Daido Metal and The Motor Oil Geek Take a System-Level Approach to Advanced Engine Failure Analysis

Engine bearing failures are rarely as simple as choosing the wrong oil, running too little oil pressure or setting the wrong bearing clearance. In a high-performance engine, lubrication, bearing geometry, crankshaft motion, contamination, temperature, load and component deformation operate as an interconnected system—and diagnosing a failure requires understanding how those variables interact.

That was the central theme of EPARTRADE's latest Race Industry Now technical webinar, "Advanced Engine Failure Analysis: Diagnosing Root Causes & Wear Mechanisms with Daido Metal and The Motor Oil Geek," featuring Dustin Kull, Account Manager – Racing and Aftermarket at Daido Metal, and Lake Speed, Jr., Tribologist and The Motor Oil Geek. The session was hosted by Brad Gillie of SiriusXM, Channel 90, Late Shift.

Kull and Speed approached engine failure analysis from complementary sides of tribology—the science of friction, wear and lubrication. With Daido Metal's expertise in engine bearings and Speed's experience in lubrication and used-oil analysis, the discussion went well beyond identifying damaged parts to determining why the damage occurred in the first place.

"Proper lubrication can be defined as the four R's," Speed explained. "The right oil, the right place, the right time and the right amount."

Only one of those four variables is the oil itself.

Contamination: A Leading Cause of Bearing Damage

One of the strongest messages from the session was the importance of oil cleanliness.

According to Speed, contamination is the number-one source of bearing failure he has encountered across multiple bearing applications. Drawing from more than 20,000 used-oil samples analyzed through SPEEDiagnostix, he said abnormal contamination—whether from fuel dilution, dirt, dust or other wear debris—is one of the most common contributors to abnormal engine wear.

The scale of the problem becomes apparent when actual operating oil-film thickness is considered.

An engine may be assembled with 0.0025 or 0.003 inch of vertical bearing clearance, but that does not mean the crankshaft operates concentrically within that clearance. Kull explained that Daido analyzes the orbital path of the crankshaft journal, along with shaft size, oil-hole timing, groove length, pressure distribution and other variables.

Under actual operating conditions, minimum oil-film thickness can be dramatically smaller than assembly clearance.

"We see all the time conditions where these things are operating at 0.6, 0.7 micron oil-film thickness," Kull said.

That means a contaminant particle several microns in diameter can be many times larger than the minimum lubricating film separating the crankshaft from the bearing.

Speed noted that particles in the 5- to 10-micron range can cause substantial damage even though they are invisible to the naked eye. Many conventional full-flow oil filters are also substantially more efficient at capturing larger particles than contaminants in this extremely small size range.

The result is an important lesson for engine builders: oil can appear clean while still containing particles capable of disrupting a sub-micron bearing oil film.

Viscosity, Speed and Load Determine Oil-Film Thickness

Speed reduced hydrodynamic bearing lubrication to three fundamental variables: viscosity, speed and load.

For a crankshaft to operate without contacting the bearing surface, the rotating journal must generate a hydrodynamic oil wedge strong enough to support the applied load. Increase viscosity or surface speed and oil-film thickness can increase; increase load and maintaining that film becomes more difficult.

But simply reaching for a higher-viscosity oil is not necessarily the answer.

Kull pointed to intermittent rod-bearing failures as an example. Increasing viscosity or oil pressure may appear to be a logical response, but neither addresses the root cause if excessive oil is bleeding from the main bearings because of vertical clearance, bearing eccentricity or incorrect oil-hole timing.

"There are so many different factors that can affect the amount of oil that's getting to the rod," Kull explained, "and it has absolutely nothing to do with viscosity or oil pressure."

Speed also emphasized that viscosity must be considered at actual operating temperature—not simply by reading the SAE grade printed on the bottle.

The viscosity represented by the second number in a multigrade oil designation is measured at 100°C/212°F. Racing engines, however, can operate at dramatically different oil temperatures.

Speed used a Pro Stock engine as an extreme example. A very low-viscosity racing oil at approximately 100°F can actually be more viscous at that temperature than a 15W-40 diesel oil operating at 212°F.

The implication is significant: bearing clearance and actual oil operating temperature need to be considered together when selecting viscosity.

The Bearings Tell a Story

When a failure does occur, Kull emphasized the importance of cataloging as much information as possible rather than immediately changing components.

Used bearings can provide a map of what happened inside the engine. Wear location and morphology can indicate insufficient oil film, crankshaft shape or movement, contamination, housing deformation and other operating conditions.

But similar-looking damage can have very different causes.

Speed highlighted edge loading as an increasingly relevant example in modern performance engines, particularly when production short blocks are subjected to power levels well beyond their original design targets.

Wear concentrated along one edge of multiple bearings can reveal crankshaft or block deflection. Looking at the complete bearing set rather than a single damaged shell can expose a pattern as the loaded area moves from one bearing to another.

The crankshaft, Speed explained, may no longer be operating straight under load.

That system-level view becomes particularly important because bearing damage that appears to be a lubrication failure may actually originate somewhere else entirely.

When “Oil-Starvation” Damage Is Actually Detonation

One of the most revealing case studies discussed during the webinar involved an engine in which five of eight bearings exhibited unusual side-loading damage.

At first glance, the pattern resembled compromised oil-film lubrication. But instead of the typical smeared appearance associated with edge loading, the bearings displayed more of a pockmarked surface.

That raised the possibility of cavitation erosion associated with detonation.

Rather than diagnosing the problem solely from the bearings, Speed recommended comparing another component: the top piston rings.

The top rings from the five affected cylinders were grouped together and their free gaps compared with the rings from the three apparently healthy cylinders. The five cylinders associated with the damaged bearings showed substantially smaller ring free gaps.

According to Speed, detonation can collapse the free gap of the piston ring, providing another piece of physical evidence that abnormal combustion had occurred.

The analysis therefore worked backward through the engine.

Detonation created extreme cylinder-pressure spikes. Those loads overwhelmed the hydrodynamic oil film, allowing increased bearing contact and producing wear and fatigue cracking. The resulting bearing damage could easily have been interpreted simply as inadequate lubrication, even though the root cause was the engine tune-up.

"The bearings will tell you a story, but also look around at the other parts of the engine," Speed said.

For Kull, the example demonstrated why successful failure analysis requires evidence from multiple sources. The bearing showed that the oil film had been overloaded; the piston-ring measurements helped establish why.

Bearing Clearance Is More Than a Vertical Measurement

Bearing-clearance questions generated considerable discussion during the webinar, particularly for engines modified with boost or significantly increased power.

Kull cautioned against treating bearing clearance as a single universal specification.

Under load, connecting-rod big ends and other engine structures deform. Increased cylinder pressure, engine speed and reciprocating mass can change housing shape enough that additional clearance may be necessary simply to prevent the deformed housing from physically pinching the journal.

Bearing eccentricity is also critical. The bearing must provide sufficient geometry for oil flow while accommodating the movement of the housing and crankshaft.

Daido uses several methods to investigate these conditions, including simulation, pressure mapping, bearing-temperature measurement, profilometry, static load testing and finite element analysis (FEA). Connecting rods, for example, can be loaded under controlled conditions to measure housing deformation and estimate how increased power or speed may affect bearing operation.

The objective is not simply "more clearance," but the correct geometry for the complete operating condition.

Bearing Material Must Accommodate What the Crankshaft Is Doing

Crankshaft bending and torsional vibration add another dimension.

Kull explained that minimum oil-film thickness remains the priority, but bearing-material selection also becomes critical when the crankshaft and housing are moving significantly under load.

A more conformable bearing material can accommodate some of that movement, effectively allowing the bearing surface to respond to the crankshaft's dynamic path while maintaining or rebuilding the hydrodynamic oil film.

This is one reason bearing design cannot be separated from the mechanical structure surrounding it.

Journal diameter, surface speed, crankshaft stiffness, block rigidity, bearing geometry, oil viscosity, temperature and load all contribute to the final operating condition.

RPM Alone Does Not Define Bearing Speed

The discussion also challenged the common assumption that higher engine RPM automatically creates a more difficult lubrication environment.

For bearings, Kull explained, journal surface speed is more meaningful than crankshaft RPM by itself. A large-diameter journal rotating at a lower RPM may have a surface speed comparable to—or greater than—a smaller journal operating at substantially higher RPM.

Speed added that, from a hydrodynamic lubrication standpoint, speed can actually help generate the oil film. With journal size held constant, increased rotational speed can make it easier to establish hydrodynamic separation.

But increasing stroke introduces other variables.

A stroker crankshaft can alter oil-delivery timing and increase windage in a wet-sump engine. Greater interaction between the crankshaft and oil can entrain air and generate foam.

"Air is a terrible lubricant," Speed said.

An oil-pressure trace that falls significantly as RPM increases can therefore be evidence of excessive oil aeration or an incorrect oil level. Changes in stroke may require reconsidering oil-pan configuration, capacity and oil level to keep the rotating assembly from interacting excessively with the sump oil.

As Speed summarized, engines are systems rather than "collections of random parts." Changing one component changes operating conditions elsewhere.

Microscopic Debris Can Identify the Source of a Failure

Daido Metal's failure-analysis capabilities also include scanning electron microscopy (SEM), which can be used to examine foreign particles embedded in a bearing surface.

The technique allows engineers to investigate both particle size and material composition. Debris may be identified as aluminum, iron, titanium, bearing material or another substance, providing a path back toward the component generating it.

That information can also help determine whether a contaminant originated upstream or downstream of filtration.

Speed offered titanium valve-spring retainers as an example of why material identification matters. Uncoated titanium components can generate extremely fine, sharp wear debris. In used-oil analysis, elevated titanium can therefore provide a clue to the source of abrasive contamination elsewhere in the engine.

The larger point is that contamination analysis should not stop at finding "metal in the oil." Identifying what the metal is, its size and where it could have originated can turn an observation into a diagnosis.

Don't Try to Fix the Oil With an Additive

When asked about aftermarket oil additives for additional performance or protection, Speed's recommendation was unequivocal.

"You should never use an oil additive," he said. "If you're thinking you need to use an oil additive, it means you need a different oil."

In other words, an additive should not be used to compensate for an oil that does not provide the required viscosity or performance characteristics.

Fuel additives require a more nuanced approach.

Speed said diesel fuel additives can be beneficial, particularly where fuel lubricity is a concern, but excessive treat rates can introduce another problem. Much of a bottled additive may consist of carrier fluid, and excessive use can contribute to fuel dilution of the engine oil.

He described oil-analysis cases showing 6%, 7% or even 8% diesel fuel dilution in which excessive fuel-additive use was a contributing factor. Reducing the treat rate reduced dilution and allowed oil viscosity to recover.

The lesson: more additive is not automatically more protection.

Oil Can Also Run Too Cold

Another frequently overlooked operating variable is oil temperature.

Asked about a performance engine whose oil temperature rarely exceeded approximately 160°F, Speed expressed concern. Ideally, he said, oil should reach approximately 200°F to 220°F in operation.

Running continuously at low oil temperature can prevent fuel and moisture from evaporating effectively from the lubricant. Oil additives are also temperature dependent, and insufficient temperature can prevent them from operating in their intended range.

For race and performance applications, this is an important counterpoint to the common emphasis on controlling excessive temperature. Oversized coolers and aggressive cooling strategies can create their own lubrication problems if the oil never reaches an appropriate operating temperature.

Failure Analysis Means Finding the Cause Behind the Cause

Perhaps the most important takeaway from the session was that the visibly failed component may only be the final link in a much longer chain.

A damaged bearing does not automatically indicate a defective bearing. A thin oil film does not automatically mean the oil viscosity was too low. A rod-bearing failure does not automatically require more oil pressure. And opening bearing clearance does not necessarily solve an oil-supply problem.

Contamination, crankshaft deflection, housing deformation, oil aeration, detonation, oil-hole timing, operating temperature, component wear and even microscopic debris generated elsewhere in the engine can ultimately produce similar-looking damage at the bearing.

For professional engine builders, race teams and performance engineers, effective failure analysis therefore becomes an exercise in correlation: inspect the complete bearing set, examine surrounding components, analyze the lubricant and debris, understand actual operating temperatures and loads, and compare the physical evidence against the engine's architecture and operating data.

The goal is not merely to identify what failed.

It is to determine what caused it to fail—and then correct the system rather than the symptom.

"Advanced Engine Failure Analysis: Diagnosing Root Causes & Wear Mechanisms with Daido Metal and The Motor Oil Geek" was presented as part of EPARTRADE's Race Industry Now webinar series. The session featured Dustin Kull, Account Manager – Racing and Aftermarket, Daido Metal, and Lake Speed, Jr., Tribologist, and was hosted by Brad Gillie of SiriusXM, Channel 90, Late Shift.

For more information, **watch the full webinar here.**