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EVALUATION OF A METHOD TO SHIELD A WELDING ELECTRON BEAM FROM MAGNETIC INTERFERENCE

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16. ABSTRACT

It is known that electron beams are easily deflected by magnetic and electrostatic fields. Therefore, to prevent weld defects, stray electromagnetic fields are avoided in electron beam welding chambers if at all possible. Since all stray fields may not be eliminated due to uncontrollable circumstances, this report discloses the successful results of tests conducted at MSFC to evaluate a simple magnetic shield made from steel tubing. Tests indicate that this shield was up to 85 percent effective in reducing magnetic effects on the electron beam of a welding machine. In addition, residual magnetic fields within the shield were so nearly uniform that the net effect on the beam alignment was negligible. It is concluded that the shield, with the addition of a tungsten liner, could be used in production welding.

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PURPOSE

The purpose of this report is to describe the results of a series of tests conducted to evaluate a method of magnetically and electrostatically shielding the electron beam (EB) of an electron beam welder during welding operations to prevent unintentional deflection of the beam by stray magnetic fields. Although the evaluation procedure was not totally comprehensive, it was conducted in sufficient depth to prove that a simple concept would provide shielding and not adversely affect beam alignment.

BACKGROUND

In November 1974 it was learned that Rocketdyne was possibly experiencing magnetic or electrostatic deflection effects during a critical SSME electron beam welding operation. In this case the beam had to travel 20 to 23 cm (8 to 9 in.) from the exit end of the EB gun to the workpiece. This distance is sufficient in length to leave the beam vulnerable to the effects of relatively weak magnetic fields. Laboratory Support Branch of the Materials and Processes Laboratory was directed to investigate the possibility of magnetically and electrostatically shielding the beam with a simple tube. There was no doubt that the tube would help shield the beam, but the magnitude and overall effects of residual magnetic fields within the tube were of major concern.

DISCUSSION

It is known that the deflection of an electron beam is very closely described by the following relation[1] and Figure 1:

$$\frac{D}{B} = \frac{\ell L}{\sqrt{E_a}} \sqrt{\frac{e}{2m\,10^9}} \text{ cm/gauss} \quad , \qquad (1)$$

where B is the magnetic field strength in gauss, D is beam deflection at the impingement point, e is the electron charge (1.601×10^{-19} coulombs), E_a is the accelerating voltage, ℓ is the length of a constant magnetic field acting on the beam, L is the average distance from the magnetic field to the beam impingement point, and m is electron mass (9.10×10^{-28} grams).

Since $\sqrt{\frac{e}{2m\,10^9}}$ is very nearly a constant, the formula can be condensed to:

$$\frac{D}{B} = \frac{\ell L}{\sqrt{E_a}} (0.296) \text{ cm/gauss} \quad . \qquad (2)$$

Again, if one assumes that a uniform magnetic field of average length $\ell = 20$ cm prevails along the full length of the beam (20 cm), then L = 20 cm/2 = 10 cm. Also, assuming that the welding voltage is typically 47 kV,

$$\frac{D}{B} = \frac{20 \times 10}{\sqrt{47\,000}} (0.296) \times 10 \text{ mm/cm} = 2.73 \text{ mm/gauss} \quad .$$

Since ± 0.50 mm (± 0.020 in.) is about the maximum deviation which can be tolerated from the true centerline of a typical EB weld, it can be seen by solving for B that the maximum tolerable field strength of this hypothetical situation is:

1. Millman and Seely: Electronics. McGraw-Hill, New York, 1941, p. 71.

$$B = \frac{0.50}{2.73} = 0.183 \text{ gauss} \quad .$$

Of course, if ℓ and L are close to the work, then the average magnetic strength which can be tolerated is much greater, perhaps 10 to 20 times greater. Therefore, the critical portion of the beam which must be protected is that part which is farthest away from the workpiece, i.e., closest to the EB gun. Also, since the beam deflects at right angles to the magnetic field, it is most important that any shield bypass fields which are in a plane parallel to the weld joint.

Electrostatic deflection is somewhat different in that the beam is sensitive according to the following relation[2] and Figure 2:

$$S = \frac{\ell L}{2 d E_a} \text{ cm/volt} \quad , \tag{3}$$

where d is the distance between electrostatic plates, E_a is the accelerating voltage, ℓ is the length of electrostatic field (cm), L is the average distance from electrostatic field to beam impingement point, and S is sensitivity in cm/volt.

It is obvious from the inspection of equation (3) that, unless a part is being welded close to a glass window or some nonmetallic material, there is little danger of the beam being significantly affected by an electrostatic field. However, either possibility exists. Unlike magnetic fields, the electron beam will be attracted directly toward the positive plate of an electrostatic field. Fortunately, electrostatic fields can be easily blocked with a ground plane, such as screen wire, so that it is usually easy to eliminate problems caused by electrostatic fields. Also, the same shield which bypasses a magnetic field will also block the effects of an electrostatic field if the shield is at ground potential. Based on this argument, electrostatic shielding was not further considered.

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2. ibid, p. 63.

SHIELD AND TESTS

Laboratory Support Branch designed a magnetic shield consisting of a piece of 2.54 cm (1 in.) cold rolled steel tubing threaded to screw into an aluminum adapter plate bolted on the exit end of an ERI Company electron beam gun (Fig. 3). The cold rolled steel tube was deliberately slit from end to end about 0.80 mm wide to provide an air gap the total length of the tube. The purpose of this air gap was to minimize circulating currents in the shield. To aid in evacuating the gun, the tube was also drilled near the top with four 1.25 cm holes. It was decided that a series of test welds would be run on Inconel metal by starting the weld without a magnetic field and then applying the field after several centimeters of weld. Next, the shield would be installed and the test repeated to determine the effectiveness of the steel pipe shield in reducing beam deflection. Finally, without disturbing the setup, the beam would be rerun over the first part of the weld, where the magnetic field was purposely not applied, to check for the effects of residual magnetic fields in the shield. The test apparatus is depicted in Figures 3 and 4 to illustrate how the regular ERI X-Y beam deflection coil was lowered to a point approximately midway the shield. During the tests, voltage was always applied simultaneously to the coils which cause both cross-seam and in-line beam deflection. Also, the field strength magnitude was held constant throughout the test series.

TEST RESULTS

Initially, it was thought that several tests would be necessary, but the results were so consistent that testing was stopped after only four tests had been completed. The first test, Weld No. 1, was made without the magnetic shield (Fig. 5). At point A (shown in Figure 5) the X-Y deflection coils were energized and the beam deflected 1.11 cm (0.437 in.) to point B where the bead-on-plate run continued until it was terminated. Note that the beam was also deflected backward since both X and Y coils were energized. This weld was made with 47 kV and 20 mA beam current. Next, the magnetic shield was installed with the slit at right angles to the direction of welding, and the weld begun at Weld Start over the previous weld. This time, the weld continued to point C (Fig. 5), where the X-Y coils were energized. The beam deflected only 0.158 cm (0.0625 in.) and continued uniformly straight (see Weld No. 2, Figure 5) until the run was stopped. After completing the weld with the X-Y coils energized, the coils were de-energized and another pass was made over the initial portion of the weld for a distance of 5 to 10 cm to check for disturbance from residual magnetic fields. No disturbance was detected. Next, test welds 3, 4, and 5 were made at weld currents of 20, 50, and 85 mA, respectively, to see if higher currents would induce sufficient residual magnetism in the shield to cause problems. The results were the same as Test No. 2, in that the 1.58 mm deflection remained constant after energizing the X-Y coils, and a final run back over the initial length of the weld visually indicated no deflections due to residual magnetism or any other cause.

It should be noted that the steel tube alone should not be used for production welds due to the possibility of alloying some of the steel tube into the weld. It would be safer to line the tube with a thin shell of tungsten which would not vaporize as quickly as steel due to stray electrons. Otherwise, the shield design was satisfactory and is easy to build and modify.

POST TEST EVALUATION

After the tests were completed, the X-Y coils were removed from the ERI gun and tested in the laboratory with a Model 660 F. W. Bell Digital Gaussmeter and a No. Z0B6-3236 F. W. Bell 3-axis magnetic flux probe. The X-Y coils were energized with the same value current used during the five weld tests, and a magnetic flux plot of the cross-seam deflecting field strength was made. This plot is shown in Figure 6. By sectioning this plot into three parts and computing the effect on the beam from each part using equation (1), it was verified that the measured field strength measurements and beam deflections were mathematically consistent.

DISCUSSION OF RESULTS

The results of these tests indicate that the simple steel tube is up to 85 percent effective in magnetically shielding the beam. Since steel does not have a particularly high magnetic permeability, it certainly is not the optimum magnetic shield material. On the other hand, it performed well enough for most production applications since EB welding chambers are purged of any significant magnetic fields as a matter of normal housekeeping.

It is significant that the residual magnetic fields in the steel tube had no visible effect on the beam. This is noteworthy because very small magnetic fields can cause major perturbations in the electron beam alignment as evidenced by the calculations in the text of this report. The classical explanation is that, while it is known that residual fields exist in the steel tube, the fact that the tube is round causes the fields to be distributed almost uniformly and the net effect of the residual magnetism is near zero. Only one type shield was tested and additional work could be performed to improve the technique if some special welding problem justified the effort.

CONCLUSIONS

It is concluded that the electron beam can be easily magnetically and electrostatically shielded by a simple steel tube. The shielding technique which was tested is not elaborate, in fact it is very simple, but it proved very effective during this evaluation and could be used in EB welding operations where the beam must travel a considerable distance. Three basic precautions which should be taken in designing any production type electromagnetic electron beam shield are:

1. Do not allow a path for circulating currents.

2. Provide a tungsten liner inside the magnetic shield to prevent sputtering of any shield constituents into the weld.

3. Provide adequate openings near the exit end of the EB gun to assure proper vacuum pumping of the gun.

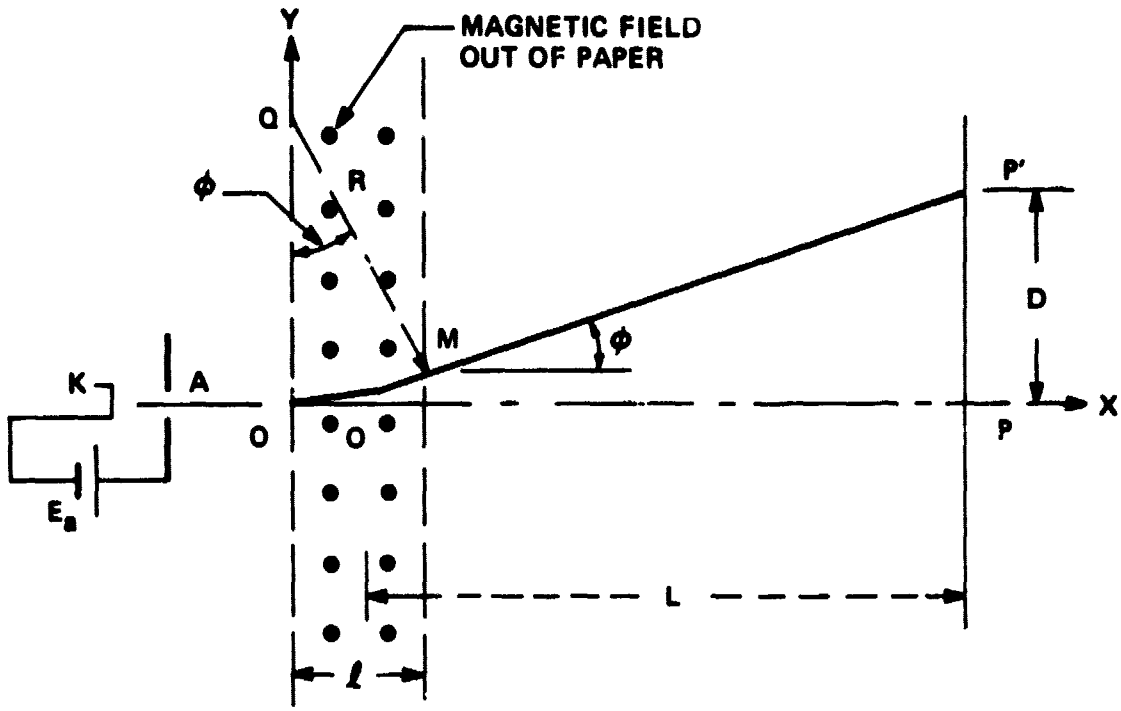

Figure 1. Magnetic deflection in a cathode ray tube.

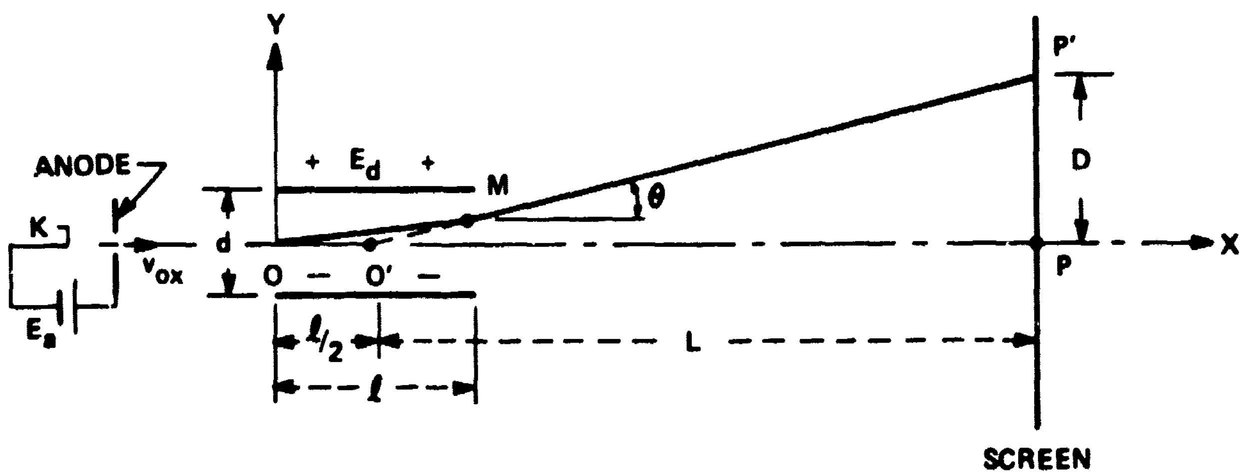

Figure 2. Electrostatic deflection in a cathode ray tube.

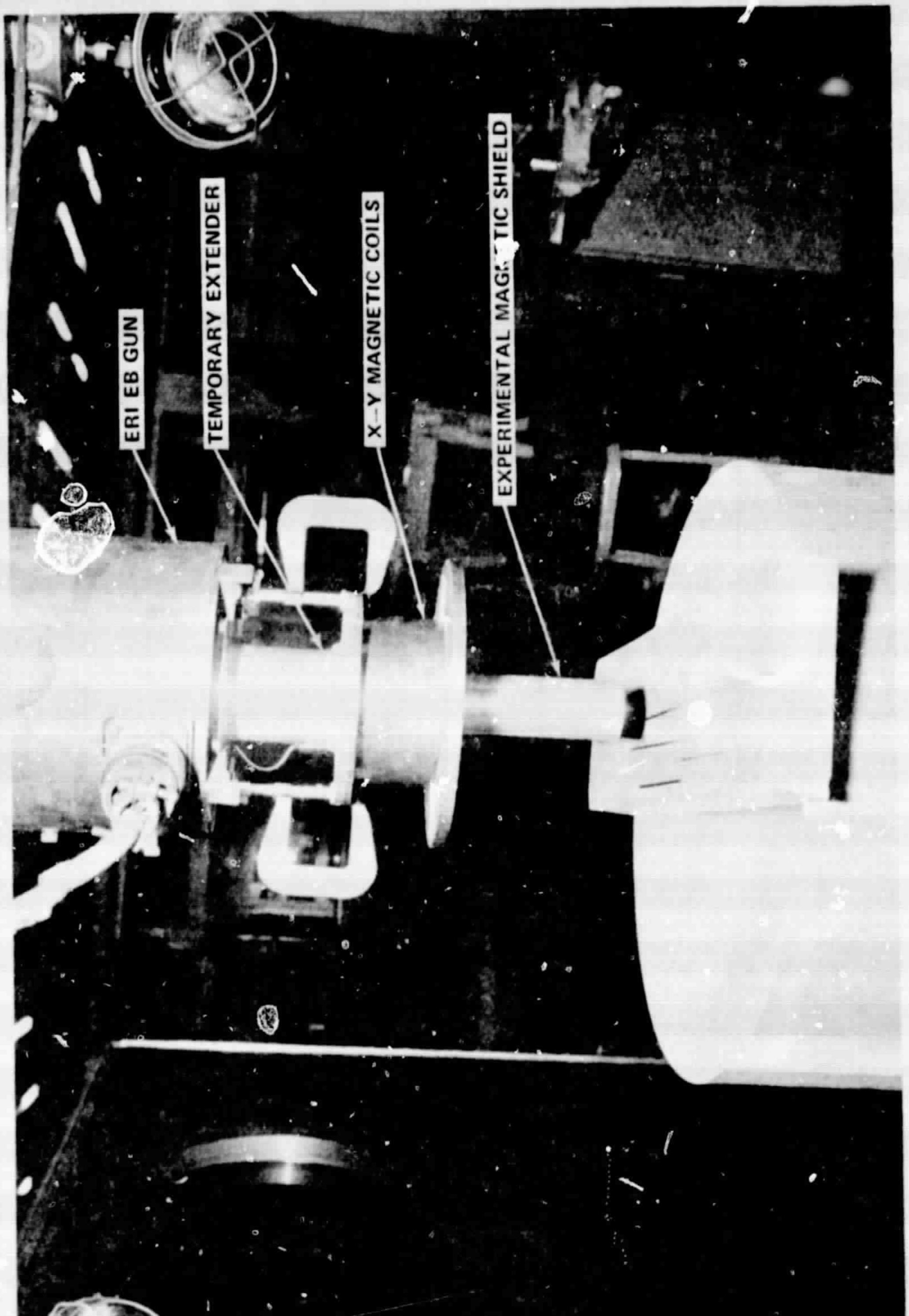

Figure 3. Magnetic shield test setup.

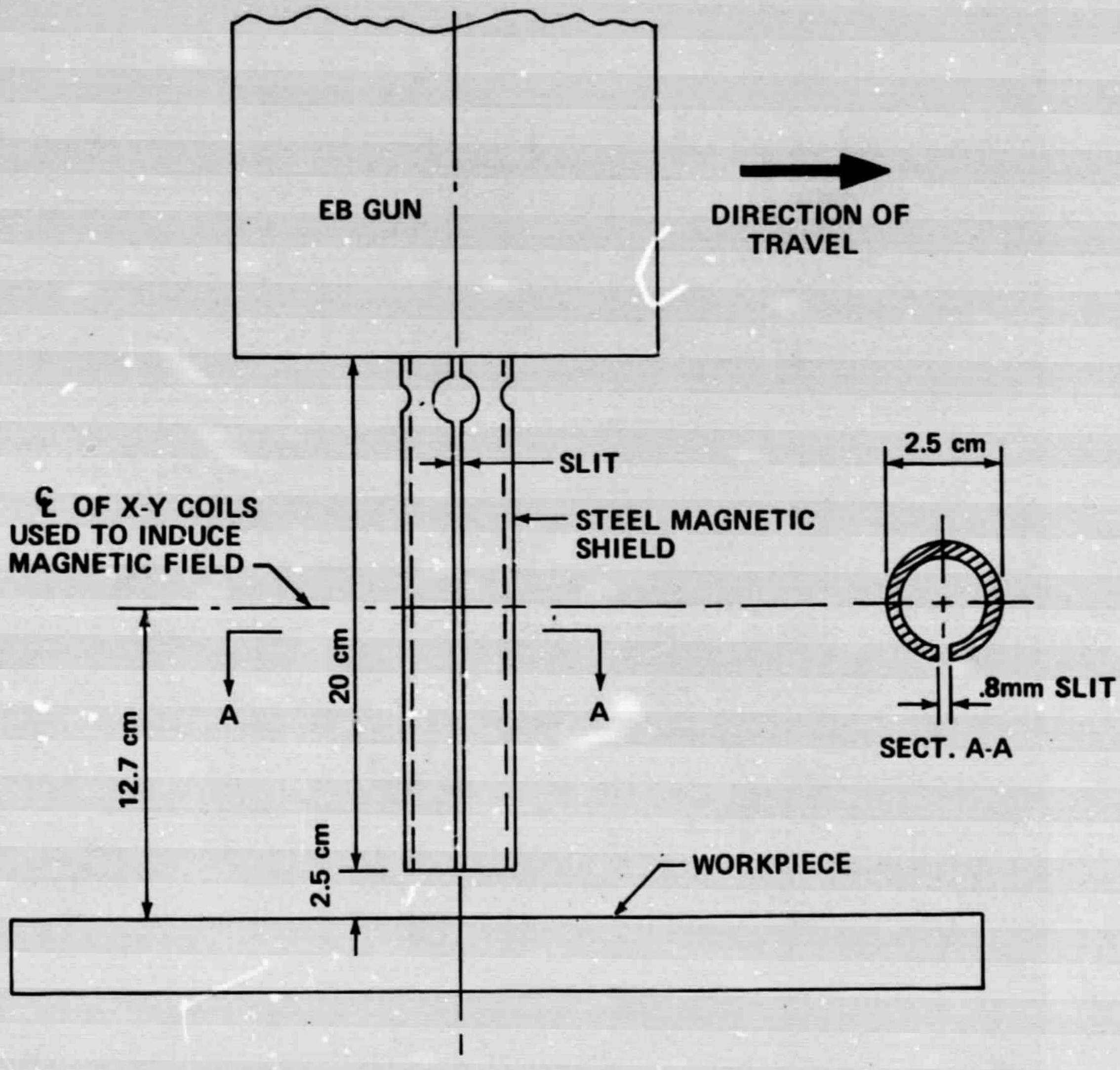

Figure 4. EB magnetic test shield.

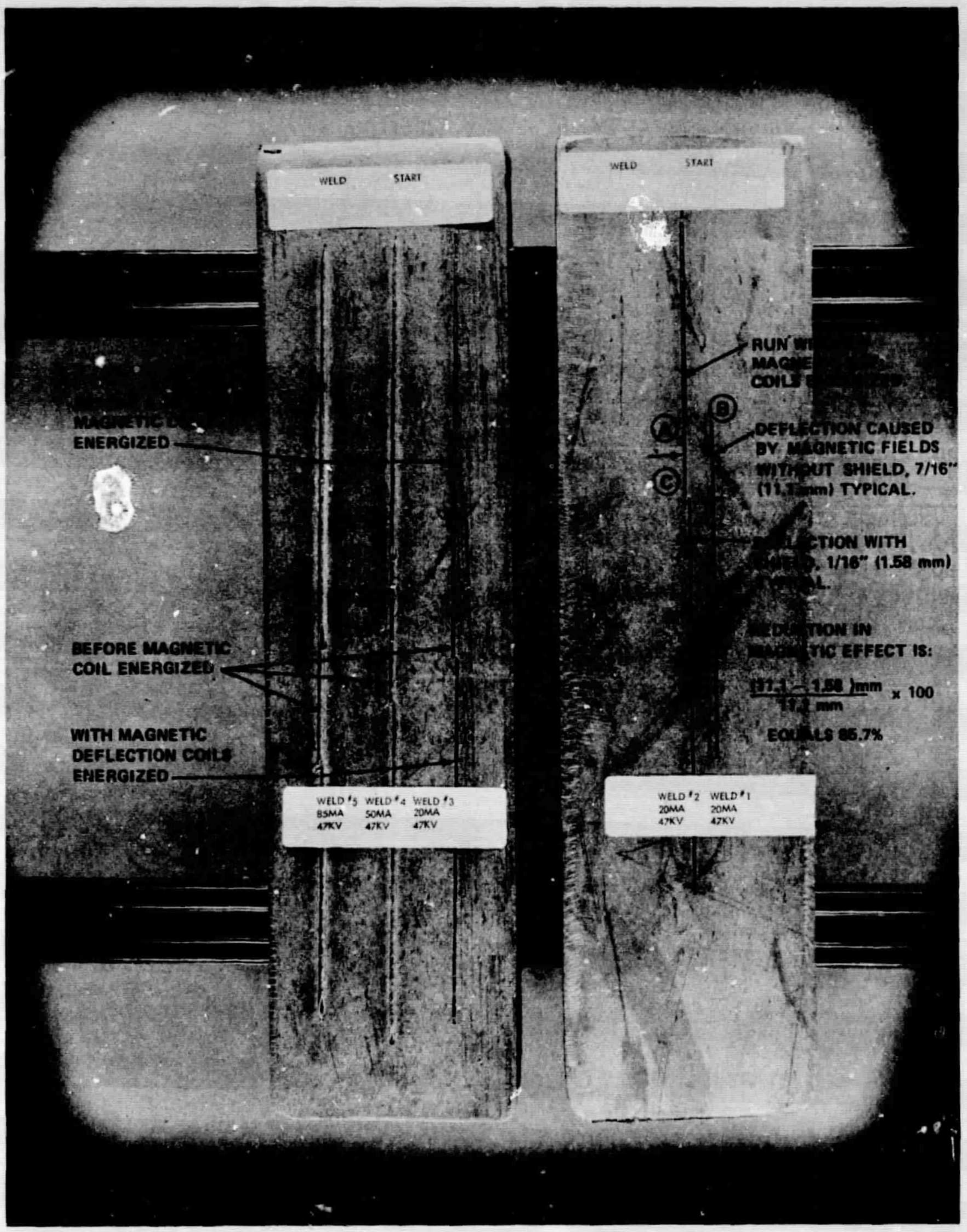

Figure 5. M[illegible]netic shield weld test specimen.

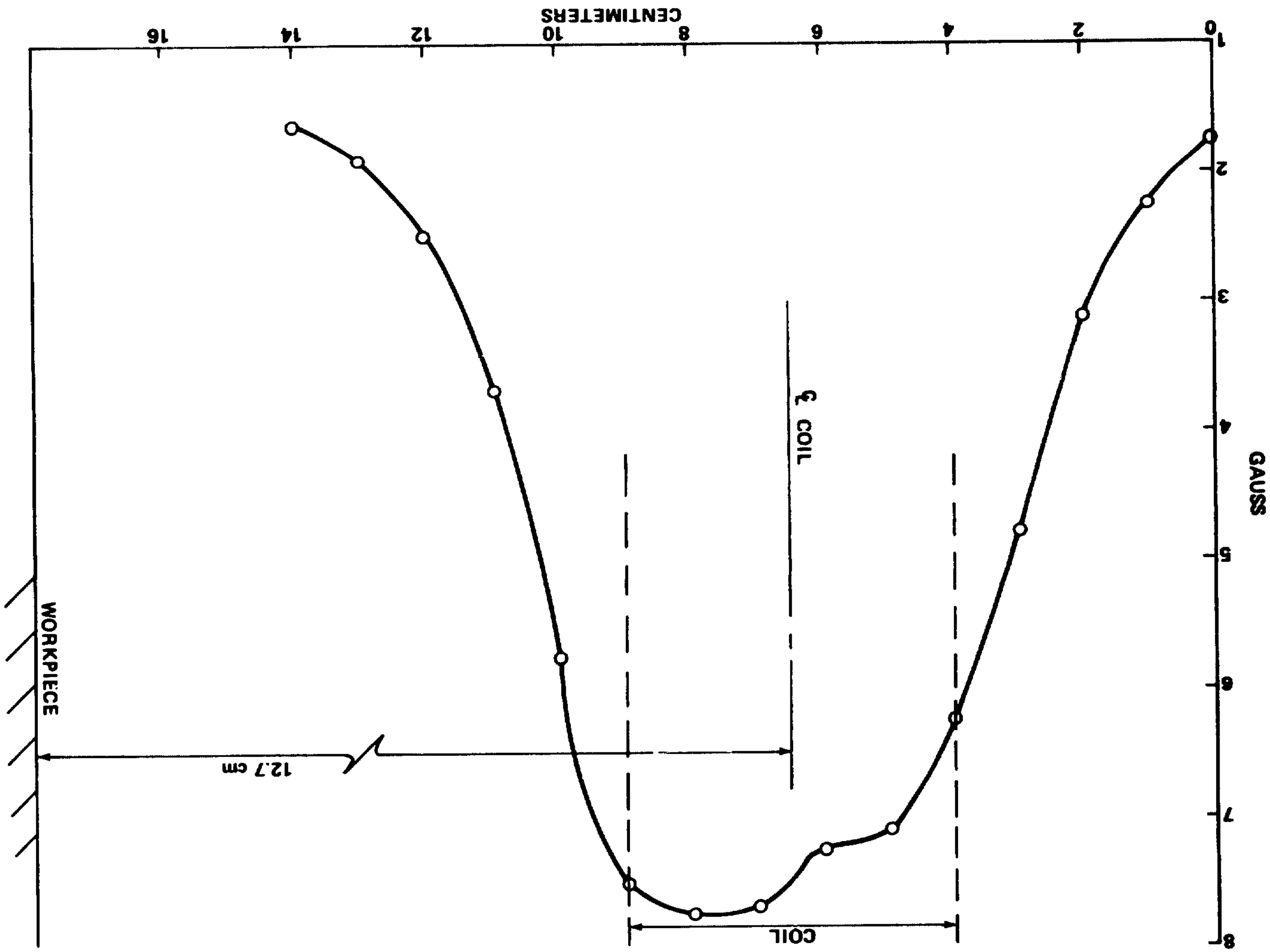

Figure 6. Plot of flux field in direction to cause cross-seam deflection.

APPROVAL

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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