Oil-Out Endurance Under the Lens

Oil-out durability in gears is becoming more important for the aerospace industry, prompting researchers to look for new, more powerful solutions.

Alex Cannella, News Editor

Oil-out conditions, or conditions in which an aircraft is operating without any oil in its gearbox or transmission, are devastating for an aircraft's hardware. Even the sturdiest gears usually can't last 30 minutes under such conditions before they catastrophically fail, and the whole system usually follows shortly after. That doesn't leave pilots with a whole lot of time to find a suitable location to land in the case of an oil-out emergency.

But an oil-out (or oil-off or loss-of-lubrication) incident is almost as rare as it is damaging, and so the topic falls in and out of the public eye every few years.

Currently, oil-out testing is back in vogue and research is ramping up to find ways to extend how long gears can last without oil. The military in particular is interested in extending oil-out time. In an article published this past fall, the Joint Aircraft Survivability Program (JASP) cited an increase in future aircraft's range and endurance as a primary factor in the military's increasing interest, as such improvements would lead to missions that would take military aircraft farther afield and require "corresponding improvement in loss-of-lubrication performance to enable long-distance exit from hostile areas." According to the article, NASA and the U.S. Army Research Laboratory have teamed up to study multiple potential solutions to the issue.

That alone should be enough for anyone working with the military to take notice and start looking into their own gears' oil-out performance, but it's also important to consider on the commercial side of aerospace, as well. Case in point: the 2009 crash of a Sikorsky S-92 helicopter that resulted in the deaths of the pilots along with 15 oil rig workers.

The folks over at Penn State University's Gear Research Institute (GRI) are doing their own testing for both military and commercial sponsors and are looking at different strategies to improve oil-out gear performance by targeting the root of the problem: heat.

The primary cause of failure in an oil-out incident is heat. Without any lubrication, the gears have more friction, which in turn produces more heat. The heat, in turn, has nowhere to go without any coolant to carry it away causing the gears to expand, which can result in a loss of backlash, and so on until the gears fail or seizure becomes imminent. For some gears, the whole process doesn't even take a full minute.

"There's a lot of interest in trying to understand the root cause of the failures," Aaron Isaacson, GRI's managing director, said. "And I think we understand certainly that heat generation is the problem, but fixing or even mitigating it is a challenge."

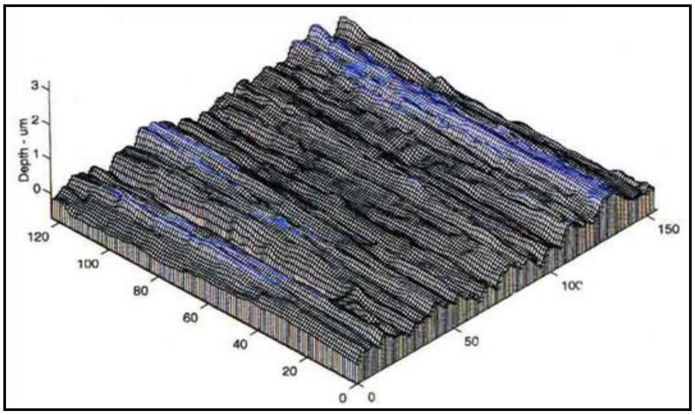
Much of the GRI's research is still in its formative stages, but in general, the institute has managed to narrow their options down to two broad approaches. One major focus is to slow the process of gear failure by reducing the friction, and thus the amount of heat, present in a gearbox without relying on lubrication.

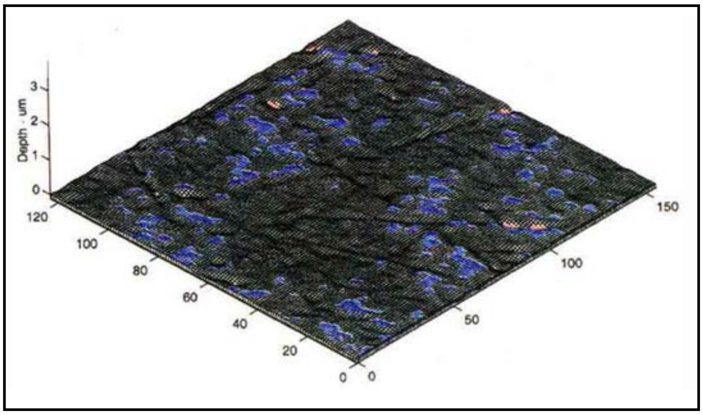
Much of the study in this vein is looking at potential coatings, particularly the study of diamond-like carbon (DLC) coatings. DLC coatings initially popped up on GRI's radar when they were doing unrelated contact fatigue tests, but after seeing some coatings perform well there, the institute is interested in seeing if they can be applied to this new challenge.

"[Certain DLC coatings] appeared to work reasonably well, so the thought was, let's look at them in oil-out situations, as well," Isaacson said.

The other approach looks at improving a gear's oil-out durability by raising the thermal capability of the gear's material, increasing the amount of time the gear will remain operable in spite of rising friction and heat levels. Many of the steels the GRI is looking at here are newly developed alloys that temper at higher temperatures known as high hot hardness steels, which maintain their properties at temperatures well above most carburizing grades.

"We're going to accept the friction and the heat generation that occurs and real-





A machine surface finish (left) compared with an isotropic superfinish (right). Images courtesy of REM Surface Engineering.


BEFORE
AFTER

ize that we can't get rid of it," Isaacson said. "So we're going to try to deal with it and manage it in a different way by using a material that can take it, or at least take a little more of it."

Another interesting solution the GRI is looking at is a proprietary nanoparticulate oil. While Isaacson notes that the product still needs to be put to the test, the theory goes that even in an oil-out incident, the lost oil would leave a permanent film on the gear, improving lubrication in the system and extending gear durability.

"Even though the lubricant is no longer there in an oil-out situation, when it's operating, it's reacting and it's forming a tribological film on the surface of the teeth that will remain in the event of an oil-off situation," Isaacson said. "And that tribofilm will theoretically affect how the gears perform once the oil goes away."

It's also theorized that it may not be necessary to use the oil for more than a "break-in" period, lowering the cost of including oil-out protection for manufacturers.

Cost is certainly one of the GRI's chief concerns. Many potential products the GRI is studying either use expensive materials or require additional time for machining or heat treatment, something the GRI is acutely aware of.

"Cost is always a driver here," Isaacson said. "None of these are cheap solutions."

One potential solution that the GRI hasn't yet investigated is superfinishing. Ask REM Surface Engineering's Vice President, Justin Michaud, and he'll tell you that isotropic superfinishing isn't just a way to improve an aircraft's oil-out performance, but part of the future of aerospace gearing.

"REM's isotropic superfinishing process is a real technology that represents a fundamental improvement over pre-existing gear forming operations," Michaud said. "We aren't putting a coating on that might have adhesion problems or thickness irregularities. We aren't just knocking the tops off some of the peak asperities like honing and some of the more advanced super-grinding/polish-grinding machines. We are taking a distressed, periodically textured surface and polishing it to a particularly ideal state."

The list of ways REM's isotropic superfinishing process, which they've coined and trademarked as the ISF© Process, improves gear performance is extensive. Increased resistance to contact fatigue, bending fatigue and scuffing, elimination of micropitting, increased load carrying capacity/power density, reduced friction, elimination of the run-in/break-in step, increased lambda ratio, increased lubricant performance via reduced operating temperatures, reductions in structure born noise, reduced wear and improved coating adhesion are just some of the benefits REM attributes to their superfinishing technique.

That's quite a checklist of benefits that might make isotropic superfinishing sound like a cure-all that's just too good to be true, but Michaud's got the evidence to back his claims up. For example, an AGMA study found that spur gears treated with the ISF Process could run at a lubricant supply temperature 60 degrees Fahrenheit higher than ground spur gears before scuffing. In another study, isotropically superfinished gears survived 30 minutes at 400 ksi without lubrication, while ground gears failed within one minute.

The ISF Process's main benefit is that it reduces a gear's surface roughness to decrease friction between mating surfaces, but the technique's other major feature is the isotropic texture it creates, which improves contact fatigue resistance and lubricant adhesion. This improves gear durability in oil-out conditions by reducing friction and lengthening the time it takes for the gears to overheat and start breaking down.

The rest of the process's laundry list of other advantages stem from the combination of these two features. Both features, for example, improve a gear's lambda ratio, which in turn reduces how much oil is required to stay fully lubricated. With an improved lambda ratio, gears treated with the ISF Process can maintain full-film or mixed lubrication status in situations that would leave ground gears insufficiently lubricated. In an oil-out situation where there may still be residual trace of oil on the gears' mating surfaces, increasing the gear's lambda ratio is yet another theoretical way to improve a gear's durability.

For the cash-strapped gear manufacturer, it may be difficult to justify spending more than the bare minimum required to protect against oil-out conditions. It's understandable that manufacturers may not be in a rush to sink major costs into a feature that may never be used in a gear's life. But one of the ISF Process's selling points is that many of the features that improve gear durability in oil-out conditions also benefit gears during normal operation. The technique also requires no changes to a gear's design, just an additional manufacturing step, saving manufacturers some time and worry alongside money.

"Certainly, in normal operating conditions, you don't need to worry about a complete or nearly complete loss of lubrication," Michaud said. "But just as isotropic superfinishing will increase gear life during oil out conditions, in normal operation, an isotropically superfinished gear will have significant lifespan improvements over a ground gear."

Looking at it that way, the ISF Process's oil-out protection properties are almost more of a bonus than a central feature. Many of the same features that increase gear durability in oil-out conditions also contribute to reducing the risk of gears scuffing, another major concern for the aerospace industry. While modifying a gear's design to account for oil-out incidents may be more expensive than some would like, methods like REM's superfinishing process can help soften the financial cost with additional benefits.

According to Michaud, isotropic superfinishing shines most in "extreme" high-load, high-speed functions, such as with the rotorcraft gearboxes being studied by the U.S. Army Research Laboratory, as well as high-load, low-speed functions, but can be utilized across a broad spectrum of hardened gear applications. Michaud also noted that the ISF Process can also work as a solution to problems found late in the design or even manufacturing process.

"Isotropic superfinishing can absolutely be used as a quick fix to solve late stage design or in production issues," Michaud said. "If a gear design or system is experiencing failures or isn't operating to the levels of performance to which it was specified and surface finish is a factor, then applying the isotropic superfinishing is good path to consider."

REM has also invested a significant amount of time expanding the range of gears their superfinishing process supports. Some of the main alloys their process is compatible with include SAE 8620 and 9310, Pyrowear 53 and 675, Ferrium C61 and C64, M50/M50-Nil, CSS-42L, Nitralloys, AerMets and 440C. It's worth noting that some of those materials are the same alloys that the GRI is currently looking at in their own oil-out studies. The process has been used on gears as heavy as 10,000 pounds and gears with diametral pitches as high as 96, as well as multi-geared shafts, gear assemblies and gears with integral bearing races or seats.

Despite Michaud's belief in REM's ISF Process as a baseline innovation for the aerospace industry, growth has remained steady. Michaud attributes this to the nature of the industry, which he characterizes as understandably cautious when implementing new technology.

"It is one thing if your car breaks down, you're going to be inconvenienced and probably upset," Michaud said. "It is quite another thing if a helicopter transmission or turbo-fan gear fails, so you really can't take chances."

But between the ISF Process's numerous advantages, the multiple industry woes it provides a solution for and a growing pile of studies and papers verifying the process's benefits, REM is slowly winning the industry over. Whether the process will also become a commonly sought out solution for oil-out durability in gears remains to be seen, as REM certainly has a number of contenders to compete with. We're still far out from seeing a new de facto standard for oil-out durability in gears, with most current studies still in their planning stages, but going forward, it's going to be important to keep an eye on which processes perform best in those tests. The aerospace industry as a whole certainly will.

For more information:

Gear Research Institute
Phone: (814) 865-5832
www.gearresearch.org

REM Surface Engineering
Phone: (860) 621-6755
www.remchem.com

For Related Articles Search
loss-of-lubrication
at www.geartechnology.com