Fun with rheometers: Unconventional applications beyond standard shear rheology

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Rotational rheometers with their ability to perform measurements under well-defined flow conditions, have become the primary technique for fully characterizing the flow and deformation behavior of viscoelastic fluids and solids. The use of many different standard and advanced test modes, as well as the development of special environmental and accessories systems, have vastly expanded the application range of such instruments to cover almost all rheological aspects in research, development, and quality control of all types of liquids and solids.

The addition of a second rotational motor in the adds new capabilities such as counter- or co-rotation. While counter-rotation is already more established, e.g., for generating a stagnation plane in rheo-microscopy, co-rotation has been successfully employed to generate a shear flow in fast rotating samples for rheo-X-ray tomography, producing time-resolved 3D images under shear[1]. Another rather unconventional application is the measurement of stick-slip behavior in mechanical contacts by developing a so-called slip-stick mode. Here, the lower motor rotates at a certain speed and the upper motor mimics a mechanical spring, i.e., a recoil torque is applied that is proportional to the deflection angle. When the contact "sticks" the friction deflect the upper part of the contact until the force exceeds a certain value and it "slips" back to its initial position, then the process starts again. Since the spring is not mechanical, the spring constant can be easily changed via software, making the setup a versatile stick-slip tester. An initial example was characterizing the stick-slip behavior of coatings for touch displays, where the results correlated well with haptic sensation.

With a linear motor in the bottom of the rheometer, in addition to standard dynamic mechanical analysis (DMA) on solids, a relatively simple determination of Possion's ratio of solids as well as orthogonal superposition rheology on liquids and semi-solids is possible in combination with the upper rotational drive. The linear motor has been used to determine the pressing and break-away forces of medical syringes and, in combination with a fast visualization setup, for capillary breakup rheometry.

The motor of a modern rotational rheometer allows the control and measurements of angle, rotational speed and torque in a wide range and with highest accuracy. This led to the idea of using a rheometer for metrological purposes, such as sensitive torque measurements. By using various specially designed holding mechanisms it has been possible to study: 1. Cogging and hysteresis torque and iron loss determination of sub-fractional horsepower motors[2]; 2. Torque in mechanical counters; 3. Torque in clockworks of mechanical watches; 4. Spring constants in tiny springs as those used in watches; 5. Friction behavior of small ball bearings and sealing O-rings; 6. Friction and wear behavior of textile threads; 7. Torsional strength of nanocarbon fibers and microwires.

The examples discussed illustrate that a modern rotational rheometer is not only suitable for standard shear rheology, but that many new, unusual applications can be tackled.

[1] S. Gstöhl, PhD thesis, ETH-Zürich; Diss. ETH No. 27103 (2020).
[2] S. Leitner, et al., IEEE Transactions on Industry applications 56(4), 3679 (2020).