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# A magnetic susceptibility measurement system for para- and diamagnetic materials by a pulse method

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## 1. Introduction.

Gouy method is a well-established technique to measure magnetic susceptibilities of para- or diamagnetic materials. The instrument to measure the weak magnetic susceptibilities should include a big magnet and a cooling system which caused a high cost in performing the experiment. A technique using a pulse magnet was reported in order to overcome these problems. However, there have been some ambiguities in interpreting the transient response of the piezoelectric transducer.

In this report, we are presenting an efficient pulse measurement method with a high sensitivity. A technique to obtain a high sensitivity of the sensor and its calibration method will be discussed.

## 2. Experimental setup.

The schematic diagram of the measurement system is shown in Fig. 1.

The ratio of the field generated by the magnet to the input current was 161 Oe/A measured by the pick-up coil method. This empirical value showed good agreement with a theoretical value. The magnetic field was obtained up to 44.5 kOe at the input current of 277 A by a capacitor discharge system consisting of 4.8 mF initially charged at 400 V.

Samples were packed into a thin plastic or glass tube. The magnetic field measured at the upper end of the sample was only 1.5 % of the field at the lower. The sample was suspended at the free end of a piezoelectric cantilever torque sensor. When the magnet was activated by a pulse current, a sample was pulled down and up in case of a paramagnetic and a diamagnetic sample, respectively. The output of the piezoelectric sensor was fed to a high input impedance amplifier and a phase selector. The gain of the phase selector was selected as +1 for a paramagnetic sample or -1 for a diamagnetic one. The signal was finally displayed on Channel 1 trace of a digital storage oscilloscope and a positive peak hold digital voltmeter. The voltage proportional to the exciting current of the magnet was recorded on Channel 2 trace of the oscilloscope and the peak hold meter. All experiments were performed at room temperature.

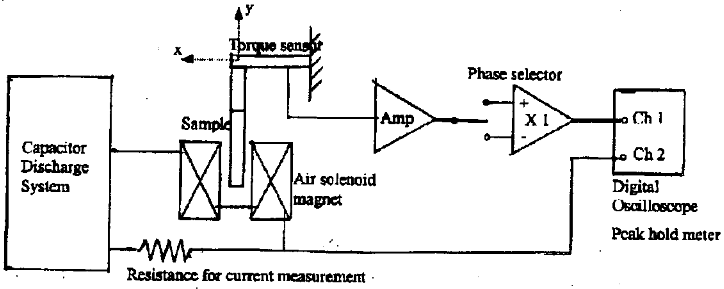


Figure 1. The diagram of the experimental setup

3. Measurement theory.

A displacement $\Delta y$ of the free end of the cantilever piezoelectric force sensor by an impulse generates a voltage ($v$) which is proportional to $\Delta y$. As the width of the cantilever is about 1/3 of the length, $\Delta y$ can be obtained from the solution of Eq. 1 simplified to an equation with one degree of freedom

$$I\ddot{\theta} + c\dot{\theta} + k\theta = \frac{1}{2} m_s \chi_m H_c^2(t) \qquad (1)$$

where $I$, $c$, and $k$ are the moment of inertia including a sample, a sample tube, and a cantilever, a damping coefficient, and the force constant, respectively. The particular solution is given by a convolution integral as

$$\theta(t) = \int_0^t f(t-\tau)\, h(\tau)\, d\tau = \frac{1}{2} m_s \chi_m H_{cp}^2 \int_0^t \left\{\frac{H_c(\tau)}{H_{cp}}\right\}^2 h(t-\tau)\, d\tau \qquad (2)$$

where $h(t-\tau)$ is the complementary solution of Eq. 1 at time $t-\tau$ and the response to the unit impulse at that time denoted delta function, $\delta(t-\tau)$, and $H_{cp}$ is the peak value of impulse field $H_c$. If the moment of inertia and the charged voltage of the capacitor are made constants regardless of sample types, the value of the convolution integral calculated from Eq. 2 becomes invariable with a type of a sample. Accordingly, the output voltage of the cantilever ($v$) can be expressed as

$$v = \frac{1}{2} m_s \chi_m H_{cp}^2 S \qquad (3)$$

where $S$ is a system constant including the convolution integral.

4. Results and discussion.

The data obtained from water (297 mg) and NaCl (423 mg) are shown in Fig. 2 and 3, respectively. The relations between output voltages of the sensors and the magnetic field are shown in Figure 4. The slopes of two lines shown in Fig. 4 are 2. The published susceptibility of water is $-$ 0.72 x $10^{-6}$ emu/(g Oe). We took this value as a standard for calibration. The susceptibility of NaCl was calculated as $-$ 0.50 x $10^{-6}$ emu/(g Oe) from this standard using Eq. 3. The details and data obtained from other salts will be discussed in the conference.

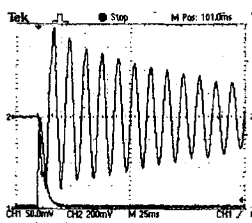
Figure2

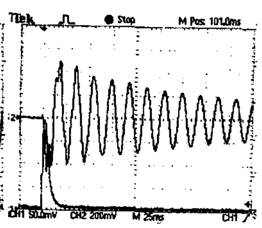
Figure 3

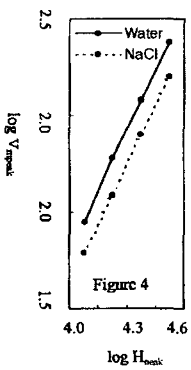

Figure 4