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EP&S DIVISION TECHNICAL NOTE

No. 43

MEASUREMENT OF RADIATIVE HEAT INPUT TO OBJECT NEAR AN EXTERNAL PROTON BEAM TARGET

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Introduction

The slow external proton beam of the AGS (SEB) carries fairly large amounts of energy. For example if there are 10^{12} protons extracted per AGS cycle and the repetition rate of the AGS is 1.8 sec, the average energy of the beam is $\sim$ 2500 watts. If the beam strikes a target, most of this energy is deposited not in the target itself but in objects downstream of the target, for example, magnets of secondary beams. With room temperature copper magnets this heat load is negligible compared to I^2R losses, and the water cooling of the copper conductors can easily dispose of this additional heat. On the other hand, if the front-end elements of secondary beams are cryogenic or superconducting, the heat load due to secondary particles from the primary target may be large compared to the heat load from other sources. A superconducting septum magnet has been proposed for Phase II of the medium energy separated beam at target station B. Before proceeding with the design of such a septum, it seems prudent to make a measurement of the heat input to a piece of dense material in the vicinity of a primary target to determine whether such a septum is feasible. This report describes a measurement of the heat input to a block of copper that was placed near target station A of the SEB in approximately the position that would be occuped by a septum magnet.

Experimental Method

There are two problems that make the measurement of heat input to a secondary target difficult: (1) Fluctuations in the room temperature mask the very small input to the sample (2) The yield of the AGS is erratic in time so that it is not easy to estimate the average number of protons incident on the primary target. To overcome these difficulties, a technique was used in which the AGS intensity fluctuations could be used to advantage. The present AGS operation is characterized by frequent shutdowns of 10 minutes to an hour in length with fairly steady intensity the rest of the time. Thus the AGS provides a "chopped signal" heat input that can be detected above the room temperature fluctuation noise. Two sensing elements were placed in the secondary beam cave. One of these was placed so that it would be illuminated by secondary particles from target station A. The other was placed behind about 75" of iron shielding so that it would be exposed to the same ambient room temperature but receive a negligible flux of secondary particles. Measurement of the activation showed that the illuminated element received at least 40 times more flux than the shielded element (neutrons, which are more important for activation than charged particles, could be expected to penetrate rather easily the iron shield; on the other hand it is the charged particles that make the important contribution to heating, and these should be mainly stopped by the iron). The sensing element was placed 40 in. downstream and 5-in. off axis with respect to target station A. Target station A was .200 in. x .100 in. x 4.73 in. beryllium. Each element consisted of a piece of copper 1/2 in. x 1/2 in. x 2-3/4 in. weighing 100 $\pm$ .5 gm, enclosed in a styrofoam thermal shield. Each element had a thermocouple embedded in it and was surrounded by a nichrome wire heating element. The thermal time constants were measured: 56.3 minutes for the illuminated element and 53.2 minutes for the shielded unit. The thermocouples were arranged so that when both blocks of copper were at the same temperature zero voltage is produced. Figure 1 shows a schematic diagram of the experiment. The idea is to drive the reference element in such a manner that its temperature will track the temperature of the illuminated block through any variations of AGS intensity. Protons incident on target station A pass through the R25 secondary emission chamber (SEC) and generate a signal that is converted into a voltage by the SEC integrator. This voltage is converted into time by means of a standard ramp technique and the time is used to switch a voltage V_o into the heater coil of the reference block. Note that the heat input is linear with SEB intensity; driving the reference element with the SEC voltage directly would produce a signal that varied as the square of the SEB intensity. The experiment consists of finding a voltage, V_o, for which the temperature in the two copper blocks will track and the effect of the AGS is cancelled. Some typical data is shown in Figure 2. In this figure, heating the sensing element pulls the pen to the right, and heating the reference block pulls the pen to the left. The other channel displays the SEC voltages and serves mainly to tell when the AGS shuts off. When V_o is 20 volts the pen is pushed to the right by the AGS and the slope changes to the left when the AGS goes off. Thus 20 volts is not enough. When V_o is 30 volts, the pen is pushed to the left by the AGS, and the slope changes to the right when the AGS goes off; thus 30 volts is too much. Figure 3 shows similar data for V_o = 25 and 28 volts. The gain in the chart recorder has been increased here, and the signal is noisier; it appears that 25 volts is too little and 28 volts is too much. On the basis of the data in Figure 3 we have taken

(1) $$V_o = 26.5 \pm 1 \text{ volt}$$

as the voltage needed to balance the heat input to the illuminated element using the circuit of Figure 1.

Analysis of Data

The heat input to the reference element for 10^{12} protons through the SEC is given by

$$J = (\tau/K)\, V_o^2\, R_1/(R_2 + R_1)^2$$

where V_o is the voltage needed to balance as determined above

τ is the conversion constant of the voltage to time circuit. This was held at .1 scr/volt during the experiment

K is the calibration constant of the R25 SEC. This was measured on 1/14/72 as $.96 \times 10^{11}$ protons/volt[1]

R_1 is the resistance of the heater coil in the reference element; this was 85.7 ± .1 volt.

R_2 was a series resistance, 251.9 Ω, that was used as shown in Fig. 1

so as to allow V_o and τ to have convenient values. Substituting the above values into equation 2 we find

(3) $$J = 5.50 \pm .45 \times 10^{-2} \text{ joules}/10^{12} \text{ protons.}$$

This is then the heat input to a 100 gm piece of copper 40 in. downstream of target station A. The error in (3) is assumed to be the error in estimating V_o from the data of Fig. 3. There is also some probable error, which is very hard to estimate but probably also on the order of 10%, in the calibration of the R25 SEC. Other errors are probably of minor importance. The time deviation of the heat pulse included some delay due to the mechanical opening and closing of the mercury-wetted relay. A calibration circuit was used to measure the relay closed time on every pulse. This could be compared with the R25 SEC readout, so it was possible to hold the value of τ to the desired 100 msec/volt within about 1% throughout the experiment in spite of the tendency of relay opening and closing times to change after many thousands of cycles of operation.

Conclusions

Very roughly a superconducting magnet for the B station MESB might have 5 kG of superconductor and 100 kG of iron exposed to a heat flux comparable to that measured in this experiment. Scaling up (3) and assuming 4×10^{12} protons/pulse with a 2 sec AGS rep. rate, we find that the heat input to the superconductor would be 6 watts and to the iron,120 watts. The latter figure is clearly unacceptable for 4°K cooling,and the MESB septum would have to be designed so that the coil itself is thermally isolated from the iron return yoke. A 6 watt heat load at 4°K is possibly acceptable, but it would be easier to handle this load at 20°K. Serious consideration should be given, therefore, to a cryogenic rather than a superconducting septum.

There is, moreover, the possibility that this experiment seriously underestimates the heat input that would occur to a septum for the following reasons: (1) The A target was only $\sim .25$ interaction lengths; the B target is likely to be longer. (2) The sensing element was placed at a farily large angle $\sim 7.1^{\circ}$ with respect to the A target; because of vacuum pipes it was not possible to get closer. A septum would have to be at $\sim 2^{\circ}$ with respect to the B target. (3) The sensing element was a rather small piece of copper. Because of cascade effects a thick septum may be more efficient in removing heat from the secondary particle flux at B station. For these reasons it appears prudent to consider (3) as a lower limit to the heat input that would be experienced by a septum in the vicinity of target station B.

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References

1. G. Bennett. Private communication Jan. 1972.

Distribution: C.T. Murphy, Carnegie-Mellon, AGS Div. Staff, EP&S Div. Staff.

FIGURE 1

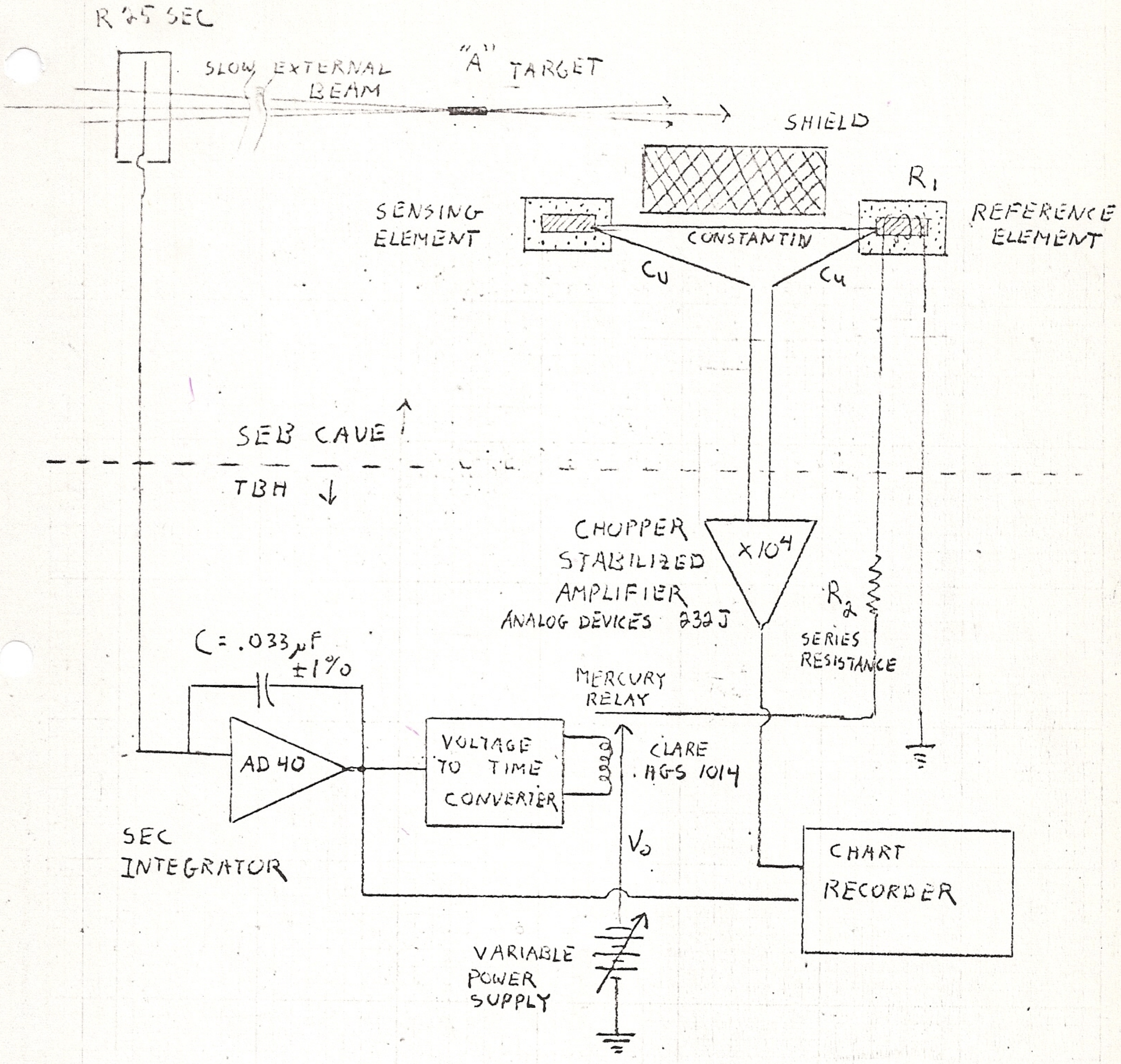

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FIG. 2

V_o = 20V

V_o = 30V

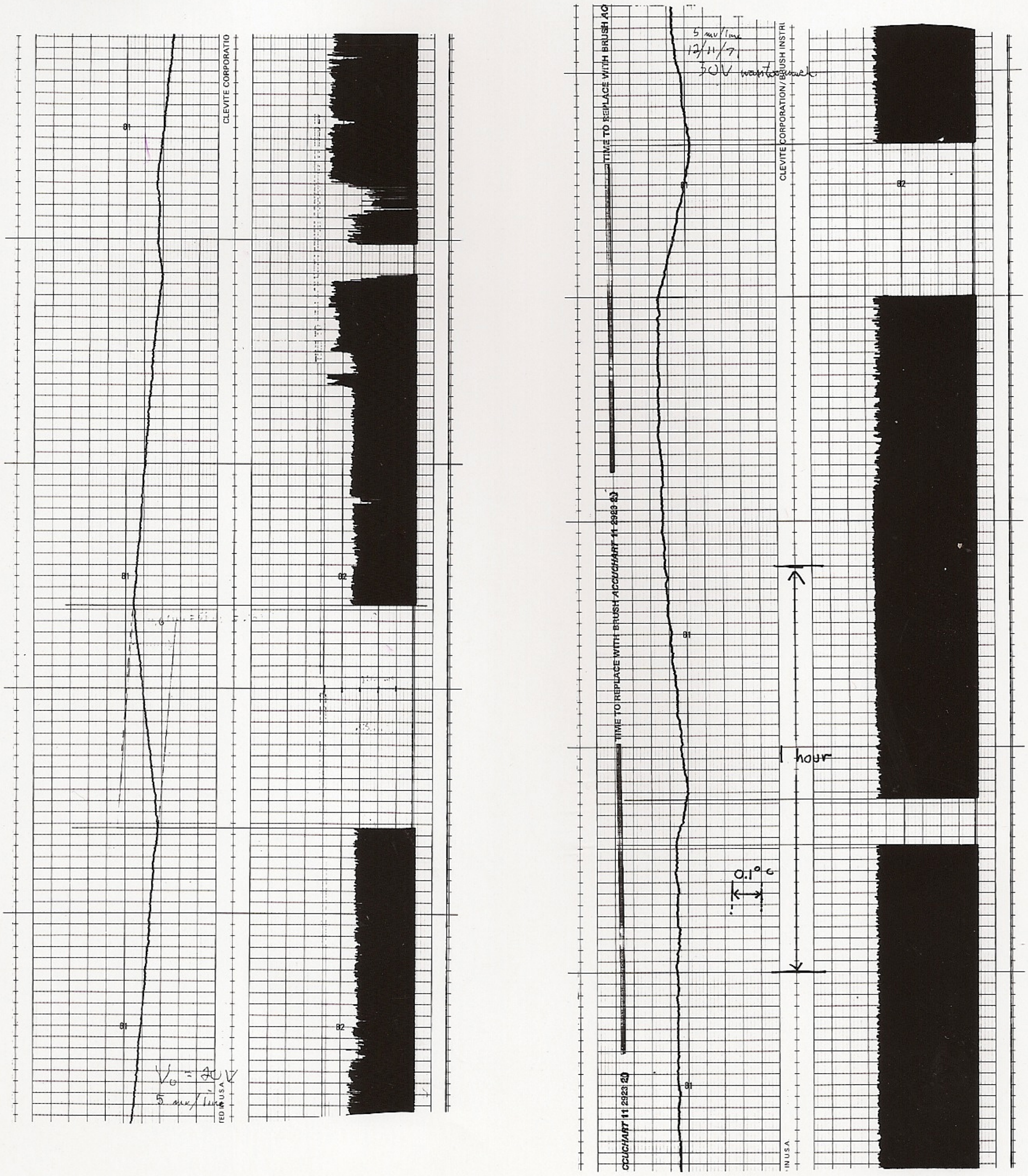
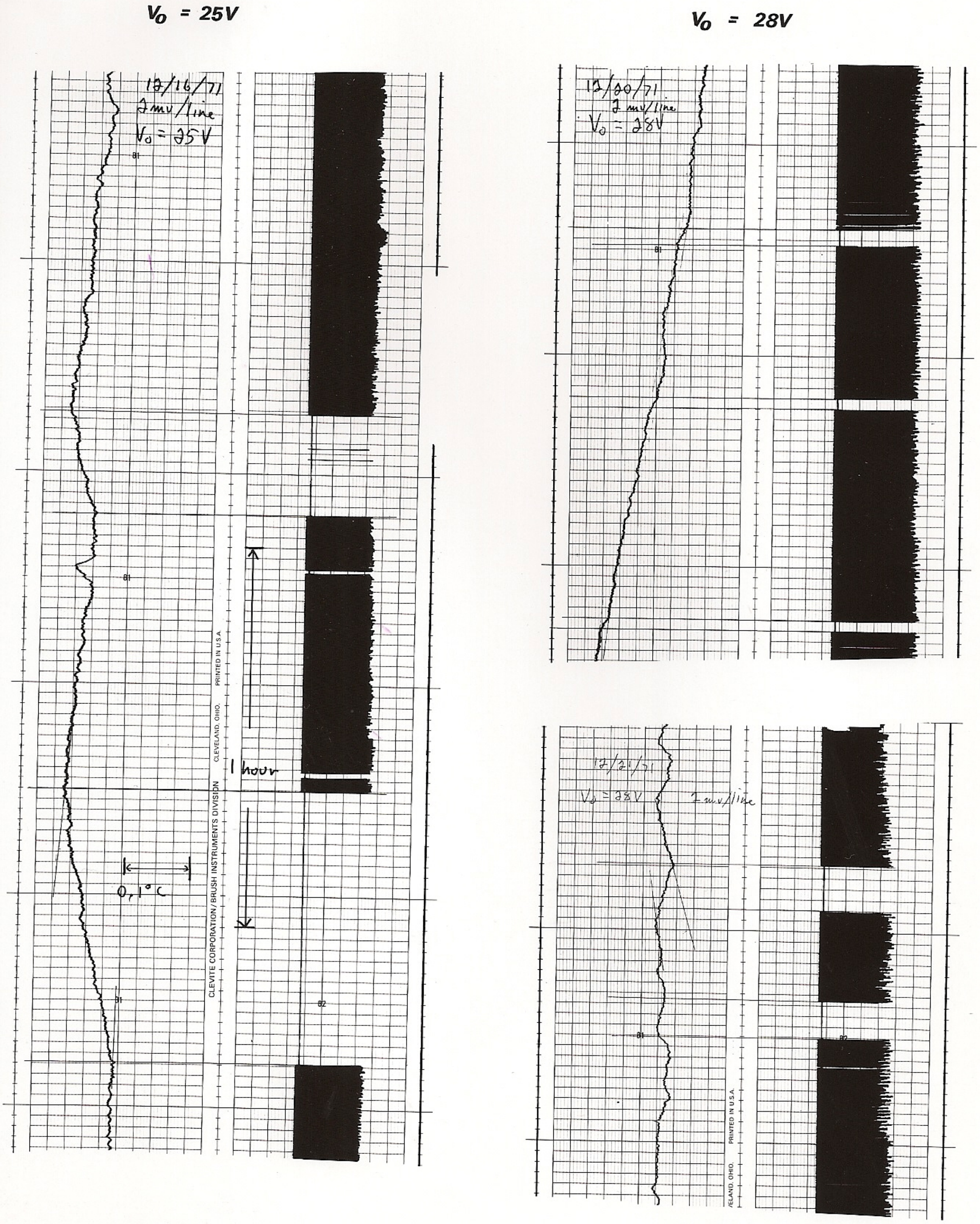


FIG. 3



V_o = 25V
V_o = 28V
12/16/71
2mv/line
V_o = 25V
1 hour
0.1°C
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12/20/71
2 mv/line
V_o = 28V
12/21/71
V_o = 28V
2 mv/line
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