

Design and fabrication of few devices for dynamic measurement of magneto-electric effect

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Measurement of dynamic behaviour of magneto-electric (ME) effect for sintered ceramics has been done by an experimental set-up involving several devices, designed and fabricated in our laboratory. In dynamic method ME signal is registered by measuring the electric potential across the sample under variable dc magnetic field in presence of an ac magnetic field. The relevant devices are dedicated for such measurements only with due consideration to their cost effectiveness. The primary devices begin with the poling system both (a) electric and (b) magnetic, to pole the magneto-electric ceramics. Because of the smallness of ME signal precaution against the noise catch-up is also considered with proper shielding. A lock-in device is used to detect and measure small signals accurately with proper choice of frequency tuned to the frequency of the signal as provided by the frequency generator. The performance of the fabricated devices has been found satisfactory in conducting the dynamic measurement of ME effect for ceramic magneto-electric materials.

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Magneto-electric (ME) materials are capable of converting a magnetic field into an electric field and vice versa. They are considered to be an important futuristic progressive entity for making sensors, processor, actuators and feedback system. To realize the ME effect in a ceramic it should possess simultaneously piezoelectric (PE) and piezomagnetic (PM) properties. In the present experimental set-up we apply magnetic field on electrically and magnetically poled ME sample, which involves distortion in PM phase and distorts PE phase to generate electric field across it. Magneto-electric investigations are then performed by registering the electric signal generated across the sample with an ac technique called dynamic method where the measurement is carried out with a variable dc magnetic field in the presence of biased ac magnetic field. The biased ac magnetic field employed will not allow the charges to move towards the electrode since a suitable signal with an appropriate frequency is used, when the polarity of the signal changes with time. As the output signal is very weak, the appearance of noises should be avoided. The origin of noises may be categorized as endogenous or exogenous depending on their origin, i.e., within the system or outside the system respectively. The latter

category is easier to reduce than the former. Few devices are then required for measurement of ME coefficients, which are based on fundamental electronic circuit concept¹⁻¹⁰, i.e, (i) Electric poling unit for the piezoelectric component phase, (ii) Magnetic poling unit for piezomagnetic component phase, (iii) Frequency generator unit for producing an ac magnetic field in a Helmholtz coil with a desired frequency, (iv) Ripple free dc power supply for producing a stable dc magnetic field over desired range by using an electromagnet, (v) A band pass filter tuned to the frequency of the signal provided by the frequency generator for locking the frequency of output signal at a desired value, and (vi) Sample holder with proper shielding called the Faraday shielding as required for the noise catch up.

The present paper describes the entire experimental set-up with full illustrations of the devices as developed in our laboratory. With these devices the dynamic measurement of ME effect have been made for few samples as reported earlier^{11,12}.

Theoretical

The basic equation¹³ necessary to evaluate ME coefficients from the voltage is described as follows. When a dc magnetic field is applied, the ME output voltage (V) in a polycrystalline material showing the second order effect is given by

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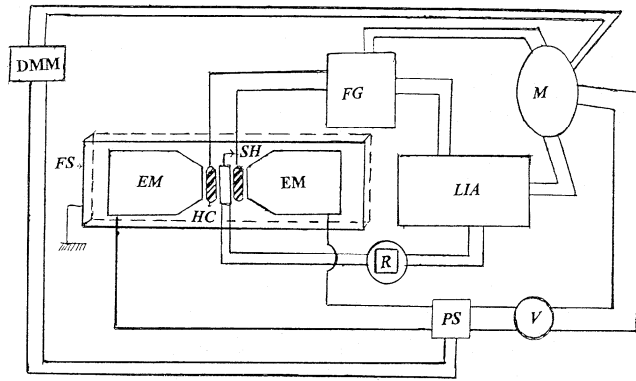


Fig. 1—Block diagram for magneto-electric measurement set-up [DMM-digital multimeter, EM-electro magnet, V-variatic, FG-frequency generator, LIA-lock in amplifier, M-mains, PS-power supply, R-resistance, SH-sample holder, HC-Helmholtz coil, FS-Faraday shielding]

$$V \propto (\alpha H + \beta H.H)$$

where α and β are respectively the coefficients of linear and quadratic components of ME sample. If an ac field h_0 is superimposed over the dc field H_0 , the effective field is,

$$H = H_0 + h_0 \sin(\omega t).$$

A lock in amplifier tuned to the frequency ω ($\omega = 2\pi f$) would measure the output emf giving the ME output. Then, we can write,

$$V \propto (\alpha + \beta H_0) h_0 = \alpha^*(H_0) h_0$$

When H_0 is zero, it is possible to find out the linear term α and hence the second order term β is evaluated in the presence of a dc magnetic field.

Experimental Procedure

Fig. 1 shows a schematic diagram of the apparatus used for measuring the ME value in poled magneto-electric ceramics. Ceramic samples with thickness less than < 0.1 cm was used for the ME measurement.

Electric poling unit

We required a 1 kV/mm electric potential gradient supply between two electrodes. The poling electrodes with sample was placed within a small muffle furnace, having controlled temperature environment during electric poling. The poling temperature depends on the Curie temperature of the piezoelectric ceramic phase. The electrically poled sample was kept wrapped in a silver foil for charge compensation. The electric poling set-up is shown in Fig. 2a, and the corresponding electronic circuit for poling unit is given in Fig. 2b.

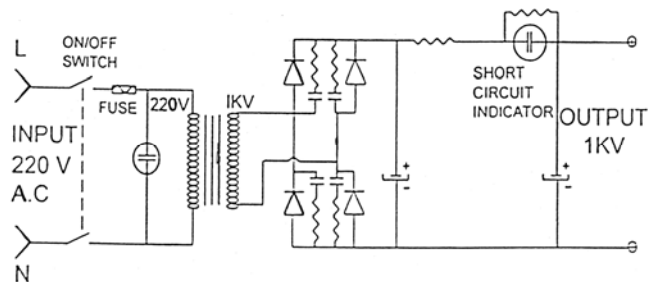
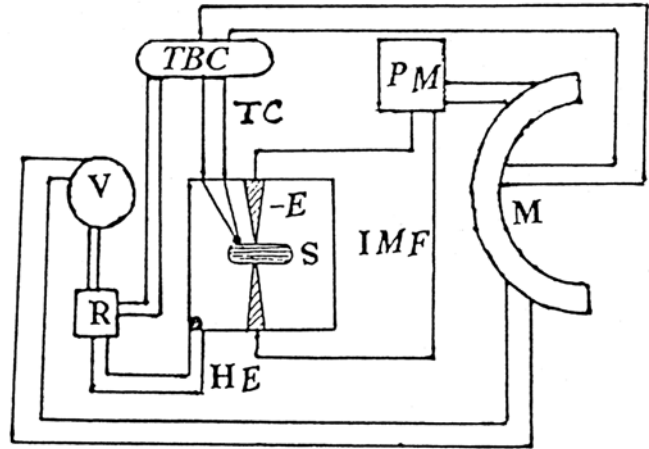


Fig. 2—1 kV/mm electric poling set-up [M-mains, V-variatic, TC-termocouple, E-electrode, HE-heating element, R-relay, S-sample, PM-electricpoling machine, IMF-insulated muffle furnace, TEC-temperature controller]

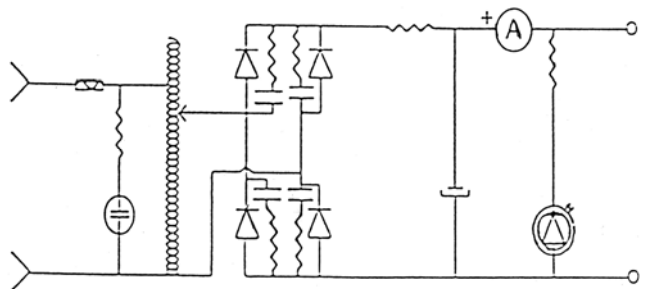


Fig. 3—180 V/2 A dc power supply for electromagnet

Magnetic poling unit

Magnetic poling was done at 1.3 Tesla for 30 min. The electromagnet had been made of soft iron cylindrical core provided with two soft iron dummy pieces at the poles giving a pole separation of 1.5 cm, maximum current and voltage applicable to the system were respectively 2 A and 180 V. Fig. 3, represents the magnetic poling set-up as used for the present investigation.

Frequency generator

It had been necessary to use a frequency high enough to avoid parasites of 50 Hz, but low enough to

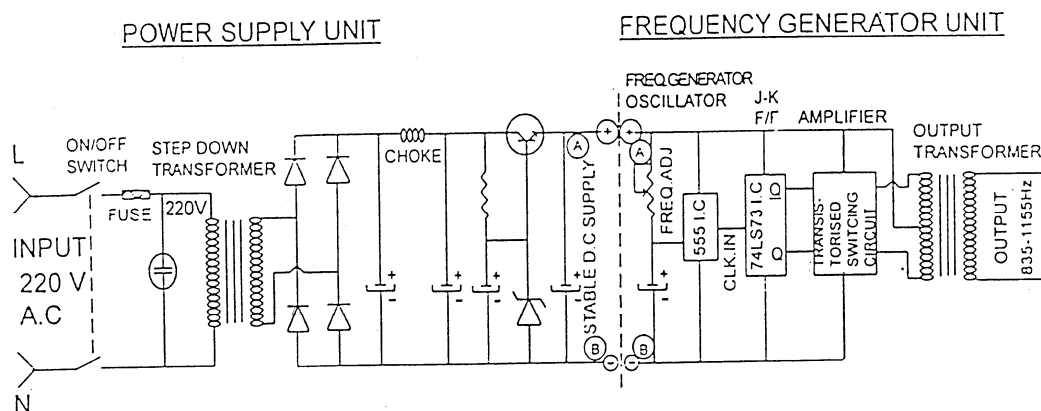


Fig. 4—835-1155 Hz Frequency generator with power supply unit as used for producing ac magnetic field within the frequency limit

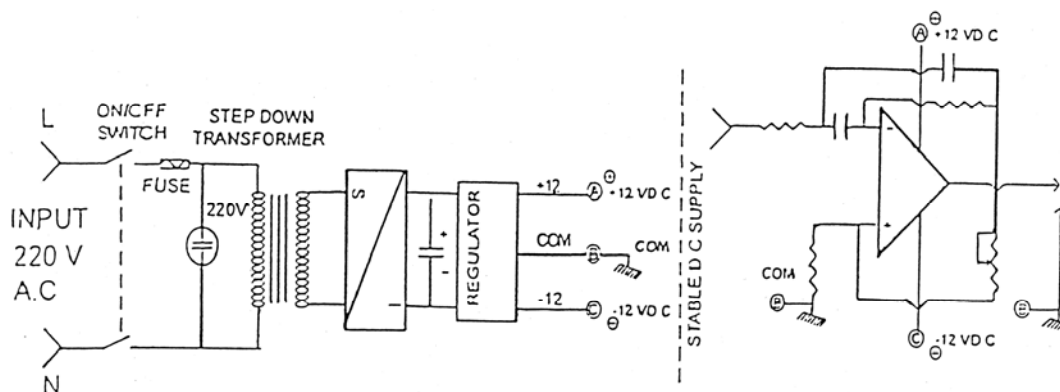


Fig. 5—1070 Hz band pass filter

reduce capacity coupling. The choice was 1070 Hz. The frequency generator along with the power supply as fabricated is shown in Fig. 4. AC magnetic field was provided by a Helmholtz coil (HC) with 20 laps in the form of two annular drums having a thickness of 10 mm, the inner and outer diameter being 10 mm and 30 mm respectively. The HC was fed with a frequency generator provided with a power supply for producing the bias ac magnetic field at a desired frequency. The magnetic field as generated by the HC was nearly 30 Oe. A special type sample holder (male/female combination with magnetic field entry) made of Bakelite with two fixed silver electrode was used.

Bandpass filterH

Band pass filter was used in a dedicated way for measuring the output signal at signal frequency. The generated potential was then measured with electrometer or with the help of a

nano/microvoltmeter having a proper shielding. The relevant circuit is given Fig. 5. An alternative method for measuring such small output signal is the use of a standard lock in amplifier tuned to the frequency of the signal.

Pick-up and shielding

The experiment related to signal dispatch/receive needs precaution against noise capture to get a proper output signal. Due to the smallness of magneto electric signal it is necessary to have not more than $0.1 \mu\text{V}$ of pick-up signal. A good shielding eliminates the electrostatic pick-up. The sample as placed between the magnetic poles was totally covered by a conducting box. We provided spikes on the shielding box (high stress concentration zone), which acted as aerials in grounding noises. The use of coaxial cables was good to reduce the noise travel along with the true signal. Here the concentric braided wire shielding surrounded the central wire carrying the signal of

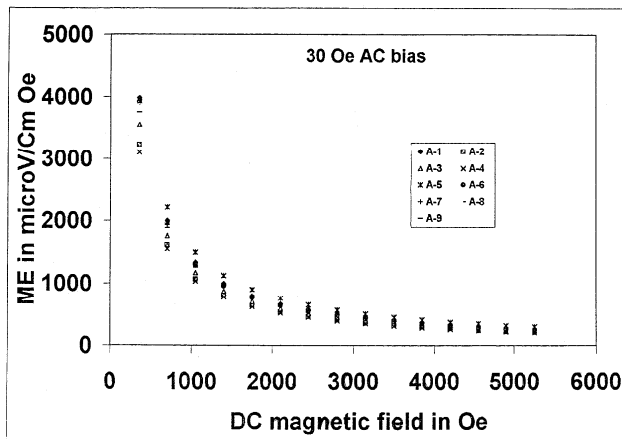


Fig. 6— ME values of a series of ceramic composites (A1-A9) with increasing dc magnetic field under a bias 30 Oe ac magnetic field

interest. The differential electrode noises were avoided by using similar metal both for sample electrode paint as well as sample holder electrode paint.

Magneto-electric measurements

In dynamic measurement of ME effect, a 30 Oe ac magnetic field with 1070 Hz frequency was applied collinearly with the variable dc magnetic field from 0 – 1.3 kOe. In case of static measurements only ac magnetic field was applied to get linear term of magneto electric coefficient (α) and the second order term (β) was evaluated in the presence of DC magnetic field from known values of α , h_0 , H_0 and V . The signal output in voltage represented the true value. An alternative use of lock in amplifier [EG&G PAR-5210] was made to measure the output signal.

Results and Discussion

Magneto-electric measurements were made for few ceramic samples in the form of disc with the present

set-up. Typical variation of ME values¹² for few samples are given in Fig. 6, under variable dc magnetic field when a bias 30 Oe ac magnetic field was applied. The ME measurement techniques are actually time-dependent self-betterment experiment and demand modification. One can suitably tailor them for dedicated purpose under specific duty condition. This is economic and handy from the size point of view. The set-up was found to give reliable performance.

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