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Program for Field Validation of the Synthetic Aperture Focusing Technique for Ultrasonic Testing (SAFT UT)

Quarterly Progress Report
February - April 1981

Prepared by D. R. Hamlin, J. L. Jackson

Southwest Research Institute

Prepared for
U.S. Nuclear Regulatory
Commission

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February - April 1981

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Washington, D.C. 20555
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ABSTRACT

This progress report describes work performed by Southwest Research Institute (SwRI) for the Nuclear Regulatory Commission (NRC) in fulfillment of NRC Contract No. NRC-04-77-145: "Program for Field Validation of the Synthetic Aperture Focusing Technique for Ultrasonic Testing (SAFT UT)."

The purpose of the project is to validate the usefulness of SAFT UT for industrial nondestructive evaluations (NDE). SAFT UT is an ultrasonic imaging method for accurate measurement of the spatial location and extent of acoustically reflective surfaces (flaws) contained in objects such as structural components and weldments in nuclear power reactor systems. The increased measurement accuracy offered by SAFT, when compared with that provided by measurement methods now in use, will improve the reliability of flaw severity assessments with resultant safety and economic benefits to the nuclear power industry.

To accomplish the objective, SwRI is to design and construct an imaging system, suitable for field use, using the SAFT UT and to conduct sufficient tests with the system to fully characterize its performance and usefulness for the intended purpose. The ultimate goal is to produce a field-rated system for highly accurate flaw size measurements and to conduct sufficient testing of that system to promote its acceptance by industrial and regulatory authorities.

The following document describes the accomplishments completed since submission of the mid-year progress report.

TABLE OF CONTENTS

		Page
1.0	INTRODUCTION.	1
2.0	IMAGE RECONSTRUCTION SIGNAL PROCESSING METHODS.	2
2.1	DC Component Removal from Unprocessed RF Waveforms.	2
2.2	DC Component Removal from the Processed Data Waveforms. . .	3
2.3	Envelope Detection of the Processed Data Waveforms.	3
2.4	Selected Processed Data Frequency Spectrum Analysis	3
3.0	RESULTS FROM PROCESSING SAFT UT EXAMINATION DATA.	6
3.1	Aluminum Test Block Containing Machined Reflectors.	6
3.2	Butt-Welded Carbon Steel Plate Specimen	10
4.0	TASKS REQUIRED TO PERMIT EXAMINATION OF CYLINDRICALLY-SHAPED TEST SPECIMENS	21
4.1	Design Considerations	21
5.0	SUMMARY	24
REFERENCES.		25

LIST OF FIGURES

Figure	Title	Page
1	Frequency Spectrum of Processed Data Showing Effect of Aliasing.	5
2	Frequency Spectrum of Processed Data Showing Effect of No Aliasing	5
3	Aluminum Test Block Dimensions	7
4	Processed Data Orientations.	7
5	Aluminum Test Block - Six Bottom-Drilled Holes (Top View)	8
6	Aluminum Test Block - Six Bottom-Drilled Holes (Cross Section View)	9
7	Point Spread Function.	11
8	Carbon Steel Plate	12
9	Butt-Welded Carbon Steel Plate - Porosity (Top View) . . .	13
10	Butt-Welded Carbon Steel Plate - Porosity (Cross Section View)	14
11	Butt-Welded Carbon Steel Plate - Slag Inclusion (Top View)	15
12	Butt-Welded Carbon Steel Plate - Slag Inclusion (Cross Section View)	16
13	Butt-Welded Carbon Steel Plate - Heat Affected Zone Crack (Top View)	17
14	Butt-Welded Carbon Steel Plate - Heat Affected Zone Crack (Cross Section View)	18
15	Butt-Welded Carbon Steel Plate - Tungsten Inclusion and Heat Affected Zone Cracking (Top View)	19
16	Butt-Welded Carbon Steel Plate - Tungsten Inclusion and Heat Affected Zone Cracking (Cross Section View) . . .	20
17	Cylindrical Test Specimen Transducer Holder.	22
18	Cylindrical Test Block	23

1.0 INTRODUCTION

Southwest Research Institute (SwRI) is conducting a project entitled "Program for Field Validation of the Synethtic Aperture Focusing Technique for Ultrasonic Testing (SAFT UT)." The project's purpose is to continue the development of SAFT UT and to validate its usefulness for inservice inspection applications. SAFT UT is an ultrasonic imaging method for accurately measuring the spatial locations and extent of flaws contained in objects such as structural components and weldments in nuclear power reactor systems. The increased measurement accuracy offered by SAFT UT, when compared with that provided by measurement methods now in use, will improve the reliability of flaw severity assessments with resultant safety and economic benefits to the nuclear power industry.

This project is one part of a team effort being conducted by the University of Michigan (U of M) and SwRI. Although the two groups are working under separate contracts, their efforts are integrated and synergetic. The U of M group is concentrating on theoretical aspects of SAFT UT while SwRI, working with information and advice supplied by U of M, is contributing the engineering and performance evaluations necessary to produce and validate a practical field tool.

The objectives of this program are to:

- Produce a SAFT UT system in a form useful for field test.
- Validate the performance of that system for characterizing both real and simulated flaws in realistic test specimens.
- Conduct field trials using the system on actual structures.
- Estimate the reliability and confidence level for SAFT UT examinations and compare those results with similar estimates made for conventional ultrasonic methods.

The ultimate goal is to produce a field-rated system for highly accurate flaw size measurements and to conduct sufficient testing of that system to promote its acceptance by industrial and regulatory authorities.

This report presents the results of work accomplished since submittal of the February 1981 mid-year report. Specifically, three areas will be covered: (1) description of signal processing methods utilized to improve the reconstructed image, (2) presentation of processed data images for the butt-welded carbon steel plate specimen, and (3) discussion of tasks required to permit SAFT UT examination of cylindrically-shaped test specimens.

2.0 IMAGE RECONSTRUCTION SIGNAL PROCESSING METHODS

The SAFT UT system image reconstruction algorithm was discussed in detail in the November 1980 quarterly report. While this algorithm provides good reconstructed images, moderate, but useful, improvement to the signal-to-noise ratio (SNR) is obtained by employing several computer programs which perform signal processing functions on SAFT data. These measures are designed to remove constant terms and out-of-band noise, which sometimes contribute to background noise and clutter.

The signal processing functions described in the following sections are currently being utilized to process all SAFT UT examination data.

2.1 DC Component Removal from Unprocessed RF Waveforms

The reconstructed image is derived from information contained in the signals produced within the useful bandwidth of the transducer. The fundamental image reconstruction operation involves summing the radio frequency (RF) signal amplitude, occurring at a predicted time of flight, into a pixel representing a discrete element (cell) of the inspected volume. The resulting final amplitude value within the pixel will determine how that pixel influences the reconstructed image. If the raw data waveform contains any energy outside the useful bandwidth, that energy will not add useful information to the final image but will contribute noise and clutter which lowers the SNR. For example, varying DC levels among the many contributing RF sample amplitudes will introduce errors into the final pixel amplitude. For this reason, the RF signal waveforms are filtered prior to performing the image reconstruction process. The filter is implemented according to procedures developed by Dr. V. Schmitz[1] while conducting research at SwRI. The procedures are:

(1) The RF signal waveform is fed into an array representing the real part of a complex field.

(2) Zeros are fed into an array representing the imaginary part of a complex field.

(3) The complex field is Fourier transformed into the frequency domain.

(4) The real and imaginary parts of the frequency domain are multiplied by a high-pass-filter function. To minimize the effects of truncation, undulations or ripples in the amplitude response, the Martin-Graham filter[2] (which includes a cosine roll-off) is utilized as shown below.

$$H(w)=\begin{cases} \frac{1}{2}\left(1+\cos\frac{\pi(w_H-w)}{w_H}\right) & 0 \le w \le w_H \\ \frac{1}{2}\left(1+\cos\frac{\pi(w_H+w)}{w_H}\right) & 0 \le w \le w_H \\ 1 & w_H \le |w| \end{cases} \qquad (1)$$

This filter exhibits uniform transmission outside the band $w = w_H$ and zero inside.

(5) The resulting data is reverse-Fourier transformed into the time domain. The DC component has now been removed without introducing waveform distortion in the RF signals.

2.2 DC Component Removal from the Processed Data Waveforms

The results of utilizing the SAFT image reconstruction algorithm are processed data waveforms (Z pixel columns within the inspected volume) having oscillating signal characteristics identical to the ultrasonic transducer frequency used in the inspection. Research conducted at SwRI[1] has shown that even though the DC component was removed from the unprocessed RF signals prior to image reconstruction, DC terms can appear in the processed data. The cause of this effect is thought to be aliasing of high frequency noise contained in raw data. These DC terms degrade the image and are therefore removed using the same high-pass-filter function discussed in Section 2.1.

2.3 Envelope Detection of the Processed Data Waveforms

To enhance interpretation of the reconstructed image, an envelope detection process identical to that utilized at the University of Michigan is employed. This process involves performing the following functions:

(1) The processed RF signal waveform is fed into an array representing the real part of a complex field.

(2) Zeros are fed into an array representing the imaginary part of a complex field.

(3) The complex field is Fourier transformed into the frequency domain.

(4) The real and imaginary parts of the frequency domain are multiplied by the following filter function:

$$\text{Filter} = \begin{cases} 1 \text{ for } f \geq \emptyset \\ \emptyset \text{ for } f < \emptyset \end{cases}$$

(5) The resulting data is reverse-Fourier transformed into the time domain.

(6) The absolute value of the sum of the squares of the real and imaginary parts is obtained as video data.

In actual implementation, the processed data undergoes envelope detection and DC component removal during one operation.

2.4 Selected Processed Data Frequency Spectrum Analysis

Instances were encountered of aliasing resulting from the sampling process inherent to the reconstruction algorithm. The signals resulting from aliasing add noise to the image. To permit detection of aliasing caused by

improper volume sampling during image reconstruction, the operator has an option to graphically display the frequency spectrum of selected data. To illustrate the capability, Figures 1 and 2 show the frequency spectrum of the same examination data reconstructed at Z pixel sizes of 10 mils (.254 mm) and 7 mils (.178 mm) respectively. Aliasing is clearly evident in Figure 1 while no aliasing is indicated in Figure 2. Following execution of the image reconstruction algorithm (but prior to DC component removal and envelope detection), the operator can determine if aliasing has occurred and take appropriate corrective action if required.

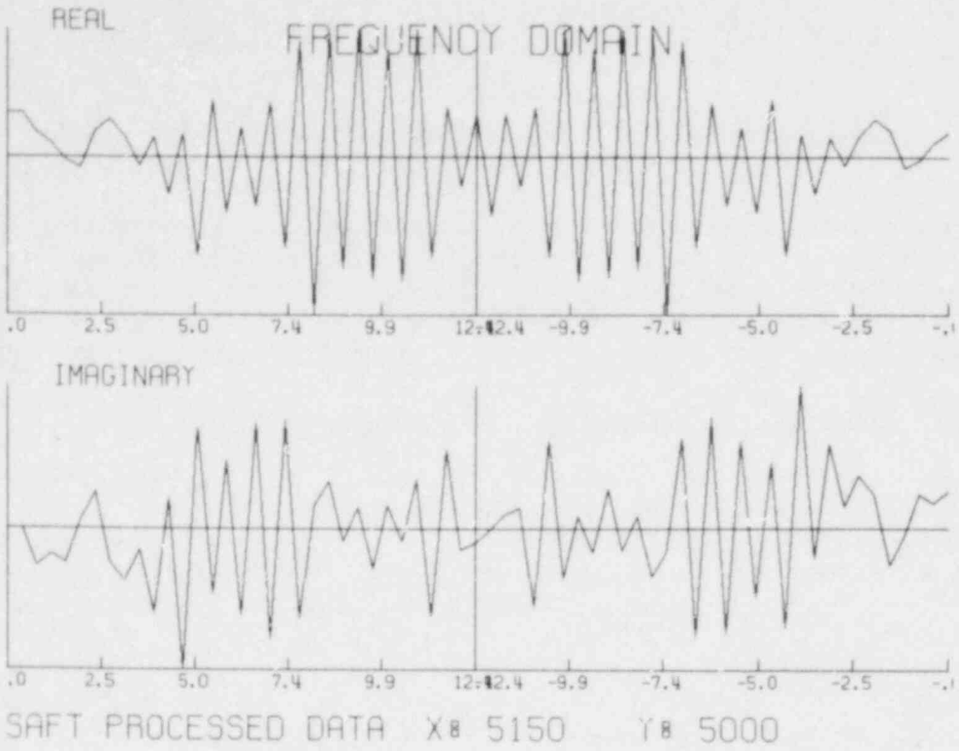

FIGURE 1. FREQUENCY SPECTRUM OF PROCESSED DATA SHOWING EFFECT OF ALIASING

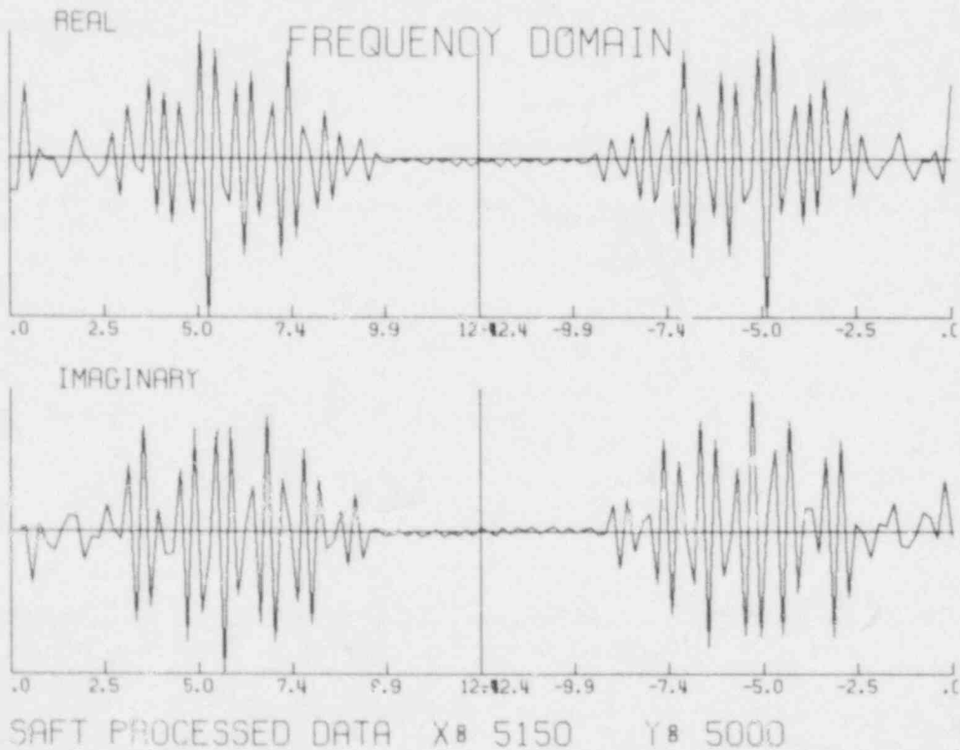

FIGURE 2. FREQUENCY SPECTRUM OF PROCESSED DATA SHOWING NO ALIASING

3.0 RESULTS FROM PROCESSING SAFT UT EXAMINATION DATA

This section presents the results obtained by combining the previously discussed signal processing methods with the image reconstruction algorithm. Two test specimens were examined in this activity. The first is a specimen containing machined reflectors of known size, location and orientation which permits the reader to understand the relationship between the image display presentation and the actual reflectors which are present. Secondly, results from the examination of a butt-welded carbon steel plate containing fabricated (but not machined) flaws of unknown size, shape and orientation are presented.

3.1 Aluminum Test Block Containing Machined Reflectors

An aluminum test block containing six bottom-drilled holes was used as a convenient test piece for evaluating the signal processing method and for estimating accuracy, resolution and SNR. The dimension of this block and image display orientations are shown in Figures 3 and 4 while Figures 5 and 6 are the processed SAFT UT image of the holes. Figure 5 is a top view (looking in the direction of the hole axis). Note the well defined images of the ends of the six holes and the excellent resolution as evidenced by the separate indications of the two most closely spaced holes. Figure 6 is a side view derived from the same data used to produce the top view. Again, all six hole ends are clearly imaged. This side view shows the holes staggered in depth in 0.05 inch (1.27 mm) increments, which are precisely the dimensions used in fabrication and thus constitute convincing evidence of the high range resolution abilities of SAFT. Such high range resolution is distinctly superior to the resolution of acoustical holography. The SNR of this image is in excess of 30 dB.

3.1.1 Point Spread Function

The image resolution exhibited by the SAFT UT system correlates well with theoretical predictions. Using results by Norton[3], the point spread function for a pulse-echo synthetic aperture focusing system can be determined from

$$\frac{A_{(p)}}{A_{(o)}} = \frac{2J_1\left(\frac{2\pi\tan\frac{\theta}{2}\cdot 2p}{\lambda}\right)}{\left(\frac{2\pi\tan\frac{\theta}{2}\cdot 2p}{\lambda}\right)}$$

where

$\frac{A_{(p)}}{A_{(o)}}$ = normalized image amplitude for a point target as measured at a lateral distance from the target

$J_1(\ )$ = Bessel function of order one

θ = included angle of the synthesized aperture

λ = wavelength

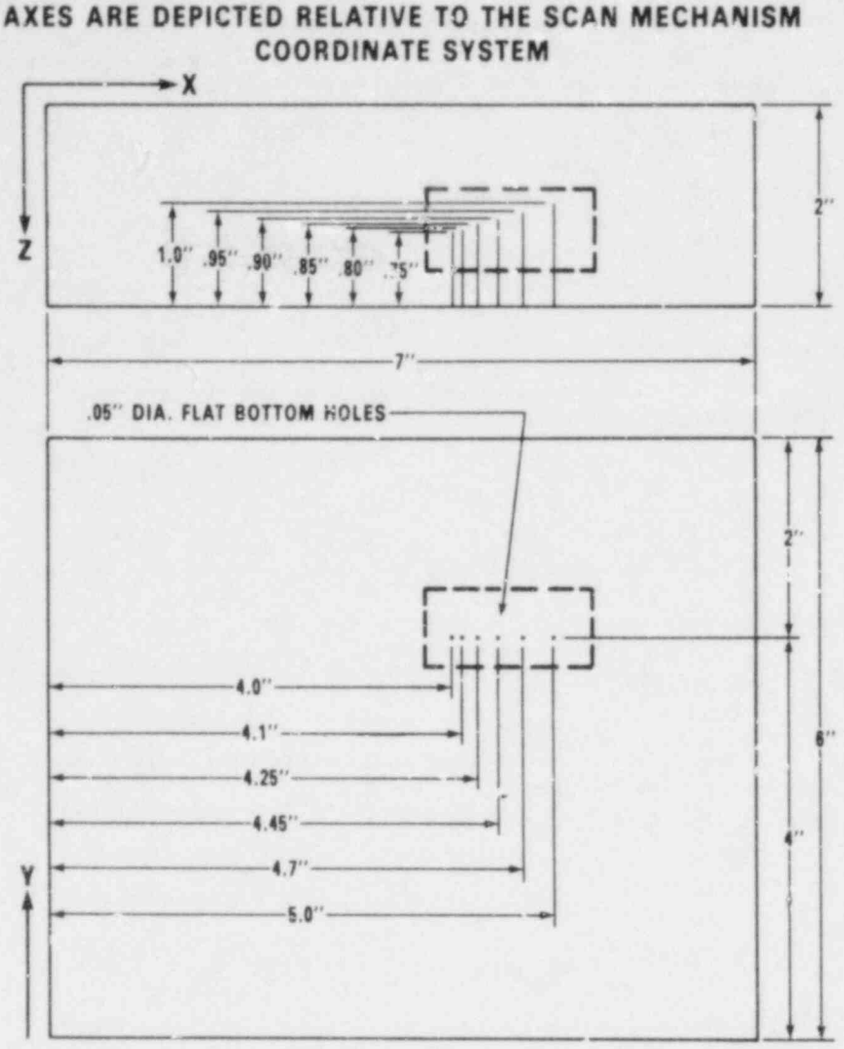

FIGURE 3. ALUMINUM TEST BLOCK DIMENSIONS

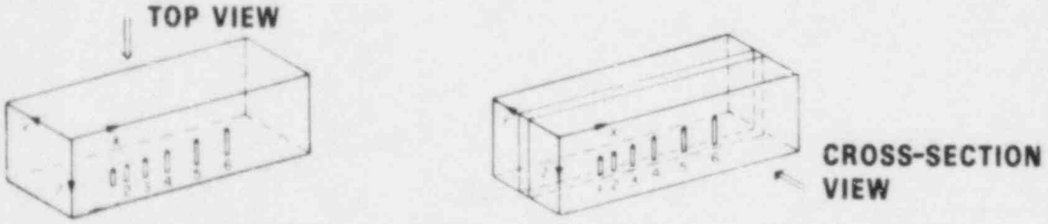

FIGURE 4. PROCESSED DATA ORIENTATIONS

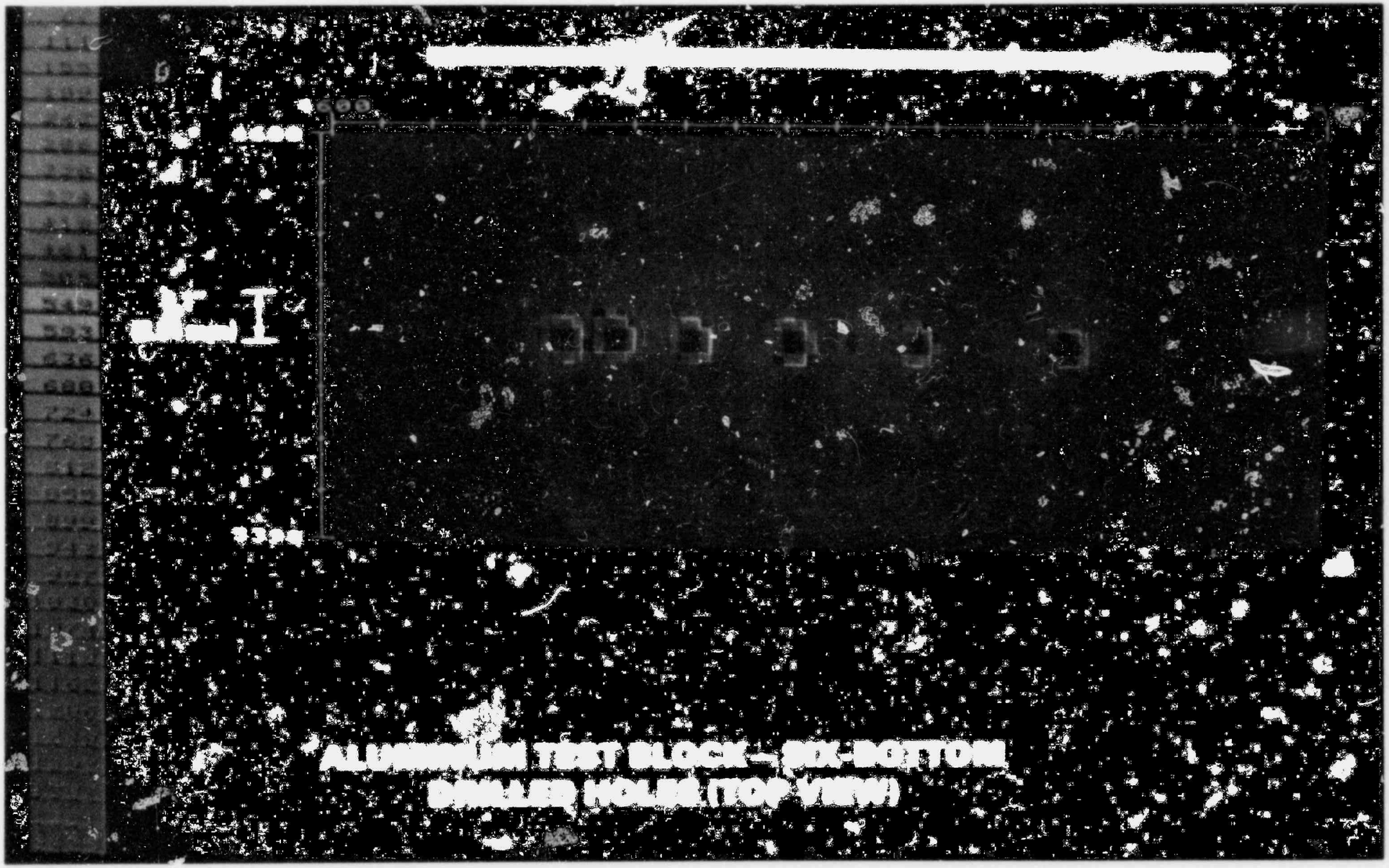

FIGURE 5

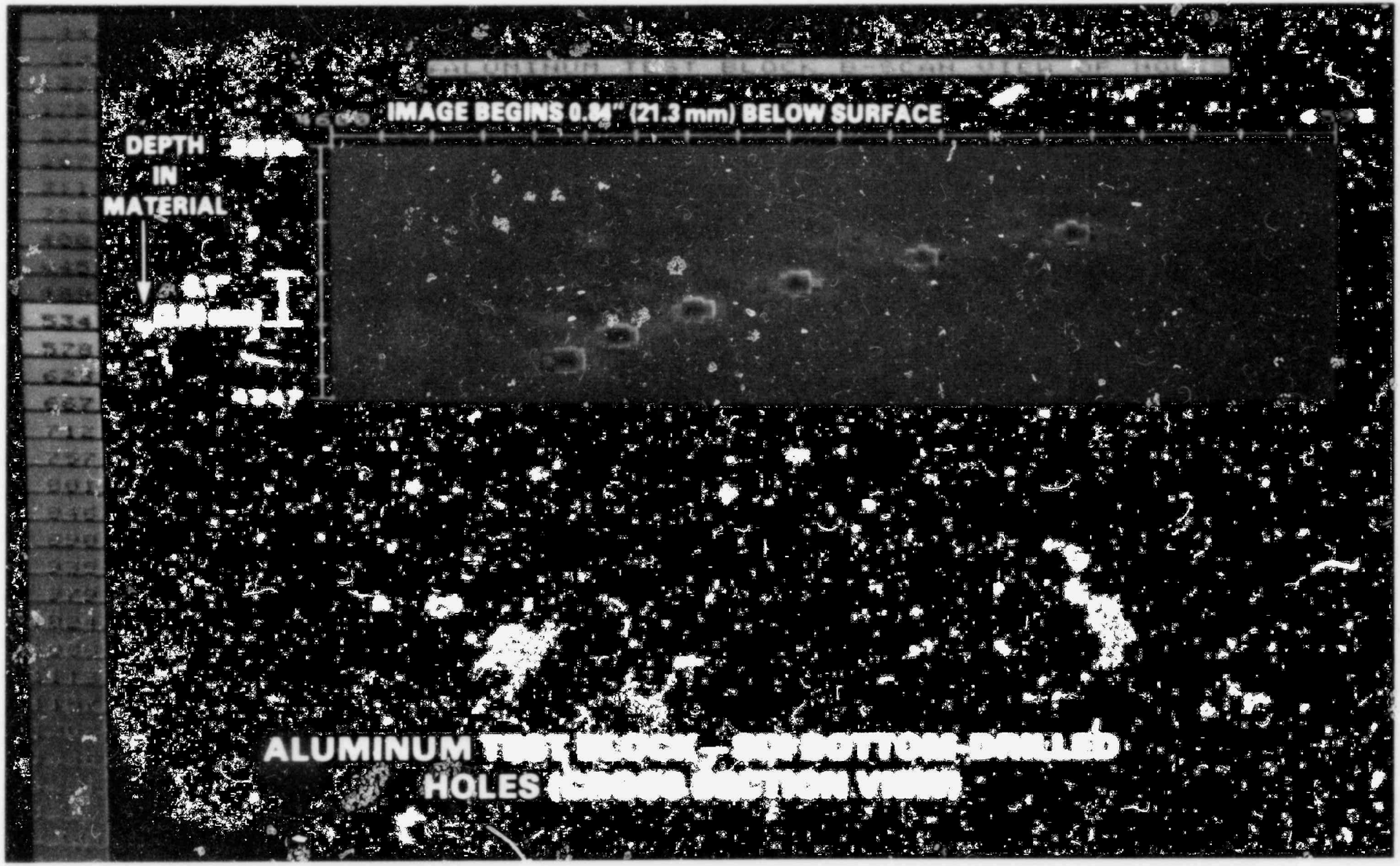
IMAGE BEGINS 0.84" (21.3 mm) BELOW SURFACE
DEPTH IN MATERIAL
ALUMINUM

FIGURE 6

Using this expression for the case of a 5 MHz focused transducer (longitudinal wave in aluminum) with θ equal to 30 degrees produces the predicted point spread function shown in Figure 7. The experimentally measured point spread function for a one wavelength reflector in the previously mentioned aluminum test block has been superimposed to allow comparison. It is seen that the experimentally measured point spread function correlates well with the predicted one; it is slightly broader and has lower sidelobes because of unequal illumination throughout the aperture. The experimental and the predicted functions are slightly displaced because of the volume sampling technique used in the reconstruction process.

3.2 Butt-Welded Carbon Steel Plate Specimen

A test specimen consisting of a butt-welded carbon steel plate approximately 4 inches (101.6 mm) thick was constructed with a variety of fabricated flaws in the weld. This test specimen is depicted in Figure 8 which also shows the flaw type and general location. After this specimen has received extensive examinations by the SAFT UT system, it will be destructively sectioned so that the true flaw size and character may be determined. The capability of SAFT UT for flaw characterization will be judged by comparing nondestructive evaluation results with the results from destructive evaluation.

This test specimen contains four flaw regions. The type of flaws represented are: (1) porosity as shown in Figures 9 and 10, (2) slag inclusion as shown in Figures 11 and 12, (3) heat affected zone cracking as shown in Figures 13 and 14, and (4) heat affected zone cracking and/or base metal cracking with a tungsten inclusion as shown in Figures 15 and 16. The SNR for each of the reconstructed images is in excess of 30 dB. For each examination region, two views are shown. The first is a C scan view in which the examined area is viewed from above. The second is a B scan view parallel to the longitudinal axis of the weld and passing through the region containing the pixel of maximum signal amplitude. It should be noted that each flaw region was examined once by using a surface scan aperture located on top of the specimen. The processed data resulting from this single examination represents a three-dimensional (volumetric) region containing the reconstructed image of the flaw. The figures presented in this report represent two different views of selected portions of this volume. Many additional displays representing other portions of the processed volume could have been presented. However, the displays presented in this report are intended to illustrate the type of tests being conducted and the images which result.

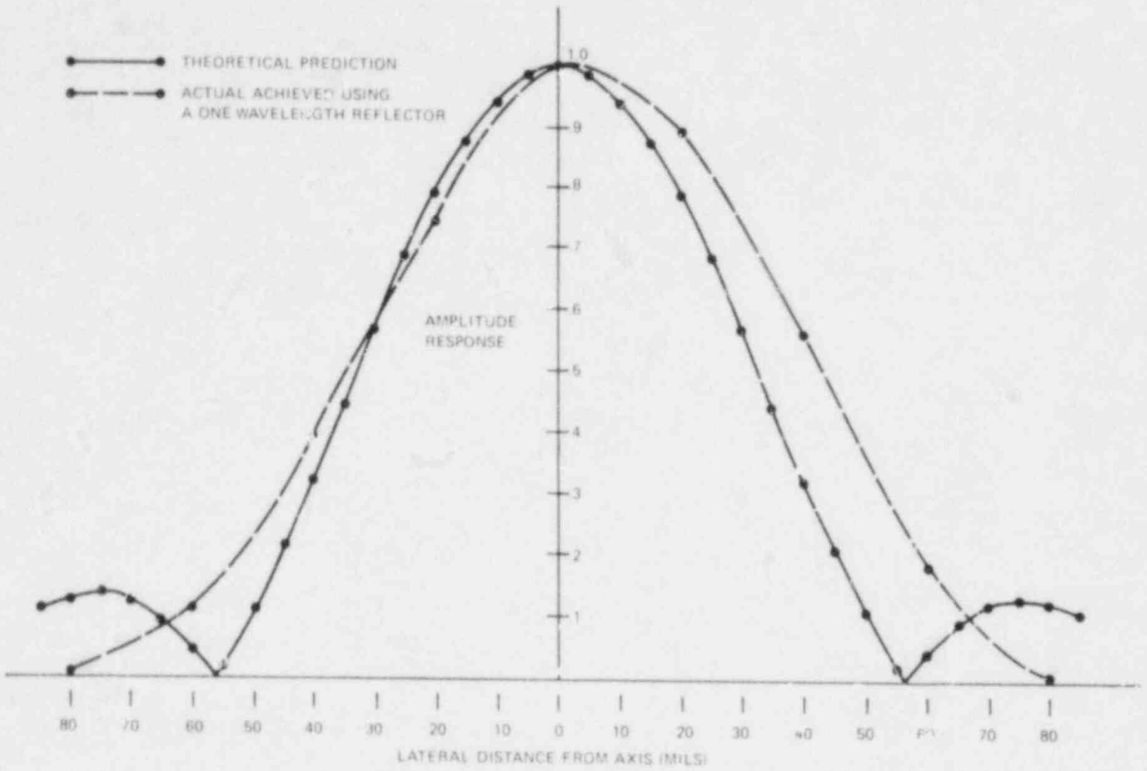

FIGURE 7. POINT SPREAD FUNCTION

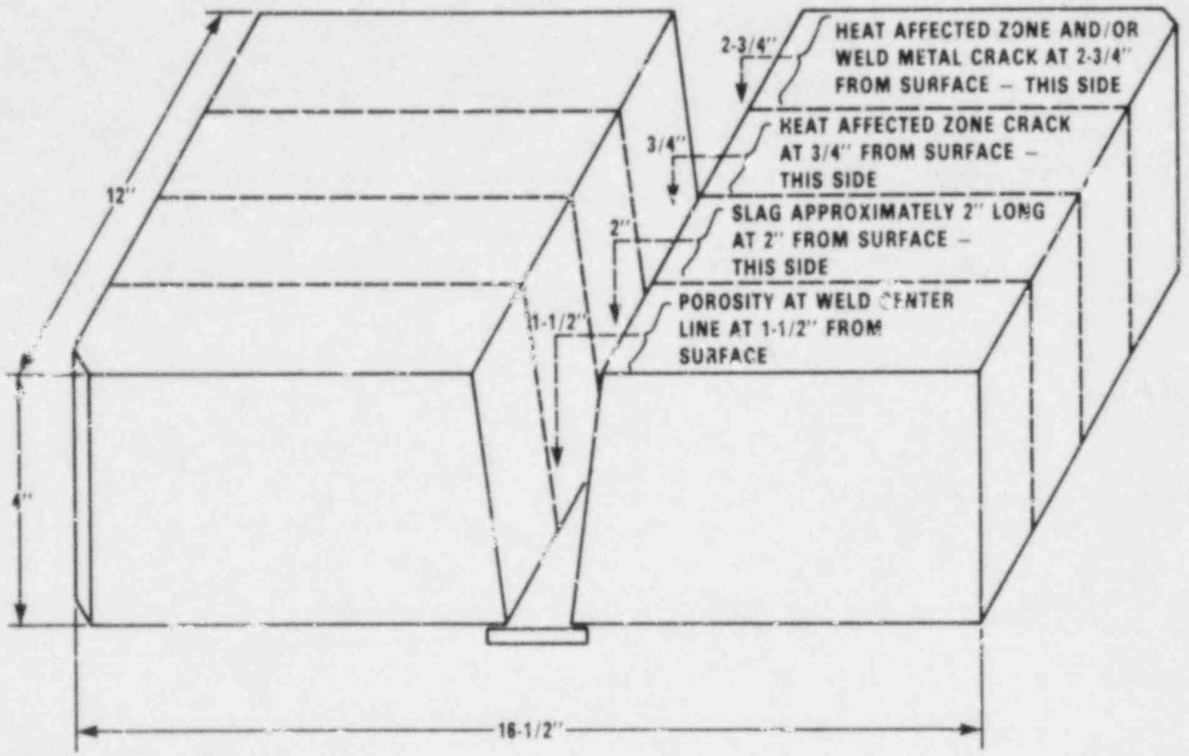

FIGURE 8. CARBON STEEL PLATE

VERTICAL
AXIS IS
LONGITUDINAL
TO WELD
HORIZONTAL AXIS IS TRANSVERSE TO WELD AXIS
BUTT-WELDED CARBON STEEL
PLATE — POROSITY (TOP VIEW)

FIGURE 9

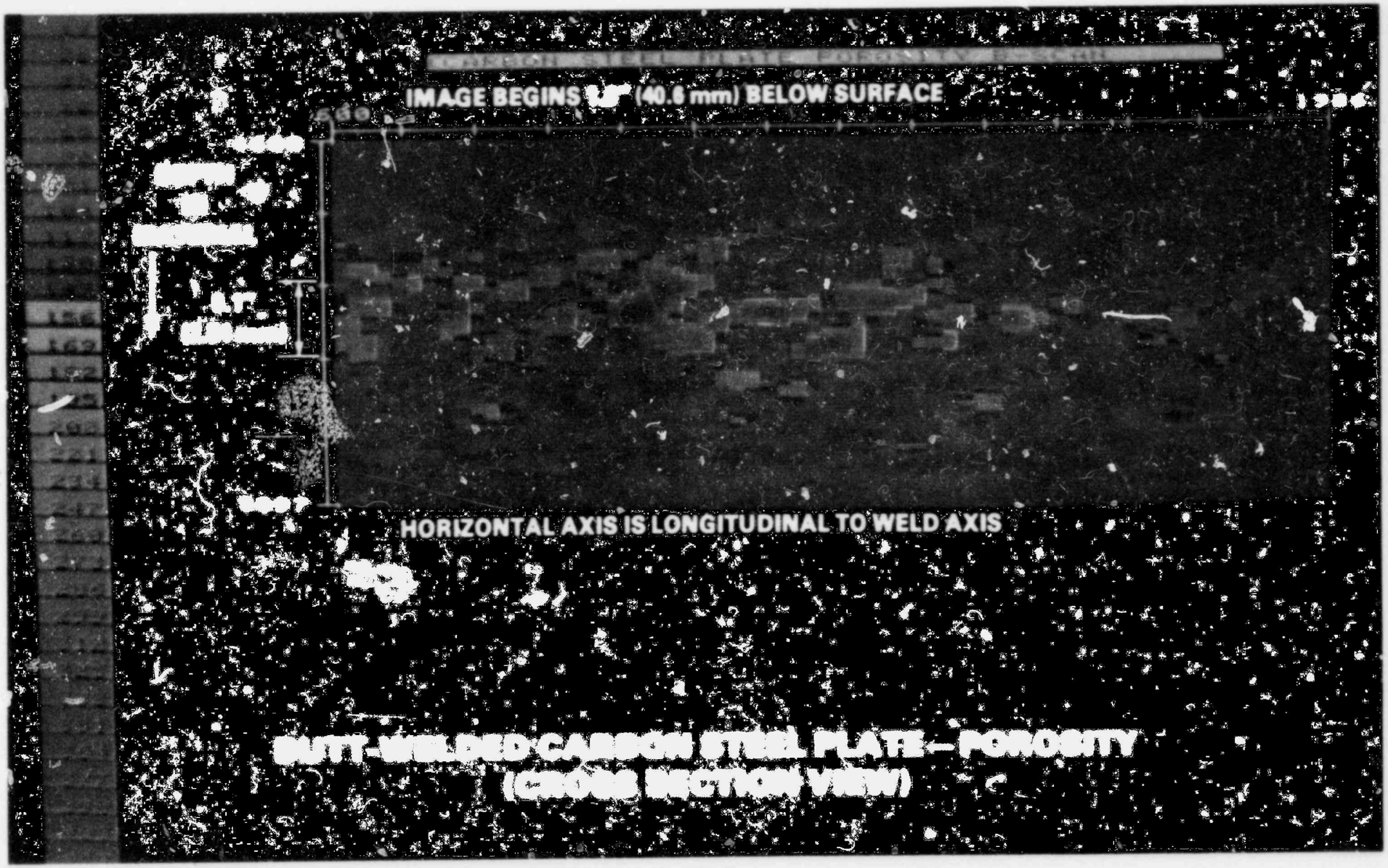
IMAGE BEGINS
(40.6 mm) BELOW SURFACE
HORIZONTAL AXIS IS LONGITUDINAL TO WELD AXIS

FIGURE 10

VERTICAL
AXIS IS
LONGITUDINAL
TO WELD
AXIS
BUTT-WELDED CARBON
SLAG INCLUSION (TOP
HORIZONTAL AXIS IS TRANSVERSE TO WELD AXIS

FIGURE 11

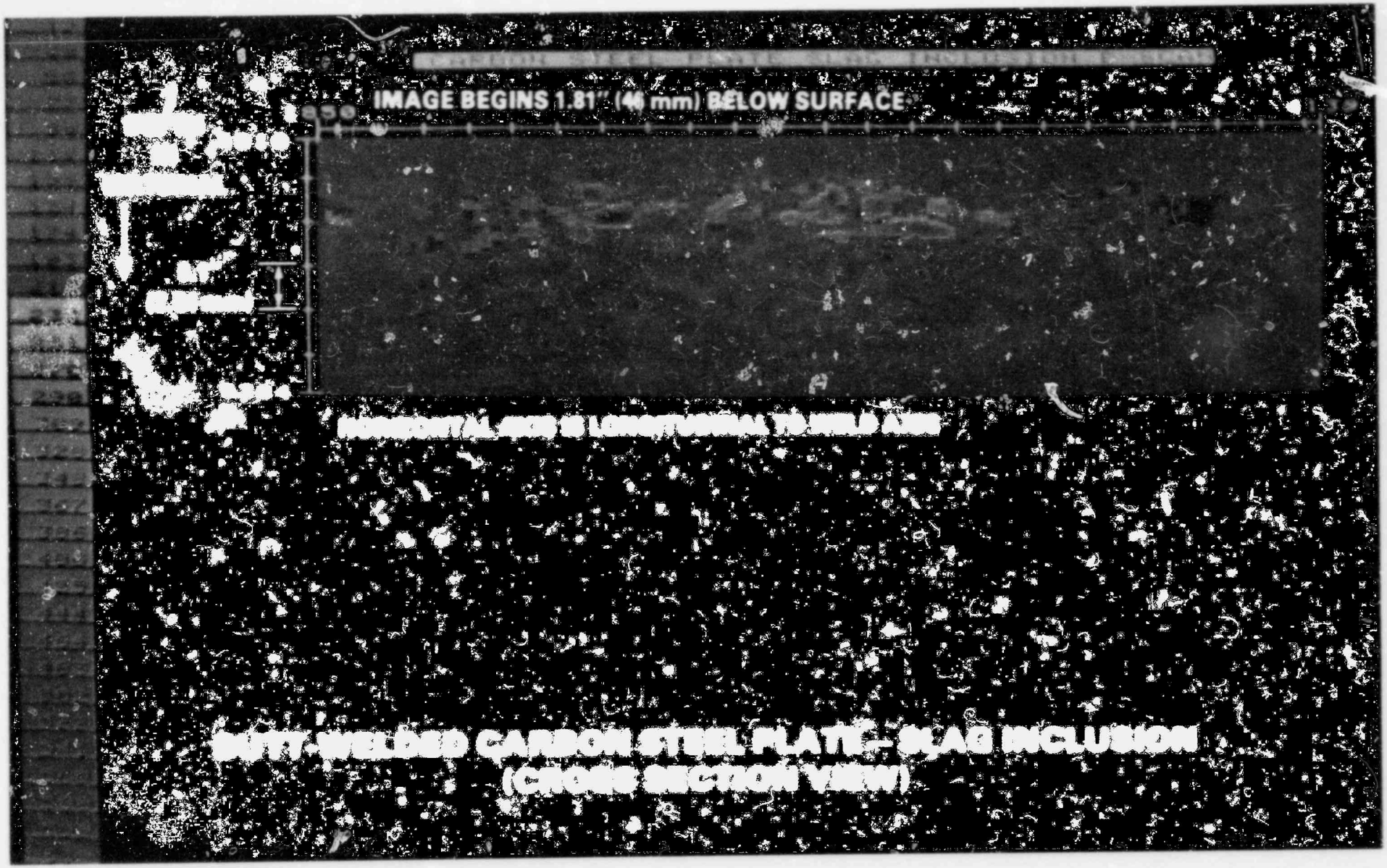

FIGURE 12

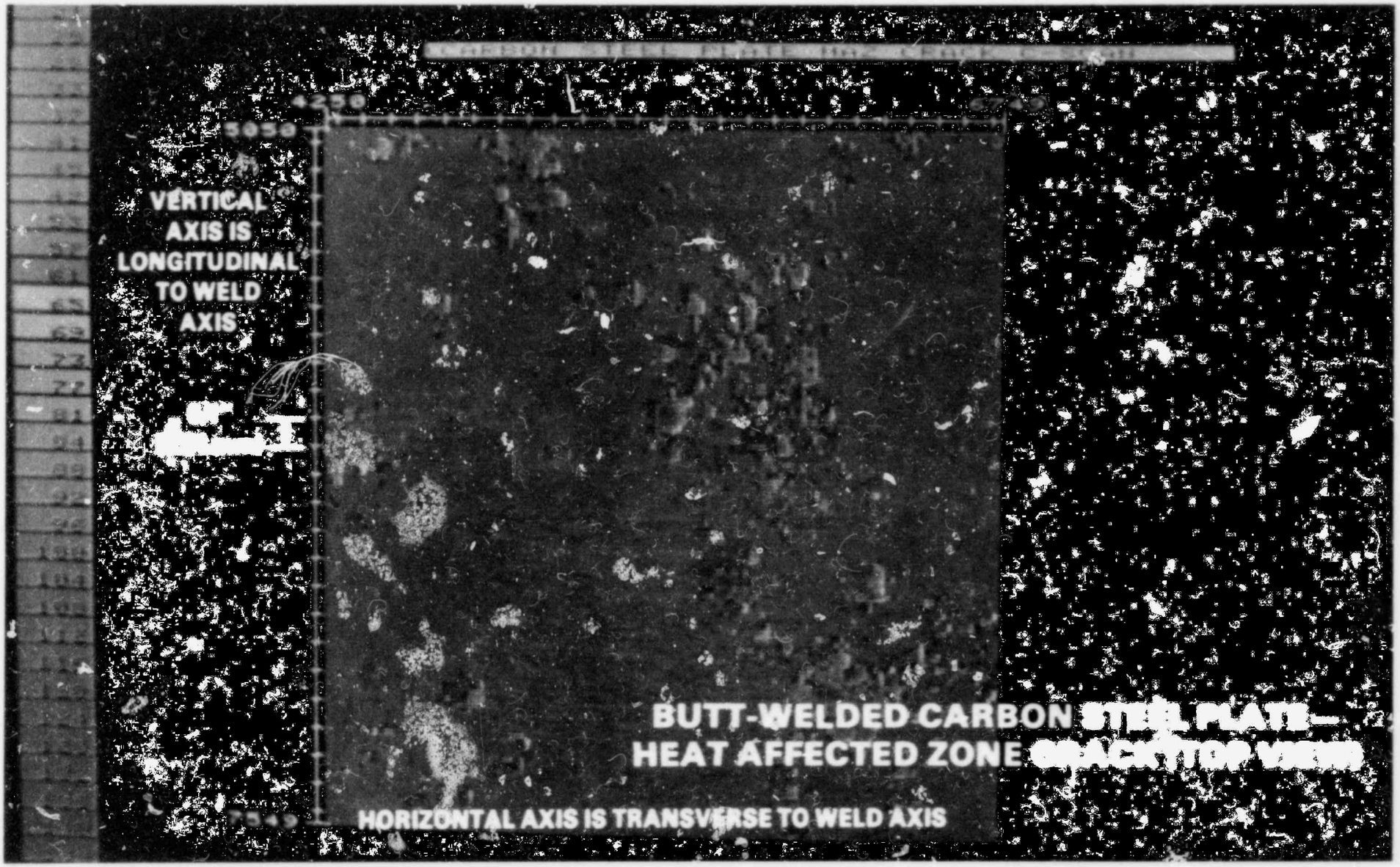
VERTICAL AXIS IS LONGITUDINAL TO WELD AXIS
BUTT-WELDED CARBON STEEL PLATE
HEAT AFFECTED ZONE
HORIZONTAL AXIS IS TRANSVERSE TO WELD AXIS

FIGURE 13

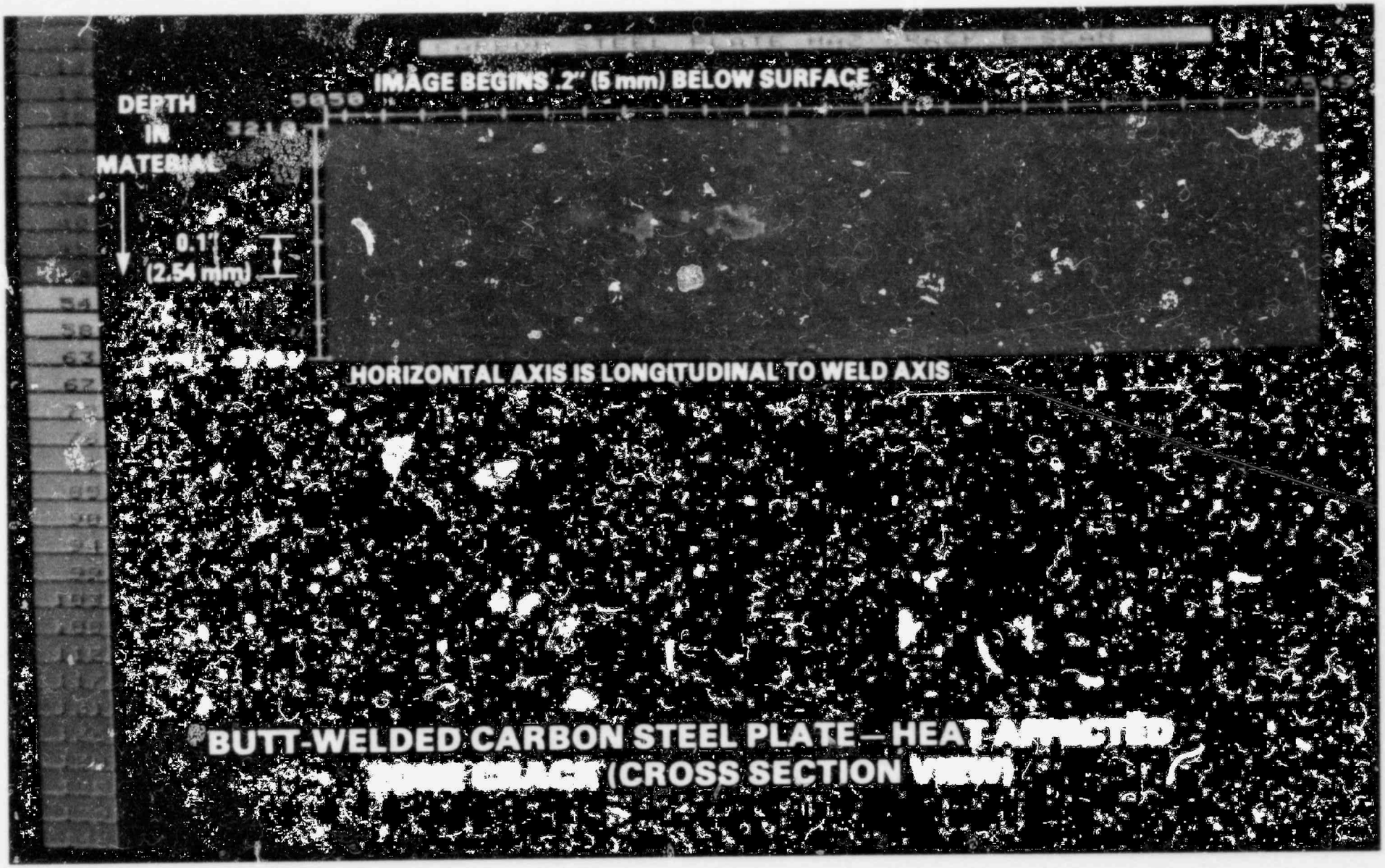
IMAGE BEGINS .2" (5 mm) BELOW SURFACE
DEPTH IN MATERIAL
0.1"
(2.54 mm)
HORIZONTAL AXIS IS LONGITUDINAL TO WELD AXIS
BUTT-WELDED CARBON STEEL PLATE – HEAT
(CROSS SECTION

FIGURE 14

VERTICAL AXIS IS LONGITUDINAL TO WELD AXIS
0.1"
(2.54 mm)
HORIZONTAL AXIS IS TRANSVERSE TO WELD AXIS
BUTT-WELDED CARBON STEEL PLATE—TUNGSTEN INCLUSION AND HEAT AFFECTED ZONE CRACKING
(TOP VIEW)

FIGURE 13

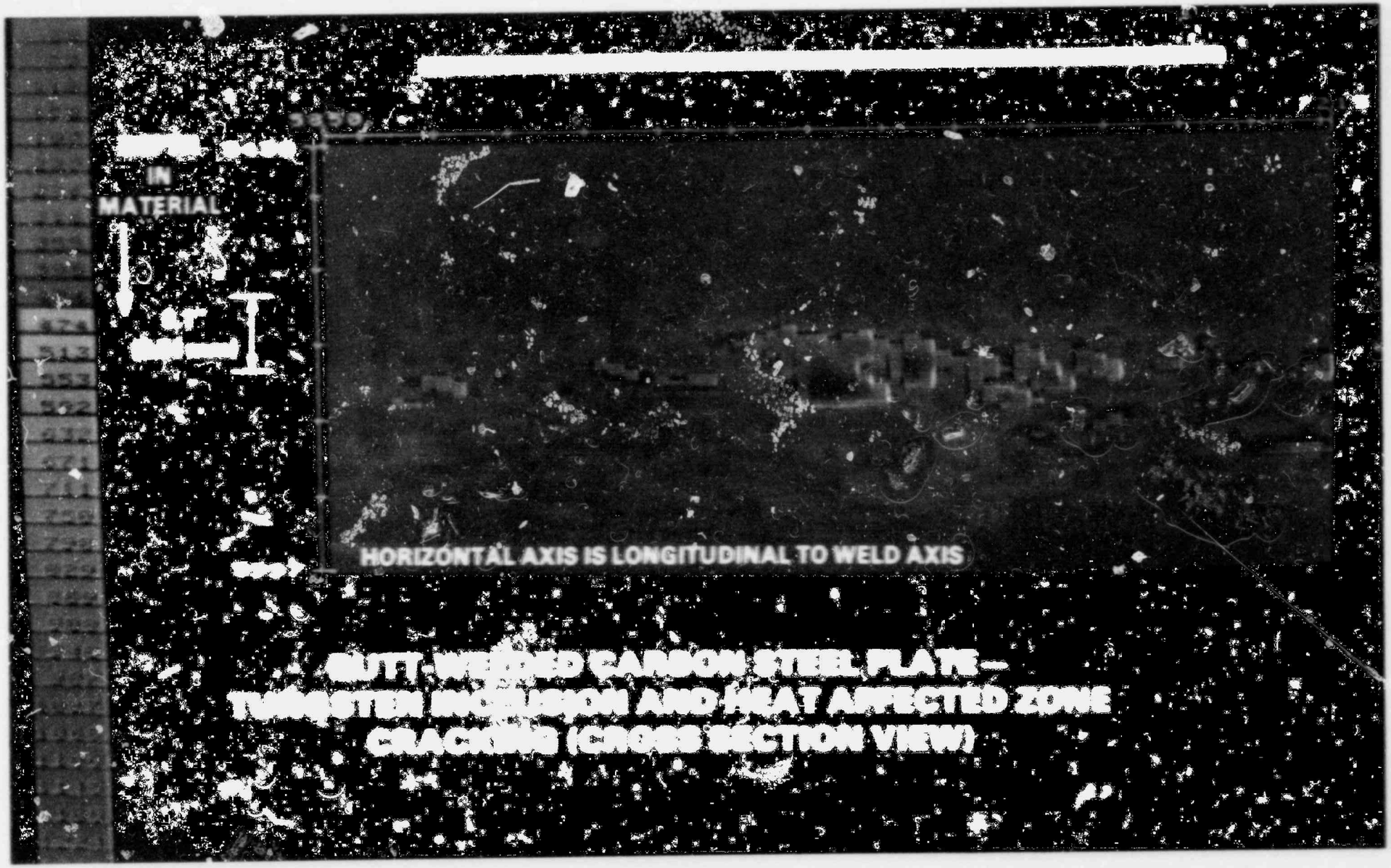

FIGURE 16

4.0 TASKS REQUIRED TO PERMIT EXAMINATION OF CYLINDRICALLY-SHAPED TEST SPECIMENS

The SAFT UT system's ability to conduct examinations of cylindrically-shaped surfaces was originally based on utilizing a focused beam transducer which, among other requirements, provided a good front surface echo over a broad range of incident angles so that the component surface could be properly tracked. This capability ensured that the focal point of the transducer could be precisely positioned on the surface even though the focused beam was angulated relative to the component surface. Another equally important requirement is that the focused transducer must provide a SNR sufficient to permit detection of echoes from weakly reflective surfaces within the material. However, as a result of extensive evaluations conducted during this program, it has been determined that the SNR is a sensitive function of lens F/- number. In effect, as the F/- number increases (as focusing becomes weaker), two advantageous effects occur simultaneously: the flaw signals become stronger whereas the noise signals become weaker. Changing from an F/1 lens to an F/4 lens improves the SNR by 15 to 20 dB. Currently, SwRI is operating by using a 3/4-inch diameter, 3 inch focal length lens (F/4) operating at 5 MHz. As a result of steps taken to ensure good SNR (adoption of less strongly focused transducers), the adaptability of existing scan mechanisms to examine components with moderate-to-strong surface curvature has been reduced. It was necessary, therefore, to make improvements to the existing system so that cylindrical test specimens could be examined.

4.1 Design Considerations

An engineering evaluation has established that the most direct way to avoid present limitations is to add either one or two degrees of transducer freedom operating under passive control. In this case, passive control means the use of self-activating mechanical means without the assistance of electronic or software operations.

This has been accomplished by retrofitting a different transducer holder to the existing scan mechanism. This holder employs an unusual mechanical design which permits the transducer to rotate in a single degree of freedom about a point that can (by existing controls) be adjusted and controlled to be coincident with the component surface and thus accommodate near-cylindrical and near-flat surfaces. The holder is fitted with two spring-loaded arms contacting the component's surface and exerting forces to cause the holder to assume a position approximately normal to the surface. This action will be maintained throughout scan movement over curved surfaces. The holder is shown in figure 17. The small fixture shown at the lower right serves as an alignment tool and permits the focused transducer to be installed so that the focal point is coincident with the axis of rotation of the transducer holder. A cylindrical test specimen has been fabricated to evaluate the operational effectiveness of this holder. Figure 18 is a photograph of this specimen and shows the machined reflectors contained within the specimen. Two sets of six bottom-drilled holes have been created which are indentical in size and spacing to the holes machined in the aluminum test block discussed in Section 3.1. One set of holes is oriented axially while the other set is oriented circumferentially. Upon achieving satisfactory SAFT UT examination results of this test speciman, the new holder will be utilized in examining the cylindrical test specimens in which realistic type flaws have been fabricated.

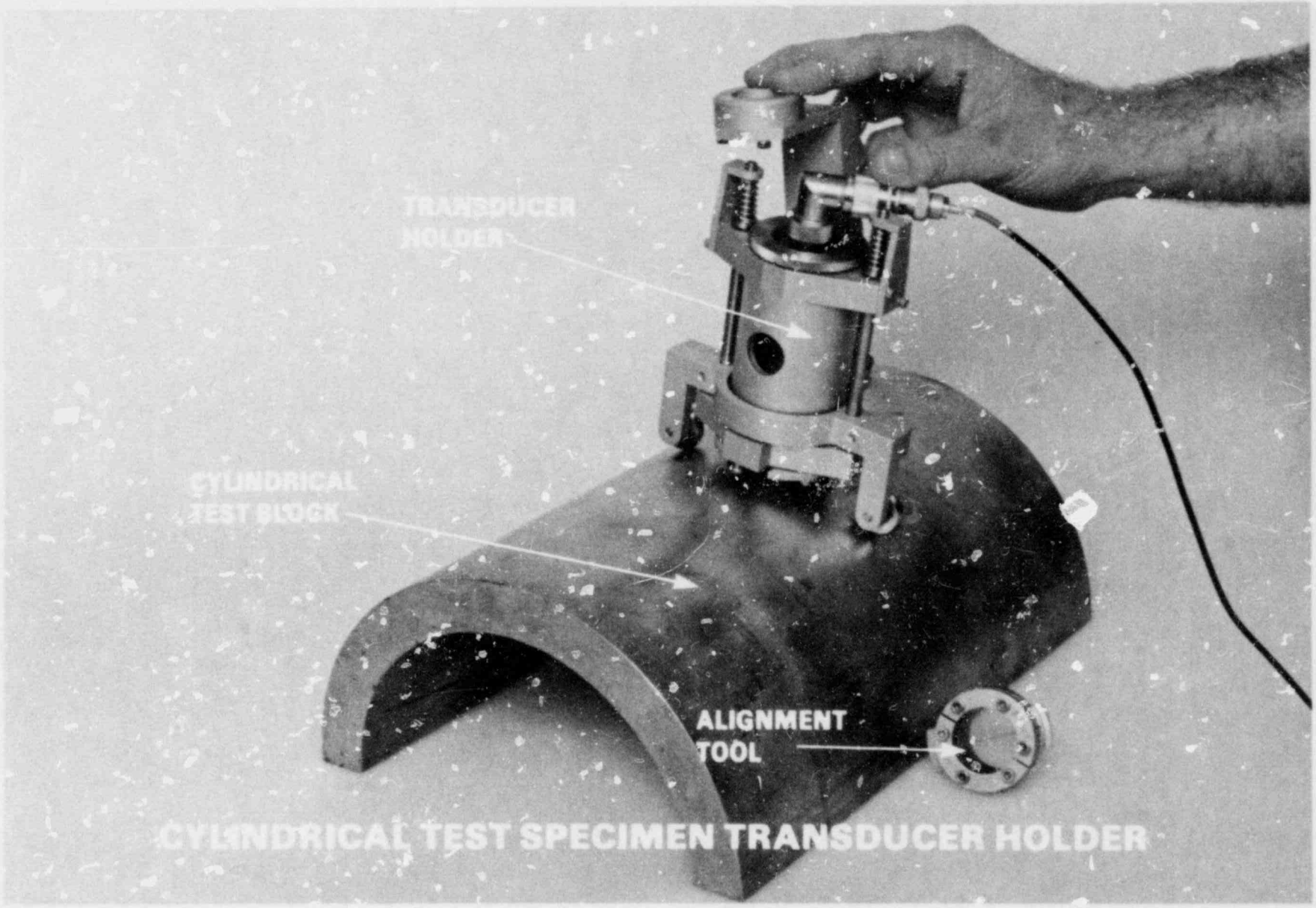
TRANSDUCER
HOLDER
CYLINDRICAL
TEST BLOCK
ALIGNMENT
TOOL
CYLINDRICAL TEST SPECIMEN TRANSDUCER HOLDER

FIGURE 17

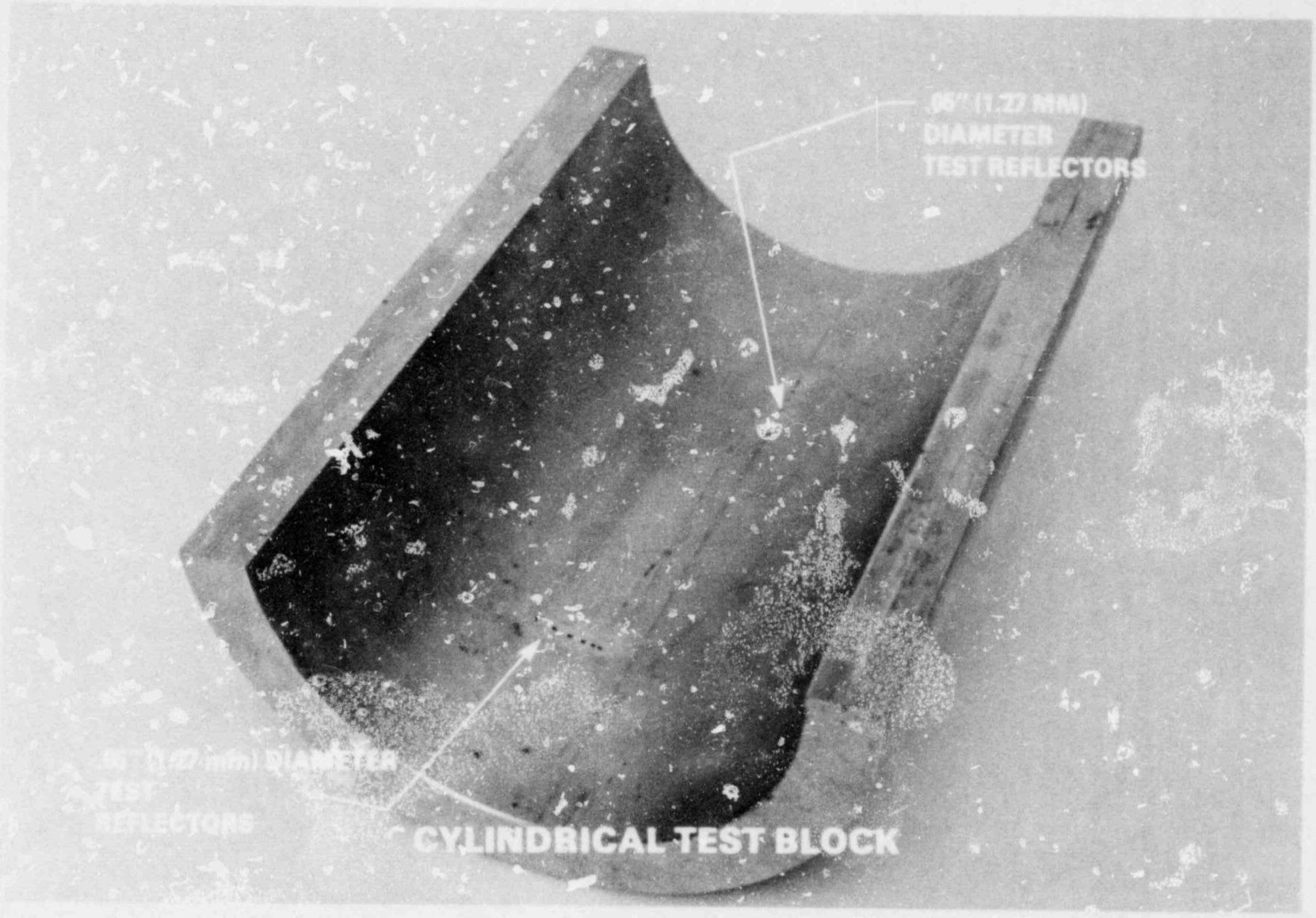

FIGURE 18

5.0 SUMMARY

Signal processing methods have been defined and are being utilized in processing SAFT UT examination data. A butt-welded carbon steel plate specimen consisting of four flaw regions containing realistic type defects has been examined and reconstructed images produced. These images exhibit a good degree of clarity and possess a SNR in excess of 30 dB. A new transducer holder and cylindrical test block has been fabricated and is undergoing testing. Upon completion of these tests, a series of SAFT UT examinations will be conducted on cylindrical test specimens containing a variety of fabricated realistic type flaws.

REFERENCES

1. "Line Synthetic Aperture Focusing Technique," Dr. Volker V. Schmitz, University, B.37, Saarbruecken, West Germany, February, 1981.

2. Ota Kulhanek, Introduction to Digital Filtering in Geophysics, Elsevier Scientific Publishing Company, New York, 1976, p. 86.

3. "Theory of Acoustic Imaging," Norton, Stephen John. A dissertation submitted to the Department of Applied Physics and the Committee on Graduate Studies of Stanford University, December, 1976.

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15. SUPPLEMENTARY NOTES

14. (Leave blank)

16. ABSTRACT (200 words or less)

The purpose of the project is to validate the usefulness of SAFT UT for industrial nondestructive evaluations (NDE). SAFT UT is an ultrasonic imaging method for accurate measurement of the spatial location and extent of acoustically reflective surfaces (flaws) contained in objects such as structural components and weldments in nuclear power reactor systems. The increased measurement accuracy offered by SAFT, when compared with that provided by measurement methods now in use, will improve the reliability of flaw severity assessments with resultant safety and economic benefits to the nuclear power industry.

To accomplish the objective, SwRI is to design and construct an imaging system, suitable for field use, using the SAFT UT and to conduct sufficient tests with the system to fully characterize its performance and usefulness for the intended purpose. The ultimate goal is to produce a field-rated system for highly accurate flaw size measurements and to conduct sufficient testing of that system to promote its acceptance by industrial and regulatory authorities.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

17b. IDENTIFIERS/OPEN-ENDED TERMS

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JUNE 1981