SV-10 Sine wave Vibro Viscometer

New Viscosity Measurement Instrument

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This report presents an overview of our new viscometer, SV-10. This instrument is designed to measure the viscosity of liquids and, as a result of an advanced new technology, provides accuracy and performance not normally found with other devices of this nature.

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The SV-10 utilizes a whole new concept in the method of measuring viscosity, employing a tuning forks vibration system as a detector. It is designed to measure the viscosity of fluids in either a stationary or flowing state and is used in both laboratory and process control applications.

The SV-10 is designed so that a pair of plate springs with a sensitive plate mounted on the end is subjected to a resonance vibration in reverse phase, at a constant frequency, to detect a difference in viscous resistance generated between the sensitive plates inserted in the sample and the sample as a vibration of the driving current. The drive current is proportional to the viscosity resistance. Calibration is accomplished by using a liquid of standard viscosity and the measurement is stored in memory. The viscosity of a sample can be obtained by measuring the drive current for constant amplitude at the plate springs.

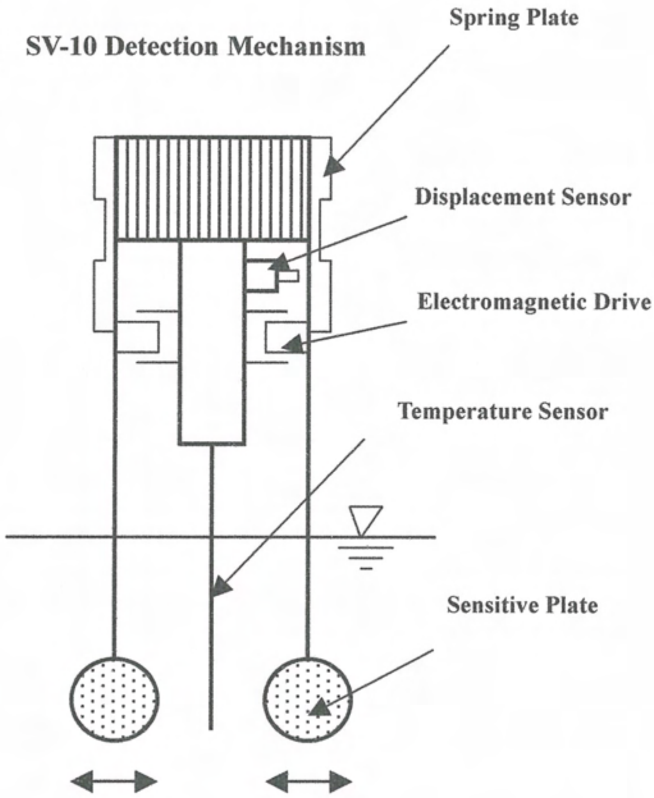
Measurement Principle

The specific feature of SV-10 is to employ a tuning fork vibration technology and a resonance feature for sensors. This feature removes the repulsive force to the main frame generated during measurement and thus stabilizes the sine-wave vibration. Consequently, high accurate viscosity measurement can be conducted.

Figure-1 shows the viscosity detection mechanism of SV-10. The operation is briefly described as follows;

1. A pair of plate springs with a sensitive plate mounted on the end is vibrated at a resonance frequency in reverse phase at 30Hz.
2. The difference in the viscous drag generated between the sensitive plates and samples is detected as the budget of the driving current, which is necessary to maintain constant amplitude.
3. The viscosity of samples is calculated by using the proportional relation between the driving current and the viscous resistance.

Figure-1   SV-10 Detection Mechanism



Vibration in a free vibrating system will decay as viscous drag energy vanishes, but if a driving force is applied to the system from outside, it can be sustained with constant amplitude.
For a system vibrating under a driving force F=F0 sin ωt, the following kinetic equation generally holds in a viscous damping vibration system of 1 degree of freedom.

$$F = m \cdot d^2x/dt^2 + C \cdot dx/dt + K \cdot X \quad \textit{(Equation 1)}$$

Where, $m \cdot d^2x/dt^2$: inertial force of vibration
$C \cdot dx/dt$: viscous damping force
$K \cdot X$: righting force of spring

When resonated, such system will vibrate continuously with the amplitude determined by viscous drag as long as forced vibration is applied to the system from the exterior, because inertial and righting forces are well balanced with each other. The amplitude is given by the following equation, because it is constant at a resonant point:

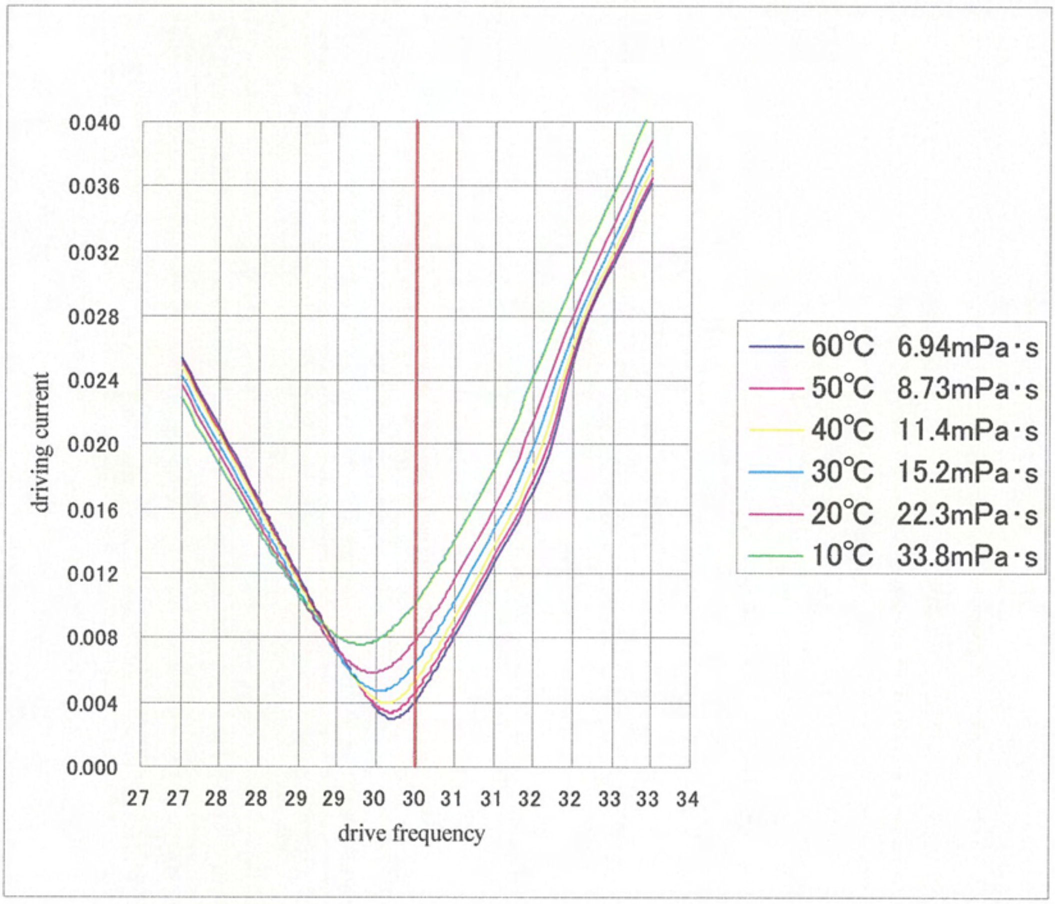
$$X = F / C \cdot \omega n \quad \textit{(Equation 2)}$$

Where; X : amplitude, F : driving force, C : coefficient of viscous damping
ω n : natural frequency of system

The driving force is inversely proportional to the coefficient of viscous damping if the amplitude is constant with the natural frequency of the system.

Figure-2 shows the resonance characteristic of the sensor elements when used Standard Calibration Solution of Viscosity, “JS20”. It is graphically shown how the driving current was varied along with the drive frequency under constant amplitude. In these tests, viscosity differentials were created by changing temperature from 10C to 60C, 10C intervals.

Figure-2 Resonance characteristic of the sensor elements



The graph indicates that the driving current was at the lowest level for each tested samples, because inertial and righting forces were well balanced with each other, and that the lower the viscosity was, the lower the driving current became.

The vibration characteristic of the SV-10’s detector results in a high repeatability as a viscous damping vibration system of 1 degree of freedom. And the driving force at a resonant point balances only with the viscous damping force.

The viscosity can be measured by comparing the coefficient of viscous damping and the driving current, because the plate springs are vibrated at the driving frequency, 30Hz, which is the natural frequency of the detector, under constant amplitude.

For a system vibrating a sensitive plate under driving force F, F equals to the sum of the force ($Rz \cdot Ve^{j\omega t}$) from viscous drag of liquid and the characteristic resistance of the system

Equation 3 is the relational expression of the above. At a resonant point, the reactance Xz equals to Zero.

$$Rz = A\sqrt{\pi f \eta \rho} \quad (Xz=0) \qquad \textit{(Equation3)}$$

Where; f : frequency $\omega = 2\pi f$ (Hz), A : surface area of sensitive plate

η : viscosity, ρ : density

In the new viscometer, Rz = Force (F) / $Ve^{j\omega t}$, the resistance of the mechanical impetus (Z), can be calculated as the function, I / X, under the following assumption of (a), (b), (c).

(a) $F(N) = K \cdot B \cdot L \cdot I$

Where; K: compensating rate (from the center of sensitivity plates to the center of the ferrite)

B: magnetic flux density (T), L: coil length (m), I: driving current (I)

(b) $Ve^{j\omega t} = \omega X = 2\pi fX$

Where; X: amplitude (μ m), calculated from output voltage of displacement sensors

f: frequency (Hz)

(c) I, X, A, B, L, ω are constant.

Where; I: driving current, X: amplitude, A: surface area of sensitive plate,

B: magnetic flux density (T), L: coil length (m), ω : angular frequency (rad/s),

Therefore if the resistance Rz of the mechanical impetus Z can be calculated at a resonant point, both viscosity and density can be determined.

In the SV-10, the basic equation of viscosity is defined as the differentials of the driving current, using Standard Calibration Solution of Viscosity, whose viscosity and density are well known, because the amplitude is controlled within a certain range.

Theoretically the correlation of Rz and $A\sqrt{\pi f \eta \rho}$ is liner, but in the SV-10 it is non-liner because the following conditions are assumed. Consequently, the basic equation of the viscosity measurement of SV-10 is defined as the quadratic equation of the differentials of the driving current.

$$\mathrm{Log}\,\eta \cdot \rho = a\,\mathrm{Log}\,I^2 + b\,\mathrm{Log}\,I + c$$

Where; η : viscosity (Pa・s), I : driving current (A), ρ : density

a,b,c : constant numbers

Conditions:

- There is an influence of reactance Xz, because the driving frequency is not adjusted to the variation of the resonant frequency caused by viscosity changes, the driving frequency being fixed at 30 Hz (the resonant frequency of the system) in the atmosphere.
- There are such influences as the edge effect of sensitivity plates, atmospheric resistance, and the mechanical resistance of the viscometer ($Rm \cdot Ve^{j\omega t}$) such as structural viscous resistance of spring plates.

The viscosity of SV-10 is subject to the state of the density, 1.00, so that Rz should be calculated as the product of viscosity (η) and density (ρ). If the density of a tested sample changes, the calibration of the density should be conducted.

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Specifications

- Model Name : SV-10 (Sine-wave Vibro Viscometer)
- Measuring method : Tuning Fork Vibration Method ("SV type")
  - / Natural frequency 30 Hz
- Viscosity measuring range : 0.3 mPa.s ～ 10,000 mPa.s
- Repeatability : ±1%
- Operating temperature : 10～40℃ (50～104 F)
- Sample Weight : 35ml and more
- Temperature Indicator
  Measuring Range : 0～100℃ (32～212 F) with the resolution of 0.1℃ (0.18 F)