NASA TECHNICAL MEMORANDUM

Report No. 53966

ARC GUIDANCE DEVELOPMENT WORK FOR TACK-WELDED JOINTS

By James Chadbourne and W. A. Wall
Manufacturing Engineering Laboratory

November 17, 1969

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

MANUFACTURING DEVELOPMENT MEMORANDUM May 13, 1965
MDM-R-ME-ME-5-65

Changed to TM X-53966
vember 17, 1969

ARC GUIDANCE DEVELOPMENT WORK FOR TACK-WELDED JOINTS

By
James Chadbourne
W. A. Wall

ABSTRACT

Research into the behavior of MSFC's electro-inductive arc guidance transducer around tack welds has produced invaluable data about weld ripple frequency pickup in the transducer. Corrective circuitry was designed and employed to eliminate pickup noise and counter its undesirable side effects. In an attempt to "leap-frog" long tack welds, a reliable tack weld detector was developed to sense approaching tack welds. This sensor is perhaps the most significant development to result from this phase of the program.

It is concluded that the present MSFC system should not be located close to the torch when tack welds are employed to hold the weld joint; however, it is recommended that the present electro-inductive system should be considered a boon for the development of an automatic tack welder because of its homing capabilities. With a memory system, it seems feasible that the MSFC developed system could be used with short tack welds.

As an evaluation aid, a comparison of MSFC's transducer with the latest optical tracking transducer is drawn to emphasize the strengths and weaknesses of each transducer.

James Chadbourne
James Chadbourne
Automation & Design Section

W. A. Wall
W. A. Wall
Chief, Automation & Design Section

J. D. Bennight
J. D. Bennight
Chief, Experimental Electronics
Development Branch

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTION

At the time inductive arc guidance equipment was being prepared for use on the Saturn S-IC meridian welder, it was determined that the final solution to holding bulkhead gore sections together was to tack weld the joints. Simultaneously, work on the 200-inch experimental multicell indicated that the same procedure was necessary to align and hold the cell parts together. This requirement completely voided the immediate use of any type of arc guidance equipment, either optical or induction. Furthermore, work on the 200-inch experimental multicell tank clearly demonstrated that tracking tack welded joints was a necessity for welding tanks of that complexity. Although tack welded joints present numerous process problems, this technique is the best method of economically holding large parts together. The difficulty remains, however, that the weld arc should center the unfused portion of the tack welded joint.

In addition to the problem of tack welds, the system continued to drive the torch approximately 1/16 of an inch to the left of the seam upon ignition of the arc.

A study was undertaken to analyze both of these problems. This study resulted in the complete elimination of the pullover condition upon arc ignition and in a partial solution to welding over tacks.

DISCUSSION

A. Weld Current Induced Pickup

Manufacturing Development Memorandum, MDM-R-ME-ME-3-63, dated September 20, 1963, explained the difficulty encountered with tack welded joints and the reasons for favoring of 300 cps over 60 cps as a tracking frequency. However, signal analysis showed that the 360 cps weld current ripple induced a signal in the seam tracking transducer output that was 100 times greater (300 MV to 3 MV) than the 400 cps tracking signal output. Incorporation of a 400 cps bandpass filter in the transducer output line failed to eliminate the 360 cps pickup. When this failed, three major steps were taken:

1. The tracking frequency was lowered to 215 cps to provide enough separation between the tracking signal and the pickup to permit the pickup to be filtered out.

2. A five-stage, cascade, electronic filter-amplifier was developed to filter the pickup signal and pass the tracking signal. The signal passed is down 30 db at frequencies 25 cps on either side of 215 cps.

Steps 1 and 2 successfully eliminated the amplitude effects of the pickup, but the culprit proved to be the phase shift that the ripple signal caused in the tracking signal. The demodulator (Figure 10) is a phase sensitive circuit that produces a d.c. output only when the phase relationship between its reference input and signal input varies. Because of this phase sensitivity, pullover of the torch still occurred upon ignition of the arc. This condition led to step three:

3. A bias circuit was incorporated to compensate for the tracking signal phase shift caused by the 360 cps pickup.

The nature of the 360 cps pickup and its effects are discussed more thoroughly in Section B.

B. 360 CPS Pickup

The transducer and its associated output bridge circuitry are presented schematically in Figure 3. An equivalent bridge circuit is shown in Figure 4. Because the induced voltages, E_1 and E_2, are of the same polarity, the sum of the clockwise voltages between B and A will be equal and of opposite polarity to the counterclockwise voltages. The output, E_o, is the vectorial sum of E_1 and E_2. The balanced condition, where Eo is zero, is represented in Figure 5.

The unbalanced condition is illustrated in Figure 6. Before examining the unbalanced vector diagram, the following should be noted:

1. The term "unbalanced" means that the transducer is not centered over the seam.

2. Test data indicated that as the transducer moves away from the seam, one transducer secondary voltage increases while the other remains constant. In Figure 6, E_2 is held constant.

The relationships between transducer coils, metal cores, magnetic fields, and currents are depicted in Figure 7. The primary and secondary coils on each core are actually wound bi-filar; however, they are separated in the illustration for clarity. Note that the currents generated in the secondary coils flow in the same direction and add in the bridge circuit.

The above information is presented to show how the transducer works when only the 215 cps excitation signal is present. When the arc is ignited, the 215 cps transducer output is swamped by a 360 cps induced ripple from the 3-phase, full-wave d.c. welding power supply. This unwanted 360 cps signal is 100 times greater than the 215 cps tracking signal, and is a .300 volt rms 360 cps pickup signal, as compared to a .003 volt rms 215 cps tracking signal. The 360 cps pickup causes the servo to drive to the left by causing a phase shift of the tracking signal which, in turn, produces a d.c. output from the demodulator.

Since the transducer coils are connected in a bridge, it would seem that the 360 cps pickup would null at some balance pot setting similiar to the 215 cps signal; however, such is not the case. The 360 cps pickup appearing at E_0 cannot be nulled, and is of nearly constant amplitude regardless of the balance pot setting. This phenomenon can be understood by referring to Figure 8a and 8b. The torch flux path through the transducer is such that the induced 360 cps voltages in the two coils are in opposition. The bridge circuit behaves like the analog shown in Figure 8b. In Figure 8b, it is obvious that E_0 will be constant, independent of the pot setting, and will be greater than zero in amplitude.

To eliminate the 360 cps ripple, a cascaded narrow bandpass filter was developed to pass 215 cps. When properly tuned, the output voltage is down 30 db at 25 cps on each side of center frequency. In addition to filtering, this circuit amplifies the basic tracking frequency. All trace of interference can be cancelled, except a slight phase shift of the tracking signal.

Phase shifting of the basic tracking signal is directly proportional to the amplitude of the 360 cps ripple flux which links the transducer from the torch. Apparently, the induced 360 cps voltage causes a slight hystersis of the transducer iron and the undesirable 215 cps phase shift results. This effect has always been present to a degree and varies in intensity from transducer to transducer. Since the effect is proportional to the weld current ripple amplitude, a corrective circuit, Figure 9, to counter this bias effect, was added. A d.c. signal is then proportional to the amplitude of the weld current ripple, and is summed with the tracking signal in the correct polarity and amplitude to cancel the slight pullover, or biasing, of the 215 cps phase shift. The electronic technicians will have this adjustment available during periods of weld testing to make bias adjustments as required.

C. Shielding and Grounding

Several attempts were made to magnetically shield the coils, but magnetic shielding invariably reduced the tracking signal. Magnetic effects of the d.c. weld component were re-examined and it was verified that there are no magnetic effects due to the d.c. component of the weld current. Pickup in the signal lead has been a serious problem in the past. Elimination of this pickup has been accomplished by re-locating the signal balance pot at the servo amplifier input and by utilizing a balance pot in the 215 cps demodulator for operative electrical centering control. This modification has eliminated the critical nature of the signal electromagnetic and electrostatic cable shielding. Up to now, accidental double grounding of the signal cable shield has been a major trouble source. The effect of ground loops on a 7 MV p-p signal is tremendous because circulating ground currents will cause large error signals. The balance circuits have now been re-designed and all transducer signals transmitted over any long distance will be in the order of volts, rather than millivolts.

D. Circuit Diagram

Figure 10 shows a block diagram of the arc guidance control circuit as presently engineered. The a.c. signal from the joint detection transducer (1) is fed into a balance pot (2) located at the input to the bandpass filter-amplifier (3). After pre-amplification and filtering, the a.c. signal is changed to d.c. by the ring demodulator (4). A demodulator balance pot (5) is wired back to the operator for his use to align the transducer with the center of the seam. The differential signal from the ring demodulator (4) is next summed at point (9) with the d.c. signal from the bias demodulator (8). During set-up, the transducer is centered over the seam with the operator electrical centering controls (5) and remains there until the weld arc is ignited. Arc ignition causes a phase shift in the 215 cps signal from the transducer (1) which results in a tracking error proportional to the amplitude of the weld current ripple. Amplification and rectification of the a.c. ripple generates a counter bias voltage which is equal in amplitude and opposite in polarity to the d.c. error voltage caused by phase shifting of the 215 cps signal voltage. The net result is cancellation of the bias pull-over. The servo-amplifier (10) uses a transistor chopper modulator to convert d.c. into a.c. for stable amplification. Amplifier (10) drives the cross seam motor to position both the transducer (1) and the welding torch.

It is obvious to those who have followed this project that the circuitry is more complicated than was initially imagined. The additional components, however, will result in increased reliability, control, and overall performance. For a complete wiring diagram, see NASA Drawing MR&T SK-798.

E. Tack Weld Effect on Eddy Currents

Tack welds have a shunting effect on the eddy currents induced in the two pieces of material to be welded together. In the zone near a tack weld the induced field sees a much lower reluctance through the tack weld than through the material joint. This shunting causes the normal tracking signal to be vastly reduced in amplitude. Loss of the signal allows the electrical unbalances in the transducer and electrical system to take over. Unfortunately, tack welds will shunt the tracking signal from a distance of 6 inches from the tack when the seam behind the seam tracking transducer is being welded. Seam tracking was unsuccessful when tried from the side opposite a tack weld. We also tried machining a "V" groove in the tack, but this method was not effective. Both automatic and manual tack welds were tested; however, no difference in signal behavior was observed. Bench studies of the induced field were conducted using a detector coil and oscilloscope, and invariably, the induced field strength was reduced to noise when the transducer was over a long tack weld.

F. Tack Weld Detector Development

Use was made of the signal strength reduction about tack welds to build an electro-inductive tack weld detector. The detector coils are similar to the coils of the arc guidance transducer. The output of the tack weld detector, Figures 1 and 2, is balanced, filtered, amplified, and then rectified. The resulting output is fed into a sensitive relay. Normally, the induced tracking signal in the workpiece is sufficient, when amplified, to keep the reference voltage from de-energizing the sensitive relay; however, the presence of a tack weld will shunt the signal voltage and the relay will drop out. This relay can be used to either lock the tracking mechanism, or shift the operating mode of the guidance system. The detector is simple, straight-forward, and can be relied upon for consistent results.

Originally, the idea was to track up to the edge of a tack weld and lock the tracking mechanism while the transducer was over the tack. This idea works well when not welding. During welding, however, this approach is not satisfactory because the tracking head must be locked about 6 inches away from the leading edge of the tack. The manipulator must remain locked until the torch has virtually cleared the other end of the tack. Since 6 inch tack welds are spaced about every 8 inches on Saturn S-IC parts, it turns out that only 2 inches out of every 14 inches of weld joint is tracked. Using a tack weld detector with light beam guidance, such as the Cayuga System, would allow tracking about half the time. A disadvantage here is that rapid corrections of the head after release might cause jogs in the weld seam due to joing deviations during the period the head was locked. In general, it does not seem that locking the head is a very satisfactory solution. Out of this phase of the project, the automatic tack weld detector appears to be the best device developed. The detector would be used in future automatic systems to warn of approaching tack welds and initiate an automatic action.

G. Advantages and Disadvantages of the MSFC Developed Arc Guidance System

The principle advantages of MSFC's arc guidance system for aluminum material are that the transducer:

1). Can inherently locate and home in on a weld joint from some distance away,

2). Is not inherently proximity sensitive.

3). Is not overly sensitive to weld joing offset within weld tolerances.

4.) Can operate in a range from 1/4 to 3/4 inches above the work.

5.) Can be used with a regular Linde TIG cold wire feeder for the TIG process.

6.) Is not effected by compression forces on the weld joint.

7.) Will center a gap in the weld joint.

8.) Will track almost any consistent configuration of weld joint.

9.) Requires no special weld joint preparation for guidance purposes.

10.) Is uneffected by the metal surface finish, brightness, or blemished.

11.) Is impervious to arc light.

12.) Cannot be mis-directed by scratches or shadows caused by weld joint curvature.

The chief disadvantages of MSFC's arc guidance system for aluminum material are that the transducer:

1.) Is sensitive to movement of ferrous metal within 3 inches of the transducer case. Metal such as the Linde Wire Guide does not effect the transducer, however, because the guide does not move with respect to the transducer.

2.) Is effected by tack welds when over them during dry runs. A dry run is defined as tracking, but not welding.

3.) Is sensitive to approaching tack welds within 6 inches during welding.

4.) Requires special circuitry to eliminate the effects of 360 cps weld ripple current induced pickup.

5.) Cannot reliably track a long tack weld even with a small "V" groove machined in its surface.

H. Summary of Advantages and Disadvantages

Selecting the best arc guidance equipment for a given application on aluminum materials is very critical. It requires a very special knowledge of the joint and surrounding hold-down apparatus, materials, and conditions to properly select the best equipment for a particular job.

The welding process, whether MIG or TIG, also enters into the picture. For most purposes, MSFC's arc guidance system seems inherently limited only by tack welds and aluminum materials thinner than .090 inches. This system overcomes most of the pitfalls of the higher frequency systems. Figure 11 lists a number of factors to be considered when selecting an automatic arc guidance system. It may be noted that there are far more dissimilarities than agreements between the electro-inductive and the light beam systems. These disagreements are caused by the fact that the light beam system tracks a shadow. Once off the shadow, the optical system is lost.

On the other hand, the electro-inductive transducer can locate the seam from up to three inches away. When using the optical system with TIG welding, the cold wire must be fed in from the side or it will interfere with the optical beam. The depth-of-field of the light beam optical system is very shallow, so proximity of the optical head to the work is still a critical item. Both seam tracking systems, however, will perform adequately under the right conditions.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that:

1). The MSFC system may be used to accurately track aluminum weld seams if the material is over .090 inches thick and if there are no initial tack welds, except at the terminal ends of the weld.

2). The tracking frequency must be coordinated with the type of welding power supply.

a). A 215 cps transducer frequency should be used with a full wave, 3-phase, 60 cps supply.

b). A 400 cps transducer frequency should be used with a half wave, 3-phase, 60 cps supply.

3). The tack weld detector proved very reliable during tests.

It is recommended that:

1). The MSFC arc guidance system should be seriously considered for any type of automatic tack welding equipment. Its ability to home in on the seam and its low proximity sensitivity renders it excellent as the heart of a portable automatic tack welding rig.

2). The merits of electro-inductive homing and tracking should be made known within MSFC and elsewhere for possible use in mating vehicles in space. This principle would be worth considering because it can home in and locate an aluminum edge within ± .003 inch accuracy at a ½ inch proximity distance. Micro-miniature circuitry would reduce the electronic package to very small proportions.

3). It was noted that short tack welds, when properly spaced, do not effect the transducer except for a very short distance during dry runs. To gain the ability to track and weld curved joints and at the same time utilize short (1 to 2 inch) tack welds, it is recommended that the transducer be moved ahead of the tack (7 or 8 inches) and a memory system inserted to provide instantaneous torch positioning. Equipment is on hand to develop this approach. A memory system would be equally adaptable to either electro-inductive or light beam arc guidance with no alterations.

DISTRIBUTION

R-ME-DIR
Mr. Küers
Mr. Wuenscher

R-ME-M
Mr. Orr
Mr. Schwinghamer

R-ME-MW
Mr. Parks

R-ME-MM
Mr. Wilson

R-ME-D
Mr. Eisenhardt

R-ME-T
Mr. Franklin

R-ME-TD
Mr. Martin

R-ME-X
Mr. Berge

R-ME-MEA
File (12)

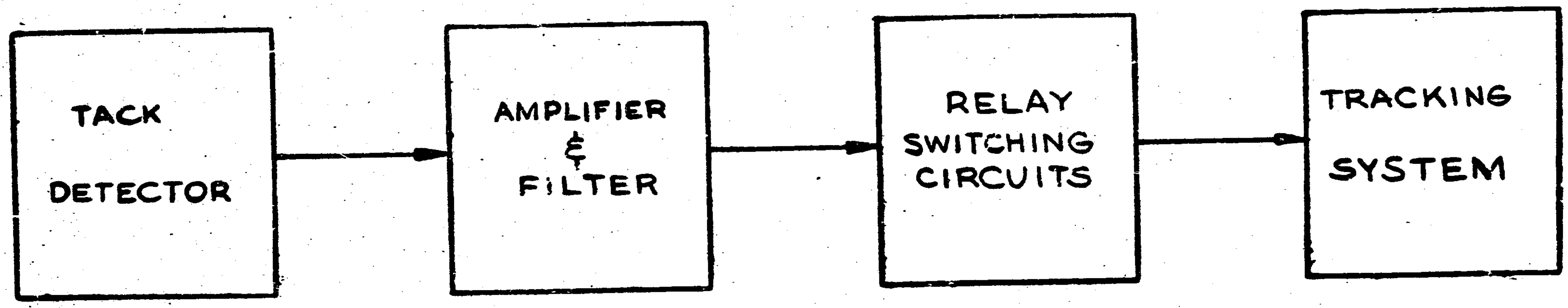


FIGURE 1. BLOCK DIAGRAM, TACK WELD DETECTOR.

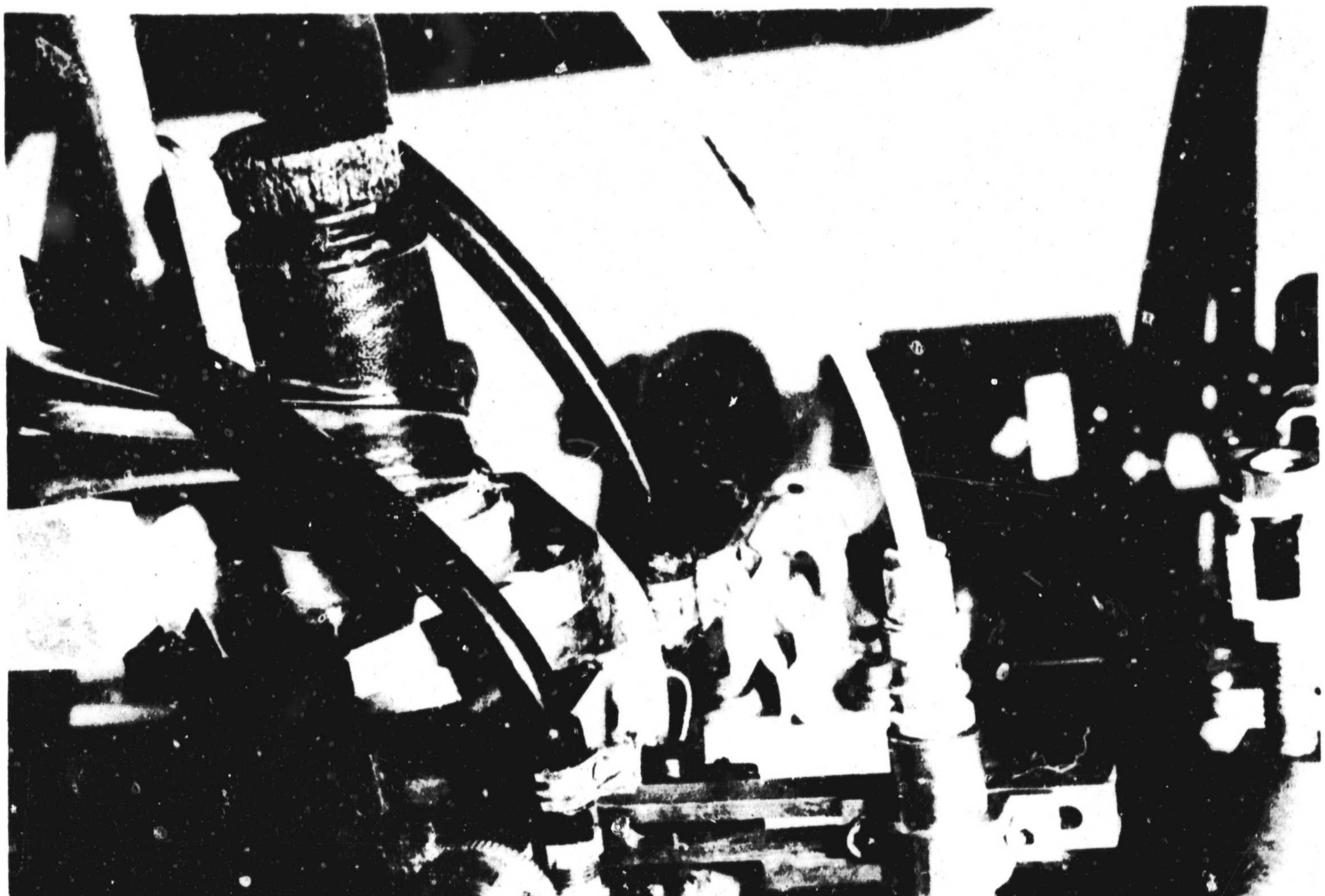


Figure 2.
TACK WELD AND ARC GUIDANCE TRANSDUCER

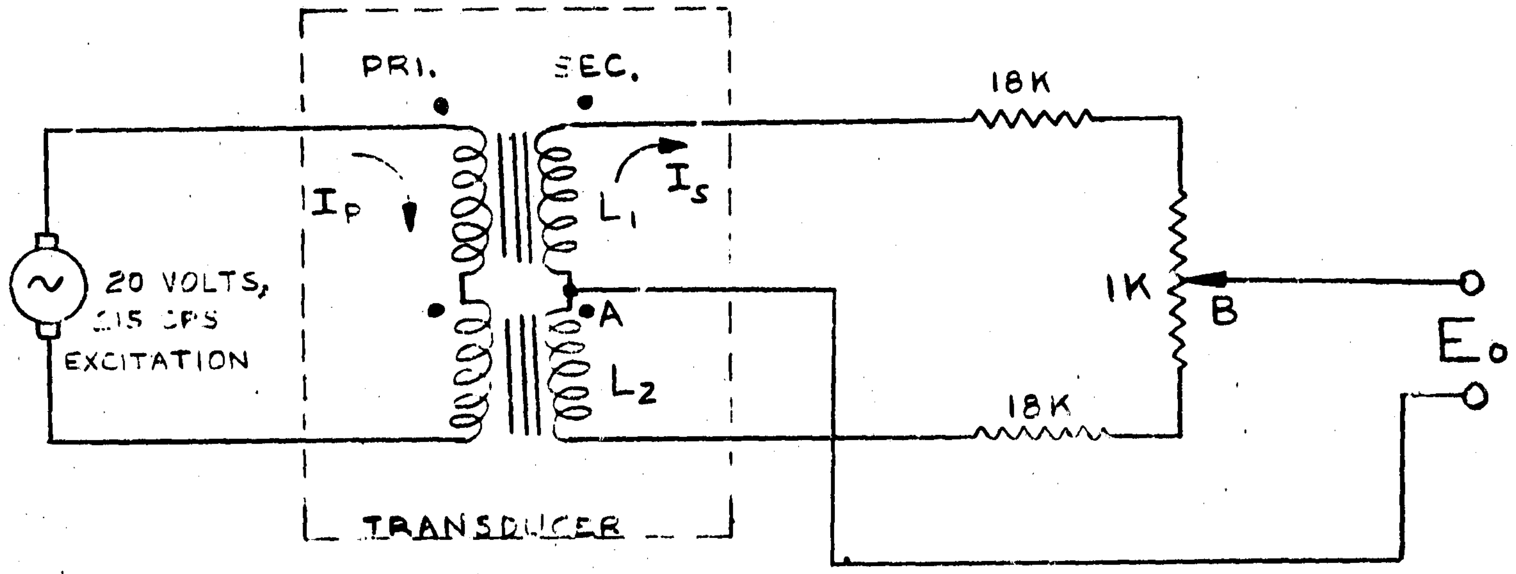


FIGURE 3. TRANSDUCER BRIDGE CIRCUIT.

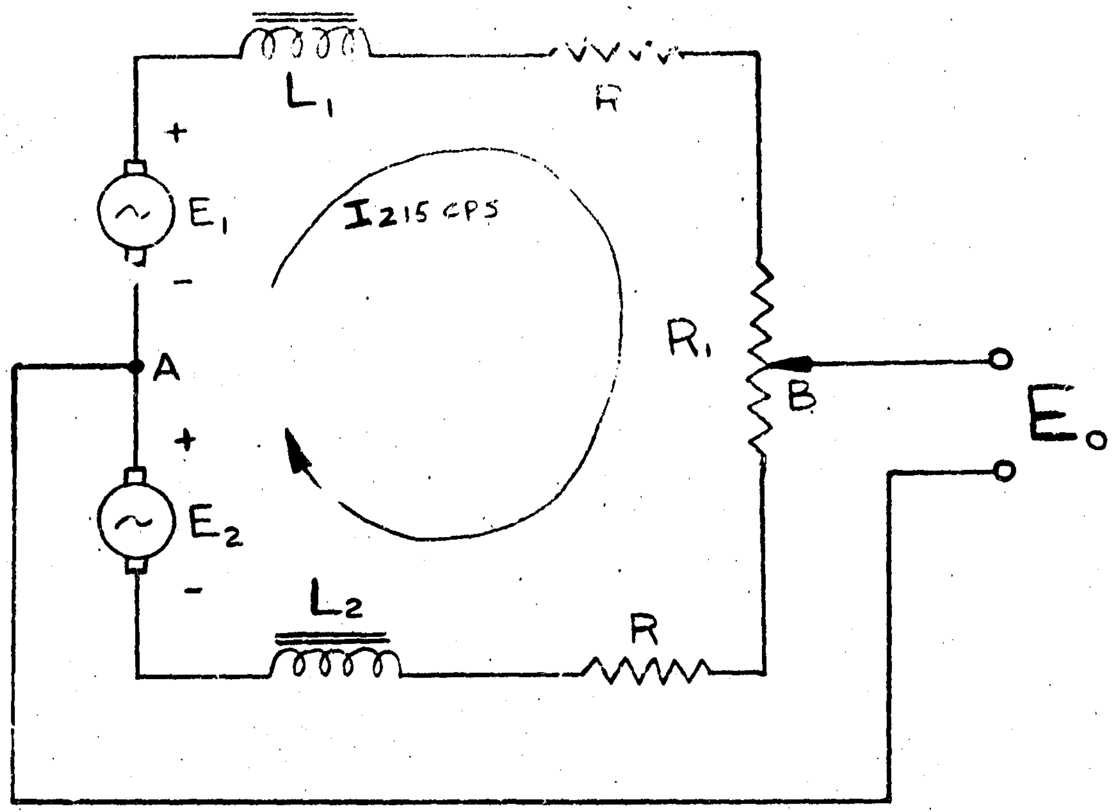


FIGURE 4. EQUIVALENT CIRCUIT.

FIGURES 3 & 4

$$E_0 = E_1 + E_2$$
$$E_0 = 0$$

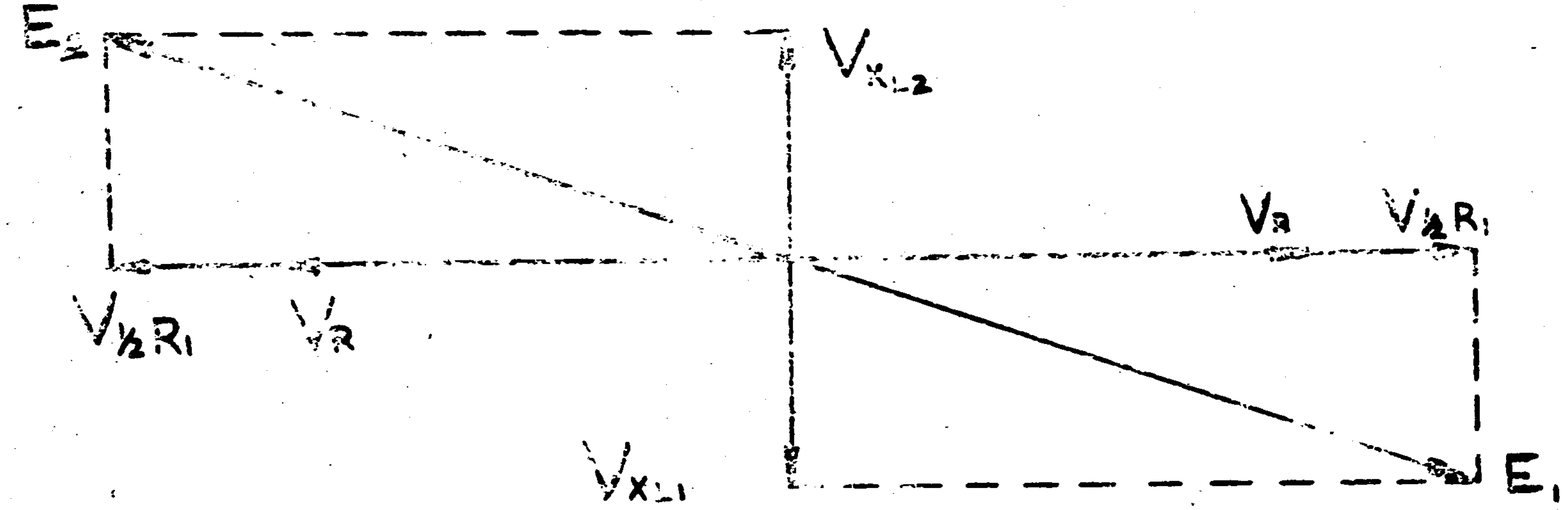


FIGURE 5. VOLTAGE VECTORS FOR BALANCED BRIDGE.

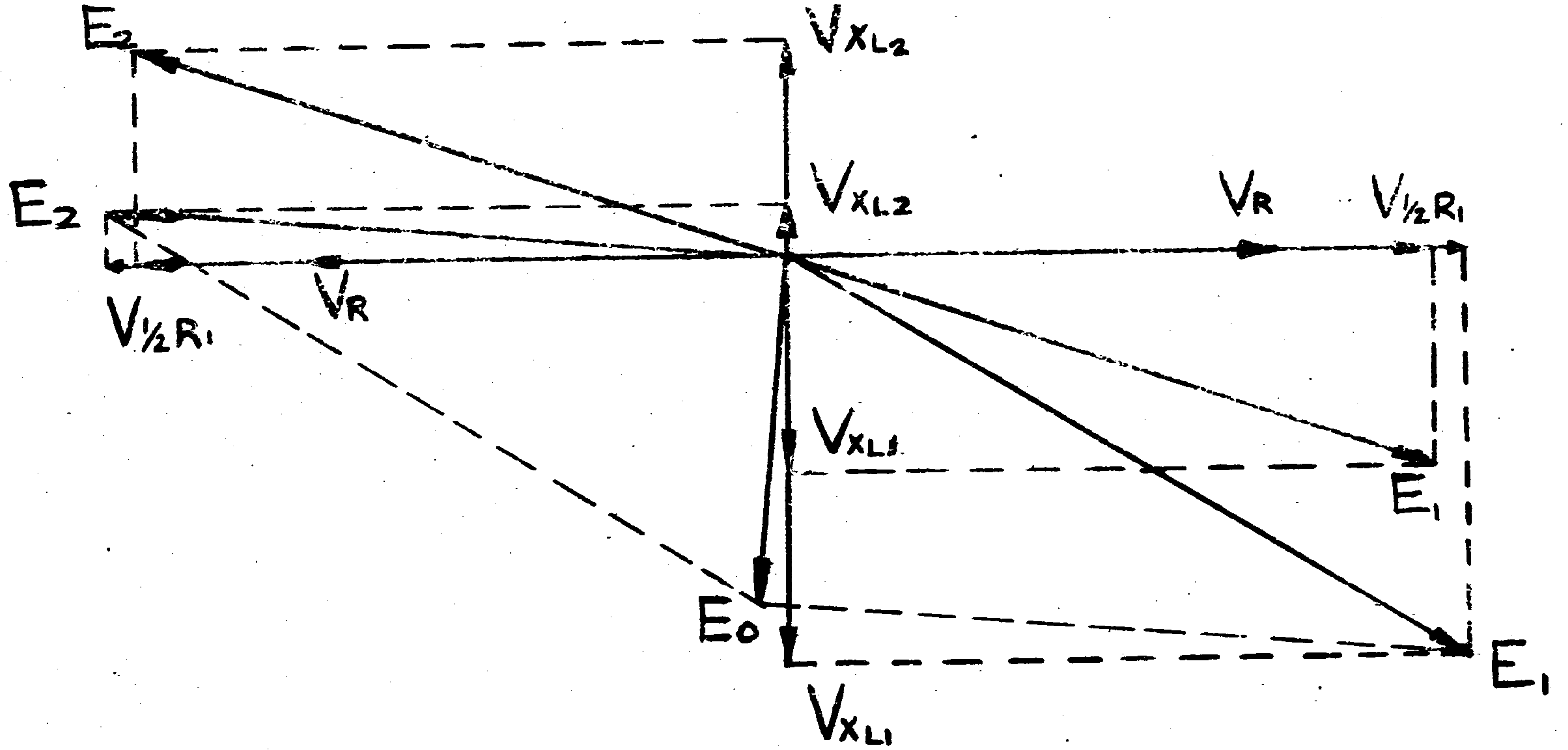


FIGURE 6. UNBALANCED VOLTAGE VECTOR DIAGRAM.

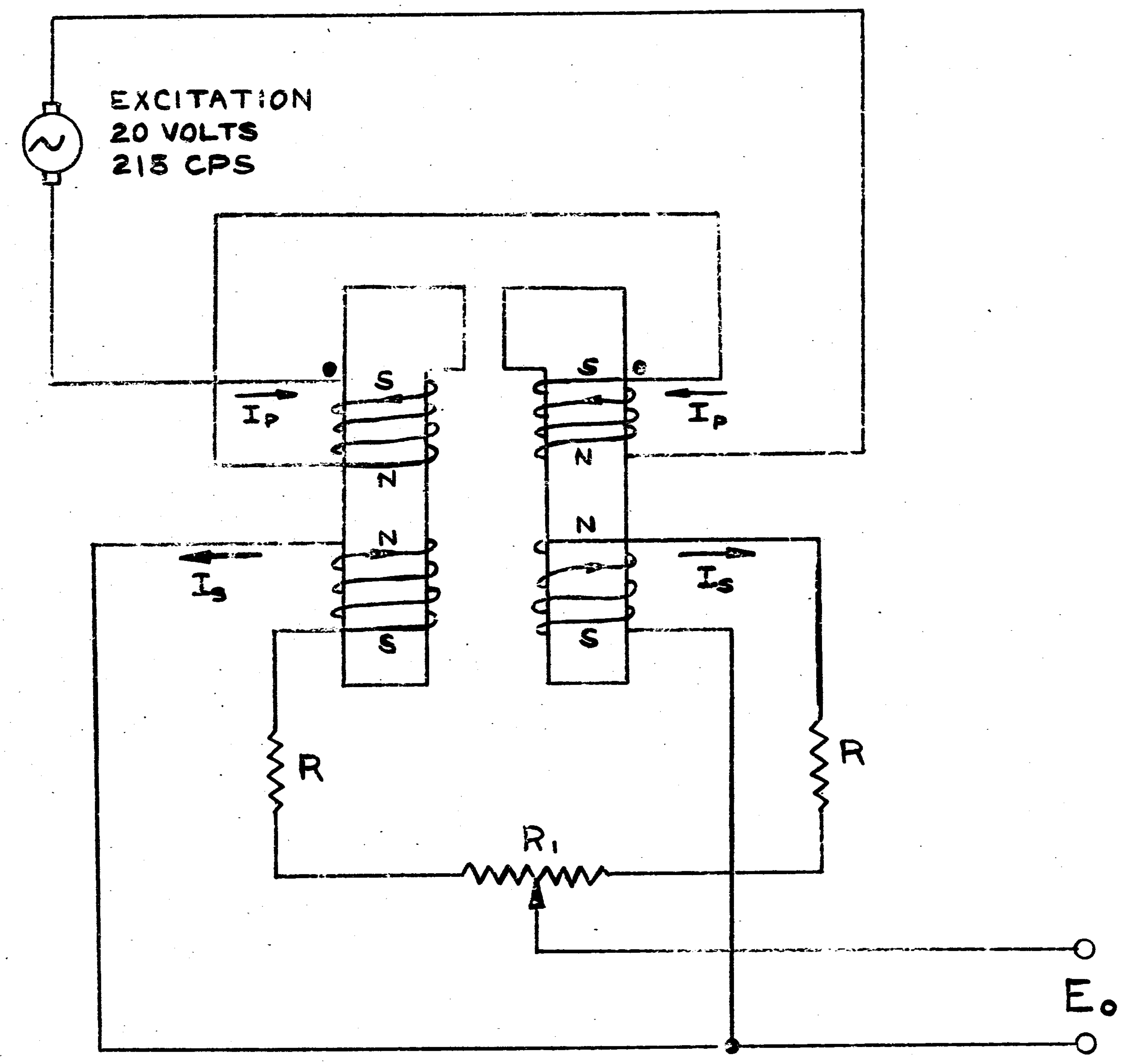
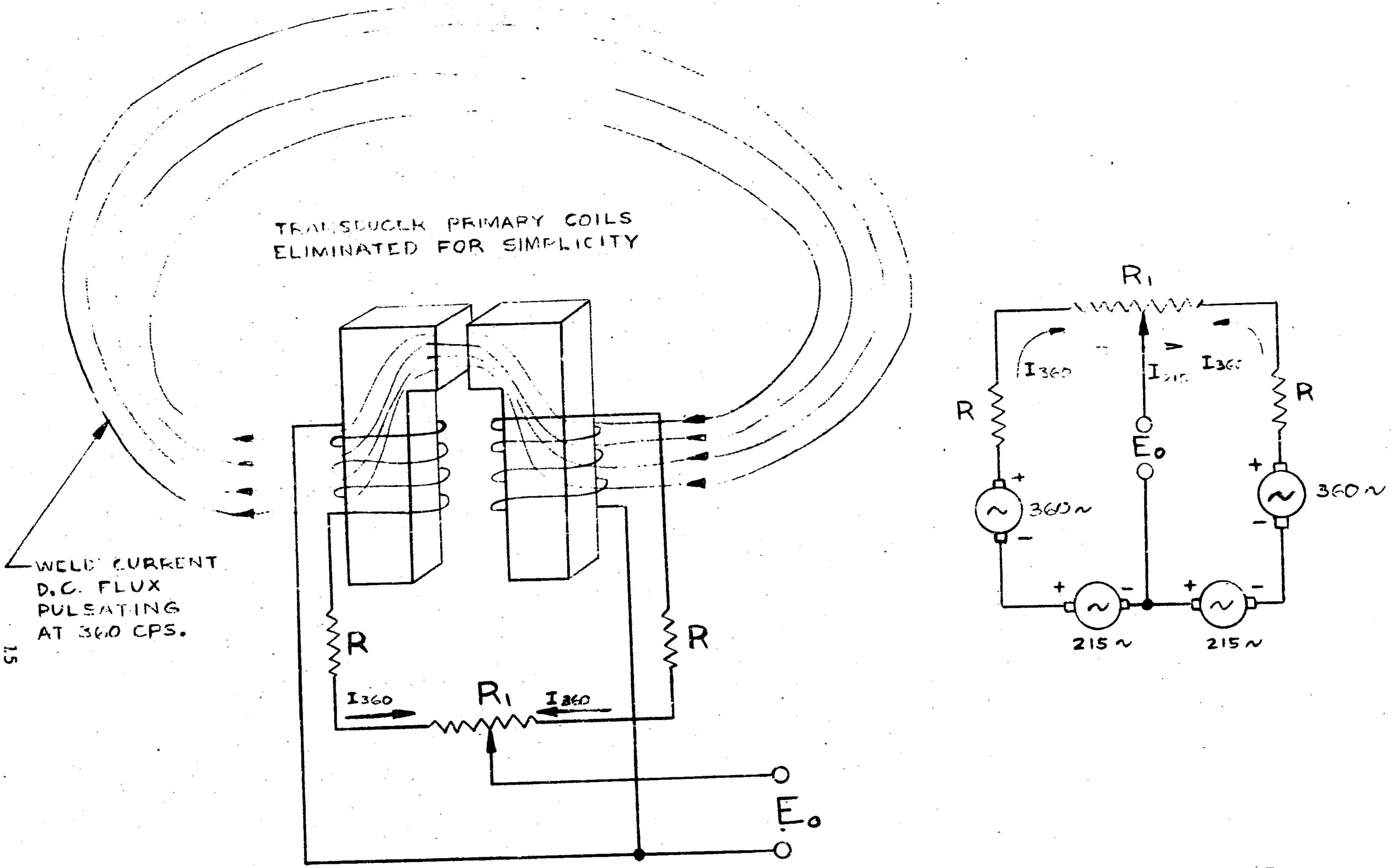


FIGURE 7. TRANSDUCER AND BRIDGE CIRCUIT POLARITY DIAGRAM.



(a) TORCH FLUX EFFECT ON TRANSDUCER

(b) ANALOGOUS CIRCUIT.

FIGURE 8. WELD CURRENT RIPPLE PICKUP DIAGRAM.

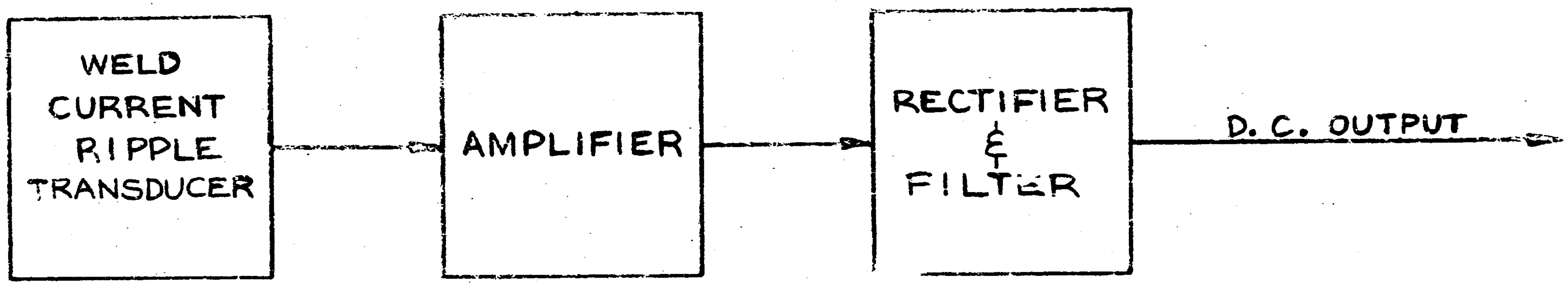


FIGURE 9. BIAS CIRCUIT BLOCK DIAGRAM.

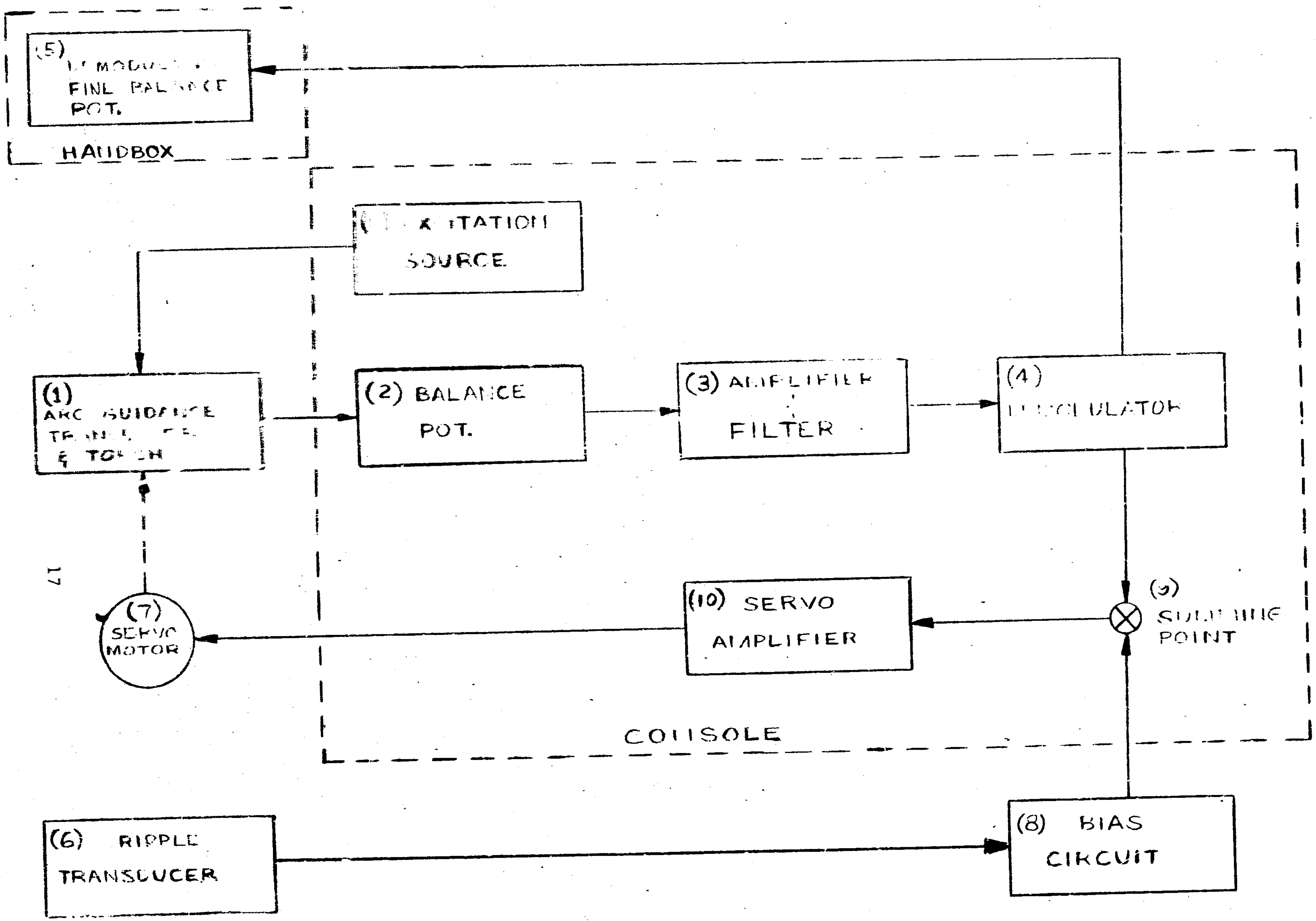


FIGURE 10. BLOCK DIAGRAM, ELECTRO-INDUCTIVE ARC GUIDANCE SYSTEM.

COMPARISON DATA

MSFC ELECTRO-INDUCTIVE SYSTEM VERSUS LIGHT BEAM TRACKING SYSTEM

MSFC ELECTRO-INDUCTIVE SYSTEM	CAYUGA LIGHT BEAM SYSTEM	UTILIZATION CONSIDERATIONS
± .005" Measured	± .001" Claimed	Tracking accuracy of a perfect joint.
No	Yes	Proximity Sensitive
LOW	LOW	Joint offset sensitivity
NO	NO	Arc Light Sensitive
NO	YES	Light Shadow Sensitive
NO	YES	Special joint preparation required
YES	NO	Centers a gap in a weld joint
YES	NO	Sensitive to moving ferrous metal
NO	YES	Sensitive to finish of the metal
NO	NO	Can track a hand tack welded joint
NO	YES	Can track tack welded joint with a machined "V" groove 1/16" wide x 45° chamfer.
NO	YES	Can track a black line
YES	NO	Easily usable with the TIG process
YES	NO	Can sense a weld joint from 1 inch away
NO	YES	Is adversely effected by cold wire feed for TIG welding
YES	NO	Occupies the least amount of space around the torch.
YES	NO	Uses the most standard-off-the-shelf equipment
NO	YES	Can be used on the thinnest aluminum material

Figure 11

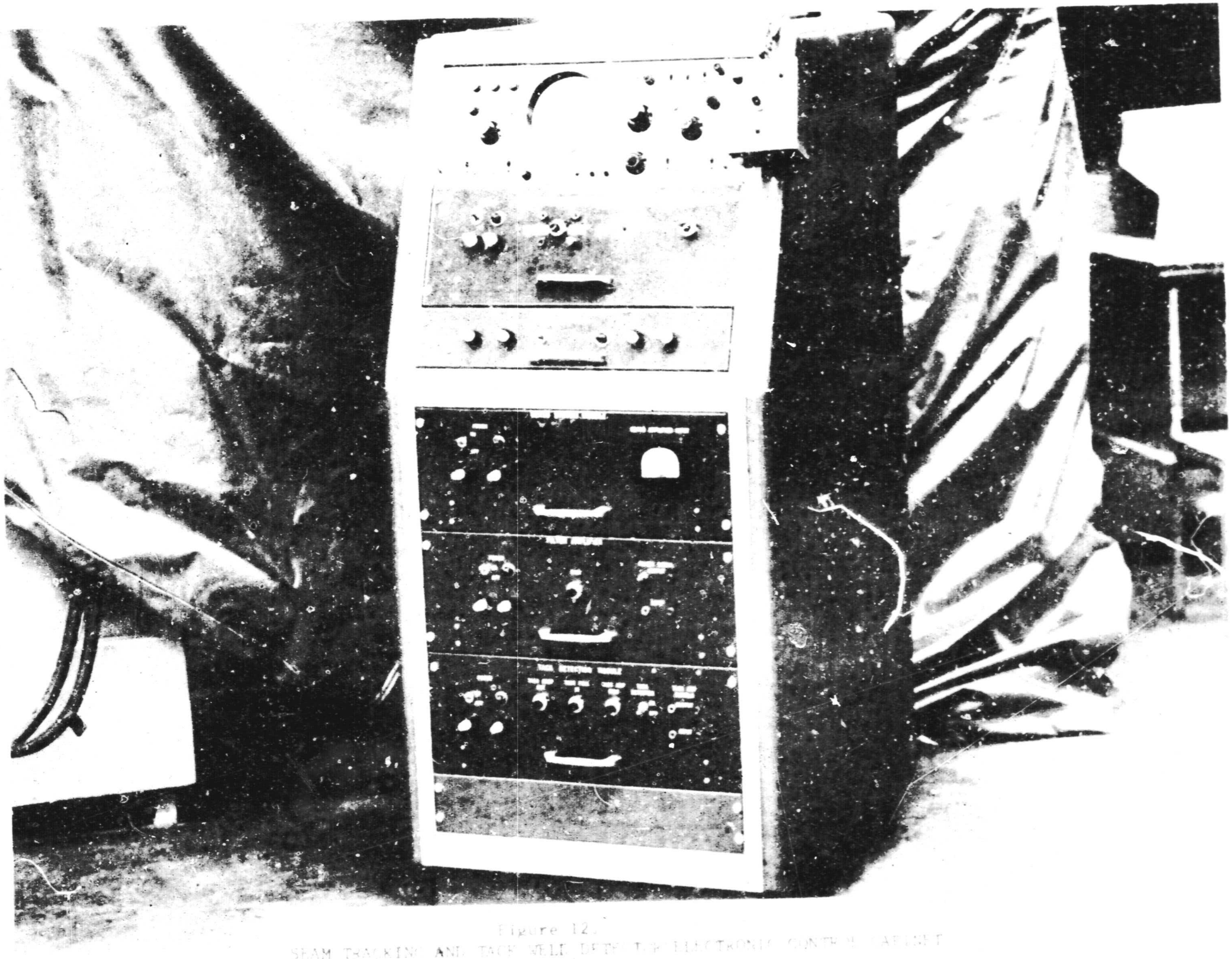


Figure 12.
SEAM TRACKING AND TACK WELD DETECTOR ELECTRONIC CONTROL CABINET