Tuning fork rheometer to measure fluid rheological properties for industrial measurement applications

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Though the rheological properties of the complex fluids used across various industries have major impacts on the efficiency of their processes/operations, many of the currently used practices for monitoring these properties are time-consuming and reliant on manual measurements. As such, continuous monitoring of these fluid properties is an excellent candidate for automation to improve operational efficiency. Here, we propose a method of obtaining more accurate, automated rheological measurements of these complex fluids using a tuning fork-based sensor capable of monitoring properties like the complex viscosity.

These tuning forks are comprised of slender beams with lengths of several millimeters machined on the flexible diaphragm of a resonating cup and actuated internally by a piezoelectric stack at the base of the beam pair. An oscillating voltage is applied to the piezoelectric stacks, which then induces an oscillation of the tuning fork beams, allowing to obtain the resonant response of the system through a frequency sweep. The amplitude of the motion was measured both optically and by detection of the induced current on the stack when going through the resonance. A phase-sensitive detection scheme was used to demodulate the two signals simultaneously. In order to obtain accurate rheological measurements at the resonant frequency of the fluid-beam assembly, the system is modeled using the well-known analysis of a cantilever beam in a viscous fluid presented originally by Sader[1], with further modifications described by Maali and coworkers[2] and the adaptation for viscoelastic fluids developed by Lemaire and coworkerss[3]. This model enables calculation of the complex viscosity based on the observed deflection of the cantilever beam immersed in the fluid in response to the sinusoidal forcing function. We explore further refinements of the model, including a method for fitting key rheological parameters of this coupled fluid-solid system model to ensure accuracy, and demonstrate the use of the tuning fork rheometer by measuring the rheological properties of several Newtonian and complex fluids.

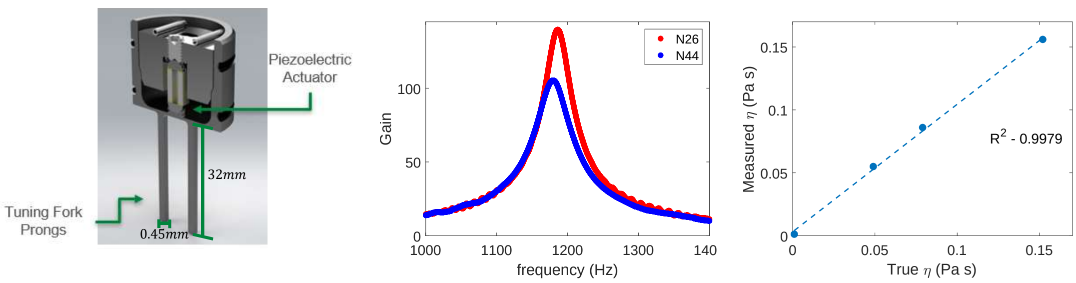

Figure 1: (a) Rendering of the tuning-fork rheometer. (b) Measured resonance curves for the tuning fork rheometer in two Newtonian fluids. As fluid viscosity increases, the resonance peak flattens and broadens. (c) Parity plot showing measured viscosity vs known viscosity for four Newtonian fluids.

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