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EVALUATION and OPTIMIZATION of the ADVANCED SIGNAL COUNTING TECHNIQUES on WELDMENTS

MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

GENERAL DYNAMICS
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EVALUATION AND OPTIMIZATION OF THE ADVANCED SIGNAL COUNTING TECHNIQUES ON WELDMENTS

FINAL REPORT

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Prepared Under Contract No.
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FOREWORD

This final report was prepared by Convair Aerospace, Fort Worth Operation, under NASA Contract No. NAS8-27014. Under this contract, a study was made to determine the practicality of the signal-counting and/or amplitude-gate methods of the Delta Scan to detect flaws in aluminum welds. These welds have mis-match from few to over 100 mils. The operational principle of the signal counting technique is also discussed in this report.

Personnel involved in the execution of this program are (a) CA/FWO: Dr. B. G. W. Yee, A. H. Gardner, L. Hillhouse, D. R. Russell; and (b) NASA/MSFC: Mel McIlwain.

ABSTRACT

The signal counting technique with the Delta ultrasonic method is evaluated and optimized for flaw detection in aluminum welds. A comparison is made between the counting and conventional amplitude-gate methods to detect flaws. No conclusion is drawn on the sensitivity of these two methods to detect flaws when the mis-match at the welds is small (25 mils or less). When the mismatch is 25 mils or more, the signal counting method is more sensitive.

Of the twenty-four welded specimens (16 inches in length), twelve ¼-inch and twelve ½-inch thick, fifty flaws were found by x-ray inspection and fifty-nine by the Delta method. A total of forty flaws were found by both methods. The disagreement comes mainly from areas identified by x-ray as incomplete penetration. On the ¼-inch thick welds, x-ray is equal to or slightly more sensitive than Delta Method, but on the ½-inch thick welds Delta ultrasonic appears more sensitive in flaw detection.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. INTRODUCTION

Under the current implementation of the Delta Scan Method, a great deal of the information in the return signal is being ignored. Only the amplitude of the signal falling within the gated zone, which is about 20% of the information available from the received signal, is used as a defect indicator. The remaining information contained in the amplitude of the signal falling outside of the gated zone, the phase and frequency shift, the time-rate-of-delay, the rise time, and other characteristics are not used in flaw detection. All these characteristics can be used individually or collectively to indicate the presence of flaws. However, with the exception of the presently used amplitude-gate method, new electronic instrumentations must be developed to process these characteristics as flaw indicators.

The Delta Scan method has proved to be a fairly useful nondestructive testing method in the detection of randomly oriented flaws. The versatility of this method stems mainly from the use of focused transducers which can fill a localized region under inspection with nearly equal sound energy intensity. Although it is still strongly dependent on flaw orientation, it is not as much as the conventional shear wave method.

II. SIGNAL ANALYSIS OF THE DELTA SCAN METHOD

Although many arrangements of transducers are possible to form a Delta configuration, the present discussion is centered mainly on a two-transducer arrangement, one as transmitter and one as receiver. A typical Delta-Scan configuration is shown in Figure 2-1. The ultrasonic transducer T injects compressional waves through a liquid coupling and into the test components. These waves are incident upon the liquid-solid interface at an angle such that some of the energy is mode converted into shear wave in the solid, some reflected at the interface, some propagated in the proximity of the interface in some forms of surface wave, etc. When some of these sound energies strike the bottom of the solid-liquid (air) interface, they are re-directed according to Snell's law. When sound energy is incident on a discontinuity, it will be reflected, refracted, mode converted, and possibly scattered, depending on the shape and size of the discontinuity. Before any of these re-directed energies can reach the receiving transducer, they must be mode converted at the top solid-liquid interface into compressional waves. Depending on the incident angle and plate thickness, multiple reflection of the shear wave is possible. With the use of focus transducers, many angles of propagation are possible for the shear wave inside the plate. The picture is even more complicated when the dispersion and beam spread of the sound energy are taken into consideration.

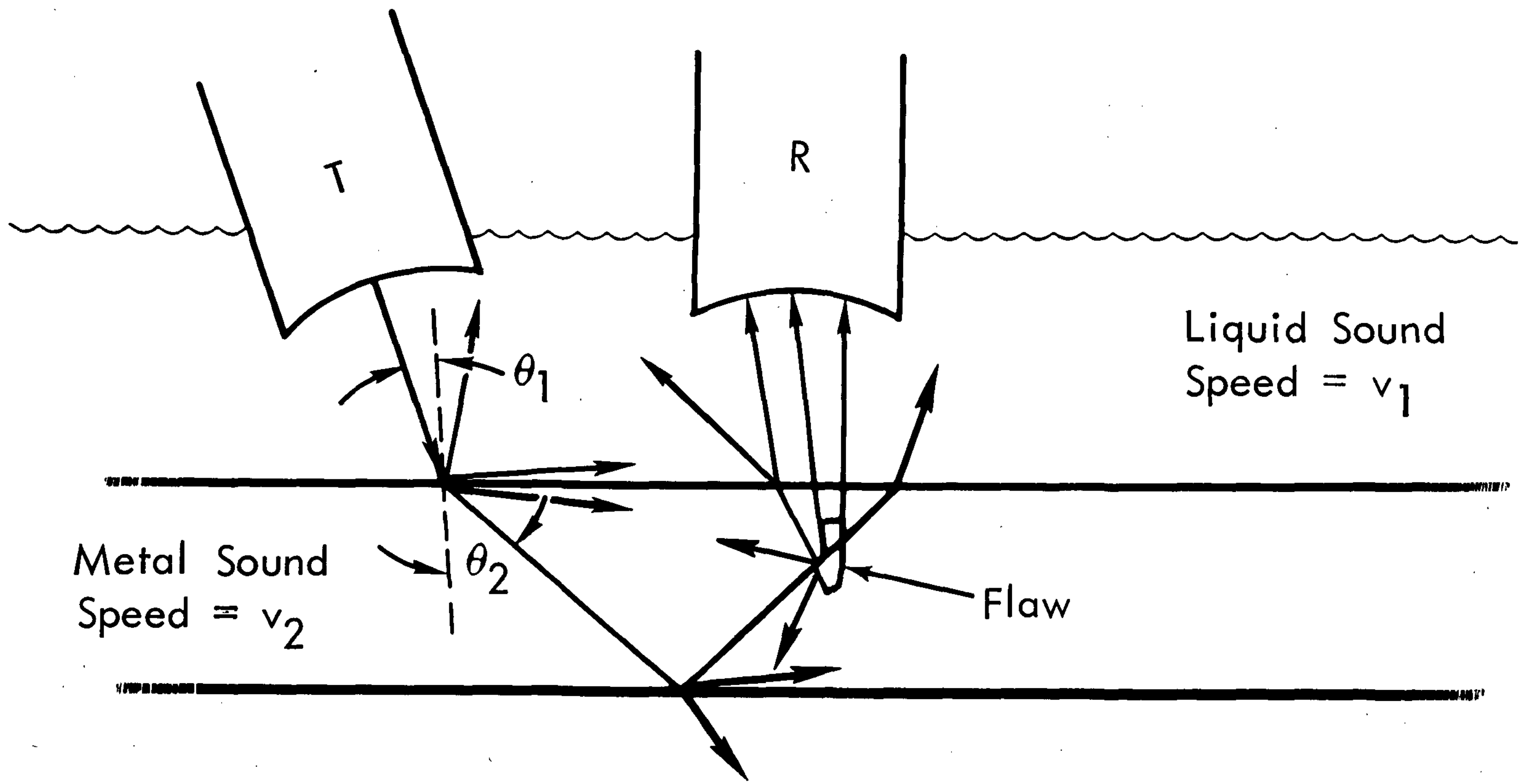

Figure 2-1 Delta-Scan Configuration

For a given Delta arrangement (incident angle, distance between transducers, distance between receiving transducer and flaw, etc.), there are several modes of body and surface waves generated that propagate with different velocities as well as a given mode traversing a different path length. The result is a burst of sound energy which will occur either at a different time zone or at the same time zone. If the latter is the case, they will interfere with each other destructively or constructively. The location with respect to the top or bottom surface and the shape of the flaw or discontinuity also affect the arrival time of these modes of sound energies.

Figure 2-2 shows a raw Delta Scan received signal in the absence of a flaw at 5 MHz with a lead zirconate transmitter and a lithium sulfate receiver. Both transducers are ½-inch in diameter and have a 2.7-inch focal length in water. The background signal is caused primarily by reflection of the sound energy at the two interfaces. The magnitude and location of this background signal is influenced by the various physical parameters of the Delta head, the geometry of the component under evaluation, and the surface conditions of the component. Figure 2-3 is a presentation of both the raw and the rectified and integrated signal with a flaw. There are three salient features of this returned signal that should be noted. First, there were sound energies occurring in several different time zones that were not noticeable

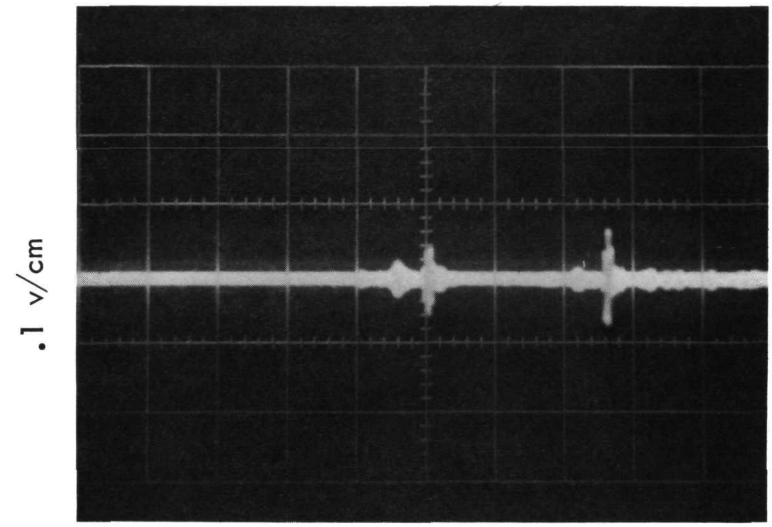

Figure 2-2 Raw Delta-Scan with No Flaw

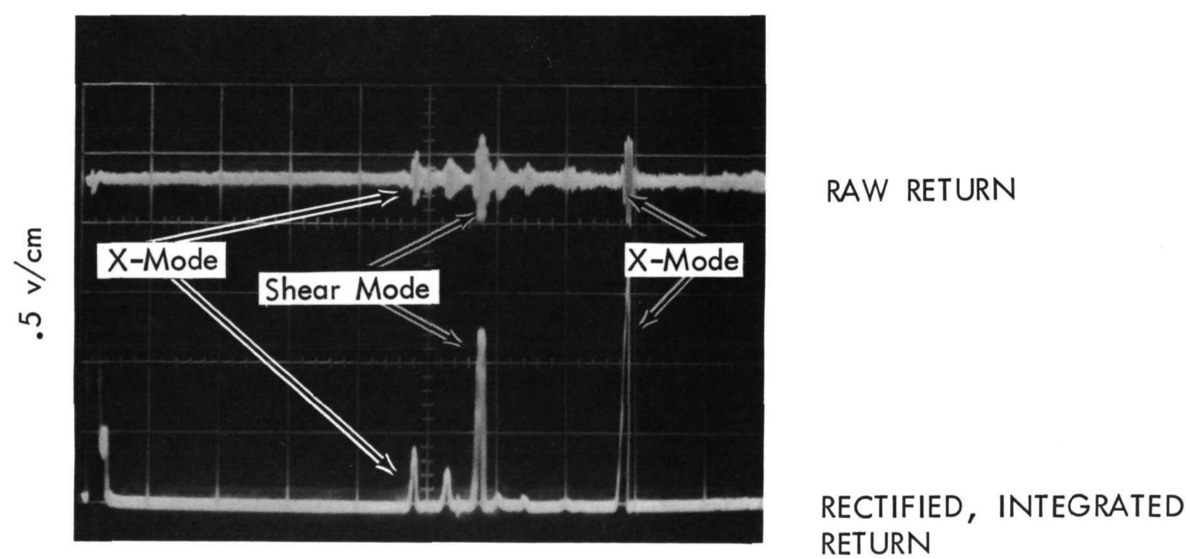

Figure 2-3 Delta-Scan Return with Flawed Specimen

in the background signal, including the shear mode. Second, the amplitude of the background signals becomes larger; in most cases it is caused by the superposition of another signal. Third, the amplitude of the x-mode becomes significantly larger than the background only if the flaw is on the top surface.

Current practice in Delta Scan operation is to use the shear mode peak as a flaw indicator by establishing an electronic gate at the location of the simple shear peak. For most applications, this mode gives the best signal-to-noise ratio for flaw detection. A shear mode peak whose amplitude is above a certain level triggers an audible and visible signal to alert the operator. Signals outside the gate are not used. It is apparent that other characteristics of the signal structure are dependent on the presence or absence of a flaw and are not being utilized. For example, the present Delta arrangement produces three prominent peaks which are shown in Figure 2-3 as Y, shear, and X mode. The exact characters of the X and Y modes are not well understood at this time. However, the X mode behaves very similar to Stoneley waves which propagate at a liquid-solid interface with a velocity less than that of compressional or shear waves in either medium. This mode can be used rather effectively to detect surface flaws.

III. ADVANCED SIGNAL COUNTING TECHNIQUE

At the present time only the amplitude of a portion of the Delta Scan signal is being used as a flaw indicator. In an attempt to utilize more information contained in the total signal in hope of improving the detection capability of the Delta Scan, the advanced signal counting technique was developed. It uses most of the received signal, requires uncomplicated and inexpensive electronic equipment, operates in parallel with the present amplitude-gate method, and offers the advantage of digital output for direct insertion into a digital computer for further data processing.

3.1 Principle of Operation

The signal counting technique operates by counting the number of oscillations in the received raw signal with excursions above and below a settable reference level, over a settable time span, or gating period. In practice, the reference level is set so that the background signal gives only one or two counts per gating period. Figure 3-1 shows three pictures of a raw Delta Scan signal from a crack. The upper right and the lower pictures show the expanded (time) view of the signal at regions marked as 3 and 7. The signal at region 3 is the shear mode and at region 7 is the X mode. The upper left picture shows that there are at least 8 regions where the oscillations probably contribute to the total count.

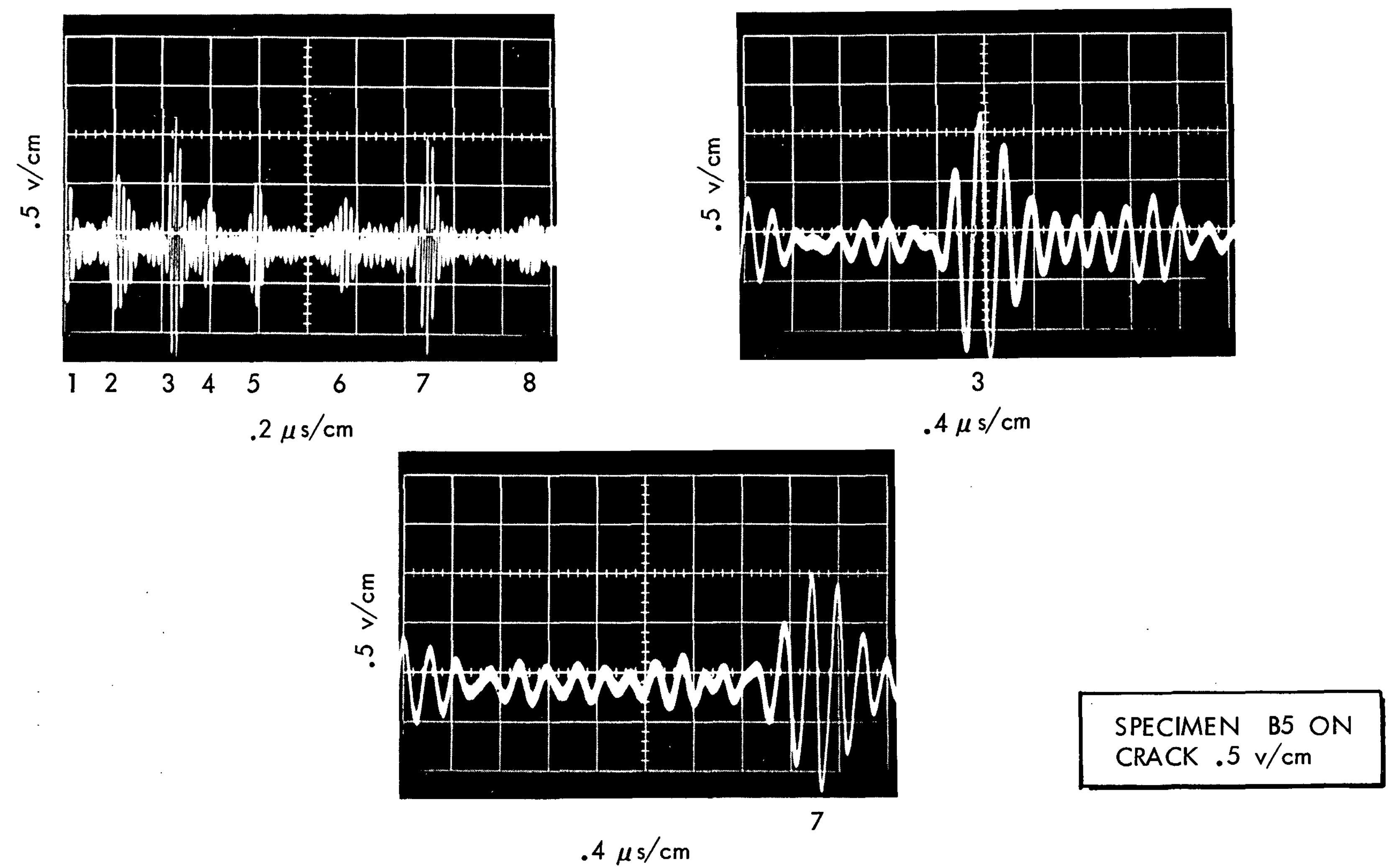

Figure 3-1 Raw Delta Scan Return from Fatigue Crack

There are actually four amplitude sensors; each is set to a different amplitude level (A_3 A_2 A_1 A_0). Those oscillations with amplitude equal to or greater than level A_0 produce one count each; equal to or greater than level A_1 produce two counts each; equal to or greater than level A_2 produce four counts each; and equal to or greater than level A_3 produce eight counts each. That is, those with higher amplitude produce higher count, and thus, contribute more to the total count. More sensors with weighted factors of 16, 32, etc. can be added, but the complexity and cost of such electronics circuits goes up.

The gating period is set by the repetition rate of the transmitted pulses (few hundred to few thousand pulses per second). The present operation uses the nth pulse to open the gate and (n + 1)th pulse to close the gate. With a repetition rate of 1,000 pulses per second, the gating period is one millisecond. The gating period can be lengthened to include many periods of the repetition rate thereby increasing the total count by manyfold. However, the gating period cannot be very long because the combined time of gating period plus the display time by the counter are inversely proportional to the scanning speed of the Delta head. That is, if the combined gate and display time are shorter, the scanning speed can be faster without losing the ability to resolve closely spaced flaws.

At the present stage of development, the counting method has not proved to be more sensitive than the amplitude-gate method, but it can be made more sensitive by adding more amplitude sensors. However, when compared to the flaw-orientational and lateral-displacement dependence, the signal counting is definitely superior to the amplitude-gate method. Figure 3-2 shows the relative amplitude (count) versus angle "θ" (the angle between the direction of maximum amplitude (count) and the direction of sound propagation). The solid curve shows that the amplitude falls from 80% to 20% of maximum at an angle of about 22 degrees, and the count falls from 80% to 20% of maximum at an angle of about 70 degrees. Thus, the Delta Scan with the signal counting technique can detect more flaws with random orientation and permits faster scanning operation of a test component than the conventional amplitude-gate method.

Figure 3-3 shows relative amplitude (counts) as a function of lateral displacement or indexing distance. The solid curve shows that if 0.125" is used as distance of index and a 0.06"L x 0.01"W x 0.03"D elox slot is located midway between scans, the signal amplitude is only about 50% of maximum. However, the count is over 80% of maximum. These two curves show that a larger scanning index can be used with the counting method than the amplitude-gate method to obtain equal sensitivity, or the same scanning index with increased sensitivity.

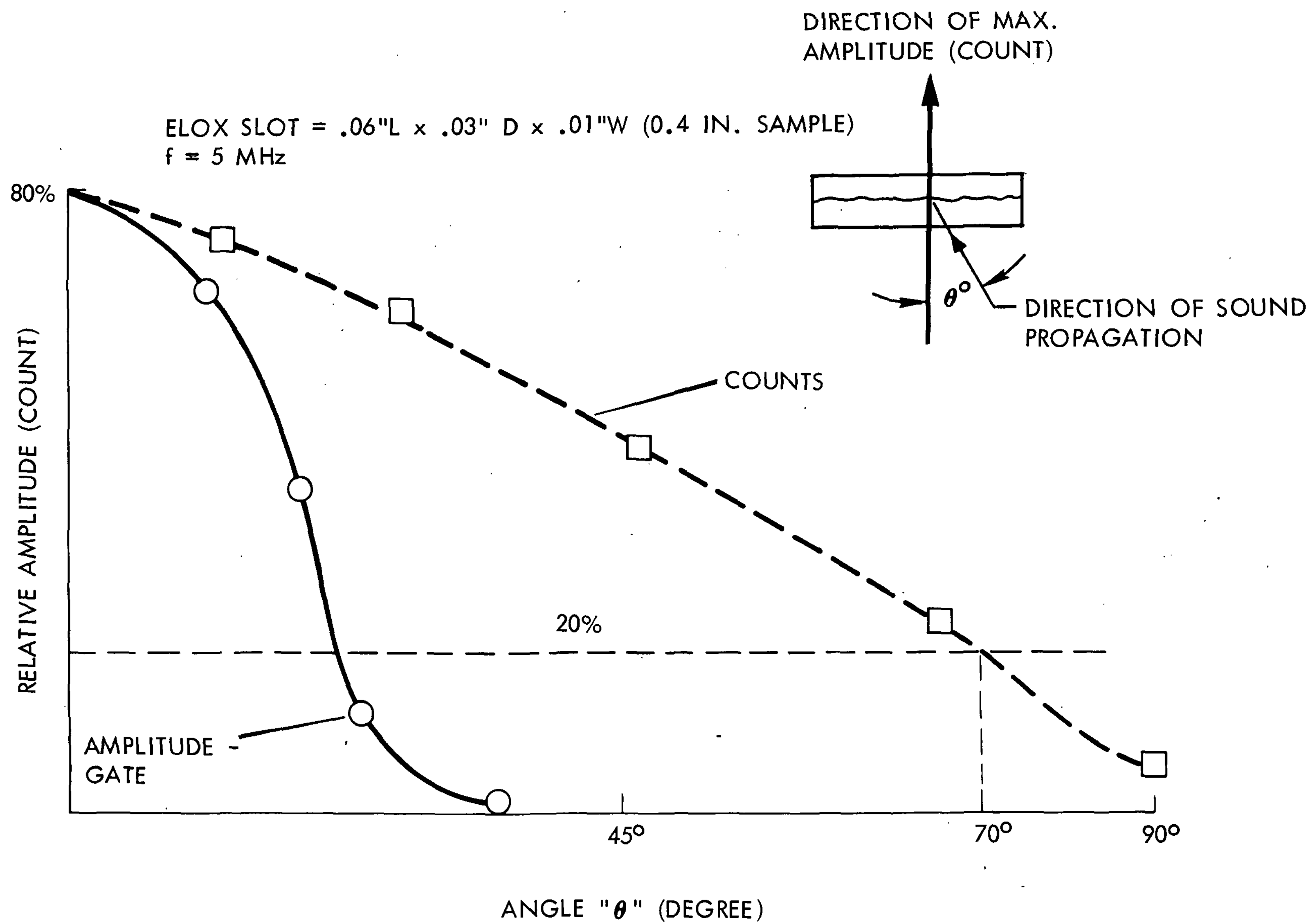

Figure 3-2 Angular Sensitivity of Delta-Scan

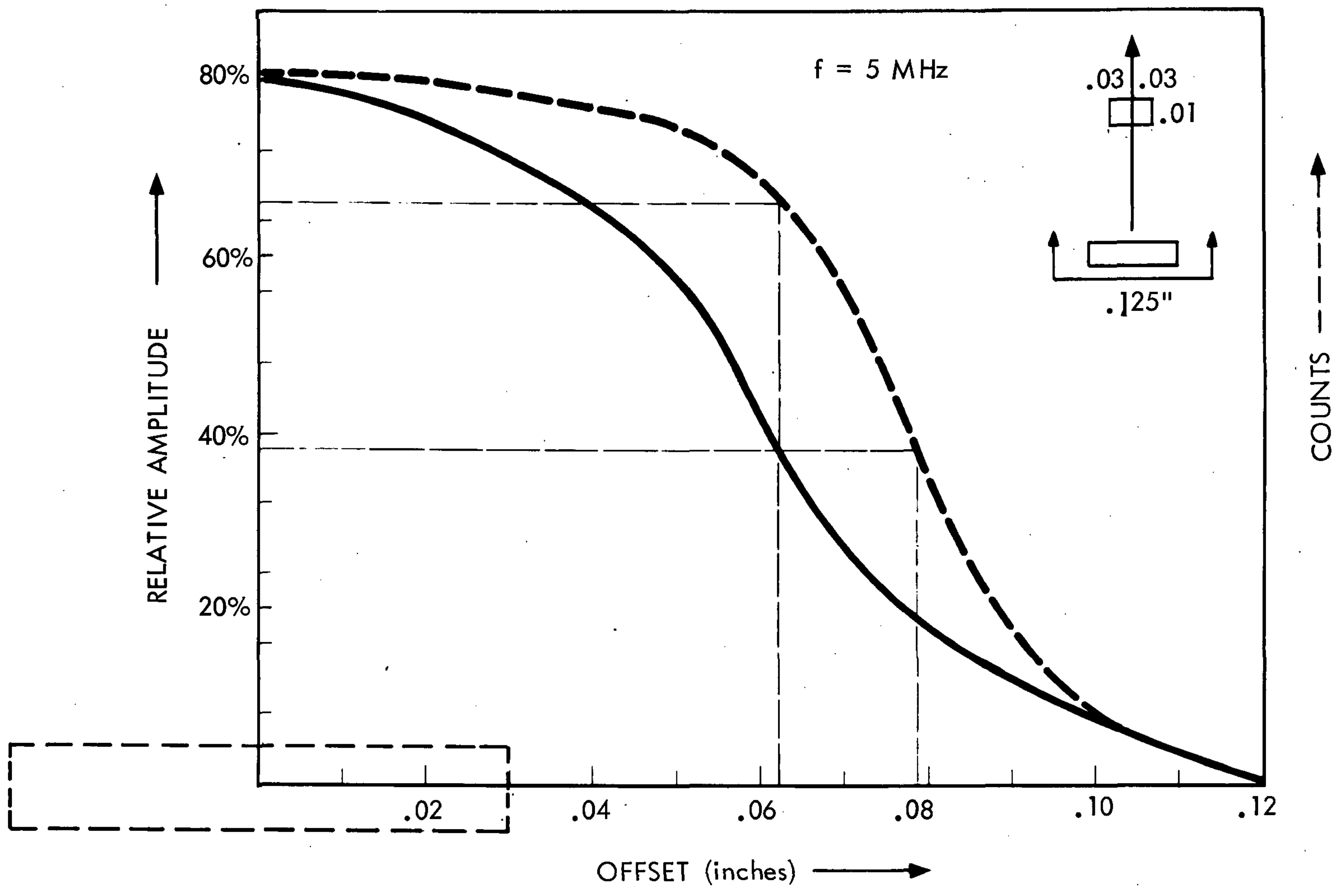

Figure 3-3 Effect of Lateral Displacement on Signal Strength for an Elox Slot of .06"L x .01"W x .03"D

3.2 Experimental Setup

In the actual experiment, a Sperry 721-UM reflectoscope with a 10N pulser-receiver and E550 transigate plug-in was used. The receiver signal was amplified with a Hewlett-Packard 461A wideband amplifier. The output goes to the advanced signal counting circuit which consists of the four-level amplitude sensor and gate. The output from this circuit then goes to a Hewlett-Packard 5216A frequency counter. A block diagram showing the experimental hookup is shown in Figure 3-4. The use of the Sperry 721-UM reflectoscope as pulser-receiver permits parallel data taking with the amplitude-gate method and the signal counting method for direct comparison.

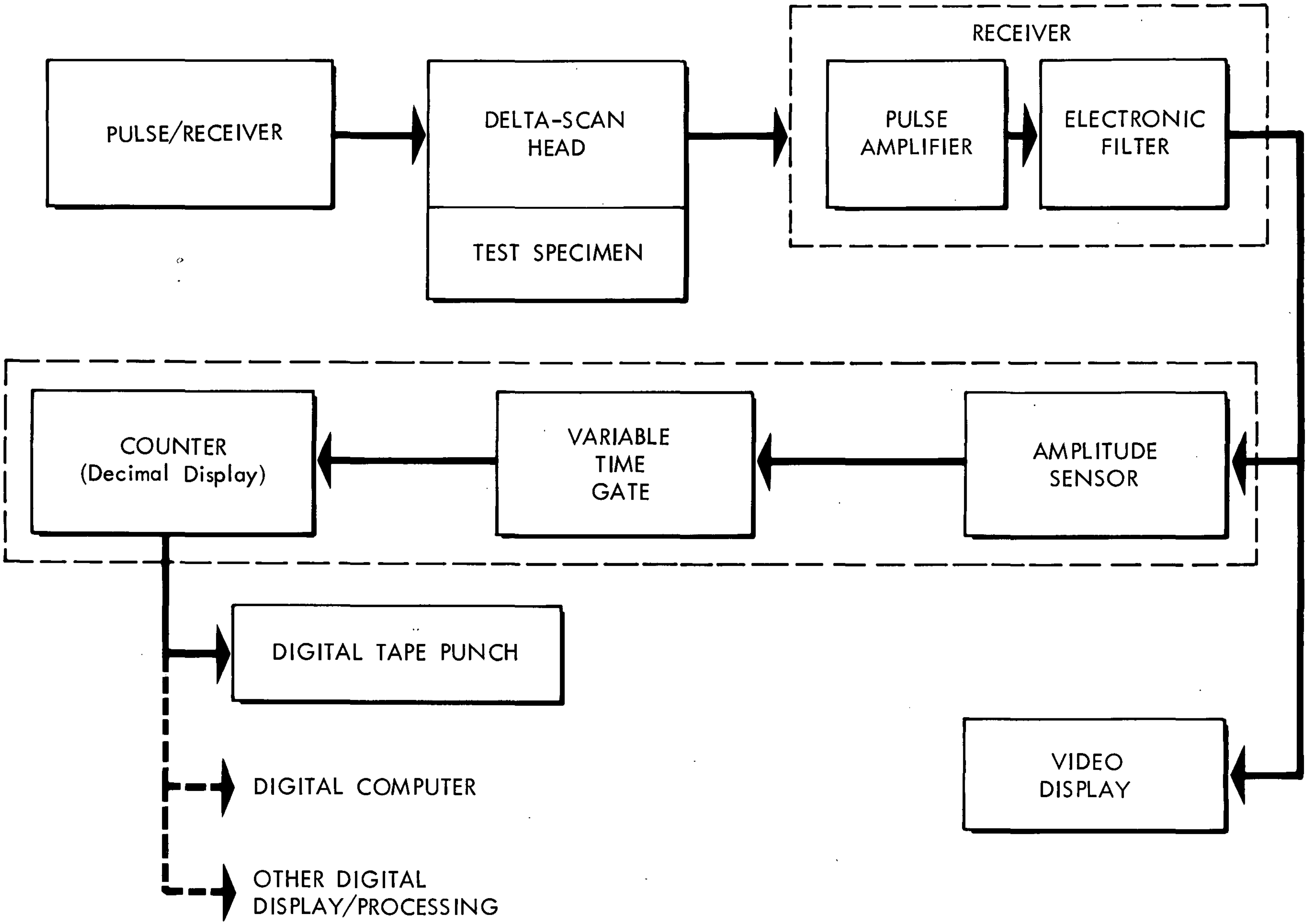

Figure 3-4 Flow Diagram for Signal-Counting Technique

IV. RESULTS AND DISCUSSION ON ALUMINUM WELDS

4.1 Delta Configuration Used on ¼- and ½-Inch Thick Welds

Because the sensitivity of the Delta is dependent on the thickness of the material, it was necessary to arrive at a optimum Delta configuration for the ¼- and ½-inch thick welds. These configurations are also optimized for maximum signal-to-noise ratio and to obtain equal sensitivity for an identical flaw on the top and bottom surfaces.

Figures 4-1 and 4-2 are a plot of amplitude of shear peak and "X" peak, respectively, versus distance between the receiving transducer and the specimen surface for an elox slot of 0.06"L x 0.01"W x 0.03"D in a 0.3" and 0.5" thick plate. Again using 5 MHz focus transducers, the transmitter is lead zirconate and the receiver is lithium sulfate. In the 0.5" plate, the various modes of sound energies interfered constructively and destructively to produce large amplitude variations for the shear and "X" mode for the first 60 mils. Thereafter, the two signals no longer coincide and the shear signal remains relatively constant out to 0.5 inch. For the 0.3-inch plate, the amplitude of the shear signal decreases monolonically from zero to about 0.25 inch and remains relatively constant from 0.25-0.5 inch. The amplitude of "X" mode signal for both the 0.3 and 0.5-inch thick plate decreases from about 2.3 inches (80%) of screen indication to about

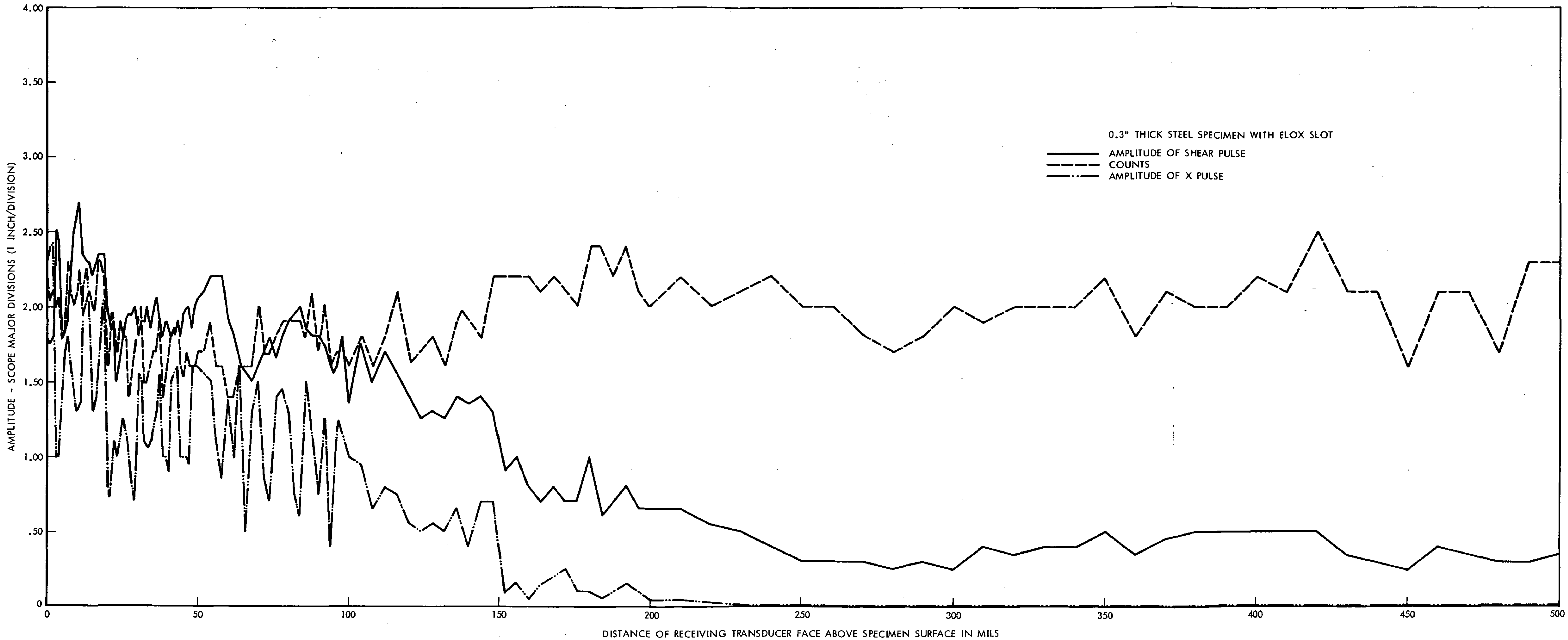

Figure 4-1 Relative Amplitude (Count) Versus Distance between Receiving Transducer and Material Surface (.3" Plate)

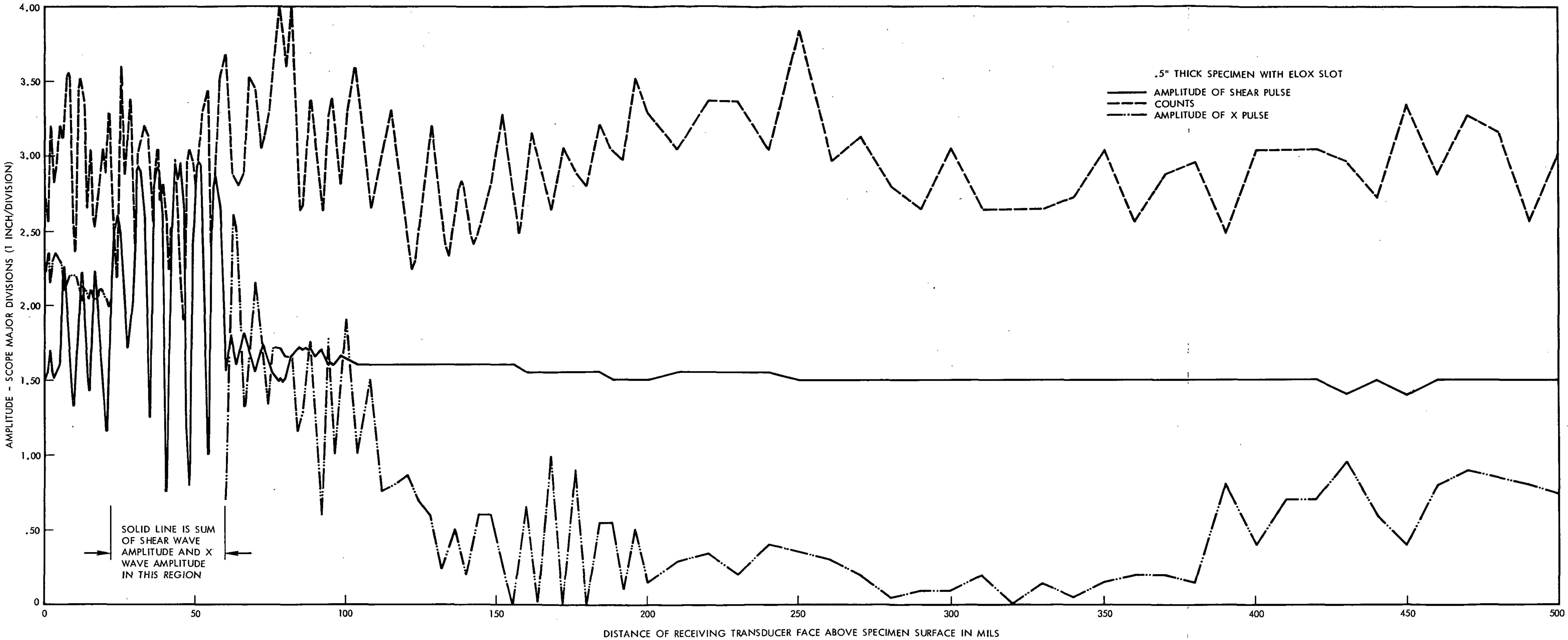

Figure 4-2 Relative Amplitude (Count) Versus Distance between Receiving Transducer and Material Surface (.5" Plate)

zero when the distance of separation goes from zero to about 0.15 inch. There is a small amplitude fluctuation from 0.15 to 0.5 inch of separation. The "X" mode definitely falls off faster for both thicknesses.

From practical considerations a frequency of 5 MHz was selected, and to produce equal sensitivity, ½-inch diameter focus transducers with a focal length of 2.7 inches in water were selected. To obtain the optimum configuration, the physical parameters such as the distance of separation between the transducers, the angle of incidence, etc. are obtained from Snell's law and empirical determinations. However, because of the irregularities and non-uniformities in the commercially-available transducers and the complexity of the problem, the optimum configurations, are generally obtained empirically. The parameters that produced optimum response for the ¼- and ½-inch thick aluminum welds are:

Angle of Incidence	28 degrees (¼ inch)	25 degrees (½inch)
Transducer Separation (center-center)	1.10 inches	1.47 inches
Separation between Receiving Transducer and Metal Surface	0.38 inch	0.38 inch

Using these parameters, the amplitude and count were almost identical when an elox slot 0.06-inch long x 0.03-inch deep x 0.01-inch wide was located on the top or bottom surface. These parameters also produce the maximum signal-to-noise ratio.

4.2 Experimental Procedures

A scanning mechanism was designed to clamp on the ends of the sixteen-inch specimens with a long free-turning bolt running the length of the specimen. The Delta head or sensors were fixed in proper position in a plexiglas block, and this block was attached to the long bolt. A picture showing this arrangement is shown in Figure 4-3. With the block attached to the bolt, the transmitting transducer was away from the receiving transducer in a direction 90 degrees from the length of the weld. The bolt had twenty threads per inch; therefore, when the bolt was turned twenty complete revolutions, the sensors would have travelled one inch along the length of the panel. Due to the slowness of this procedure and the time limit on the test, it was decided to move the sensors in increments of one-tenth inch. It was possible to miss a small flaw between these steps, but time was limited, and even one hundred and sixty increments per specimen were very time consuming. To reduce the possibility of missing a flaw, each specimen was scanned with the head held in the hand. The head was first slowly moved along the weld with the transmitting transducer 90 degrees from the direction of scan. It was then slowly moved along this weld with the head oriented 90 degrees to the previous scan. The counts, amplitude, and alarm were observed during these scans and the approximate location of each signal was noted.

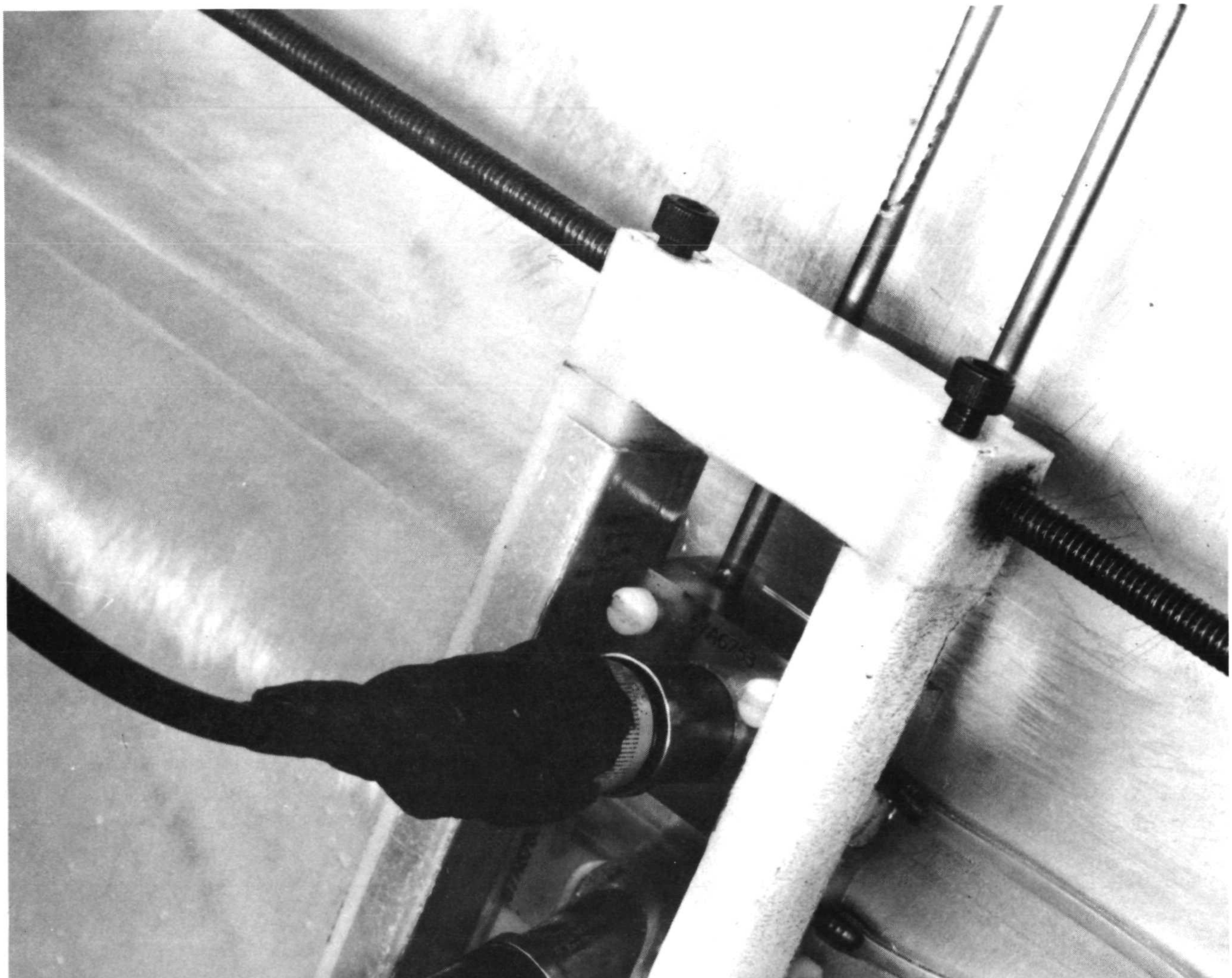

Figure 4-3 Arrangement of the Delta Head

The plexiglas block holding the sensors had a short bolt attached in such a manner as to make it possible to move the block over the specimen in a direction perpendicular to the weld. Thus, the sensors could be moved across the width of the weld. As the sensors moved over the weld, the maximum amplitude and the maximum number of counts received were monitored continuously. If either of these reached a predetermined minimum value, the maximum value within each tenth of an inch was recorded. Although the original intent was to make a one-inch scan across the weld at each of the one hundred and sixty increments, this proved to be too time-consuming and was eventually shortened to six-tenths of an inch. This shortening of the scan cut down the number of data points from 1760 to 1120 per specimen, a substantial saving in time.

The Reflectoscope is adjusted for MHz, minimum pulse width and THRU mode. The receiver gain switch is set for X1. The Delta Scan head is positioned over the specimen elox slot for maximum amplitude of the shear mode signal. The sweep speed and delay are adjusted for complete display of the received signal envelope. The gate is positioned to coincide with the shear mode echo from the elox slot and its width is adjusted slightly wider than this signal. The receiver variable gain control is set to give 2.4 inches of amplitude for the gated signal on the scope screen. This is approximately 80% of maximum deflection. The transigate alarm level is adjusted to give an alarm when the signal in the gate is above 0.6 inches amplitude. This is approximately 25% of the elox slot signal.

The signal counting circuit requires only the adjustment of its amplifier gain. This is accomplished by placing the Delta Scan head on a surface of a specimen that is known to be free of defects. The gain control is then adjusted to give a count of 1 on the Hewlett/Packard 5216A counter. After this adjustment, the scanning head is placed over the elox slot in the specimen and positioned to obtain a maximum count. Twenty-five percent of this maximum count is considered a threshold below which counts are considered noise and are ignored.

Before each specimen was scanned, the setup was checked using an elox slot measuring 0.060 x 0.010 x 0.030 inch deep. Looking at this slot, the sensors saw a hole equivalent in area to a three/sixty-four inch flat-bottomed hole. The maximum amplitude and number of counts were recorded. Then, as the specimen was scanned, if either the amplitude or the counts reached as much as twenty-five percent of the readings from the elox slot, both were recorded.

The equipment was calibrated using an elox slot 0.06-inch long x 0.01-inch wide x 0.03-inch deep as a reference standard. In the case of the amplitude-gate method, the reject and gain levels were set so that there would not be any background signal visible within the gate when the transducer was not on the slot. The levels are set so the amplitude of the shear wave peak would be 80% of screen saturation (maximum obtainable with the reference slot) when the receiving transducer is over the reference slot. Because the Delta head does not always produce identical amplitudes for an identical reference slot when it is located on the top and bottom surfaces, the gain level is set to produce 80% screen saturation with the less sensitive side. If the less sensitive side happens to be when the slot is on the bottom surface, then the amplitude will be greater than 80% screen saturation when the slot is on the top surface.

In the case of pulse-echo using compressional waves, the electronic gate is placed between the echoes reflected by the top and bottom surfaces. The situation is considerably more complicated for the Delta since there are no two echoes representing the top and bottom surfaces. Since the shear wave mode generally gives the best signal-to-noise ratio, the gate is set to encompass the shear wave signal for the reference slot located on the top and bottom surfaces. Generally, an oscilloscope and a simple calculation involving the velocity of the shear wave, angle of propagation, and material thickness, are needed to locate the shear wave signal.

In the case of the signal counting method, the amplifier gain and amplitude sensors were set to produce one to two counts with the background signal and the maximum obtainable count with the reference slot. The counting period is the period of the repetition rate of the transmitted pulse.

4.3 Ultrasonic Test Results

4.3.1 Effects of Mismatch

There are a total of eight 48 x 14 x ¼-inch and eight 48 x 14 x ½-inch welds. For ease of handling, the 48-inch length was cut into three 16-inch length specimens to give a total of twenty-four ¼-inch thick welds and twenty-four ½-inch thick welds which will be called Groups I and II, respectively. Half of the specimens in each group have mismatch at the weld varying from zero to over 100 mils, with no intentionally induced flaws and the other half contains different types and sizes of flaws with mismatch varying from zero to less than 20 mils. In addition to the mismatch and flaws, almost all of the ¼-inch welds are worked from welding, which resulted in varying degrees of radius of curvature.

Following the procedures described in the previous section, all forty-eight specimens were scanned and the indications recorded in their proper locations. Figure 4-4 is a plot of both the amplitude ratio and count ratio (ratio of flaw to the reference standard) for one of the ¼-inch specimens, 2A-1 (the first 16 inches of the weld). The amount of mismatch, taken at 2-inch intervals, is written on the top of the plot. Data were taken at every 0.10-inch along the weld; those areas showing neither amplitude nor count imply that both were less than 25% that of the reference standard.

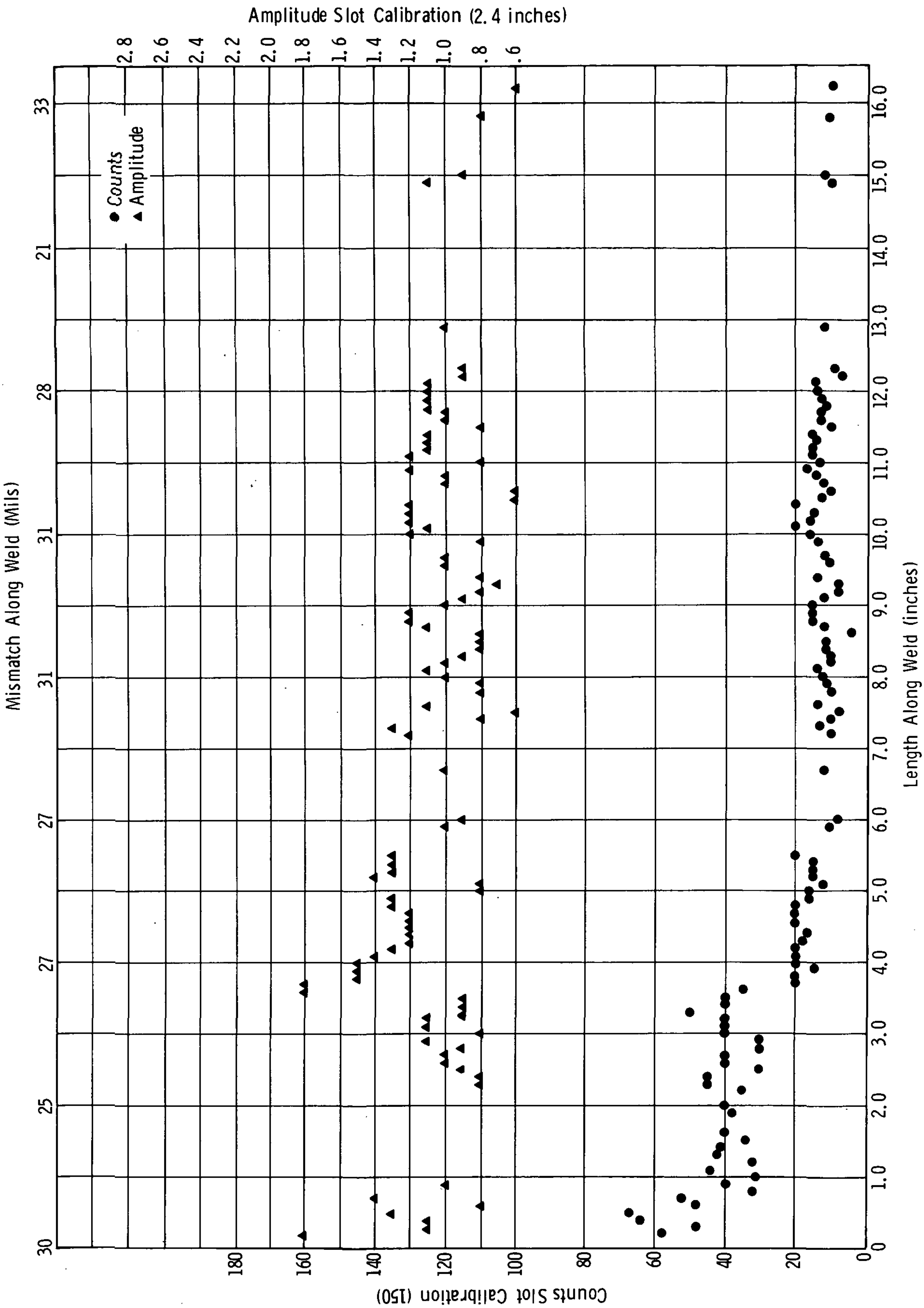

Figure 4-4 Amplitude and Counts vs Specimen Length for Specimen 2A-1

From this and results of other specimens with different amounts of mismatch, the following conclusions are drawn.

1. If the mismatch is 25 mils or less, (a) the amplitude in the gate is less than 25% that of the reference standard and (b) the count is also less than 25% that of the reference standard.
2. If the mismatch is more than 25 mils, the amplitude ratio is larger than the count ratio.
3. If the mismatch is around 50 mils or more, (a) the amplitude in the gate completely saturated the CRT screen so additional amplitude caused by a flaw can not be shown, but (b) the total count is higher than the count caused by the mismatch when a flaw is present at the mismatch. That is, the counting method has a higher dynamic response than the amplitude method.

Item (3) can best be illustrated by the results from Specimen 2D-1 (½-inch weld) as shown in Figure 4-5. The mismatch varied from about 30-105 mils and the amplitude in the gate completely saturated the screen starting at about 50 mils. No difference in the amplitude can be discerned in the regions of 50-105 mils of mismatch. However, the count easily reveals the difference between 50-105 mils of mismatch.

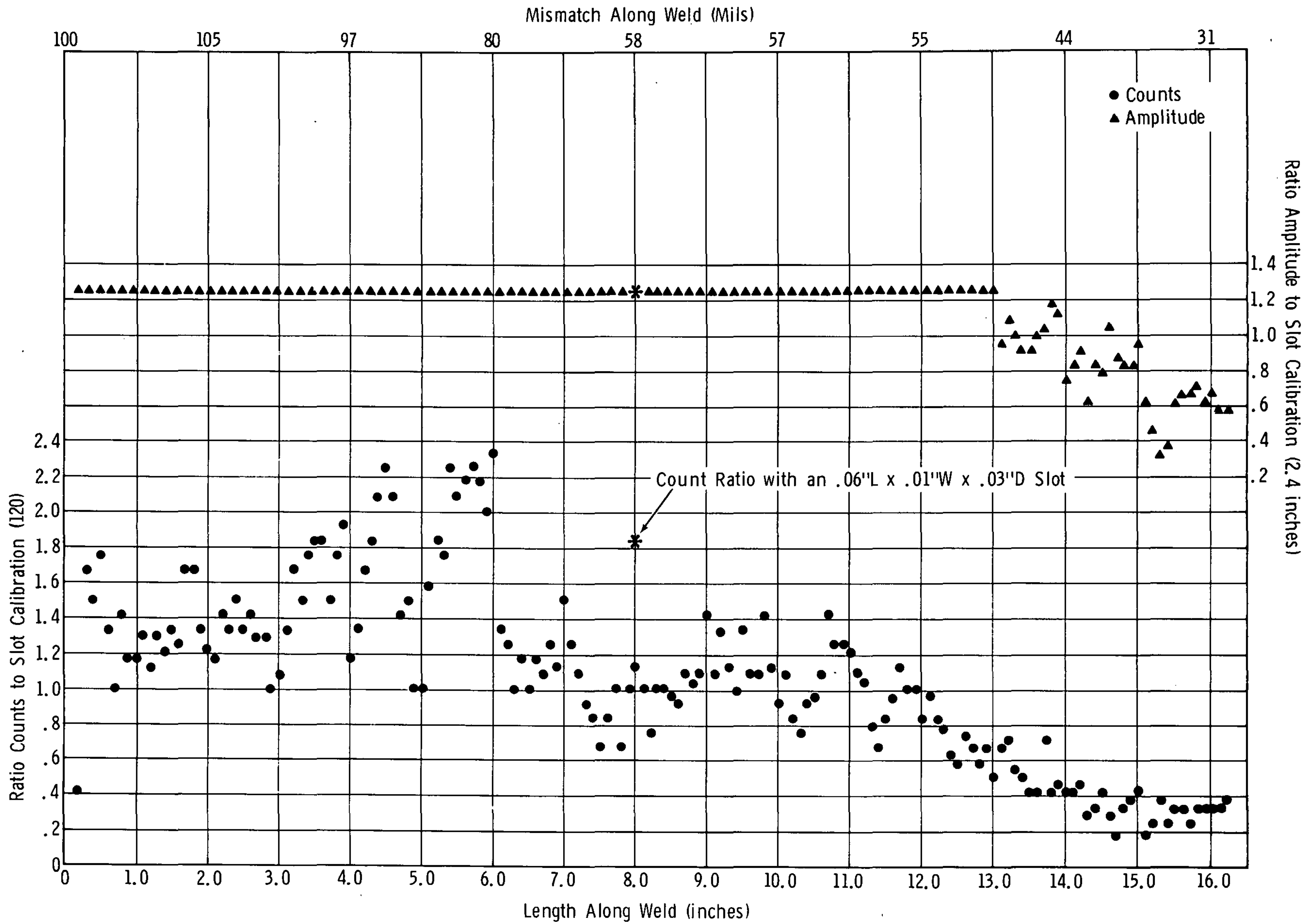

Figure 4-5 Amplitude and Count Ratio vs Specimen Length for Specimen 2D-1

An elox slot was placed on the mismatch at approximately 8 inches from the end on Specimen 2D-1. The amplitude was saturated before the slot was introduced, so no change in amplitude can be seen. However, the count ratio went from about 1.1 to 1.8, which is a noticeable change. This change in count ratio can be repeated even if the slot is placed about 1/8-inch away from the mismatch.

4.3.2 Results on Flawed Specimens

There were a total of twenty-four specimens with various types and sizes of induced flaws that have been inspected: twelve were ¼-inch thick and twelve were ½-inch thick. All these specimens are sixteen inches in length. The results for the ¼-inch welds and for the ½-inch welds are summarized in Tables 4-1 and 4-2, respectively. The amplitude ratio (AR) and count ratio (CR) of an identified flaw are recorded in the corresponding location. Both the AR and CR are the maximum found in the transverse direction of the weld and along the length of the weld. These data could also have been recorded in the C-scan recorder for presentation; however, C-scan presentation does not show the small (or tight) flaws and the curvature in the specimens make it difficult to scan them without building a rather sophisticated scanning mechanism.

TABLE 4-1
Delta Scan Ultrasonic Results for 1/4 Inch Thick Welds

Specimen No.	Length of Weld in Inches																
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
3A-1 AR*					1.16	0.35		0.66									
3A-1 CR**					0.70	0.07		0.41									
3A-2 AR														0.77			
3A-2 CR														1.0			
3A-3 AR				0.46								0.54	0.31				
3A-3 CR				0.20								0.20	0.25				
3B-1 AR		0.38					0.38										
3B-1 CR		0.32					0.20										
3B-2 AR																	
3B-2 CR																	
3B-3 AR				0.58 0.81		0.31											
3B-3 CR				0.43 0.96		0.13											
3C-1 AR			0.25			0.375								0.33			
3C-1 CR			0.27			0.21								0.18			
3C-2 AR		0.42															
3C-2 CR		0.68															
3C-3 AR				0.27					0.29					0.27			
3C-3 CR				0.07					0.14					0.15			
3D-1 AR												0.27					
3D-1 CR												0.21					
3D-2 AR													0.25	0.58 0.78		0.83	
3D-2 CR													0.22	0.57 0.92		1.14	
3D-3 AR				0.27													
3D-3 CR				0.17													

*AR = Amplitude Ratio
**CR = Count Ratio

TABLE 4-2

Delta Scan Ultrasonic Results for 1/2 Inch Thick Welds

Specimen No.	Length of Weld in Inches																
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
3E-1 AR*								1.18					0.27	0.73			
3E-1 CR**								1.64					0.59	1.27			
3E-2 AR			0.36	0.68		0.36				1.36						0.86	
3E-2 CR			0.64	1.23		0.55				1.45						1.32	
3E-3 AR			0.27		0.91						0.36						
3E-3 CR			0.23		1.41						0.86						
3F-1 AR		1.36															
3F-1 CR		0.82															
3F-2 AR										0.27					1.36		
3F-2 CR										0.66					0.39		
3F-3 AR				1.27					0.27			0.27			0.27		0.41
3F-3 CR				0.79					0.33			0.08			0.25		0.42
3G-1 AR							0.50		1.36								
3G-1 CR							0.20		1.70								
3G-2 AR					1.27	0.45	0.45		0.64					0.32			
3G-2 CR					1.28	0.35	0.42		1.25					0.30			
3G-3 AR												1.36	0.59			1.36	
3G-3 CR												0.72	0.50			1.0	
3H-1 AR											0.32						
3H-1 CR											0.83						
3H-2 AR	0.64										1.27					0.91	
3H-2 CR	0.90										1.33					1.42	
3H-3 AR				0.68					0.73						0.27		0.32
3H-3 CR				0.96					0.71						0.13		0.33

*AR = Amplitude Ratio

**CR = Count Ratio

All of the flaws were found when scanning in the transverse direction to the welds. However, after a flaw has been found, a hand-held Delta unit was used to scan along the weld. No flaws were found when scanning in this direction that have not been found already. Those that could be found from both directions of scan were classified as voids or inclusions. Those that would produce an indication in only one direction of scan were classified as cracks. Unlike x-ray, ultrasonic methods cannot differentiate cracks, lack of fusion, and imperfect penetration.

4.3.3 Comparison of Ultrasonic and X-ray Results

Tables 4-3 and 4-4 are the x-ray results of the ¼-inch and ½-inch thick welds, respectively. The estimated flaw types are written along with the estimated sizes in these tables. Of the twenty-four specimens, twelve ¼-inch and twelve ½-inch thick, a total of fifty-nine flaws or areas with flaws were found by the Delta Scan and fifty by x-ray. As shown in Table 4-5, forty flawed areas were found by both ultrasonics and x-ray, so these are confirmed. All of the flawed areas called out by x-ray as inclusion (I), improper fusion (IF), porosity with sharp termination (PC), undercut (U), and cracks (C) were found by ultrasonics. The disagreement comes mainly from areas called out by x-ray as incompleted penetration (IP). Of the twenty-four areas identified as IP, only twelve were confirmed by ultrasonics. The remaining twelve areas must be confirmed by either metallurgical analysis or mechanical testing.

TABLE 4-3
X-Ray Results for 1/4 Inch Welds

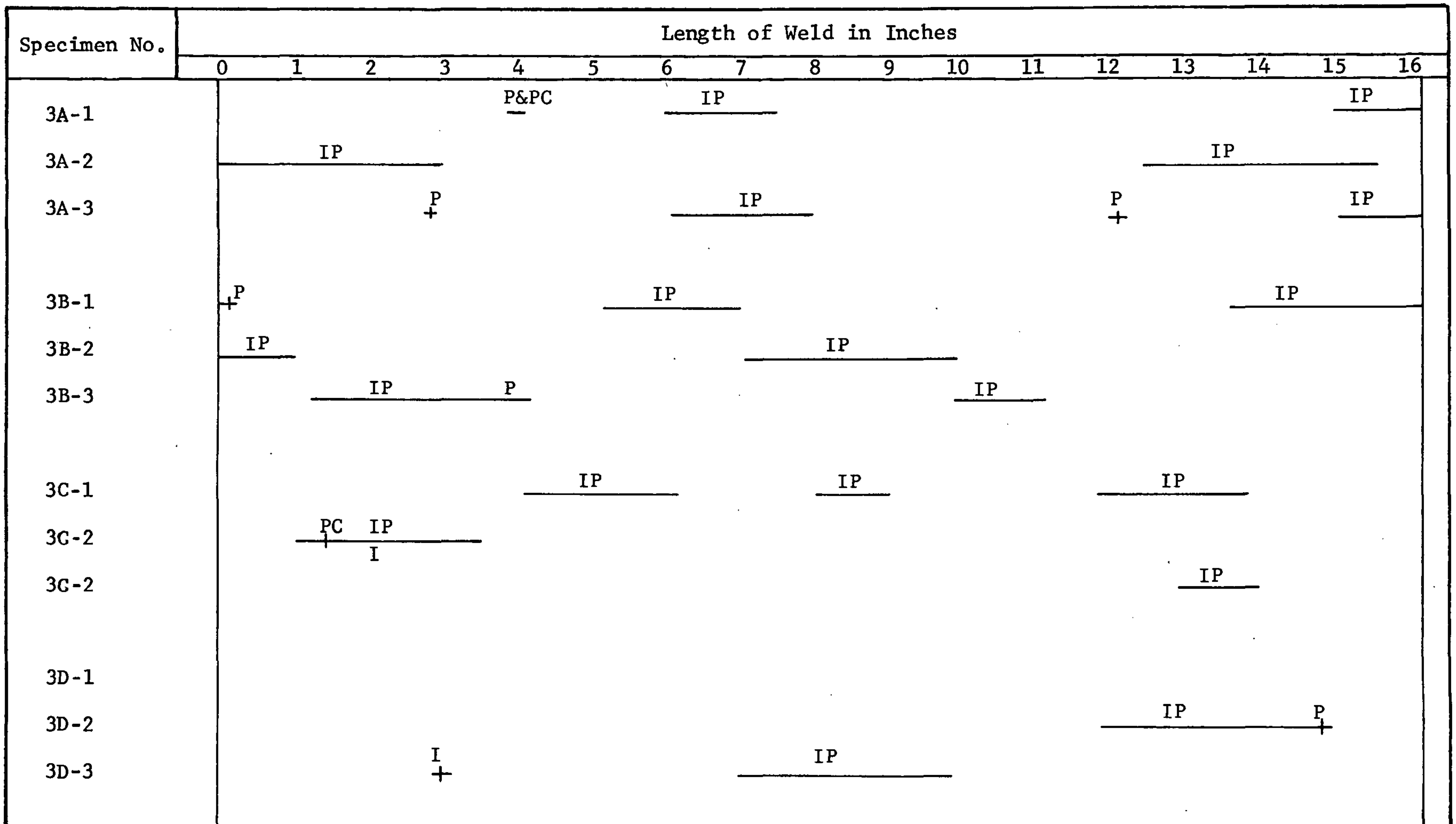

TABLE 4-4
X-Ray Results for 1/2 Inch Welds

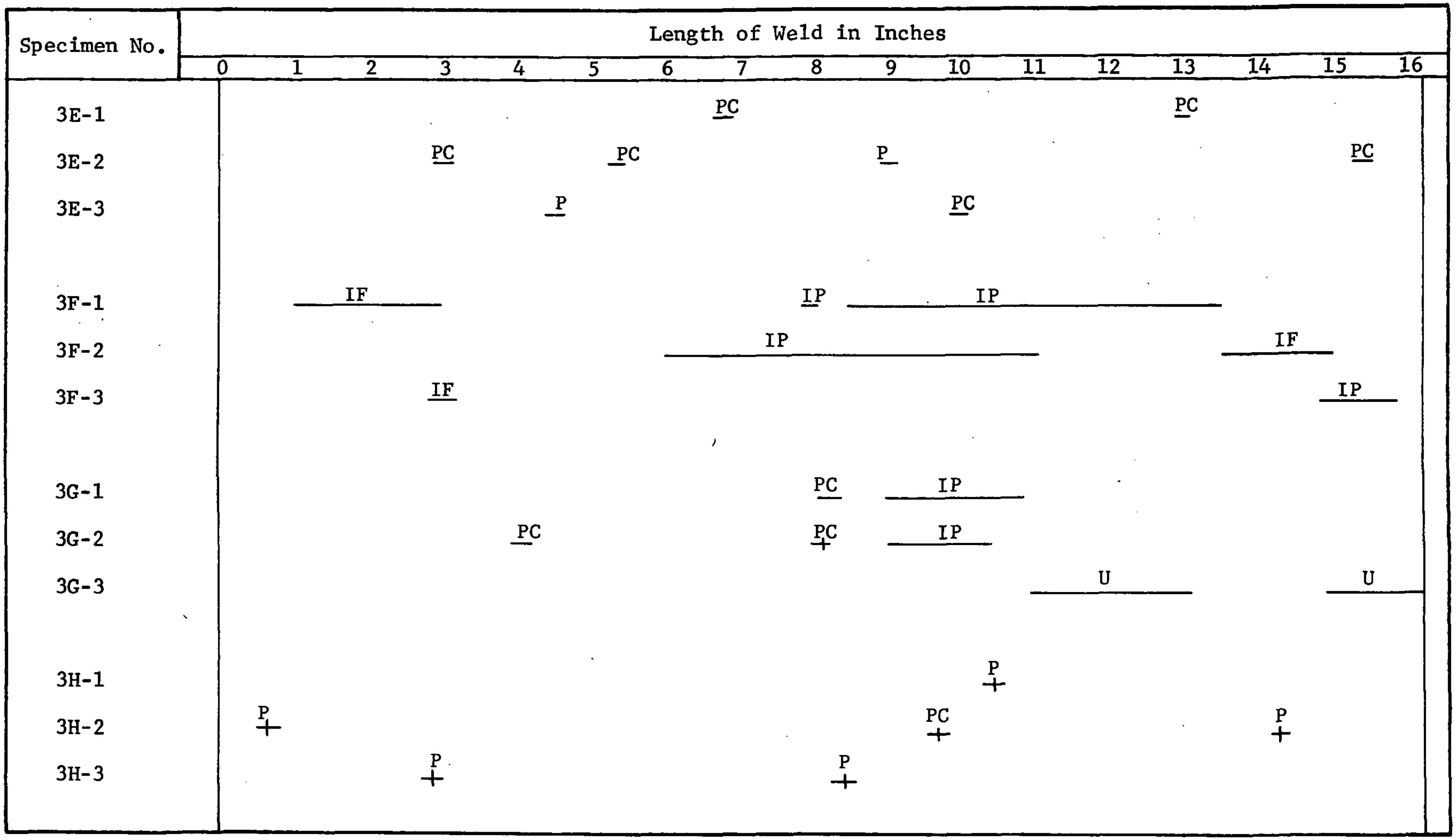

Table 4-5

COMPARISON OF ULTRASONICS TO X-RAY RESULTS

Specimens	Flaws Found By UT	Flaws Found By X-Ray	Agreement
3A	7	8	5
3B	5	7	4
3C	7	5	4
3D	3	3	2
3E	11	8	8
3F	8	6	5
3G	10	7	6
3H	8	6	6
Totals	59	50	40

On the ¼-inch specimens, only one flaw found by ultrasonics which produced an indication equal to 54% that of the reference was missed by x-ray. On the ½-inch specimens, five flaws that were found by ultrasonics which produced indications equal to 45%, 45%, 50%, 59%, and 64% that of the reference were missed by x-ray. All the other flaws missed by x-ray are equivalent to 27%-33% that of the ultrasonic reference standard. As indicated earlier, all ultrasonic indications below 25% that of the reference standard are not recorded.

SECTION V

CONCLUSIONS

The signal counting technique with the Delta ultrasonic method can definitely be used to detect flaws in welds. Based on the results of this work, it does not show a clear-cut advantage over the conventional amplitude-gate technique of the Delta method when the mismatch at the welds is small (less than 25 mils). When the mismatch is more than 25 mils, the count approach is definitely more sensitive. This is particularly true when the mismatch is 50 mils or more as demonstrated by placing an elox slot of 0.06" x 0.01" x 0.03" deep on an area with a mixmatch of 58 mils. The amplitude in the gate saturated the screen before the placing of the elox slot, so no difference in the amplitude can be observed. The count went from 1.1 to 1.8 that of the reference slot count. In short, the signal counting technique offers a larger dynamic range of response and is much less sensitive to flaw orientation than the amplitude-gate technique of the Delta ultrasonic method.

The results of the x-ray indicate that for the ¼-inch thick welds, it is at least as sensitive, if not slightly more so than the Delta ultrasonic method (employing either the amplitude-gate or counting technique) in flaw detection. However, for the ½-inch thick welds, the Delta ultrasonic is apparently more sensitive. For both thicknesses, Delta ultrasonic method appears to hold the edge in flaw detection capability over x-ray when the mismatch at the weld is 25 mils or less. The two methods appear to be equal when the mismatch is between 25-40 mils. When the mismatch is greater than 40 mils, x-ray probably has a higher flaw detection capability than the ultrasonic.

Of the 24 specimens (16 inches in length), twelve ¼-inch and twelve ½-inch, ultrasonic found 59 and x-ray found 50 flaws or flawed areas. Forty were found by both methods. The disagreement comes mainly from areas identified by x-ray as incomplete penetration. A positive identification of the number of flaws and flaw type will come from metallurgical examination, and that will be performed by Mel McIlwain at MSFC.

VI. RECOMMENDATIONS

The signal counting technique should be operated in parallel with the conventional amplitude-gate approach with the Delta ultrasonic method for flaw detection in welds. Since the same pulser-receiver is used for both approaches, the only added cost is a modified low-cost frequency counter and an amplifier.

Using ½-inch diameter focused transducers, the distance of index used in scanning should be 1/16 to 1/8 of an inch, depending on the sizes of flaws which must be found. An 0.10 inch index was used in this work. The maximum response in the direction of scan was recorded to the nearest 0.10 inch in this work. The response should be recorded every few mils to obtain a detailed representation of flaw sizes. To accomplish this, a mechanical scanner with a data acquisition system must be utilized to rapidly record and print out the results. The present C-scan recording and presentation is slow, cumbersome to apply, and not quantitative.

Since neither Delta ultrasonic or X-ray found all the flaws in welds, because of flaw orientation and types, both should be used when high reliability of structural components is desired.

GENERAL DYNAMICS

Convair Aerospace Division

Fort Worth Operation