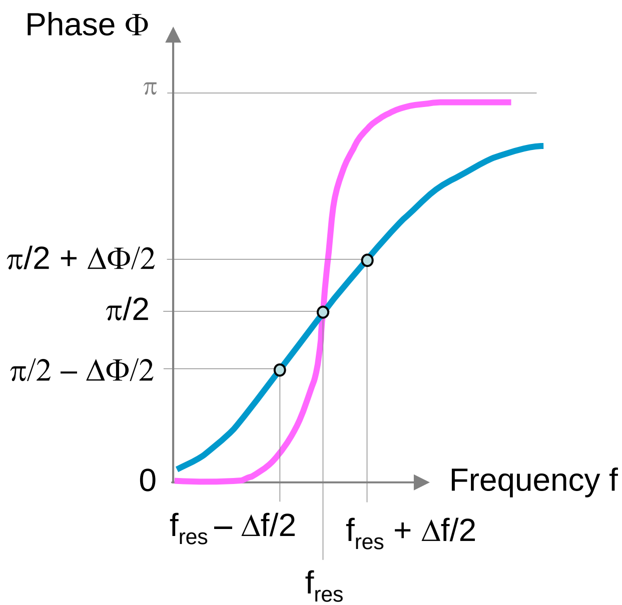
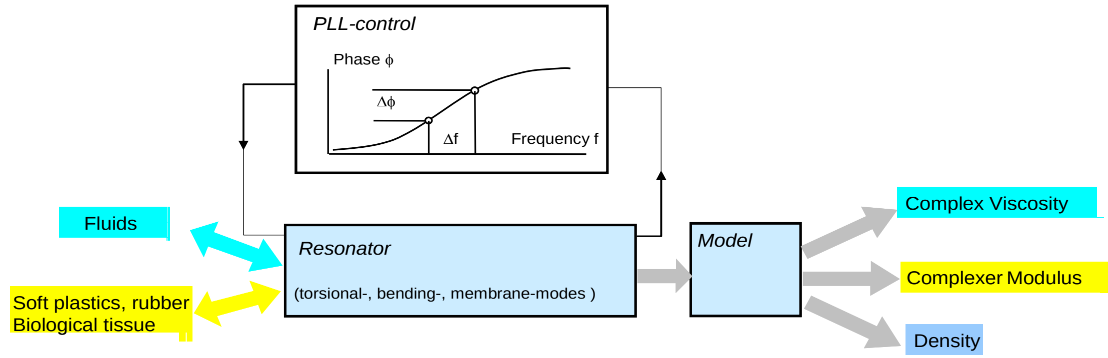
# Principle of Measurement

A mechanical resonator is characterized by its resonance frequency and the damping or Q-factor. If a resonator is brought into contact with a fluid or solid medium both resonance frequency and damping are changed.

For a fluid the motion of the resonator induces a sinusoidal shear in the fluid, therefore the damping is increased due to the viscous shear stress acting on the resonator.




Phase shift vs. excitation frequency for different damping values.



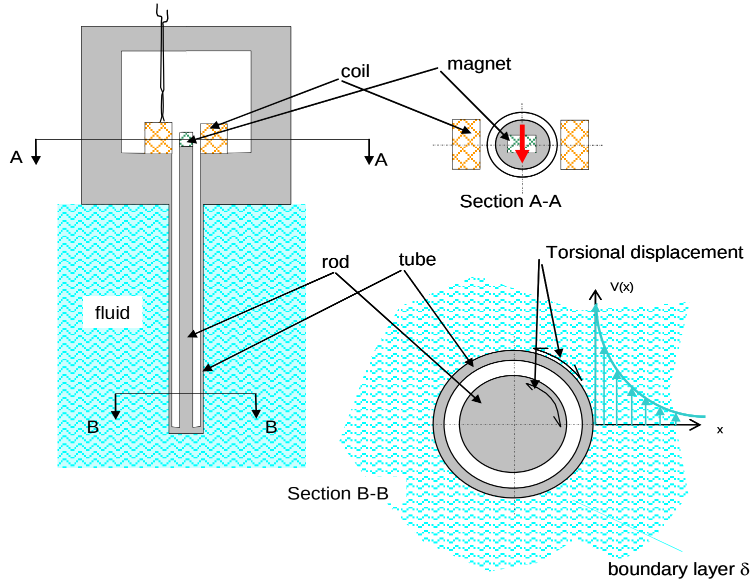

Schematics of resonator control

Using a PLL-control to drive the resonator, its damping can be determined from the slope of the phase curve near the resonance with great accuracy and stability. Modeling the fluid motion the vicinity of the resonator, i.e. the shear stress acting on it, the viscosity of the fluid can be determined from the damping of the resonator. The slope $\Delta f/\Delta\Phi$ of phase curve near resonance is a measure of damping. The viscosity is given by: Viscosity = const. $\Delta f^{2}$

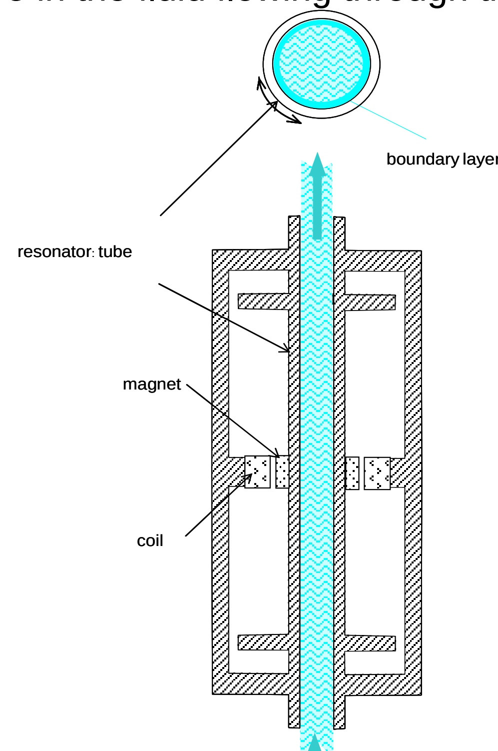
# Basic configurations

The schematic on the left side shows a *dip-in* or *rod-type* probe. A rod is excited on one end electromagnetically in torsion. The other end of the rod is attached to a tube exciting it in a torsional mode. This assembly is plunged into the fluid sample.

On the right side a *flow-through or tube-type* of probe is shown. A tube is excited at the center in a torsional mode inducing a standing shear wave in the fluid flowing through the tube.




V(x) fluid velocity: decays exponentially with distance x from wall :
Boundary layer: δ = Sqrt(viscosity/ (Pi frequency density))




Surface loading probes actually measure a thin fluid film, whose thickness equals the penetration depth d of the viscous shear wave, which is a function of viscosity and frequency.

d = 5.5 Microns for water at 20°C and 10kHz.

# Characteristics of the Dynamic Viscometer

As shown in the schematics we use the same transducer for both excitation and sensing. This is possible because the resonator is driven in an intermittent mode of excitation and sensing. The advantage of this mode of operation is twofold:

- (i) absence of crosstalk between excitation and sensing transducers
- (ii) it is possible to miniaturize the resonator design

Main characteristics of the our Dynamic Viscometer:

- Frequency: 200 Hz to 40 kHz (design)
- Frequency stability and resolution: 0.01 Hz (design)
- Q-factor: 5000 - 10 000 depending on design
- Measurement cycle < 5 s
- Robust operation: compared to other existing oscillating viscometers our system is insensitive against environmental shocks and vibrations.
- Temperature range: -20° to 200 °C
- Non-destructive measurement: displacement amplitudes at the wall in contact with the medium: 0.05 to 2 Micrometers

# Process Viscometer

The technology using a resonator controlled in a specific manner to measure the characteristics of a oscillator is patented (US Pat. No. 4920787, EU Pat. No. 749 570 B1).

A rod-type of resonator (AST 100) for applications in the field of industrial fluid process control and monitoring is at the present time manufactured and sold under a license agreement by Brookfield Engineering Laboratories, Middleboro, Mass. U.S.A.

Prototypes of rod-type and tube-type probes have been used in number of applications by:

- NESTLÉ, food processing, pilot plant, Beauvais (F),
- DANONE, food processing, pilot plant, Ochsenfurt (D)
- DOW, paper coating, pilot plant, Horgen (CH)
- INFINEON, monitoring of photo lacquer, Dresden (D)
- BASF, monitoring of polymer solutions, Friedrichshafen (D)