ENGINE BUILDER

ENGINE BEARING SUMMIT

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Transcript of Question 3

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Engine Builder Engine Bearing Summit Participants

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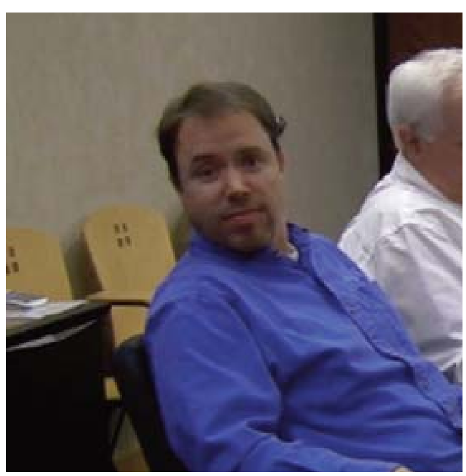

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Engine Builder magazine

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To answer questions and allow an open discussion about engine bearings without falling into a "pizza wars" debate we convened the inaugural *Engine Builder* Engine Bearing Summit on March 31 at the Babcox Media corporate headquarters. We invited participants from the leading bearing manufacturers to participate in a roundtable discussion on pre-determined topics.

To say the day exceeded expectations would be an understatement. Participants were prepared, cooperative and frank about engine bearing technology and applications.

The following industry experts participated in the Summit. From Federal-Mogul Corporation: **Bob Sturk**, Chief Applications Engineer, Bearings: North America; and **Raymond King**, Director of Global Engine Parts. From King Engine Bearings: **Dr. Dmitri Kopeliovich**, R&D Manager at King's manufacturing facility in Israel; and **Michael James**, with King's export and high performance programs. From MAHLE Clevite Inc.: **John Havel**, former Director of Aftermarket Engineering (Retired); and **Bill McKnight**, Team Leader – Training.

Brendan Baker, senior editor and **Larry Carley**, technical editor of Engine Builder joined editor **Doug Kaufman** in moderating the discussion.

Question 3: What other engine factors, including the parts do you have to take into consideration when you are designing bearings and when selecting a bearing?

KOPELIOVICH (King Engine Bearings): The engine parameters determine the loads applied to the bearings. The load is the resultant force created by two sources, one of them is combustion in the cylinder and then the other is inertial forces created by the moving parts of the engine. The load applied to the bearing at any angle of the crankshaft may be calculated and so too can the hydrodynamic bearing parameters, like minimum oil film thickness and energy loss and oil temperature rise and oil flow, etc. We at King are using our calculation software for proper bearing material selections. But we can determine several main parameters that influence the load applied to the bearing. The parameters are as follows:

Compression ratio –The higher the compression ratio, the higher the pressure of the gas in the top dead center and the higher the bearing load.

Displacement per one cylinder – Larger displacement means larger amount of fuel-air mixture is taken into the cylinder. It means that the larger energy is discharged in the one cycle and the larger load is applied to the bearing.

Fuel type –Gasoline fuel with higher octane number allows working with higher compression ratio without detonation, so the higher-octane fuel produces higher load. Methanol fuel may be used with even higher compression ratio, about 16. So they load even higher than gasoline fuel.

Engine type – Diesel engines, especially diesel engines with direct injection, produced highest pressure in the combustion cylinder, which may reach 220 bar, and of course highest load applied to the bearings, mostly connecting rod bearings, upper connecting rod bearings.

Aspiration type – Turbo and supercharged engines use compressed air in the air-fuel mixture. And compressed air allows to intake a larger amount of air and larger amount of fuel in one cycle so the larger energy discharge is formed and the larger load is applied to the bearing.

Bore diameter – The same cylinder pressure produces higher absolute load in the cylinder with higher bore diameter.

Piston and conrod weights and the rotation speed – Inertial forces developed by the moving piston and the conrod decreased the resultant force acting on the upper connecting load bearing. And at the same time they increase the force acting on the lower part of the connected rod bearing. The inertial forces are proportional to weight of the moving parts, and therefore, the effect of inertia forces is particularly high at high RPM, such as 6,000 to 10,000 RPM, which is realistic for racing cars. In the same question there was a question about the shaft material. I will add that, regarding the crankshaft, nodular cast iron crankshafts work better with aluminum/silicon material because of the ability of silicon to polish the ferrite peaks. And tri-metal bearings are recommended for steel crankshafts.

HAVEL (MAHLE Clevite): I basically think I followed everything you were talking about. And I think you did an excellent job of explaining where the loads applied or the loads that occur within an engine come from. Bearings are engineered to meet certain specific design requirements primarily relating to the level of loading in the engine. And also you have to look at the type of performance that the engine is intended for, is it going to be passenger car, street high performance, competition high performance, heavy duty diesel or whatever? Since passenger car engines seldom if ever operate at wide open throttle, full loaded rated speed in the actual environment they are installed in, let's skip over passenger car applications and talk about three applications where loading is pretty much wide open throttle, full load at rated speed or even above.

We know from personal experience that rod bearings can survive in a supercharged nitromethane fuel dragster engine at loads in excess of 63,000 psi – for four seconds. In NASCAR, Formula 1, Indy car, the rod bearings operate successfully in the range of (in some cases we don't even known what the loads are because they don't even give you all of the operating conditions), I would say conservatively, 14 to 16,000 psi at least and especially in Formula 1. And they can operate under those conditions for 500 miles or even more.

In an over-the-road diesel truck engine, however, we typically limit the rod bearing loads to about 6,500 psi because the life expectancy is in the range of 500,000 miles. So if you compare those numbers, you can see that by reducing the level of loading in the bearing by a factor of ten, let's round the numbers off and say from 65,000 psi to 60 6,500 psi, you extend the life expectancy from four seconds or a quarter of a mile to 500,000 miles. So that's how much loading can affect a bearing.

A byproduct of the load level, of course, is the lubrication. The more load you put on a bearing, the more difficult it is to maintain an oil film between the shaft and the bearing. And separate from the level of loading, you were talking about gross loads from combustion process and inertia forces and so on.

But the thing you have to take into consideration is the bearing proportion in comparison to the level of loading. And we have to look at that unit loading. How many pounds per square inch, not pure pounds of load. Not only do the bearing proportions determine the level of loading, they also determine the ability to create a lubricating oil film between the shaft and the bearing. And we learned the hard way many, many years ago when we were trying to develop bearings for a particular engine manufacturer that thought that they could make very short engines by making them big in diameter and narrow in axle length that it didn't work. The bearing has to have the proper proportions. And a length-to-diameter ratio about one-third is pretty much ideal. So you can thumbnail, look at a bearing and say that bearing is going to work, it's either going to work or it's probably destined to experience some problems. So oil film thickness really is what is probably going to have the greatest influence on durability of a bearing as long as it doesn't fail in fatigue or from some other external influence.

Crankshaft type is another concern. And we have been talking about that, the cast iron shafts and so on. Early in the automotive industry's use of cast iron shafts, they were made by a different process. The cast iron shafts were made in baked sand molds where they actually made a mold, put the mold in an oven, baked it and brought it out as a hard block of baked sand and then poured the molten metal in.

The problem with that process was that the binders used to hold the sand together were polluting the atmosphere when they poured the hot iron into the mold. And EPA got involved and said you can't do that anymore. So back in the early to mid '80s, the industry basically all changed over to what we call today green sand molding where nothing but water moisture is used to hold the sand together. And when you pour the hot molten metal into a green sand mold, the only thing that goes into the atmosphere is water vapor, no pollutants.

The problem was that with the baked sand mold the quality of the iron was excellent, and with the green sand mold you get a much coarser graphite structure in these cast iron cranks, which makes them considerably more difficult to grind and polish and finish. And as we have been talking about, the grinding opens up these little graphite cells in the surface of the shaft that leave little ragged edges and microscopic disparities standing up on the surface of the shaft. And there again, to repeat, this is why even though we are mostly noted for tri-metal bearings, this is why we have come up with a fairly recent addition of a line of bi-metal aluminum bearings, to meet the marketplace's demand for a bi-metal bearing that can resist this type of abrasion from cast iron shafts.

Over the years the original equipment-manufacturing people have improved their processes tremendously. Today the automotive industry can produce tolerances and finishes that they couldn't even dream of years ago. And that coupled with improved cleanliness, as Bob mentioned earlier, the assembly processes and so on have really helped make the use of bi-metal aluminum bearings and cast iron crankshafts feasible and as popular really as they are today.

And while improving manufacturing processes in original equipment is the norm today, we still have to be aware of the fact that variations in process capabilities employed during the rebuilding process can have much broader variation than what we experience in original equipment marketplace. This is why we have provided a diagnostic tool on our website that shows an assortment of different types of bearing distress and a cause and effect discussion of each. So if you go to our *mahleclevite.com* website and look, and Bill can elaborate more on this. He and I worked together on trying to come up with descriptions and explanations and potential solutions to these problems. But it's there as a diagnostic tool for the guy that doesn't know bearings, doesn't understand them and doesn't work with them every day. He has a problem, he looks at the bearing and says what happened? We get a lot of phone calls. And one of the nice things, we can tell a guy to go to our website and look at a particular picture number, and if that looks like your bearing, this is probably what might have caused the failure. So it's a diagnostic aid to help in solving some of these problems that people may experience.

KOPELIOVICH: I saw your site and the distress guide. It is very good and impressive. I think that it is very good to understand what happened to bearing. But I think there is another thing that is necessary for engine builders: to forecast what happens if they change some parameters of their engine? It may be software that we can calculate or maybe something else.

HAVEL: Well, you know, there is an excellent example. And we are kind of getting into the discussion phase before Bob has had his turn to talk. But I remember years ago when we designed some new bearings for the old Offenhauser Indy race engine. And they had designed a new connecting rod. And we did the studies and analysis and came up and designed a bearing to work in that rod. We get to Indy in the beginning of the month of May. And teams start practicing and they're having failures left and right. And we couldn't figure out what happened until we went back to the guy that designed the connecting rod and asked him if he made any changes. He said yeah, as a matter of fact, I did. And he didn't tell us what he changed. And that's exactly what you are talking about.

KOPELIOVICH: Yes, they have to have some instruments to understand what they are doing.

HAVEL: Exactly.

KOPELIOVICH: What happens to bearings.

HAVEL: And that's why we have tried for years. I personally have given, I don't know, probably hundreds of presentations on bearing performance to try to help people understand how they work or how they are supposed to work and why they don't work and what you need to get over that why they don't work situation.

KAUFMAN (*Engine Builder* magazine): I think we are starting to jump ahead to question number five, "what are our guys doing wrong?"

HAVEL: I didn't give Bob a chance to get his pitch in.

STURK (Federal-Mogul Corp.): These are all good conversations really, but what I wanted to talk about earlier is we have a large group of analysis people in our R & D section that do nothing but analysis work on engine bearings. And that would be to quantify oil film parameters both by rigid method and elastohydrodynamic method.

And we design and have forgings made to optimize our bearing performance. We have a very large group of guys now that are rod designers – we had to do this just to understand how our bearings operate today; we've become rod designers by force. We've had to, just to understand how they work. And then we can make recommendations to add metal in certain areas of the rod or make some changes to help the bearings survive. So we have become rod designers and it's a fact of life.

And now on the analysis side, as long as I'm talking about analysis, we continue to work with the elastohydrodynamic code to understand what we think are the fundamental problems today in seizure because of this dynamic distortion of this connecting rod and the high centrifugal loading on the lower bearing that you had referred to, Dimitri. This is the killer of bearings today is seizure phenomenon. I think we have a good handle on fatigue. But this bending fatigue thing that we see as a result of the connecting rod moving is something new that we need to get over.

HAVEL: And Raymond kind of alluded to that, to the new design engine designers try to make that power package smaller and smaller because they are being crowded out of the vehicle because we want smaller vehicles and still need passenger space so where do you put the engine, you know.

STURK: And I agree 100 percent with you. When I look at a new application, it's all about unit loads, that's what I am concerned with. How much bearing area do I have to handle the combustion?

HAVEL: And how long does this thing have to live?

STURK: Exactly. So a unit load is something that we can get our arms around quickly. It's a relatively straightforward calculation. When you start calculating oil film pressures and oil film thicknesses, we get a little -- there is a lot of assumption that goes into a lot of those calculations. But with a lot of the new code today, the EHL code, we're getting over that. And it's really making old bearing guys like me think in a different way because we are actually finding out some things about dynamic distortion that's actually favorable for the bearing in some cases. So there is a lot of analysis work now that's done before we come out with a bearing design.

Talking about crankshafts a little bit, we have done that in terms of nodular cast iron, but let's talk about what are the trends in crankshaft design today and where do we see that going. And as these engines become downsized and bearings become downsized, higher cylinder pressures, what we see is higher loads on bearings. And as a result of that, nodular cast iron crankshafts just don't measure up anymore. There is a move more towards forged steel cranks for today's modern, newly designed engines.

HAVEL: Well, you have higher specific outputs.

STURK: Right. Now this comes back to our R & D and materials development in formulating materials specifically for a crankshaft material. We see advantages of certain bearings systems, aluminum/tin/silicon absolutely for sure with cast iron. But is a big chunky silicon good for steel?

HAVEL: Probably going to cause wear.

STURK: I'm not going to answer that because we don't know yet. But I'm going to tell you that we don't think it is. And we are developing new aluminum materials without that – I won't say without silicon but with much refined silicon size.

HAVEL: And I think there are also some new overlays that have been created that contain some of these harder, more wear resistant particles within the plated overlay layer to help that tri-metal bearing resist wear like the bi-metal aluminum bearing has been able to do.

STURK: Right. And then there are other things in bearing design that we are looking at differently to counteract some of the dynamic distortions. Not only is the connecting rod distorted, but the crankshaft bends like crazy. Just look at the bearings. I mean, they are edge loaded. So what are you going to do to combat that? Well, there is profiling of -- the axial profile of the bearing is something that I think most bearing people are looking at today. It's been done in small end for quite sometime. Trumpeting the –

KING (Federal-Mogul Corp.): We tried bushing mains for NASCAR because the crankshaft –

STURK: We tried for the airplane industry a long time ago. So profiling, axial profiling is another thing we are doing to try to relieve some of the edge loading that we are seeing. And one other thing, and we haven't really talked about it yet to any extent, but new bearing materials are all going to be without lead. We are in a lead-free world today. There is no legislation in the United States that says we can't use it. There is in Europe. Anything under three and a half metric tons has to be lead-free. So every bearing maker in the world is now developing new materials that are lead free to meet that. And we feel that in time we'll see legislation here in the U.S.

KOPELIOVICH: Lead free and stronger because you need the material working with high loads.

STURK: And what we see when we go lead free is generally you take the lead out of a bearing material, you get higher strength for free. Lead's tribological properties are terrific – it's one of the best bearing metals out there, but it's still a relatively weak metal.

So you have taken the soft phase out. What do we do wrong now? Our sliding properties have gone out the window.

HAVEL: Sure. It's a compromise.

STURK: It's a compromise. So there we are. We take out the lead, the soft phase metal. We have to replace it with something that has good surface action. A different metal or a different material.

KOPELIOVICH: There are different metals or materials that have different anti-friction properties, anti-seizure properties like lead and environmentally friendly.

STURK: What I wanted to say was as we take the lead out, we made the bearing system more sensitive. The materials that we have developed or that we have left right now without any new development just don't get us through those transient conditions where we get edge contact or low oil delivery or problems like that where lead has always gotten us through that. Now we have got to come up with new materials to get us through those tough times and those transients. And maybe it's bearing design profiling and so forth. Tri-bore, I think is what MAHLE Clevite calls it, is one way to do it. It's going to be a combination of material and bearing design that will get us through that.

Next Question: What effect have low viscosity, low-ZDDP motor oils, and the changes in emissions had on bearing construction and selection? *(see Bearings Q4 transcript)*