Although the shock wave propagation distance through Lucite must be kept to a minimum because of Lucite's deteriorating effect on the shock wave rise time,[8] the magnetic sample must be located far enough away from the solenoid face to avoid the ripple effect in the magnetic field produced by the periodicity of the solenoid windings. This ripple effect can be shown to reduce to $1/e$ in a distance

$$y_0 = a/2\pi, \tag{3}$$

where a is the period of the grid.[9]

The pickup coil consists of 10 turns of fine manganin ribbon wound closely around the specimen center as indicated in Fig. 3. The active recording region, defined by the face of the pickup coil, is about 1 cm^2. Manganin ribbon was originally chosen for the pickup coil because of its distributed resistance. It was thought that this resistance might tend to damp parasitic oscillations in the pickup circuit. No attempt has been made to test the merit of this precaution. The pressure dependence of the resistance is negligible for this experimental configuration. A twisted pair of insulated copper wires is solder connected to the pickup coil immediately behind the YIG sample and brought out the end of the solenoid. This twisted pair and connections are not disturbed by the stress wave during the recording time. The solenoid and its associated electrical components and ballast inductor are mounted in a target assembly which is completely potted in epoxy.

III. APPLICATION OF STRAIN FIELD

The target assembly (Fig. 3) is subject to planar impact by the projectile. The subsequent shock wave propagates through the solenoid face and into the magnetic material creating, behind the shock wave, a state of uniaxial strain. This state of strain in the magnetic material is determined from the measured projectile velocity and the known equations of state of the projectile material, intermediate material, and magnetic material. The projectile face should be an insulating material since metal in motion will disturb the magnetic flux in the vicinity of the solenoid. This can seriously perturb the demagnetization measurement.

There are several problems associated with propagating a planar shock wave through the periodic grid defined by the front surface of the solenoid. First, the copper–epoxy interface is a region of mechanical impedance mismatch through which the wave must travel. The resulting ringup in this region degrades the wave and lends a finite rise time to an initial step stress wave. Second, the periodicity of the grid creates a corrugated wave effect due to the differing material impedances. The errors resulting from this can be made small by making the thickness of the solenoid winding small.

A technique capable of eliminating the problems associated with propagating a wave through the solenoid grid was developed during the course of this work. The method requires use of aluminum oxide as the material on the impact surface (see Fig. 3). The stress wave then propagates through aluminum oxide, the copper–epoxy grid, and Lucite, respectively. The material characteristics which make this technique successful are the mechanical impedance similarities of aluminum oxide and copper on one hand and Lucite and epoxy on the other, along with the similar shock velocities of copper and epoxy. This combination of properties creates a single, somewhat irregular, interface. An experiment was performed in which quartz gauges analyzed waveforms propagated through identical geometries with the exception that one contained a copper–epoxy grid while the other did not. The waveforms were experimentally identical, verifying this technique.

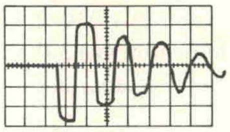

FIG. 4. Oscilloscope record of shock induced demagnetization in YIG. Periodicity corresponds to reverberation of stress wave in YIG platelet. Time scale is 0.2 μsec/div.

IV. DEMAGNETIZATION ANALYSIS

Shock induced demagnetization of the magnetic specimen is determined from the emf developed across the pickup coil. A high impedance pickup circuit is used to minimize current flow in the pickup coil. A typical oscilloscope record from which magnetic information is deduced is shown in Fig. 4. A negative emf is developed during the first transit of the shock wave resulting from the expected demagnetization of the material. The subsequent oscillation is produced by alternate remagnetization and demagnetization as the stress wave reverberates back and forth in the slab of magnetic material.

To relate demagnetization to the developed emf, it is assumed that a steady state shock profile S is progressing through the magnetic material as shown in Fig. 5. In the spirit of mechanical shock wave jump condition calculations,[10] consider, prior to passage of the shock wave, an element of area $bD\delta t$ which is compressed to $b(D-u)\delta t$ after passage of the shock wave. b is the width of the pickup coil, D is the shock velocity, and u is the particle velocity behind the shock. The change in magnetic flux across the shock wave is

$$\delta\Phi = b[B(D-u) - B_0 D]\delta t,$$

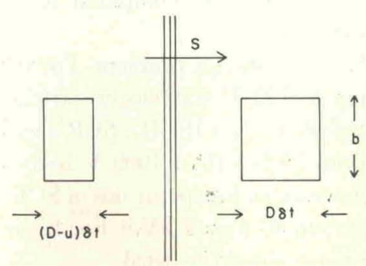

FIG. 5. Geometry for magnetic flux jump condition. Area compression due to shock propagating through magnetic medium at rest is represented. Magnetic field is normal to the page.

where B_0 is the initial magnetic induction in front of the shock and B is the final magnetic induction behind the shock. If the external applied field is constant and the demagnetizing field is zero, using

$$B=H_e+4\pi M \qquad (4)$$

along with the conservation of mass jump condition

$$(D-u)\rho=D\rho_0 \qquad (5)$$

yields

$$\delta\Phi=bD[4\pi(M\rho_0/\rho-M_0)+(\rho_0/\rho-1)H_e]\delta t. \qquad (6)$$

M_0 is the initial magnetization per unit initial volume and M is the final magnetization per unit final volume. Since

$$u=D(1-\rho_0/\rho) \qquad (7)$$

from Eq. (5) and $M\rho_0/\rho$ is the final magnetization per unit initial volume, the rate of flux change becomes

$$d\Phi/dt=4\pi bD\Delta M-buH_e. \qquad (8)$$

The first term is the flux change due to the reduction in magnetization. The second term is the flux change due to the motion of the front surface of the pickup coil in the manner of a magnetic velocity gauge. In the present work the second term was quite small compared to the first. With Eq. (8), the demagnetization can be related to the recorded emf through Faraday's law.

The only significant complication encountered in using this analysis to reduce the demagnetization data was created by lateral relief waves in the platelets of YIG. The stretching of the relieved material increased the induced anisotropy effect in this region. A correction of this relief wave problem was necessary.

V. DISCUSSION

The present work for which the experimental technique was designed did not test the limits of its capabilities. The maximum fields obtained were about 1 kG. This requires a maximum current of about 35–40 A with an initial capacitor voltage of 750 V. The system is capable of carrying 150 A maximum current with only 10° to 15° temperature rise in the solenoid windings. This is substantially below the softening point of epoxy (~80°C). The technique is easily capable of producing pulsed fields up to 5 kG. The magnetic forces involved are still small compared to the strength of the materials used.

Switching the high voltage becomes a problem. For this work, a maximum voltage of 750 V was easily switched with a single silicon controlled rectifier (SCR). SCR's with blocking voltage capabilities higher than 1000 V become increasingly expensive. However, series operations of SCR's allow switching of voltages up to 3 or 4 kV.[11] For higher voltage, a spark gap technique should be used.

Since most impact studies are carried out in evacuated chambers, electrical breakdown and discharge is a potential difficulty. Care must be used in selection of cables and tank connectors for carrying the high voltages. All electrical circuitry within the chamber should be potted in insulating epoxy.

In the present work, maximum shock pressures in the solenoid and specimen were on the order of 45 kilobars. The survival time of the solenoid was about 15 to 20 μsec while that of the pickup coil was about 2 μsec. This was substantially more time than was required to perform the measurement. Survival would become a problem with increasing stress.

Although this technique was invented for investigation of shock induced anisotropy in yttrium iron garnet, it is potentially capable and sensitive enough for impact study of other magnetic and magnetostructural properties. The following possible application is suggested. Volume dependence of magnetic properties such as ferromagnetic or ferrimagnetic exchange integrals has usually been studied by hydrostatic techniques. This becomes increasingly cumbersome with increasing pressure. Shock wave techniques represent a highly sensitive means for investigating pressure dependent magnetic properties. This is because of the extremely high strain rates obtained and, therefore, extremely high flux rates expected. Unfortunately observation of this effect in homogeneous ferromagnetic material is prohibited by the much larger shock induced anisotropy effect. A possible method for circumventing the shock induced anisotropy effect would be to introduce the magnetic material, in powder form, into a low yield matrix such as Lucite or epoxy.[12] For properly chosen powder size, nearly hydrostatic conditions would obtain in the magnetic particles within a reasonable time behind the shock front. With a steady state stress profile in the magnetic composite, the analysis in the last section would provide the change in magnetization. The sensitivity of the technique is on the order of 1 V/G. This sensitivity should be more than sufficient for measuring expected demagnetization in many magnetic materials.

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† Present address, Stanford Research Institute, Menlo Park, Calif. 94025.