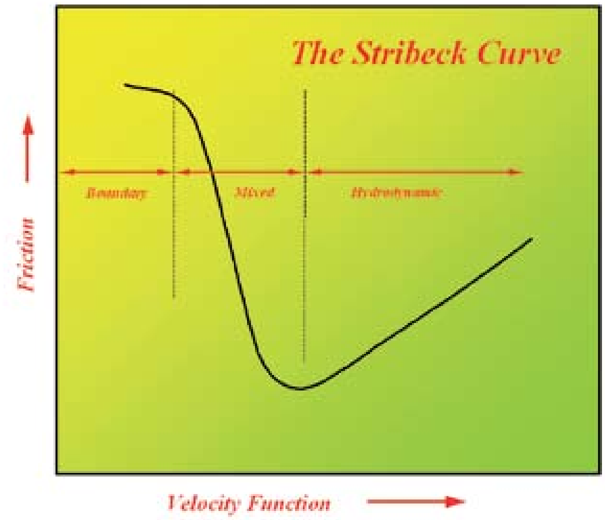
The forces on a typical engine bearing originate from one of two sources. The first source is as a result of fluctuating gas pressure on the piston crown, while the second is due to the inertia of the rotating engine components themselves. While the latter are somewhat smooth and progressive, and varying with the speed of rotation, the former by their very nature can change rapidly and depend on the load requested of the engine.

Consisting of a smooth and circular journal running inside an equally smooth (but far from circular) outer ring, a bearing has to accommodate all these fluctuating loads over the full range of engine speeds and applied loads without damage to the surface of either the bearing or its corresponding journal. To minimise the friction involved, oil is fed into the centre of the bearing, which builds up a 'wedge' of fluid against the direction of journal surface movement. When the shaft is at rest the journal resides at the bottom of the bearing (see figure 1).

As the shaft begins to move it will start to climb up the wall of the oil film, and friction is at its highest. As speed increases, the journal will begin to drag the lubricant into the wedge of oil, the journal is forced away from the bearing and the friction will begin to fall. As the journal speeds up, the thickness of the oil film increases and the friction bottoms out before beginning to increase again as the shaft speed increases further. These three phases form the outline of the basis of all lubrication, and together manifest themselves in the Stribeck curve (see figure 2 below).

As regular readers will know, the three zones of this curve are the boundary zone when friction (and consequently wear) is high, the mixed zone where friction is rapidly falling, and the hydrodynamic zone when no physical contact between surfaces is apparent and no wear can therefore take place. The precise surface speeds at which these zones take place depend on the instantaneous load on the

Figure 2 – Stribeck curve



bearing. Assuming it has been correctly specified for the task, the greatest wear in any engine fluid-film bearing will therefore take place when the journal is just beginning to rotate – in other words at the point of first cranking. This is not only because the oil pressure hasn't built up (although it might not help) but simply a function of the boundary conditions prevailing at that instant.

The oil pressure to the engine and in the bearings are different things. Engine oil pressure is principally to overcome the restrictions in the oil galleries and the centrifugal force in the crankshaft. Typically measured at the entrance to the cylinder block, this might be 40-60 psi depending on the throw and speed of the crank.

Once the oil is introduced into the bearing the maximum pressure generated by the rotation of the journal and the load applied will be much greater, and vary around it radially as well as to either side. It can be appreciated that with bearing loads calculated at many thousands of pounds when distributed over a bearing whose diameter might only be 2 in (50 mm), the maximum pressure in the oil film will be much greater than 60 psi!

As regards the oil pressure generated in the bearing, a significant factor is the bearing clearance. Defined as the difference between the diameter of the circular journal and the average diameter of the slightly non-circular bearing, this will typically be about 0.002 in or less. In road car applications, where the extremes of performance are not demanded and manufacturers are more interested in the noise generated as the journal effectively rattles around in the shell, these clearances can be far less. Remember that under an ideal, smooth surface finish, the oil film can be as little as 0.0001 in thick, so this potential for reducing oil flow by tightening up on this clearance can be very attractive.

Material technology

While the primary function of any bearing is to allow or enable the rotation of a shaft to minimise friction, when we talk about plain or fluid-film bearings the materials used are generally much different from those ordinarily seen elsewhere.

In a perfect world we would have perfectly round journals in perfectly circular bearings, fully rigid so that they didn't distort, and use contaminant-free lubrication. In the real world, however, journals are not round, crankshafts are not 100% rigid and with lubricants, although they may not be contaminant-free at the beginning, it's never that long until hard particles somehow find a way in. These particles may be from the products of combustion or simply as a result of poor build cleanliness, but no matter how clean the build, somehow dirt always manages to find a way in.

In selecting the best material for a bearing the following attributes therefore need to be met:

- The mechanical strength needs to be as great as possible to resist the high dynamic pressures present in the lubricant film.
- The melting point of the material needs to be as high as possible to resist any damage at the temperatures that might be expected. These temperatures will be a function of those generated by combustion as well as friction in the bearing itself.
- The bearing needs to be able to dissipate heat.
- The bearing material must be resistant to corrosion. The products of combustion inevitably find their way into the oil. Strong acids thus formed will be neutralised by the base products blended into the oil, but weak acids may still be present and could cause chemical attack at the grain boundaries.
- No matter how hard we try, dirt always seems to get into the bearing at some stage. Any bearing material therefore needs to have good embeddability to absorb this dirt and prevent subsequent scoring of the journal at high loads.
- As an apparent contrast to the above, the bearing needs to have sufficient hardness to resist abrasive wear and cavitation.
- We have already talked about how journals may not be 100% rigid. The bearing material therefore needs to have good conformability to yield easily when the shaft becomes misshapen or misaligned as a result of the mechanical loads.
- The material needs to be compatible with the journal material to prevent seizure when the bearing is loaded and speeds are not high enough to generate hydrodynamic films.

Although highly desirable, it may not be possible to incorporate all these into a single material or design, and is perhaps part of the reason why even today much development work continues. But the quality of a bearing will depend on how each of these criteria is satisfied for a particular application.

Some of the earliest bearing materials were based on white metal alloys, and are still considered by many to be some of the best around when it comes to their anti-friction properties. Their limitation is solely in the inadequacy of their strength when heavily loaded.

Consequently, bearings of this type can still be found in large rotating machinery – steam turbines, large oil engines and the like as well as many historic vehicles that haven't or can't be updated to a more modern design. Names such as Hoyt, Ecka and Tegostar are all associated with the alloys used in this world, which are cast in the bearing housing and then machined or line-bored to size in the crankcase. Divided into two types, lead- or tin-based, the latter are often called 'babbitt', but this term would now seem to be applied to any lead- or tin-based bearing material.

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CERAMIC BEARINGS

Valve train components in ceramic
(courtesy Cerobear GmbH)

Although not seen as relevant to mass production, ceramic bearings still appear to have benefits over traditional rolling-element materials. Full ceramic bearings are so called when the outer race, inner race and balls are all made from a ceramic. The other type, often referred to as hybrid ceramic bearings, are when only the balls are ceramic. In this case the inner and outer rings will be superfinished steel rings. In this way some of the superior properties of ceramics will be obtained at a more cost-effective price.

Characteristic	**Units**	**Si_3N_4**	**$Zr0_2$**	**100Cr6**
Density	g/mm^3	3.2	6.1	7.8
Elastic modulus	Gpa	320	200	210
Hardness	N/mm^2	1600	1200	700
Bending strength	N/mm^2	700	1000	>2500
Temperature limit	Deg C	1000	400	180
Heat conductivity	W/mK	35	2	45
Heat transfer Coef.	10-^{6}/K	2.8	9.6	11.5

Comparison of ceramic materials

Principally there are three types of ceramic common in rolling-element bearing technology – silicon nitride (Si_3N_4) and silicon carbide (SiC), which are both coloured black, and zirconia or zirconium dioxide ($Zr0_2$), which is white. With a density about 40% of that of steel (for silicon nitride) and a modulus of elasticity at least 50% greater, bearing parts made from these materials are not only lighter but stiffer too. The reduced weight produces far less centrifugal force and enables much higher running speeds than the steel equivalent.

The important parameter, however, is the stiffness and reducing the amount of distortion under load. A bearing made from ceramic spheres is stiffer than an equivalent steel version, the reduced deformation creating a smaller footprint. But with this smaller footprint comes higher Hertzian stresses with which the material can easily cope.

The smoother finish to the ceramic balls also gives a much lower coefficient of friction and requires much less in the way of lubrication. More resistant to corrosion and capable of withstanding higher temperatures, but not necessarily stronger, they are more suited to extreme environments where high temperatures or corrosive substances are present. Nevertheless, when correctly designed to suit the application, the lower frictional losses generated and the better heat dissipation can produce a much longer operating life – sometimes as much as ten times that of an equivalent steel bearing.

Tin-based babbitts normally contain up to 10% antimony, which precipitates out as small cuboid crystals of hard SnSb during casting and when the molten mixture cools quickly. A uniform consistency, however, can be difficult to achieve. Adding small amounts of copper to the mix improves uniformity and encourages the formation of Cu6Sn5 [a copper-tin mix] needles that prevent the free movement of these hard cuboids.

When lead is added, often to reduce the cost, the embeddability might increase but only at the expense of reduced strength. When lead is alloyed with 15% antimony 1% tin and 1% arsenic, a similar performance is produced consisting of antimony-arsenic crystals in a lead-antimony eutectic.

Over the years these alloys have varied in composition according to the application, but all have invariably involved tin, lead, antimony and copper in varying amounts plus one or two other undisclosed 'magic' ingredients. In times when such materials were used in bi-metal form, deposited onto a much stronger steel or bronze backing, engine manufacturers in the UK would specify the tin-based products while those in the US and Australia would choose lead-based materials. In the case of the tin-based babbitt, this may have been inoculated with tellurium for increased strength. Today babbitts might only be found on some forms of cam bearings or used as a very thin (0.0005 in) overlay on much stronger tri-metal, copper-lead designs.

Early bearings were made by casting the alloy into the block or housing and then machining or line boring to suit. Hand scraping the high spots using engineer's 'blue' to get a perfectly even contact around the journal was inexact and time-consuming. The development of the quickly replaceable shell bearing made with a strong steel backing changed all that and revolutionised the technology of engine bearings.

Copper-lead quickly replaced white metal, producing an altogether much stronger product, and variations of these are commonly used even today. Consisting of 20-40% lead, the rest copper and perhaps with small amounts of tin, silver or nickel, the copper and lead feature as two distinct phases in the alloy. Normally too soft on its own, the material was bonded to the steel backing and the strength subsequently generated depended greatly on the method of manufacture.

Copper and lead are only slightly miscible in each other in the liquid state, but as they cool they tend to separate out during solidification. When a high level of tin is present, the lead exists as isolated pools in a copper matrix. Using a different process the lead might take the form of dendrites (small Christmas tree-like crystals) growing from the steel backing up to the surface of the bearing. So the method of manufacture – whether it is ordinary casting, centrifugal casting or sintering – has an enormous influence on how these phases occur and the subsequent properties of the bearing.

As an alternative to casting, a sound copper-lead alloy can be accomplished with a good lead distribution using powder metallurgy. In this process, a copper-lead powder is applied to a prepared steel backing plate, sintered in a reducing atmosphere and then compacted by rolling and re-sintered. Pressed into bearings and with an overlay if required, the lead is uniformly distributed throughout the whole of the material so there are no planes of weakness in the material.

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Figure 3 - Mahle VP2 material structure (x 175 magnification)

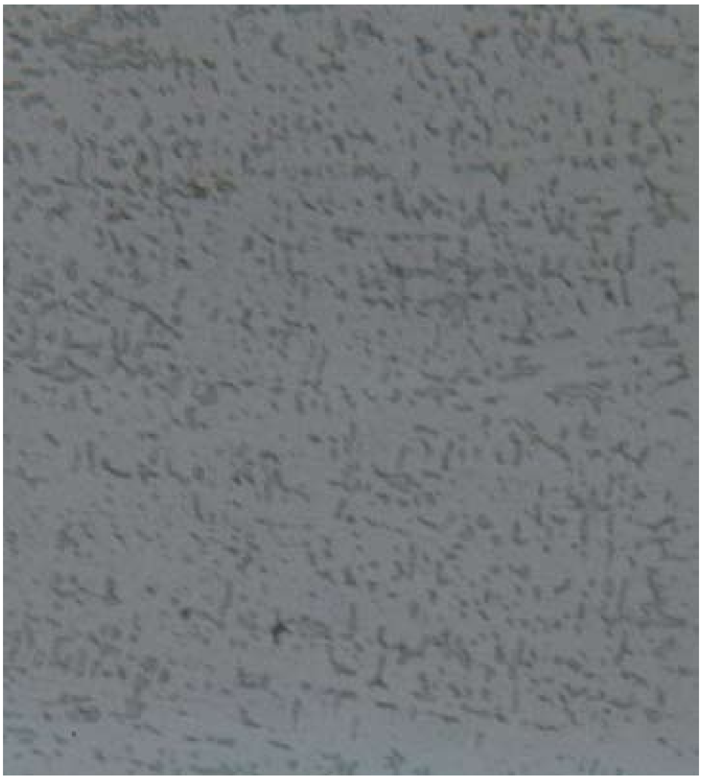
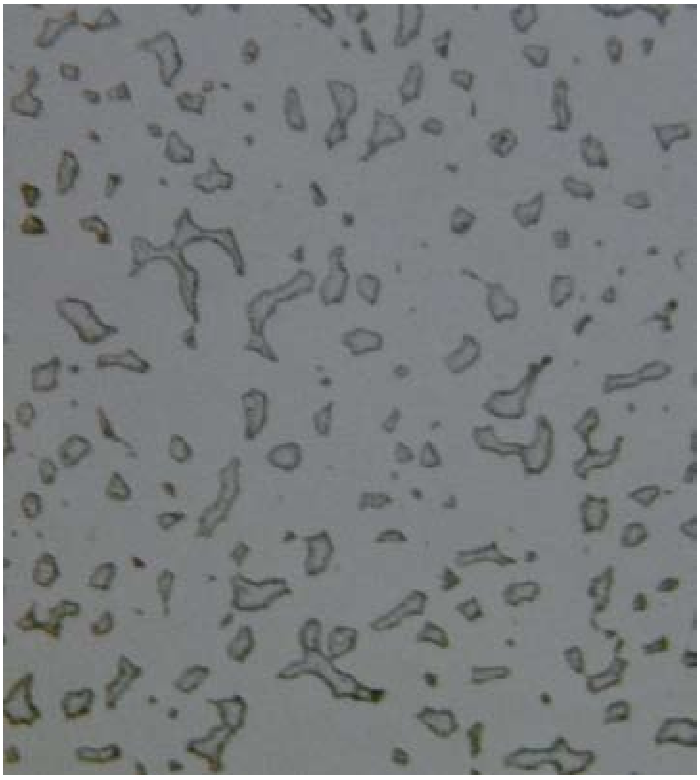


Figure 4 - Mahle VP1 material structure (x 175 magnification)



Some of the most commonly used competition bearings, formerly made by Vandervell Bearings but now incorporated into the Mahle range, use strip-cast leaded bronze cast onto a steel backing plate. Vandervell VP1 (lead 14-20%, tin 4-6%, iron 0.5%) and VP2 (lead 20-26%, tin 1-2%, iron 0.5%) materials undergo carefully controlled casting conditions to ensure the alloy contains almost vertical columns of bronze through the material, which are ideally orientated to take the compressive loads. Unlike earlier casting technology, the lead is presented in a way that cannot give a plane of weakness.

The load-carrying capacity of VP1 is about 30% greater than VP2, which reflects the lower proportion of lead therein. Of the two, VP2 may be considered the better as it has the correct balance between embeddability, conformability and strength, but VP1 has the greater load-carrying capacity.

The basic design of these bearings goes back many years but since there are no new elements in the world, new bearing technology is simply a refined jumble of these elements. One of the key areas in modern race engine design is the steel backing to the bearing. Race engines need to take a much greater interference fit during installation without yielding the steel, and the simplest way to do this is to use higher strength steels. Twenty years or so ago we may have used the higher-lead VP2 version in a big-end bearing in Formula One. Today, however, since loads have increased the preferred route would be nearer to that of VP1 or VP10 (9-11% lead, 9-11% tin). A stronger bearing with less lead perhaps, but the main issue is not one of fatigue or that of wear but simply cavitation erosion. In these circumstances the lead is attacked at the grain boundaries and the bearing becomes contaminated with hard, bronze particles, which eventually destroy it.

Although copper-lead will run satisfactorily against most crankshaft materials if the journal surface is slightly soft or the lubricant not entirely free of contaminants, under start-up or mixed lubrication conditions, wear can easily occur. To guard against this a thin layer of soft alloy – referred to as an overlay – is often applied. Lead-tin or lead-indium babbitts were the most common at one time but more sophisticated coatings are now being developed. The overlay also protects the copper alloy from corrosion, since anything other than fresh lubricant can contain weak acids. Bearings with a steel backing, a copper-lead supporting material and an overlay are generally called tri-metal bearings. Those without an overlay are called bi-metal bearings.

As an alternative to copper-lead, aluminium in a bearing has much to recommend itself. Stronger than babbitt, yet cheaper than copper-lead, aluminium alloys are much less prone to attack by acid oils. Alloyed with about 20% tin, the resulting product consists of ‘lakes’ of tin within an aluminium-tin matrix, giving good load bearing capacity with adequate embeddability. Its resistance to acid attack also often makes the presence of an overlay unnecessary, but bonding the alloy onto the steel shell can be difficult, so a thin layer of aluminium has to be deposited on the steel before the bearing material can be laid.

All told, aluminium-tin alloys possess good frictional properties and comparatively high strength, but will not seize under the emergency running conditions of poor lubrication. Comparatively high strength (but not as high as copper-lead), however, implies poor embeddability, so bearings like these may still have some form of soft overlay if deemed necessary.

In Europe in the past few years the ‘End of Life’ EU Directive has required that all lead, no matter how small the amount, be removed from the vehicle. Compliance with the Directive was originally required by 2008 but this has now been extended until 2011. Nevertheless, in removing lead from the possible options, bearings are being redesigned around a totally different approach.

Some manufacturers have opted for a form of aluminium-silicon for their bi-metal construction, while others have developed a tin-

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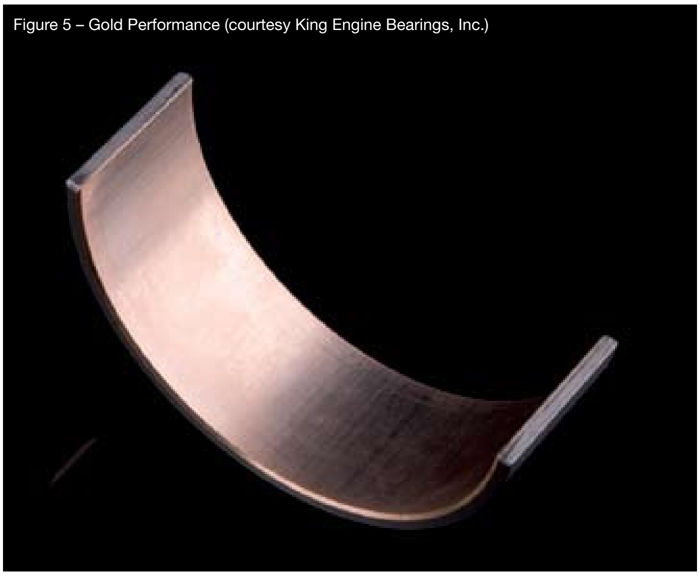
TONDA
GTO

Figure 5 – Gold Performance (courtesy King Engine Bearings, Inc.)



silicon-copper additive to an aluminium matrix to give the conflicting properties of strength, compatibility and embeddability. When a higher load capacity is needed, say for performance vehicles, one European manufacturer has developed a copper-nickel-silicon substrate deposited onto the steel backing, using one of two electroplated overlay methods depending on the application.

One such overlay is a copper-tin mixture on top of a nickel barrier, while the other has a nickel-tin and copper-tin layer over a similar nickel barrier. The nickel-tin intermediate layer is to improve the wear resistance of the bearing since the hardness of the barrier is quite small.

Bearings of this type are now used on many high-performance OE vehicles in Europe, such as those from Porsche and BMW. In the racing industry though, where lead – considered by many to be the best bearing material of all – has not been outlawed, manufacturers seem to be looking more at the construction of the overlay than the copper-lead substrates underneath. One US-based supplier has developed a special metal matrix composite (non-babbitt) overlay which improves the fatigue strength of the bearing, taking it up to a staggering quoted 18,000 psi load capacity, while its more classic tri-metal babbitt overlay can reliably manage only 10,000 psi.

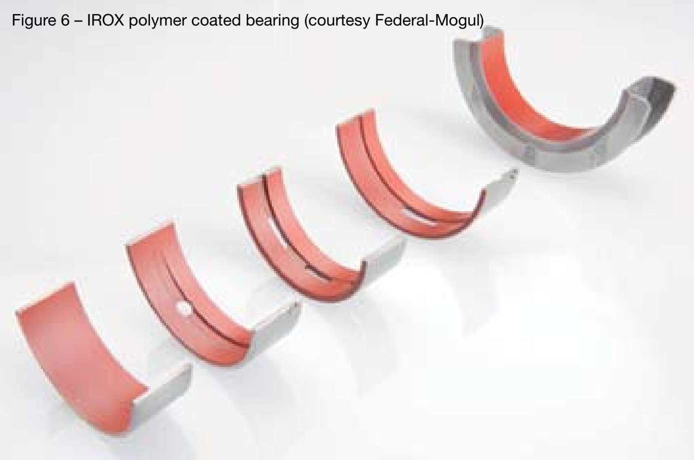
According to the company, this metal matrix is completely lead-free and comprises two primary materials. The base material is quite hard, but has a superior seizure resistance compared with copper alloys. The second material takes the form of solid lubricant and is evenly distributed throughout its host. As such, it enhances the anti-friction properties of the whole overlay. With the metal matrix overlay, however, a hardened steel crankshaft (as opposed to a cast-iron version) is mandatory.

For drag racing applications requiring a harder overlay than babbitt can provide, this same company advises using its aluminium-tin-silicon bi-metal product (see figure 5). “When the life of a classic tri-metal bearing is compromised – due to the overlay being extruded or displaced – a conventional lead-tin-copper overlay has proved a winner in drag racing applications.”

But racing isn’t the most arduous application for bearings. According to most vehicle original equipment suppliers, race engine bearings are fairly undemanding in some ways as the drive for increased engine (fuel) efficiency is placing demands on crankshaft bearings that require new designs and material applications.

Engines with direct injection systems or those with stop-start capability are placing much greater demands on traditional bearing designs, especially when thinner oils are used. In the case of stop-start systems, bearings will be running much more in boundary and mixed lubrication conditions, and metal-to-metal contact is more likely as a result at the low running speeds involved.

Figure 6 – IROX polymer coated bearing (courtesy Federal-Mogul)



To counteract this, another European supplier has developed a polymer overlay consisting of a number of undisclosed additives within a PAI (PolyAmidelmide) resin binder. Placed directly over an aluminium bearing substrate, the load bearing capacity increases by about 20%, it is claimed (see figure 6).

At the moment, however, this technology cannot be used in high-speed applications, although high-speed tests have so far proved very encouraging. However, bearings are a very complex product and caution has to be the watch word when durability of the order of 150,000 miles is required. With the future of road transport applications moving more towards stop-start, hybrid systems with longer oil drains and no lead, the challenge is considerable!

In racing, however, with no current restrictions on lead, copper-lead substrates seem to be staying for a while yet, with the emphasis on polymer overlays mixed with copper.

Rolling contact bearings

Sliding contact, fluid-film bearings are not the only type used in racing engines, however; those with some form of rolling contact are regularly used away from the crankshaft. Ball and roller bearings are consequently found in five main areas.

- Engine ancillaries, such as pumps and alternators/motors in hybridisation, stop-start systems or high-performance e-motors.
- Engine timing systems such as belt tensioners or bearing supporting gear drives.
- Turbocharger ball bearings.
- Rocker arms.
- Crankshafts and camshafts – standard technology for small two-stroke engines, and used commonly before more durable shell bearings were invented.

Rolling contact bearings cover a wide range of applications, and use spherical balls or rollers of various sizes and shapes. Consisting more often than not of an outer and an inner element, between which is a row of balls or rollers retained in position by a cage, the bearings are designed to take radial or thrust loads, or a combination of the two. In theory, because there is only rolling-point contact on any of the surfaces, friction should be almost negligible. In practice though, some sliding does occur but nevertheless at slow speeds this friction is very much less than the traditional fluid film bearing.

Figure 7 – Double Roller bearing (courtesy FAG)

Rolling-contact bearings are essentially anti-friction devices, notes one manufacturer. It explains that with hydrodynamic bearings you have issues with start-up, particularly cold start-up, and at very high speeds data suggests that rolling-element bearings can have an advantage. This is explained by the fact that rolling-element units have friction characteristics more or less linear with speed. On the other hand, fluid-film bearings, once they're operating in the hydrodynamic range, have friction characteristics proportional to the speed squared.

However against all this we also have to consider the power necessary to drive the oil pump. In roller-element units the drain is very much less, since these bearings require oil only for minimal lubrication and possibly cooling.

Taking all this into account there would seem to be much to be gained from rolling-element units. In alternators, front-end accessory drives and pumps, therefore, since minimal lubrication is required, bearings can be filled with high-temperature grease and sealed for life. For these applications much development work has been undertaken on low-friction greases.

This benefit at high speed would also seem to have a great advantage over fully floating bearing systems in turbochargers. In reducing the friction it also reduces the reaction time, and turbo lag is therefore less of an issue. Furthermore, the roller bearings need less lubrication, so the oil feed rate can also be reduced.

For racing purposes, therefore, turbos with ball bearings can have a significant benefit. Of those available there are two options. The first uses two separate bearings preloaded with a spring, but what is generally preferred and coming to market very shortly by at least one supplier is a cartridge system. In place of the fully floating system, the design is quite clever but still needs to be designed in and does not easily replace the standard system. Despite this, aftermarket turbo suppliers are already offering turbo ball-race retrofits.

Figure 8 - Two-stroke little end

As interesting as turbochargers are, however, as power unit engineers our real interest is in the crank and big-end journals, possibly even the camshaft. Going back many years and before the advent of reliable shell bearings, roller bearings were commonly found on the crank or cam of many racing engines. So, as the Vandervell-inspired thin-wall bearing revolution (no pun intended) started, so the era of the roller bearing in top-class racing ended. And while many of the pre-World War II car racing engines had main or big-end roller bearings, by the beginning of the 1960s, designs of this type were relegated to history.

These days the small two-stroke is about the only engine still using a ball or roller crank and needle roller little and big end. In the UK and Europe, a company has recently launched a new product to the two-stroke kart market that replaces the crankshaft ball bearings with a cylindrical roller version – a straight retrofit that doubles the lifetime between crank rebuilds.

"Although there is a slight friction reduction," says an insider, "this is not easy to measure. The real benefit, however, is in the durability as a result of the improved stiffness and reduced heat build-up." In the area of the con rod little end, there was nothing special to report but like all products of this type, they are subject to a programme of steady and incremental improvements.

Historically, when fitting ball or roller products to multi-cylinder crankshafts, you needed to be innovative. Assembly is the big issue, and every ten years or so, engine manufacturers take another look at it.

When it comes to fitting ball or roller bearings onto crankshafts, essentially there are three ways to do it. The first is to use some sort of built-up crankshaft, while the second is to use a split bearing. The third is to have a crank where you can fiddle the bearing around into position. Of those, as part of on-going technology review most companies in this sector are currently looking at split bearings again – more exactly split cages and outer rings while the rollers themselves would run on the main bearing journal of the crank. This would seem to be the consensus. Since the interest from motorsport is always sporadic, these companies are looking at it from the mass production viewpoint driven by the needs of its OE customers for even more fuel-efficient and emission-friendly engines. Some years ago one particular supplier (*RET* Issue 020 February 2007) looked at a split-bearing

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Figure 9 - Split bearing design (courtesy Cerobear GmbH)

Figure 10 - Split bearing design (courtesy SKF Industrie S.p.A.)

approach to Formula One but then the engine regulations were frozen and the work stopped. At the time the company claimed they were very close to a solution – not a cheap one but there again nothing in Formula One is cheap. Today the emphasis is very much on making it to a price.

Using split-bearing technology as currently developed, the standard V8 crankshaft main bearings could easily be fitted with roller technology. The big ends, however, would be another matter. As it was explained to me, “the extra accelerations of the eccentric motion, together with the often forgotten Coriolis accelerations when acting on the relatively flexible split cage, can produce all manner of strange effects. A split cage on the main bearing of a crankshaft or camshaft is manageable, but using a similar technology on the big-end bearing is altogether far more challenging.”

For bearing cages the preferred material would seem to be PEEK (PolyEtherEtherKeytone), a high-performance engineering thermoplastic that can be used up to 250° C. An inert material, it can be used in applications where the fuels used can be very aggressive. In Brazil, for instance, ethanol-based E85 and E100 fuels can dissolve cages made from many other polymers. But in applications where PEEK is not up to the task then brass or even steel will be the reserve choice.

Over the past 20 years or so the main developments in rolling-element bearings have been in improved materials. For the vast majority of bearing applications, the base material of chromium steel, 100Cr6 (AISI-52100), has been difficult to beat because of its legendary high hardness and resistance to wear.

So since bearing design is all about fatigue, the major thrust in developments over this time has been a progressive increase in the quality or cleanliness of the steel. Reducing the impurities – the number, type and size of any inclusions – has made a significant change to the overall fatigue strength of the units. Together with improved machining technology to give better control of surface roughness and topology, when the design will allow, this has enabled smaller units to be used. And when bearings with the same capacity and size as their forerunners have been used, savings in friction of 30-50% have been obtained.

But what of the future, and where is the technology push in years to come? This, of course depends on who you speak to but for mass production a move towards even higher temperature capability and even more hardness is to be expected. At the moment steels of between 58-63 Rockwell are being used. In future these will be higher. Likewise, 100Cr6 is typically tempered at 160-180° C. For the coming years, 400° C may be a more realistic target using steels technology derived from the aero engine or gas turbine worlds. ■

EXAMPLES OF BEARINGS SUPPLIERS

GERMANY		
Cerobear	+49 240 795 560	www.cerobear.de
FAG	+49 9132 82 7557	www.fag.de
ITALY		
SKF	+39 011 985 2467	www.skf.com
JAPAN		
Nachi	+81 76 423 5111	www.nachi-fujikoshi.co.jp
UK		
Brush Wellman	+44 118 9300 105	www.brushwellman.com
Carter Manufacturing	+44 1865 821720	www.carterbearings.co.uk
Godiva Bearings	+44 1384 456 137	www.godiva-bearings.co.uk
HB Bearings	+44 1484 665 116	www.hb-bearings.com
Revolvo (SRB)	+44 1384 245370	www.revolvo.com
USA		
Accurate Bushing Company (Smith Bearing)	+1 800 932 0076	www.smithbearing.com
ACL Bearing Company	+1 800 847 5521	www.acl.com.au
Bearing Tech Inc	+1 503 852 6030	www.precisionbearings.net
Dura-Bond Bearing Co.	+1 775 883 8998	www.dura-bondbearing.com
Federal Mogul	-	www.federalmogul.com
King Engine Bearings	+1 973 857 0705	www.kingbearings.com
Koyo	+1 734 454 1500	www.koyousa.com
Mahle Clevite	+1 734 975 4777	www.mahle.com
Performance Bearing	+1 520 466 9176	www.performancebearing.com
The Timken Company	+1 330 438-3000	www.timken.com
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