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METHODS OF BOND TESTING

by

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ABSTRACT

A composite laminated type of construction which was used in a reactor necessitated fusion bonding of components for good heat transmission. A nondestructive test was needed which could differentiate between areas of intimate metal-to-metal contact with no bond and areas where the components were fused together. A further requirement was that the test should be able to detect areas of poor bond as small as 1/8 in. by 1/8 in. The laminated structure to be tested was a flat plate having an over-all thickness of approximately 0.100 in. Three methods of testing were investigated:

(1) Thermographic Method: A thermo-sensitive phosphor was used to indicate temperature distribution over the surface of a sample.

(2) Electrode Potential Method: The electrical potential drop across a sample was measured using special electrodes.

(3) Ultrasonic Transmission Method: The attenuation of an ultrasonic beam as it passed through a sample was measured.

Known defect blocks having varying degrees of metal-to-metal contact were made. The comparative sensitivity of the three methods was determined using two of the known defect blocks. The experimental data show that the ultrasonic transmission method was the most sensitive, the electrode potential method moderately sensitive, and the thermographic method the least sensitive.

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I. INTRODUCTION

In a certain reactor application it was necessary that a laminated structure be used. Because of the anticipated high heat flux passing through this laminated structure, it was felt that the components must be fusion bonded, in effect, equivalent to one continuous piece of metal.

The specific problem discussed in this paper was that of finding a non-destructive test to differentiate between areas of intimate metal-to-metal contact with no bond and areas where the two metals were fused together. It was desired that the test be sufficiently sensitive to detect areas of poor bond as small as 1/8 in. by 1/8 in. Additional requirements were that the method should lend itself to permanent recording and should be sufficiently rapid for production inspection. The particular laminated structure to be tested was a flat plate made by hot rolling together two sheets of non-ferrous material. After rolling the material had an over-all thickness of approximately 0.100 in.

A preliminary survey and study of possible methods for detecting lack of bond was made. This study indicated that three methods had definite possibilities for differentiating metal-to-metal contact from a fusion bond. These three methods, namely, (1) Thermographic Method, (2) Electrode Potential Method, and (3) Ultrasonic Transmission Method were investigated in detail at the Argonne National Laboratory.

II. TEST METHODS

A. Thermographic Method

In 1950 Dr. F. Urbach of the Eastman Kodak Company published a paper entitled "Thermography". In this paper Dr. Urbach pointed out that certain phosphors are so temperature sensitive that localized small changes in temperature reveal themselves as color changes when the phosphors are illuminated by ultraviolet light. The use of these phosphors make it possible to observe a detailed pattern of the temperature distribution on a surface.

In these particular experiments, Eastman Kodak Phosphor No. 2849 was used. In the temperature range of 5C-55C the emissivity of this phosphor changes by about 20 per cent per degree centigrade. The phosphor is also sensitive to the intensity and wavelength of the ultraviolet radiation impinging on its surface. The optimum wavelength for this phosphor is 3650Å. If the intensity of the ultraviolet light falling on the phosphor is too large or too small, the change in emitted visible light per degree change in temperature becomes smaller.

The phosphor was applied as a paint pigment on the surface to be tested. The paint vehicle must be a material that will not fluoresce when subjected to ultraviolet light, otherwise the fluorescence of the vehicle would more or less obscure the heat sensitive properties of the phosphor pigment. Beetleware 227, a liquid plastic, is a vehicle possessing this important property. To make a suitable paint vehicle, the plastic is thinned in these proportions: Bettleware 227, 680 gms, butanol, 75 cc; and zylene, 45 cc. The pigment and vehicle are mixed in the proportions of 100 gm phosphor to 110 gm of vehicle. This mixture can be sprayed or painted on the test surface.

The test samples were coated on one side with the phosphor paint to an approximate thickness of one mil. If heavier coatings are employed, the sensitivity of the phosphor is diminished due to the fact that the fact that the paint itself is a heat insulator which retards the flow of heat. After coating, the samples were mounted in a lucite plate.

A 250-watt Switzer ultraviolet lamp filtered to 3650Å was set up about 24 in. distant and facing the phosphor coated sample at an angle of approximately 30 degrees. A 16 mm movie camera was set up directly in front of the sample at a distance of 30 in. The lens was set at f/1.9. XX Super-panchromatic film was used and exposures were made at 8, 16, and 32 frames per second.

In the early experiments the samples were alternately heated with infrared radiation and cooled with a blast of air. However, when the back of the plate was subjected alternately to a flow of hot water at 55C and cold water at approximately OC, the test was more sensitive. The color of the ultraviolet irradiated phosphor at OC was yellow and at 55C it became a brownish yellow. On changing from hot to cold water or vice versa, the new temperature was attained more slowly in the regions of the front face, lying over areas of poor thermal conductivity. The corresponding brightness pattern of the phosphor was observed visually and recorded with motion pictures.

The following technique was used after a few preliminary experiments. A stream of cold water (OC) was sprayed over the back of the block for several seconds, establishing an approximate temperature equilibrium. At this temperature the glow of the phosphor surface was bright and even. The cold water flow was then turned off and hot water (55C) suddenly applied. Within a few seconds the block was in equilibrium with the hot water. During the short transient period the bright fluorescence was more persistent over spots of poor thermal conductivity which becomes visible to the eye for about a second, being most distinct only for a fraction of a second. The experiment was then reversed, the hot water being replaced suddenly by the cold water. This time the regions of poor conductivity became visible momentarily as dark streaks or spots on the more rapidly brightening background.

B. Electrode Potential Method

The electrode potential method makes use of the fact that the electric resistivity in the immediate neighborhood of a flaw differs from that in solid metal. However, it uses potential difference directly as a flaw indicator. Special electrodes have reduced the disturbing effect of surface contact resistance common to resistance methods to a negligible factor and have made continuous scanning of a test plate possible.

The fundamental principle on which the Electrode Potential Method is based may readily be explained by reference to Figure 1A. As indicated in this figure, C and C' represent current electrodes, P and P' represent potential electrodes and D represents a thin metal test plate. The potential electrodes are electrically insulated from the current electrodes. In operation, a 60-cycle sinusoidal current denoted by I is sent through the test plates between electrodes C and C'. A difference in potential denoted by E is set up between the opposite faces of the test plate to maintain this current. The potential electrodes P and P' make contact with the surfaces of the test plate and consequently they also have a difference in potential between them.

The two pairs of electrodes and the test plate constitute a four-terminal resistor, as may be seen more easily from the equivalent circuit diagram of Figure 1B in which the parts are rearranged. From this figure it is apparent that surface contact resistances between the current electrodes and the test plate are included in the current circuit between C and C' but are not included in the potential circuit between the electrodes P and P'. Variations in the se surface contact resistances between the potential electrodes P and P'. Surface contact resistances between the potential electrodes P and P' and the test plate are in series with the potential measuring circuit, whose internal resistance is very high. Variations in these contact resistances are therefore of negligible importance.

A block diagram of the component parts of the electrode potential bond tester is shown in Figure 2. The current supply furnishes an essentially constant 60 cycle current to the electrodes. Currents from 20 to 25 amperes are used in normal operation. Figure 3 shows the special electrode assembly developed for this work. Each electrode assembly is a dual unit consisting of a current electrode which completely surrounds the concentric potential electrode. These two electrodes are electrically insulated by means of a ceramic sleeve. The current electrode terminates in a replaceable tip which makes contact with the surface of the test plate. Tips having a diameter of 3/16 in. and 1/8 in. have been used. Voltages developed across a 0.100 in. thick test plate are of the order of 1 millivolt. These voltages need to be amplified for satisfactory operation of an oscillograph or Brush recorder. The voltage gain of the amplifier built for this use was continuously variable up to a maximum of 2000. A limiter was incorporated as a means of protecting the Brush recorder from accidental damage due to excessive voltages. A rectifier filter was used to rectify the 60-cycle overput voltage. The output of the filter circuit which followed the rectifier was a undirectional voltage whose magnitude varied with the AC voltage developed in the test plate between the potential electrodes.

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FIG. I - PRINCIPLE OF ELECTRODE POTENTIAL METHOD

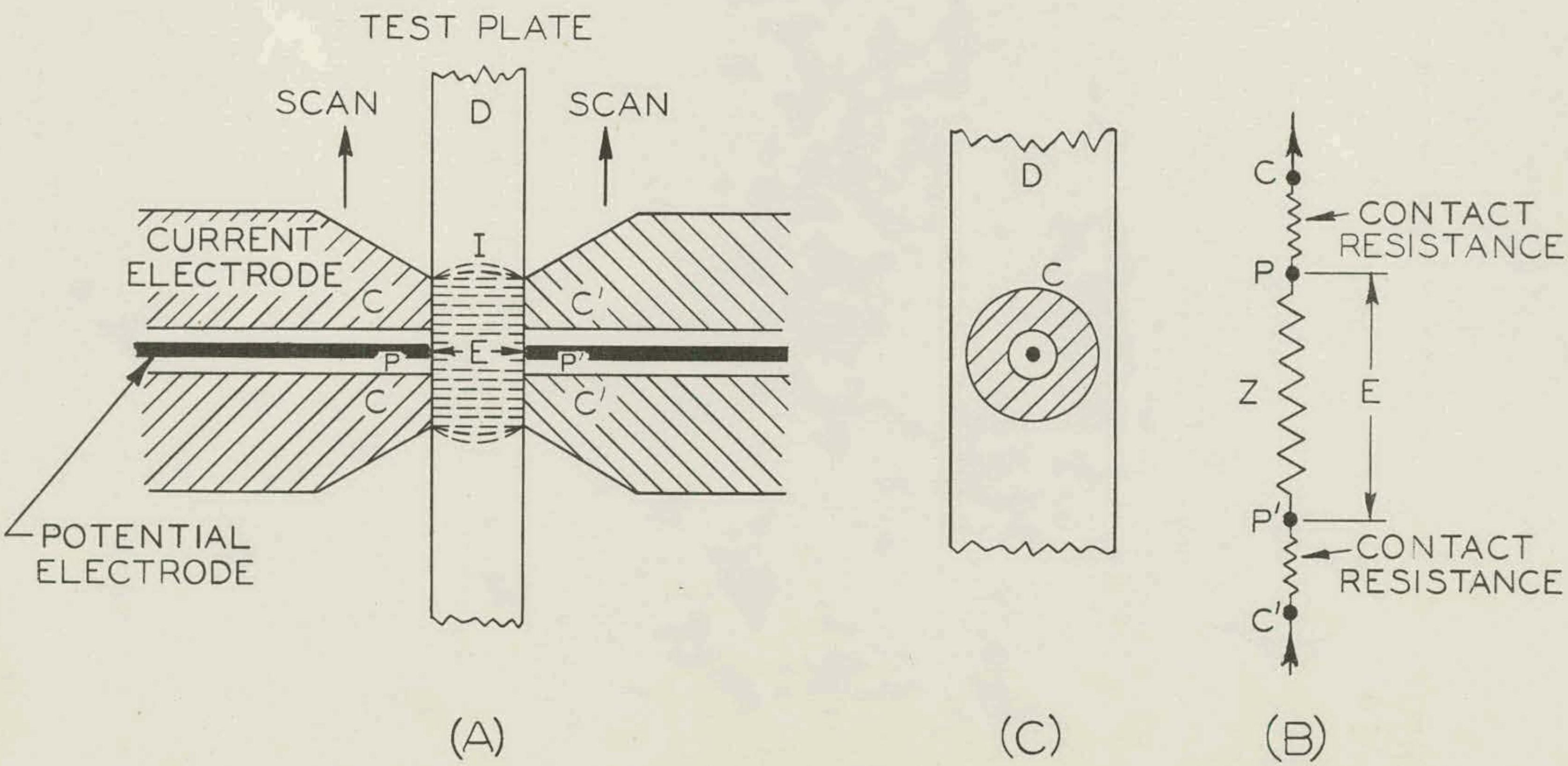

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FIG. 2 -BLOCK DIAGRAM OF
ELECTRODE POTENTIAL BOND TESTER

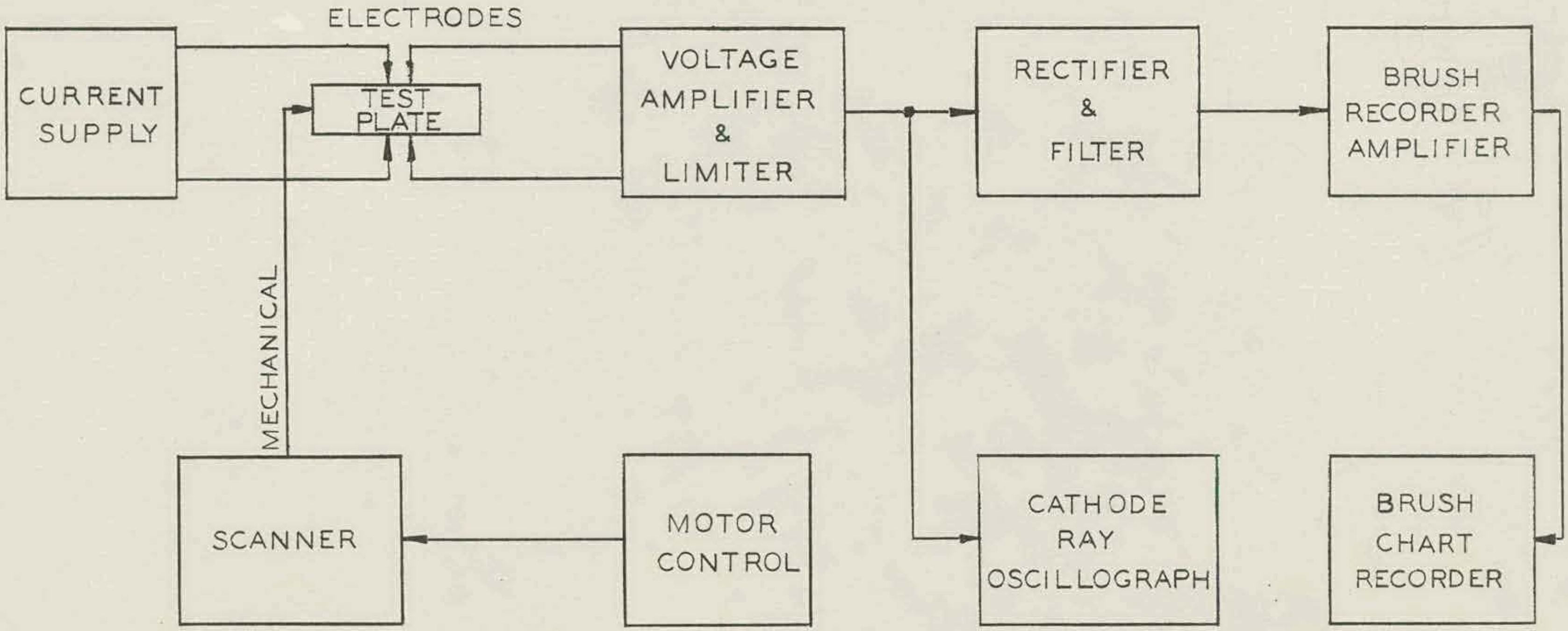

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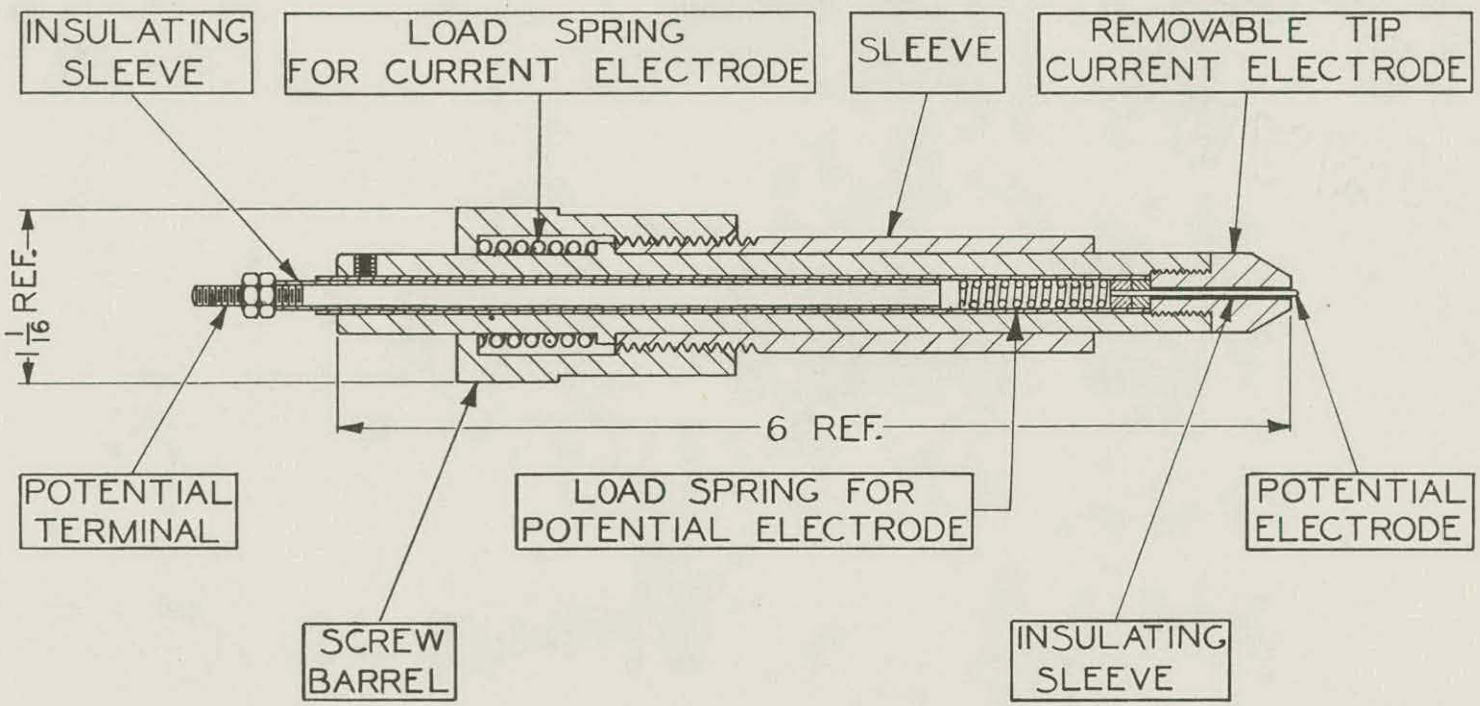
FIG. 3 – SECTION THRU ELECTRODE POTENTIAL – ELECTRODE



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A Brush Model BL-905 recorder amplifier and a Brush Model BL-201 oscillograph were used to record the data. Figure 4 is a photograph of the scanner used in this work. The scanner is a mechanical device for moving the contacting plate electrodes uniformly and systematically along the surface of the test plate. It consists of a screw-driven carriage which slides on accurately machined ways. An assembly for holding the electrodes is mounted on the carriage. This assembly can be raised or lowered manually. The screw of the scanner is driven by a 1/8 horsepower reversible AC motor through a Graham Variable Speed Transmission. Microswitches for stopping and reversing the motor (through a motor control box) at the ends of a scan could be set at any desired positions.

An estimate of the approximate size of the smallest defect detectable by the electrode potential method can be made from measurable physical quantities involved. For a metal of relatively high electric resistivity, the impedance measured is practically a pure resistance.

When E and I have been measured the value of the equivalent resistance R can readily be found from Ohm's Law relation,

$$R = \frac{E}{I} \qquad (1)$$

The actual current flow lines through the test plate are not confined to the right cylinder, included between the electrode contact areas, but fringe out from the perimeters of these areas to form a barrel shaped pattern, as indicated by Figure 1A. This actual pattern may be considered as replaced by an equivalent cylinder, whose length would be the same as the thickness of the test plate and whose cross section area A_e would be of such size to make the electric resistance from end to end of the equivalent cylinder the same as the actual resistance R defined by equation (1). The cross section area of this hypothetical cylinder would thus have to be:

$$A_e = \frac{\rho t}{R}$$

ρ = resistivity of the metal of the plate,
t = thickness of the plate, and
R = equivalent resistance of the plate, defined by equation (1).

If it is assumed that a 20 per cent change in the potential difference, E, is the minimum that can be clearly recognized as significant, then it follows that, on the average, the smallest defect that can be detected must have a projected area normal to the flow lines equivalent to that of a complete void whose area is $0.2\ A_e$.

Measurements on a test plate, using 1/8 in. electrodes, yielded the following values: (47×10^{-6} ohm-cm used for ρ).

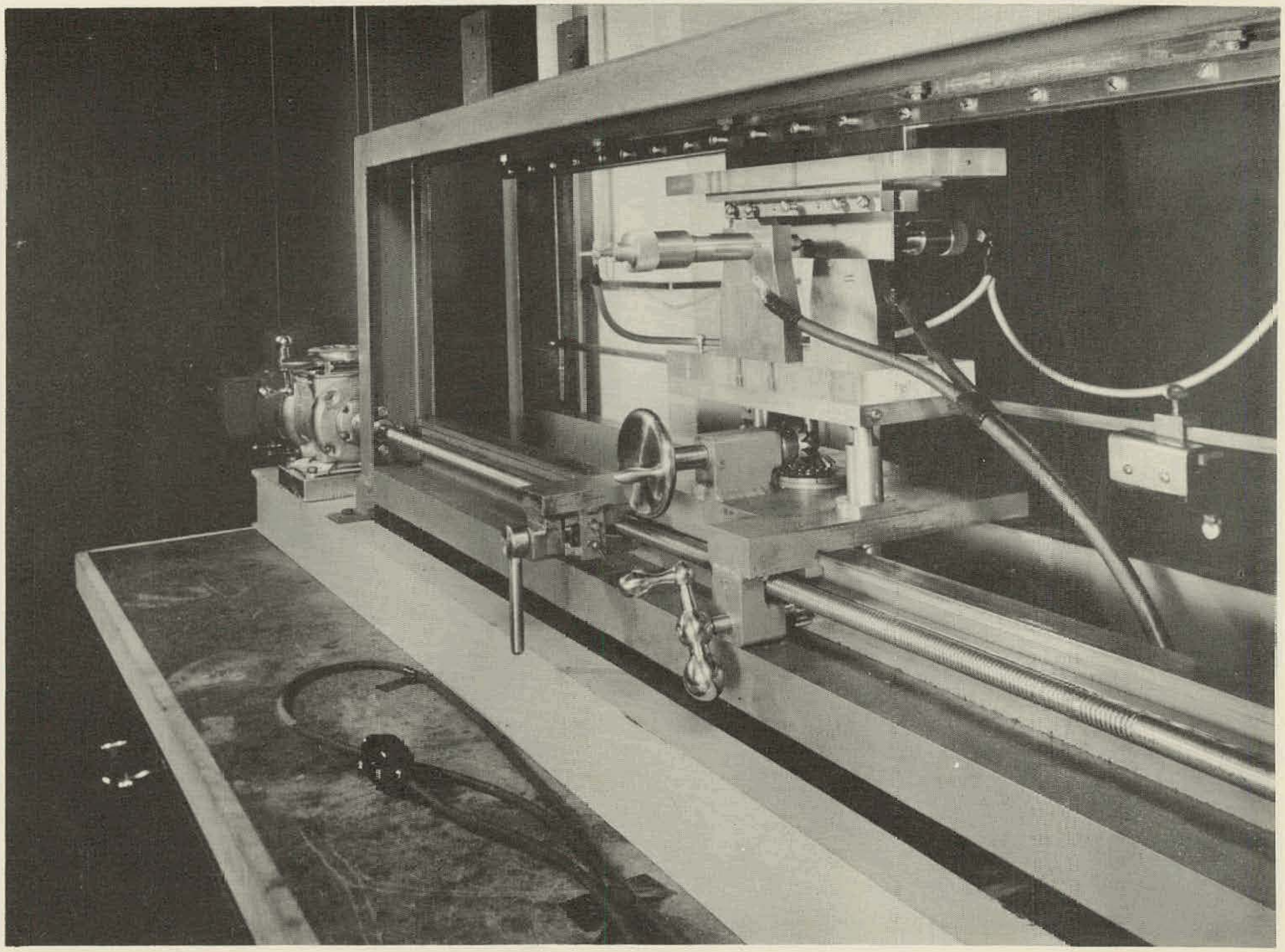


FIG.4 - ELECTRODE POTENTIAL
BOND TEST SCANNER ASSEMBLY

	Thickness of Test Plate, Inches		
	0.249	0.128	0.0625
A_e, cross section area of equivalent conducting cylinder, square inch.	0.0419	0.0255	0.0222
0.2 A_e, equivalent projected area of smallest detectable void, square inch.	0.00838	0.00510	0.00444
D, diameter of smallest detectable void, if circular, inch.	0.033	0.026	0.024

It will be seen from these data that the cross section area of the equiv lent conducting cylinder and the diameter of the smallest detectable void are le for a thinner plate. Thus the sensitivity of this method of bond testing is greater for a thinner plate of a given material.

In practice, the smallest detectable defect may, in some cases, be even smaller than indicated by the preceding analysis. For example, a defect midway between the electrodes may be just small enough to escape detection, whereas a similar defect of the same size nearer either electrode may be clearly detected. It is also probable that changes in E smaller than 20 per cent may be detectable

C. Ultrasonic Transmission Method

The ultrasonic method is applicable for detecting flaws in materials capable of transmitting ultrasonic vibrations. Some of the properties of ultrasonic waves that make them useful for this type of testing are:

(1) An ultrasonic beam is propagated through a material in essentially a straight line.

(2) Metals in general readily transmit ultrasonic waves. If the sample contains voids, cracks, or other inhomogeneities, a measurable loss of energy due to reflection and scattering of the beam take place at these irregularities.

(3) The minimum size of void or crack or other defect that can be detected depends upon the frequency used, the higher the frequency the smaller the defect that can be located; however as the frequency is increased, the penetration of the beam is decreased and consequently a practical limit is set to the frequency that can be successfully used.

The Sperry Products Company manufactures an ultrasonic testing device developed by F. Firestone called a "Reflectoscope".

A complete description of this instrument can be found in bulletins of the Sperry Products Company. A discussion of the electronic circuits for the commercial model Reflectoscope can be found in a paper by R. B. Delano, Jr.[1] The instrument as usually sold by the Sperry Products Company was not applicable to the particular problem under study. Since the ultrasonic beam travels through an 1/8 in. thickness of metal and returns in approximately 1 micro-second the echo and initial pulse are not separated on the reflectoscope screen when the sample is only 0.100 in. thick.

A commercial model Reflectoscope was modified so that the sending crystal and the pulse generator were separated from the receiving crystal and the receiving amplifier. This required, among other things, additional connections for a second transducer. Frequencies available from the Reflectoscope are 0.5, 1, 2.25, and 5 megacycles.

The transmission of ultrasonic waves through thin plates immersed in water has been discussed by several authors, among them F. A. Sanders.[2] Sanders made some careful transmission measurements and found at least two oblique angles of incidence at which strong transmission occurs. The particular angles giving maximum transmission are determined by the frequency-thickness product of the test plate.

It was found at Argonne that: (1) a transmission maximum also existed for the laminate type construction, (2) at the orientation giving maximum transmission, the "pip" on the Reflectoscope screen was sharper and that there were fewer multiple reflections present, and (3) at this angle of incidence a smaller change in intensity could be detected than at other angles of incidence.

The sensitivity and resolution of the ultrasonic transmission method of bond testing has been found to be influenced by such factors as the effective cross-section of the ultrasonic beam. This was done by covering the transmitting transducer with an absorbing material (mask) through which a hole had been drilled.

The material used as an absorber was cloth (linen) impregnated with a bakelite resin. The circular masks were provided with a shoulder so that they could be slipped over the face of the transducer and held firmly in place. Three masks were made 1/4 in. thick with straight holes 1/4 in., 3/16 in., and 1/8 in. in diameter drilled through them. A fourth mask was made 1 in. thick with a tapered hole (11 degrees taper) drilled through it. The opening in the front of this mask was 1/8 in.

The masks with the straight holes 1/4 in. and 3/16 in. in diameter improved the sensitivity. The mask with thestraight hole 1/8 in. in diameter reduced the intensity of the beam too much and could not be used satisfactorily. The mask with the 1/8 in. tapared hole improved the sensitivity. The effectiveness of these absorption masks will be discussed later in connection with the test results.

When the modified Reflectoscope is being used for testing, two significant high frequency pulses appear on the oscilloscope screen. The initial pulse, consisting of 10 to 15 cycles of 5 megacycle voltage picked up directly from the generating circuit, appears at the left of the screen. This pulse has a duration of 2 or 3 microseconds. The initial pulse is followed in 50 or more microseconds (depending on transducer spacing and on the nature and thickness of the test sample) by a corresponding pulse originating from the ultrasonic signal that impinges on the receiving transducer.

When the transducers are moved with respect to the test plate, the ultrasonic beam passes through different areas of the test plate. If the intensity of the transmitted beam through these areas is altered, the amplitude of the received pulse displayed on the Reflectoscope screen as the test plate is scanned may indicate defective bond. A permanent record of these variations, which can be correlated with position on the faces of the test plate, is desirable. An electronic method was developed for recording the variations in the amplitude of the received electronic pulse as an aid in interpreting the observed data.

The basic recording device employed is a Brush Model BL-201 Oscillograph, preceded by its companion amplifier, Brush Model BL-905. Electronic units have been constructed for adapting the high frequency pulse voltage available at the output of the Reflectoscope amplifier to a form suitable for the Brush Amplifier input. The electronic units consist of: (1) a cathode follower to isolate the other electronic units from the circuits within the Reflectoscope and to act as an impedance transformer, (2) a demodulator which changes the 5 megacycle pulses to a single voltage pulse, and (3) a RC filter circuit which integrates the 60 cycle component and gives an output voltage dependent on the maximum amplitude of the original 5 megacycle pulses.

It was found that changes in amplitude of the signal from the receiving transducer are completely masked by the effect of the initial pulse when the amplitude of the initial pulse exceeds that of the received pulse. Two steps were taken to reduce the amplitude of the initial pulse. A grounded electrostatic shield of thin aluminum foil was placed around the receiving transducer. This practically eliminated direct electromagnetic pickup in the transducer and coaxial cable. Some incidental pickup within the Reflectoscope case still remained. A single stage pre-amplifier with a broadly tuned input circuit was inserted between the receiving transducer and the Reflectoscope. This amplifier increased the voltage from the receiving transducer without affecting appreciably the incidental pickup of the initial pulse. These measures reduced the relative amplitude of the initial pulse sufficiently to permit satisfactory recording of variations in the received signal.

Variations in the trace on the Brush Recorder Chart seemed in general to follow closely variations in the amplitude of the received pulse as seen on the Reflectoscope screen.

A scanner was designed and built to move the transducers with respect to the sample. A photograph of this scanner is shown in Figure 5.

The lead screw of the scanner drives a transducer carriage along accurately machined ways. The lead screw is driven by a 1/12 horsepower AC reversible motor through a Graham Variable Speed Transmission. The speed of the lead screw could be varied from 0 to 550 rpm and the linear speed of the transducer carriage thus could be varied from 0 to 110 inches per minute. The two quartz transducers were held rigidly in a brass holder. This holder was made so the face of the receiving crystal was accurately parallel with the face of the transmitting crystal. The transducer carriage was so constructed that the transducer holder could be moved horizontally, vertically, and rotated about a vertical axis.

Microswitches for stopping and reversing the driving motor at the end of a scan could be set at any desired position along the ways. A manually operated switch was also provided for stopping the transducer carriage at any desired position during a scan.

Since nearly all of the incident ultrasonic energy is reflected at an air-solid interface, it is necessary to use some acoustically transparent substance or couplant to conduct the acoustic energy from the transducer into the sample. Many liquids such as oil, water, and glycerin are suitable couplants. In this experimental work, tap water was used as the couplant. Aerosol, a wetting agent, was added to prevent the formation of bubbles on the transducer faces and to thoroughly wet the sample to be tested.

A tank was built so that the test specimens could be completely immersed in the water couplant. This tank was made of 3/16 in. sheet steel. The sides and ends of the tank were lined with 3/8 in. thick sheet rubber to prevent ultrasonic reflections from the metal surfaces.

It was experimentally found that the scanning speed and the recording speed of the Brush Recorder had a definite effect on the sensitivity and resolution of this method of bond testing. If the speed of scanning is too low, the variations in voltage caused by the presence of defects will be too slow to pass through the Brush Recorder amplifier. If the scanning speed is too high, the changes in voltage will be so rapid that the RC filter will reduce their amplitude materially. If the speed of recording is too slow the variations in the trace will not be sharp. If the speed of recording is too fast, the recorder may not be able to follow the variations in voltage accurately.

A linear scanning speed of five feet per minute has been found most satisfactory in the present application. A Brush Recorder Chart speed of 0.5 cm per second has been found to be most satisfactory. The beginning and end of the test sample are easily identified. On the Reflectoscope, the amplitude of the transmitted pip decreases greatly when the ultrasonic beam is being transmitted through the sample. On the Brush Recorder Chart the ends are identified by large deflections of the pen.

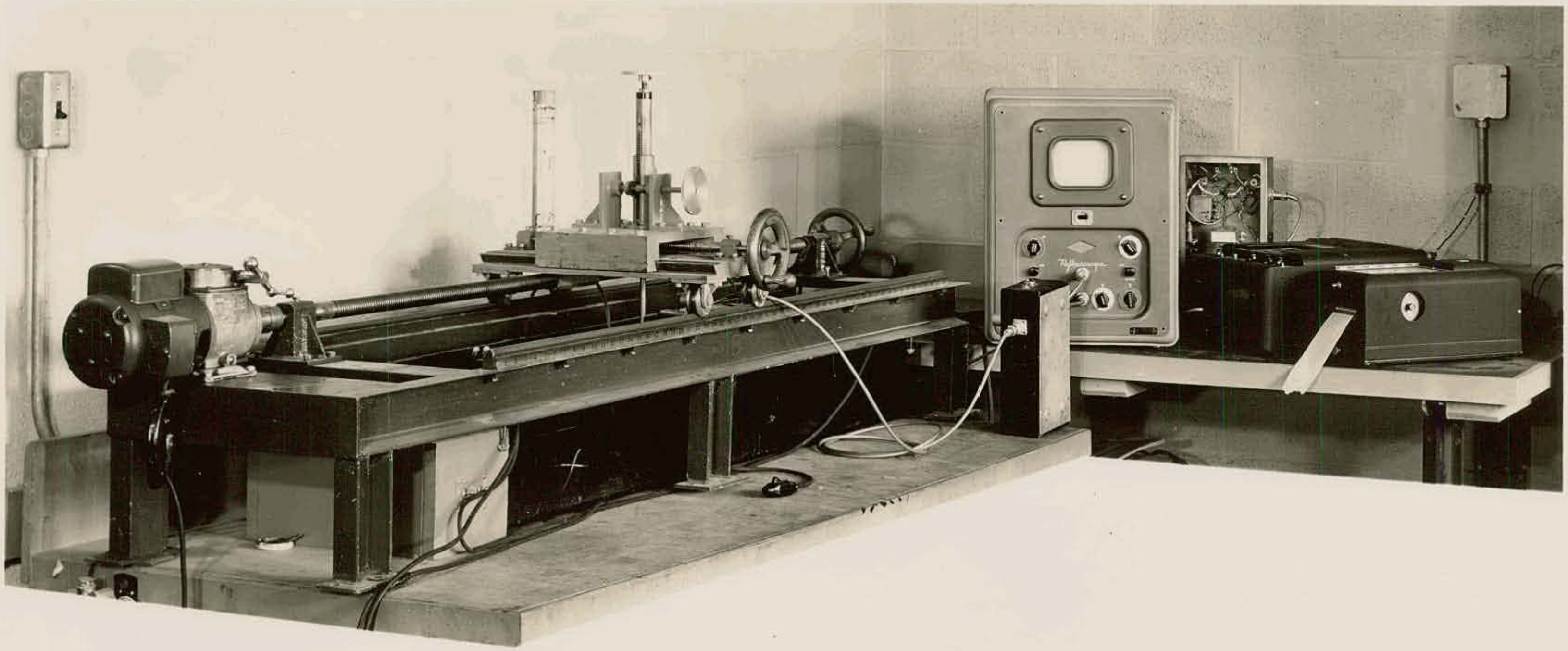


FIGURE 5 - ULTRASONIC SCANNER

III. KNOWN DEFECT BLOCKS

In order to evaluate the usefulness of and sensitivity of these methods, it was necessary to have samples containing known defects. "Known Defect Blocks" were made in an endeavor to get various degrees of metal-to-metal contact. Since zirconium had been proposed for this application, it was decided to make the known defect blocks from zirconium. Three different types of defect blocks were made: (1) samples containing inclusions, (2) samples made by drilling holes into zirconium plates perpendicular to the edge of the plate and after drilling the plates were reduced in thickness by rolling, and (3) samples made the same as in (2) above except that before rolling the holes were filled with zirconium wire of approximately the same diameter as the hole.

Block No. 13: This defect block was made by rolling together three zirconium plates. The plates were each 2-3/4 in. long and 1-1/2 in. wide. The cover plates were each 0.090 in. thick and the center plate was 0.045 in. thick. The center plate had two slots and two holes machined completely through it perpendicular to the face of the plate. The slot located near one end of the plate was 0.060 in. wide and 1/4 in. long and the slot located at the opposite end was 0.040 in. wide and 1/2 in. long. The two holes were 0.060 in. and 0.040 in. in diameter respectively. The slot and holes were filled with uranium oxide. The three plates were hot rolled together to a final thickness of 0.090 in. After rolling, the block was X-rayed to show the exact location of the holes and slots.

Block No. 102: This known defect block, made from zirconium, was 2-3/4 in. long by 1-1/2 in. wide by 0.250 in. thick. A hole 0.113 in. in diameter was drilled in the block perpendicular to the edge 0.75 in. from the end. A zirconium wire 0.110 in. in diameter was placed in the hole and the block warm rolled at a temperature of 1100F in air to a thickness of 0.112 in. Examination of the edge revealed that in rolling the wire flattened out into an elongated ellipse (major axis - 0.0225 in. - minor axis - 0.035 in.) giving metal-to-metal contact between the zirconium wire and the block. In addition the hole collapsed at one end of the ellipse giving an additional metal-to-metal contact along a line 0.007 in. long.

Block No. 107: This defect block 1/2 in. thick, 1 in. wide, and 2-1/2 in. long was made from a piece of zirconium. One hole, 0.040 in. in diameter, was drilled into the blocks 3/4 in. from one end and perpendicular to the edge. Another hole, 0.020 in. in diameter, was drilled perpendicular to the edge 3/4 in. from the other end. Zirconium wire slightly smaller than 0.020 in. in diameter was placed in the holes and the block was warm rolled to 0.250 in. thickness. Figures 6 and 7 show how the wall of the hole completely collapsed about the wires after rolling giving metal-to-metal contact of approximately 0.095 in. and 0.045 in. respectively for the large and small defects. This block, after testing at the original thickness of 0.250 in., was subsequently machined to 0.160 in., 0.120 in., 0.090 in., 0.060 in., and 0.030 in. thicknesses and tested at each thickness.

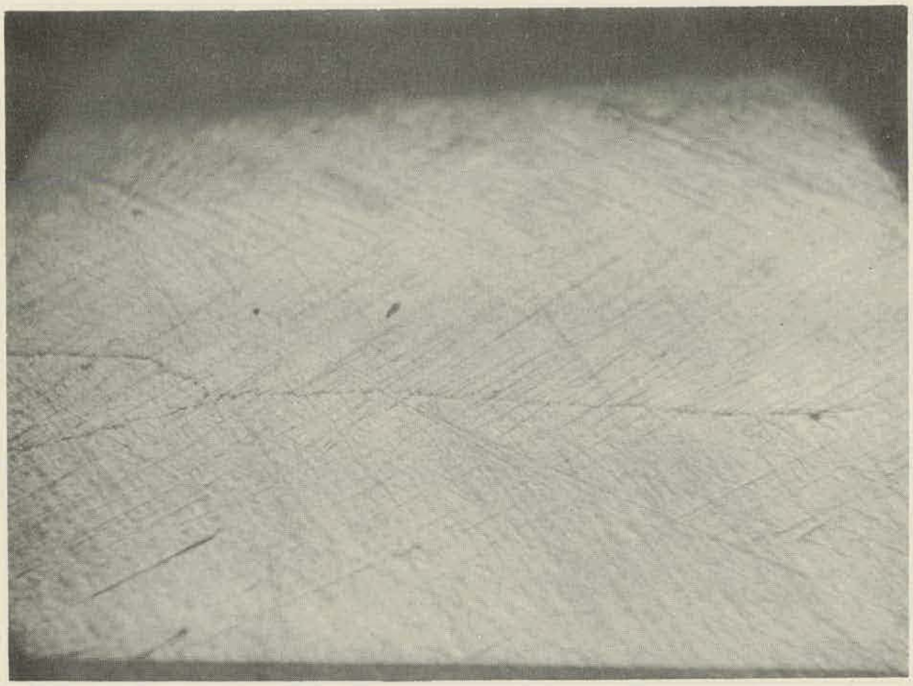


FIG. 6 - MICROGRAPH OF SECTION CUT THROUGH LARGE ZIRCONIUM WIRE FILLED HOLE IN BLOCK NO. 107

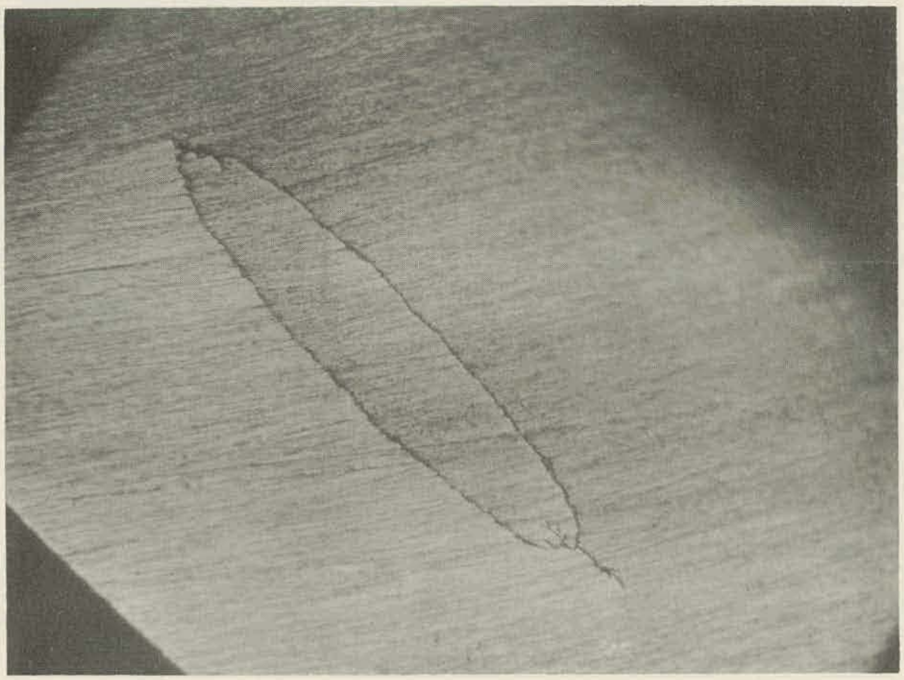


FIG. 7 - MICROGRAPH OF SECTION CUT THROUGH SMALL ZIRCONIUM WIRE FILLED HOLE IN BLOCK NO. 107

Block No. 108: This block was similar to No. 107. A hole 0.013 in. in diameter was drilled perpendicular to the edge and filled with zirconium wire 0.010 in. in diameter. The block was warm rolled to a thickness of 0.250 in. Examination of the edge showed the wall of the hole completely collapsed about the wire after rolling. This block was machined and tested at the same thickness as No. 107.

IV. RESULTS

A. Thermographic Method

Figure 8 shows that the thermographic method positively detected the intentional defect in Known Defect Block No. 102. The comparative sensitivity of the thermographic, electrode-potential, and ultrasonic methods was determined by examination of Known Defect Blocks No. 107 and 108. The individual results are discussed under each of the three methods. Block No. 107 was first examined at a thickness of 0.025 in. Subsequent tests were made after machining the block to thicknesses of 0.160 in., 0.120 in., 0.090 in., 0.060 in., and 0.030 in The larger defect was detected at thicknesses of 0.060 in. and 0.030 in. Thermographic results are recorded on the movie film as shown in Figure 9. The smalle defect was not discerned at any thickness. The known defect incorporated in Block No. 108 was smaller than that of the small defect in Block No. 107 and could not be detected. The results of these tests are summarized in Table I.

These data show that the thermographic method can be used to detect metal-to-metal contact of approximately 0.095 in. in width when the material is a maximum of 0.060 in. thick.

B. Electrode Potential Method

Figures 10 and 11 show the results obtained using the Electrode Potentia Method with Blocks No. 13 and 102.

Known Defect Blocks No. 107 and 108 were tested to compare the electrode potential method with the thermographic and ultrasonic methods. Block No. 107 was tested at thicknesses of 0.250, 0.160, 0.120, 0.090, 0.060, and 0.030 in. The larger defect was found at thicknesses of 0.120 in. and less. The smaller defect was found only for thicknesses of 0.060 in. and 0.030 in.

Block No. 108 was tested at the same thicknesses as Block No. 107. The defect was not clearly indicated at any thickness. A summary of the experiment with Block No. 107 and 108 showing the sensitivity of this method is given in Table II and Figures 12 and 13.

The Electrode Potential Method is capable of indicating and producing a permanent record of bond defects. The smallest detectable defect is one equivalent to a circular void of the order of 0.030 in. in diameter. The sensitivity of the method is greater for thinner test plates.

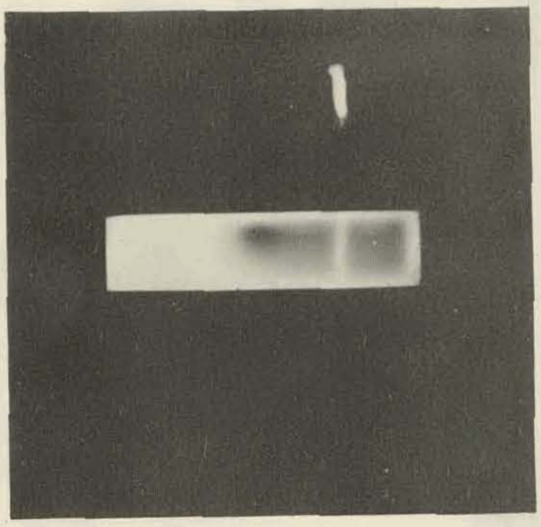
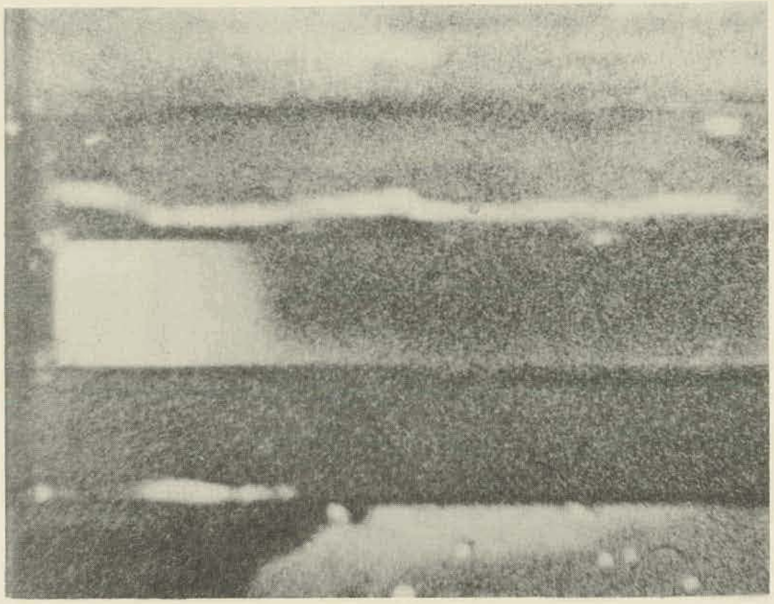
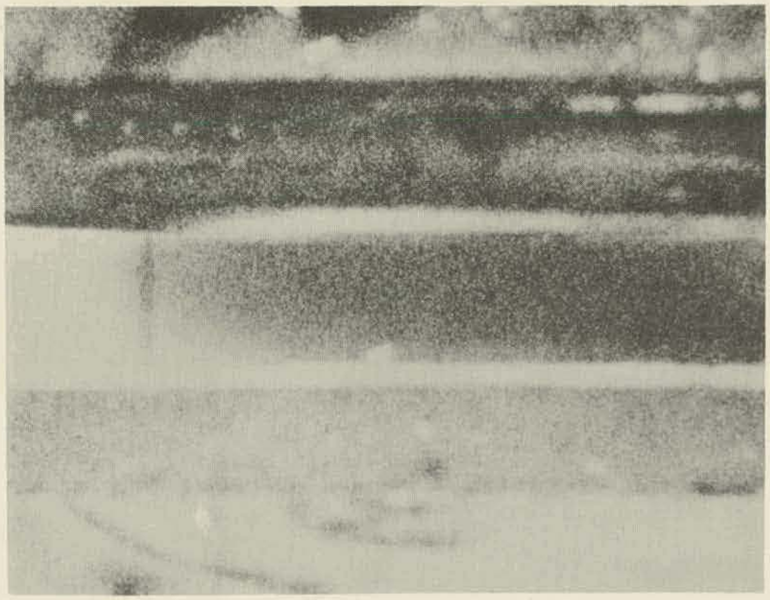


Figure 8 - Thermograph of Block No. 102



A. THICKNESS - 0.060 IN.



B. THICKNESS - 0.030 IN.

FIG. 9 - THERMOGRAPH OF ZIRCONIUM WIRE FILLED HOLE IN KNOWN DEFECT BLOCK NO. 107

TABLE I - THERMOGRAPHIC METHOD RESULTS ON DEFECT BLOCKS NO. 107 AND 108

Thickness of Block, in.	Block No. 107 Large Defect	Block No. 107 Small Defect	Block No. 108
0.250	NR	NR	NR
0.160	NR	NR	NR
0.120	NR	NR	NR
0.090	PR	NR	NR
0.060	R	NR	NR
0.030	R	NR	NR

NR - Not revealed
PR - Partially revealed
R - Revealed

TABLE II - ELECTRODE POTENTIAL METHOD RESULTS ON DEFECT BLOCKS NO. 107 AND 108

Thickness of Block, in.	Block No. 107 Large Defect	Block No. 107 Small Defect	Block No. 108
0.250	NR	NR	NR
0.160	NR	NR	NR
0.120	PR	NR	NR
0.090	R	NR	NR
0.060	R	R	NR
0.030	R	R	NR

NR - Not revealed
PR - Partially revealed
R - Revealed

FIG. 10 – ELECTRODE POTENTIAL SCAN OF KNOWN DEFECT BLOCK NO. 13

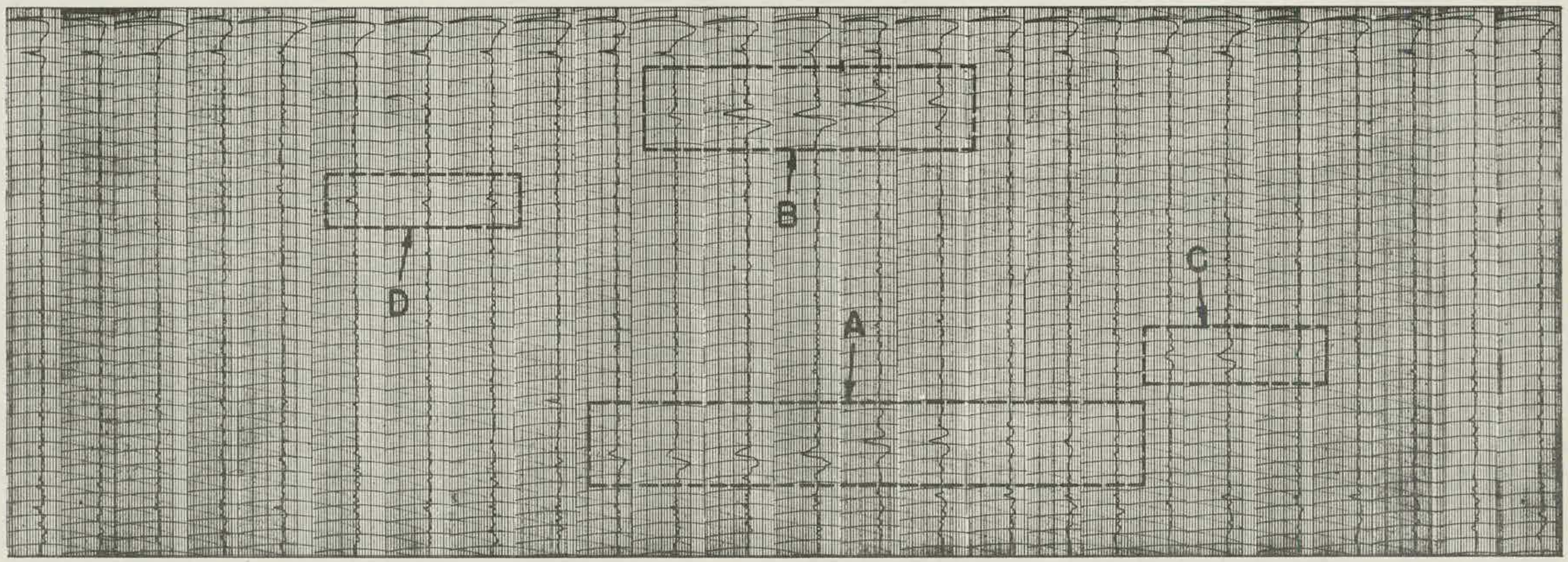


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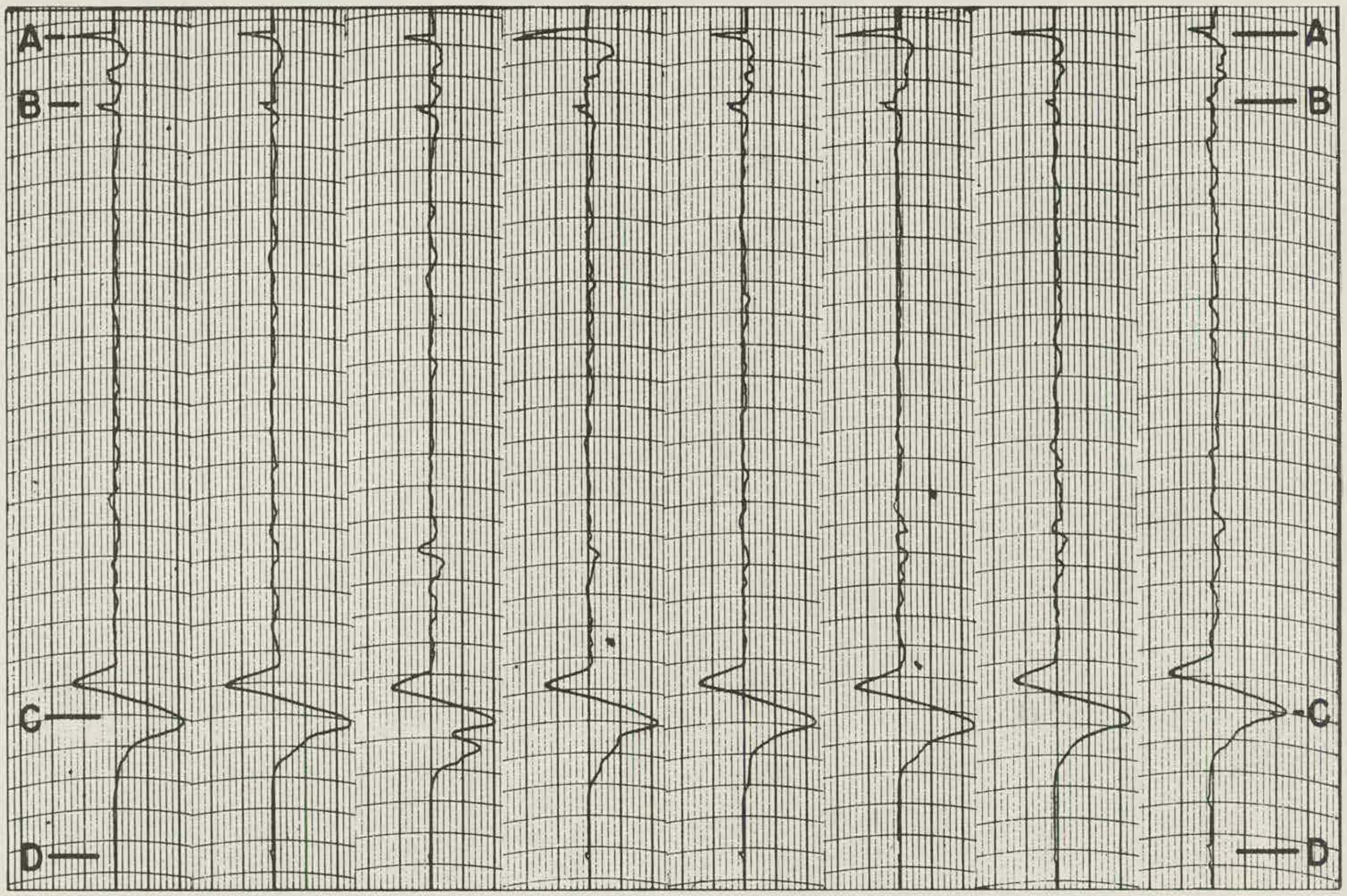
FIG. 11-ELECTRODE POTENTIAL SCAN
KNOWN DEFECT BLOCK NO. 102



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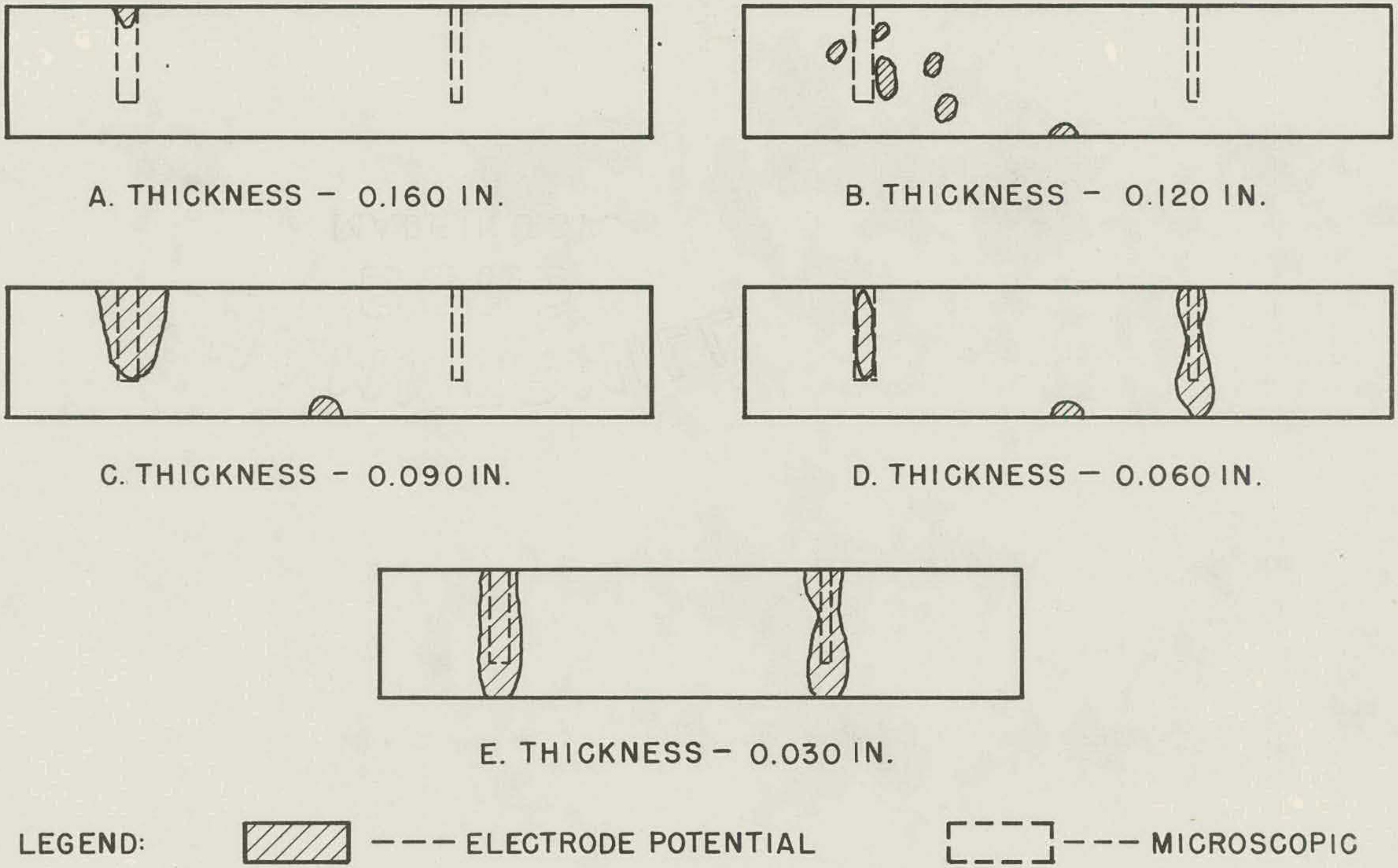

FIG. 12 – ELECTRODE POTENTIAL SCAN OF KNOWN DEFECT BLOCK Nº 107

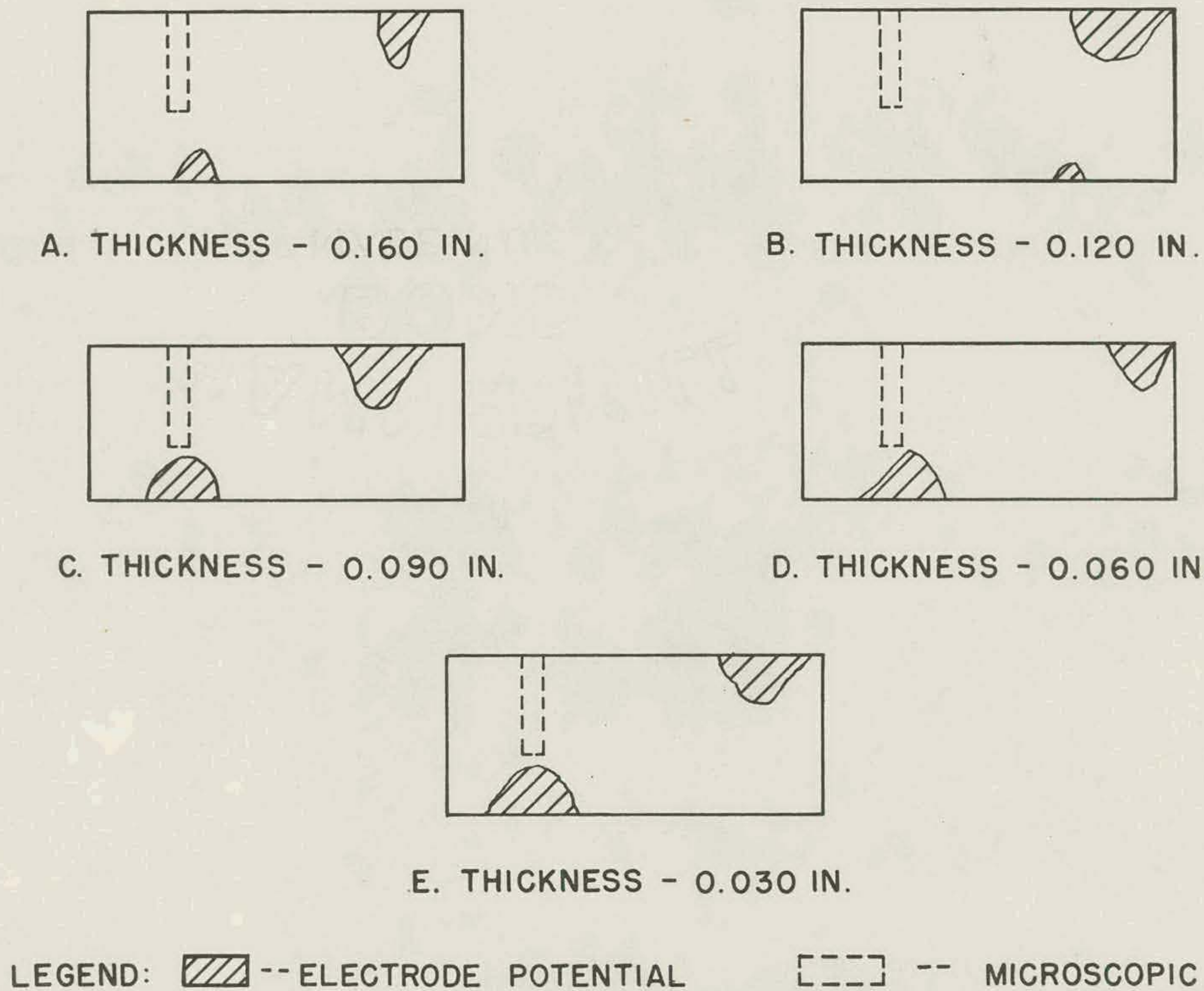

FIG. 13-ELECTRODE POTENTIAL SCAN OF KNOWN DEFECT BLOCK NO. 108.

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C. Ultrasonic Transmission Method

Figures 14 and 15 show the results with Block No. 13 using the ultrasonic transmission method.

Known Defect Blocks No. 107 and 108 were tested to compare the ultrasonic transmission method with the thermographic and electrode potential method. Block No. 107 was tested at thicknesses of 0.250 in., 0.160 in., 0.120 in., 0.090 in., 0.060 in., and 0.030 in. The larger defect was found at all thicknesses except 0.250. This latter known defect appeared to have a rather broad area or to be separated into two parts.

Known Defect Block No. 108 was tested at the same thicknesses as Block No. 107. A large blistered area, visible on the surface, was indicated at all thicknesses. At a thickness of 0.250, two defects in the region of the intentional defect were found. At a thickness of 0.160 in. the known defect was found. At 0.120 in. thickness, a very broad defect surrounding the known defect was found. Two additional defects were found in this block; one on the edge opposite the intentional defect and the other near the middle of the block. At thicknesses of 0.090 in., 0.060 in., and 0.030 in., the intentional defect was readily located. The defect opposite the known defect was indicated in each case and at 0.030 in. appeared to merge with the intentional defect. At 0.030 in. the small defect near the middle of the block disappeared and a small defect appeared near one edge.

Table III and Figures 16 and 17 summarize the results obtained by this method.

The ultrasonic transmission method is a method of bond testing capable of differentiating between areas of intimate metal-to-metal contact and areas where the two metals are fused together. The method is sufficiently sensitive in that it will detect areas of poor bond smaller than 1/8 in. by 1/8 in. This method of bond testing also lends itself to permanent recording of the desired information and at the same time is sufficiently rapid for production testing.

V. SUMMARY

The thermographic, electrode potential, and ultrasonic transmission methods of bond testing are the best of those studied for detecting discontinuities consisting of voids, occlusions, and metal-to-metal contact with no bond and areas where the components are fused together. However, even with metal-to-metal contact, areas of no diffusion bonding with one dimension as small as 1/8 in. are discernible on thin sections by all three methods.

A summary of the results obtained by the thermographic, electrode potential, and ultrasonic methods with Known Defect Blocks 107 and 108 is given in Table IV.

FIG. 14 - ULTRASONIC SCAN OF KNOWN DEFECT BLOCK NO. 13 (UNMASKED)

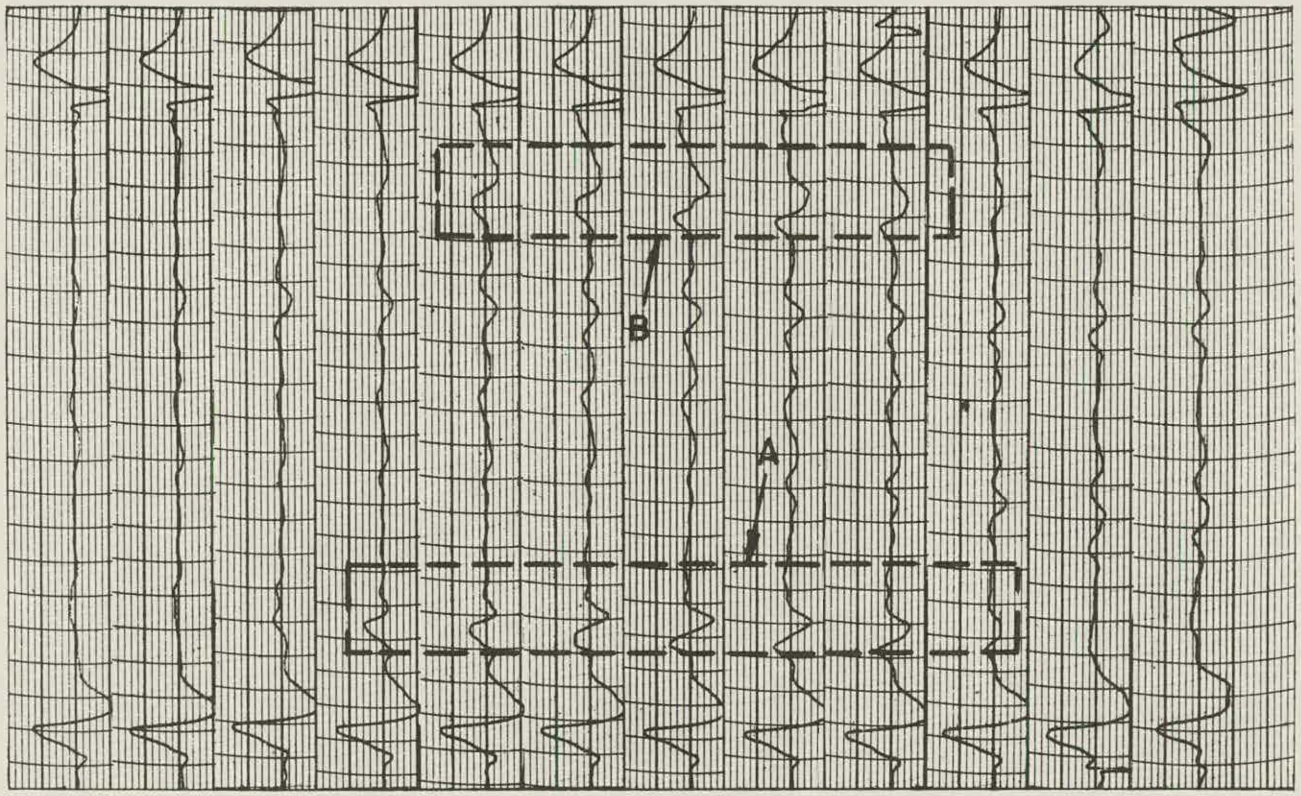
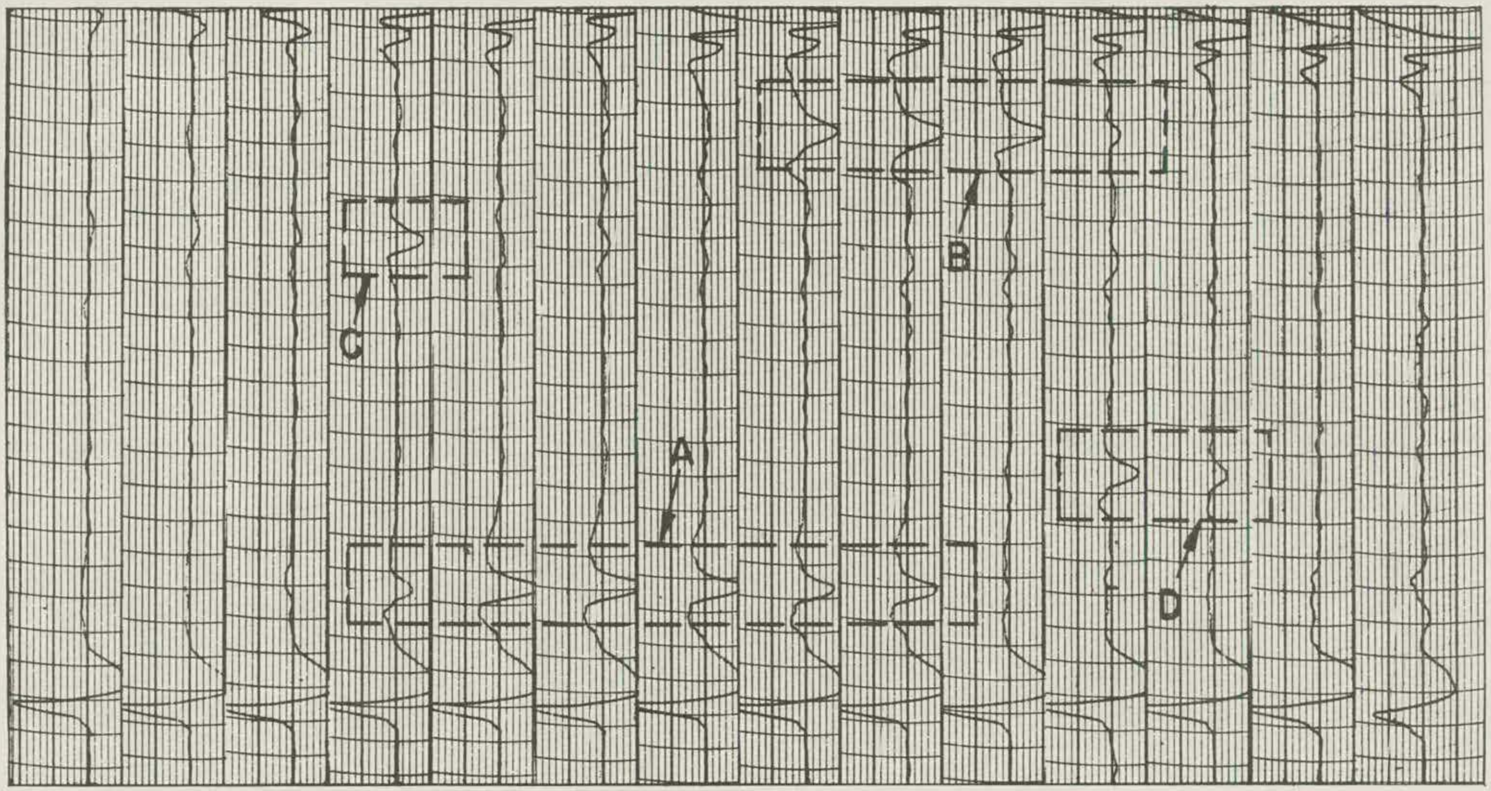


FIG. 15 - ULTRASONIC SCAN OF KNOWN DEFECT BLOCK NO. 13 ($\frac{3}{16}$ MASK)



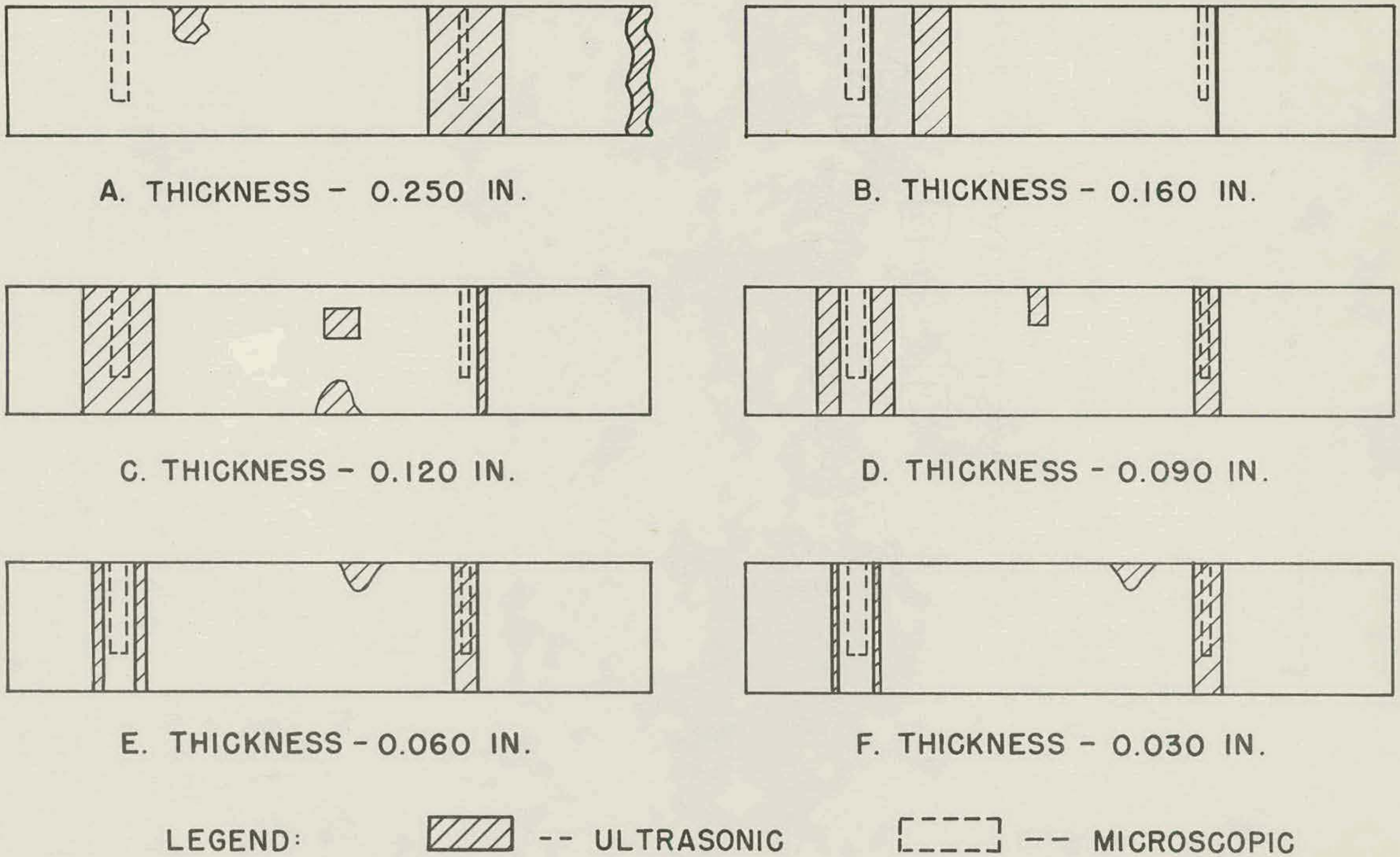


FIG. 16 - ULTRASONIC SCAN OF KNOWN DEFECT BLOCK NO. 107

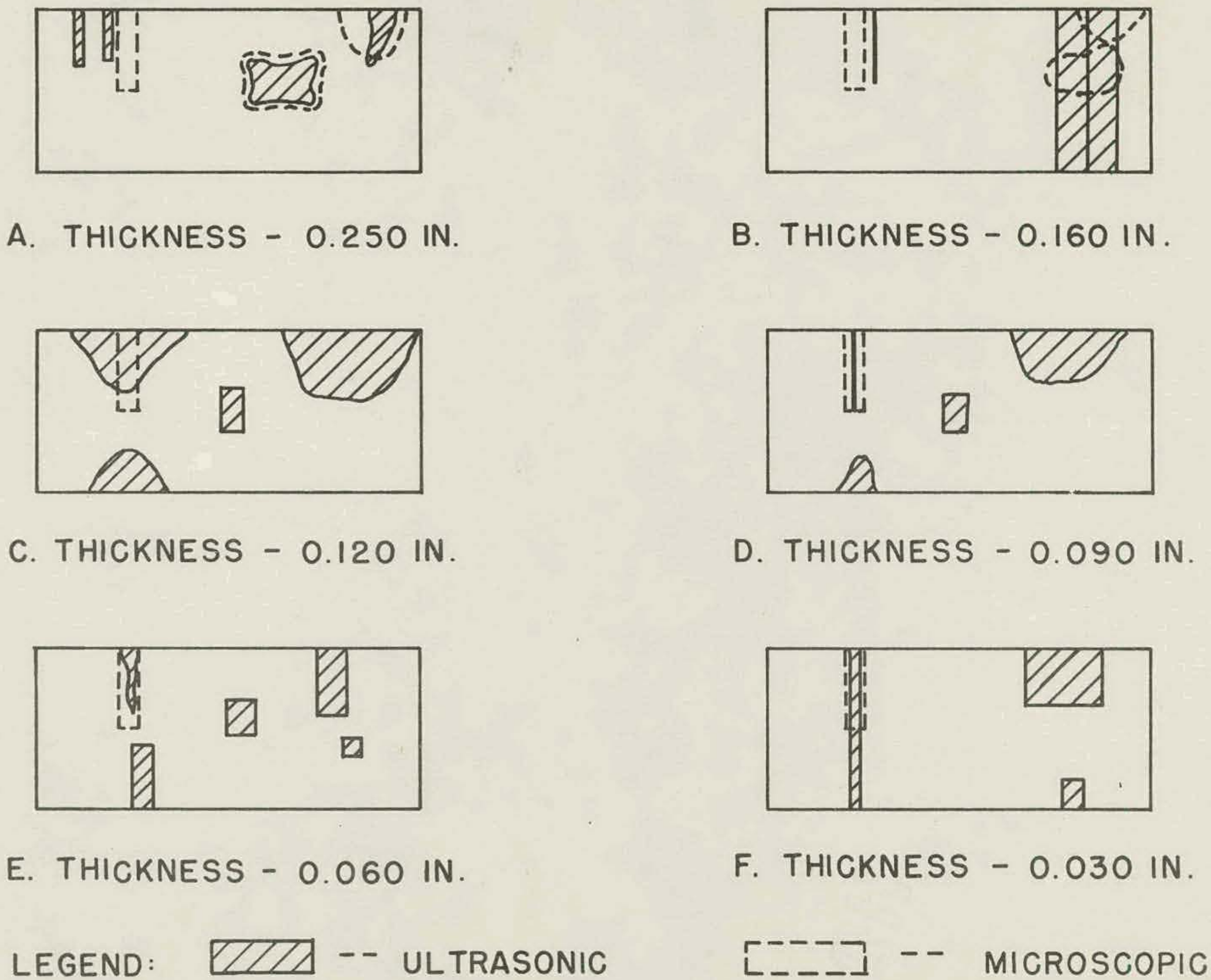


FIG. 17 - ULTRASONIC SCAN OF KNOWN DEFECT BLOCK NO. 108

TABLE III - ULTRASONIC TRANSMISSION METHOD RESULTS ON DEFECT BLOCKS NO. 107 AND 108

Thickness of Block, in.	Block No. 107 Large Defect	Block No. 107 Small Defect	Block No. 108
0.250	PR	NR	NR
0.160	R	R	R
0.120	R	R	NR
0.090	R	R	R
0.060	R	R	R
0.030	R	R	R

NR - Not revealed
PR - Partially revealed
R - Revealed

TABLE IV - SUMMARY OF RESULTS ON KNOWN DEFECT BLOCKS 107 AND 108

Method of Determination*

Thickness of Block, in.	Thermographic 1*	2*	3*	Electrode Potential 1	2	3	Ultrasonic 1	2	3
0.250	NR	NR	NR	NR	NR	NR	PR	NR	NR
0.160	NR	NR	NR	NR	NR	NR	R	R	R
0.120	NR	NR	NR	PR	NR	NR	R	R	NR
0.090	PR	NR	NR	R	NR	NR	R	R	R
0.060	R	NR	NR	R	R	PR	R	R	R
0.030	R	NR	NR	R	R	NR	R	R	R

* Notation for defect observed.

1 Block 107 - 0.018 in. wire in 0.030 in. hole before rolling.
2 Block 107 - 0.018 in. wire in 0.020 in. hole before rolling.
3 Block 108 - 0.010 in. wire in 0.013 in. hole before rolling.

NR - Not revealed
P - Partially revealed
R - Revealed

These experimental data show the ultrasonic method of testing to be the most sensitive with the electrode potential method moderately sensitive and the thermographic method least sensitive. The electrode potential and thermographic methods require thinner sections for maximum sensitivity while the sensitivity of the ultrasonic method seems to be about constant for all thickness of material The ultrasonic and electrode potential methods with their scanning devices give immediate record of the defect while there is a lapse of time in thermography due to photographic development. One advantage peculiar to the thermographic method is that this method tests thermal conductivity at room or slightly elevated temperature, regardless of the nature of the defect.

VI. BIBLIOGRAPHY

1. Transactions of the American Institute of Electrical Engineers, Vol. 67, Part 1, Page 128.

2. Canadian Journal of Research, A17, 179, (1939).

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These experiments [illegible] show the ultrasonic [illegible] most sensitive with the electrode potential method [illegible] thermographic method least sensitive. The electrode potential [illegible] methods require thin sections for maximum sensitivity [illegible] of the ultrasonic method seems to be most consistent for all thickness [illegible]. The ultrasonic and electrode potential methods with their [illegible] immediate record of the defect while there is a lapse of time [illegible] due to photographic development. One advantage peculiar to the thermographic method is that this method [illegible] thermal conductivity at room or [illegible] varied temperature, regardless of the nature of the defect.

VI. BIBLIOGRAPHY

1. Transactions of the American Institute of Electrical Engineers, Vol. 67, Part [illegible], Page [illegible].
2. Canadian Journal of Research, A17, 179, (1939).

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