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Surface finish improvement for gear and bearing system gains

As demand for higher performance and more efficient gearboxes and drivetrains — especially in electric vehicles — continues to grow, broader system-based improvements using advanced manufacturing processes will be required. One area with potential to improve gearbox and drivetrain performance without requiring substantial redesign efforts is gear (and bearing) surface properties.

In many gearboxes, the gears and bearings share a common lubrication system. Leaving to the side greased applications, these lubrication systems typically use a simple oil bath/splash method or, for more demanding applications, forced/spray lubrication. In both of these "oil" based systems, gearbox designers and/or end users have to choose a single lubricant for both the gears and the bearings. This choice may lead to compromises in the overall system performance and individual component performance/life.

Oil or synthetic lubricants serve many purposes in a gearbox, including the dissipation of heat, preventing corrosion, reducing noise, and providing some shock-load protection. However, arguably, their primary purpose is to reduce friction and wear by providing some level of film separation between mating gears and, separately, bearings components. While higher viscosity lubricants provide more film separation, they also cause higher drag/churning losses [1]. These drag/churning losses are exacerbated at higher operating speeds for gears and bearings [2]. Thus, it would be beneficial to reduce the lubricant viscosity in order to improve gearbox efficiency; but by reducing lubricant viscosity, the potential risk of mixed or boundary film lubrication for the gears is increased unless composite roughness can be otherwise reduced.

REM previously discussed the potential for isotropic superfinishing processes (such as REM's ISF® Process) to drastically reduce the surface roughness of machined components such as gears while modifying the surface texture to a non-directional pattern. These surfaces commonly achieve roughness values of Ra <0.1 µm/4 µin [3] [4] and offer significant performance benefits for gears including resistance to contact fatigue, micropitting [5], and scuffing [6]. While machining methods such as fine or polish grinding can also reduce surface roughness, they generally result in higher roughness values (0.15 µm Ra [7] or greater). Moreover, the texture of these (and all) ground/machined surfaces will be fundamentally directional (rather than isotropic), and in almost all cases, the directionality of the remaining surface texture will be such that the residual peak (or perhaps plateau) and valley features will be perpendicular to the rolling and/or sliding motion of the gears. This directional texture, while greatly improved as compared to standard grinding processes, is still less than optimal when considering contact fatigue and scuffing risks. However, for the purpose of improving film separation and enabling lower viscosity lubricant usage, these finely machined surfaces may prove adequate, but safety factors for the gear system must be considered as Ra values alone may not adequately predict gear life.

Returning to the above referenced premise, if lubricant viscosity can be reduced, thereby improving gear efficiency, while also reducing gear flank roughness/composite roughness, a lambda ratio can be maintained to ensure full film separation. The reduced composite roughness will have the additional benefit of reducing friction between the mating gears, further increasing gear efficiency; in 2007, General Motors, in a study with The Ohio State University, found that isotropically superfinished spur gears showed an approximately 17 percent increase in efficiency as compared to standard ground gears in both course and fine pitch applications.[8] These conclusions are all generally logical and straightforward. However, beyond the somewhat obvious gear benefits of combining an isotropic superfinishing (or other roughness reducing operation step) with a lower viscosity lubricant, additional benefits can be obtained relative to the gearbox or system bearings, but there are also potential concerns and barriers that must be overcome.

In many gearboxes, the contact speeds of the gears will be higher than the contact speeds of the bearings. Certainly, this is not the case for all bearings, but it is a reality that must be considered if lower viscosity lubricants are being proposed in conjunction with superfinished/isotropically superfinished gears for efficiency gains.





Given this lower contact speed in the bearings and, derivatively, the lower entrainment speed for the lubricant, coupled with the generally higher Hertzian pressures that the bearings experience, there is a higher risk of mixed or boundary lubrication regimes in the bearings. As bearings generally have very low surface roughness already, the application of an isotropic superfinishing process or the like, while in some cases still beneficial, does not have the same potential to address this potential mixed/boundary lubrication dynamic and the associated contact fatigue issues. Thus, without an alternative solution, the potential to increase gearbox efficiency by reducing gear roughness and lubricant viscosity is limited and/or would require a more complex redesign to the overall gearbox; perhaps a separate, additional lubricant system for the bearings could be proposed, but this modification would almost assuredly negate some or all of the benefits of the increased gear efficiency due to an increase in gearbox weight.

Luckily, there are alternative solutions that are worth considering — coatings, specifically diamond-like carbon (DLC) coatings. DLC coatings have been studied since the 1970s and they have been commonly used in bearing applications since the early to mid-2000s. DLC coatings, assuming adequate adhesion properties, can offer significant benefits for rolling and sliding bearing applications where lubricant conditions may be compromised given the extremely high hardness (well above 70 HRC) and extremely low coefficient of friction of the coating. Thus, DLC coatings offer additional safety factors for the bearings in the event lower viscosity lubricants are used and film thickness becomes a concern.

In conclusion, in order to increase the efficiency of gearboxes beyond current standards, broader, system-based optimizations may be necessary. The complex interactions between the gears and bearings of high-speed gearboxes require careful consideration. Potential efficiency gains can be found from a combined approach of reducing the roughness on the gears to increase efficiency and to allow for the use of a lower viscosity lubricant further increasing efficiency by reducing drag losses. However, the impact on the bearings must be considered, and potentially using a DLC coating on said bearings to address contact fatigue or other risks may be required. A large advantage of such an approach is that isotropic superfinishing and DLC coating can generally be applied to existing gear and bearing designs given how little material they are taking away or adding. As such, they represent an "easy" option to implement without requiring a costly redesign effort.

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