OPERATING MANUAL FOR 200 kG PULSE MAGNET

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September, 1976

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K. Hemachalam

Materials and Molecular Research Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

INTRODUCTION

High field magnets have become necessary for measuring properties of superconducting materials. The generation of steady high magnetic fields by conventional copper magnets or by superconducting magnets requires great cost for construction as well as operation. Transient fields, however, can be produced less expensively. For this reason, it has been customary to measure high-field properties of superconductors in pulsed magnets.[1-5] The objective of this report is two-fold: (1) to describe a pulse magnet apparatus in use at this Laboratory, and (2) to present an operating procedure to measure current-carrying behavior of superconductors as a function of magnetic field.

DESCRIPTION OF APPARATUS

Pulse Magnet

The apparatus capable of producing fields in excess of 200 kG is shown schematically in Fig. 1(b).[6] It consists of a capacitor bank and a helical magnet coil. The coil (Fig. 1(a)) is made from hardened high-conductivity copper sheets and has a 75 mm long bore of 19 mm diameter. Electrical energy stored in the charged capacitor bank is released as a large current pulse through an ignitron to the magnet. The rise time (time between the zero point and the quarter sine-wave point) of the pulse is about 8 milliseconds. The peak value of magnet current (and thus the field) is controlled by the voltage to which the capacitor bank is charged. The magnetic field is measured by recording the magnet current using a calibrated Rogowski belt. The magnet is immersed in a bath of liquid nitrogen (Fig. 2) to facilitate removal of the Joule heat produced by the coil resistance. Operation of the magnet at liquid nitrogen temperature further helps to reduce the coil resistance. The relation between the capacitor bank charging voltage and the value of peak field developed in the magnet bore is plotted in Fig. 4. The variation of field strength, measured by a calibrated search coil, along the axis of the magnet is shown in Fig. 3. The magnet current peak was kept constant for all the pulses. The voltage induced in the Rogowski belt had a peak value of 0.29V when the search coil recorded a magnetic field of 162 kG. For a field of 84 kG, the voltage induced in the belt was 0.15V. Therefore, the scale of conversion is 560 kG to 1 V.

Two 6-volt lead-acid batteries connected in series supply the necessary sample current in a rectangular pulse. The duration of this pulse can be varied from 0.5 to 10 milliseconds. However, in the normal operation, the current pulse is set for the maximum duration such that the sample current begins before the field pulse and ends after the field reaches its maximum. This method of scheduling the pulses reduces undue sample heating when the superconducting to normal (S-N) transition is made to take place close to the peak of the field pulse.

Sample Probe

The construction of the probe (Fig. 5) is based on the usual 4 wire testing method. A predetermined current is passed through the sample and the voltage drop across the sample is measured. The probe is also equipped with an auxiliary coil which is connected to a potentiometer. The two pairs of auxiliary coil wires and sample voltage wires are twisted together along the length of the probe. When the magnet is pulsed, voltages are induced in both the auxiliary coil and the voltage taps on the sample. With no sample current, the potentiometer is adjusted until the two opposing inductive voltage signals cancel each other as much as possible. This adjustment makes it possible to observe resistive voltage developed in the sample as a result of the transport current alone.

A word of caution is necessary in regard to the sample mounting. When the current transfer length between the current leads and the sample is small, as is the case with a short straight 1 cm long specimen, the heat generated at the current contacts may raise the sample temperature. This sample heating can lead to erroneous critical current measurements. In one instance, mounting of a straight sample resulted in critical currents that were about 30% lower than those carried by a 3 cm long hair pin shaped specimen cut from the same batch of wire. The curved sample has the advantages of increasing the current transfer length as well as the separation of the potential leads from the current contacts. In the case of testing superconducting tapes, U-shaped sections are carefully cut before mounting on the probe. Figure 2 shows schematically the sample placed inside the finger of a double walled glass dewar that holds liquid helium. The sample orientation is such that the magnetic field is perpendicular to the transport current. For any other orientations, the sample mounting may be modified to suit the particular need. Care should be taken, however, that the Lorentz force, (I_c x H), presses the sample against the mount surface. This is achieved by maintaining the polarity of the sample current leads as indicated in Fig. 5(a). Otherwise, the electromagnetic force can bend the specimen causing mechanical damage.

OPERATING PROCEDURE

1. The batteries that supply the sample current are fully charged. This charging should preferably be done prior to the critical current test.
2. The evacuated glass helium cryostat is carefully lowered in the magnet assembly so that the finger rests inside the bore of the coil.
3. The stainless steel dewar is filled to about 80% with liquid nitrogen.
4. Liquid helium is transferred into the glass cryostat to a desired level. The cryostat has a capacity of 3 litres; and for normal operation, the liquid helium consumption is approximately 0.5 litre per sample.
5. The probe with the sample properly mounted on it is first dipped in the liquid nitrogen for precooling and then gradually lowered into the liquid helium. When the top flange of the probe is sitting on the rim of the cryostat, the sample should be in the finger at a level where the magnetic field is uniform.
6. The electrical connections for sample current, sample voltage and auxiliary coil are made at the magnet assembly as shown in Fig. 6.
7. The power to the front panel and to all the individual control units (Fig. 7) is turned on after closing the interlocked wooden door adjacent to the panel. The key

to the interlocked door is used to turn on the capacitor bank power supply. The dual-beam oscilloscope is also switched on.

8. The auxiliary coil and the voltage contacts are respectively connected to the "A" and "B" input channels of the D amplifier of the oscilloscope (Fig. 7). The output leads from the magnetic field measuring circuit are connected to the type 1A1 amplifier.
9. The high voltage (HV) knob of the pulser power-supply (Fig. 8) is turned until the output voltage reads between 1 to 2 kV. The purpose of this voltage is to trigger the thyratron in the capacitor bank discharging circuit.
10. The capacitor bank is charged to a desired voltage (about 200V), by turning the variac on the capacitor bank power supply unit. With the sample current set at zero, and the field Pulse Switch at "ON" position (Fig. 8), the magnet is pulsed by depressing the single pulse switch. The auxiliary coil potentiometer is adjusted until the voltage induced in the auxiliary coil is equal and opposite to that induced in the voltage leads. This compensation is done by trial and error. For other settings of charging voltages, the auxiliary coil potentiometer need not be readjusted unless the sample voltage signal ceases to show a definite superconducting to normal (S-N) transition.

Operating Procedure - (Cont'd)

11. The capacitor bank is charged to a certain voltage and the sample current is set at a suitable value so that when the magnet is pulsed the S-N transition takes place as close to the peak of the field pulse as possible. The actual sample current in amperes is approximately 70% of the figure at which the current dial is set. First, the magnetic field and the sample voltage are photographed while pulsing the magnet. Then, the sample current and the base line for the field are recorded. A typical oscillograph record is shown in Fig. 9(b). Each such picture gives one data point on the J_c(or I_c) vs. H curve.
12. For other values of field peaks (i.e., for other settings of capacitor charging voltages), Step 11 is repeated until enough data points are obtained.
13. For changing a specimen, only the capacitor bank power supply needs to be turned off. The sample probe is removed from the cryostat. The next sample is mounted on the probe and the procedure starting with Step 5 is repeated.
14. Finally, when the testing is completed, the power to all the control units including the main power on the front panel is turned off. The sample probe is removed from the helium cryostat. The cryostat may be allowed to warm-up either in the nitrogen dewar or outside.

DATA REDUCTION AND COMMENTS

The sample current is measured from each picture. If the current pulse is not truly rectangular, the critical current I_c is taken at a point corresponding to the beginning of the S-N transition. Magnetic fields H_1 and if possible, H_2 at the beginning and the end of the transition respectively, are also measured as shown in Fig. 9(a). When the sample voltage wave form contains noise and is not completely compensated by the auxiliary coil, (as typified in Fig. 9(c)), the data points can still be determined at the S-N transition. Since H_1 is extremely sensitive to the time rate of change of field, $\left(\frac{dH}{dt}\right)$, transitions occurring while the field is still rapidly rising tend to yield degraded critical parameters. The values of I_c, H_1 and H_2 are then tabulated and the J_c(or I_c) vs. H curve is obtained by plotting the J_c(or I_c) against H_1 on a semi-log paper. Typical results plotted in Fig. 10[7] show good agreement between the pulsed field data and the data obtained under steady field conditions at a resistivity level of 10^{-12} Ωcm. The sample tested here was a filamentary Nb_3Sn wire made by the tin infiltration method. At fields below 50 kG, the critical currents measured under pulsed fields are low relative to the values determined under steady fields. This disagreement is attributed to Joule heating at the current contacts of the short sample used in the pulsed field experiments.

POTENTIAL PROBLEMS AND SOLUTIONS

1. The capacitor bank is charged slowly such that the charging current does not exceed 20A - the limit of the current fuse.
2. Pulsing the magnet for peak fields above 200 kG is not advised. Energy dissipation in the magnet coil for fields exceeding 200 kG may produce serious mechanical, thermal and/or electrical effects (for example, failure of restraining bolts, annealing of hardened copper coils, damage of insulation, etc.) leading to magnet failure. For under 200 kG pulses, waiting 3 to 5 minutes between successive discharges is a good practice to allow for cooling of the magnet coil in liquid nitrogen.
3. In order to avoid possible shock to operator(s), the interlocked door mechanism should not be disconnected and it should be used while charging and discharging the capacitor bank.
4. The glass cryostat for liquid helium is weakest at the finger and extreme care should be taken in handling the cryostat. At the end of testing, any liquid helium still remaining in the cryostat is allowed to evaporate by itself. No attempt should be made to pour it out since a thermal shock at the mouth of the glass cryostat can shatter the dewar.
5. For any help with the electronics of the apparatus, James Severns (Building 62 - Room 149 - Extension 6058)

may be contacted. Other persons familiar with the pulse magnet are Daniel Curtis (Building 47 - Room 115 - Extension 6372) and Paul Salz (Building 25A - Room 119 - Extension 5051).

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FIGURE CAPTIONS

1. (a). Pulse magnet, and (b) a schematic representation of the electrical circuits of the pulsed field apparatus.
2. Schematic of the cryogenic unit.
3. Variation of field strength along the axis of the magnet bore.
4. Variation of peak field as a function of capacitor bank charging voltage.
5. (a). Front, and (b) back views of the sample probe.
6. Photograph showing the electrical connections to the sample probe at the cryostat.
7. View of the front panel with control units, and connections leading to the oscilloscope.
8. A close-up view of the front panel detailing the different electrical controls, switches and output leads.
9. Typical oscilloscope tracings of sample current, sample voltage and magnetic field. Fields H_1 and H_2 in (a) correspond to the beginning and the end of the S-N transition. Tracings in (b) and (c) are recorded at low field (H_{max} = 67 kG) and high field (H_{max} = 174 kG) pulses respectively. The horizontal scale in both (b) and (c) is 2 milliseconds per cm.
10. Critical current density of $Nb+Nb_3Sn$ core as a function of magnetic field under pulsed and steady field conditions.

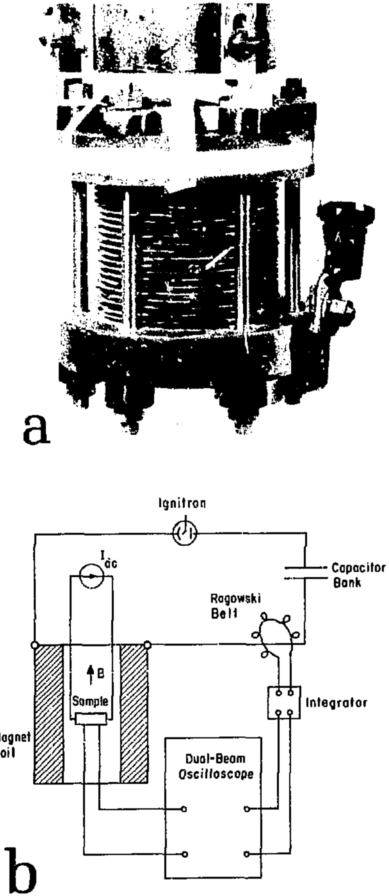

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Fig. 1 (a) - Pulse magnet, and
(b) - a schematic representation of the electrical circuits of the pulsed field apparatus.

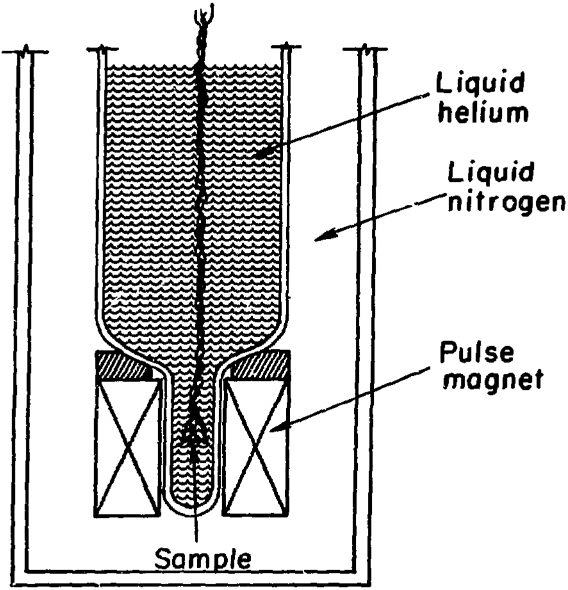

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Fig. 2 Schematic of the cryogenic unit.

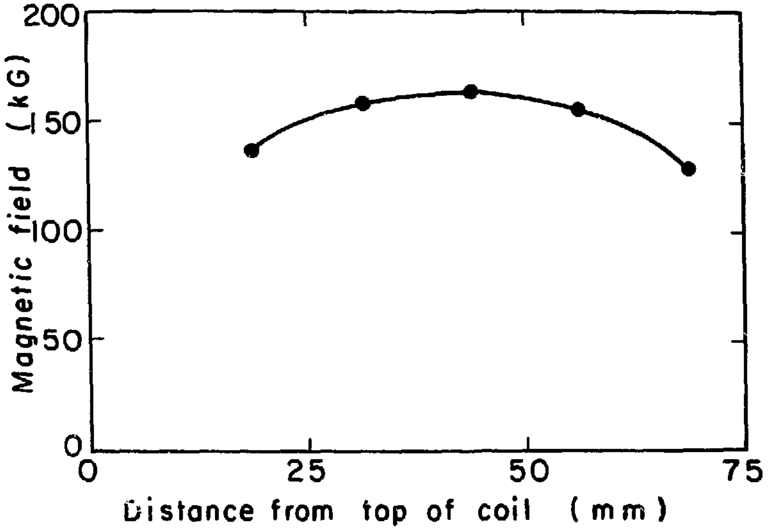

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Fig. 3 Variation of field strength along the axis of the magnet bore.

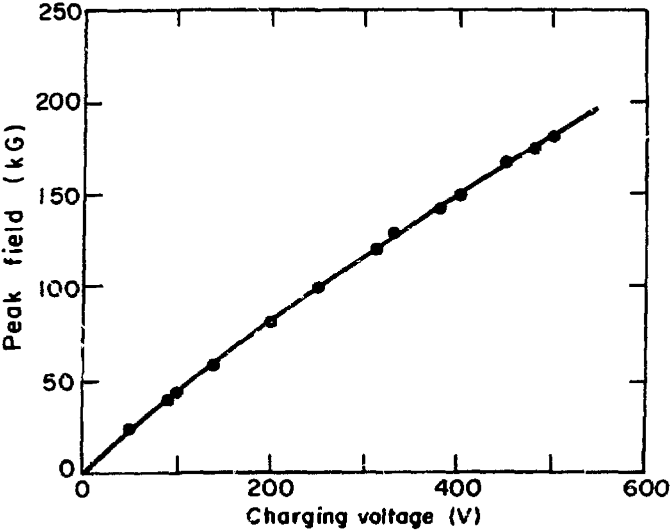

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Fig. 4 Variation of peak field as a function of capacitor bank charging voltage.

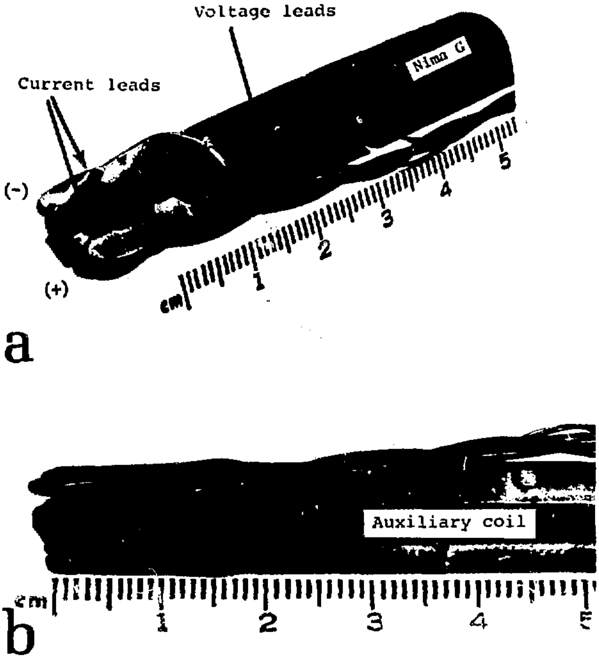

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Fig. 5 (a) - Front, and
(b) - back views of the sample probe.

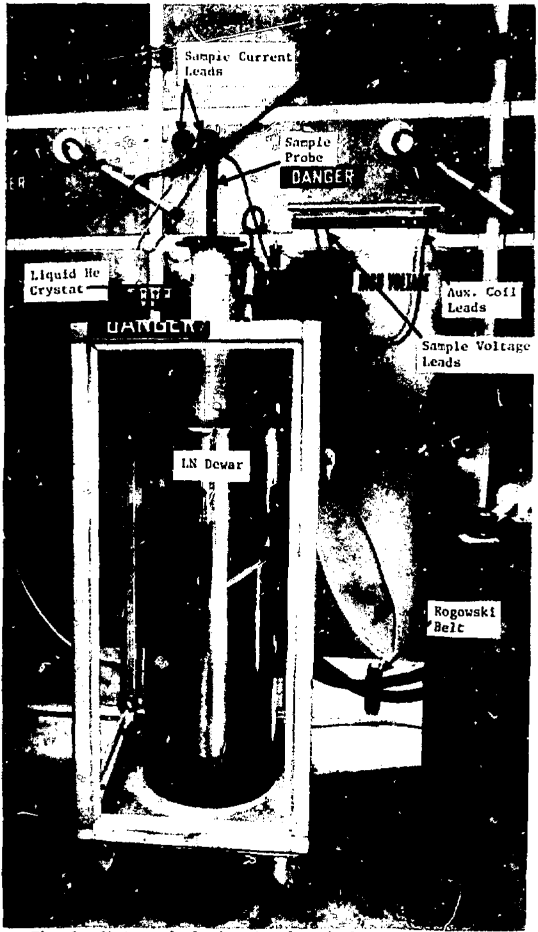

Fig. 6 Photograph showing the electrical connections to the sample probe at the cryostat.

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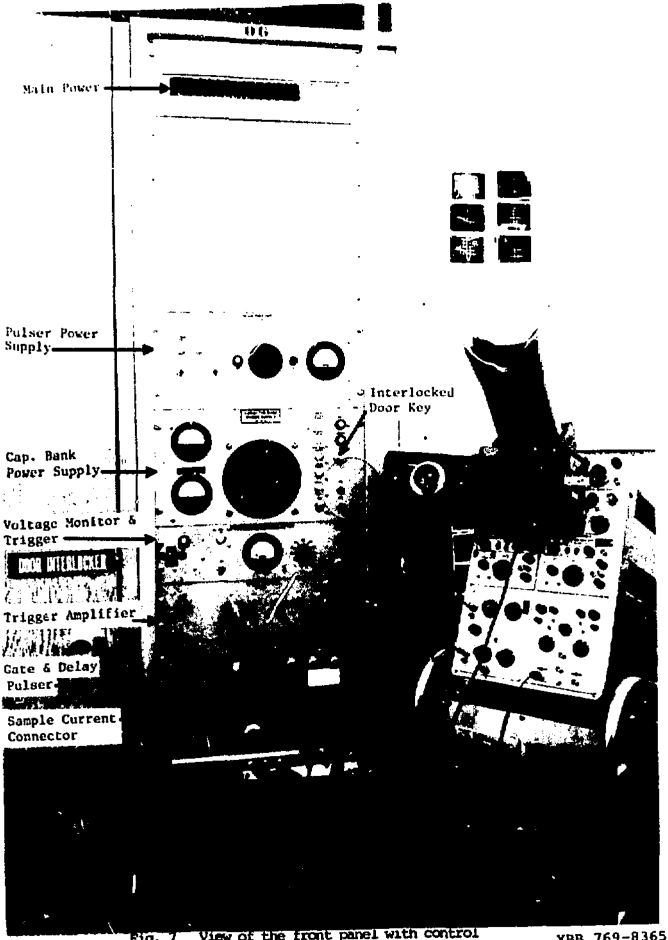

Fig. 7 View of the front panel with control units, and connections leading to the oscilloscope.

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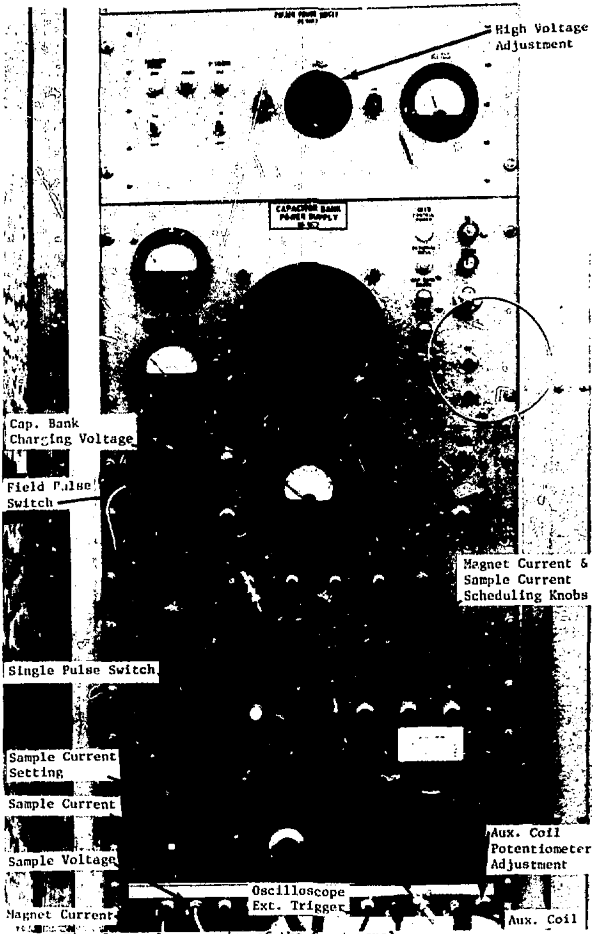

Fig. 8 A close-up view of the front panel detailing the different electrical controls, switches and output leads.

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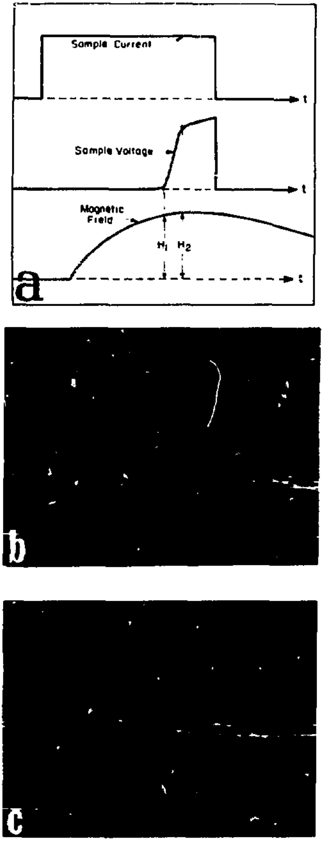

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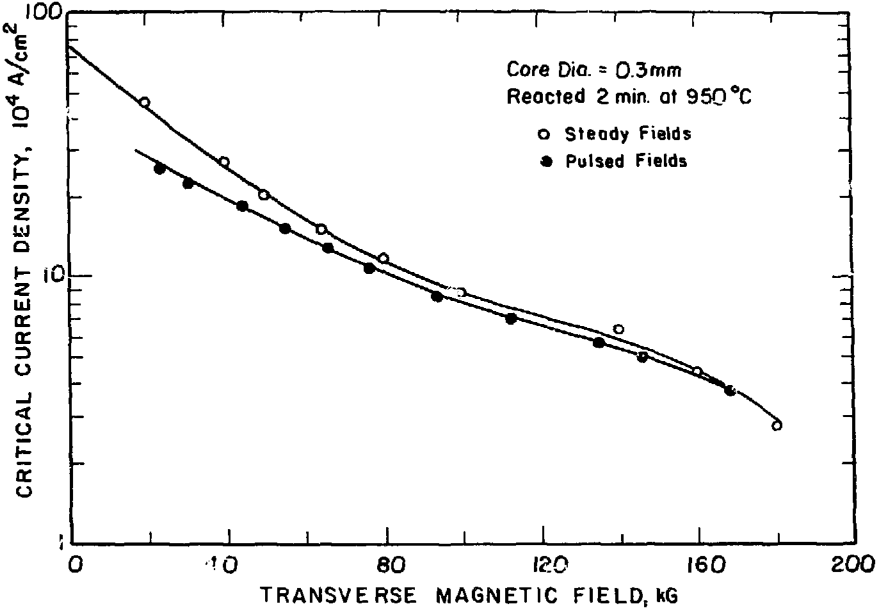
Fig. 9 Typical oscilloscope tracings of sample current, sample voltage and magnetic field. Fields H_1 and H_2 in (a) correspond to the beginning and the end of the S-N transition. Tracings in (b) and (c) are recorded at low field (H_{max}=67 kG) and high field (H_{max}=174 kG) pulses respectively. The horizontal scale in both (b) and (c) is 2 milliseconds per cm.



XBL 7512-9472 A

Fig. 10 Critical current density of Nb+Nb_3Sn core as a function of magnetic field under pulsed and steady field conditions.