

Active Control of Friction Coefficient with Electro-sensitive Biolubricants

Relevant for: **Electro-tribology, Electro-active control, Smart Lubrication, Tribotronics**

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The electro-active control of friction is an incipient area of growing interest, and one of the greatest challenges of Tribology. At present, one of the most promising technological innovations in lubrication is linked to the use of electro-rheological (ER) fluids. These “smart materials” allow instant and on-demand control of their friction behavior through the application of an electric potential. The development of a new generation of instruments aimed to their comprehensive tribological characterization under external electric fields is yet to be explored.



1 Introduction

Current technological strategies developed by the lubricants industry are mainly oriented towards sophisticated formulations capable of reducing energy consumption and extending the useful life of mechanical elements.

Even so, all these advances have only supposed a mere “passive” control of lubrication. Thereby, it continues to be very sensitive to sudden changes in operating conditions, such as vibrations or starting and stopping times, and to wear.

In turn, the use of electro-rheological (ER) fluids constituted by polarizable nanoparticles suspended in

a non-conductive oil enables an “active” control of the lubrication process (1). The so-called “electro-viscous” effect arises from the orientation and arrangement of polarized particles into organized columnar structures when subjected to an electric field (Figure 1). Hence, its contribution to lubrication is twofold: i) on-demand control of friction coefficient in order to optimally dampen friction perturbations; ii) enhanced load carrying capacity of the lubricant film to withstand heavier loads.

Consequently, the above technological innovation goes far beyond the mere formulation of a lubricating oil with a specific viscosity or the traditional lubricating grease based on mineral/synthetic oil and a metallic soap thickener. The incorporation of electro-active nanoparticles to a base oil may enable, in the presence of an electric field, to adapt the lubricity of the same lubricant to changing working conditions.

In this sense, experimental prototypes which allow an adequate tribological characterization of ER fluids under electric potentials result to be of prime importance. They may assist in the development of active lubricants and may help to elucidate the different mechanisms involved in their lubrication process under such condition. However, to date, commercially available measuring cells of this type are practically non-existent.

Based on all above ideas, this report presents a cutting-edge technology designed by Anton Paar in collaboration with the University of Huelva (Spain) for the precise control of friction coefficient (COF) through electro-sensitive fluids under controlled electric potentials. Such a prototype is based on a ball-on-three-plates configuration (T-PTD 200 tribology cell), a well-established method to analyze lubricant performance. When coupled to an Anton Paar MCR

rheometer, measurements can be developed within a wide range of load, sliding speed, temperature and electric potential.

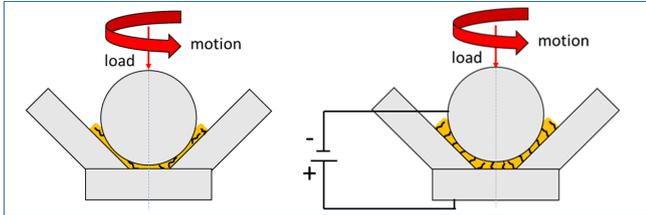


Figure 1: Schematic of the proposed lubrication mechanism (in a ball-on-three-plates setup) based on the so-called "electro-viscous" effect triggered by an electric field.

2 Experimental

2.1 The Electro-tribology Cell

Electro-tribological tests were carried out on the MCR tribometer from Anton Paar. The rheometer was equipped with a special ball-on-three-plates configuration, as shown in Figure 2.

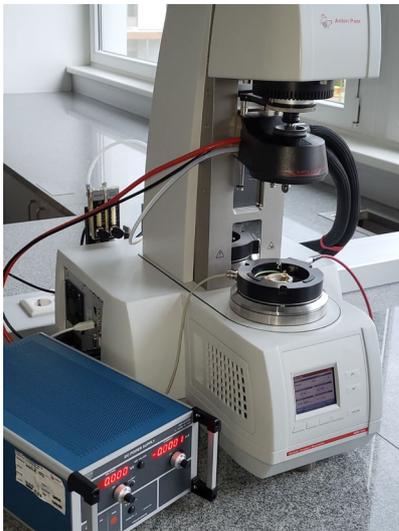


Figure 2: Anton Paar MCR tribometer, featured with a special ball-on-three-plates configuration for electro-tribological characterization, and external high voltage supply.

This new measuring cell combines features of two existing Anton Paar devices: i) the ERD electro-rheological device; ii) the T-PTD 200 tribology cell. Thereby, the resulting instrument allows measuring the influence of a defined electric potential on the friction behavior of an ER fluid, whilst ensuring precise alignment and therefore a homogeneous distribution of normal forces on the measured samples. Temperature is controlled with a Peltier system (the H-PTD 200 hood is suitably adapted). The electric potential strength can be varied, through the Anton

Paar RheoCompass software using an external high voltage supply, up to a maximum voltage of 12.5 kVDC. A special ceramic isolated shaft holds the ball, in such a way that damage by electric shock is prevented up to 4 kVDC. The upper shaft is electrified by means of a metal spring contact, whilst each plate is in contact with an electrified gold pin (see Figure 3 Right).

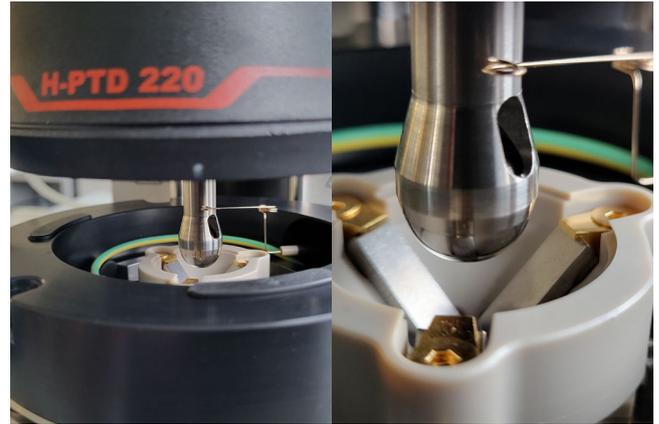


Figure 3: **Left.** Special tribology cell configuration for electro-tribological characterization including ball-on-three-plates setup, adapted hood and ceramic isolated shaft. **Right.** Detailed view of the ball-on-three-plates setup.

2.2 The ER Fluid

The fluid, having a Newtonian viscosity of about 1 Pa·s at 25 °C, consisted of a dispersion of polarizable nanoparticles in vegetable oil. The fluid demonstrated a very high electro-rheological performance, as denoted by a yield stress value in the vicinity of 100 Pa at 4 kV/mm, at 25 °C (3). Broadband dielectric spectroscopy measurements allowed concluding on the interfacial (Maxwell-Wagner) polarization as the origin of its ER capability (4).



Figure 4: Optical microscopy visualization. **Left.** No electric field. **Right.** Under an electric field of 0.4 kV/mm

A proof of its electro-active potential is provided in Figure 4. The torque on the polarized rod-like particles placed in a uniform electric field yielded the formation of strings that bridged the electrodes between which the fluid was confined.

2.3 The Test Protocols

Time evolution of friction coefficient was performed, at 25 °C, at specified values of rotational speed and load, 40 rpm and 3 N, respectively. Voltage profiles are displayed in Table 1. Tests were preferably conducted within the so-called mixed lubrication regime. Such regime is characterized by two solid surfaces which are not fully separated by the fluid film and some contact of asperities occurs, along with resultant wear (2). Fully flooded conditions were always used in order to ensure good lubrication and better reproducibility.

Tests	Voltage Program
Type 1 (Figure 5)	Constant value: 0 V and 90 V
Type 2 (Figure 6)	Tooth profile: 90-0-90-0-90-0 V

Table 1: Voltage profiles, for time-dependent tests of friction coefficient, at 40 rpm and 3 N

3 Results and Discussion

Under mixed lubrication, characterized by some contact of asperities, the lubricant viscosity needs to be increased in order to avoid wear. Obviously, it entails larger values of friction coefficient.

The lubrication mechanism of the ER fluid studied is as follows. The nanoparticles fall into the area of action of the electric field. Thus, the surrounding oil-wetted nanoparticles are forced to concentrate at and around the zone where the electric field strength is the highest, i.e., the ball-plate contact point. The electrical stimulus triggers the structuring of the internal morphology of the lubricant film. It consists in interfacial polarization of particles, accumulation at the contact point and subsequent arrangement into strings. The nanoparticles shield the oil from leaking, thereby enhancing fully flooded lubrication.

Based on that, Figure 5 displays the variation of friction coefficient with time, at a rotational speed of 40 rpm and a load of 3 N. In the absence of voltage, and after an initial decay due to lubricant conditioning, COF was seen to level off at 0.065, followed by a mild increase up to 0.07 over the last 10 minutes. When the same test was performed at 90 V, friction coefficient initially reached a value of nearly 0.085, i.e., an enhancement of 42 %. This fact can be attributed to an increase in the lubricant dynamic viscosity due to the above mentioned electro-viscous effect upon internal structuring. With time, friction

coefficient was seen to monotonously drop down and converge to the off-field value after 30 minutes.

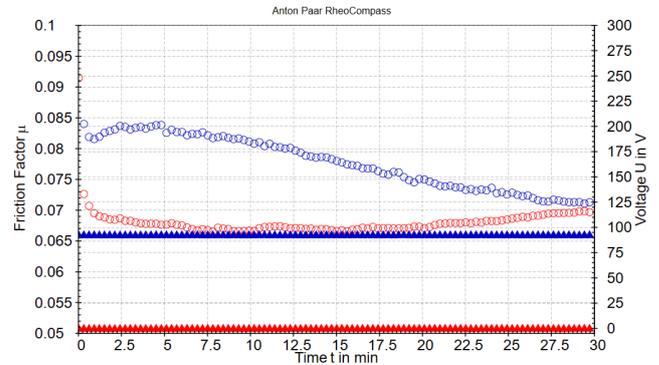


Figure 5: Time evolution of friction coefficient, at 0 V (red) and under an electric potential of 90 V (blue). **Left axis.** Friction factor (empty circles). **Right axis.** Voltage, in volts (solid triangles)

It is noteworthy that the electro-active control depicted in Figure 5 stands for a unique opportunity to accommodate optimally varying operating conditions. For the sake of looking further into the issue, Figure 6 exemplifies how the new electro-tribology cell enabled friction coefficient to be actively adjusted on demand. When an electric potential of 90 V was initially imposed, a COF value of 0.093-0.084 was observed. In average, such value coincides with that corresponding to the first 5 minutes in the blue curve in Figure 5. The effect was reversed when the external stimulus that produced the morphology change within the lubricant film, i.e., electric potential, ceased. Even so, friction coefficient did not drop down to its original off-field value of 0.065 (red curve in Figure 5), but just to 0.075.

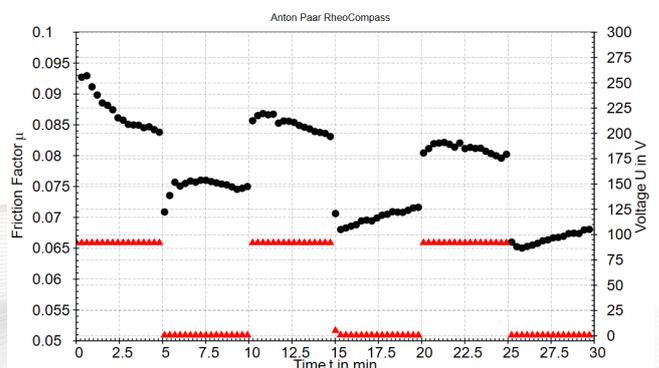


Figure 6: Time evolution of friction coefficient, during a voltage program of 90-0-90-0-90-0 V. **Left axis.** Friction factor (black circles). **Right axis.** Voltage, in volts (red triangles)

The reason may be twofold: i) the particles seemed to partially retain their polarization state (5); ii) a larger particles concentration at the zone with the highest electric field strength, i.e., the contact point. Moreover,

the magnitude of the electro-viscous effect seemed to diminish at every new 0 V / 90 V cycle.

4 Summary

This new measuring prototype has been proven successful in evaluating active control of friction through the application of an electric potential in a ball-on-three-plates configuration. As shown by tests developed on the new electro-tribology cell, the electric potential seems to have contributed to the formation of structures which enhanced the load carrying capacity of the lubricant film. This is a consequence of the so-called “electro-viscous” effect. Hence, the “smart lubricant” enabled an “on demand” control of friction coefficient under the presence of an external electric field. These promising results leave the door open to a new concept of tribological characterization.

5 References

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