A high current pulse generator for magnetizing thin magnetic films

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A bipolar, high-current (10 000 A) pulse generator, used to magnetically saturate thin films during spin-polarized electron and dynamic response measurements, is described. Bipolar operation is achieved by discharging a bank of capacitors through selected pairs of high-power silicon-controlled rectifiers connected to a coil in an H bridge configuration. The pulse generator can be controlled either manually or by means of a computer. © *1996 American Institute of Physics.* [S0034-6748(96)01811-4]

I. INTRODUCTION

A variety of experimental techniques utilized to probe magnetic properties of magnetic materials based on spin-polarized electron spectroscopy/microscopy require samples to be prepared with a stable domain structure in the absence of an applied magnetic field.[1,2] Examples of these techniques include scanning electron microscopy with spin-polarization analysis (SEMPA), spin-polarized photoelectron emission spectroscopy, and spin-polarized Auger electron spectroscopy. The latter two techniques generally require a single magnetic domain over the region probed by the source (a synchrotron radiation beam line or a high-current, high-resolution electron gun). In addition, in the spectroscopy experiments, it is necessary to repeatedly reverse the sample magnetization direction during the measurement to separate spin-orbit effects from ferromagnetic exchange effects. The requirements for both the polarized electron microscopy and spectroscopy experiments are best achieved by an air coil magnet which produces sufficiently high applied fields to magnetically saturate the film, but produces zero residual field at zero current. This article describes a bipolar high-current pulse generator that meets these requirements for polarized electron spectroscopy/microscopy of thin magnetic films.

II. CIRCUIT DESCRIPTION

Figure 1 presents a block diagram of the high-current pulse generator. A capacitor bank, C1–C4 is charged by an external power supply through switch S1 and current limiting resistor R1, which also serves to discharge the capacitors when the pulser is turned off. S1 also switches line power (115 Vac) to internal power supplies which provide voltages to the logic and firing circuitry. The capacitor bank consists of four 2000 mFd electrolytic capacitors rated at 450 Vdc. The silicon-controlled rectifier (SCR) bridge consists of four stud-mounted PRX-T700063504BY (Powerex) SCRs. These SCRs are designed to handle intermittent 10 000 A 60 Hz half-wave rectified sine waves at 125 °C. The load is an air coil (Helmholtz configuration) made by winding a few 1 in. diam turns of No. 10 solid copper wire. Sequential pulses of opposite polarity are generated by firing the appropriate SCRs in the SCR bridge.

Figure 2 presents a circuit diagram of the logic circuits and SCR drivers. Front panel switches select manual or computer operation (S2) and pulse polarity (S3). A push button switch (S4) permits manual firing of the pulse generator. The 12 V complementary metal-oxide semiconductor (CMOS) logic family was chosen for control circuitry because it provided better noise immunity and for its capability to interface directly with the coil-driving metal-oxide-semiconductor-field-effect transistors (MOSFETS). Computer operation is achieved through transistor–transistor logic (TTL) (5 V) signals which are coupled to the CMOS multiplexer MUX(Z3) through TTL to CMOS level converters. Fire and polarity commands are directed to logic circuitry which generates status signals for the computer, and which trigger the

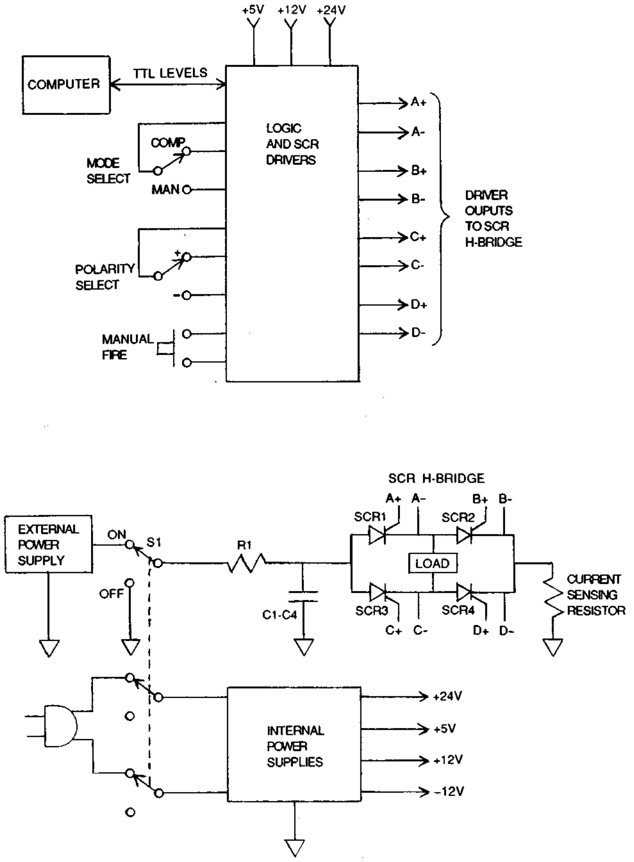

FIG. 1. (a) Block diagram showing input and output functions of the logic and SCR driver board; (b) block diagram of the bipolar pulser showing the H-bridge configuration and external charging power supply.

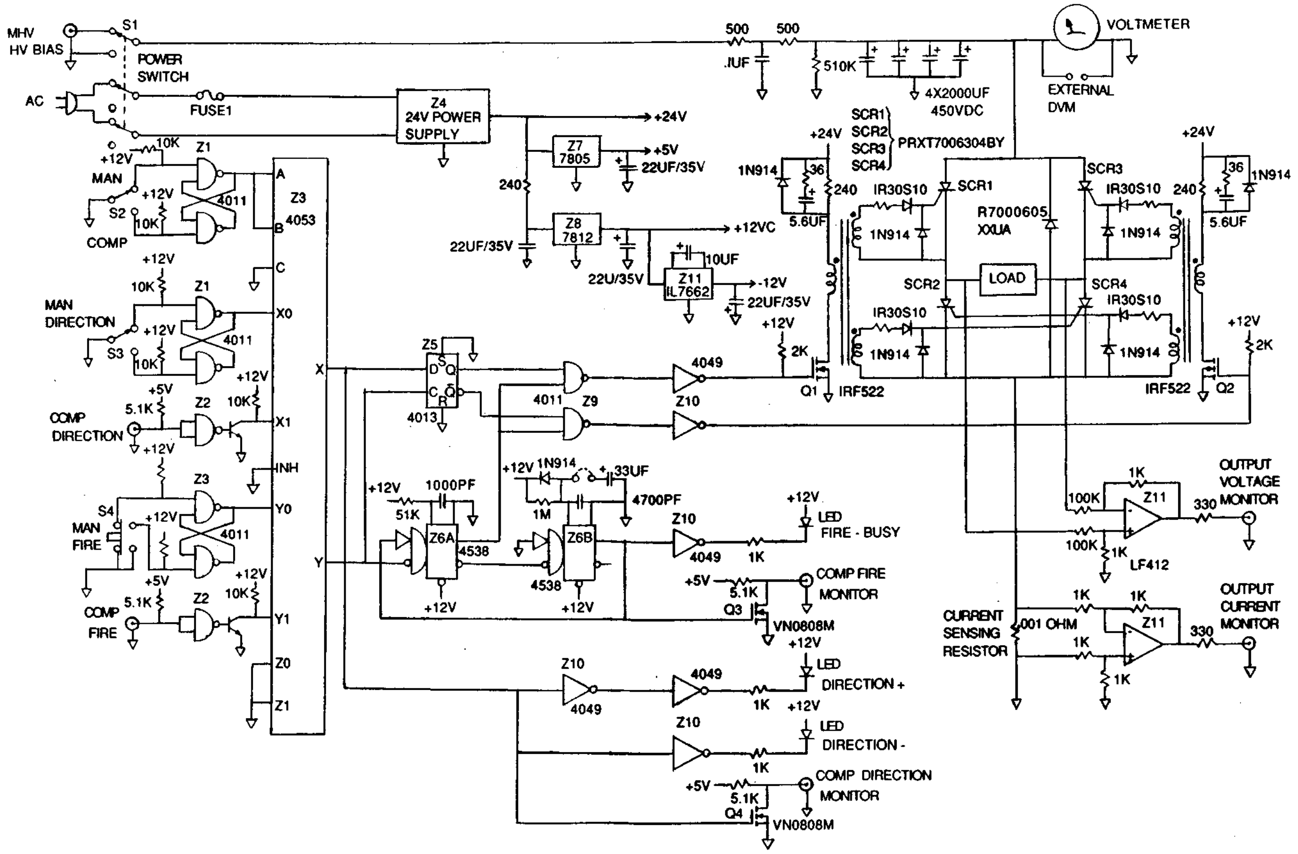

FIG. 2. Detailed circuit diagram of logic board and SCR driver. Refer to the text for description.

MOSFET pulse transformer drivers Q_1 and Q_2. Each pulse transformer provides pulses to the appropriate pair of SCR gates in the H bridge.

The manually or computer selected polarity from the multiplexer is latched into the input of the flip-flop (Z5) by the rising edge of the firing pulse. Complementary outputs from the flip-flop applied to NAND gates govern which MOSFET driver is activated by fire commands delivered to the NAND gates by the one-shot Z6A. The one-shot (Z6A) provides a 30 μs pulse required at the SCR gates, while one-shot Z6B generates a prescribed (~1 min) busy time that prevents retriggering during the charging cycle. All manual switches have logic latches to ensure immunity from contact bounce.

The pulse transformers are constructed by winding No. 28 magnet wire on ferrite core toroids having dimensions of 0.75 in. o.d.×1.30 in. o.d.×0.5 in. thick. The 1:1 (100 turn) windings are wound in three separate sections to provide high voltage isolation. A layer of fabric coil tape is wound on the bare core to provide some cushion so that the windings can be pulled tight, and to provide additional electrical isolation from the core.

The initial breadboard model of the pulse generator incorporated standard pulse snubber circuitry for the SCRs (RC network between trigger gate and cathode), but these circuits appeared to introduce coupling between the SCRs resulting in firing of nontriggered SCRs at higher capacitor charge voltages. The circuit performs correctly without snubber circuitry with no adverse effects, so these circuits are not incorporated into the final design.

The pulse generator is packaged in a standard 3-1/2 in. high ×20 in. deep rack mount chassis. The SCR H bridge is mounted on electrically isolated heavy copper brackets near the rear of the chassis where 3/4 in. diam copper lugs provide rugged current output terminals (refer to Fig. 3). The capacitors are bolted to copper buses (1/2 in. wide×1/8 in. thick) which are connected to the H bridge via heavy copper straps. Several front panel LEDs provide status information (polarity, busy), and a front panel analog meter monitors capacitor voltage. A noninductive resistor (1.0 mΩ) constructed from a strip of Ta provides a current monitor with a sensitivity of 10 V/10 000 A.

III. TESTS AND APPLICATION

The pulser is generally used to drive a Helmholtz coil[3] consisting of a pair of coaxial coils of radius R separated by R. The axial field at the center is given by

$$B=\mu_0\,\frac{8}{5\sqrt{5}}\,\frac{NI}{R}\ \text{Wb/m}^2.$$

A 20 turn, 2.5 cm diam Helmholtz coil carrying 10 000 A will produce a field of 7.2 Wb/m^2. Normally, films can be switched at currents of a few hundred A.

Figure 4 displays a typical current pulse produced by the pulse generator into a short circuit at a peak current of

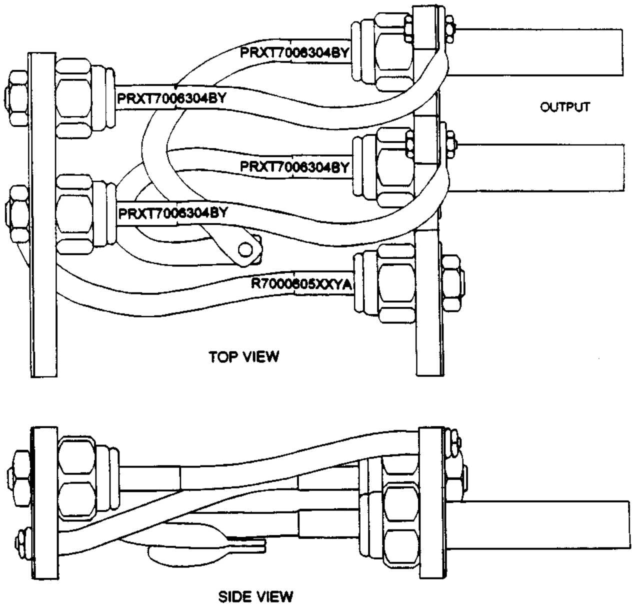

FIG. 3. Layout of the SCR H bridge.

10 000 A. Figure 5 displays corresponding results for a test load (small air coil including cables). The load in this test was a single 4 cm diam two turn coil connected to the pulser via a pair of heavy braided cables about 2 m long. The current rises from 0 to over 10 000 A in less than 10 μs, and decays to zero with a time constant (36% measured from 10 000 A at 100 μs) of about 200 μs.

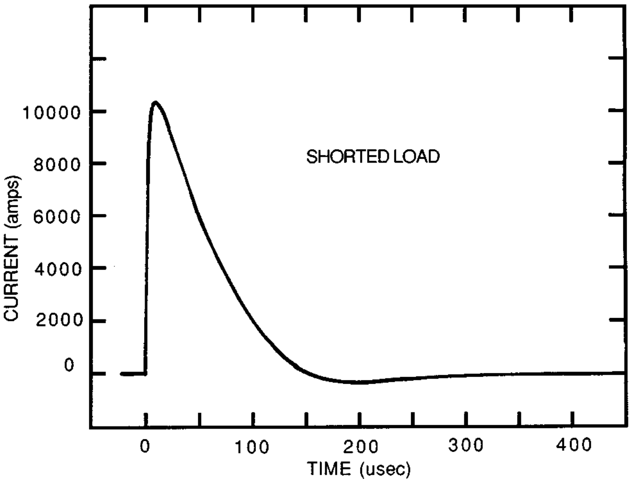

FIG. 4. Typical pulse waveform from pulser into short circuit load at peak current of 10 000 A.

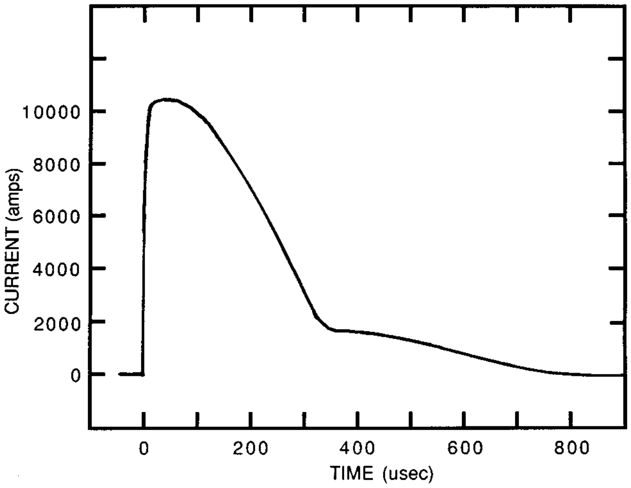

FIG. 5. Typical pulse waveform from pulser into a small inductive load at peak current of 10 000 A (refer to the text).

The high current fast rise time pulse illustrated in Fig. 5 corresponds to a magnetic field rate of change $dB/dt(dH/dt)$ in the range 4.5×10^4 Wb/m^2/s (4.5×10^5 kOe/s or 3.5×10^{-10} AT/ms) within a volume of a few cm^3. This has important implications in the emerging efforts that study dynamical properties of magnetization reversal in ultrathin films.[4–7] The highest values of dH/dt reported using cw measurements (burst mode cw) is on the order of 6×10^3 kOe/s. Pulse techniques applied to these systems offer prospects for extending the dynamic range covered by at least two orders of magnitude.

ACKNOWLEDGMENT

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