GENERAL DYNAMICS

Convair Division

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GENERAL DYNAMICS
CONVAIR DIVISION

RESISTANCE WELD MONITORING

CENTAUR TANKS 55-0501-22, 55-0501-23

(AC-21, AC-22)

CONTRACT NAS 3-8711

GDC-AGD-68-002A

PRELIMINARY REPORT

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ABSTRACT

Two "in-process" methods of determining the quality of resistance welds were evaluated in this program: 1) the ultrasonic method which utilizes piezo-electric transducers installed in the welding electrodes, and which monitors the effects upon the transmitted sound produced by the weld cycle; and 2) the thermal expansion method, which measures the rate of expansion produced by each weld. Both of these methods were used to monitor actual production welding of Centaur Tank AC-21. The results were compared with x-ray to determine correlation. Problems encountered during weld monitoring are discussed and preliminary results are given.

INTRODUCTION

The use of nondestructive in-process inspection of resistance welds has been under study by General Dynamics Convair Division since early 1965. In 1966, a German ultrasonic unit and a British thermal expansion unit were obtained for evaluation purposes. Tests conducted during 1966 and 1967 indicated the potential of these units to detect substandard welds. In 1967, the British expansion unit was updated to a solid state configuration and improvements in sensing capability were incorporated. Also, in 1967, a new American-manufactured ultrasonic unit was developed as a result of cooperation between Automation Industries (Sperry Division) and the Convair Division. This unit had increased capability and offered ease of maintenance and parts replacement.

As a result of earlier tests, it was proposed to NASA that these monitors be used to monitor actual production welding of several Centaur tanks for the purpose of determining actual capability under production conditions. The information collected would be for data evaluation only and would not be used for weld acceptance or rejection. Since the Centaur tank is 100% x-rayed, good data comparison could be made. This preliminary report will concern itself mainly with the general results and problems encountered during actual welding and testing of Centaur Tank 55-0501-22.

The detection of substandard welds at the time they are made is the goal of this program. Although x-ray is capable of detecting internal defects, such as cracks and voids, it will not detect substandard penetration or weld diameter. Structural failure is more likely to occur from the latter. Two test methods were evaluated in this program: the ultrasonic through-transmission method and the thermal expansion method.

Also used, but not a part of this program, is a Convair-designed and built "Energy Limiter" or failsafe unit. The energy level, as measured by this unit, is used as a basis for comparison with thermal expansion data when recording instrumentation is not used for ultrasonic data.

SUMMARY

Two methods of nondestructive testing for quality assurance of resistance welds were investigated in this program. Resistance welds on Centaur Tank AC-21 were monitored with, (a) ultrasonic through-transmission, with transducers mounted within the electrodes, and (b) thermal expansion measurements of the resistance weld during the welding cycle. All tests were conducted under production conditions and results were correlated with those obtained from x-ray examination. Although x-ray examination will detect internal defects, such as cracks or voids, it will not detect substandard penetration or weld diameter. The detection of these defects at the time of their formation was the goal of this program.

Over 28,000 resistance welds were inspected by x-ray and thermal-expansion methods. Approximately 9,000 of these were also monitored with the ultrasonic inspection system. General comments of each test system are as follows.

Ultrasonic Test Method

Excellent data correlation of ultrasonic inspection with x-ray examination was obtained in detecting substandard resistance welds. In total, only seven of 28,206 welds were found defective by both methods. These substandard welds were spits (5), cracks (1) and voids (1).

Problems were experienced with excessive "noise" in the ultrasonic signal, caused by temperature variations and turbulence in the electrode cooling water. Some sacrifice in signal stability was necessary due to the high rate of production welding.

Thermal Expansion Method

Thermal expansion data showed a wide range of results. Incorrect sensor gap settings (resulting from variations in expansion experienced on the assembly versus a test sample), part fitup and weld machine to tank assembly alignment appeared to cause a major portion of this data scatter.

A total of 70 of the 28,206 welds inspected were considered undersize. The expansion rates of these welds were considerably less than rates normally observed for the given joint configuration. This method did not detect welds with defects such as cracks, spits or voids.

Thermal expansion characteristics were found to be dependent upon energy application (single impulse, multiple impulse, single or three-phase). Additional work is recommended in this area to more accurately establish sensor gap.

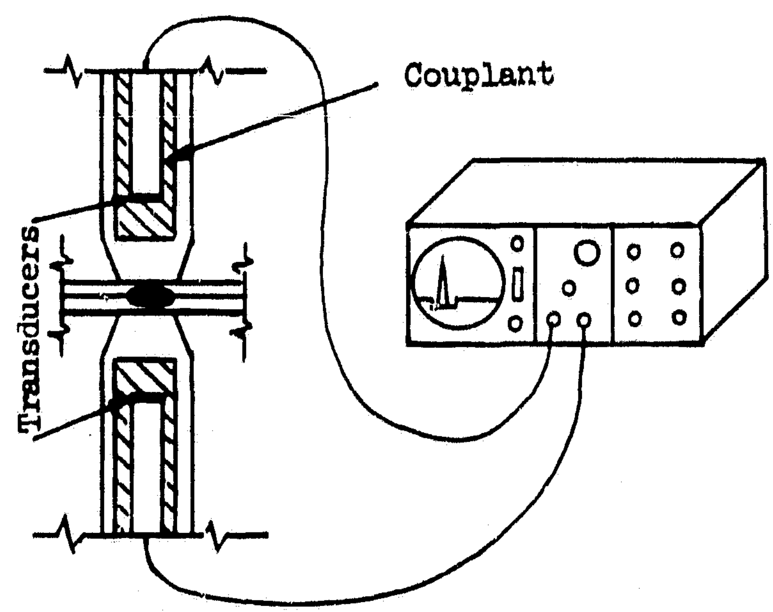
DISCUSSION

Monitoring and Instrumentation

The settings used on the various monitors are shown in Table 2. Joints monitored are depicted in Figure 1. The arrangement of the various monitors and recorders is shown in Figure 2. A photograph of the monitors in place on the welding machine is shown in Figure 3.

Ultrasonic Method

Standard electrode holders and electrodes were modified to allow for installation of the ultrasonic transducers and connecting cables. The cooling water is also the sound couplant and is introduced and removed at the base of the electrode through tubes fitted to the electrode holder. (See Figures 4 and 5). Water is prevented from reaching the cable connection by the "O" rings mounted on the transducer adaptor body. Electrodes are removed by displacement accomplished by turning the large screw at the end of the electrode holder shown in Figure 5. This method of electrode removal prevents damage to the transducer as well as electrodes and the tapered electrode seat in the holder.



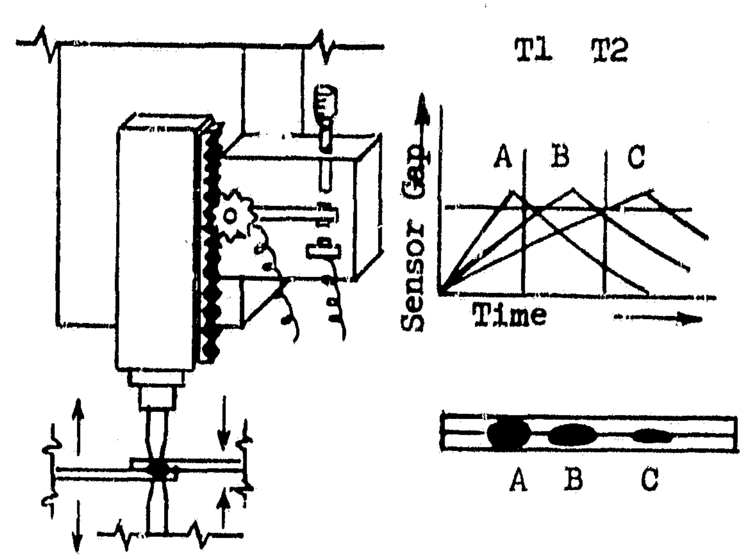
Ultrasonic through transmission is accomplished by the use of two transducers, one acting as the pulser and the other as the receiver (as pictured). The weld pressure negates the need for a wet couplant between the electrodes and the work piece. Each electrode cavity is checked for the presence of air bubbles by switching to pulse echo mode of transmission and examining the first returned signal. In this mode, each ultrasonic transducer acts as both pulser and receiver. The echo returning from the flat bottom hole of the electrode will indicate the presence of air bubbles by loss of amplitude or signal instability. When both electrode cavities check satisfactorily, the monitor is returned to the through-transmission mode and preweld signal amplitude is established. This is accomplished by inserting test samples representative of the joint between the electrodes and bringing the electrodes

Ultrasonic Method (Continued)

together on the test sample at the pressure required by the weld schedule. Signal amplitude is adjusted by sensitivity control to 50% of scale to allow excursion during the weld cycle. (See Figure 6). "A" scan presentation is used and this signal is fed to an oscillographic recorder for permanent record. Sensitivity for the ultrasonic trace was 200 millivolts per division with adjustments made on the ultrasonic sensitivity control. Previous tests have shown that for a good weld, a general increase in signal amplitude over the weld period will occur. Drastic loss of amplitude indicates a defective weld.

Thermal Expansion Method

The thermal expansion sensor is mounted on the stationary portion of the upper electrode assembly and the rack is attached on one end via ball socket to the movable ram assembly. (See Figures 7 and 8). The rack passes through the sensor and is meshed with a pinion attached to a lever arm positioned between two stops as shown at the right. The pinion is mounted on an electromagnetic clutch so that no lever movement takes place until the clutch is energized. The lever is spring-loaded to one side to provide return. Clutch energization and count gate start are triggered simultaneously. This initiation pulse is obtained from the heat-cool panel of the weld machine control. Since cool time counts first, the clutch is energized and count gate starts at the beginning of the weld cool-heat sequence. To check for proper and consistent initiation, output is taken from the clutch circuit and fed to an oscillographic recorder. (See Figure 9). Both the initiation point and the total count shown by the monitor, as well as the portion of the weld cycle monitored, may be checked in this manner. The monitor count is fed to a digital printer for permanent record. The low limit on the expansion monitor was set to allow for longest expected count. The count circuit is automatically reset and the clutch de-energized 280 milliseconds (ms) after low limit set if the lever arm does not contact the lower stop. The printer will then print zero. Tectoweld digital information is in milliseconds, counting from the left, hundreds, tens, units and tenths. In Figures 10 through 19, a Hewlett-Packard printer was used. Figures 19 through 24, a Franklin printer was used, and the two right hand columns are not significant. In general, once the expansion rate for a good weld has been established via test samples, then variations may be interpreted as follows: shorter expansion rates (lower number) indicate a hotter or larger weld; longer expansion rates (higher number) indicate a colder or smaller weld.



As a basis for comparison for all data, the complete weld cycle is recorded via inductive pickup from the throat of the weld machine and fed to the oscillographic recorder. The sensitivity for the weld trace was maintained at 20 millivolts per division at all times. Chart speed was maintained at 5 millimeters per second with 25 and 125 mm/sec. traces run intermittently for clarity.

Observations

Ultrasonic Method

Although the ultrasonic signal trace configuration varied considerably from those experienced during previous testing, the drastic change in configuration caused by defective welds is still quite evident. No problem in identifying these welds was experienced, however, during the monitoring of over 8,000 welds, very few defective welds were produced so that the total capability of the ultrasonic unit to detect defects has not yet been determined under production conditions.

The changes noted in signal configuration a [illegible] ributed to the various weld energy wave forms used on the widely [illegible] ng joint thickness build-ups. These variations in signal configur [illegible] will make it more difficult to gate the signal to "Go", "No Go" limits [illegible] automatic monitoring.

Signal amplitude instability was also noted and this is caused by variation in the electrode cooling water temperature which affects ultrasonic transmission.

The affect of part fit is evidenced by the variation in initial signal transmission level just prior to weld heat application. Automatic gain control could be used for this period, but evidence of poor fit would then be lost.

Thermal Expansion Method

The nearly linear relationship between the rate of expansion and weld size produced by welds during tests using standard test specimens also suffers the affects of fit and alignment on large production hardware. An additional factor is the friction and inertia inherent in the pressure systems of each machine. Further, the expansion characteristic is dependent upon energy application (single impulse, multiple impulse, single or three-phase). As a norm, nearly identical expansion rates were experienced between test samples and the production hardware in the thin gauge buildups, but increased significantly from test samples on the heavier buildups. Because of this, there was a tendency to set the gap shorter than desirable, resulting in data covering too little of the weld cycle. This was corrected for the heavier buildups at Sta. 412 and more complete data was generated. Also observed is the fact that in some cases fit and alignment had the affect of reducing the total expansion, so that no reading was obtained even though some expansion had occurred.

RESULTS AND COMMENTS

A general breakdown of ultrasonic and thermal expansion monitoring results is illustrated in Table 1. Excellent correlation may be seen between x-ray and ultrasonic methods. Seven defective welds (crack - 1, spit - 5, void - 1) were observed with both systems. The number of defective welds in the total welds produced (only seven in 28,206) restricted the complete evaluation of this system. Table 1 also indicates 70 undersize welds in the approximately 28,000 welds inspected by x-ray and thermal expansion. Joint expansion rates of these 70 welds were considerably less than rates normally observed for the given joint configuration.

Figures 10 through 24 represent a cross section of the data collected on the more than 28,000 welds monitored. Fifteen different thickness combinations are involved. It is not practical to make general comments covering all buildups, since each joint presents differing conditions relative to monitor response. Therefore, each joint result is explained where other than normal results were obtained.

Figures 10 and 11 show typical results for the three rows of spotwelds attaching the large ring at Sta. 219. On all three rows, a general increase in ultrasonic signal amplitude is noted. No defects were found in x-ray examination. Tectoweld data for Row B is higher than Row C which is the result of restraint and shunt from Row C which was welded first. The average reading for Row A test samples was 86 ms. A number of very low readings were recorded in each row indicating substandard welds.

Figure 12, Joint D_1, shows the effect of varying the sensor gap on this seamweld. The rhythm of the count may be attributable to the alternating polarity of the first weld impulse. Average expansion reading for the test sample at .005" gap was 51 ms.

Figure 13, Joint "D", contained two defective welds, both having voids as well as metal expulsion. The Tectoweld data, although indicating a warming trend, is not significant. This is due to too short a gap setting. The ultrasonic response is significant and clearly indicates the change.

Figure 14, Row "E" also contained two defective welds and the ultrasonic traces show a drastic response. It would appear that the spit in the upper left hand trace occurred somewhat earlier in the weld cycle than the other. No significant change was noted in the expansion rate. The rates recorded for both Joints "E" and "F" (shown in Figure 15) indicate that the count was completed prior to the spits.

RESULTS AND COMMENTS (Continued)

In Figure 16, Joint "H", Sta. 282, the ultrasonic trace indicates a trend just prior to the spit spotweld. The expansion rate also indicates the spit again showing that a larger sensor gap would have shown better response.

Figure 17, Row "G", Sta. 344, shows typical traces for the same thickness as "H". Lower trace was made at 125 mm/sec. The expansion rates show the effect of rewelding a tackweld slightly off center. Unfortunately, none of the defective welds were recorded at high chart speed which would be easier to correlate to actual weld sequence. No additional defective welds were detected by x-ray on the balance of welds monitored.

Figure 18 depicts typical response for Joints "K" and "K_1".

Figure 19 shows typical expansion rates experienced when welding the doublers and brackets just aft of Sta. 219. The doubler welds were made on a "C" gun weld machine on the same fixture as Machine 101. This "C" gun is mounted on a pivot pin and is somewhat self-centering regarding alignment to tank. This may account for the fact that of the 1800 welds made with this machine, the expansion rates varied less than 1 millisecond.

The balance of welds were made on Machine 107 aft gantry. The ultrasonic unit is not adaptable to this machine. Therefore, it was decided to record the output from the energy limiter for comparison to weld trace and expansion data. The output from the energy limiter is essentially the energy level in watt seconds expended for each weld. Two energy levels are shown when both weld and temper are used in the weld sequence. This is neceaary since failure can occur in either circuit.

Figure 20 shows the results of the seamweld just forward of the ring at Sta. 412. Great difficulty was experienced in setting the sensor gap for this weld. Constant weld machine position adjustment is required to track this seam in order to clear the edge of the ring. This adjustment had a dampening affect upon the expansion with subsequent loss of data. The start and final test showed comparable data and the energy levels did not indicate any great deviation, although greater amplitude was obtained on the test sample than was experienced on the tank.

Figure 21 shows the results of the final test compared to data obtained from the production part. As a check to account for the difference in data, an additional test sample was welded with reduced weld heat. Although dampening effect and reduced heat input may account for the similarity of expansion readings, the energy levels indicate that less energy is delivered to the production part and may in fact produce the weld shown at the lower right hand.

RESULTS AND COMMENTS (Continued)

Figure 22 shows a comparison of energy levels and expansion rates for the production part and final test sample. The same trend of reduced energy level from that obtained on the test sample is noted. Data identified as "2" is the result of rewelding a tackweld.

Figure 23 shows the results from Joint "O" for test and production part. Finally, Figure 24, Joint "P", shows energy level variation and expansion rates during the production run. Sensor gap was difficult to establish for this joint because of the 8° taper at this joint. A wide variation in total expansion was experienced with subsequent loss of data. Expansion rates at .045" sensor gap, however, were comparable from test sample to production part. Variations in energy levels did not always agree with expansion variation.

CONCLUSIONS

Ultrasonic Method

Good correlation of data indicating defective welds on production parts has been obtained. Very few defects were actually produced so the full capability of the ultrasonic unit has not been determined under actual production conditions.

Signal instability produced by temperature variations and turbulence of the electrode cooling water must be resolved in order to determine the feasibility of automatic "Go", "No Go" gating and the desirability of adapting automatic control.

Thermal Expansion Method

Expansion rate differences between test samples and the production parts indicate that the standard test sample does not give sufficient assurance of proper weld machine setting for heavy buildups.

The effect of poor fit is evidenced by reduced expansion rates, but since this cannot be simulated on the standard test samples, the exact effect on the production weld is not known.

More information relative to differing expansion characteristics caused by the various weld energy forms is required in order to more accurately establish sensor gap.

The additional data now being collected on a second tank may provide additional data to clarify these problems.

TABLE 1

SUMMARY OF RESISTANCE WELD MONITORING
OF CENTAUR TANK (AC-21)

	INSPECTION METHOD EMPLOYED		
	X-RAY	ULTRASONIC MONITOR	THERMAL EXPANSION MONITOR
TOTAL WELDS INSPECTED	28,206	8,890	28,206
CRACK	1	1	0
VOID	1	1	0
SPIT	5	5	0
UNDERSIZE	0	0	70
TOTAL SUBSTANDARD	7 (a)	7 (a)	70 (b)

NOTES: (a) Defects indicated by x-ray and ultrasonic are the same welds.

(b) The 70 welds indicated as undersize had expansion rates considerably below the rates normally recorded for that joint (colder weld).

Since the expansion rate is taken only from the initial part of the weld cycle, internal defects are not indicated unless accompanied by a change in energy input during this time.

TABLE 2

MONITOR SETTINGS

JOINT	MACHINE	TECTOWELD		ULTRASONIC		FAILSAFE ENERGY LIMIT
		GAP	LIMITS	FREQUENCY	SENSITIVITY	
A	101	.025	055-155	2.5 MHZ	2.0 x 3 3.0 x 3	5.20, 5.30, 5.40
B	101	.025	055-155 055-120	2.5 MHZ	1.0 x 10 3.0 x 10	5.49, 5.52, 5.55
C	101	.025	055-095 055-120	2.5 MHZ	2.0 x 10	5.49
D	101	.010	025-095	2.5 MHZ	2.0 x 10 4.0 x 10	1.50, 1.48
D_1	101	.005, .010, .015	025-095	SEAMWELD		2.80, 3.00, 2.90
E	101	.005	025-095	2.5 MHZ	3.0 x 3 2.0 x 3	1.20
F	101	.005	025-095	2.5 MHZ	2.0 x 3	1.20
BANJO DOUBLERS	102	.005, .010	010-055			
BANJO BRACKETS	101	.010	010-055			5.50
STA. 282						
G	101	.005	050-155	2.5 MHZ	3.0 x 3	1.30
H	101	.005	050-155	2.5 MHZ	3.0 x 3	1.30
STA. 344						
G	101	.005	050-155	2.5 MHZ	2.0 x 3	1.30
H	101	.005	050-155	2.5 MHZ	3.0 x 3	1.30
K	101	.010, .015 .020	040-155	2.5 MHZ	3.0 - 6.0 x 3	3.60
K_1	101	.015	040-155	SEAMWELD		4.10, 4.20, 4.25, 4.30, 4.60
L	107	.100, .090, .080, .070, .060	055-255	SEAMWELD		2.20
M	107	.150	055-255			4.20
N	107	.100	055-255			3.20
O	107	.100	055-255			2.85
P	107	.045	055-255			1.32

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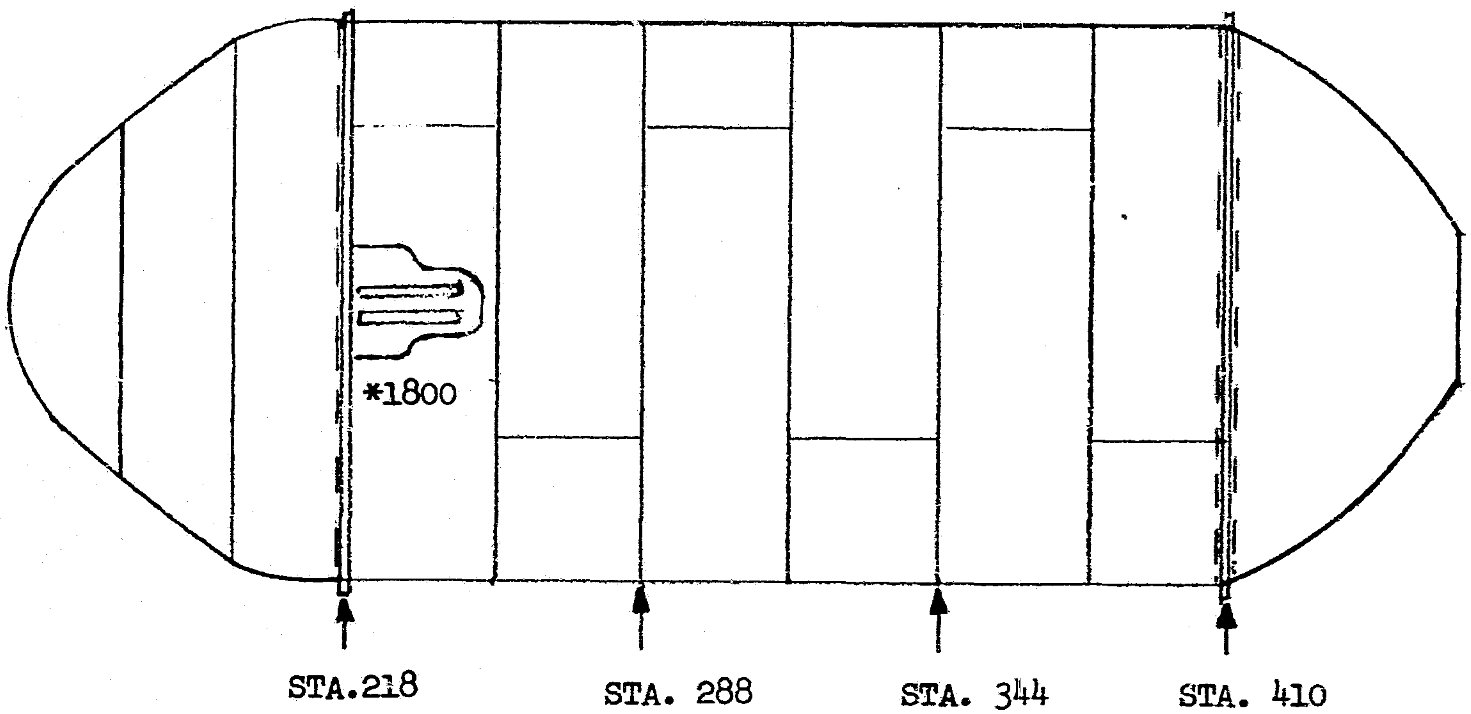
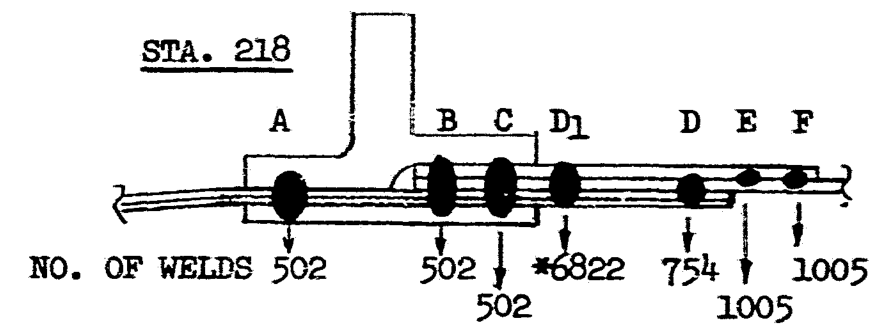
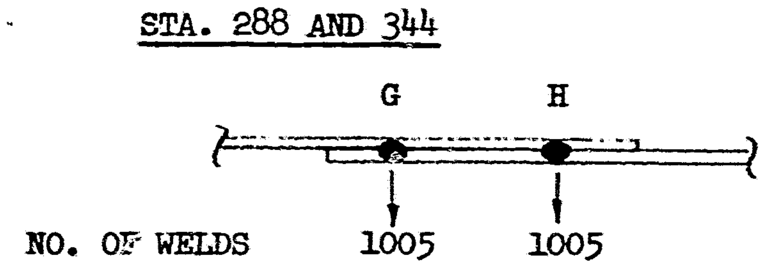
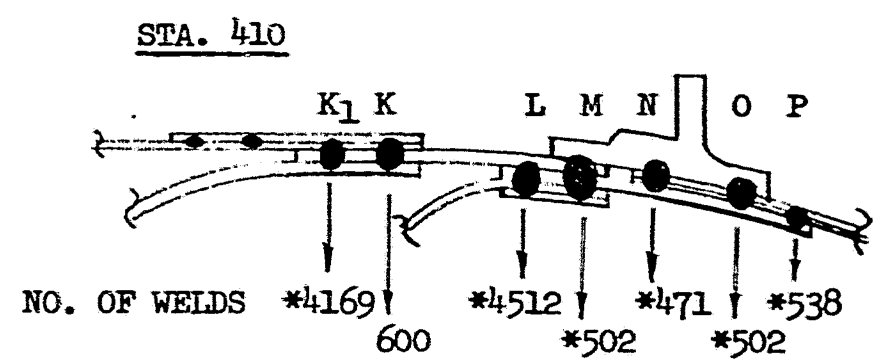








TOTAL WELDS: 28,206

*THERMAL EXPANSION MONITOR ONLY

THICKNESS COMBINATIONS
MATERIAL 301 1/2 H & UP

A	.070/.016/.010/.026
B & C	.110/.010/.014/.016/.010/.026
D & D_1	.010/.014/.016/.010
E & F	.010/.014
G & H	.014/.014
K & K_1	.014/.014/.032/.026
L	.032/.032/.016/.026
M	.070/.032/.032/.016/.026
N	.100/.018/.014/.032
O	.070/.018/.014/.032
P	.018/.014/.032

ACTUAL SEQUENCE
OF WELDING

C
B
D
E
F
D_1
BANJO DOUBLER
BANJO DOUBLER BRACKET
A
H) 282
G)
H) 344
G)
K
K_1
N
O
M
L
P

FIGURE 1

WELD JOINTS MONITORED

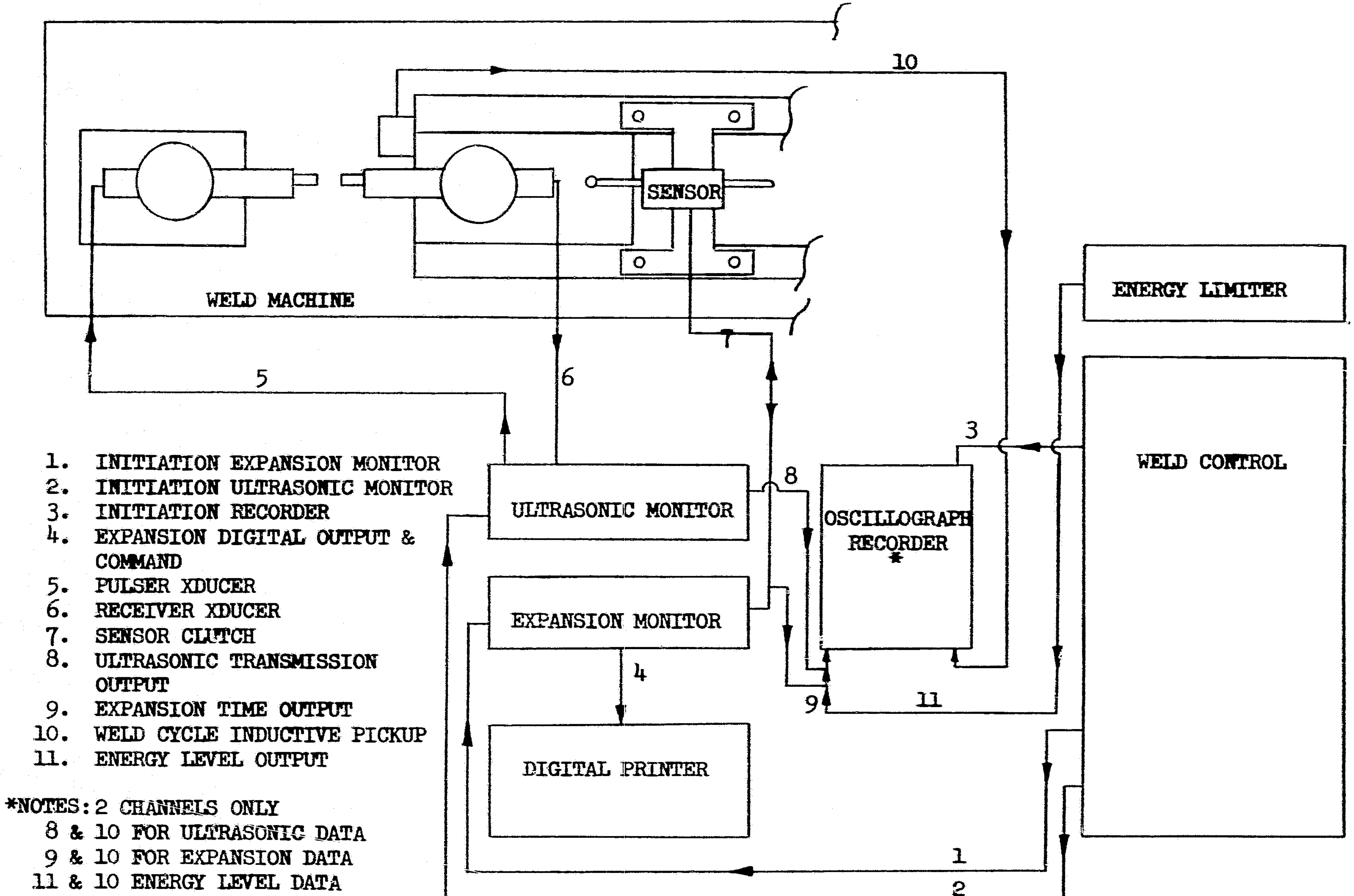


FIGURE 2

WIRING DIAGRAM WELD MONITORS

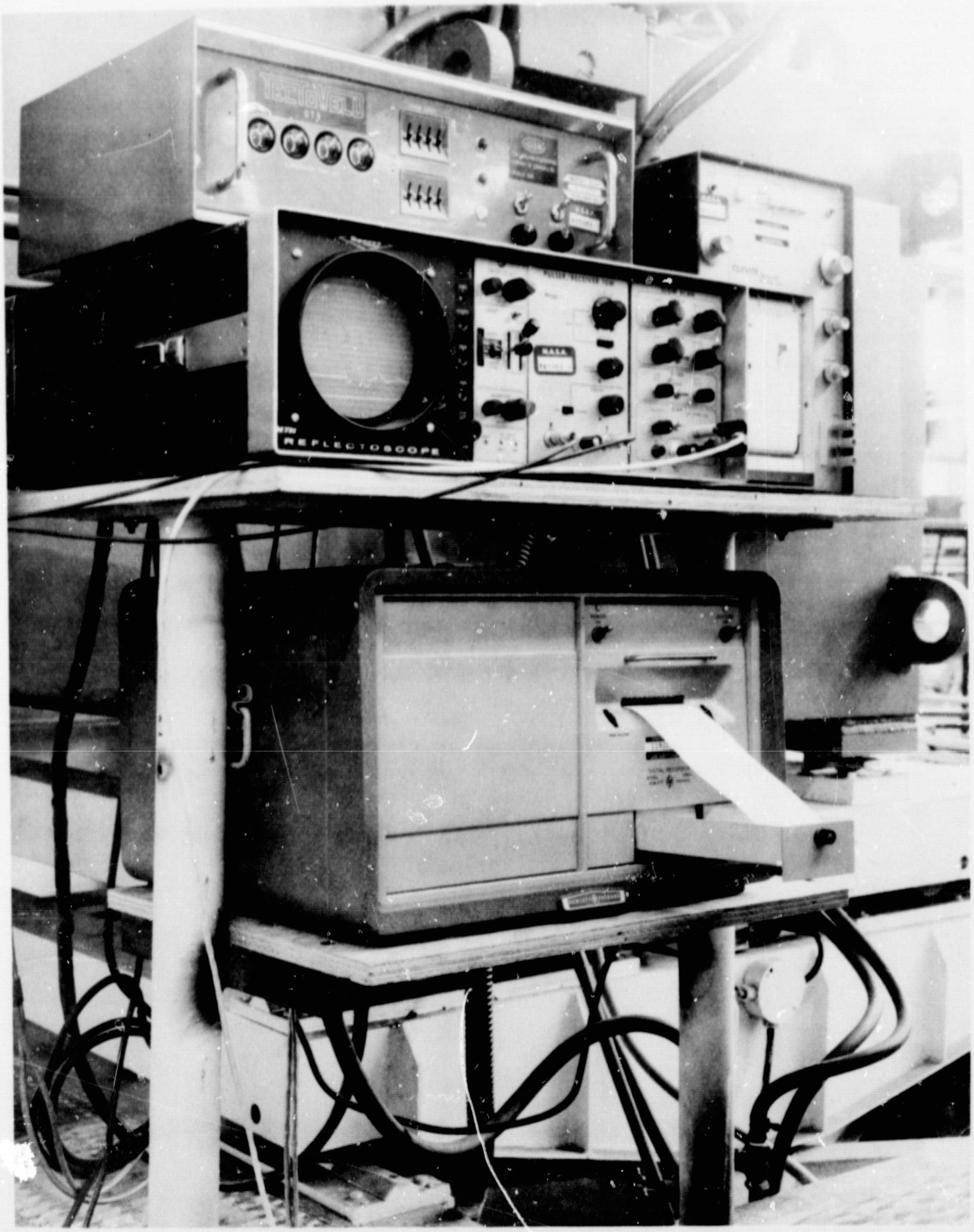


FIGURE 3

MONITORS IN PLACE ON WELD MACHINE

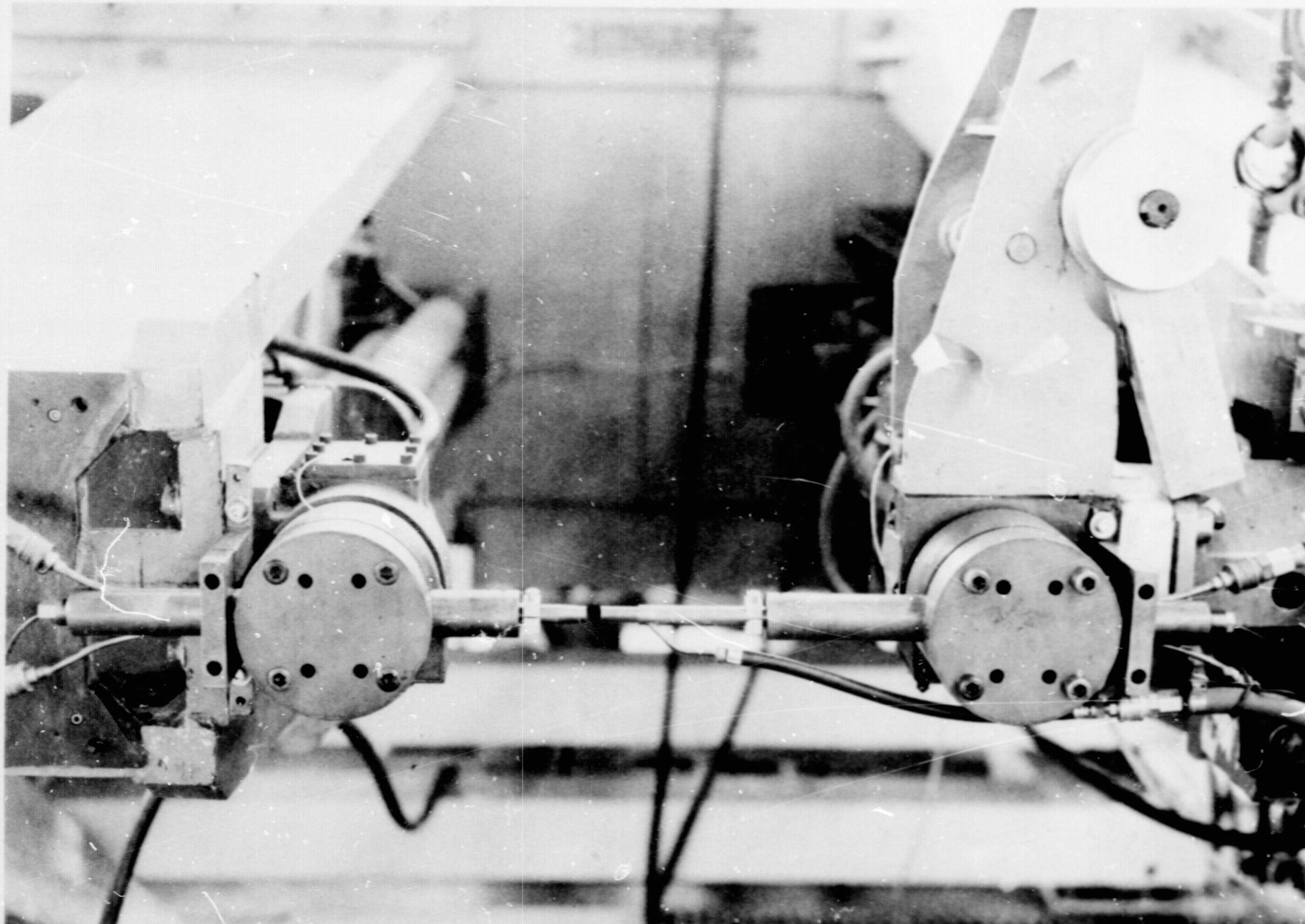


FIGURE 4

SPECIAL ELECTRODE HOLDERS INSTALLATION

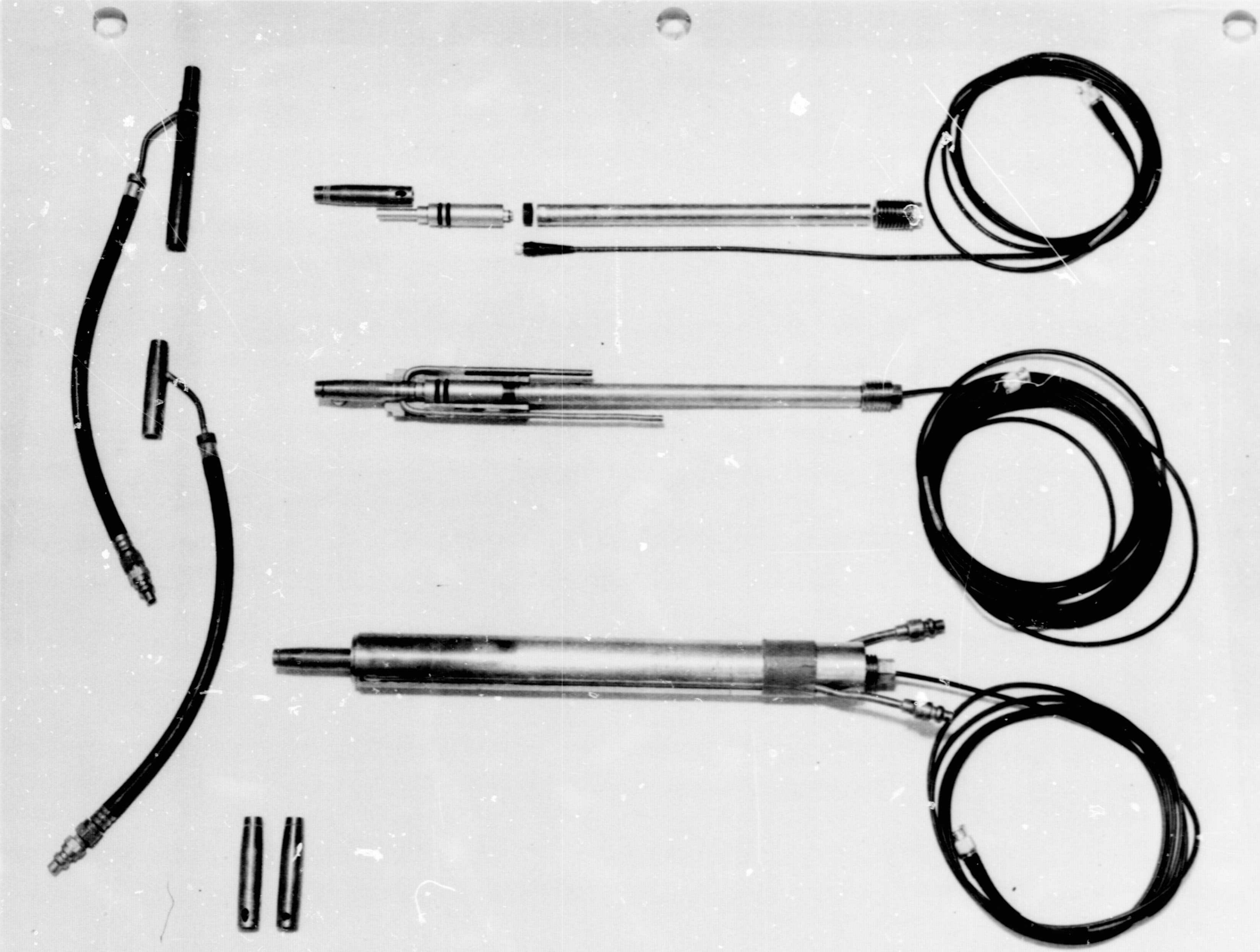
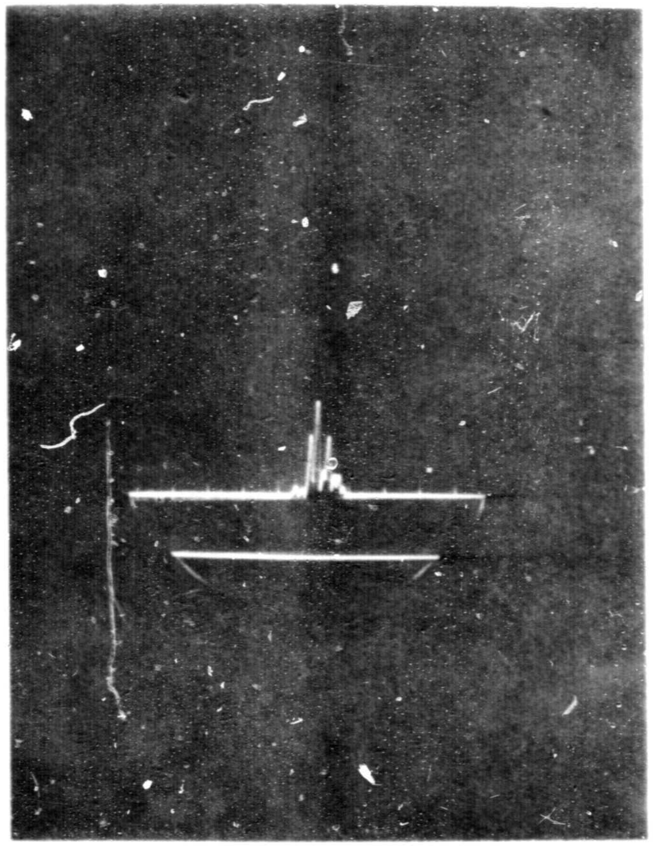
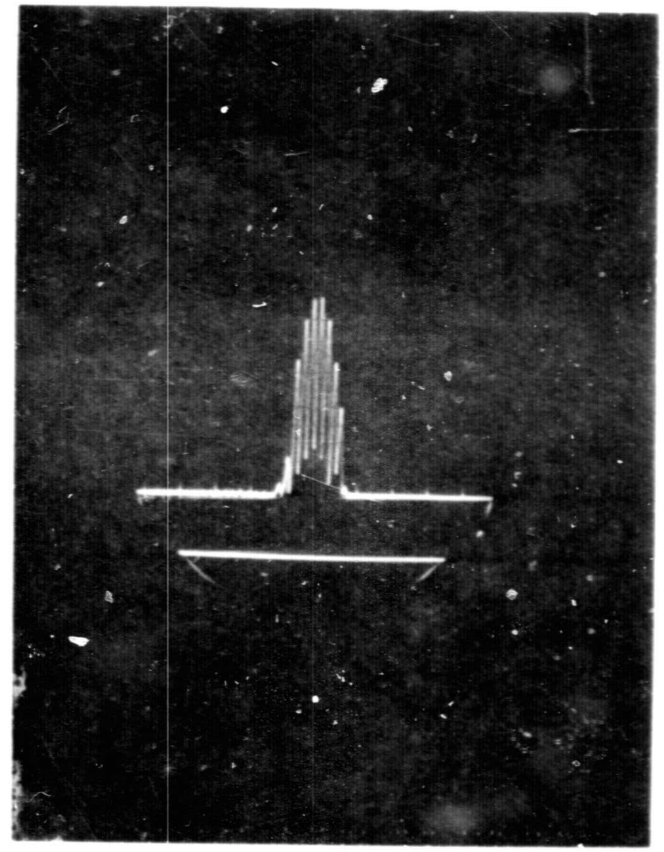


FIGURE 5

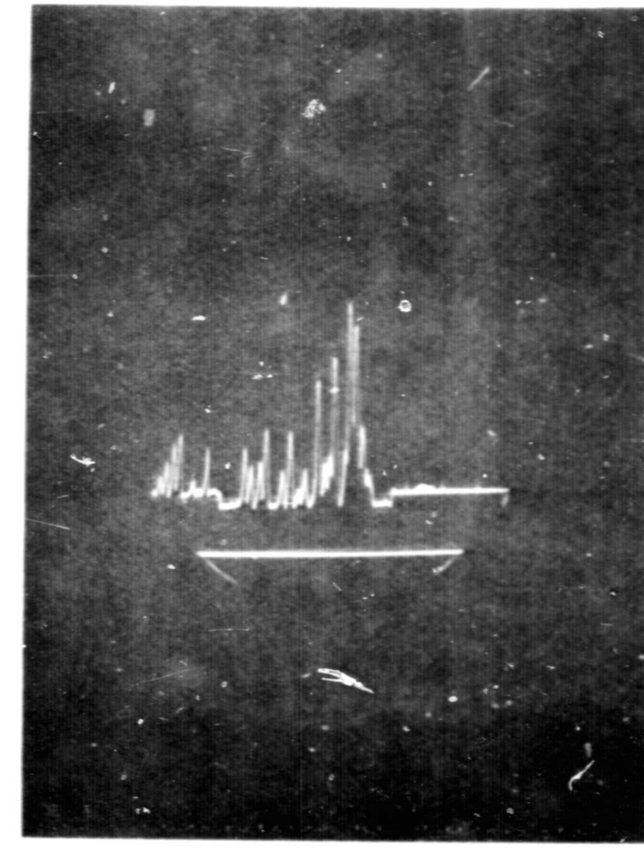
ULTRASONIC TRANSDUCER INSTALLATION IN HOLDERS



PULSE ECHO FROM TOP ELECTRODE
(RIGHT HAND IN FIGURE 4)



PULSE ECHO FROM BOTTOM ELECTRODE
(LEFT HAND IN FIGURE 4)



THROUGH TRANSMISSION
TYPICAL JOINT "C"

FIGURE 6

ULTRASONIC TRANSMISSION TEST

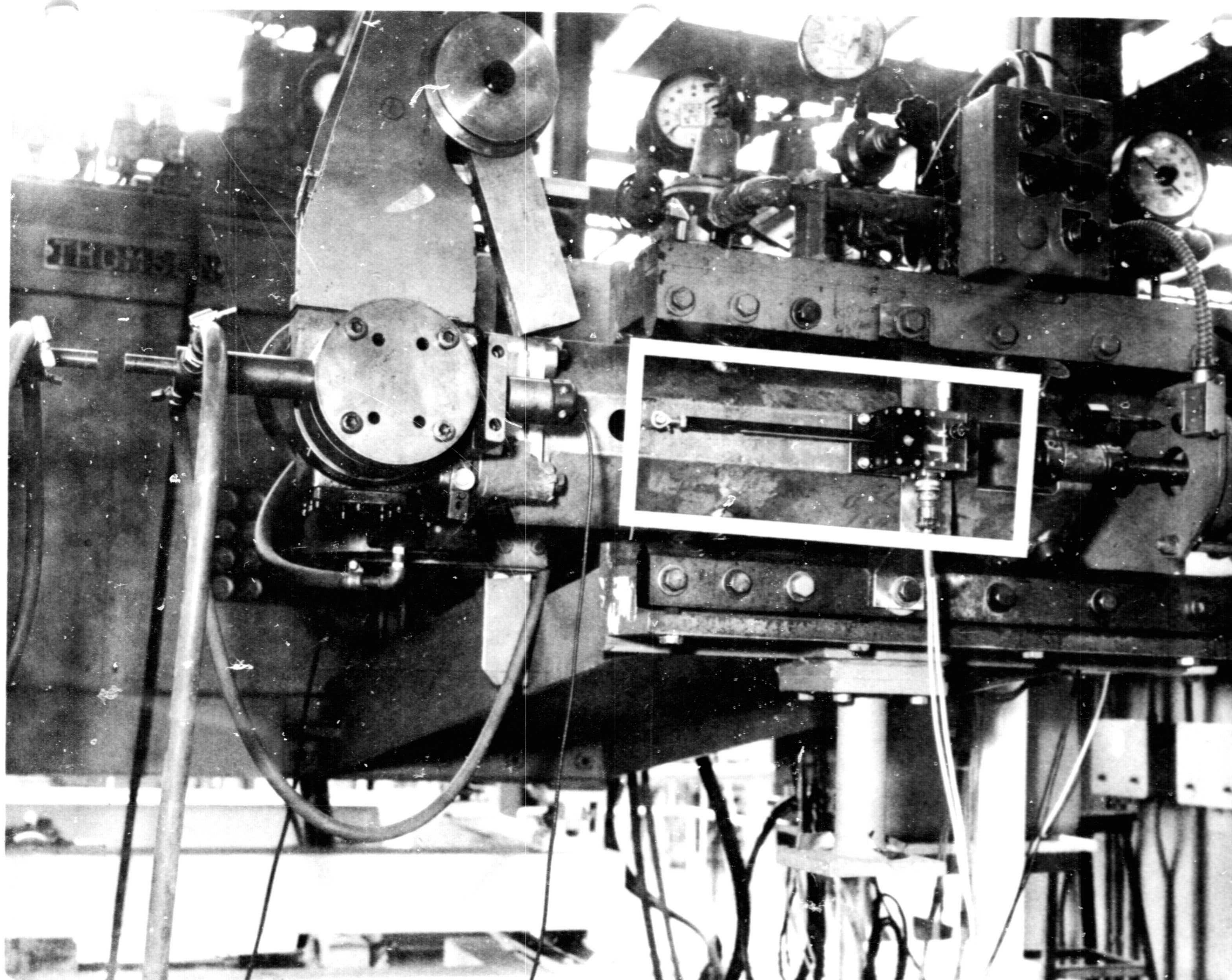


FIGURE 7

THERMAL EXPANSION SENSOR & RACK INSTALLATION

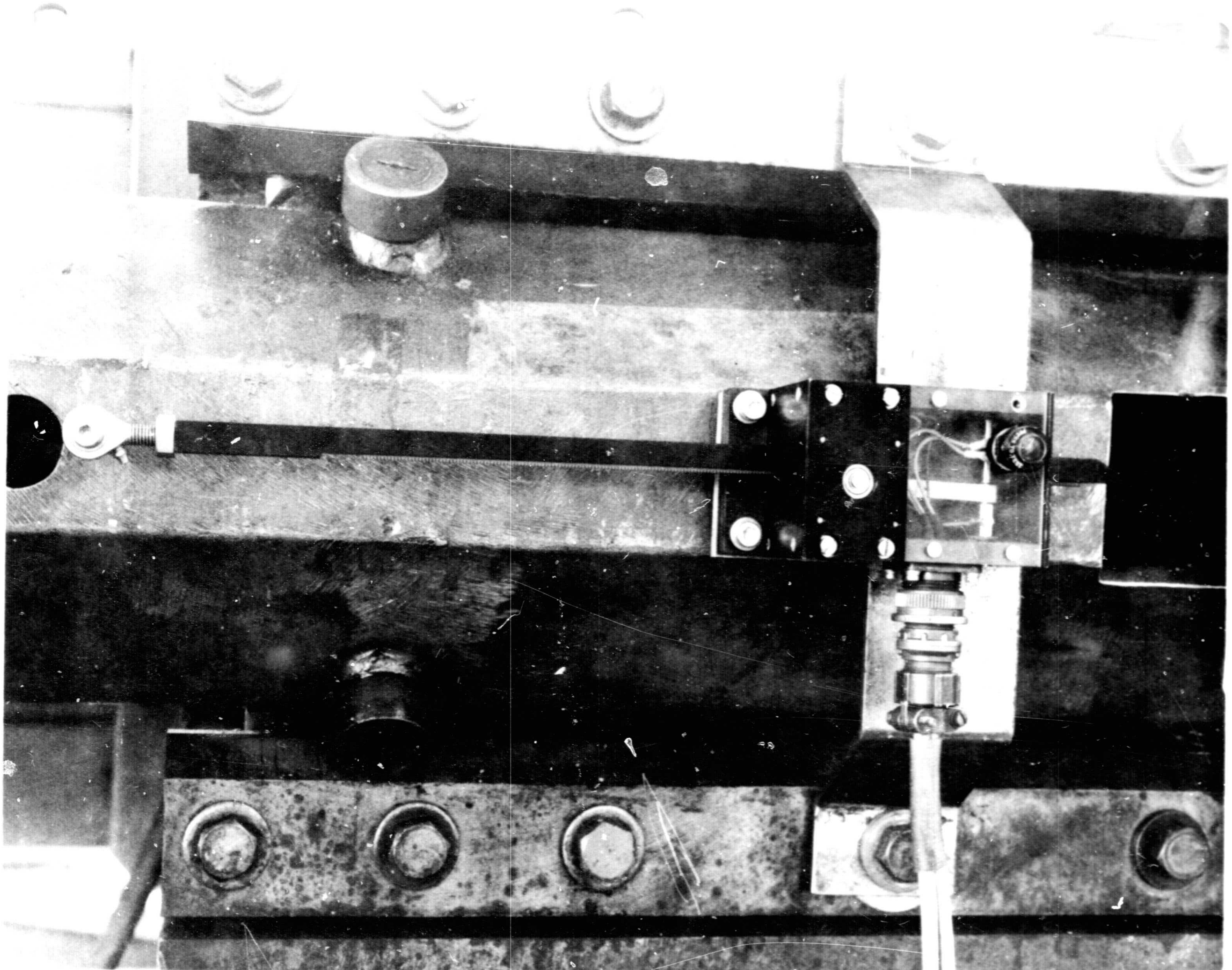
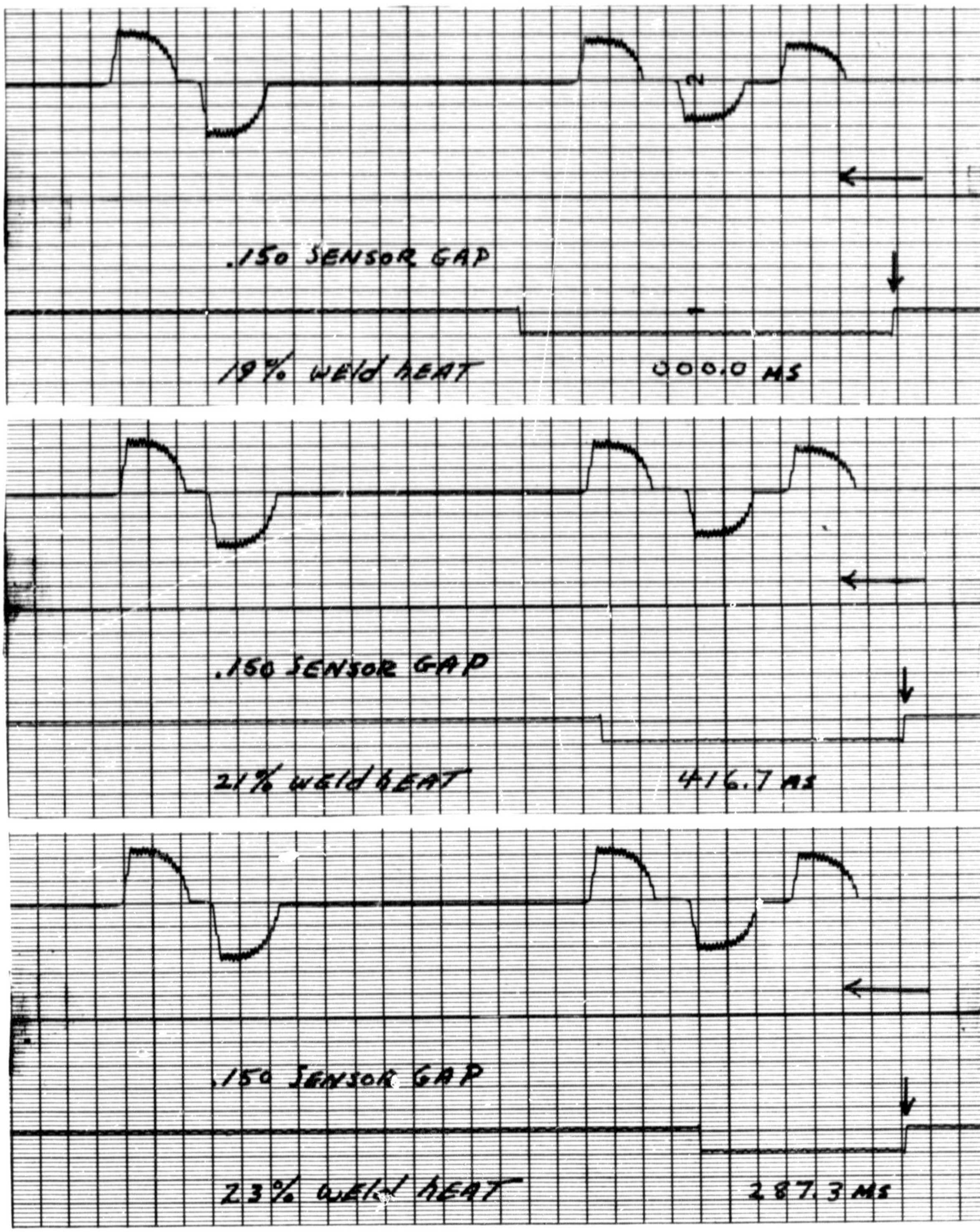


FIGURE 8

THERMAL EXPANSION SENSOR



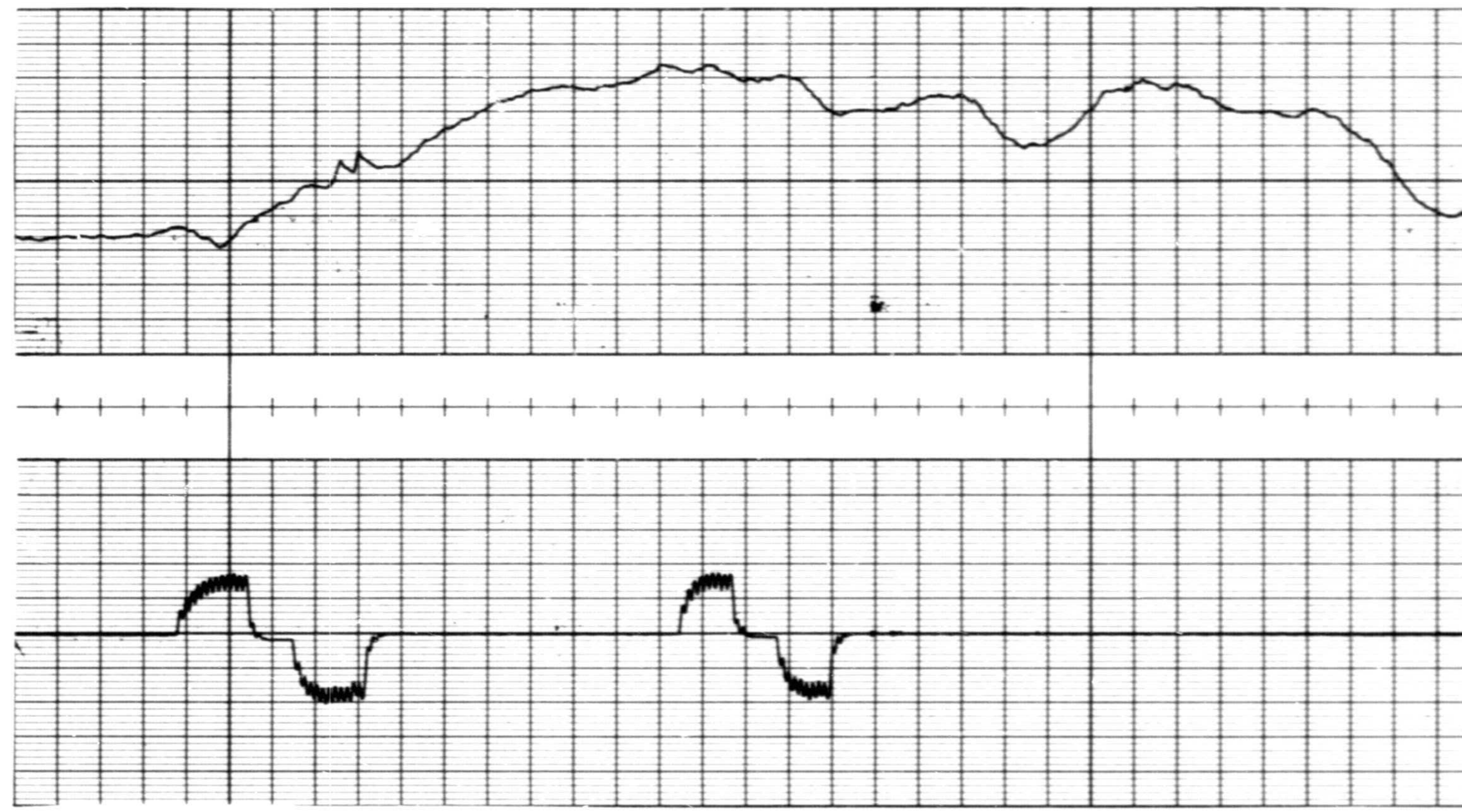
THE SQUARE WAVE IN EACH TRACE SHOWS SENSOR CLUTCH ENERGIZATION AND COUNT START. NOTE EXCELLENT RESPONSE TO HEAT CHANGE. AT 19% WELD HEAT THE LEVER DID NOT CROSS THE GAP WITHIN AUTOMATIC RESET TIME AND, THEREFORE, OUTPUT WAS ZERO.

FIGURE 9

EXPANSION CHECK TEST

1 0 2 9
1 0 3 5
1 0 4 1
1 0 4 4
1 0 3 1
1 0 4 4
1 0 3 1
1 0 0 2
1 0 2 4
1 0 1 7
1 0 1 5
1 0 3 9

TYPICAL TECTOWELD READINGS TO 0.1 MILLISECONDS.



TRACE OF THE ULTRASONIC SIGNAL (UPPER), AND THE WELD AND TEMPER CURRENT (LOWER) FOR A TYPICAL WELD.

FIGURE 10

TYPICAL RESULTS JOINT "A"

B	C
1149	0948
1144	0966
1106	0914
1140	0964
1112	0968
1123	0929
1147	0971
1135	0949
1156	0922
1139	0957

ABOVE - TYPICAL TECTOWELD READINGS FOR JOINTS "B" & "C" TO 0.1 MILLI-SECOND.

RIGHT - TRACE OF THE ULTRASONIC SIGNAL AND THE WELD AND TEMPER CURRENT FOR TYPICAL WELDS IN JOINTS "B" & "C".

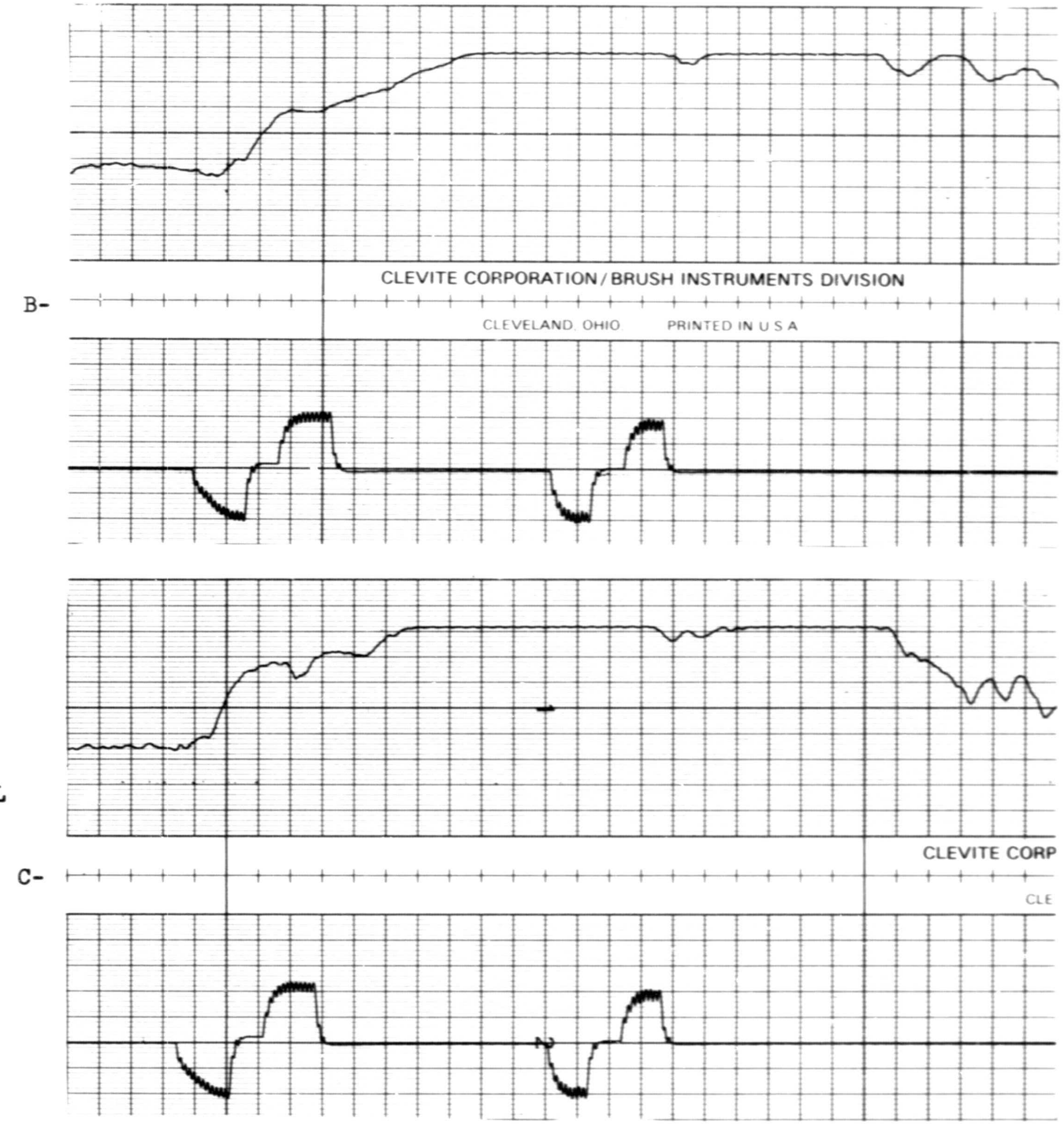


FIGURE 11

TYPICAL RESULTS JOINTS "B" & "C"

0.005" GAP	0.010" GAP	0.015" GAP
0 6 3 5	0 6 9 0	0 7 4 0
0 6 4 5	0 6 8 7	0 7 0 7
0 6 3 8	0 6 8 8	0 7 4 1
0 6 7 6	0 6 8 7	0 7 3 3
0 6 3 6	0 6 9 2	0 7 4 6
0 6 4 2	0 6 8 6	0 7 3 7
0 6 3 9	0 6 9 0	0 7 4 2
0 6 4 2	0 6 8 7	0 7 1 5
0 6 3 6	0 6 9 0	0 7 4 2
0 6 4 1	0 6 8 5	0 7 3 6
0 6 3 6	0 6 9 1	0 7 4 1
0 6 4 1	0 6 8 4	0 7 3 3
0 6 3 5	0 6 9 0	0 6 9 2

LEFT - TYPICAL TECTOWELD READINGS ON JOINT "D_1" AS THE SENSOR GAP IS CHANGED FROM 0.005" TO 0.010" TO 0.015".

BELOW - TYPICAL TRACE OF WELD AND TEMPER CURRENT ON JOINT "D_1"

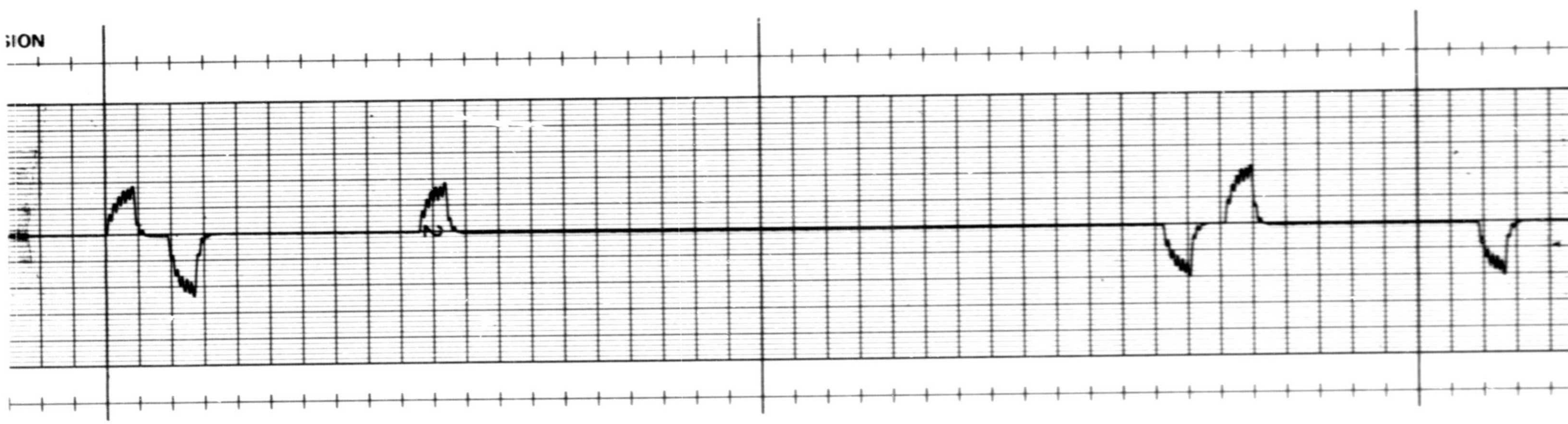


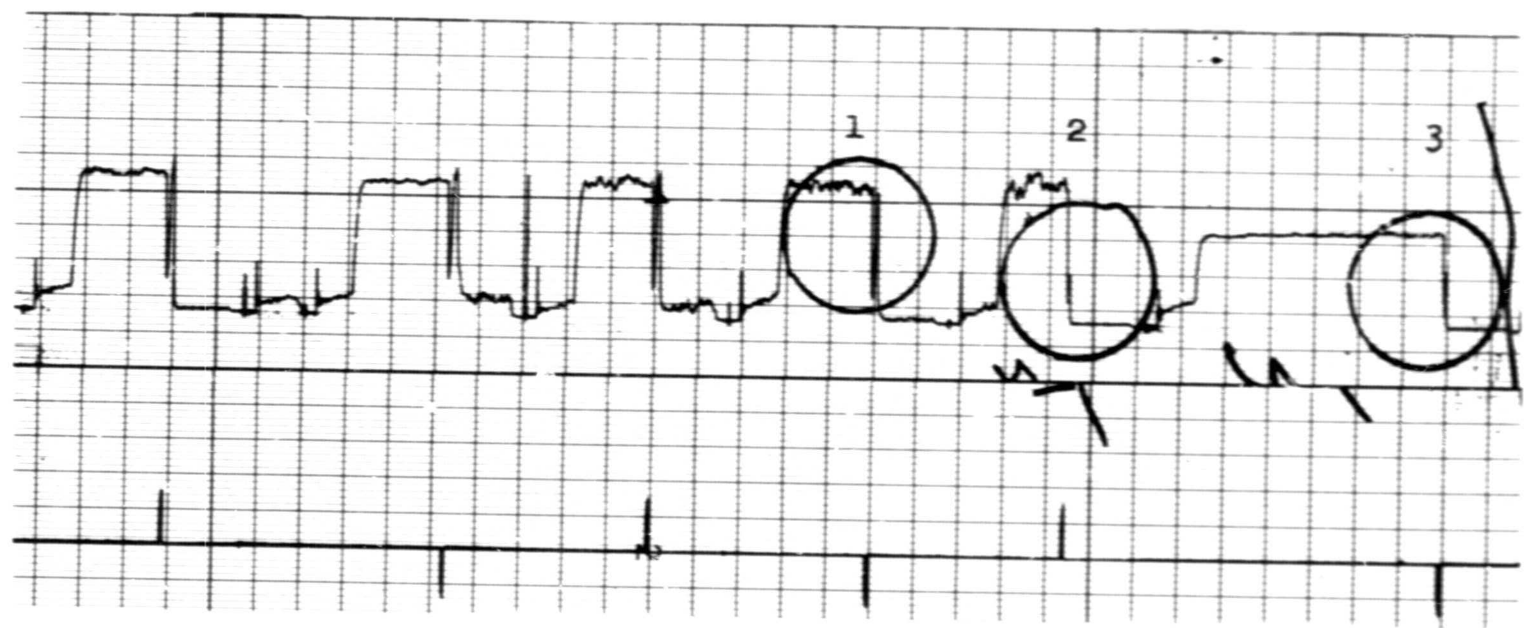
FIGURE 12

SENSOR GAP VARIATION JOINT "D_1"

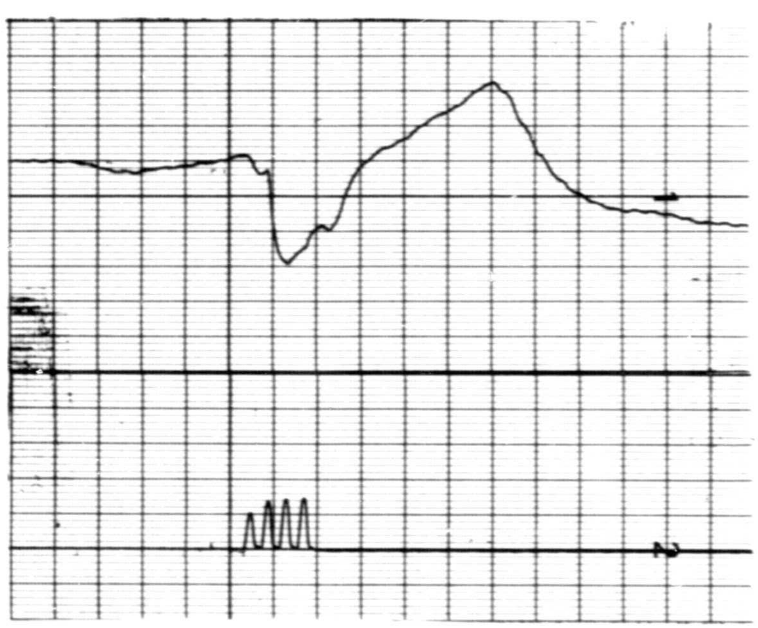
SPIT — 0 5 8 8
SPIT — 0 5 9 1

0 5 8 9
0 5 9 1
0 5 9 2
0 6 0 3
0 6 0 3
0 7 3 2
0 7 4 6

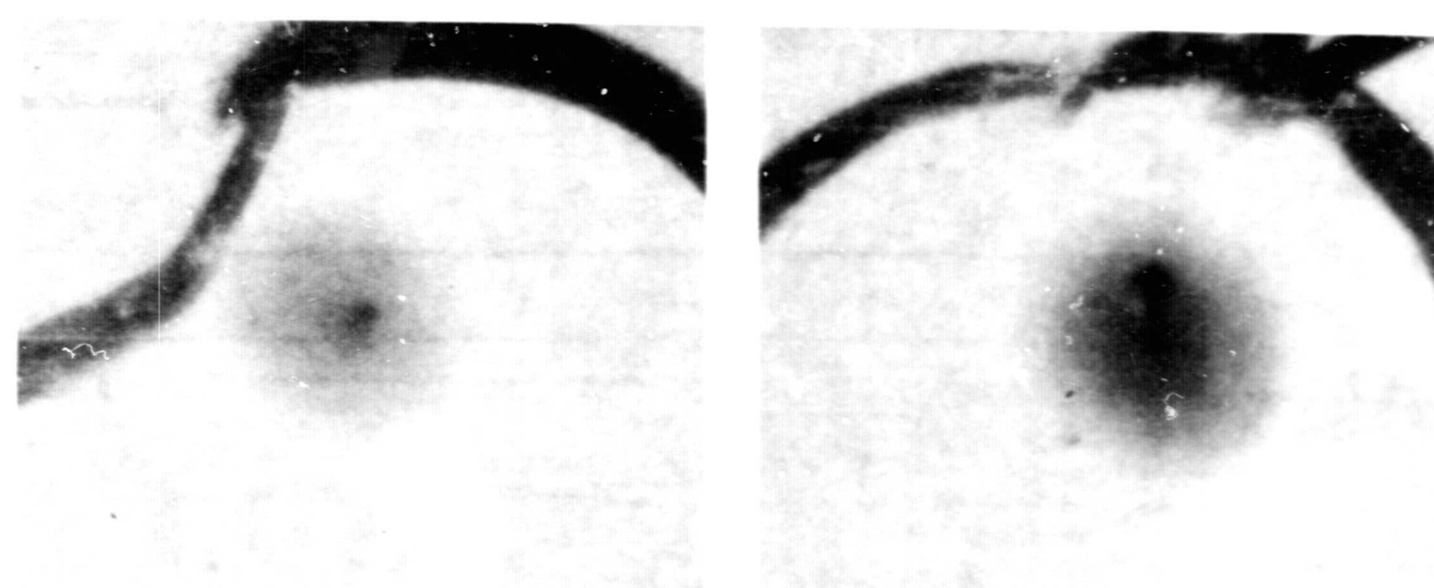
TECTOWELD READINGS INCLUDING READINGS FOR THE TWO "SPIT" WELDS.



ULTRASONIC SIGNAL TRACE OF TYPICAL WELDS AND TWO "SPIT" WELDS (#2 & #3) WITH THE WELD CURRENT TRACE SHOWN BELOW. NOTE #2 & #3 LACK TYPICAL SPIKE AT RIGHT EDGE OF TRACE.



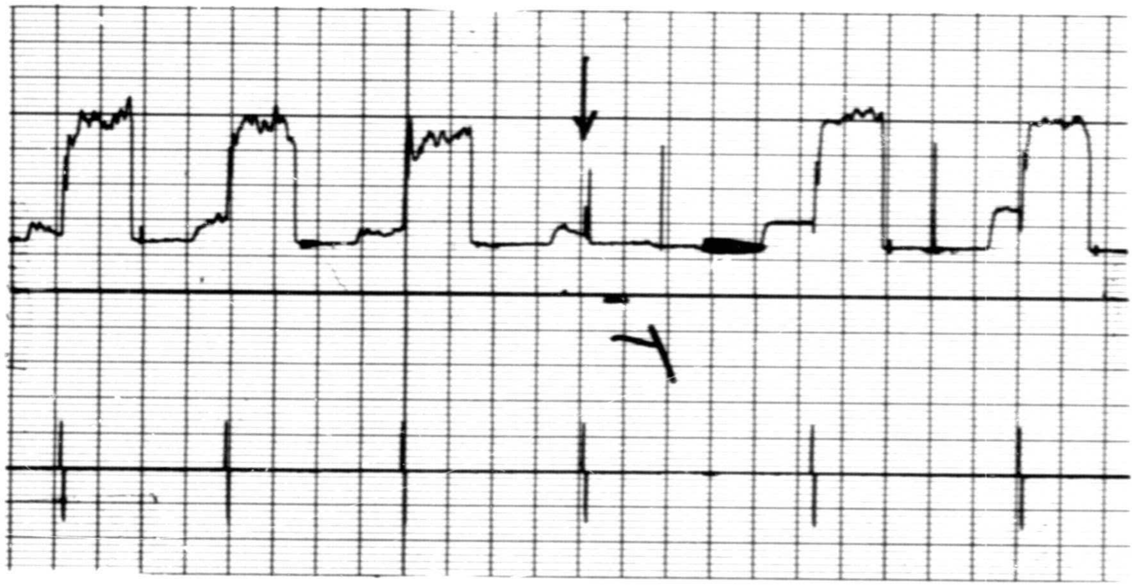
A HIGH SPEED TRACE OF THE ULTRASONIC TRACE AND WELD CURRENT - THE CIRCLED AREA (#1) IN TRACE B.



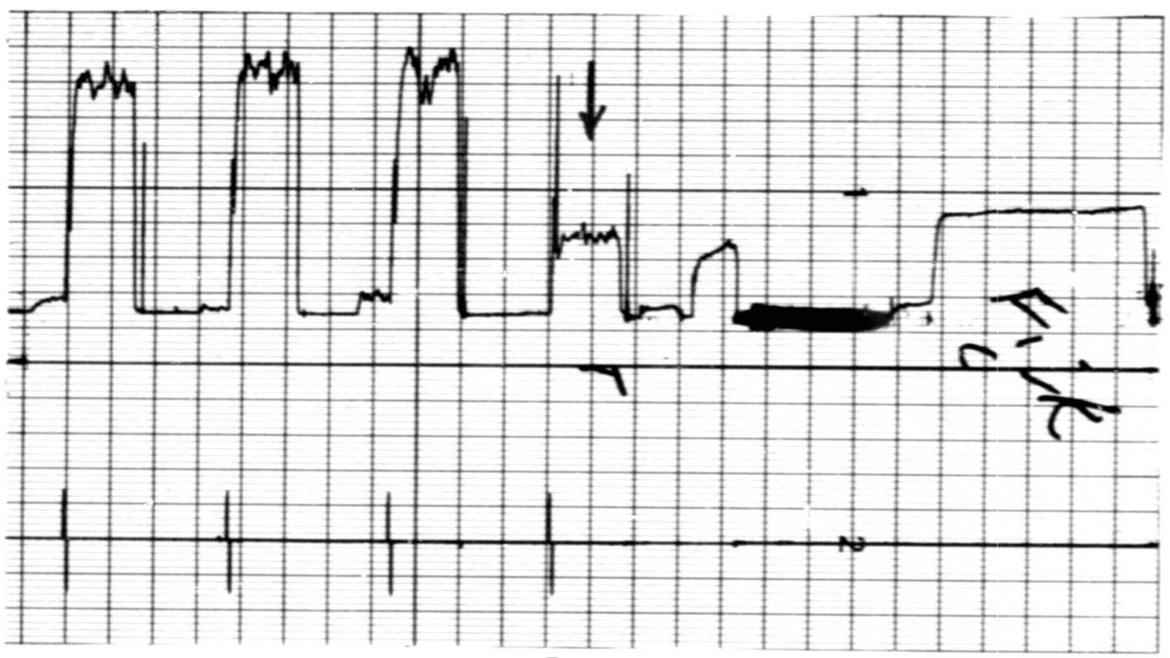
PHOTOGRAPHS OF THE X-RAY RESULTS DEPICTING THE TWO WELDS.

FIGURE 13

DEFECTS JOINT "D"

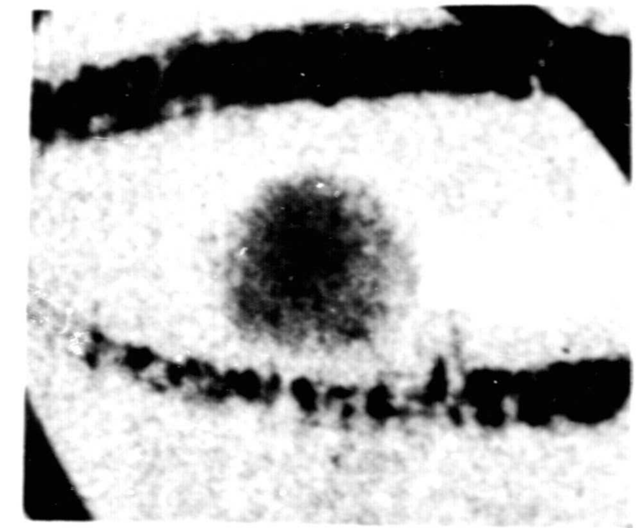


A

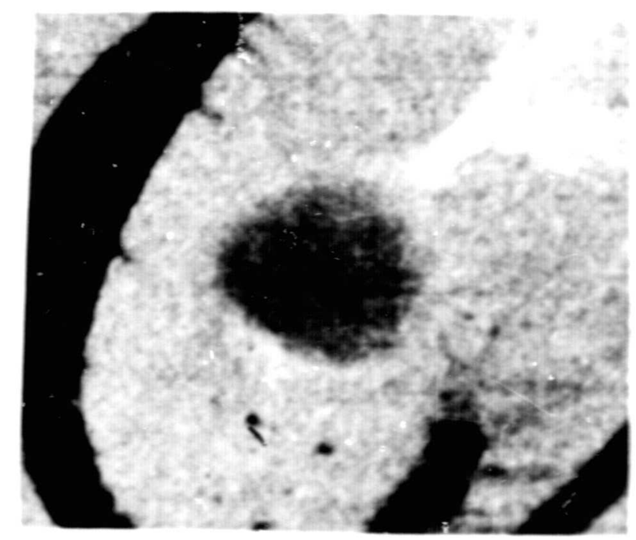


B

A & B - ULTRASONIC SIGNAL TRACES OF TYPICAL WELDS AND THE TRACES OF TWO "SPIT" WELDS.



C



D

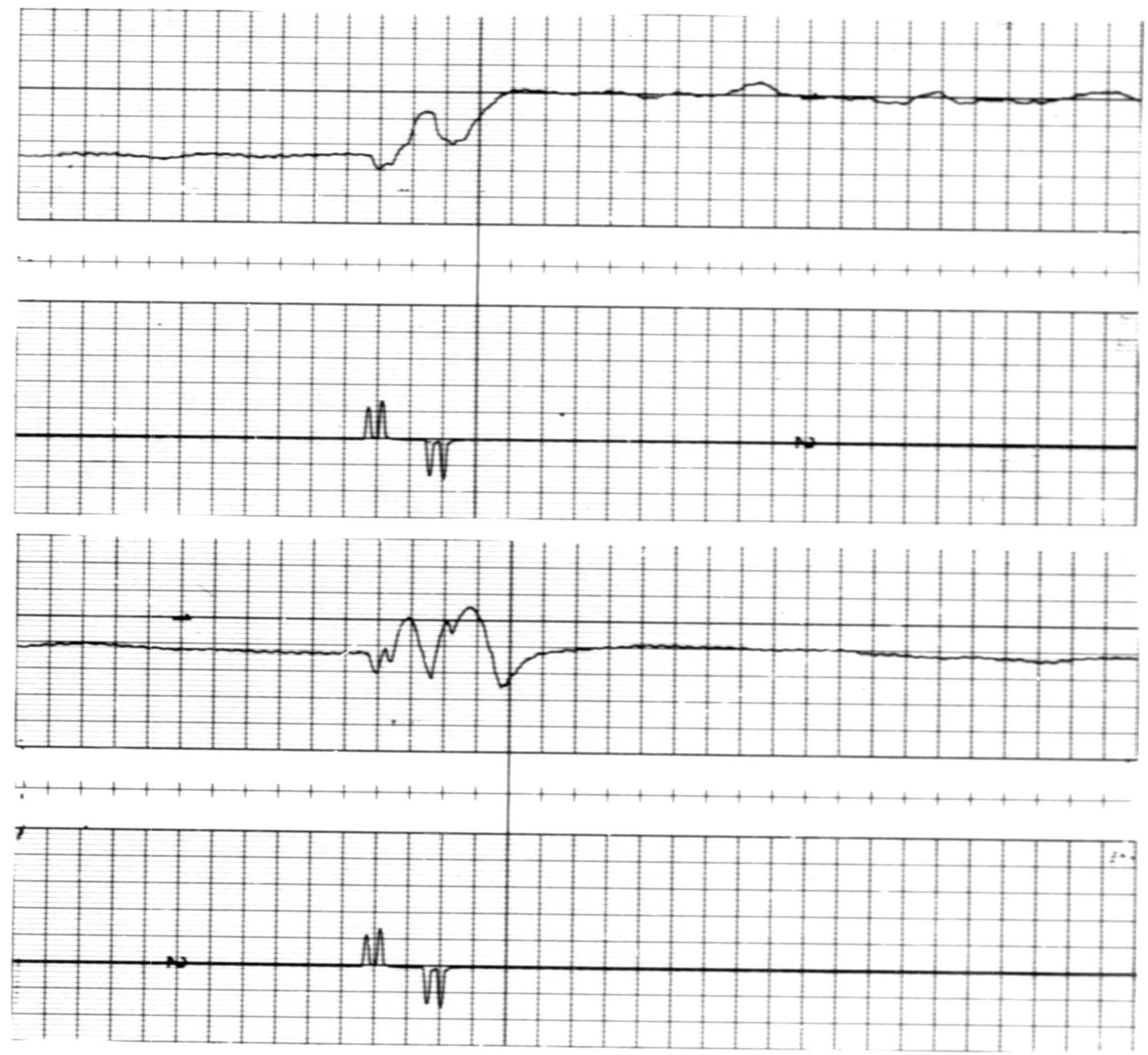
C & D - PHOTOGRAPHS OF THE X-RAY RESULTS DEPICTING THE TWO "SPIT" WELDS.

FIGURE 14

DEFECTS JOINT "E"

0	4	1	5
0	4	1	7
0	4	1	7
0	4	1	5
0	4	1	4
0	4	1	5
0	4	1	4
0	4	1	8
0	4	1	5
0	4	1	4
0	4	1	6

TYPICAL TECTOWELD READINGS FOR BOTH JOINTS.



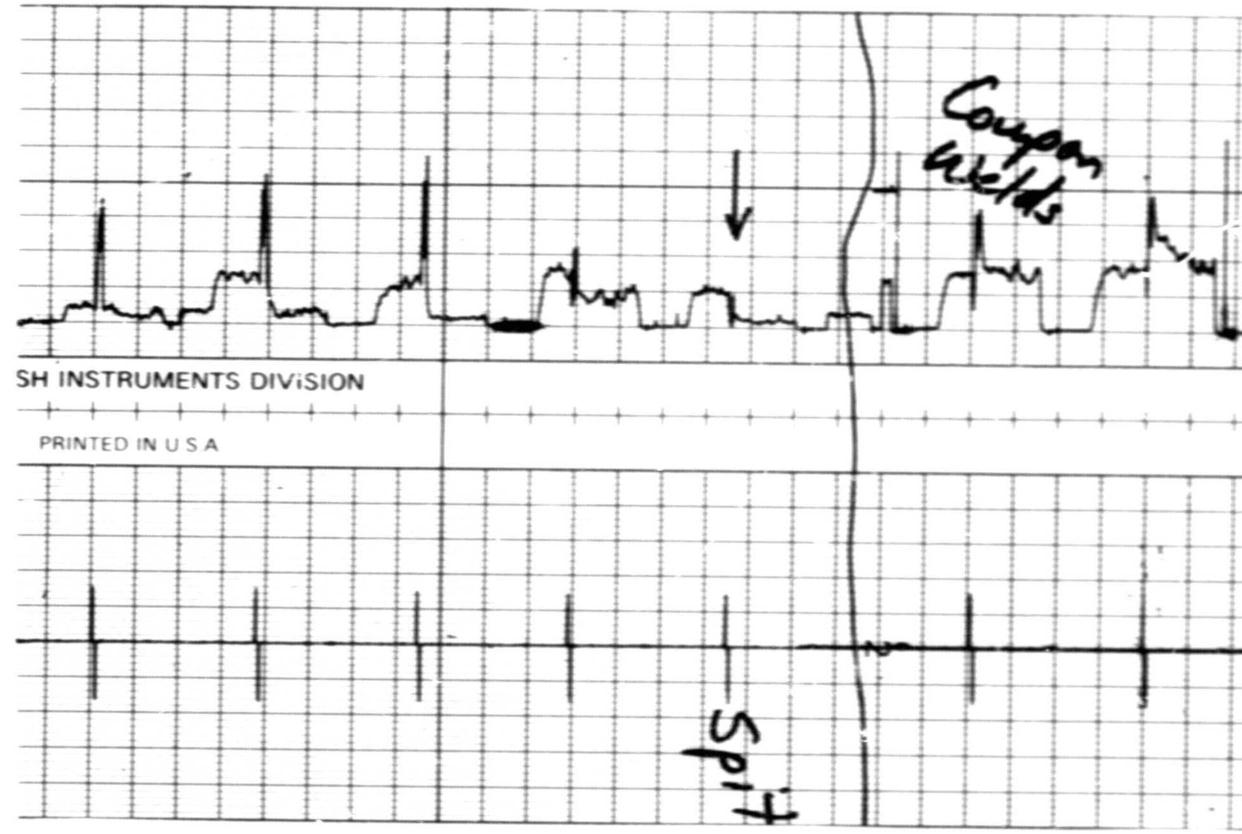
TYPICAL ULTRASONIC AND WELD CURRENT TRACES (UPPER AND LOWER TRACE RESPECTIVELY) SHOWING AN APPARENT RELATIONSHIP BETWEEN WELD CURRENT AND ULTRASONIC ENERGY LEVELS.

FIGURE 15

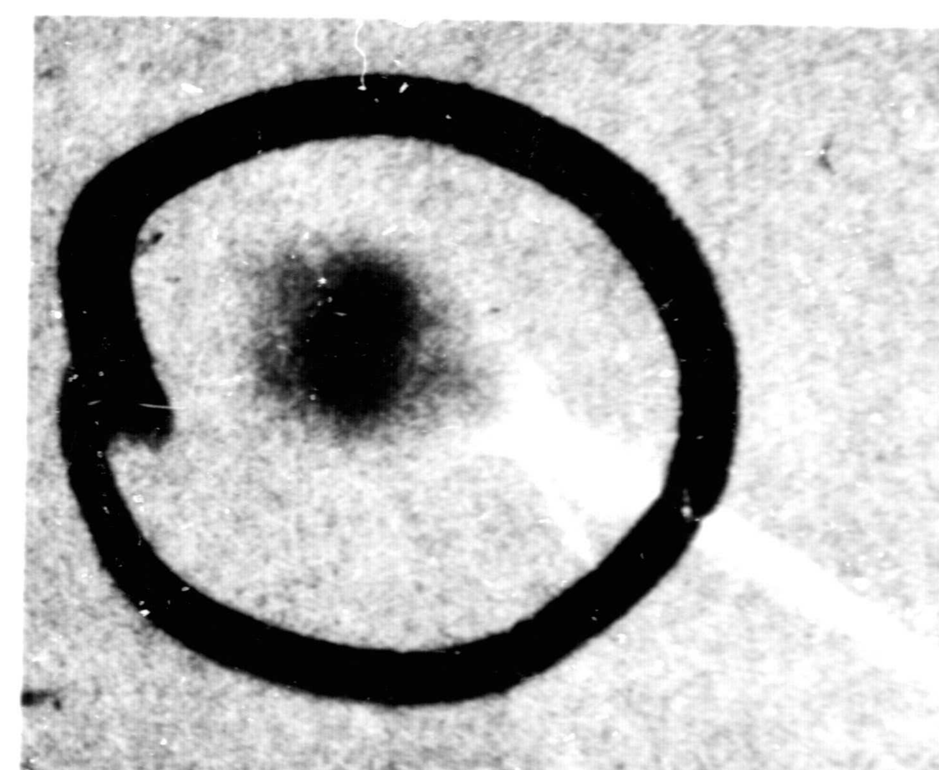
TYPICAL RESULTS JOINTS "E" & "F"

	0	5	8	2
	0	5	8	3
	0	5	8	3
	0	5	8	2
(28TH SPOT FROM XX QUAD 1/2) SPIT	0	5	7	8
	0	5	8	2
	0	5	8	1
	0	5	8	1
	0	5	8	1
	0	5	8	2
	0	5	8	3
	0	5	8	2
	0	5	8	2
	0	5	8	3
	0	5	8	5
	0	5	8	4
	0	5	8	5
	0	5	8	5
	0	5	8	7
	0	5	8	8
	0	5	8	7
CLEANED TIPS	0	5	8	9
	0	5	8	2
	0	5	8	2
	0	5	8	2
	0	5	8	2

A



B



C

A - TYPICAL TECTOWELD READINGS.

B - ULTRASONIC SIGNAL TRACE OF TYPICAL WELDS, ONE "SPIT" WELD AND THE TRACE OF A WELD APPROACHING A SPIT WELD CONDITION. (FOURTH WELD FROM THE LEFT).

C - PHOTOGRAPH OF THE X-RAY RESULTS DEPICTING THE "SPIT" WELD.

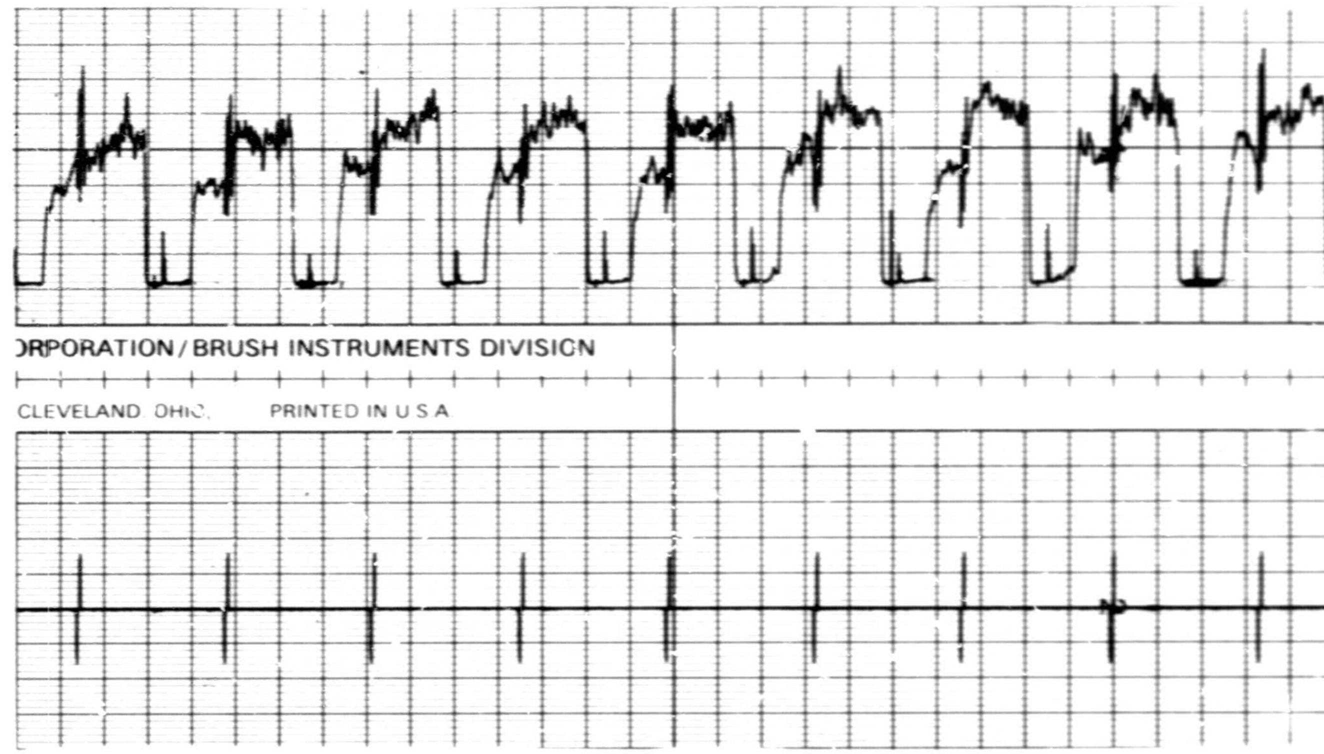
FIGURE 16

DEFECT STATION 282 JOINT "H"

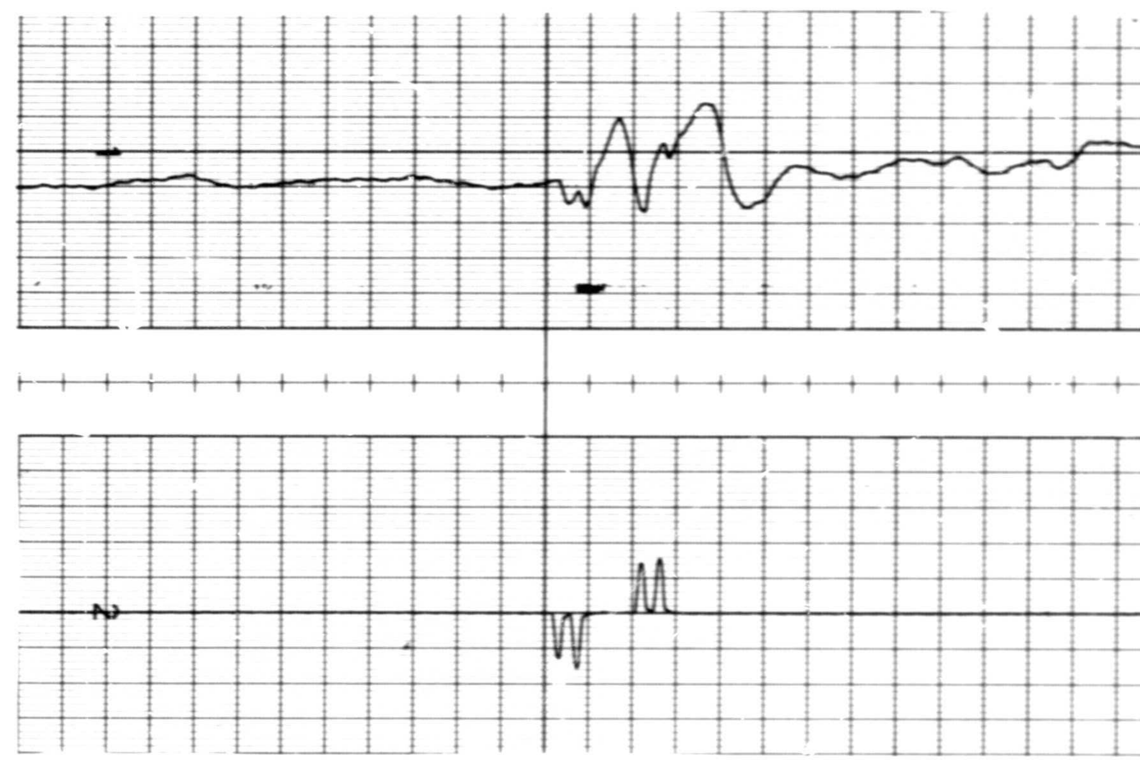
A -

0 5 9 2
0 5 9 3
0 5 9 5
0 5 9 3
0 5 9 4
QUAD 3 ——— 0 5 9 3
ON TACK ——— 0 7 6 2
0 5 9 4
0 5 9 2
0 5 9 2
0 5 9 1
0 5 9 1
0 5 9 3
0 5 9 1
0 5 9 2
0 5 9 2

B -



C -



A - TYPICAL TECTOWELD READINGS. NOTE AFFECT OF REWELDING TACK OFF CENTER.

B - ULTRASONIC SIGNAL TRACE OF TYPICAL WELDS, WITH WELD CURRENT SHOWN BELOW.

C - HIGH SPEED TRACE OF ULTRASONIC AND WELD CURRENT.

FIGURE 17

TYPICAL RESULTS STATION 344 JOINT "G"

0	4	7	3
0	4	6	9
0	4	6	7
0	4	7	1
0	4	8	0
0	4	7	6
0	5	0	5
0	4	7	5
0	4	7	4
0	4	7	2

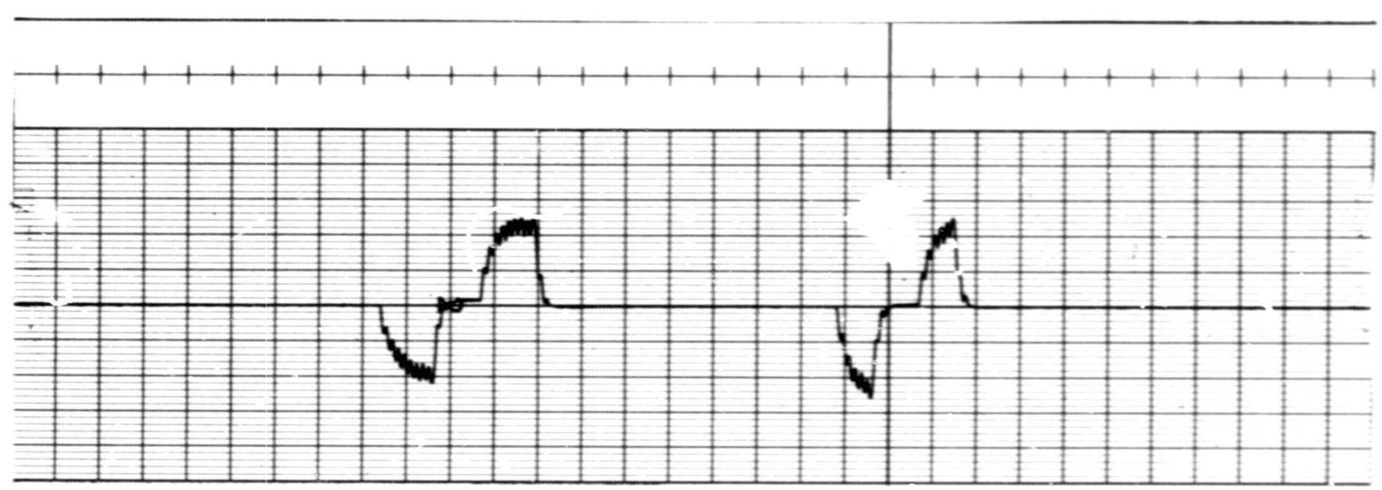
A

0	8	0	1
0	8	0	2
0	8	0	1
0	8	0	3
0	8	0	0
0	8	0	3
0	8	0	1
0	8	0	4
0	8	0	2
0	8	0	7
0	8	0	7
0	8	0	7
0	8	0	5
0	8	1	1
0	8	0	9
0	8	0	9
0	8	1	1
0	8	1	2
0	8	1	3

C

B -

D -



A - TYPICAL TECTOWELD READINGS FOR JOINT "K".

B - ULTRASONIC SIGNAL TRACE OF TYPICAL WELDS, WITH THE WELD CURRENT TRACE SHOWN BELOW (JOINT K).

C - TYPICAL TECTOWELD READINGS FOR JOINT "K_1".

D - WELD CURRENT TRACE FOR JOINT "K_1".

FIGURE 18

TYPICAL RESULTS JOINTS "K" & "K_1"

A
0 8 5 7
0 8 5 7
0 8 6 0
0 8 5 8
0 8 5 3
0 8 5 7
0 8 5 0
0 8 2 3
0 8 6 0
0 8 5 8
0 8 6 9
0 8 6 1
0 8 5 4
0 8 5 4
0 8 5 1
0 8 5 4
0 8 5 6
0 8 6 6
0 8 5 5
0 8 6 5
0 9 1 5
0 9 2 2

B	C
015200	015500
015200	015500
015100	015500
015100	015500
015100	015500
015000	015400
015000	015400
014900	015500
015000	015400
014900	015500
015000	015500
015000	015500
014900	015500
014900	015400
015000	015400
014900	015300
014900	015400
015100	015400
015100	015400
015000	015400
015100	015600
015100	015500
015000	015600
014900	015500
014900	015400
014800	015500
015000	015500
014800	015400
014800	015600
014900	015400
015000	015500
014900	015400
014800	015400
014900	015600
014900	015600
014900	015500
014200	015500
014900	015600
014900	015500
014800	015700

A - TYPICAL TECTOWELD READINGS FOR A 0.026" BRACKET ON A .003/.014/.010/.018 BUILDUP.

B - TYPICAL TECTOWELD READINGS FOR A DOUBLER BUILDUP OF .014/.010/.018.

C - TYPICAL TECTOWELD READINGS FOR A DOUBLER BUILDUP OF .014/.010

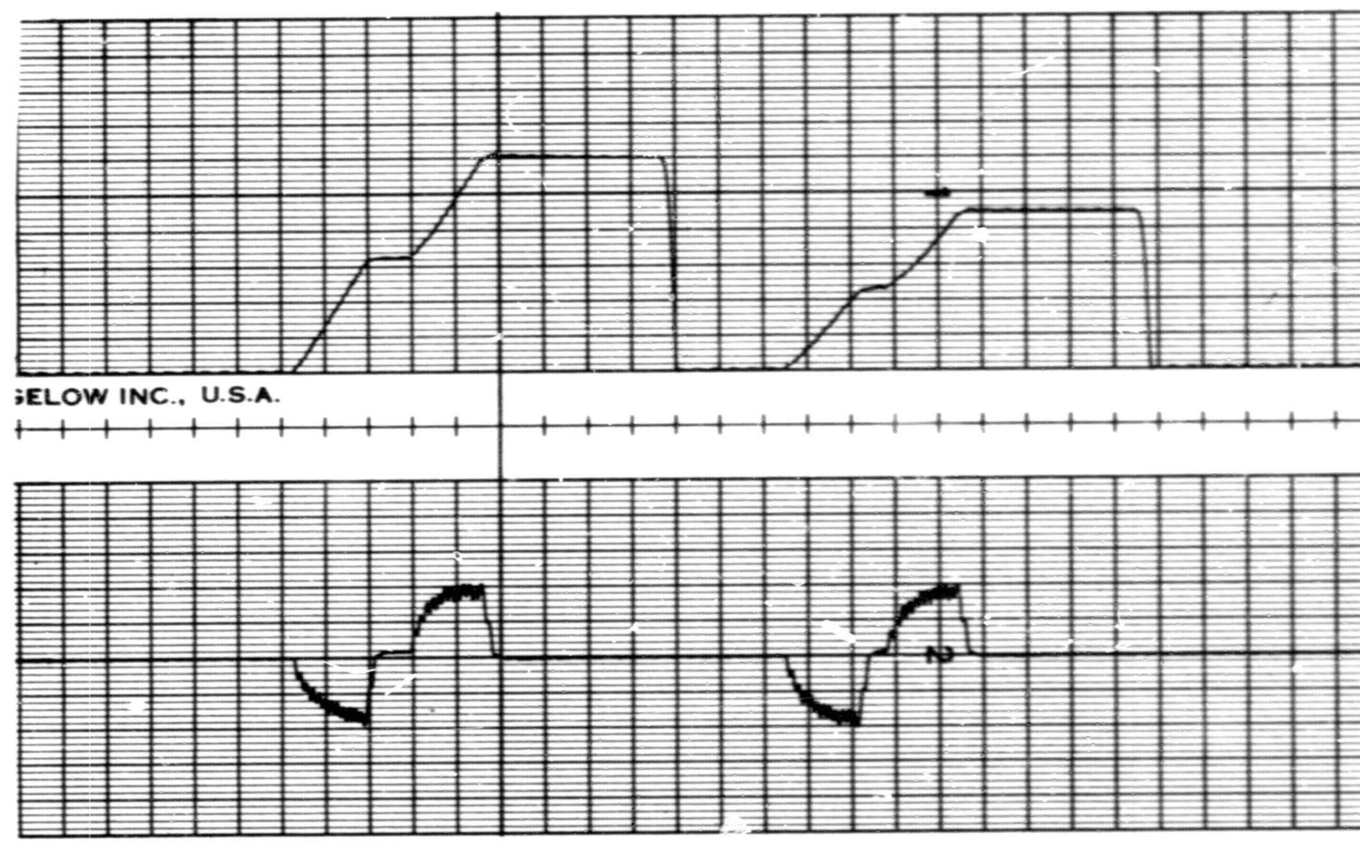
FIGURE 19

TYPICAL RESULTS FOR BANJO DOUBLERS AND BRACKETS

208600
206400
206400
204000
204900
205800
205600
205200
205500
206900
206900
204900
000000
204500
203900
000000
000000
000000
000000
000000
000000
000000
000000
000000
000000

A - TYPICAL TECTOWELD READINGS.

SENSOR GAP SETTING IS MARGINAL AND DAMPENING AFFECT OF MACHINE POSITION ADJUSTMENT CAUSED REDUCTION OF TOTAL EXPANSION AND LOSS OF DATA.

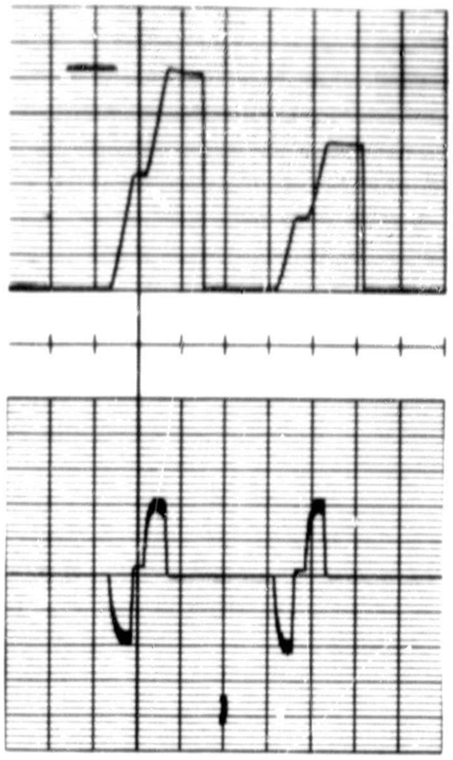


B - THE UPPER TRACE SHOWS A TYPICAL TRACE OF THE ENERGY LIMITER DEVICE OUTPUT, AND THE LOWER TRACE IS THE WELD CURRENT TRACE.

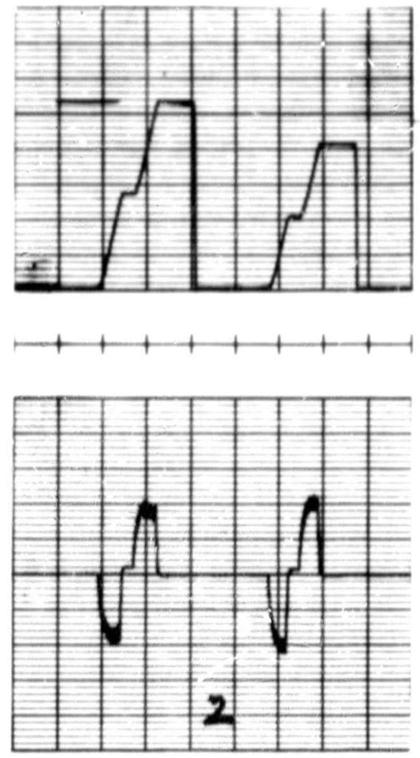
FIGURE 20

TYPICAL RESULTS JOINT "L"

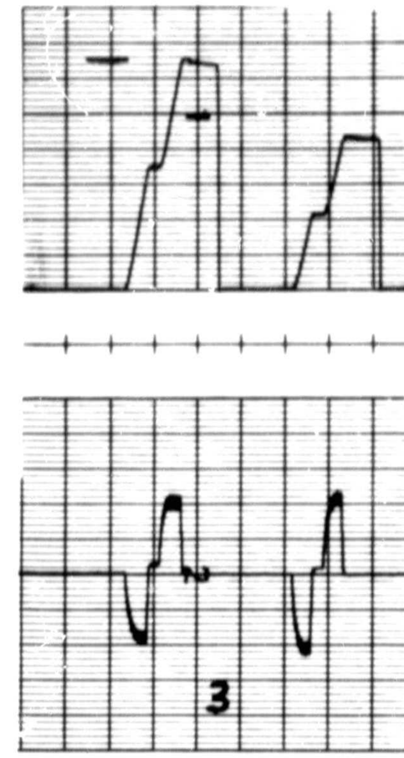
FIGURE 21 MISSING FROM THE ORIGINAL DOCUMENT



A



B



C

ENERGY LEVELS FOR "A" PRODUCTION HARDWARE, "B" REWELD OF TACKWELD ON PRODUCTION HARDWARE, AND "C" FINAL TEST SAMPLE.

28890-
28200-
28400-
28350-
28290-
28220-
28170-
(1) → 28100-
27950-
27890-
28060-
28100-
(2) → 000000
28670-
28140-
27860-
28050-
28010-
27930-
28120-
28140-
28290-
27940-
27840-

D - EXPANSION READINGS FOR "A" & "B"

141900
144700
142700
144900
141700
141600
(3) --- 149500
150300
149700

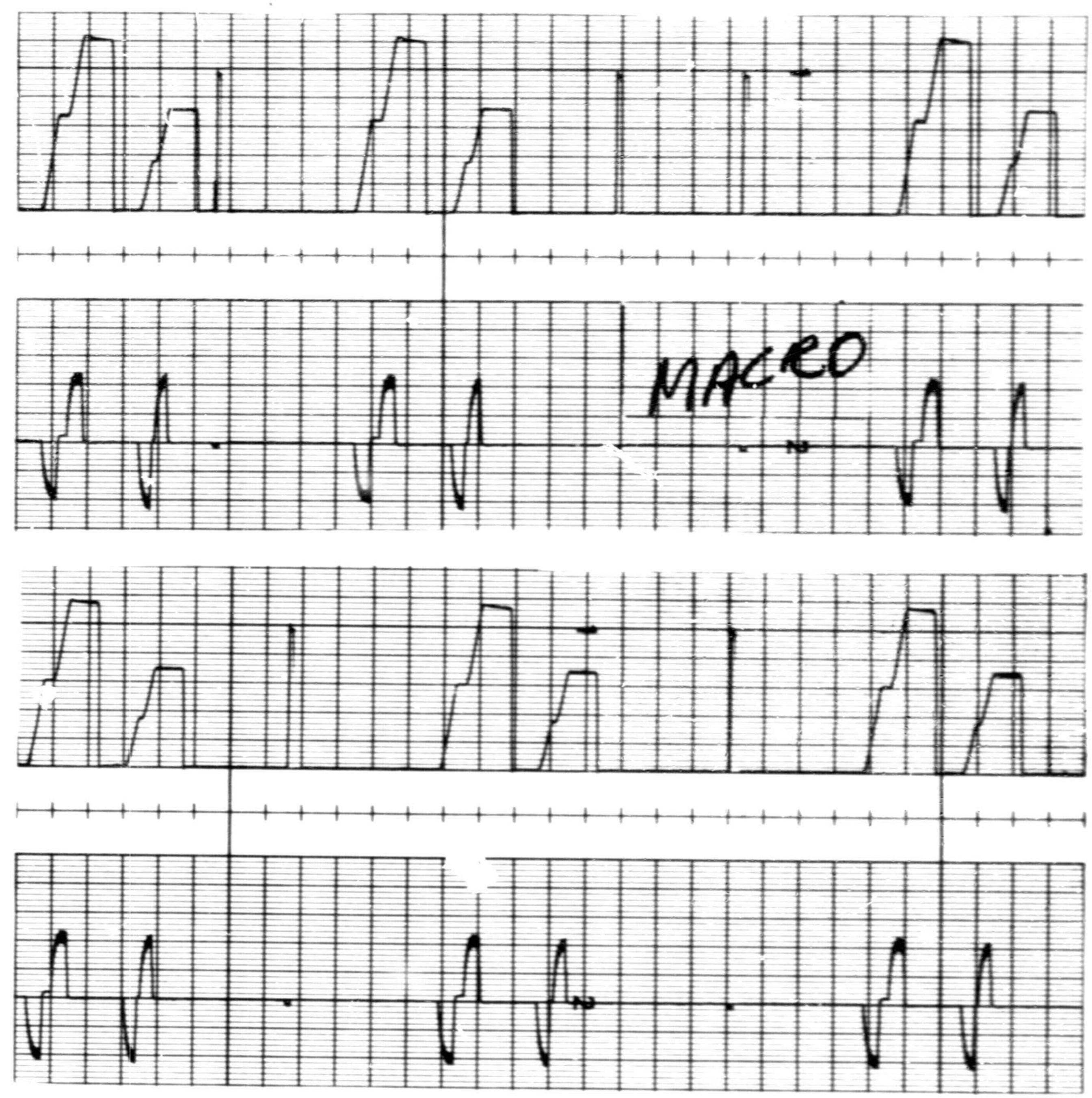
E - EXPANSION READINGS FOR FINAL TEST.

FIGURE 22

COMPARISON OF DATA JOINT "N"

127200
110000
110700
110800
112100
111500
116700
115700
130000

A



TYPICAL

252500
253300
252900
253900
252300
254600
250400
250500
250600
249100
247300
247200
247700
246100

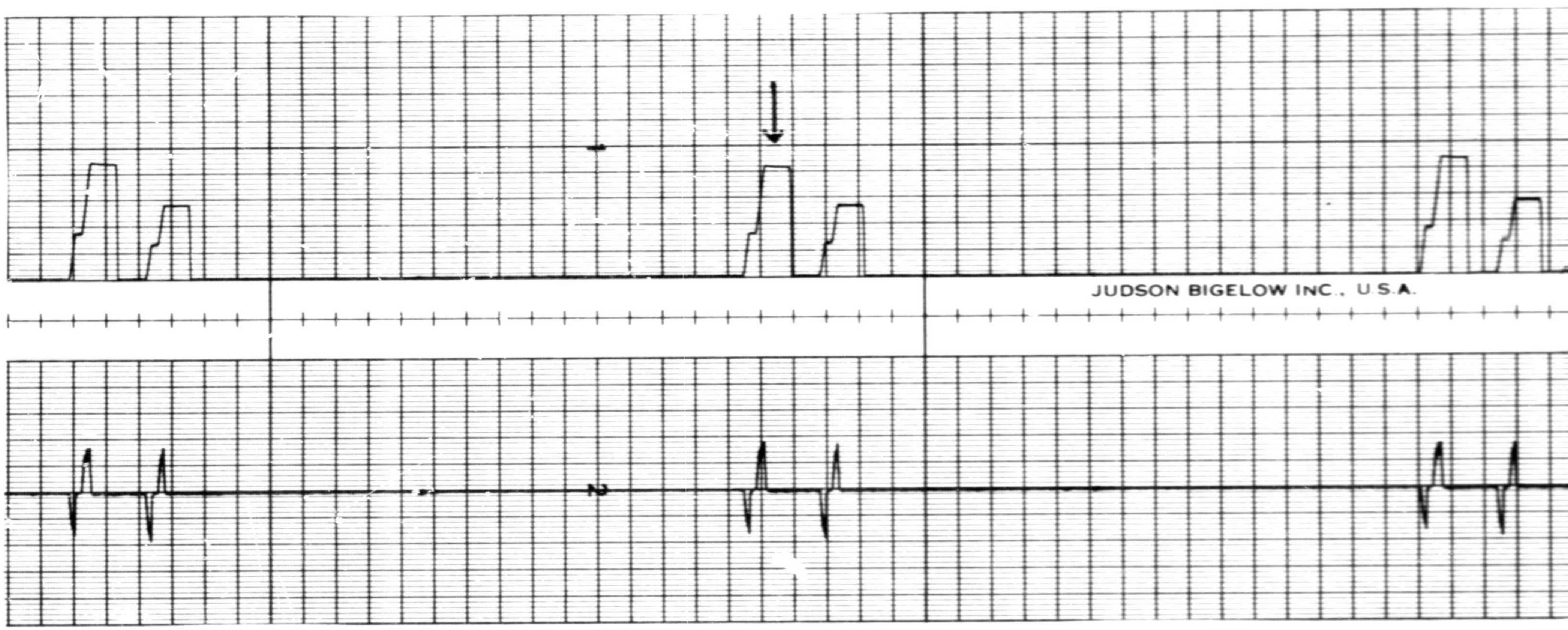
B

A - EXPANSION RATES & ENERGY LEVELS FOR FINAL TEST SAMPLES.

B - EXPANSION RATES & ENERGY LEVELS FOR PRODUCTION PART.

FIGURE 23

TYPICAL RESULTS JOINT "O"



096000
095500
095300
095700
095200
094700
093900
094300
095100
094700
→ 000000
093800
094100
094600
093200
093200
092900
092900
093700
093400
094200
094400

NOTE REDUCTION OF ENERGY LEVEL ON CENTER

WELD AND EFFECT ON EXPANSION RATE (ARROWS).

FIGURE 24

TYPICAL RESULTS JOINT "P"