ENGINE BUILDER

ENGINE BEARING SUMMIT

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Transcript of Question 2

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Engine Builder Engine Bearing Summit Participants

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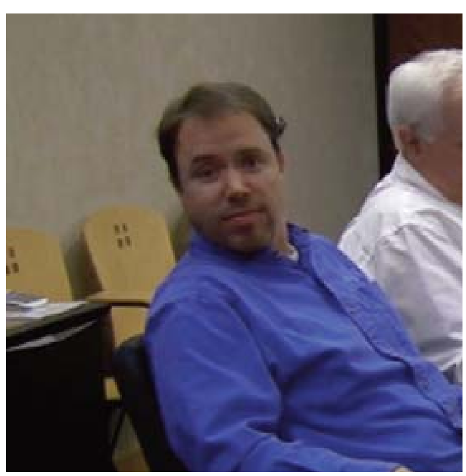

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To answer questions and allow an open discussion about engine bearings without falling into a "pizza wars" debate we convened the inaugural *Engine Builder* Engine Bearing Summit on March 31 at the Babcox Media corporate headquarters. We invited participants 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 2: How does the alloy and construction of a bearing impact its durability?

STURK (Federal-Mogul Corp.): By construction method I think what you are talking about is how the bearing metals are applied. Let's talk about the copper/leads first, the copper/lead family first. As John mentioned, there are two ways to do it, either cast – directly casting molten bronze onto steel and solidifying it. That's known as the cast copper/lead. Federal-Mogul also offers in the United States a sintered copper/lead where we take lead/tin/copper powder, atomize it, apply it to the steel and then sinter it onto the steel back. Done right, and I have worked on both sides of the fence for over 30 years, I cannot see a difference between cast copper/lead and sintered copper/lead. Copper/lead is copper/lead. If it's dense, done right and no porosity, the performance is the same.

Now, let's talk about aluminum. There are basically two ways, maybe three ways to do aluminums. And it has to with the casting and bonding methods of putting that aluminum onto steel. Federal-Mogul's A-Series bearings are roll cast, which means we have two very large water-cooled rolls. The molten aluminum is injected in between those rolls and is solidified instantly. That's called the roll cast method. Very quick and it's a very homogeneous type structure. That material then is rolled and direct bonded to steel.

Another way to do aluminums is by what's known as a belt cast method, a cold bond belt cast. The molten aluminum is put between two fiberglass belts that are cooled with water-cooled platens on each side. This material then is cast relatively thick, about three quarters of an inch or so. It's rolled down and then bonded to steel with the help of an intermediate aluminum layer. It's usually pure aluminum under a cold bond process, not a hot bond, as we use at Federal-Mogul. There is a third way, one of the ways we did in the past called extraction casting where we actually freeze the material in the mold, back it up and pull it back.

It was in a graphite mold. I'm not aware of anybody doing that process anymore. And you could bond that either directly or with a foil bond. It's really how the bond lines are set up, whether you use an aluminum inner layer or not.

Which one is better? The belt cast and graphite mold type processes can allow more soft phase into the aluminum. Hot bonding is somewhat limited to about a 10 percent soft phase. Other than that, then you start to get segregation of the soft phase. So if you are looking to get more soft phase, but generally adding more soft phase into the aluminum will lower its fatigue strength. It's good for the surface properties, good for the surface action but not good for fatigue strength. So most of the aluminum alloys developed today are lower in soft phase to get the fatigue strength component up. And it lends it to our roll cast process to do that.

KING (Federal-Mogul Corp.): I think one thing that's important that Bob was just touching on is you go through this process and you develop things. There are various manners of construction, various manners of alloy. And one of the processes that I think everyone goes through is starting to develop the right structure and the right definition that you feel fits your customers, fits the direction you are going to with the product. And so I think there is probably always some level of interpretation in all ways that you are going to look at. Every business uses their technical skills for people like Bob and the folks we get together with that to also match it with an operational component. And so there is always a design component and there is always the actual manufacturing and then the proven and the field tests and all that to see how it works. I don't know if that necessarily answers the question, but it's kind of hard to have yes/no answers when you work within a world of practical applications.

KOPELIOVICH (King Engine Bearings): I think this second question is the most important of all of the questions in my opinion and the heaviest condition. Okay. The ideal bearing material, as we already discussed, should be strong and soft at the same time. It sounds paradoxical, but all of the existing bearing materials are developed to combine those contradictory properties with a certain compromise.

In order to achieve such compromise, bearing materials have a composite structure. The structure may be a particulate like an aluminum bearing's, in which small parts soft tin and hard silicon particles are distributed over the relatively hard aluminum matrix. And the structure may be laminated like in tri-metal bearings where soft overlay is applied on hard intermediate layer. Both composite structures have advantages and disadvantages. Neither of them is better than another.

One of the main causes of bearing failure is fatigue. Therefore, fatigue strength is one of the most important bearing parameters. Fatigue is the characteristic of the material strength and hardness. Engine designers have a tendency to increase the specific load applied to the bearings. Therefore, new stronger materials are required for highly loaded engines. The high-strength bearing materials may be either aluminum bi-metal or the tri-metal with strong non-lead overlay. High-strength bearing materials also help to diminish the abrasive wear and reduce the effect of cavitation.

Bearing failure due to fatigue is different for bi-metal and tri-metal bearings. The fatigue of a tri-metal bearing starts with the fatigue of its overlay. Since the overlay is thin – about five to eight ten-thousandth of an inch – the fatigue cracks are thin and not deep. Fatigue of aluminum bi-metal bearings is characterized by deep cracks of about one-hundredths of an inch, which expand from the surface to the boundary with the steel back. Delamination of pieces of the bearing material can hasten the bearing failure. A similar situation is realized when fatigue of the intermediate layer of the tri-metal bearing occurs.

Many bearing failures are associated with its lubrication. Ideally, a journal bearing works in the hydrodynamic regime of lubrication when continuous and constant oil film separates the bearing and shaft surfaces. This is ideal bearing. However, there are some factors that adversely impact the oil film, such as high load, low RPM speed, low viscosity oil, roughness of the bearing and shaft surfaces and geometrical misalignments and distortions. The mixed lubrication regime occurs when there is some problem in oil film thickness. And it is characterized by intermittent metal-to-metal contact, which may result in bearing failure due to seizure or excessive wear.

(At this point, Dr. Kopeliovich introduced the following chart to explain his point further)

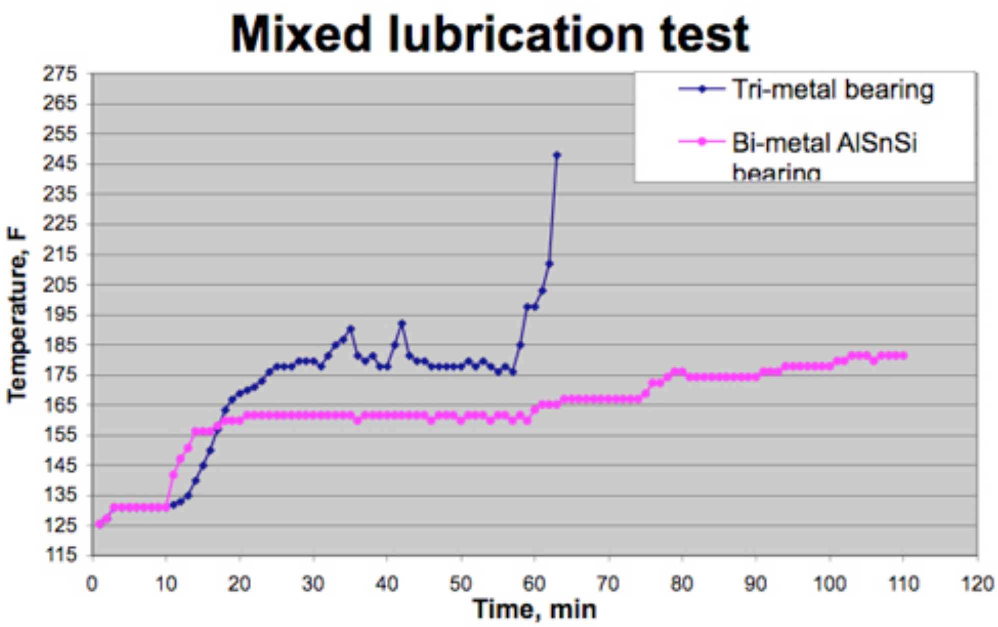

Chart 1

I would like to demonstrate a graph that we obtained from our test rig and which illustrates the different anti-seizure properties of two different materials. The tested bearings worked with insufficient oil supply under oil starvation conditions. The load applied to the bearings was increased by increments. You see this is the load, 7,250 psi, et cetera. This is the load that was increased, this is the time axis and this is the temperature of the back. The back temperature was recorded continuously. You can see that at this point the oil was disconnected from the tested bearing. And you can see this is the graph of the tri-metal bearing and this is the graph of the aluminum silicon bi-metal bearing. When the oil was disconnected, the tri-metal bearing had excellent anti-seizure properties of the overlay. The temperature of the bearing started to rise but at very low rate because of the very good anti-seizure properties of the overlay. But when the overlay was worn out, the temperature rises very sharp and it stabilizes at about 180 Fahrenheit with a few peaks of micro-seizure that you can see here. And the next time I increased the load, the seizure occurs immediately. This is the seizure. The temperature – the back temperature increased very sharply.

The behavior of aluminum silicon bearings was quite different. It demonstrated its impressive anti-seizure properties. The initial load, the back temperature, was stabilized at about 160 degrees Fahrenheit. And then after every incremental increase of the load, the temperature rose by only 5 degrees Fahrenheit and no seizure occurred even when it reached the load of about 13,000 psi.

This is the principal difference between the two materials. Really a tri-metal bearing has excellent anti-seizure materials. But under certain conditions, for example, under oil starvation, the wear of the overlay happens so fast that it is only three or four minutes before the copper/lead was exposed and there was a metal-to-metal contact between copper/lead material and its shaft surface.

HAVEL (MAHLE Clevite): I had wanted to make the point that all bearing materials and types of construction represent a series of compromises. It’s impossible to have the absolute best of all desired bearing qualities in a single material. I think everybody agrees on that. Bi-metal bearings have to depend on a single layer of bearing material to provide all of the bearing qualities that we desire in the end product. We have been talking about strength under load, embedability, surface properties, low friction and conformability and so on, in addition to high temperature strength, the ability to withstand loads at elevated temperatures, and corrosion resistance and also the ability to conduct heat away. Fatigue strength, or the ability to withstand cyclic loads, is probably the single-most important feature of a bearing. And it’s the criteria we use as the starting point to pick a basic bearing material in construction when we are looking at an individual application. Beyond that, all bearings have to exhibit sufficient surface qualities to survive during periods of marginal lubrication and such things as cold start, hot restart after the oil has had an opportunity to drain away and also under occasional lugging conditions, high load at low speed.

Conformability is one of the important factors, I think. And this is where we get into this debate, I guess, between the relative hardness of the surface layer as opposed to the composite bearing. The ability to conform to misalignments, imperfections in geometry, in alignment, shaft journal surfaces, housing bores and so on. Tri-metal bearings with their relatively thin overlay layer, do a good job of resisting high loads and provide the ability to embed particles in the surface. Plus they have an intermediate layer to help mainly to resist fatigue. I mean, it’s the intermediate layer in a copper/lead – any tri-metal bearing, whether it be copper/lead or aluminum – it’s the intermediate later that is there primarily to resist fatigue due to the cyclic loads. In most tri-metal bearings there is a nickel dam used to separate the overlay layer from the intermediate layer. And that’s there basically to preserve the metallurgical integrity of the individual layers to help resist corrosion. One thing I might also add is that in a tri-metal bearing with a nickel dam, the nickel dam is an effective barrier to cavitation erosion, which is frequently seen in high-speed applications. And this could be heavy-duty diesel or it could be race engines. There is no one application where cavitation is particularly prevalent. But the nickel dam does an excellent job of slowing down and resisting cavitation erosion. Aluminum bearings resist cavitation erosion about as good as butter. So when you look at the overall properties that are desired in a bearing, you can see that tri-metal bearings represent the fewest number of compromises necessary in designing a bearing for optimum performance. Now, while tri-metal bearings represent the best overall combination of properties, there are cases where there may be overriding concerns and in particular that would be where cast crankshafts are used. And in that case aluminum bearing alloys, in particular the MAS 19 material I talked about, with a couple percent silicon content have displayed excellent resistance to the initial abrasion from journal surface disparities and the ability to somewhat condition shafts and actually improve the shaft finish over time. So there again, it's a choice between what bearing material and type of construction is best for the individual application that you are looking at. And like we already agreed upon, there are many compromises that need to be made. And you can't just look at one and say this is always better, this is always better. So you have to look at individual cases and applications.

KAUFMAN (*Engine Builder* magazine): Does the process of conditioning the crankshaft, as you mentioned, with an aluminum bearing, if it's used with a little rougher crankshaft, does it impact its durability?

HAVEL: I don't know. Bob, you probably have more experience. I would say probably not.

STURK: No. Not durability, it's wear. It's addressing wear concerns.

KOPELIOVICH: I would not agree because I know that aluminum silicon bearing, it is totally different mechanism of preventing seizure than Babbitt. Babbitt is soft. It is a solid lubricant. But silicon is hard. But both materials prevent seizure. But the different mechanism, a silicon polishing constantly continues to polish the crankshaft. So even if there is some pre-seizure condition, it is immediately removed by silicon particles which polish.

HAVEL: We're not disagreeing. That's kind of what we've already agreed to that.
Let me toss in one more comment regarding the bi-metal and the performance with the silicon and its ability to perform in today's modern bearings compared to what we had years ago. I remember back around 1980 American Motors was developing a whole new family of engines, inline 6s and V8s. And they were testing aluminum bi-metal bearings. And at that time we had a bi-metal aluminum bearing that was made by a unique process that was not one of the processes that Bob described. It was a powdered metal process where we were able to alloy a significant amount of lead with aluminum by mixing it in the powdered state, roll compacting the powder into a strip, sintering the strip to fuse the powder together and then bonding that to a steel back. That material had about 6 percent silicon content, if I remember right.

KOPELIOVICH: It's 85 material? F85?

HAVEL: This was 66. Anyway, at that time Federal-Mogul had submitted samples of 20 percent – your AT20 material – at that time to American Motors for testing on cast shafts. And I remember reviewing the results of the dyno tests. And the wear rate of the two materials on cast shafts was 10 to 1. Two-tenths of a thousandth wear of the bearing wall on the material with silicon in it. Two-thousandths of wear on the material that didn't have silicon.

So that is the function of the silicon content in all of these bi-metal aluminum bearings that are in the marketplace today. I don't think anybody is anymore making a bi-metal aluminum bearing without any silicon in it.

STURK: The funny thing about that is, and it gave 20 percent tin/aluminum a black eye in the U.S., it wasn't just American Motors. Chrysler had the same experience. But it was the fact that the crankshaft finishing procedures that all of the manufacturers were using they thought were good enough, turned out not to be. Twenty percent tin/aluminums have enjoyed a very strong usage in Europe where crank finishing is better.

HAVEL: Right. Where they started, really.

STURK: Yes. And today it's still there. And because they have done a better job. I think they use a lot of vertical shell castings. But they just do a better job finishing. The Americans learned how to do that. That period of time was a lesson in all of the Big Three at the time on how to finish cranks. And the silicon certainly helps remove the ferrite caps. It does a marvelous job.

KOPELIOVICH: Not only about -- this test was performed with steel.

STURK: I would like to comment on these test results.

JAMES (King Engine Bearings): Just one second. Before you comment on that, I would just like to comment on Doug's question when we were asking about whether the conditioning that occurs on the crankshaft journal by a silicon bearing has any affect on that journal. I think let's conclude with the obvious conclusion, and that is simply that if there are ferrite peaks in a nodular cast iron journal whose height is greater than the minimum oil film thickness, a tri-metal copper/lead bearing is going to fail because those peaks are going to remove the Babbitt overlay. And if you have a silicon aluminum bearing, the silicon in that bearing material is going to polish and remove those peaks. And so it has a definite end conclusion, which is that you will not have a bearing failure or an engine failure.

STURK: I want to disagree with that, based on history. Because nodular cast iron was around and we were using tri-metal bearings for a long time. What happens with the tri-metal bearings is that nickel dam that's put there to prevent tin diffusion actually grows an intermetallic. You get a tin/nickel intermetallic that becomes quite hard and abrasive and wear resistant that knocks those caps off.

HAVEL: Yes, I was going to take exception to the statement that the tri-metal bearing will fail. It may wear at an accelerated rate or prematurely, but that doesn't necessarily guarantee that it's going to fail.

STURK: Right. The intermetallic is very, very strong.

JAMES: If it wears eight-tenths, how do you characterize that bearing and that engine? It's okay? No problem at all? It will keep running?

HAVEL: If it continues to function.

JAMES: There will be no knocking at eight-tenths and there will be no loss of oil pressure?

STURK: Probably not.

JAMES: And that engine will be fine?

STURK: Certainly you don't want wear, and the big advantage to me of aluminum over tri-metal is the slow wear rate.

JAMES: The aluminum with silicon will actually polish –

HAVEL: We're not arguing about the superior wear resistance of bi-metal aluminum. The only thing I'm saying is just because you get some initial wear of the tri-metal bearing doesn't guarantee that it's automatically going to fail.

STURK: Right. And I would take exception to that comment. I don't think it would fail.

JAMES: But is accelerated wear a precursor to a long-lived engine or is accelerated wear a precursor to possible failure? How would you characterize it?

KING: It's not a precursor to either one. Everything is in a certain environment and situation, it's what's the extent of the wear, what's the extent of the condition of the crankshaft and that type thing? Because there is initial wear, I don't think you can make the leap or the assumption to say well, that's a disaster waiting to happen. I think that's kind of, it's not arguing the direction of what may be happening in an environment. But I think to assume that that means catastrophic failure is a pretty big stretch.

JAMES: But can you assume the opposite, that the conditions under which this engine is functioning are the original and desirable design conditions of those bearings when you have had eight-tenths removed?

KING: You are saying had eight-tenths removed, I think. What you are saying that's –

JAMES: If a crankshaft is not polished well, you can have ferrite peaks that are half-a-thou tall. What are they going to do to it, to the Babbitt overlay?

KING: It's a dynamic atmosphere. To make that step to say that that's always going to assure that you are going to have a certain amount of removal, I think that is just –

JAMES: You can't say all.

KING: Right.

JAMES: You can't say always. But we can say it's undesirable, can't we? You would agree that that amount of wear is undesirable? Is there any disagreement on that?

MCKNIGHT (MAHLE Clevite): What we can say is that leaving ferrite caps is undesirable.

HAVEL: Let's go back to the cause. Let's not look at the victim in the process. The cause is the ferrite caps, the bearing is the victim. So let's look at the cause and not the result.

KAUFMAN: Have the crank finishing procedures gotten better?

STURK: Oh, absolutely.

KAUFMAN: That's less of an issue?

STURK: By far, by far.

HAVEL: Absolutely.

KING: Yes. I think you are looking in two different directions because we do have a pretty large aftermarket audience here. We have different stages of work that are done in every level. And we see that in engine machine and all the time. And as aftermarket suppliers, I think we all are looking at those things, so can we accommodate the majority of our customers? You can accommodate a lot of things. You can't necessarily accommodate something being done wrong. But there are different levels of quality in the machining equipment and the experience of operators.

HAVEL: You can't put a single product in the market and say this is all we're going to offer and expect everybody to buy it.

JAMES: Right.

HAVEL: I think people who are proponents of the bi-metal aluminum recognize that because they also sell tri-metal bearings, copper/lead bearings.

JAMES: Sure, you have to.

HAVEL: So you can't have tunnel vision here. You have got to look at the broad spectrum and say what does the marketplace demand, what's needed out there?

JAMES: And which product fills that need, basically.

HAVEL: And there is a place for everything.

(At this point, discussion returned to the chart presented by Dr. Kopeliovich earlier. See Figure 1.)

MCKNIGHT: I want to hear about that chart, Bob.

STURK: Well, really this is very interesting, oil starvation. Basically this is a seizure test. And it's very difficult to get good meaningful results with tri-metal bearings in a bench test because you do things to aggravate the running conditions. And here, we're increasing load, we have stopped the oil. And when these kinds of things happen, the soft Babbitt or the soft overlay materials are really in trouble because they begin to not wear but extrude and actually impede oil film formation. So they are very difficult to do a bench test. But inherently we know and we have all of this history that these are very seizure-resistant metals that we are putting on here. But they're very difficult to test for in a bench rig.

HAVEL: Well, the other comment that I have is that your first break point there is at ten minutes. What else is going to fail in the engine within a 10 minute time period prior to a bearing failure? I mean, you've got a multitude of other – that's time in minutes?

KOPELIOVICH: Ten minutes is before oil was disconnected. It's normal regime of work.

HAVEL: Okay. And then you've got about another five minutes or more, and you are all of the way out to 20 minutes before seizure occurs. The point is, you starve any engine for oil for even a minute and you've got a multitude of problems that go far beyond the bearings.

STURK: Anything in engine operation is going to be transient.

HAVEL: I realize what you are trying to do.

KOPELIOVICH: I did not say this is the real condition in real engines. This is a severe condition, artificially created. I created severe conditions to understand the behavior difference between two different materials. In the regime of metal-to-metal contact, oil starvation, mixed lubrication, no matter, it's the same.

MCKNIGHT: Well, I'll grant you there is a behavioral difference in the two materials, but I'll also contest that if you take the oil away, it really in the end is immaterial because the engine is going to fail regardless whether you've got a bi-metal bearing in it or a tri-metal bearing.

KOPELIOVICH: The oil was not taken away. The oil existed. I will explain a little bit about the experiment. I have a test rig that has three bearings, two main bearings and one tested bearing on the eccentricity part of the shaft.

HAVEL: Underwood-type test?

STURK: Sapphire, sounds like a Sapphire.

KOPELIOVICH: It's similar to Sapphire, but there is some difference. But similar. Let's say that it is a Sapphire machine. I disconnected the oil supply from the center tested bearing, but the main bearings still had oil supply. Some oil coming out from the main bearings added to the tested bearings. But it was definitely oil starvation. It was not enough for hydrodynamic regime. It was definitely oil starvation and metal-to-metal contact. It was mixed regime. And it was interesting to me to see the difference of the behaviors of these two materials. I know that the Babbitt never – or let's say in a normally operated engine never realizes such regime for a long time. Only maybe part of seconds. But if there is some problem with oil supply or are the conditions that lead to a mixed regime, these two materials behaved differently. And we have to see the fact that it behaves very well until it is worn out, but before it is excellent. When it is worn out, nobody will argue that the anti-seizure properties of the copper/lead intermediate is worse than aluminum/silicon. So this is the case that copper/lead works, no Babbitt at all.

HAVEL: Did the bearing have a nickel dam, the tri-metal bearing?

KOPELIOVICH: Yes, of course, of course. But the nickel dam was only one micron.

HAVEL: Yes, but still that's a factor in the seizure characteristics as well because you have to go through the nickel dam before you get to the copper/lead layer.

STURK: The other thing I want to point out on this chart too is how cold these temperatures are.

HAVEL: Yes, I noticed that too. You started out at 130 degrees or something like that, which is not realistic for any kind of engine operation.

STURK: Right. And this is the reason that the aluminum bi-metal in my view performed so well here is because we are well under 200 degrees Fahrenheit.

HAVEL: Right. Show me an engine today that operates steady state at less than about 250 degrees.

STURK: We don't do any seizure testing in cold temperatures like this.

BAKER (*Engine Builder* magazine): You guys talked about a Sapphire test. Could you maybe explain what that is?

STURK: Yes. There are bench rigs in the bearing industry. There are primarily two that are used today, one is called a Sapphire, one is called an Underwood. The Underwood test is old. It was developed by a GM engineer named Arthur Underwood. It's dynamically loaded, and it uses counterweights on a shaft to put a couple on create an imbalance.

HAVEL: That creates a cyclic load.

STURK: A cyclic load. The Sapphire was developed in England in conjunction with Glacier Vandervell. But it uses a servo-hydraulic piston to actuate a rod with a test bearing that is running on a shaft with a slight eccentric. It's an alternating load type test versus the Underwood, which is a rotating load type test. And materials behave differently depending on the type of loading that you put in there. You will get different results.

HAVEL: Caterpillar used to use the GMR machine, the General Motors Research machine, was another hydraulically loaded machine.

STURK: Yes. Federal-Mogul kind of emulated that machine, and they called it the FMR, but it was based on the GMR principle.

HAVEL: But the whole point of the test, regardless of the rig, is to create a cyclic type loading on a bearing much like taking a piece of metal and bending it back and forth, only all we are trying to do here is put compressive loads on. Where if you bend something, you alternate between compressive and tensile stresses. Bearings were never, ever intended to carry any kind of a tensile because the bearing materials are made primarily to resist compressive stress. So that's the nature of the machine, of the loading and depending on or basically regardless of what type of machine you used to create that cyclic load.

KOPELIOVICH: Controllable alternating load which you reset, we know.

BAKER: Do you all use kind of the same Sapphire test then?

HAVEL: I would say similar.

KOPELIOVICH: Our machine is similar to Sapphire. And the results are comparable.

KAUFMAN: Are the results different between the different types of machines?

STURK: Yes.

HAVEL: They correlate.

KAUFMAN: Not necessarily the testing machines you use, but the Sapphire and the other one that you mentioned.

HAVEL: The numbers may come out different, but I think on a relative scale you will find that they're similar.

KOPELIOVICH: But there is no standard metal in the industry.

STURK: And what we are talking about here is Sapphire and Underwood for fatigue. Now seizure testing is different.

HAVEL: That's a different ball game.

STURK: You're on your own there.

HAVEL: Everybody has created their own.

KOPELIOVICH: It's very difficult.

STURK: It's very difficult because, as I said, you try to aggravate the conditions to induce seizure.

HAVEL: One of the things that is very difficult to reproduce or control in a seizure test is the alignment. If you create just the very, very slightest little bit of edge loading, you have got totally different results.

STURK: But a couple things you said there about tensile and compressive loading, what we are seeing in modern engines today is that with everybody going to lighter weight assemblies and very lightweight rods that are almost nothing there, we're seeing more and more bending fatigue type issues.

HAVEL: The load, the bearing is subjected to -- the lining may be subjected to a tensile stress due to bending but not due to engine loading.

STURK: Right, no. But it's bending of its supporting structure.

HAVEL: Right.

KAUFMAN: The crankshaft?

STURK: The connecting rod primarily.

HAVEL: Let's talk about a connecting rod as an example. In your mind's eye don't think of it made of steel. Visualize it made of rubber. And then immediately you can figure out what goes on when the piston gets to the top of the exhaust stroke and there is no pressure up there to stop it and the piston wants to go right out the top of the cylinder and all you've got down here is the rod cap to stop it. And if that was a rubber rod, that cap is going to wrap around that bearing journal and you are going to stretch the rod. And that's basically the type of action that we have to consider. Even though the components are made of metal, you've got to understand what happens to them because metal moves, it's not quite rigid.

KING: But I think to that point, John, is we've had the evolution. We have talked a little bit of history today already between the '50s and '60s, the '70s and '80s and all. That transition or that change in a lot of the new engines that we are seeing coming out in the market is what are a lot of the objectives of the automakers and even on more the heavy side. There are a lot of concerns about emissions; there are a lot of concerns about mileage and dependability. And I almost look at it as the aspect they want an engine to weigh virtually nothing because that is part of that entire package of the vehicle. So they are doing a lot of things to reduce weight and take away weight.

If they can reduce the size of the crankshaft, they can reduce the size of some of the throws, all of those things have less parasitic horsepower loss going out to the power train, which results in better performance of the vehicle either in, you know, literally horsepower or miles per gallon. And then all of these things play together. But at the same time as they are taking that weight out, there becomes a lot more movement in everything. We are seeing cylinder heads that tend to walk 10, 12-fold what they used to do when you had big heavy bolts.

HAVEL: Yes, that's right.

KING: So there is almost this whole new world. It's definitely more exacting science I think. Whether it's the surface finishes or the fit or the alignment, where everything starts. But I think one of the challenges that all of our technical folks have to deal with today is they literally are designing a part in a moving engine, the rod is moving and the block is moving and all. So I think it's a pretty exciting time. It's pretty cool. I didn't wish some of these engines would run as long as they will, quite frankly. But the idea that we have to continue to move the evolution of the work we do, whether it's for OEMs or it's for our independent service outlet.

HAVEL: The OEMs have continued to raise the bar and the suppliers have had to try to keep over that bar in order to meet the requirements and continue to supply product.

Next Question: What other engine factors, including the parts do you have to take into consideration when you are designing bearings and when selecting a bearing?
(see Bearings Q3 transcript)