ELECTRONIC SIGNAL PROCESSING TECHNIQUES

NONDESTRUCTIVE TESTING

PHASE III
SEMI-ANNUAL REPORT
JUNE 1971

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ELECTRONIC SIGNAL PROCESSING TECHNIQUES
PHASE III
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by

James C. Kennedy
and
Wayne E. Woodmansee

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FOREWORD

This report was prepared by The Boeing Company, Aerospace Group, Seattle, Washington under Contract DAAA 25-69-C0206 and covers the work performed between December 1970 and May 1971. This is the semiannual report for Phase III of Electronic Signal Processing Techniques. Phase I was conducted between October 1968 and July 1969. Phase II was conducted between October 1969 and October 1970.

The program is sponsored by the Advanced Research Projects Agency of the Department of Defense under ARPA Order 1246, Program Element Code G1101D. The program is being administered under the direction of the Frankford Arsenal by Mr. Eugene Roffman.

The program is being conducted at The Boeing Company, Kent Space Center Materials and Processes Laboratory. Mr. Eugene Bauer is the Program Manager, Dr. Wayne E. Woodmansee is the Technical Leader and Mr. James C. Kennedy is the Principal Investigator.

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ABSTRACT

Correlation techniques have been used to improve the signal to noise ratio in the ultrasonic inspection of a simulated weld seam. A quarter inch titanium plate, containing EDM slots and drill holes, was inspected ultrasonically. The inspection was performed as if the plate contained a weld seam with potential flaws. The limiting background noise was due to surface roughness and grain boundary scattering. The weld line was inspected three times, a different transducer configuration being used for each inspection. The three sets of data were multiplied together. The signal to noise ratio for the ultrasonic reflection from a ten (10) mil drill hole was improved from a value of one to one to a value of five to one. The development of automatic scanning procedures appears possible.

LIST OF ILLUSTRATIONS

INTRODUCTION

This is the semiannual report for Phase III of a study of the applications of electronic signal processing techniques to nondestructive testing. During the first and second phase a number of areas were investigated. Signal averaging was used to reduce random noise in the through transmission ultrasonic inspection of highly attenuating media. The use of dual transducer techniques for the reduction of coherent background noise in ultrasonic flaw inspection was studied. Signal averaging was shown to be effective in the reduction of coherent noise in the ultrasonic detection of extended tight interface discontinuities. The use of a narrow automatically positioned electronic gate has been shown to reduce background noise in ultrasonic weld inspection. Methods of recording and displaying ultrasonic inspection data have been studied. Finally, a lock-in amplifier has been used to obtain quantitative data in through transmission eddy current tests and in single coil and double coil single side eddy current tests.

In Phase III there is a continuing emphasis on the reduction of coherent background noise in ultrasonic and eddy current systems. The ultimate goal is increased sensitivity and reliability in flaw detection systems. The use of multiple inspection and correlation techniques is being examined. In the present report an ultrasonic weld inspection procedure is examined in which a considerable reduction in background coherent noise is obtained. The use of optical as well as electrical signal processing techniques continues to be of interest.

DISCUSSION

THEORY

Present ultrasonic weld inspection systems are limited in sensitivity by background noise due to the scattering of sound from surface irregularities and from the granular structure of the material. Even when the surface roughness and grain structure of a part are acceptable from a metallurgical standpoint one frequently obtains ultrasonic indications from these conditions which exceed the indications obtained from small cracks. The scattering of the ultrasound by surface roughness can be reduced by grinding or machining but some surface irregularities always remain. There is little that can be done about the granularity of a material except for the avoidance of high ultrasonic frequencies. Of course, if one works at frequencies much below a megacycle resolution is severely degraded.

The noise due to surface irregularities and grain scattering is readily visible in the CRT display of the pulsed ultrasonic signals. For a fixed transducer position, it consists of a stable pattern of irregular peaks[1]. It is important to note that the noise is not random in the usual sense. The noise signal is identical for each successive ultrasonic pulse and consequently a well defined pattern appears on the screen. Furthermore, although the pattern changes considerably and in a complicated manner for small changes in position of the transducer, the pattern will reproduce in detail if the transducer is carefully returned to its original position. The noise cannot be effectively reduced by conventional signal averaging procedures.

In the case of random noise, such as that which comes from amplifiers at high gain, successive signal pulses occur in different background noise patterns. This effect can be readily observed in a series of single sweep exposures taken from the CRT display. It is this basic feature which allows the signal to noise improvements to be made. In devices such as the Princeton Applied Research Waveform Eductor, which operates on the signal averaging principle, the improvements are accomplished by the addition of signals from a large number of successive pulses. In the present work, techniques were developed for producing flaw signals immersed in various background noise patterns, and signal to noise improvement was accomplished by multiplication of the patterns. Apart from the fact that no integration is used, the multiplication is much like performing an analog correlation.

The signal processing was not performed on the video signal, but on the essentially DC gated video. The ultrasonic transducers are set up for the inspection of the weld and the electronic gate is set to receive pulses from the region of the weld. As the transducer scans along the length of the weld a signal is generated at the gate output which can be plotted on an XY pen recorder. Figure 8 is a typical example. The data contains flaw signals and an irregular noise background. Use of special transudcer techniques allows the production of several sets of data of this kind, each with a different background noise pattern. Figures 15 and 16 are examples. Multiplication of these patterns produces significant improvements in signal to noise ratio. A triple product curve appears in Figure 22. Experimental details are discussed in the sections to follow.

SPECIMEN

The specimen used in the present work is shown in Figure 1. This specimen was inspected as if it contained a weld seam with possible flaws. It is a quarter inch titanium plate one foot on a side. The specimen contains six artificial flaws in the form of drill holes and EDM slots. Dimensions are shown in the diagram. The line along which the holes and slots are located was taken to be the weld line.

EQUIPMENT AND PROCEDURE

The block in Figure 1 was initially inspected using the pulse echo shear wave immersion technique. The sound path and scanning motion are depicted in Figure 2. The inspection was performed at 5 MHz using a 1/2 inch diameter Automation Industries transducer. A Sperry UM721 Reflectoscope was used as pulser receiver. The electronic gate in the Sperry was employed and was set to encompass that time interval during which reflections were received from the narrow slice of weld shown in Figure 3. The data presented in this report represents an inspection of only that portion of the weld shown in Figure 3.

The normal procedure in an inspection of this kind is to work with a gate which will receive reflections from anywhere in the weld and to scan in the raster pattern shown in Figure 4. This procedure produces an inspection of the entire weld volume. A considerable amount of extraneous noise can be rejected, however if one uses a narrow gate which "moves through the weld" in synchronism with the scanning ultrasonic beam[2]. In this case we can select the electronic gate and scanning pattern in accordance with Figure 5. Data can be automatically collected in this way by using an electrically controllable gate delay and a position pot mounted on the scanner. The data presented in this report represents a portion of the data which would be collected using this latter scheme for the complete inspection of a weld volume.

A closeup of the transducer holder is shown in Figure 6. The transducer is firmly held in an aluminum block. A bolt has been used to fasten the block to a small vertically held aluminum plate. The block is free to rotate so that the angle between the sound beam and the normal to the surface of the test part can be adjusted. A

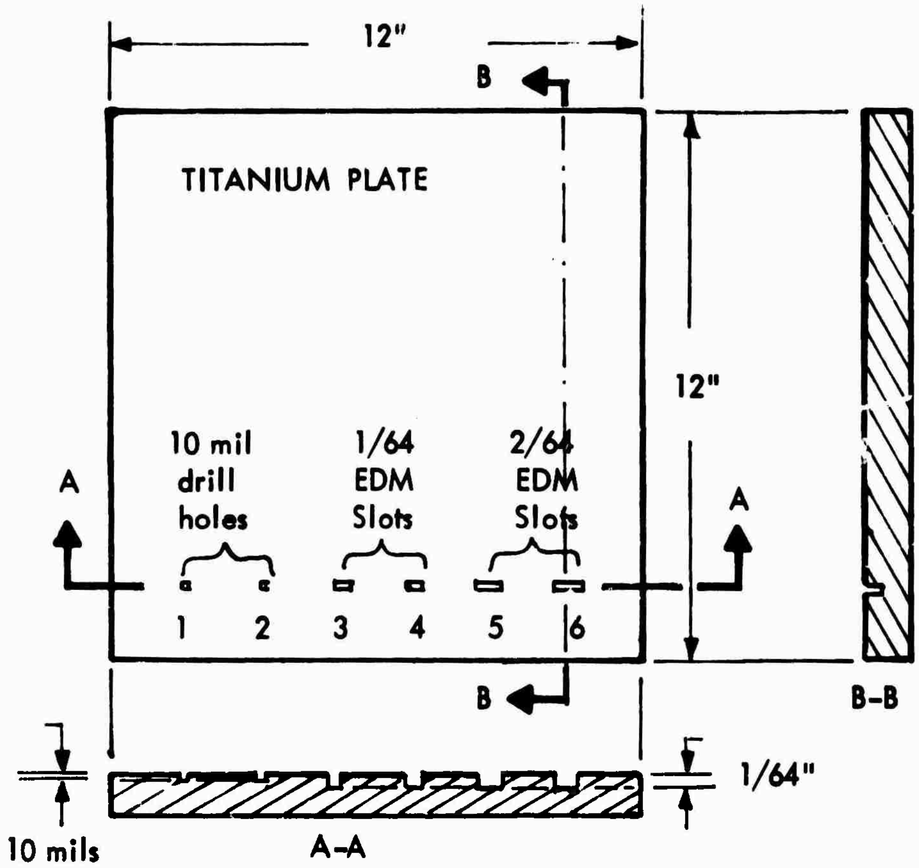


FIGURE 1 TEST SPECIMEN

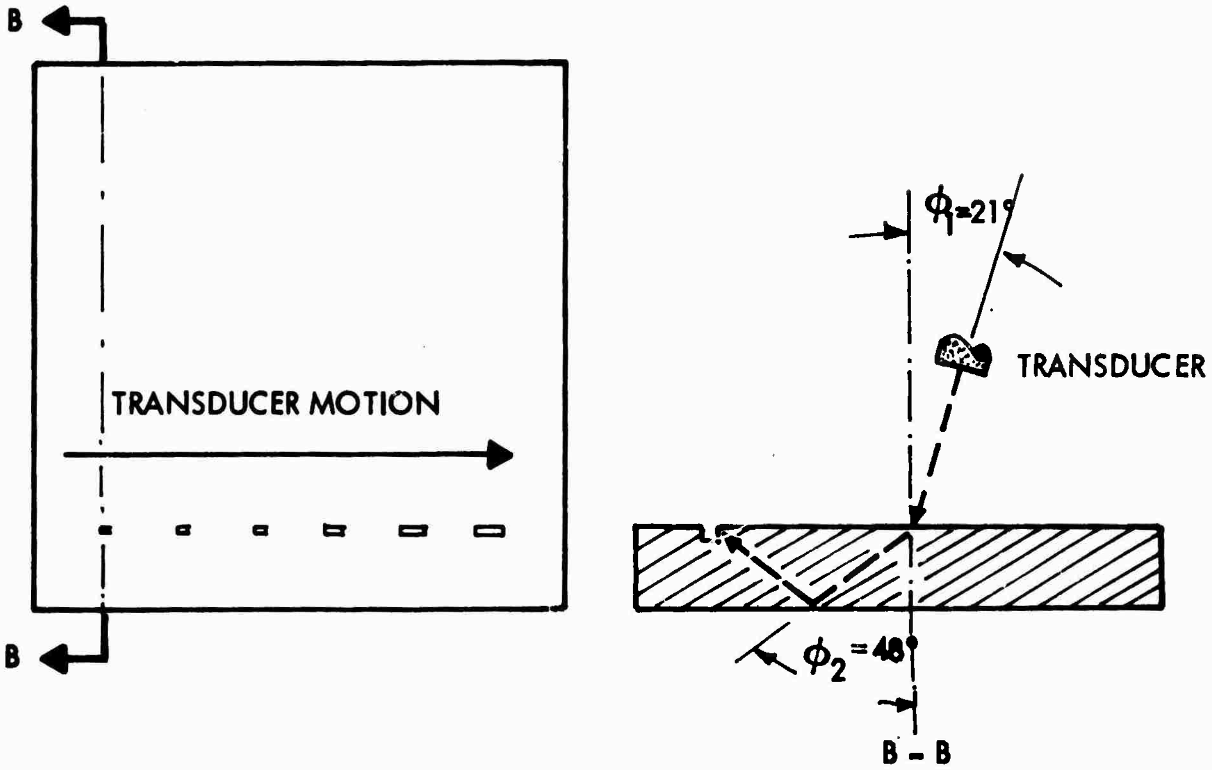
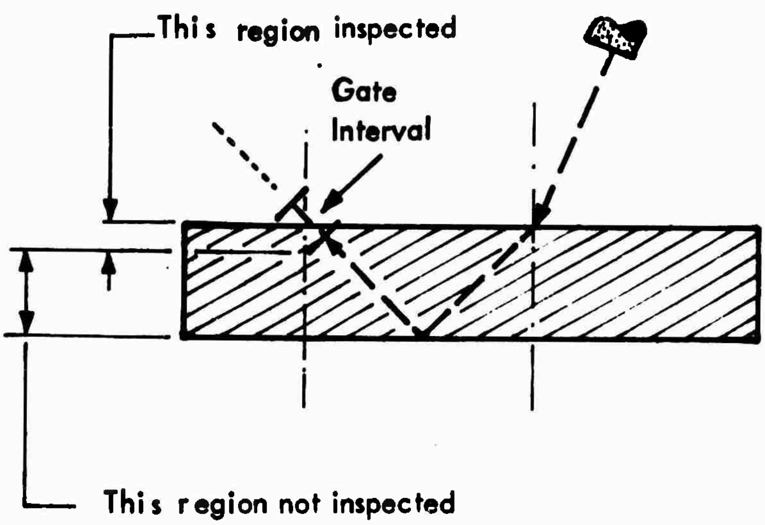


FIGURE 2 INITIAL INSPECTION GEOMETRY



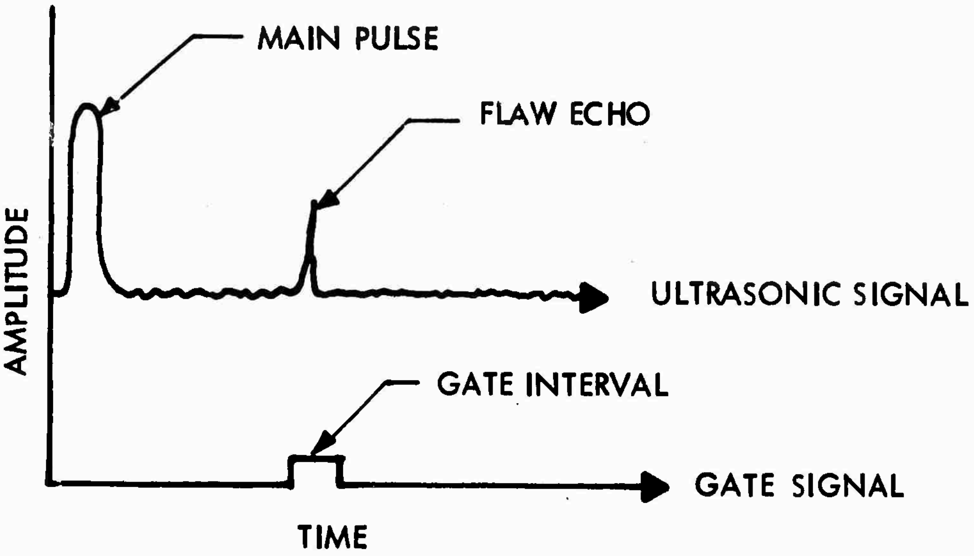


FIGURE 3 GATE SELECTION FOR INSPECTION OF TITANIUM PLATE

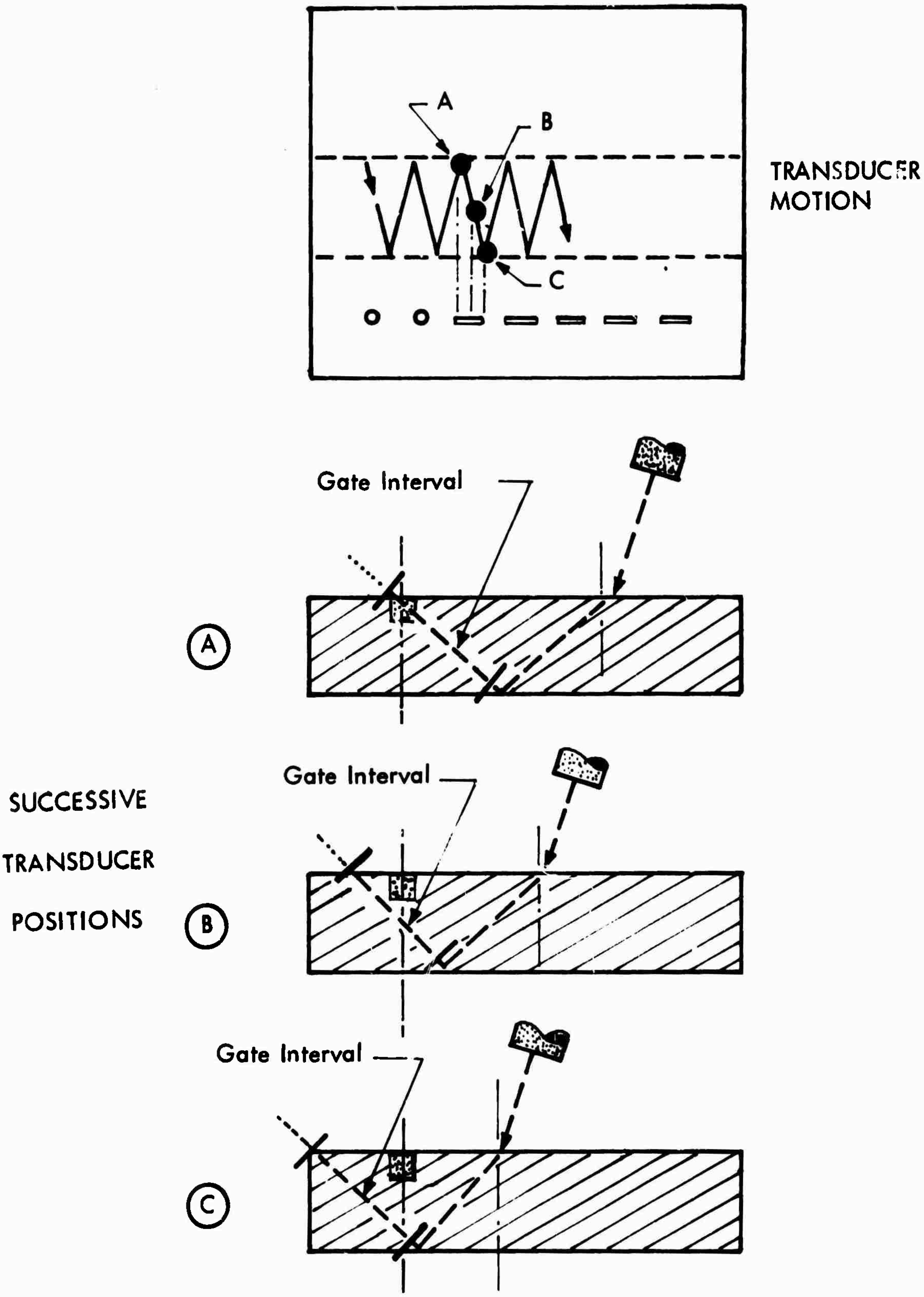


FIGURE 4 CONVENTIONAL WELD INSPECTION PROCEDURE

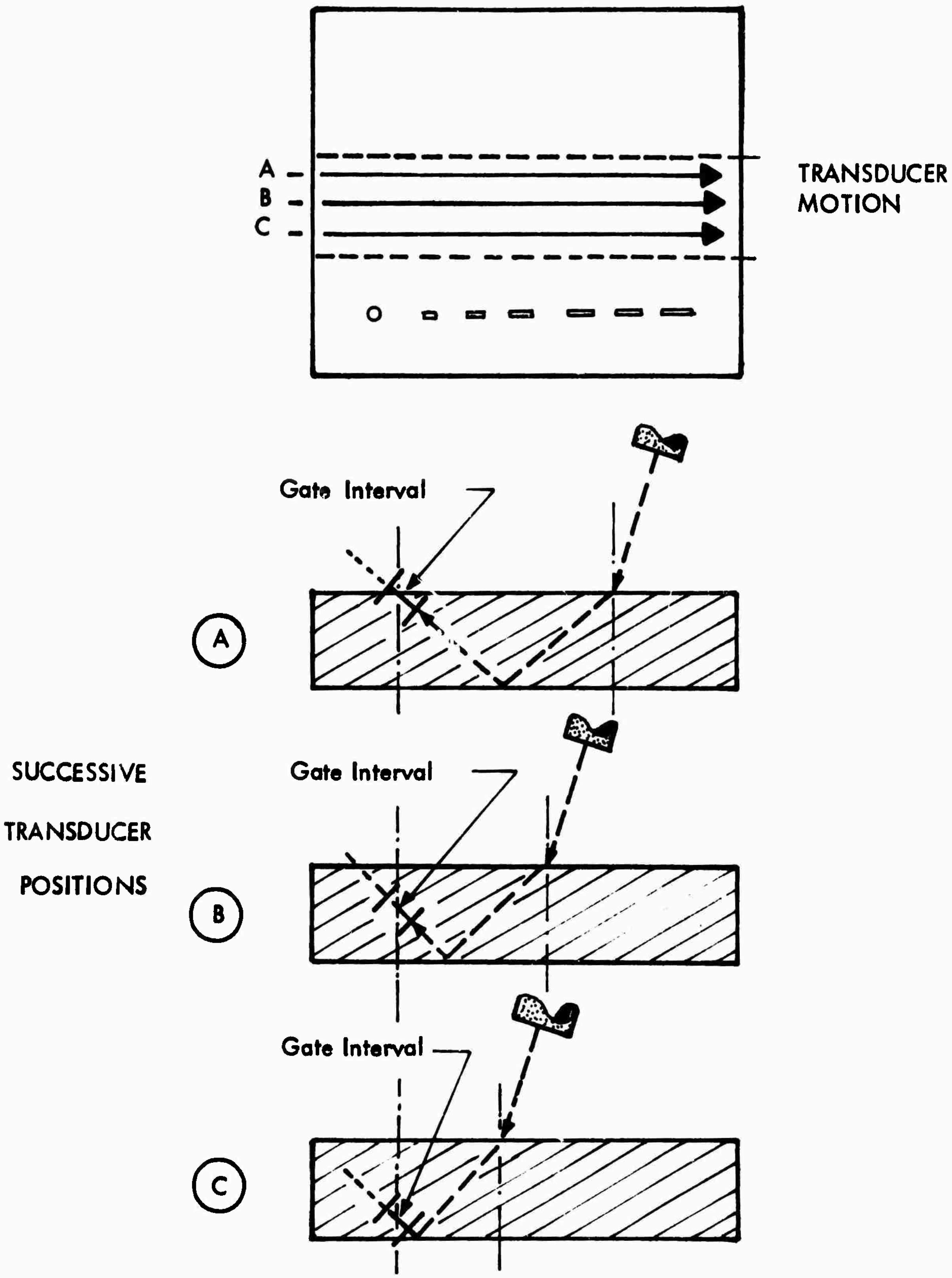


FIGURE 5 NARROW MOVING GATE WELD INSPECTION PROCEDURE

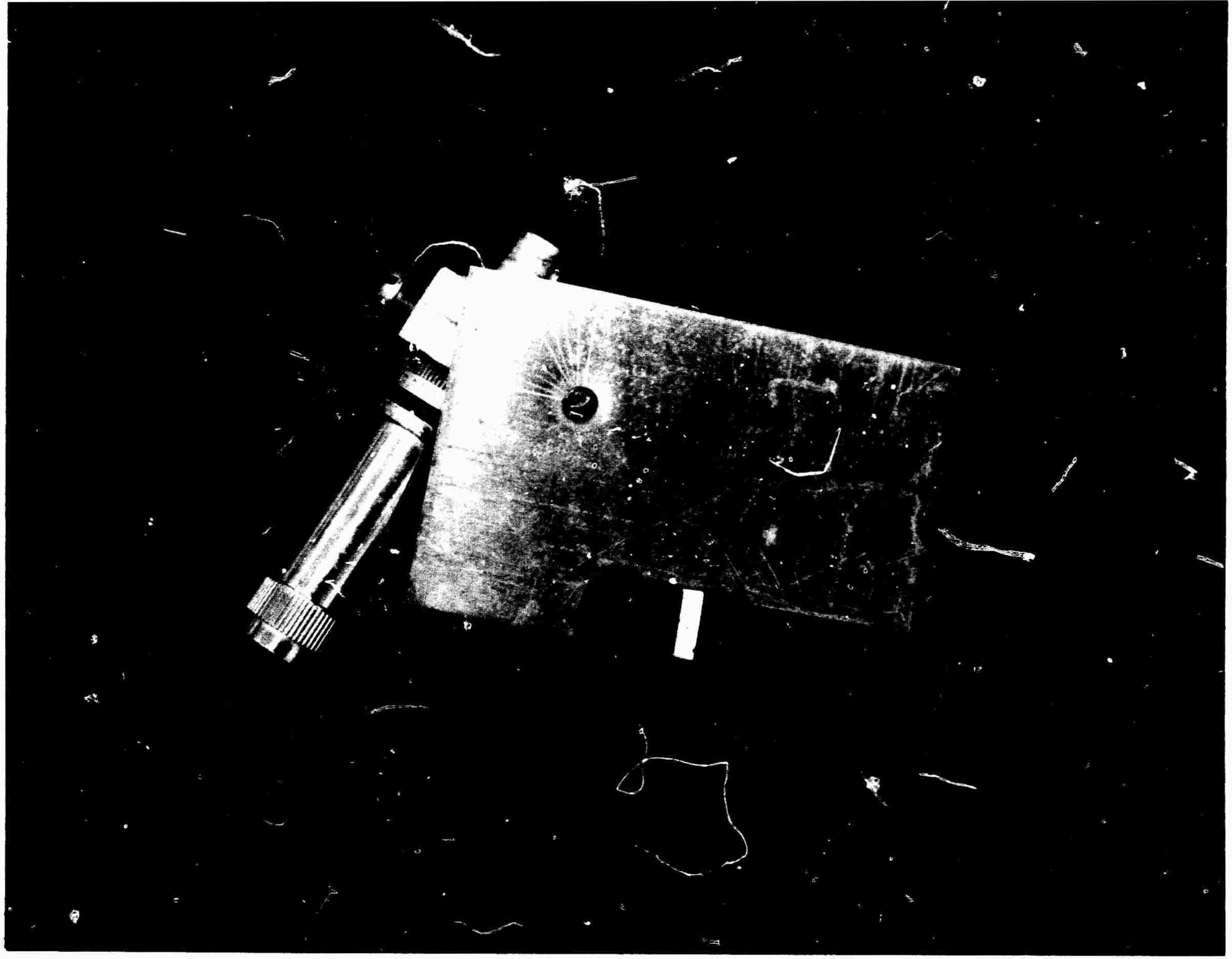


FIGURE 6 TRANSDUCER HOLDER

typical value for this angle is 21 degrees, which produces a 48 degree shear wave within the part. The aluminum plate is adhesively bonded to a small but strong ferrite permanent magnet which forms the base of the transducer holder. Figure 7 shows the transducer mounted in position for inspecting the titanium plate. The transducer holder is magnetically attached to a steel plate which is part of the scanning unit. A piece of Teflon tape placed on the bottom of the ferrite magnet allows the transducer to be slid with convenience to any desired location or angle. During inspection the entire assemblage moves from left to right along the length of the "weld" in Figure 7. The part seen on the left is a beam location plate and the part on the right is the plate to be inspected.

In the present work the data was recorded by connecting the gate output to the Y axis of a Moseley 7000 recorder. A voltage indicating the position of the transducer along the length of the weld was fed into the X axis. Figure 8 is a recording of the data obtained from the inspection of that portion of the "weld" seen in Figure 3. A complete inspection of the weld volume would produce a set of recordings of this kind. An alternative data presentation for complete inspection is, of course, the usual C scan format.

Several schemes were examined for obtaining another set of data, from this same slice of "weld", which would exhibit a different background noise pattern and at the same time contain strong flaw signals. One procedure we have used is to examine the weld from the opposite side as shown in Figure 9. As the figure indicates however, this method is reliable for vertical flaws only. Another procedure is to examine the weld from the second bounce position as shown in Figure 10. For this case we have observed a change in the fine structure of the noise but many of the larger noise peaks are the same as those obtained in the conventional configuration. The most successful scheme involved the double transducer arrangement[3] shown in Figure 11 and depicted more graphically in Figure 12. This arrangement produces strong flaw signals immersed in a totally different background noise pattern. Moreover, several different background noise patterns can be produced by selecting several different values for the angle θ. Figure 13 shows the two transducers mounted on the scanner with an included angle 2θ equal to 20 degrees. Figure 14 shows the two transducers mounted with an included angle of 80 degrees. The recording and electronic gating procedures were the same for this case as they were for the single transducer configuration. Typical data can be seen in Figure 15 and in Figure 16.

One can envision the direction of the sound path as being defined by the two angles ϕ and θ A major benefit of the transducer positioning equipment used in this work is that it provides convenient independent adjustment of these two angles. The angle ϕ is selected using the same criteria one uses in conventional pulse echo work. For the data we have collected there is no guarantee that the optimum angle has been selected. Previous work using conventional techniques has indicated that a refracted shear wave angle of 50 degrees is acceptable. This corresponds to a value of approximately 21 degrees for ϕ and this angle was selected for the present work. Both

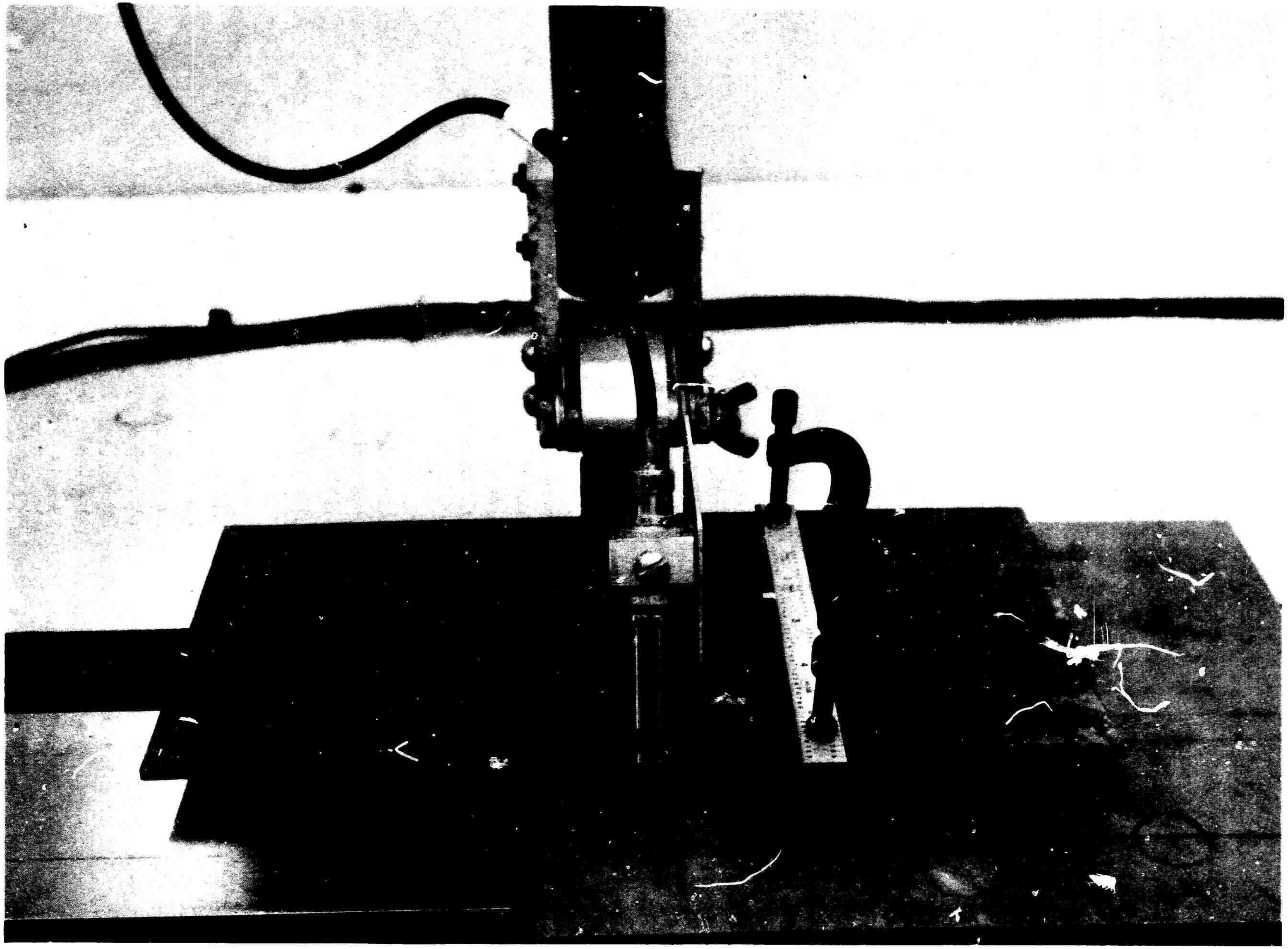


FIGURE 7 CONVENTIONAL TRANSDUCER POSITION

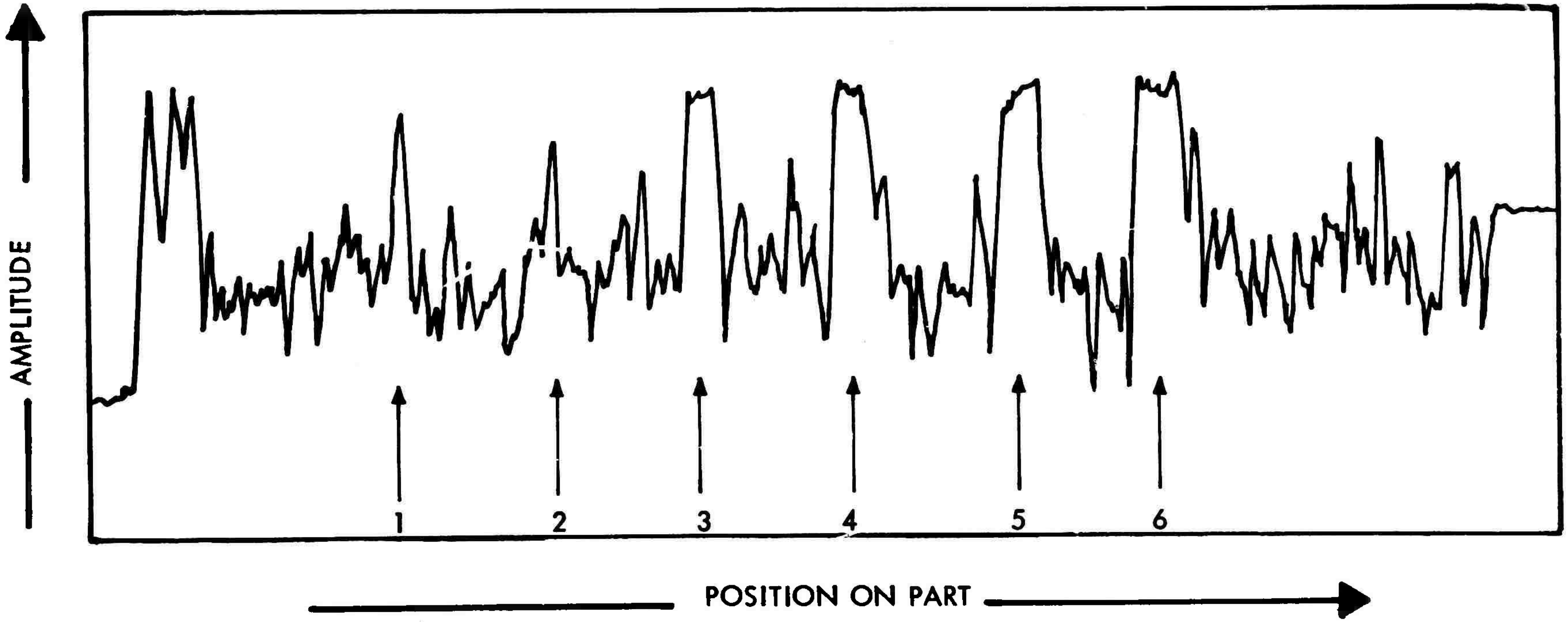


FIGURE 8 CONVENTIONAL OR ZERO DEGREE DATA

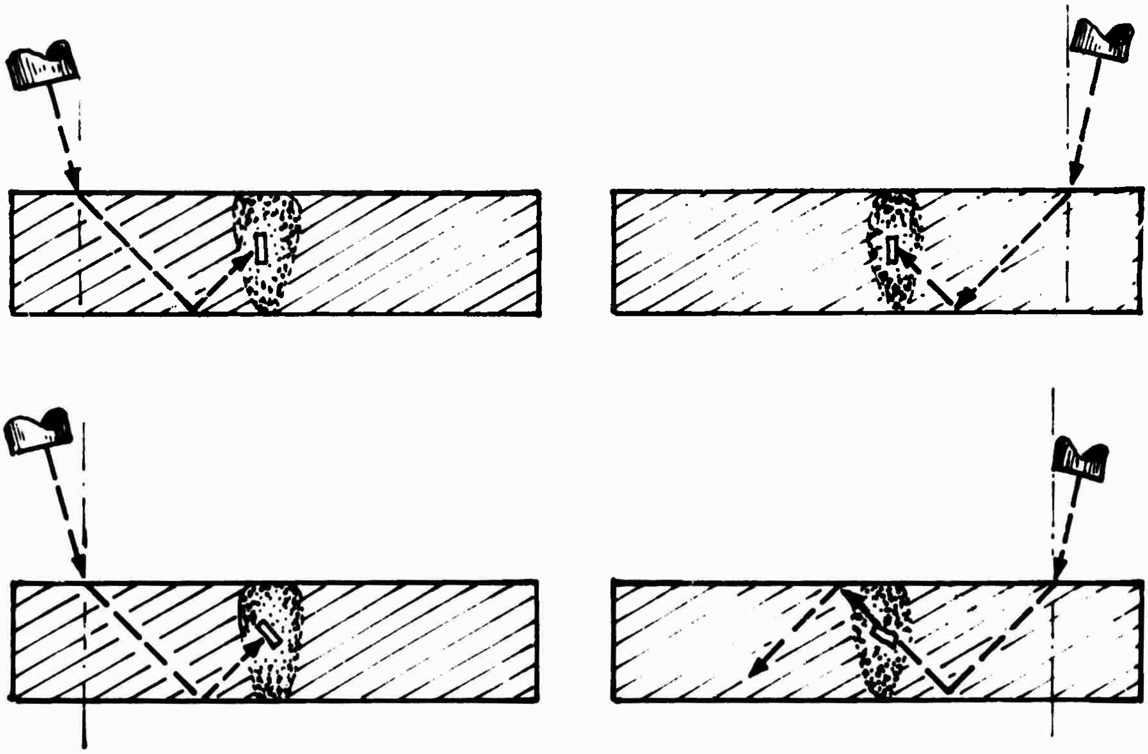


FIGURE 9 INSPECTION OF WELD FROM BOTH SIDES

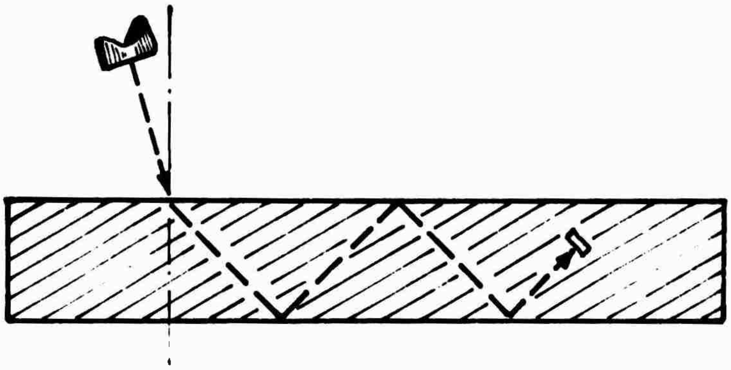
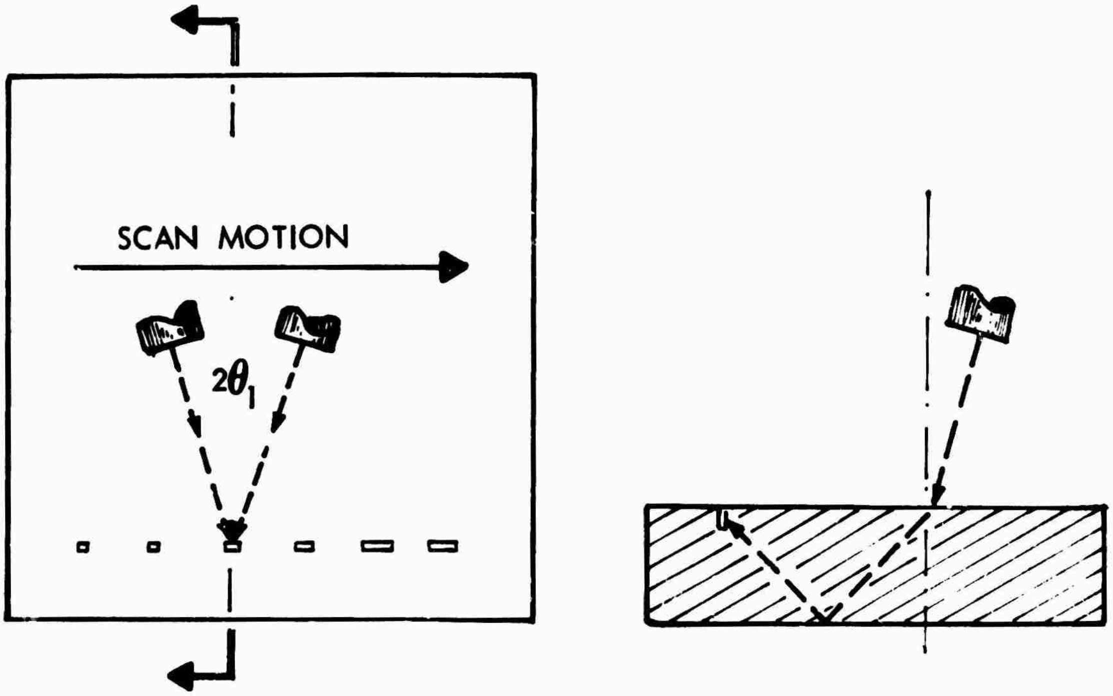


FIGURE 10 SECOND BOUNCE POSITION



DIFFERENT VALUES OF θ PRODUCE DIFFERENT BACKGROUND NOISE PATTERNS BUT SIMILAR FLAW INDICATIONS

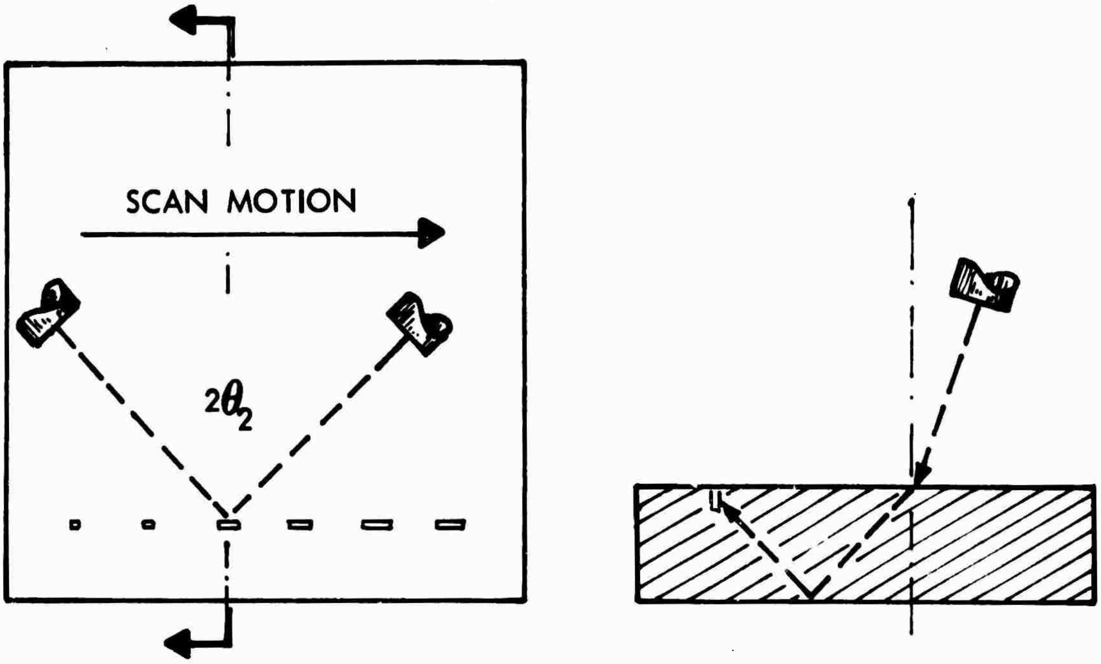


FIGURE 11 DUAL TRANSDUCER CONFIGURATION

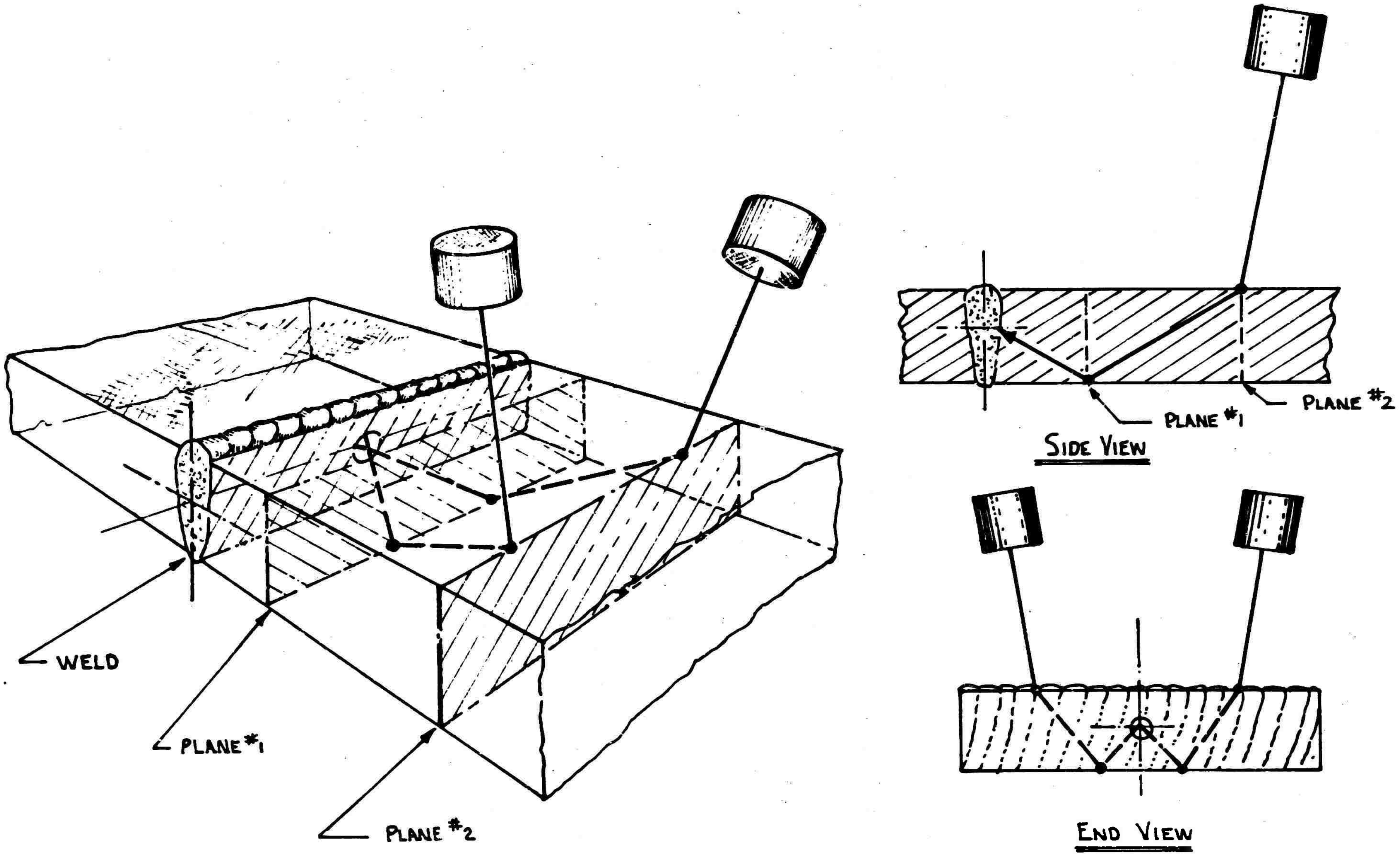


FIGURE 12 DUAL TRANSDUCER CONFIGURATION

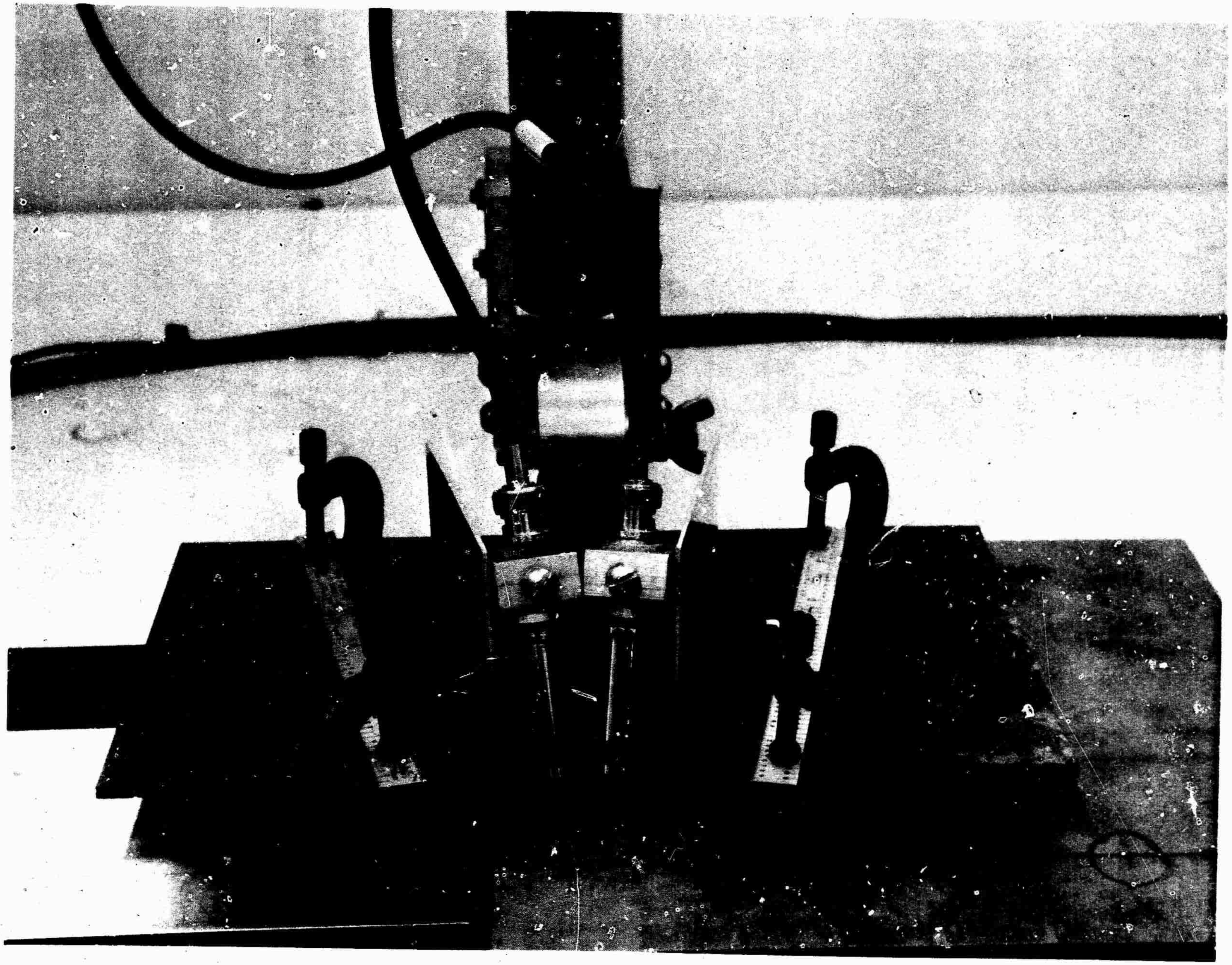


FIGURE 13   DUAL TRANSDUCER CONFIGURATION WITH 20° INCLUDED ANGLE

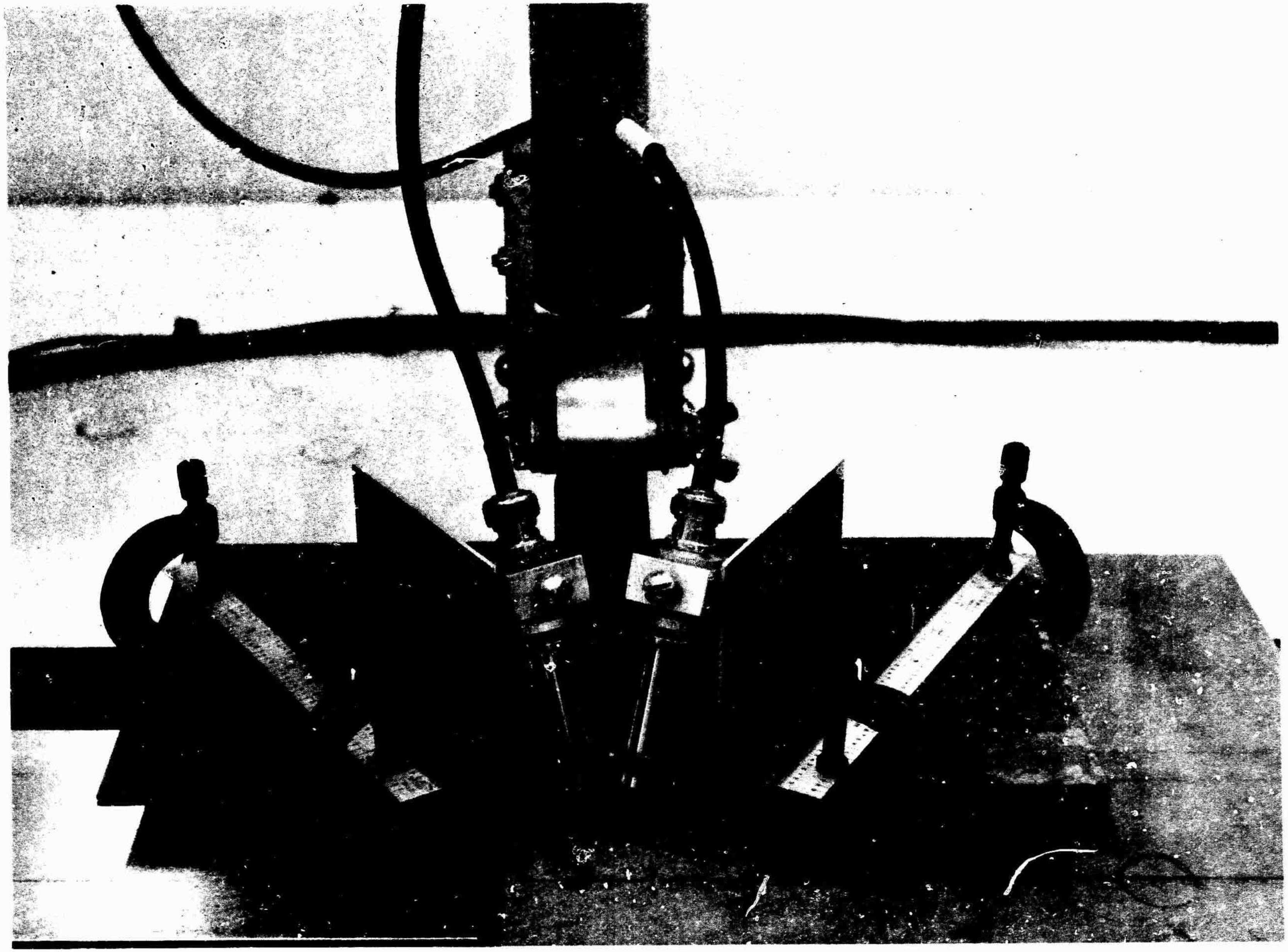


FIGURE 14 DUAL TRANSDUCER CONFIGURATION WITH 80° INCLUDED ANGLE

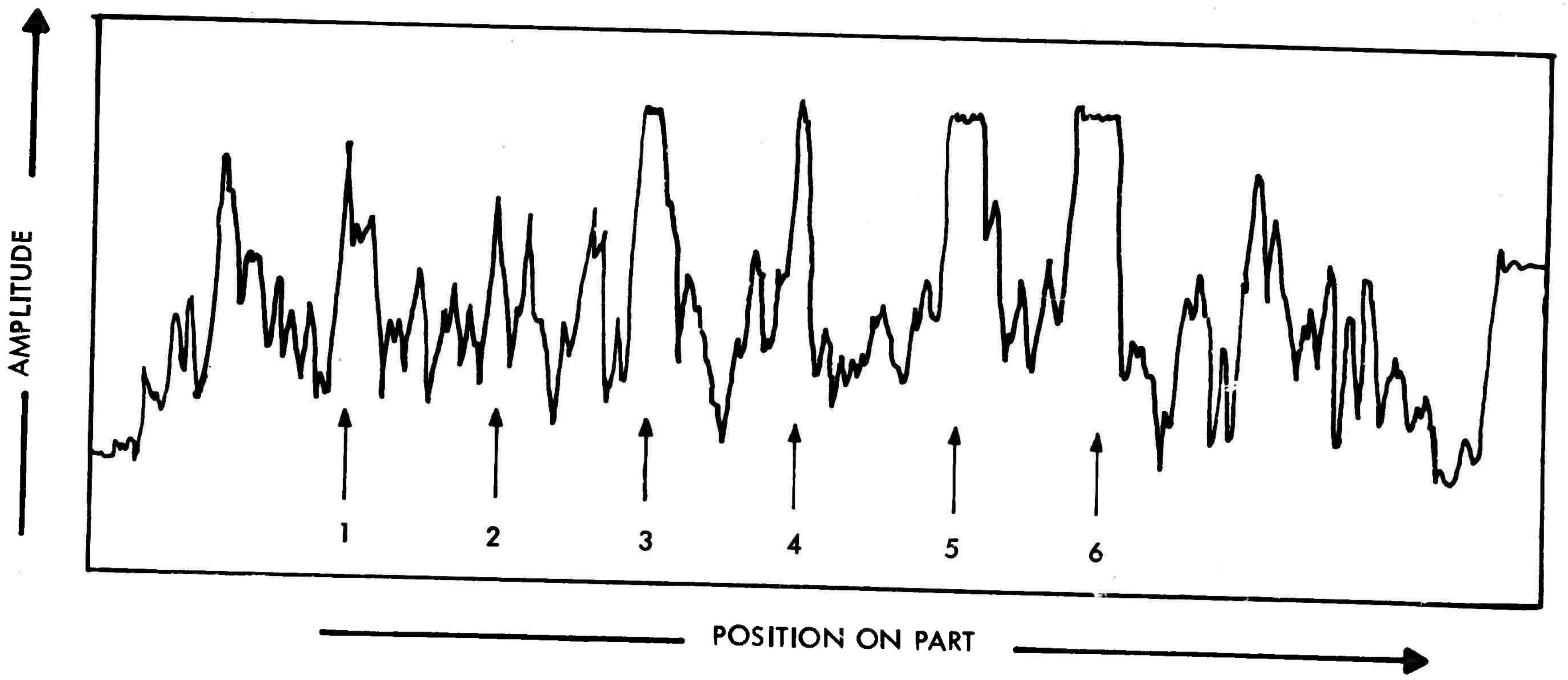


FIGURE 15 DATA FOR 40° INCLUDED ANGLE DUAL TRANSDUCER CONFIGURATION

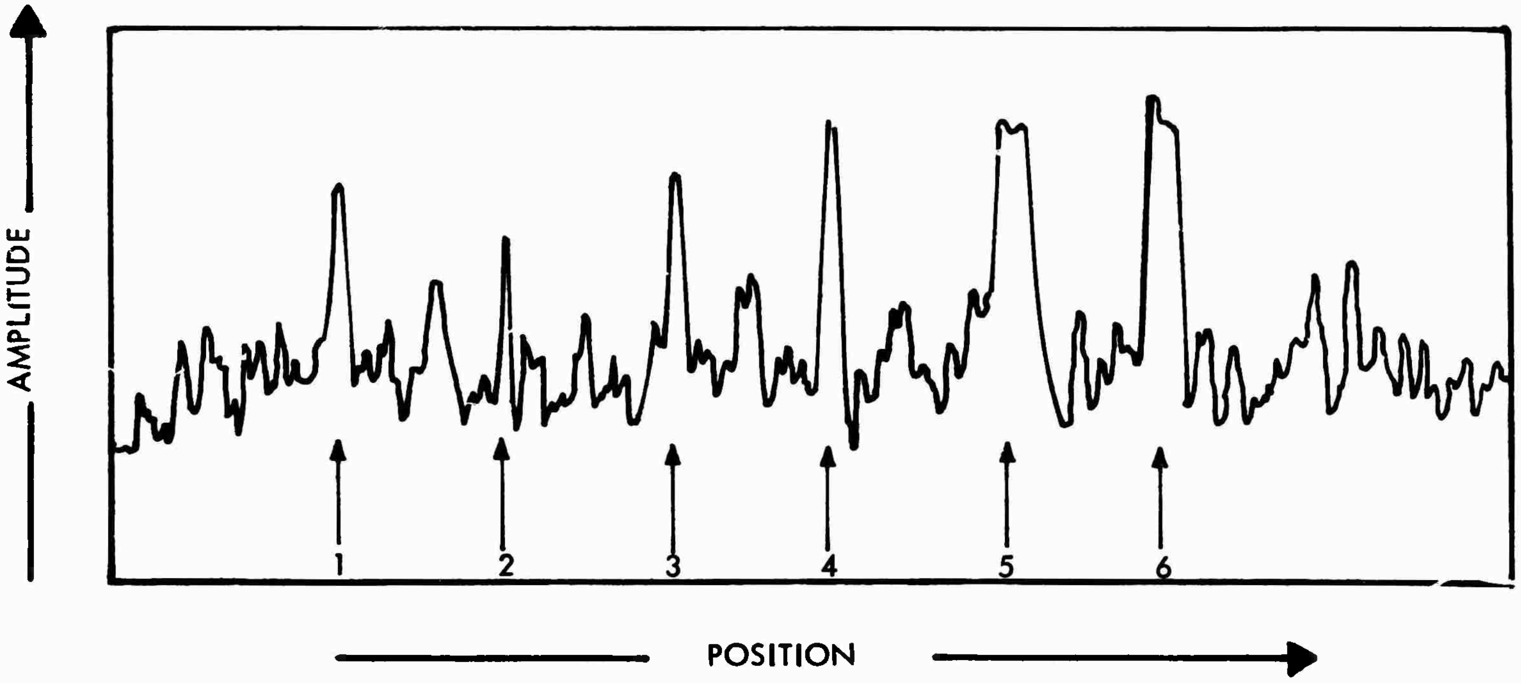


FIGURE 16 DATA FOR 60° INCLUDED ANGLE DUAL TRANSDUCER CONFIGURATION

transducers were set at an angle of 21 degrees. The angle θ is more or less arbitrary. Angles less than 10 degrees are difficult because the transducers come into physical contact with one another. In data taken to date, angles greater than 80 degrees have exhibited poor flaw sensitivity. The single transducer, conventional pulse echo configuration can be thought of as the $\theta = 0$ configuration.

There is a well defined procedure for setting up the ultrasonic probes when using the double transducer arrangement. The two transducers are aligned using a beam location plate. This plate must be of the same thickness and material as the test part and should contain drill holes as indicated in Figure 17. The plate is oriented so that the line connecting the drill holes is parallel to the line of motion of the scanner. The first transducer is set up by operating it in the pulse echo mode. It is oriented at the selected values of θ and ϕ and then located so that it receives the single bounce reflection from the top drill hole as indicated in Figure 18. The second transducer is oriented and located in the same manner. One then switches to the through transmission mode in which one transducer acts as transmitter and the other acts as receiver. Small adjustments in the position of each transducer should then be made in order to verify that the maximum signal is being obtained from the drill hole. Finally, one should verify that a strong signal can be obtained from the bottom drill hole by moving the scanner to the appropriate position and sliding the transducers foreward along the aluminum guides provided for that purpose. As can be seen in Figures 13 and 14 the weld to be inspected is placed so that its centerline is lined up with the two drill holes. In order to generate the data for this report the two transducers were placed for the inspection of a strip (Figure 3) at the top of the plate.

A tape recorder was used to produce the product data. The data seen in Figures 8, 15 and 16 were recorded on separate channels of an Ampex SP300 tape recorder, and were passed through an analog multiplier upon playback. The tape recorder and multiplier can be seen in Figure 19. Figure 20 is a circuit diagram of the electronics. The multiplier is an Analog Devices 426 A Multiplier/Divider. It is a small, relatively inexpensive, solid state device. Seen also in Figure 19 are the power supply for the multiplier and a couple of breadboard DC amplifiers and level shifters which form the interface between the tape recorder and the multiplier. Using two multipliers the triple product could probably be formed readily with one playback operation. To produce the data reported here, however, the zero degree and forty degree data were multiplied together and the result was recorded on tape. A pen recording of the first product can be seen in Figure 21. A second playback step was used to multiply the first product by the sixty degree data. A pen recording of the triple product can be seen in Figure 22.

Proper alignment of the data on the various channels of the tape recorder is essential. If the data is not accurately aligned flaw indications can be lost by taking the product. In this regard, a good safety precaution might be the recording of sum data as well as product data. Several conditions are required to obtain

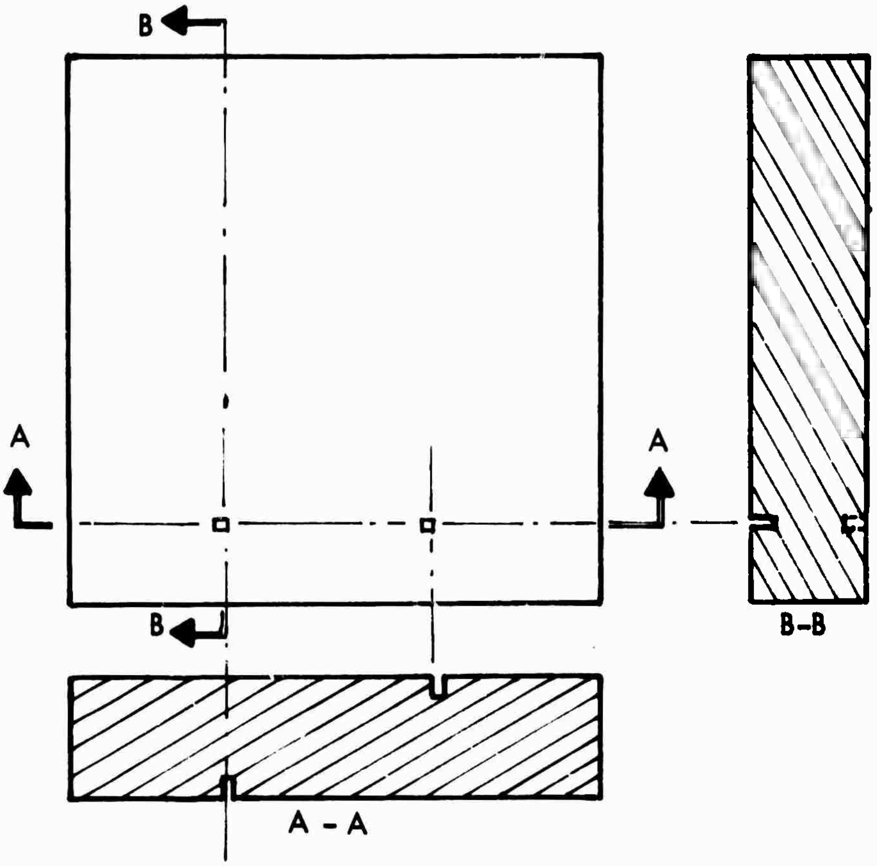


FIGURE 17 BEAM POSITION INDICATOR

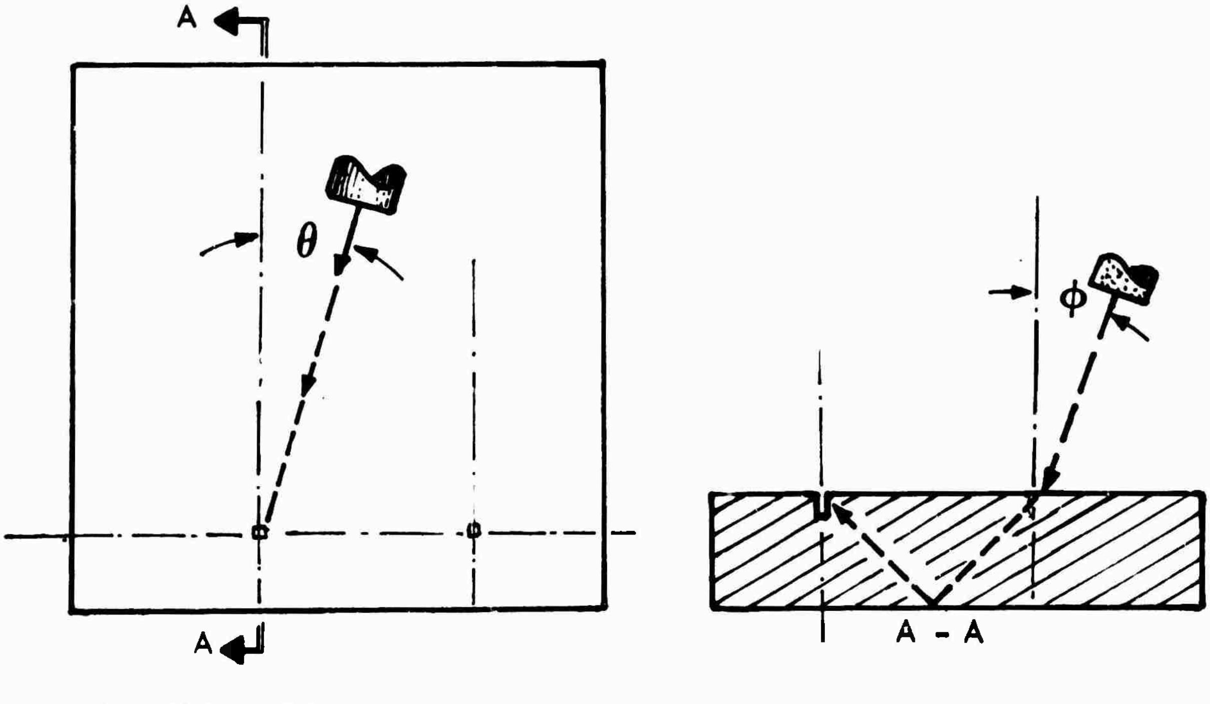


FIGURE 18 SETTING UP THE DUAL TRANSDUCER CONFIGURATION

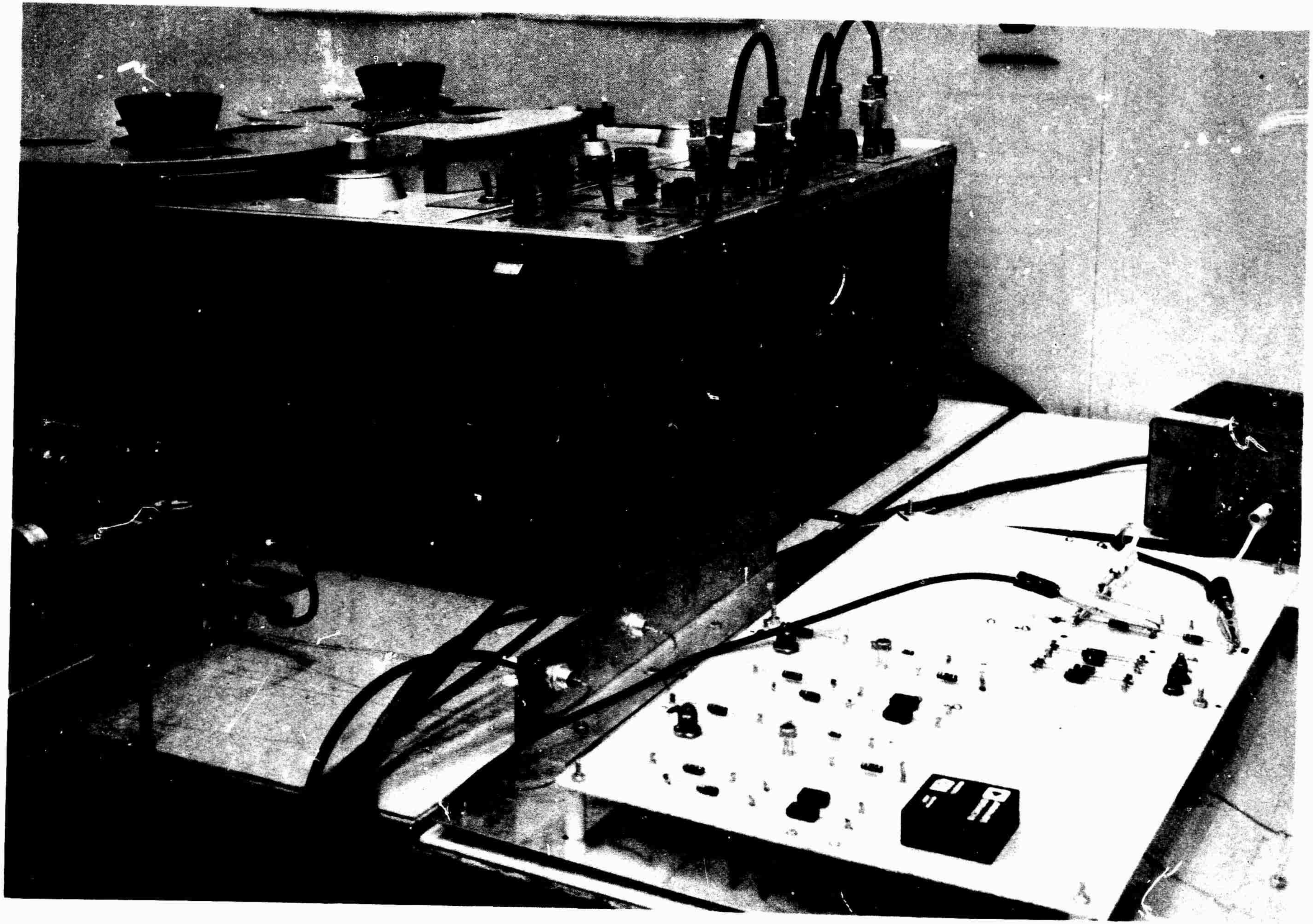


FIGURE 19 TAPE RECORDER AND MULTIPLIER

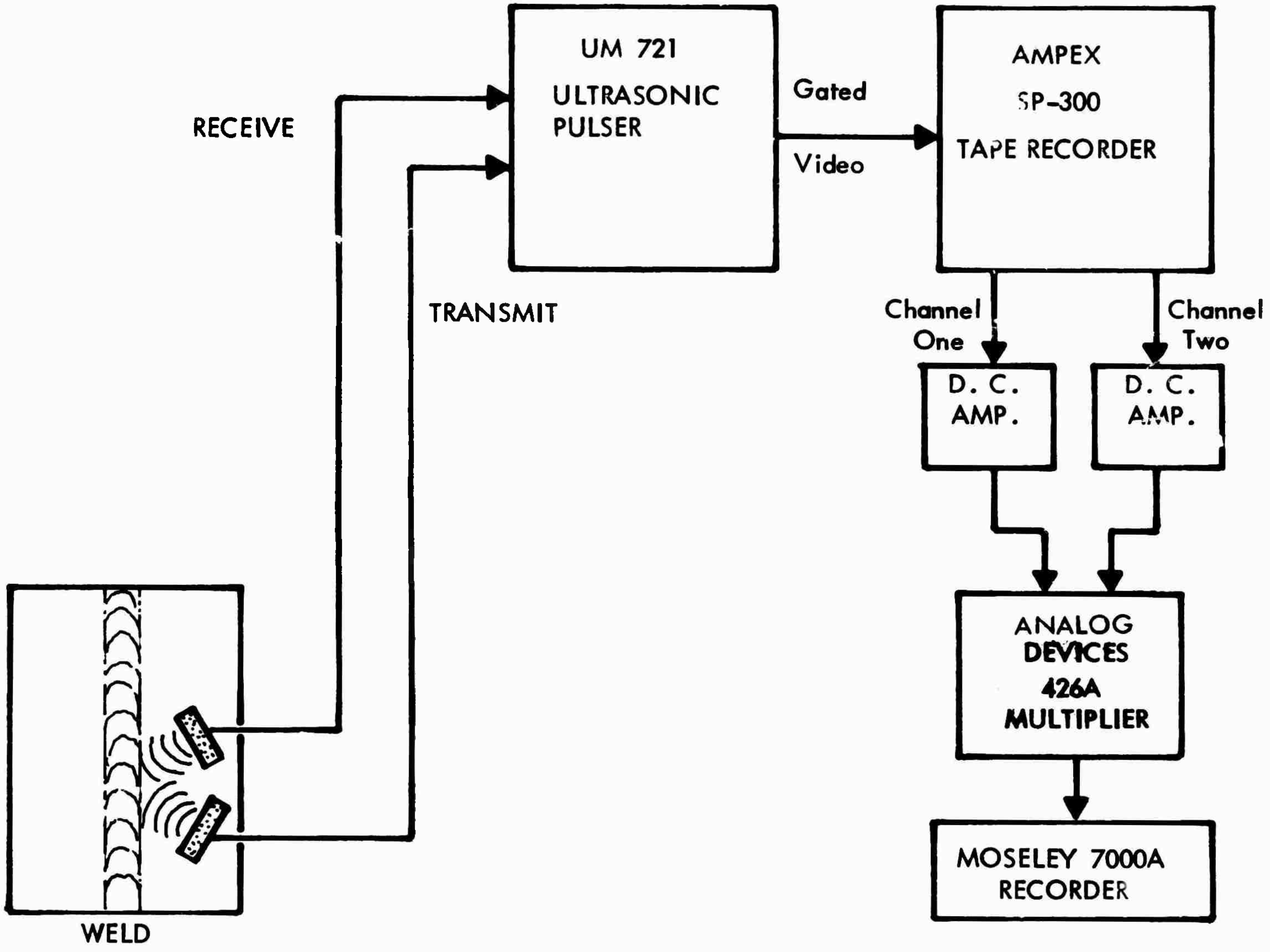


FIGURE 20. CIRCUITRY FOR THE COLLECTION, TAPE RECORDING, AND MULTIPLICATION OF ULTRASONIC WELD INSPECTION DATA

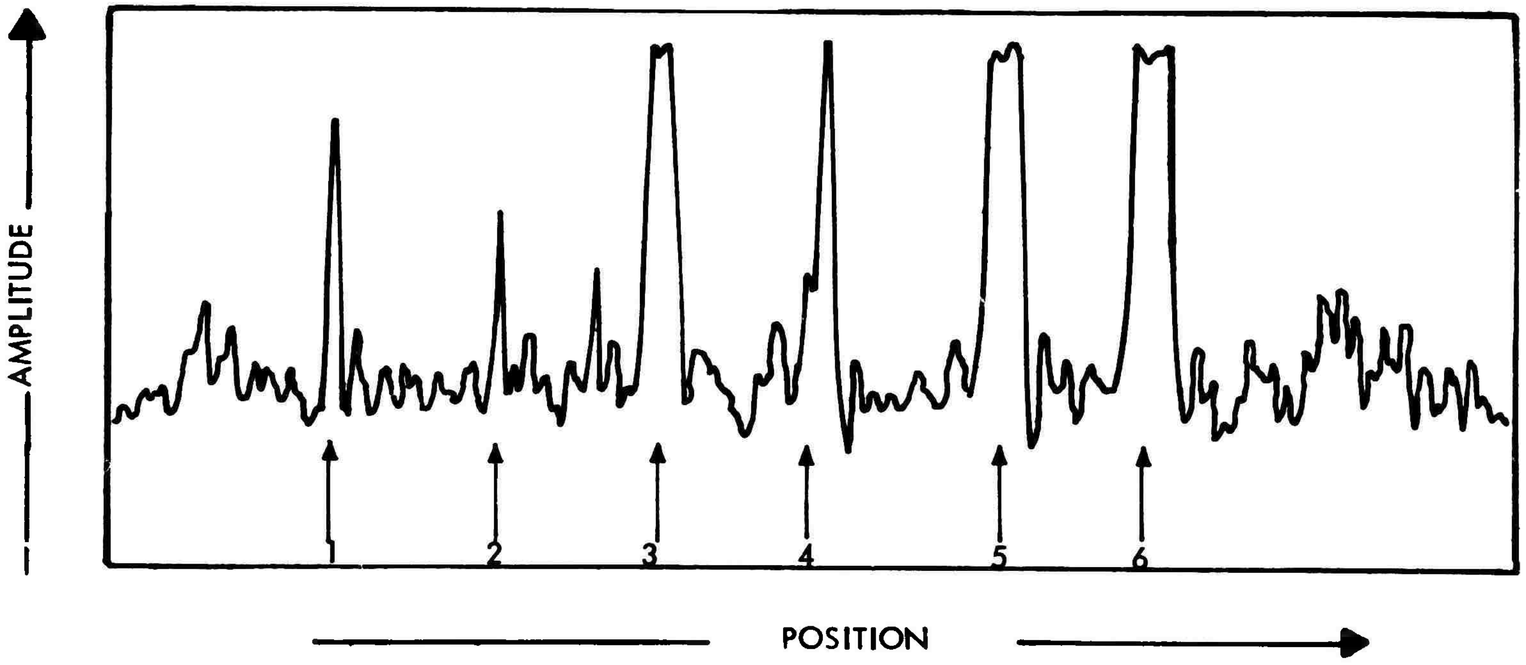


FIGURE 21 PRODUCT OF 0° DATA AND 40° DATA

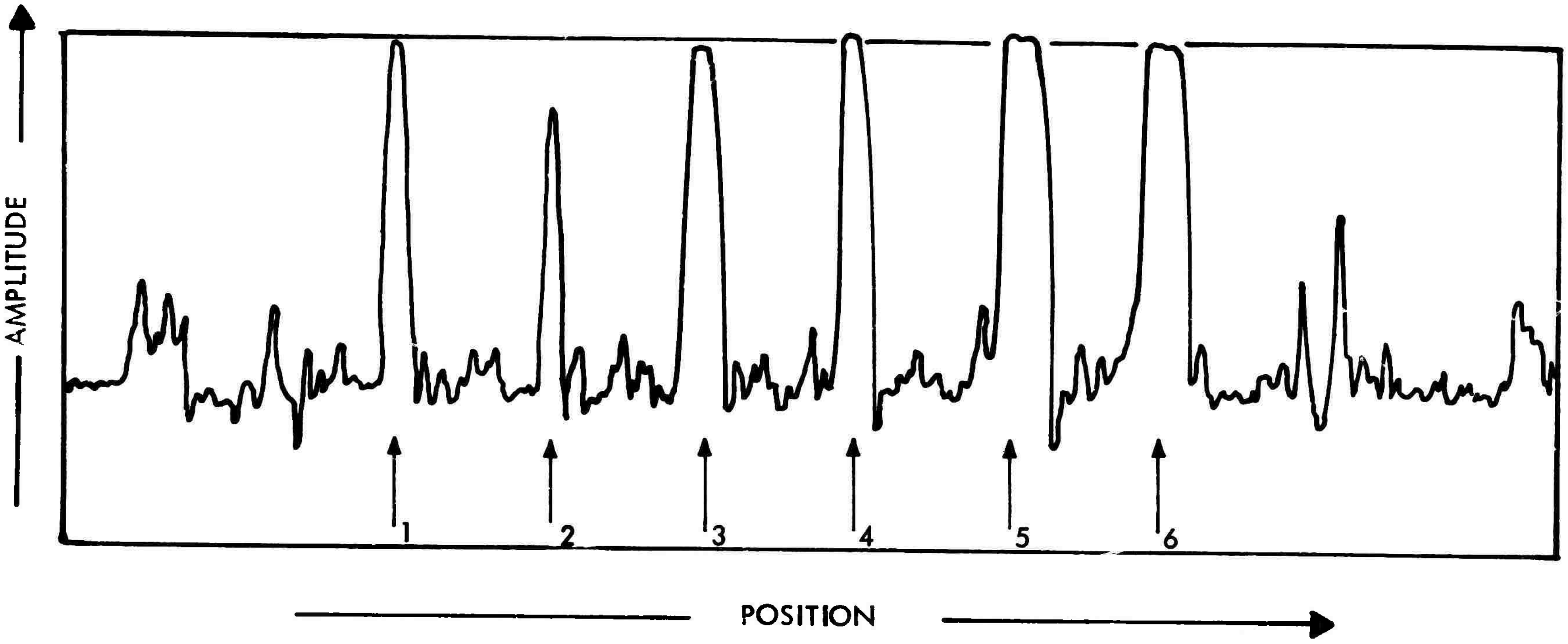


FIGURE 22 PRODUCT OF 0° 40° AND 60° DATA

properly aligned data. The SP300 record mode must be automatically initiated when the scanner reaches a given position along the length of the weld. The position in question can be defined by the receipt of an echo from one of the holes in the beam position indicator. A microswitch and relay can be used to start the recorder. In addition the magnetic tape must start from the same place each time. Immediately preceeding initiation of the record mode for a given scan along the weld, the magnetic tape must be placed in a given position, accurate to several millimeters, relative to the record head. Finally, since the recorder tape drive operates at a constant speed the scanner must move at a constant speed. If this condition is not met the data may be aligned at the beginning of a given scan but not at the end. Use of an AC synchronous motor to drive the scanner was adequate for the present work.

DATA AND CONCLUSIONS

The data shown in Figure 8 was taken from that portion of the test specimen containing the six artificial flaws, (Figure 3). Four of the "flaw" indications are readily distinguishable, one is marginal and the last is not distinguishable from the surrounding noise background. The large peak on the left is due to an edge reflection. The majority of the background noise appears to be due to the surface roughness of the plate and to the granularity of the titanium metal. Knowing the location of the artificial flaws enables one to locate the probable flaw indications even for the two marginal signals in the present data. The locations are indicated in Figure 8. Note that the curve contains a number of other peaks of height and shape approximately the same as that of the smaller of the two ten mil drill hole indications. (The approximate signal to noise ratio for the smaller ten mil drill hole indication is one to one)

The data shown in Figures 15 and 16 were also taken from the region of the test specimen containing the artificial flaws, (Figure 3). Note that the signal to noise ratio is approximately the same for all three sets of data; the zero degree or conventional data, the forty degree data, and the sixty degree data. The approximately equal quality of the data is important because improvement is unlikely if the product is taken between good and bad sets of data. Note also that each set of data exhibits a different background noise pattern. This is essential if the multiplication process is to reduce the general level of background noise. It is believed that the background noise patterns are different because, in each case, the sound enters the part at a different location and subsequently follows a different path.

Figure 21 shows the product of the zero degree and forty degree data. Note that a significant number of extraneous peaks have been removed. The signal to noise ratio appears to be on the order of two to one or two point five to one. Figure 22 shows the triple product. In this curve the signal to noise ratio has increased to a value of about five to one. Some peaks of unknown origin at the right end of the scan continue to be retained. There may be an actual localized scattering center at that location. Additional scans and products are possible and may yield further information on these indications. In Figure 23 the three scans and the triple product are brought together for ready inspection.

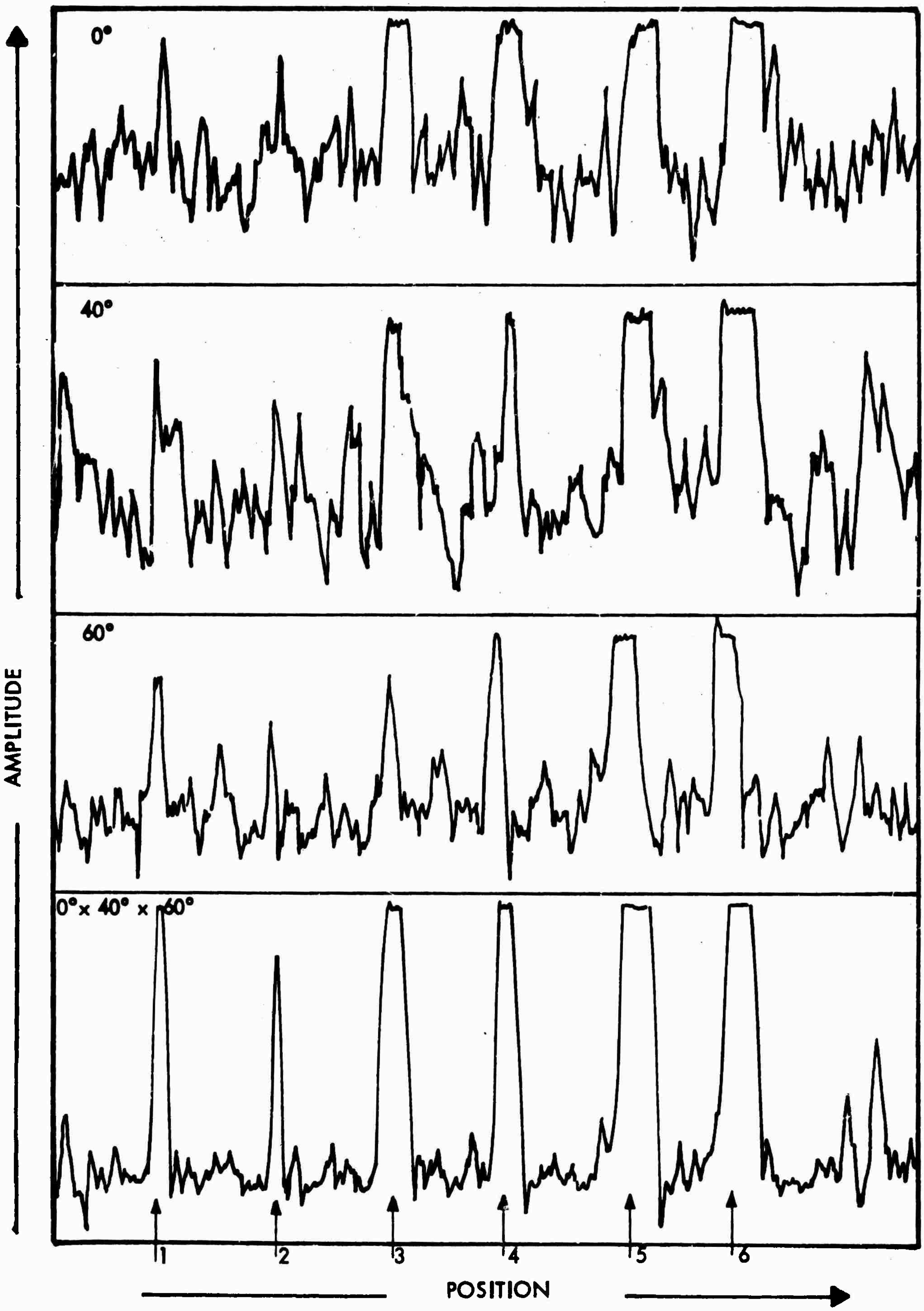


FIGURE 23 ULTRASONIC WELD INSPECTION DATA

SUMMARY

There is a continuing interest in the detection of small cracks in welds. The sensitivity of present ultrasonic inspection methods is limited by surface roughness and grain boundary scattering. Probe to test part geometry is a critical variable in such work and a number of different examinations each characterized by a different transducer orientation is advisable. The probability of finding small flaws will be increased by the employment of skilled personnel and by the use of recording methods which present all of the ultrasonic information available. The use of automatic scanning devices and immersion testing reduces noise due to uncontrollable variations in probe position and coupling. Electronic signal processing will be employed most productively in systems which have taken the above factors into consideration. In such systems correlation techniques can be used to reduce background noise due to surface roughness and grain boundary scattering. In the present work correlation by multiplication has been used to improve the signal to noise ratio by a factor of five. The signal to noise ratio for the ultrasonic reflection from a ten mil drill hole has been improved from a value of one to one to a value of five to one. Further work is required to determine the ultimate capability of such techniques and to develop automatic methods for the collection of correlated ultrasonic weld inspection data.

FUTURE WORK

The real time generation of correlated ultrasonic weld inspection data will be studied. The use of correlation techniques for the reduction of surface roughness noise in eddy current systems will be investigated. The use of optical correlation techniques in X-ray and film recorded magnetic particle tests is being considered. Efforts will be made to obtain a spectral or statistical characterization of the irregular signals obtained from ultrasonic grain boundary scattering. Both electrical and optical techniques will be examined.

ACKNOWLEDGEMENTS

We thank Mr. R. K. Vannier for helping to precisely define the limitations of conventional ultrasonic weld inspection techniques and for his continuous attention to the many small problems which arose during the performance of this work.

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