TKK Science Award in Technological Sciences

Can Friction Disappear?

By YAN Fusheng (Staff Reporter)

CAS Member Prof. LUO Jianbin, distinguished tribologist and dean of the School of Mechanical Engineering, Tsinghua University

The 2020 TKK Science Award in Technological Sciences went to CAS Member Prof. LUO Jianbin for his contribution to tribology, particularly in the field of nano-tribology and nano-fabrication.

Friction is the reason why automobiles can move when we press on the gas, and stop as we hit the brake. However, friction also accounts for, reportedly, one third of the fuel consumption in automobiles, which ends up in energy dissipation, and friction-caused wear significantly reduces the lifetime of mechanical parts. Finding ways to reduce friction and wear, and even make them disappear is thereby persistently pursued by scientists to save costs and improve industrial safety.

Lubrication, traditionally by ways of oiling mechanical parts, is an important way to reduce friction and wear. Lubricating oils, though vary in composition, are globally used to do the same trick by forming a film in-between to prevent solid contact. Nowadays, oil-based lubricants can lower the friction coefficient down to about 0.04 and it becomes quite hard to make this number any smaller, not to say by one order of magnitude smaller. Besides, the viscosity of oils changes over pressure, imposing an unstable factor to the outcome of lubrication.

To obtain an ultra-low friction, LUO's group resorts to water-based lubricants, because the viscosity of water-based lubricants hardly changes over pressure and the water has excellent fluidity even under high pressures. These two properties provide the favorable conditions to achieve "superlubricity", a lubricating state in which friction almost vanishes completely because friction coefficient would decrease by one order or even several orders of magnitude compared with that of normal lubricating oils. Practically, superlubricity is said to be achieved when the friction coefficient is at 10^{-3} level or less. Under the state of superlubricity, the wear rate would plummet accordingly.

Compared with solid superlubricity obtained mainly at the nanoscale, liquid superlubricity has gained more attention due to its practical potential for macroscopic uses. Through decades of explorations, LUO and his coworkers have achieved superlubricity using many different liquids as lubricants.

Back in 2011, they found that phosphoric acid (H_3PO_4) was able to form a solid-like film between two rubbing surfaces, which enables an ultra-low friction coefficient of about 0.004. They also revealed that the ultra-low friction is associated with the film of a hydrogen-bonded network formed by H_3PO_4 and H_2O. Based on the experimental results, they also proposed a 'sandwich-like' structure – two hydrogen bonded layers with a free layer of water in the middle – to explain how superlubricity occurs.

They then discovered many other liquid mixtures that could lead to superlubricity. By looking into these lubrication systems at the levels of macroscale and nanoscale, LUO and his coworkers built up an evolving model of liquid superlubricity. They reckon that the origin of liquid superlubricity can usually be attributed to a synergistic effect among different factors, including absorption, tribochemical reaction, and formation of various layers, and the mechanism of liquid superlubricity can be attributed to hydration force, electric double layer force, and hydrodynamic effects. More importantly, they have been successful in increasing the contact pressure capacity of liquid superlubricity state to 1.2 GPa.

Notably, LUO and his coworkers successfully achieved ultra-low friction coefficients of 0.0003 and 0.00004 for liquid and solid lubricants respectively, which are about two orders of magnitude lower than that of normal oil-based lubricants.

Apart from discovering various superlubricity systems, LUO and his coworkers developed a special instrument for measuring the nanoscale lubrication film thickness. Based on experimental results obtained using this new instrument, they proposed the physical model of molecular film lubrication and established the thin film lubrication theory. Moreover, they also successfully measured the motion state and velocity distribution of nanoparticles in liquid, and revealed the behavior of nanoparticles in liquid as well as the mechanism for the interactions between nanoparticles and solid surface. LUO's group also reported the first direct observation of the convective Marangoni flow in evaporating water droplets by using fluorescent nanoparticles as tracer particles, settling down a long-lasting dubious conjecture. They also proposed a new criterion for reversal of thermal Marangoni flow in drying drops and applied such knowledge in fabricating ultra-smooth wafers (Ra 0.05 nm) with greatly reduced residual particles attached to the surface.

"…superlubricity is still under laboratory research," wrote LUO in one review paper. However, LUO reckons that "superlubricitive engineering" – the idea of applying superlubricitive technology to gearboxes, bearings, slideways, pumps, hydraulic components, and sealing parts across industries related to transportation, fluid machinery, manufacturing, space technologies, and renewable energy – is the right path to make future industry more energy-saving and greener.

The big question goes to how can we transform these scientific discoveries into real applications.

"Practically, the key to apply superlubricitive technology to real industry lies in our ability to balance two contradicting ends. On the one hand, we need to lower intermolecular interactions to achieve superlubricity; on the other, a relatively stronger intermolecular interaction is required to prevent the lubricants from being squeezed out of the contact region," shared Prof. LUO in a public talk, "a near-zero friction in real applications thereby relies on the revealing of new superlubricity mechanisms that help us finding the balancing point."