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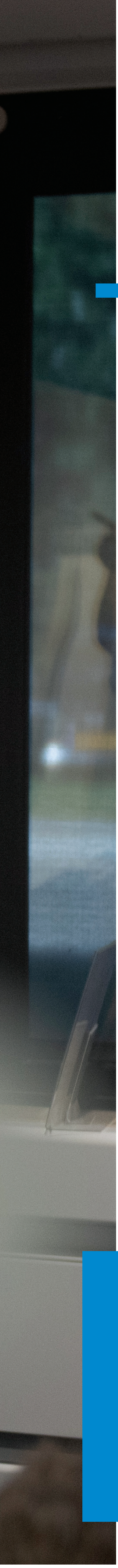

The deep science of imperfect surfaces

SKF principal scientist Guillermo Morales-Espejel was the driving force behind a radical new approach to bearing life prediction, which has important implications for design engineers, equipment makers, and end users.

The role of fatigue in bearing life is something engineers have known for a long time, but the development of models that could account for that fatigue has taken generations. "You can't predict bearing life in a deterministic way," says Guillermo Morales, Principal Scientist at SKF. "You have to combine statistics with physics to make useful predictions."

The first models that took this combined approach to bearing life prediction were published in the mid-20th century, with SKF scientists at the forefront of their development. "Those early papers introduced basic concepts that we still use today," says Morales. "Things like the difference between the static and dynamic capacity of a bearing."

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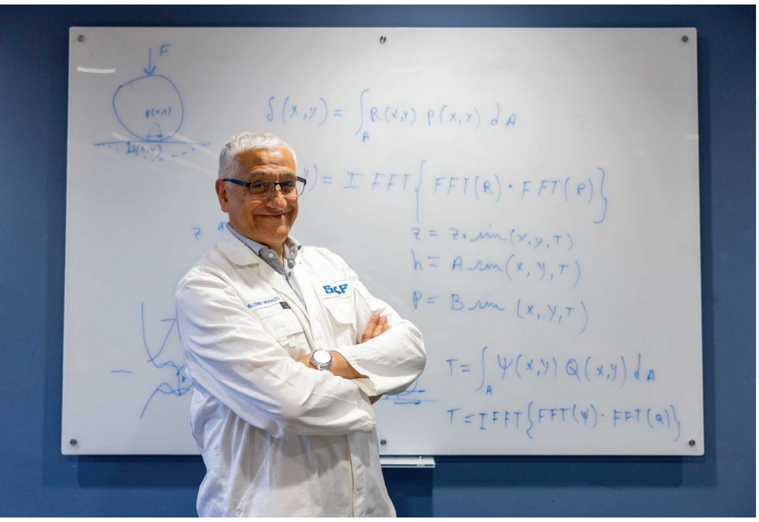

Prediction at the limit

Over the next 50 years, advances in theoretical understanding and practical experience, paved the way for more sophisticated models. In the 1980s, for example, engineers figured out how to account for the fatigue limit in predicting bearing life - a stress level below which very little fatigue accumulates in the material.

"All these 20th century models were based mainly on subsurface fatigue," Morales explains. “But thanks to advances in manufacturing technology, such as the introduction of very clean steels, the subsurface fatigue challenge has been largely solved.” Today, most bearing failures are triggered by a problem on the surface, such as including poor lubrication, contamination, frictional heat, or electrical damage.

And the surface was something Guillermo Morales knew a lot about. After earning bachelor's and master's degrees in mechanical engineering in his native Mexico, he traveled to the University of Cambridge, UK, to pursue a Ph.D. in tribology: the science of friction, lubrication, and wear.

"My Ph.D. work was trying to model the effect and behavior of roughness in lubricated contacts," he says. "In tribology, 'roughness' is a general way of describing any microgeometric feature. It can be a scratch, an indentation, or a texture on the surface." Such surface patterns are a headache for tribologists because they disrupt the thin films of lubricant that allow mechanical components to move smoothly over long periods of time.

But roughness is difficult to model. "People used to do numerical work to model roughness," recalls Morales, "but it's a very hard, time-consuming problem for a computer. You need a system of five equations with five unknowns distributed in time and space."

The key to Morales' dissertation was to find a simpler, faster way to tackle the complex mathematics of roughness. He did so by breaking it down into sinusoidal "waves". This dramatically simplified the calculations required, while still allowing any type of surface imperfection to be modeled as a collection of different waves.

Morales joined SKF’s research laboratory in January 2000 and immediately began to study the impact of surface issues in bearings. One early project simulated bearing performance in mixed lubrication environments, where contamination or lack of lubricant creates areas of direct metal-to-metal contact within a bearing. Another evaluated the effect on bearing life of the small indentations that can occur if a bearing is mishandled during manufacturing, shipping, or assembly.

Time to generalize

Fast forward a few years, Morales and his colleagues were successfully applying mixed lubrication and surface damage models to a wide range of problems within SKF and for its customers. In 2012, a new technical director approached Morales with a bigger challenge. "He said our bearing life models were useful, but they were too rigid," recalls Morales. "It takes too much effort to adapt the model to a different problem or to integrate new knowledge."

The technical director's request was simple, but daunting. Could Morales and his team take what they had learned about the effect of surface conditions on

bearing life and build a general-purpose model that would better predict bearing life in the real world?

Their answer to this challenge was two years in the making. "We already had some of the key ingredients," says Morales. "To build a general-purpose bearing life prediction model, you have to simulate the operation of different bearings, under different conditions, over millions of cycles. Without a fast solver, that would have been impossible."

Other parts of the model required the team to break new ground. In particular, Morales says, they had to develop an approach that combined their new surface damage models with traditional methods for estimating subsurface fatigue.

One model, many solutions

The first iteration of the SKF Generalized Bearing Life Model (GBLM) for conventional steel bearings was introduced as a concept to customers at the 2015 Hannover Messe. It offered the promise of an immediate solution to many challenges faced by design engineers every day. "With a better life prediction model, you can design better machines," says Morales. "Our model helps designers select the optimal size and type of bearing for their application, and allows companies to provide more reliable advice on maintenance and replacement intervals." The result is more efficient use of resources, with fewer breakdowns and less premature replacement of parts that still have life left in them.

Over the past decade, Morales and his colleagues have expanded the GBLM to include new types of bearings, notably adding models for the hybrid bearings now used in demanding applications ranging from turbomachinery to electric vehicle transmissions. They have also updated the approach to reflect ongoing improvements in conventional bearing technology, including new steels, and better heat treatment techniques.

GBLM is also helping SKF respond to other major industry trends. For example, as companies look for ways to further reduce their consumption of resources, users are increasingly turning to remanufacturing to extend the life of large bearings. The GBLM helps these users make informed decisions about remanufacturing intervals based on the likely rate at which surface damage will accumulate in their applications.

Is there more to come? As principal scientist, Guillermo Morales now has much more on his plate than bearing life models, but he maintains a strong interest in the development of the GBLM. "We have developed a flexible and extensible way to model different bearings, operating conditions and failure modes," he says, "but all such models need to be validated with data from experiments and tests. Advanced sensors are now giving us better insight into the conditions inside our bearings, and these insights will help us extend and improve our modeling approach.