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MEASURING PENETRATION DEPTH OF ELECTRON BEAM WELDS

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MEASURING PENETRATION DEPTH OF ELECTRON BEAM WELDS

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Prepared by J. W. Hill, D/142, under PDO 6989209

Holographic interferometry can yield a qualitative indication of the strength of electron beam welds. Micro-resistance measurements can distinguish relative depths of penetration and are also useful as a thickness gage. Infrared analysis was evaluated. Limitations on the effectiveness of micro-resistance measurements were also determined.

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CONTENTS

ILLUSTRATIONS

TABLE

SUMMARY

The feasibility of evaluating electron beam welds using state-of-the-art techniques in the fields of holographic interferometry, micro-resistance measurements, and heat transfer was studied.

The holographic study was aimed at evaluating weld defects by monitoring variations in weld strength under mechanical stress. The study, along with successful work at another facility, proved the feasibility of this approach for evaluating welds, but it did not assign any limitations to the technique.

The micro-resistance study was aimed at evaluating weld defects by measuring the electrical resistance across the weld junction as a function of distance along the circumference. Experimentation showed this method, although sensitive, is limited by the same factors affecting other conventional nondestructive tests. Nevertheless, it was successful at distinguishing between various depths of penetration. It was also shown to be a sensitive thickness gage for thin-walled parts.

The infrared study was aimed at evaluating weld defects by monitoring heat transfer through the weld under transient thermal conditions. Experimentation showed that this theoretically sound technique is not workable with the infrared equipment currently available at Bendix Kansas City.

DISCUSSION

SCOPE AND PURPOSE

The purpose of this project was to evaluate micro-resistance, holography, and heat transfer as means of nondestructively testing the penetration depth of electron beam welds. Because it was felt that Bendix has special capabilities in these areas, LASL recommended these investigations. The study was undertaken to demonstrate the feasibility of these techniques for nondestructive weld evaluation. Currently, there are no suitable techniques for evaluating this type weld in parts other than by destructive methods.

PRIOR WORK

Previous work on holographic interferometry was reported in BDX-613-967, *Holographic Interferometry*, by M. P. Schoeppner. Some successful work on weld evaluation has been done at Los Alamos Scientific Laboratory; however, this work was discontinued, and nothing has been reported to date.

ACTIVITY

Although this project was concerned with electron beam welds, the techniques discussed would be applicable to any welds with similar materials and metallurgical properties.

Holographic Investigation

Weld characteristics are reflected in a part's mechanical behavior under an applied stress. Holographic interferometry is used to map out the strain patterns that the part is demonstrating. This permits a qualitative look at unusual behavior along the weld line and quantitative analysis of the surface strain field across the weld. An ideal electron beam weld with 100 percent penetration would have the same properties as the base material and would show no anomalous behavior.

Further efforts in this area should include design of a suitable fixture for holding the test part. A stress analysis computer program (such as NASTRAN) should be used to supplement the study by running out the analyses for a series of different weld and weld defect conditions. As the primary tool for the study, the program would define the quantitative limits for the experiment and be geared to verification of projected results and definition of empirical parameters. Such an approach would avoid the perpetual problem of obtaining a sufficient number of appropriate samples to perform a complete experiment.

Micro-Resistance Measurements

Electrical resistance is inversely proportional to the cross-sectional area of the path of the current. A four-point resistance measurement uses separate pairs of electrodes to supply a constant current and measure the resulting voltage drop. When taking a four-point measurement across a weld seam, the value obtained will be inversely proportional to the cross-sectional area perpendicular to the seam. Because the cross-sectional area can be expected to be proportional to the depth of penetration, resistance measurements should offer a viable means of measuring depth of penetration.

Equipment used in this evaluation was an Electro-Scientific Industries Model 1700 Digital Micro-Ohmeter and an Alessi Industries Four-Point Probe.

To evaluate this concept, resistance measurements were made across several weld seams as a function of position along the circumference. Figure 1 shows the resistance versus position for one sample. Correlation with the character of the weld can be derived by comparing this data with the cross-section data depicted in Figures 2 and 3. View A in each figure, corresponding to point 17 of Figure 1, shows the point of maximum resistance. This should be the point of minimum penetration. Views B correspond to the point of minimum resistance (Point 21). This should be the point of maximum penetration.

The cross-section data indicate that the average depth of penetration is the same in both cases. The differences in the resistance are caused by the differences in the electrical cross section of the weld. Rather than depth of penetration, these differences are caused by the presence and absence of direct contact of the two members of the welded part and the diffusion bonds that form between the contacting members. The difference can be seen in Figure 3, which correspond to Points 17 and 21, respectively, in Figure 1.

Standard deviation from all sources of error at any point was 2.6 $\mu\Omega$, standard deviation resulting from probe reposition alone was 0.9 $\mu\Omega$, and standard deviation resulting from electrical noise alone was 1.8 $\mu\Omega$. The bars bracketing the curve represent the data spread for this point. Other points on this curve exhibited the same spread.

Another sample, consisting of five stainless steel rings electron-beam-welded together, was also tested. These four welds were produced with varying degrees of penetration. Table 1 shows the correlation of the resistance measured to the depth of penetration as determined by cross-sectioning the samples. The resistance across Welds 1 and 2 is shown in Figure 4 as a function of distance along the circumference.

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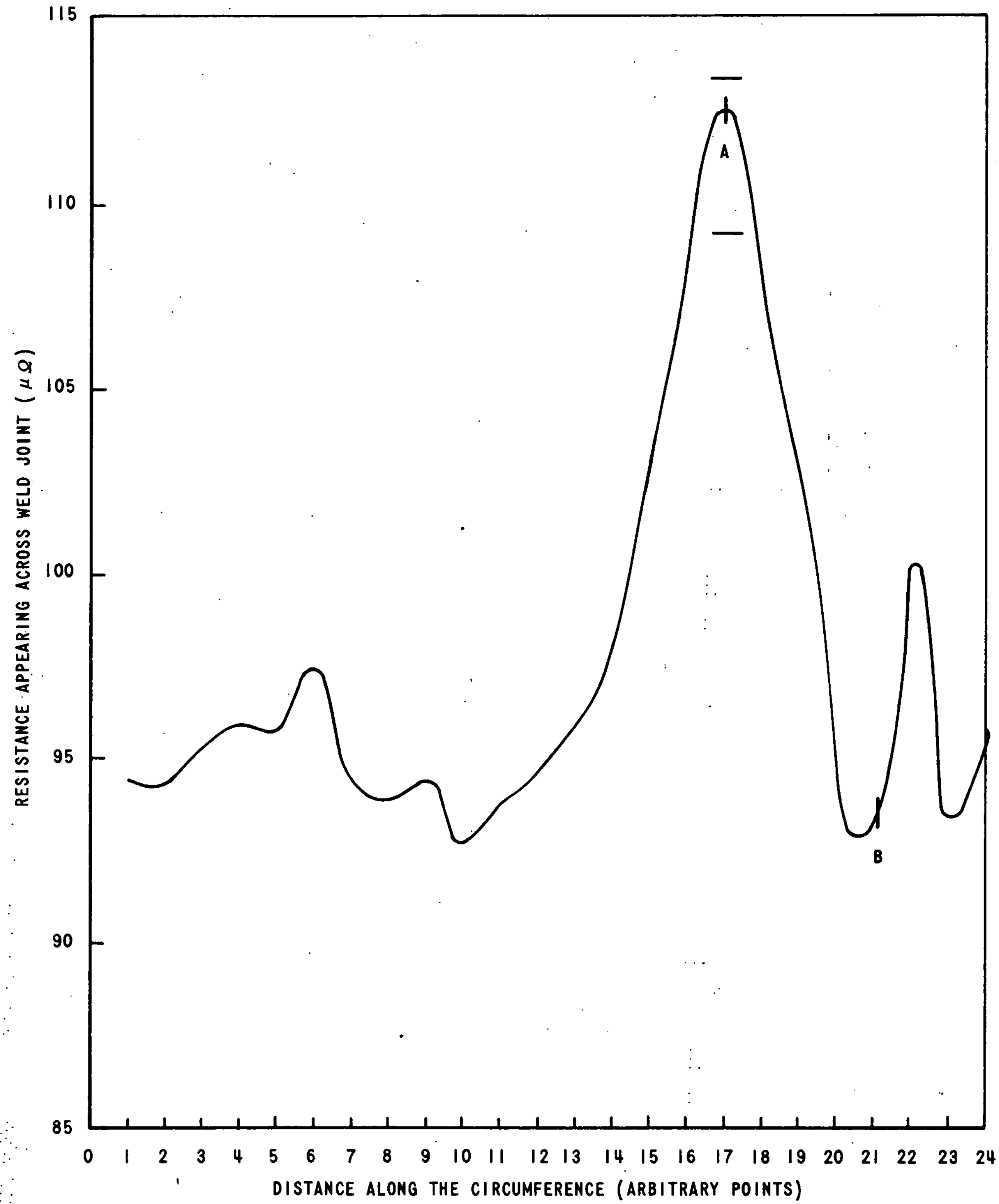
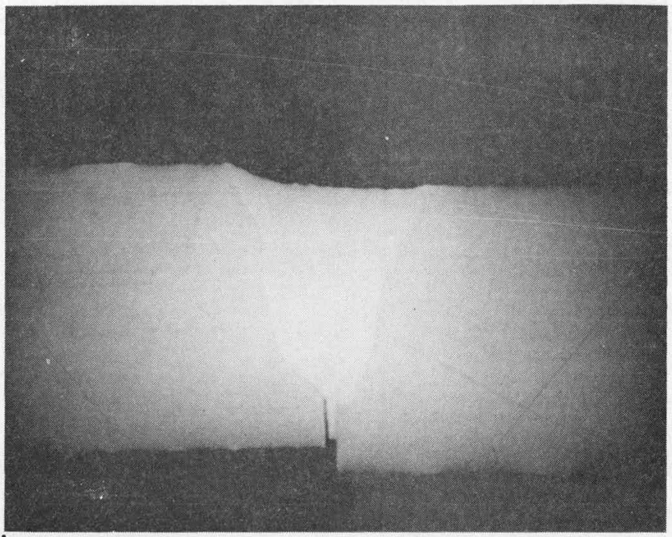


Figure 1. Resistance Versus Position for Production Test Sample



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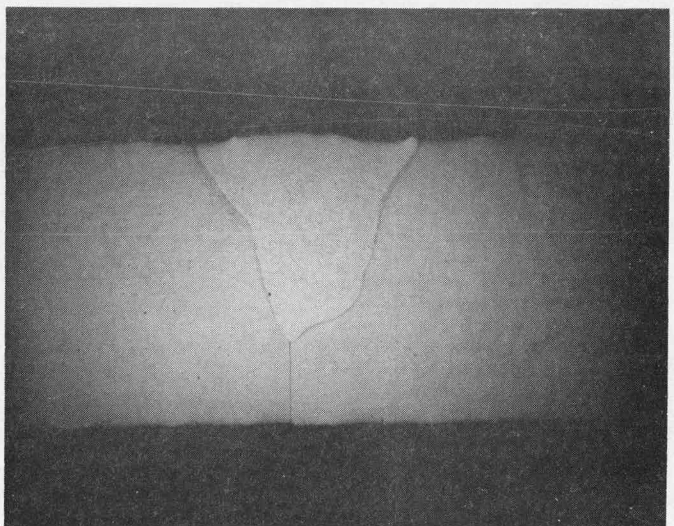
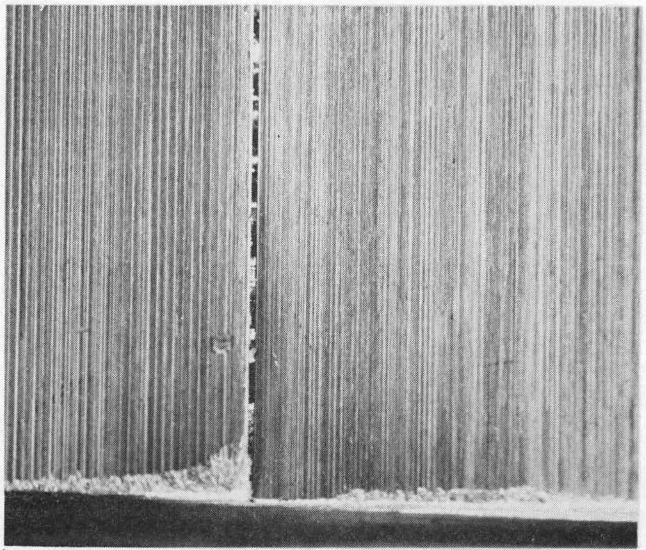


B

Figure 2. Cross Sections of Welds



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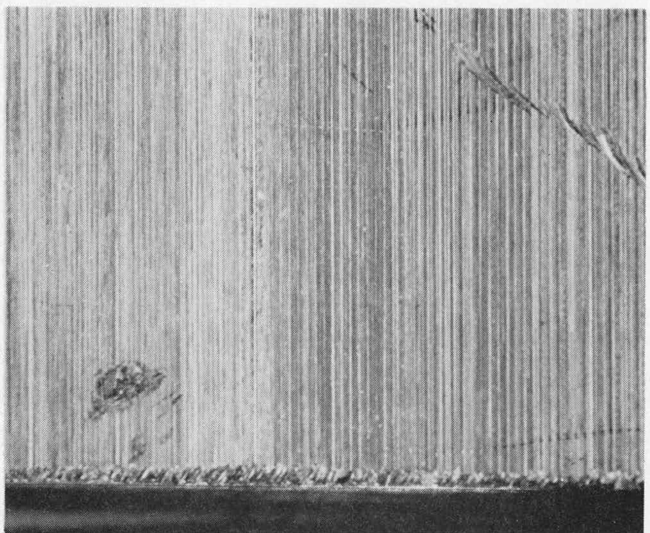

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Figure 3. Undersides of Figure 2 Sections

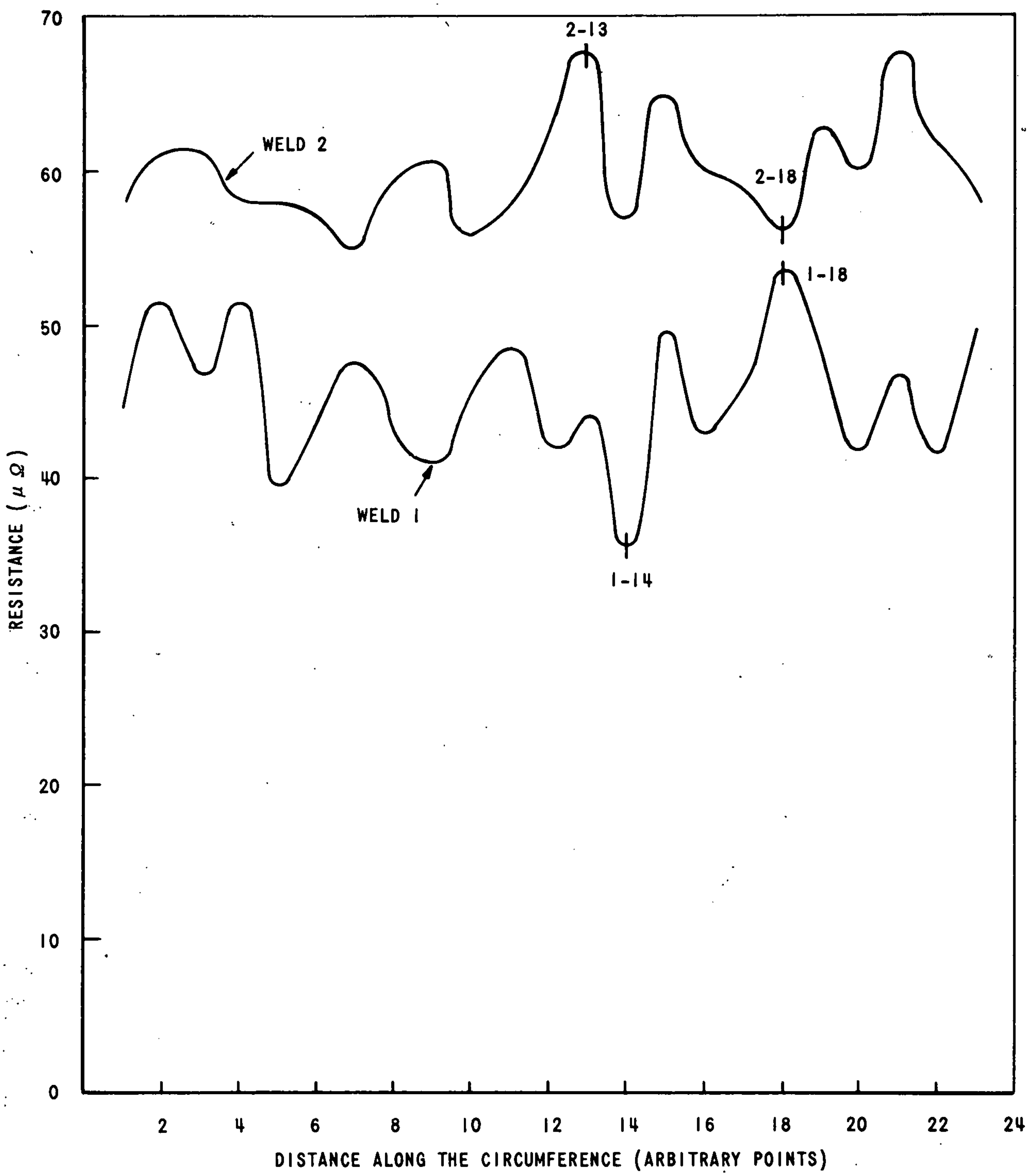


Figure 4. Resistance Versus Circumferential Position for Ring Samples

Table 1. Comparison of Depth of Penetration and Resistance

Weld Number	Penetration Depth (Percent)	Average Resistance ($\mu\Omega$)
1	79.5	43.41
2	38.46	59.73
3	46.15	54.16
4	46.15	54.45

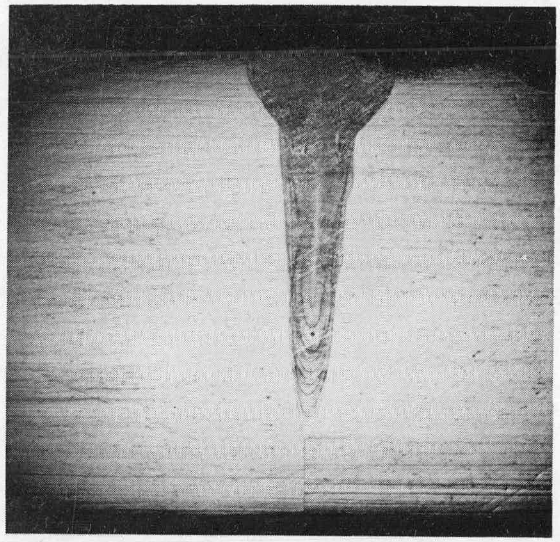
A plot of resistance versus position is shown in Figure 4 for Welds 1 and 2. The vertical lines intersecting the curves represent the points where metallurgical cross sections were made (Figure 5). Examination of the cross sections and resistance data indicates that the depth of penetration is directly proportional to the averaged resistance around the weld. The variation in the resistance around one joint appears to result neither from variation in the depth of penetration, nor from the physical separation of the weld members as in the previous example, but from variation in the amount of weld material that accumulates over the seam.

To establish the material thickness limitations of this weld evaluation technique, a series of steel gage blocks were obtained, and resistance measurements obtained as a function of thickness (Figure 6). This technique is very sensitive for parts of less than 40 mils (0.1 mm) thickness. Also, resistance represents a sensitive means of thickness gaging for samples of 40 mils thickness or less. The ring samples of Figures 4 and 5 were 175 mils (4.5 mm) thick and the samples of Figures 1, 2, and 3 were 111 mils (2.8 mm) thick.

This is a useful technique when the limitations of weld thickness, seam flatness, and seam separation are recognized and considered.

Additional work should include gathering of weld depth calibration data for the particular weld specimens of interest, investigation of conventional nondestructive testing techniques for determining the presence of error-causing flaws, and inclusion of mechanical fixtures and a data averager to simplify the inspection procedure.

1-14



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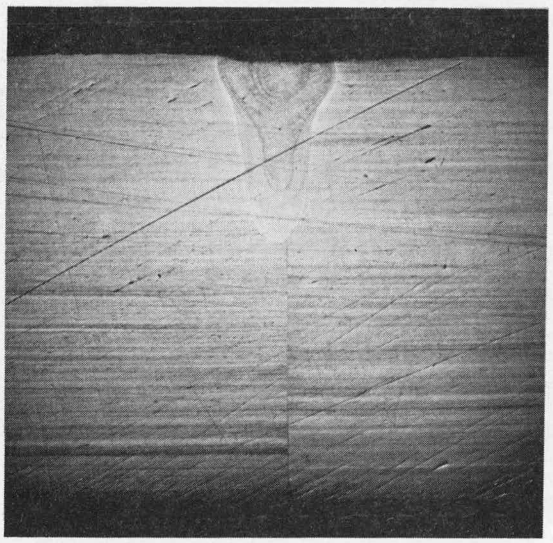

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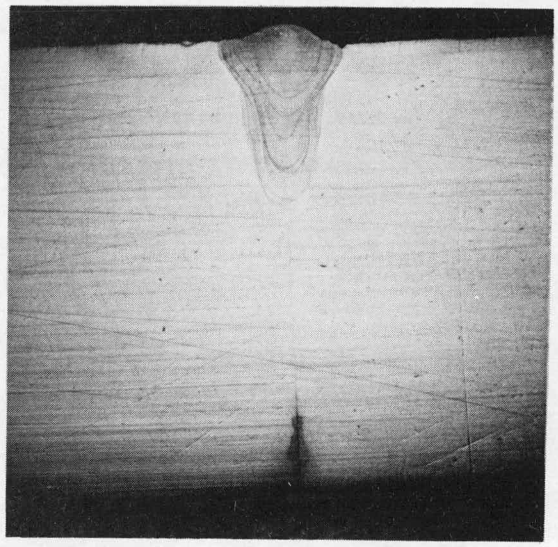

2-18

Figure 5. Cross Sections of Weld Samples

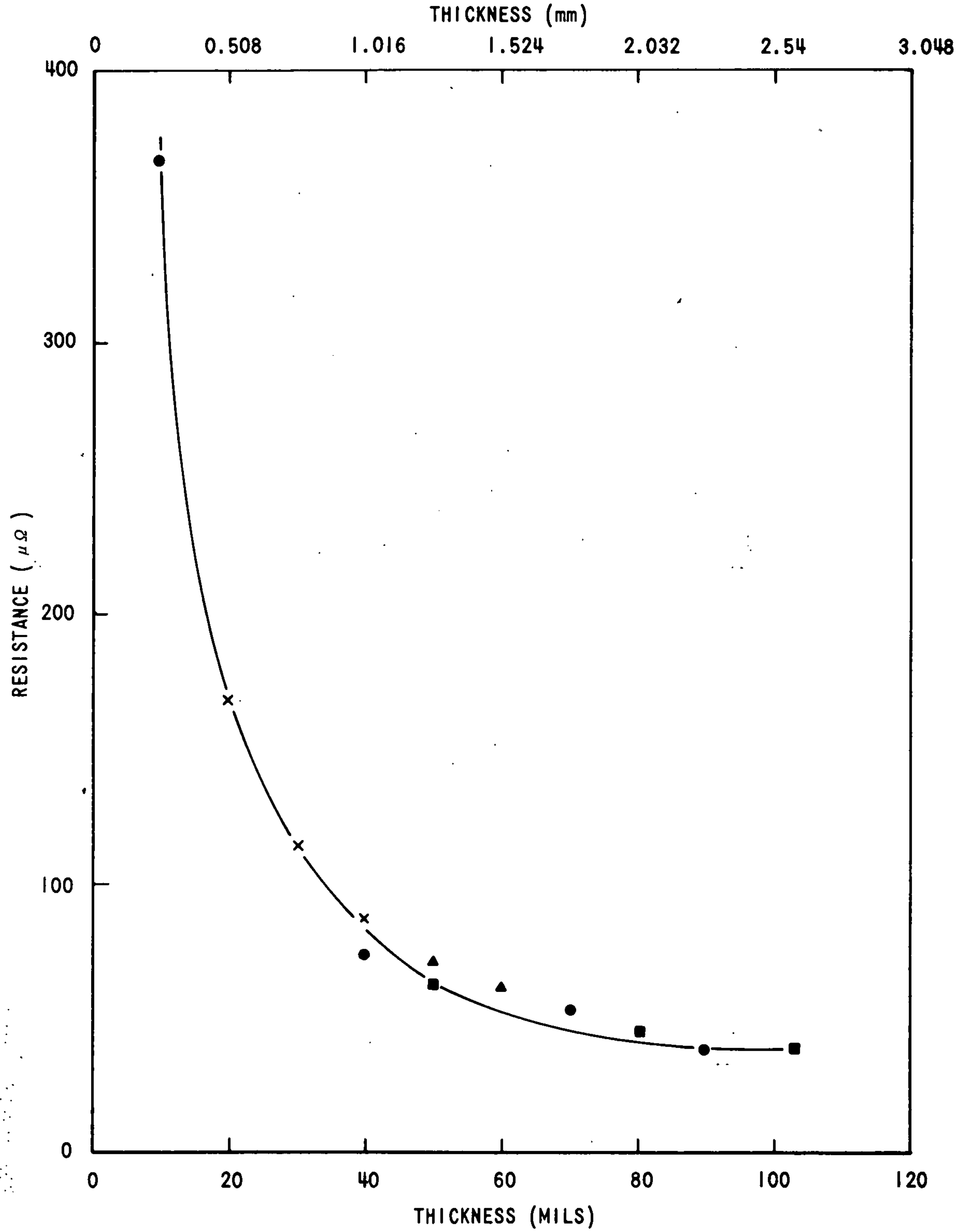

Figure 6. Thickness Versus Resistance of Steel Gage Blocks

Infrared Investigation

The heat flow through a welded section differs from that through the normal homogeneous material; therefore, a system was set up to monitor the difference between the two. Variations in this differential heat flux indicate variations in weld quality.

Two infrared sensors (Barnes Model IR microscopes) were positioned at points equidistant from the weld point and on a line perpendicular to it. A non-contact heat source was used to heat a point on one side of, but very near, the weld point. The part was then heated and the heat monitored at the two infrared sensor locations. The outputs from the two sensors are sent through a differential amplifier to eliminate the signal caused by the temperature change of the material.

The part chosen for this study was a right cylinder made up of three right cylindrical sections electron-beam-welded together along two weld lines, far enough apart to not interact in this application.

In this procedure, the heat can be pulsed at a given point, or the part can be rotated while heat is applied continuously or in repetitive pulses. Either case introduces a variable thermal gradient into the part.

Spot sizes were typically 6 mm diameter for the heat source and 1 mm diameter for the infrared sensors. Heat inputs ranged from 5 to 37 calories/cm^2 (0.21 to 1.55 MJ/m^2). Part rotation rates were below 2 rpm. To increase heat absorption and, consequently, measurement sensitivity, a high emissivity coating was put on the parts. Figure 7 shows a sketch of the typical working setup.

Defects were purposely introduced into the weld line using three methods:

- Drilling small holes in an otherwise good weld;
- Spot welding areas on the inside of the part to simulate areas where the weld was much larger than planned; and
- Leaving areas un-welded along the weld line.

Figure 8 is a typical curve showing the differential radiance output versus position around the part as it is rotated through several cycles. The dip in radiance indicates a weld defect at that angular location. This would be a smooth curve if there were no defects, as indicated on the dotted line. The gradual rise in differential radiance is caused by slow heating of the part during the test; also, the detector on the opposite side of the weld from the heat source sees a slightly altered temperature pattern from the other sensor because of the weld.

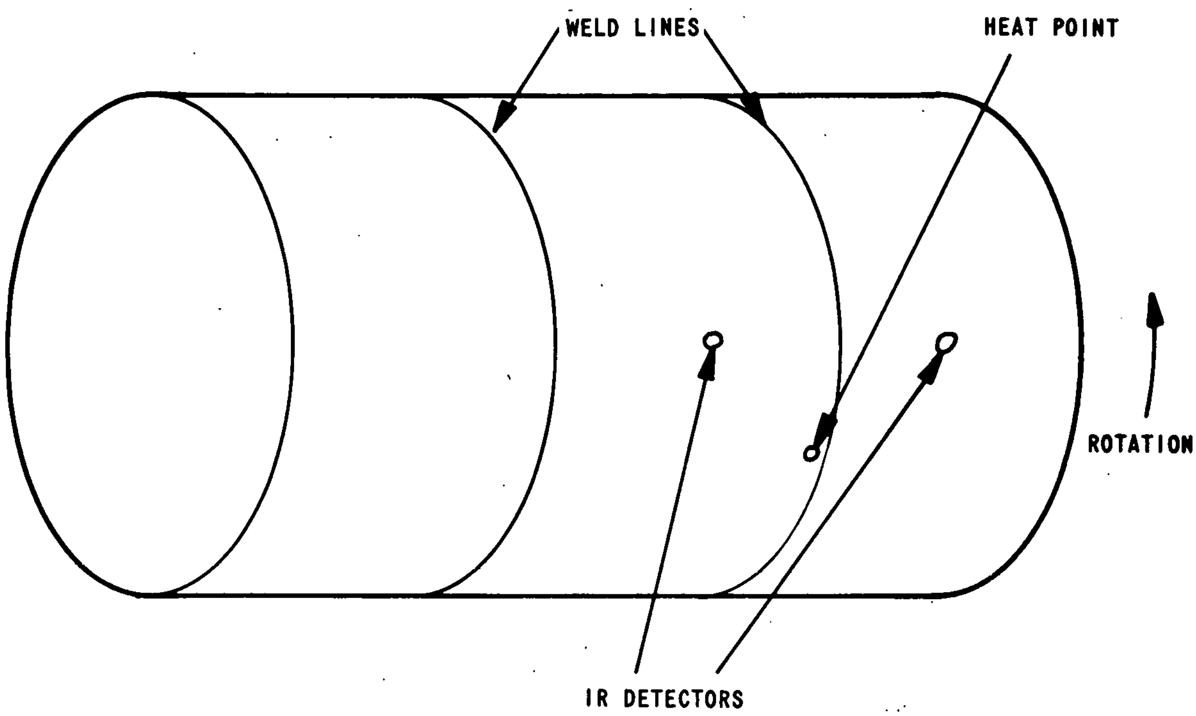

Figure 7. Typical Test Setup for Infrared Analysis

The infrared microscopes used as sensors could detect defects only in unwelded areas, and these were only for gaps of about 30 degrees of arc or more. Thermal diffusivity variations will average out over a time period because of the heat flow paths available around a defect; therefore, it is necessary to operate in very short time frames to avoid this effect. The Barnes microscopes are geared to be precision instruments, rather than to have very rapid response; thus, they are not the ideal infrared sensors for this task.

This is a feasible technique that could be pursued. Future efforts should begin with a heat transfer calculation to determine such things as required heating rates, detector response rates, optimum heat source specifications, and effects of various weld depths and defects. Availability of suitable equipment to meet these requirements can then be suitably appraised.

ACCOMPLISHMENTS

Three new approaches to electron beam weld evaluation have been proposed and investigated. Holographic interferometry is a suitable approach in its present form, although practical test

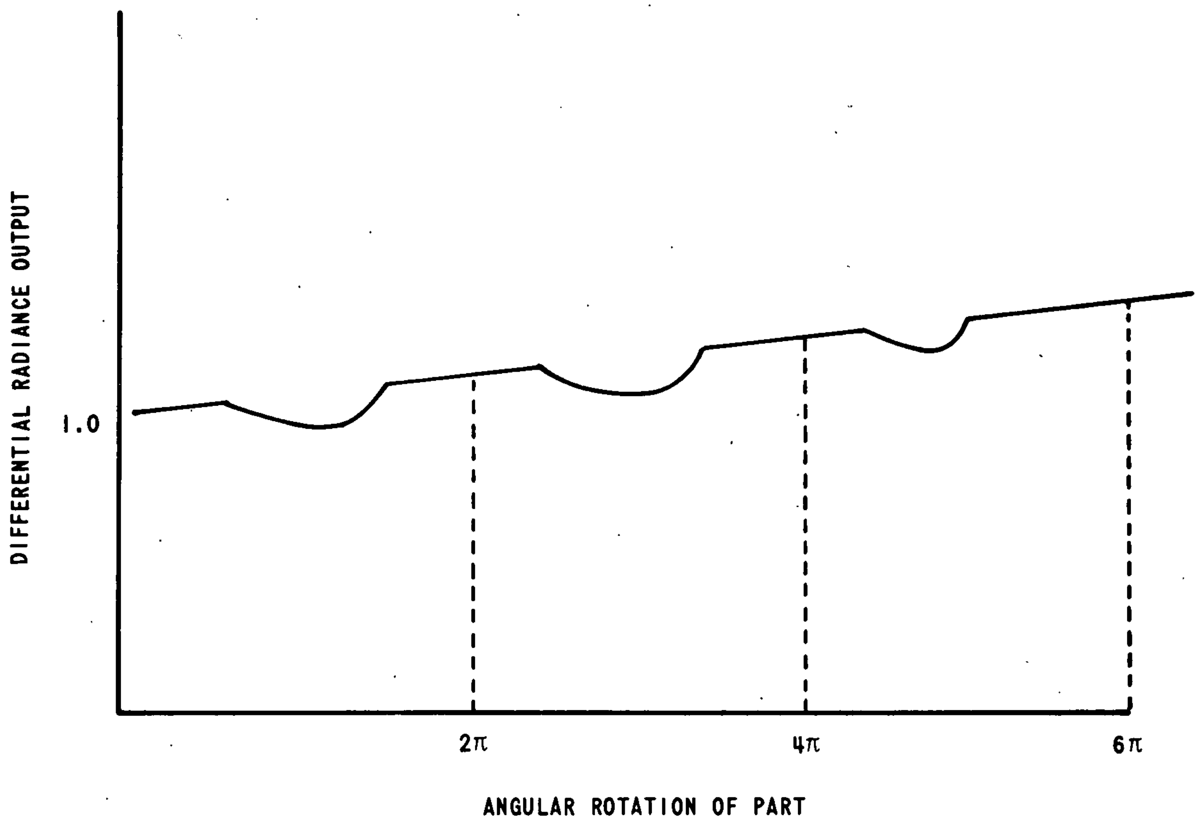

Figure 8. Typical Data Curve for Infrared Analysis

problems remain to be solved. Micro-resistance measurements are effective, but the technique has some limitations. Existing Bendix Kansas City infrared equipment is inadequate, but the basis for defining proper equipment has been determined.

FUTURE WORK

To establish a practical inspection system the following activities are recommended.

- The necessary fixturing for rapid holographic inspection should be obtained and the necessary analysis performed for interpreting results.
- Fixturing and data handling instrumentation should be obtained so that inspection can be done quickly.
- A heat transfer calculation should be performed to estimate the potential sensitivity of infrared analysis. However, this technique would require the greatest amount of development effort and expense.