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LIQUID METAL FUEL REACTOR
EXPERIMENT

INDUCTION WELDING FOR
REMOTE MAINTENANCE -- FINAL REPORT

MARCH 1960

THE BABCOCK & WILCOX COMPANY

ATOMIC ENERGY DIVISION

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INDUCTION WELDING FOR
REMOTE MAINTENANCE -- FINAL REPORT

MARCH 1960

By
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Research Center
Alliance, Ohio

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UNITED STATES ATOMIC ENERGY COMMISSION
BY
THE BABCOCK & WILCOX COMPANY

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ABSTRACT

The feasibility and techniques of induction welding for use in remote maintenance were successfully investigated. Microscopic and mechanical tests confirmed the soundness of welds made in Croloy and carbon steel pipes ranging in size from 1 1/2-in. Sch 40 to 12-in. Sch 40.*

Iron laminations on the welding inductor produce even heat around the weld, and an interrupted heating cycle aids the production of good welds.

Wall thickness of pipe to be welded is limited to between 3/16 and 1/2 in. by heat penetration and upset problems.

More precise forging pressure and the use of resistance heating with the induction heating process should further improve weld quality.

* Croloy 2-1/4 (2 1/4 Cr-1 Mo steel) and Croloy 1-1/4 (1 1/4 Cr-1/2 Mo steel)

I. INTRODUCTION

The first phase of the induction welding investigation, reported previously, was concerned with only one pipe size, 3.5-in. OD by 0.300-in. wall, and with only two pipe materials, carbon steel and Croloy 2-1/4.* A wide range of temperatures and forging pressures was used in an effort to find the basic requirements for a satisfactory joint. The primary objective in this work, however, was to establish that a weld joint could be made provided the necessary induction heat and forging pressure were available.

The most promising procedures from this preliminary work were selected, then refined so that satisfactory results could be predicted. After satisfactory welds were achieved in one size, other sizes (both larger and smaller) were given the same treatment during the phase of work reported here. Heating rates and forging pressures were proportional to the pipe size.

* LMFRE - First Progress Report on Induction Welding, BAW-1061, The Babcock and Wilcox Company, Lynchburg, October 1959.

II. DESCRIPTION OF APPARATUS

Power is supplied to the welding inductor by a totally enclosed, single-phase, high-frequency, inductor-alternator driven by a two-pole induction motor. Vertical construction places the motor and generator rotors on a common shaft. The unit is cooled by recirculated air that has passed over a finned-tube heat exchanger. The electrical output, 3000-cycle ac at 300 kw, powers the inductors through a reduced voltage transformer, a heating control station, and a multiple-tap transformer.

Forging pressure is supplied by a horizontal C-type frame with a welding fixture which positions and clamps the workpieces in line with a 50-ton hydraulic ram. Hydraulic pressure is supplied to the ram by an electrically driven pump. The pump and ram are products of a private concern; the welding fixture was designed and built at the B&W Alliance Research Center.

To accommodate planned pipe sizes, inductors were built for pipes ranging from 1-1/2 to 12-in. OD; inside diameters of these inductors ranged from 2-3/8 to 13-5/8 in. Figure 1 shows inductors covering this range of sizes. Other inductors designed to investigate special problems are shown in Figures 2-5.

The following basic mechanisms furnished a set of automatic controls

which (dependent upon the heat at the weld joint) interrupted the heating cycle during the forging process.

1. Starting switch, to start current flow through the inductor.
2. Two limit microswitches ("C" in Fig. 6), which may be actuated by a preset amount of relative movement between the workpieces. (The first microswitch interrupts the electrical current flow through the inductor, the second stops the electrical current flow at the end of the cycle.)
3. One pneumatic delay timer (2 to 30 sec range), to control the "off" time between the first and second heating cycles with an accuracy of ± 0.1 sec.

All the relays and other electrical apparatus necessary to accomplish automatic controlling of the weld cycle are contained in a compact package unit mounted on the welding fixture (Fig. 6).

Two commercial d-c milliammeter strip-chart recorders ("A" and "B" in Fig. 6) were added to the welding apparatus to obtain temperature data. The charts in these recorders are driven by electric motors which provide speeds of 3/4, 3, 6, and 12 ipm and iph through a manual speed shift. Figure 7 shows a temperature record for a weld of 6 5/8-in. OD x 0.280-in. wall Croloy-2-1/4 pipe.

Chromel-alumel thermocouples, first used in an attempt to get temperature data on the complete welding cycle, proved unsatisfactory because they did not consistently "live" through the high-temperature interval. However, platinum-rhodium thermocouples proved satisfactory.

A drop-hammer device was fabricated to supply impact forging force; Figure 8 shows this unit with the original welding fixture in place.

III. TEST PROCEDURE

The original test procedure was only slightly changed during the second phase of work. Equipment was added in order to obtain additional information on heat control. Weld quality was determined by macroscopic examination and either tensile or 180-degree guided bend tests. The stress-relieved welds were hardness-tested to determine the relative effectiveness of the different heat treatments. Photomicrographs of several weld joints (Figs. 9-12) showed the typical metallurgical structure expected.

Much work was directed toward applying the process to a greater range of material sizes, determining the approximate equipment operating range, and developing the technique. Throughout the testing program, data on each weld joint were recorded on appropriate data sheets, these sheets are as shown in the Appendix. From this information any weld listed may be reproduced. Also shown is a pictorial history of each joint, including the inside and outside appearance, bend test results, and other significant data. Each specimen is identified by a Trial No. to provide correlation between the data sheets and the pictorial record.

IV. RESULTS

After making equipment changes and developing the welding techniques, consistently good results were obtained on 3-in. Sch 80 pipe. It was then possible to apply comparable welding parameters to larger and smaller pipe.

Pipes ranging in size from 2-in. Sch 40 to 12-in. Sch 40 were satisfactorily induction-forge-welded. Weld quality was checked by 180-degree guided root and face bends, but before acceptable guided bend tests could be made on Croloy 2-1/4 or 1-1/4 the joint had to be stress-relieved either by induction heating or a furnace heat treatment. A 2-hr heat treatment at 1350 F followed by air cooling satisfactorily reduced hardness at the joint.

Bend test results and inside and outside weld appearances of successful welds are shown in Figures 13-21. Figure 22 shows hydrostatic tests of welds on 6-in. Sch 40 Croloy 2-1/4 pipe. Hydrostatic tests of joints made in 1 1/2-in. Sch 40 Croloy 2-1/4 and 1-1/4 pipe are shown in Figure 23. This smaller size approached the lower limit of the unit's capacity.

The dept of 3000-cycle high frequency heating caused the entire wall thickness of the 1 1/2-in. Sch 40 pipe (0.145-in.) to become heated very quickly; thus, precise control over the forging force is critical. Since the area of the contacting surfaces at the joint is less than 1 sq in., the

required forging force is approximately 2,000 lb. The equipment was originally designed to operate between 1,000 and 100,000 lb force, which makes accurate control in the low range (0 to 3,000 lb) difficult. However, welds were made and some satisfactory root and face bends were obtained. The lowest hydrostatic pressure causing failure was 14,900 psi, which would create an 82,700 psi fiber stress in the Croloy 2-1/4. This value is higher than that given in the "handbook" (60,000 psi) as the minimum tensile strength expected.

V. DISCUSSION OF RESULTS

Much of the work reported here was directed toward eliminating the two major difficulties encountered during the preliminary phase of study:

1. Lack of uniform peripheral heating, which caused the quality of butt joints to vary, and
2. Incomplete fusion of the inner edges of the joints.

Figures 24-27 show how iron laminations in the magnetic field of a single-turn welding inductor can influence peripheral heating. By experimenting with different combinations of iron laminations and mountings near the inductor split, good control of heating uniformity was achieved. The results of bend tests on two subsequent induction welds were superior to previous work done without laminations (Fig. 13).

The inside and outside temperatures of the weld joint were recorded during heating, and from this data was developed an interrupted heating cycle which maintained constant heat at the joint for a prolonged period while heat flowed to the joint's inner edges by conduction. Thus, the temperature difference between the inner and outer edges of the joint was minimized, as shown in Figure 7. Macroscopic examination and 180-degree guided bend tests also showed that this method improves heat penetration and results in better fusion of the inner edges of the joints.

After the welding procedure was satisfactorily developed, the process

was automated. A system of limit microswitches and a time-delay circuit allowed the weld to complete an interrupted heating cycle with constant forging pressure. By properly positioning the workpieces and inductor, consistently uniform welds were produced. Figure 16 shows several joints made under identical welding conditions.

The automatic control system helped adapt the welding process to new sizes since, by eliminating manual control, the operator could closely observe the reaction of the materials being welded. In addition, slight changes in the welding procedure could be made with no discrepancy in timing or judgment. As to the mechanism of control, the current flow through the welding inductor is stopped or interrupted by the relative movement between the workpieces, and the heat applied is thus a direct function of the heat built up in the pieces being joined.

The rate of movement of the forging head can drastically affect the characteristics of the joint. A fast forging movement offered the possibility of a good joint with less movement between the workpieces and less upset at the joint.

Since impact represented the fastest possible forging movement, six welds (Trial No. 259-264) were made with the impact device shown in Figure 8. Bend tests on several of these test joints were satisfactory when the relative movement between the two workpieces was only 1/16 in. and the upset at the joint was negligible.

VI. MAJOR INDUCTION WELDING PARAMETERS

Since the literature contains only scanty reference to induction forge butt welding, the parameters considered important to its successful application are given here. There are probably an infinite number of combinations of different parameters that can be used successfully. Therefore, the following should be considered not as infallible rules but simply as the rules that proved best in the application under study.

A. INDUCTOR DESIGN

1. Number of Turns

The inductors -- fabricated from weldable copper of high conductivity -- were limited to single-turn designs for several reasons:

1. It was found practical to limit the width of the heat band at the joint. (The width of the band is a direct function of inductor width.)
2. The minimum spacing required for insulation between coils increases the width of a multiturn inductor.
3. The high currents carried in the inductor necessitated a hollow design to accommodate a flow of cooling water.

2. Section of Inductor Width and Radial Clearance

The inductors should be wide enough to carry high currents, and

regid enough to maintain position throughout the positioning and welding cycle. The general rule of thumb used here was inducator width = 2 (tube wall thickness), and coupling = tube wall thickness. This is illustrated in the following sketch.

3. Laminations

Single-turn inductors tend to heat unevenly around the tube, leaving the area at the split of the inductor at a lower temperature than the rest of the weld. However, steel laminations in the magnetic field of the inductor does strengthen the heating effect in this area.

The laminations were fabricated from the conventional 1/32-in. thick silicon steel usually used for transformer applications. From two to five laminations on each side of the inductor effectively altered the heat pattern, producing uniform heating, as shown in Figures 24-27.

4. Alignment and Eccentricity

Positioning control should be precise enough to control concentricity and centering of the inductor over the butted ends to $\pm 1/32$ in.

B. FORGING PRESSURE

1. Type

The forging force used in this work was supplied by a hydraulic ram, which provided a wide range of controllable forces.

2. Forging Speed

The limited volume of the electrical pump, fixed the speed of the movable head at 3/4 ipm. Although this rate of travel may not be ideal it was characteristic of the available equipment, and the other welding parameters were adjusted to fit. A more versatile source of pressure, say one that could vary the rate of travel from 1/2 to 20 ipm, would be valuable in further exploration of this method.

3. Control of Forging Force

Sufficient force is applied to the workpieces to give approximately 265 psi over the joint area -- before as well as during the heating cycle. Higher pressures cause upset and prevent fusion; lower pressures cause overheating of the joint area.

Therefore, the relative movement of the two pieces is used as a measure of heat input, the limit switches being preset to stop electric power input when movement between the workpieces is optimum. This procedure gives a much more accurate measure of heat input than does the "time" method.

C. POWER INPUT

1. Required Capacity

The 300 kw, 3000-cycle alternator is rated to produce 800 at 375 amp. This output is fed into a single-turn secondary transformer which has a range, through the use of selective taps, of from 8 through 17 turns on the primary. Best results were obtained with turn ratios of 10:1 or 13:1.

See Figure 28 for the power requirements for various pipe sizes.

2. Heating Time

In working with a variety of wall thicknesses, a short heating period seems desirable. A heating time of about 10 to 15 sec per 1/8 in. of wall thickness has given good results. A shorter heating time does not allow the inner edges to reach the optimum welding temperature; a longer heating time may cause an excessively wide heat band at the joint. (A wide heat band causes flaring out at the joint area, and the loss of strength from high temperature interferes with proper forging pressure.)

3. Temperature

Platinum-rhodium thermocouples indicated temperatures during each welding cycle. Heating takes place progressively, starting on the outside and progressing inward. With wall thicknesses of 1/4 in. or more, the outside of the joint may reach the desired temperature (2400 to 2600 F) before the inside edge does. In this case, it is best to interrupt the heating cycle for 5 to 8 sec to avoid overheating of the outer edges and to permit the heat to flow toward the inner edges by conduction. Thermocouples located near the inner and outer edges showed that when the power was off, temperature differences between these points were considerable less than when the power was on. (See Fig. 7.) Mechanical tests on these joints show better fusion of the inner edges.

D. WELDING PREPARATION

The pipe ends must have a flat machined surface so that the fitup excludes most of the air and limits oxidation on the mating surfaces. As shown in Figure 29, extensive oxidation occurs when two reasonably flat surfaces are held tightly together under an oxidizing temperature and different pressures.

Figure 30 shows the fractured surface of a weld that was not prepared according to standard procedure. The fitup was very poor as were the results of hydrostatic testing. The specimen failed at the joint under an internal pressure of 4500 psi. Hydrostatic testing of two properly

prepared pipes produced rupture in the pipe walls away from the joint, at 6300 and 6400 psi respectively. (See Fig. 22 & Table I.)

TABLE I
HYDROSTATIC TESTS OF 1 1/2-IN. SCH 40
INDUCTION FORGE WELDS

(See Fig. 23)

<u>Specimen</u>	<u>Material</u>	<u>Internal Pressure at Failure, psi</u>	<u>Fiber Stress in Pipe Well, psi</u>	<u>Remarks</u>
A	Croloy 2-1/4	15,200	83,500	Pin hole in center weld
B	Croloy 1-1/4	14,900	82,700	Rupture lengthwise of specimen
C	Croloy 1-1/4	15,500	85,300	Rupture lengthwise of specimen
D	Croloy 2-1/4	15,200	83,500	Pin hole in end weld

VII. CONCLUSIONS

1. Sound butt welds can be made in Croloy pipe ranging in size from 1 1/2-in. Sch 40 to 12-in. Sch 40.
2. Satisfactory joints can be made without inert gas shielding.
3. Iron laminations mounted in the inductor's magnetic field improve both efficiency and uniformity of peripheral heating.
4. Interruption of the heating cycle with a system of automatic controls promotes better fusion of the inner edges of the joint and assures consistent results.
5. It would be difficult to join a wall thickness less than 3/16 in. or greater than 1/2 in. using equipment with a 300-cycle frequency.
6. A relative movement equal to the wall thickness is required between the parts being joined. Better control of forging speed may reduce the amount of travel required.

VIII. RECOMMENDATIONS

Although this method of welding produces consistently sound welds, further refinement is necessary to determine the merits of the different speeds of relative movement.

A precision-engineered machine with flexible pressure scheduling should be designed to include (1) controls to vary the speed of relative movement between the workpieces, and (2) enough capacity to maintain constant forging pressure and movement while the workpieces are at proper forging temperature.

A recent development that should be more thoroughly evaluated is the possibility of applying both induction and resistance heating to the joint faces. B&W's Barberton Works has applied this process to heavy-walled tubes of small diameter with excellent results. The characteristics of the two methods may be combined so as to complement each other and produce uniform peripheral heating with complete fusion of the inner edges. (This might eliminate the difficulty involved in welding heavy-walled tubes.) This combination could prove to be superior to either method used independently.

FIG. 1: WELDING INDUCTORS

FIG. 2: SPECIAL WELDING INDUCTORS

FIG. 3: SPECIAL WELDING INDUCTOR SHOWING FLEXIBLE
LAMINATION SUPPORTS

FIG. 4: TRIANGULAR-SECTIONED WELDING INDUCTOR

FIG. 5: WELDING INDUCTOR WITH INERT GAS SHIELDING

FIG. 6: HIGH FREQUENCY INDUCTION FORGE WELDING EQUIPMENT

FIG. 7: INDUCTION WELD TEMPERATURE RECORD

The solid line is the temperature indicated by the Pt-Rh thermocouple inside the joint. The dotted line indicates Δt , or the difference of the inside and outside temperatures.

Along the top of the chart is a solid line made by a chronograph pen attachment. The first mark on the extreme right indicates that the induction heat was turned on. Moving along this line from right to left, the next mark indicates that the heat was turned off; the next mark, on; the next mark, off for the final time.

FIG. 8: DROP HAMMER IMPACT DEVICE

FIG. 9: PHOTOMICROGRAPHS OF A WELD ON 2 1/2-IN. OD PIPE

2.5-in. OD x 0.25-in. Wall Croloy 2-1/4 3X

0.040 in. from outer
edge of joint upset

Typical microstructure

0.045 in. from inner
edge of joint upset

FIG. 10: PHOTOMICROGRAPHS OF A WELD ON 3-IN. OD PIPE

3-in. Sch 80 Croloy 2-1/4

3X

Typical microstructure

0.040 in. from outer
edge of joint upset

0.040 in. from inner
edge of joint upset

FIG. 11: PHOTOMICROGRAPHS OF A WELD ON 6-IN. OD PIPE

6.625-in. OD x 0.313-in. Wall Croloy 2-1/4 3X

0.050 in. from outer
edge of joint upset

Typical microstructure

0.050 in from inner
edge of joint upset

FIG. 12: PHOTOMICROGRAPHS OF A WELD ON 8-IN. OD PIPE

8.625-in. OD x 0.4375-in. Wall Croloy 2-1/4 3X

0.060 in. from outer edge of joint upset

0.060 in. from inner edge of joint upset

0.040 in. from outer edge of joint upset

Typical microstructure

0.045 in. from inner edge of joint upset

FIG. 13: BEND TEST RESULTS -- 3-IN. SCH 80 CARBON STEEL PIPE

FIG. 14: BEND TEST RESULTS -- 3-IN. SCH 80 PIPE

FIG. 15: FLATTENED BEND TEST RESULTS -- 3-IN. SCH 40 PIPE

FIG. 16: BEND TEST RESULTS -- 6-IN. SCH 40 CROLOY 2-1/4 PIPE

FIG. 17: BEND TEST RESULTS -- 2-IN. SCH 40 CROLOY 2-1/4 PIPE

FIG. 18: BEND TEST RESULTS -- 6-IN. SCH 40 CROLOY 2-1/4 PIPE

FIG. 19: FLATTENED BEND TESTS -- 6-IN. SCH 40
CROLOY 2-1/4 PIPE

FIG. 20: BEND TEST RESULTS -- 8-IN. SCH 60 CROLOY 2-1/4 PIPE

FIG. 21: BEND TEST RESULTS -- 12-IN. SCH 40 CROLOY 2-1/4 PIPE

FACE

ROOT

FIG. 22: HYDROSTATIC TEST -- 6-IN. SCH 40 CROLOY 2-1/4 PIPE

FIG. 23: HYDROSTATIC TEST -- 1 1/2-IN. SCH 40 PIPE

Specimen A
Croloy 2-1/4
15,200 psi

Specimen B
Croloy 1-1/4
14,900 psi

Specimen C
Croloy 1-1/4
15,500 psi

Specimen D
Croloy 2-1/4
15,200 psi

FIG. 24: MAGNETOGRAPHS

FIG. 25: EFFECTS OF IRON LAMINATIONS -- OUTSIDE SURFACE

With Laminations

Without Laminations

FIG. 26: EFFECTS OF IRON LAMINATIONS -- INSIDE SURFACE

With Laminations

Without Laminations

FIG. 27: POWER REQUIREMENT VERSUS JOINT AREA

FIG. 28: OXIDATION TEST RESULTS

No Argon

With Argon

Inside Only

FIG. 29: HYDROSTATIC TEST RESULTS ON IMPROPERLY
PREPARED PIPE

IX. APPENDICES

APPENDIX A

INDUCTION FORGE WELDING DATA -- TABLES

NOTES

1. The hardness shown in the "Heat Treat" column is in terms of Rockwell c.
2. "L" when shown under "Inductor Type" indicates that the inductor was fitted with laminations to equalize circumferential heating.
3. Under "Welding Temperature" the ID welding temperature is shown. When interrupted heating was used the left hand "Max." indicates the first peak, the right "Max." the second peak. The "Min." records the slightly lower temperature between peaks. "Dt" records the difference between the outside and inside pipe - OD temperature minus the ID temperature.

DATE TRIAL	V, % A, %	KW, % FIELD POWER- STAT SETTING	KVAR, %		FORCE, KIPS	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD	JOINT AREA IN. ²		H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>11-25</u> 104		<u>30</u>	6		<u>6.0</u> 2.1	2.9			<u>13</u> 1	Single turn W=5/8 H=3/4 Modified Oval	1/4	<u>5/32</u>	¹³ 3 1/4 O.D. x 2 .6 I.D. carbon steel. Heat was stopped at approx. 3/32" pushup. All face bends except quadrant "D" were good. No root bend tests were made. Joint showed signs of excessive heat excepting quadrant "D", at the inductor split.
<u>11-26</u> 105		<u>35-25</u>	"		<u>33-8</u> 3.1	10.6-2.6			"	"	"	<u>1/4</u>	Croloy 2 1/4. High pressure applied for first 1/16" of pushup. 3 out of 4 face bends were good and 2 out of 4 root bends were good. Powerstat setting was reduced with pressure.
<u>12-2</u> 106		<u>35</u>	"						"	"	"	<u>None</u>	Croloy 2 1/4. This was a first attempt at joining the butted ends by induction melting. The edges were heated till melting occurred. No gas protection or ceramic mold was used. Metal melted and ran down both sides.
<u>12-5</u> 107	<u>50</u> 50	<u>16</u> 30		0	<u>40-15</u> 6.2	6.5-2.4	113.0	113.0	<u>13</u> 1	Single turn W=1/2 H=3/4 Rect.		<u>1/4</u>	6 5/8 O.D. Croloy 2 1/4, .313" wall. This was a first attempt on the larger diam. heavier wall tube. Only 3 face bends were good. All root bends were n.g. Heating was slow and upset was rounded. Macros showed lack of penetration through wall.
<u>12-10</u> 108	<u>50</u> 60	<u>20</u> 26		10 - 0	<u>40-15</u> 6.2	6.5-2.4	139.0	139.0	<u>9</u> 1	"		<u>1/4</u>	6 5/8 O.D. Croloy 2 1/4 .313" wall. Transformer taps were changed to improve heating efficiency but heating did not show significant improvement. Heating cycle was longer and still the heat was insufficient.

DATE TRIAL	V, A	KW, FIELD POWER STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>12-11</u> 109	<u>70</u>			10 - 0	<u>40-8</u> 3.1	13.0-2.6			<u>9</u> 1	Single turn W=1/2 H=3/4 Rect. with L.		<u>1/4</u>	Carbon steel. Initial pushup 1/16". Pressure reduced after initial pushup. Placement of a 4-pc. lamination pile on either side of the split proved very helpful. Altho this weld showed evidence of excessive heat on outside and inside, good face and root bends were obtained from each quadrant.
<u>12-11</u> 110	<u>65</u>			"	"	"			"	"		<u>1/4</u>	Initial pushup 1/8. Carbon steel. Contrary to #109 this joint appeared to have not enough heat. The results of bend tests, however, were identical to #109. These were the first two joints made with the aid of laminations in the magnetic field and results were far better than anything done previous to this time.
<u>12-13</u> 111	<u>68</u>			"	"	"			"	"		<u>1/4</u>	Initial pushup 1/16". Carbon steel. Face bends from each quadrant were good. Only quadrants "B" and "D" produced good root bends.

DATE TRIAL	V, % A, %	KW, % FIELD POWER STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>12-18</u> 112	70	<u>36</u>	10		<u>40-8</u> 3.1	12.9-2.6	39.5	39.5	9/1	Single turn with L. 1/2 x 3/4 Rect.	3/8	1/4	Only 2 face bends were good. Joint showed evidence of uneven heating with highest heat at the split.
<u>12-18</u> 113	"	"	"		"	"	"	"	"	"	"	"	Adjusted laminations outward 1/16". Heating proved to be more even. All face bends were good. Only quadrant "D" produced good root bend.
<u>12-18</u> 114	"	"	"		"	"	"	"	"	"	"	"	Excess heating was again observed in quadrants "A" and "D". These quadrants produced good root and face bends. Quadrants "B" and "D" pro- duced good face bends but root bends failed at approx. 80°.
<u>12-18</u> 115	"	"	"		<u>8</u> 3.1	2.6	39.0	39.0	"	"	"	"	All face bends were ok. Outside appearance was ragged and split. Fusion appeared to be all the way thru the wall thickness but quadrants "B" and "D" root bends failed.
<u>12-18</u> 116	"	"	"		"	"	40.0	"	"	"	"	<u>5</u> 32	Only quadrant "D" face bend failed. Outside surface showed ragged narrow ridge of upset.

DATE TRIAL	V, % A, %	KW, % FIELD POWER.. STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>12-19</u> 117	<u>70</u>	<u>34</u>	10		8	2.6	40.0	40.0	9/1	Single turn with L. 1/2 x 3/4 Rect.	3/8	1/4	2 1/4 Croloy. Inside upset was excessive and ragged. Root and face bends failed with brittle fracture. Fusion was good.
<u>12-19</u> 118	<u>75-30</u> 75	<u>20</u> 35	"		"	"	35.0	35.0	"	"	"	<u>3</u> 16	2 1/4 Croloy. Root and face bends failed with brittle fracture. Incomplete penetration.
<u>12-19</u> 119	"	"	"		"	"	"	"	"	"	"	"	2 1/4 Croloy H.T. Root and face bends failed with brittle fracture. In- complete penetration.
<u>12-19</u> 120	"	"	"		"	"	"	"	"	"	"	1/8	2 1/4 Croloy Root and face bends with brittle fracture. Incomplete penetration.

DATE TRIAL	V, A,	KW, FIELD POWER- STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>12-19</u> 121	70-30	<u>20</u> 32	10		<u>8</u> 3.1	2.6			9/1	Single turn-L 1/2 x 3/4 rect.	3/8	1/8	2 1/4 Croloy. Root and face bends broke with brittle fracture. Stopped travel at 1/8" push up.
<u>1-3</u> 122	"	"	"		<u>40-9</u> 3.1	12.9-2.9	22.0	22.0	"	"	"	1/4	2 1/4 Croloy-Slow cool from welding temp. 2 1/2 hrs. (1650-1250) Two of eight bends were good, others broke with brittle fracture.
<u>1-6</u> 123	"	"	"		"	"	22.0	22.0	"	"	"	"	2 1/4 Croloy-Slow cool from welding temp. 5 hrs. (1650-1250) Weld not well centered. Four face bends and one root bend were satisfactory.
<u>1-8</u> 124	<u>54-20</u> 60	<u>10</u> 27	"		<u>40-11</u> 3.1	12.9-3.6	39.1		"	"	"	"	2 1/4 Croloy. Slow cool from weld- ing temp. 5 hrs. (1650-1250) Two face bends were good, other bends failed showing evidence of upset without fusion.
<u>1-9</u> 125	<u>60-20</u> 70	<u>13</u> 30	"		<u>40-9</u> 3.1	12.9-2.9	On 30 off 10 on 10 50		"	"	"	"	2 1/4 Croloy. First 1/16 pushup at 40,000, Second 1/16 at 9,000, 10 secs. delay in heating completed at 9,000. H.T. 1650°F 1/2 hr. Air quench 1250°F for 2 hrs. Upset was high both inside and out. Two face and two root bends were good.

DATE TRIAL	V, % A, %	KW, % FIELD POWER- STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>1-10</u> 126	<u>62</u>		10		<u>35-9</u>	11.3-2.9	30 on 10 off 10 on	All time	9/1	Single turn-L 1/2 x 3/4 rect.	3/8	1/4	Cr. 2-1/4 Two face bends and one root bend were good. Pushup both inside and out was very abrupt.
<u>1-10</u> 127	"		"		"	"	30 on 10 off 10 on 10 off 10 on	"	"	"	"	"	Cr. 2-1/4 All face bends were good. Two root bends failed showing in- complete heat penetration. Upset of these areas from which these root bends were taken was very gradually rounded.
<u>1-14</u> 128	<u>65-27</u> 74	<u>16</u> 34	"		"	"	30 on 10 off 10 on 10 off 10 on	"	"	"	"	"	Cr. 2-1/4 At this heat, O.D. was sparking and appear too hot. Root bends were good and all face bends failed. Pushup was very abrupt.
<u>1-16</u> 129	<u>63</u>		"		"	"	30 on 6 off 10 on 6 off 8 on	"	"	"	"	"	Cr. 2-1/4 No H.T. Upset on outside was abrupt and splitting of edges was consistent around periphery. Two face bends withstood 180-degree bending, others broke with brittle fracture but showed good fusion.

DATE TRIAL	V, A,	KW, FIELD POWER- STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>1-16</u> 130	<u>63-26</u> 72	<u>15</u>	10		<u>35-9</u>	11.3-2.9	30 on 6 off 10 on 6 off 8 on		9/1	Single turn-L 1/2 x 3/4 rect.	3/8	1/4	2-1/4 Groloy. 1650F 1/2 hr. air blast quench 1250F 1/2 hr. air cool four root bends were good. Two of the face bends failed. Pushup both in- side and out was very abrupt with splitting edges around the outside periphery.
<u>1-16</u> 131	"	"	"		"	"	30 on 6 off 10 on		"	"	"	"	Pres. reduced to 2,000 at 1/16", raised to 9,000 when heat was resumed Pushup was abrupt and fusion was com- plete. One root and three face bends were good.
<u>1-22</u> 132	"	"	"		"	"	30 on 5 off 5 on 5 off 5 on		"	"	"	"	H.T. 20 mins. @ 1300F. Only one face bend was good. Pushup was abrupt in- side and out. Splitting of edges around outside. Heat treatment was ineffective.
<u>1-22</u> 133	"	"	"		"	"	25 on 5 off 5 on		"	"	"	"	H.T. 20 mins. @ 1300F. Effect of less time was apparent in less abrupt pushup and incomplete fusion through wall thickness. One bend, a root bend at quadrant "C", where the pushup was noticeably more abrupt was good, other bends failed with brittle fracture.

DATE TRIAL	V, % A, %	KW, % FIELD POWER- STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>1-23</u> 134	<u>68</u> 80	<u>20</u> 34	4		<u>35-9</u> 3.1	11.3-2.9	30 on 5 off 5 on		9/1	Single turn-L 5/8 sq.	5/16	1/4	Carbon steel. Pushup was smoothly rounded inside and out. Quadrants "C" and "D" bends all failed at approx. 30 to 70 degrees.
<u>1-30</u> <u>135</u>	<u>70</u>	<u>35</u>	"		<u>35-8</u> 3.1	11.3-2.6	25 on 5 off 8 on		"	"	"	"	C-steel. Tested in the as-welded condition. Produced good root and face bends from each quadrant. Up-set was slightly more abrupt than previous lower-heat specimens.
<u>1-30</u> 136	"	"	"		"	"	"		"	"	"	"	Croloy 2-1/4 H.T. 1300F 40 mins. ea. side of joint Brinell...235. All root bends were good. Only the "C" quadrant face bend failed at 90 degrees but fusion was good.
<u>2-3</u> 137	"	"	"		"	"	25 on 5 off 5 on		"	"	"	"	Croloy 2-1/4 H.T. 1350F 40 mins. ea. side of joint. Brinell...235. Produced 3 out of 4 good face bends. Two of the root bends were good and the "A" and "B" root bends failed at approx. 90 degrees.

DATE TRIAL	V, % A, %	KW, % FIELD POWER- STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>2-4</u> 138	<u>70-30</u> 85	<u>20</u> 35	4		<u>35-9</u> 3.1	113.-2.9	25 on 5 off 5 on		9/1	Single turn-L 5/8 sq.	1/4	7/32	Face bends were good. Root bends h.g., showed incomplete fusion at root. Heat treated with #6 inductor, 45 mins. each side of joint and at center of joint. Brinell - 225.
<u>2-5</u> 139	"	"	"		9	2.9	20 on 5 off 8 on		"	"	"	9/32	Insufficient heat, poor fusion. Heat treated at dull cherry with #6 inductor at center and both sides for 1 hr. each place. Hardness about 185 Brinell.
<u>2-6</u> 140	"	"	"		8	2.6	27 on 7 off 7 on		"	"	"	1/4	Heat treated at dull cherry for 1 hr. and 15 mins. with tocco inductor. Hardness: 248 Brinell. Face bends were good. Two out of four root bends failed. Fusion appeared to be complete.
<u>2-7</u> 141	"	"	"		"	"	24 on 7 off 7 on		"	"	"	7/32	Heating cycle operated differently after servicing. Time had to be changed to obtain results similar to #140. Hardness: Brinell 200. Induction heat treated 2 hrs. and 15 mins. at dull cherry. Produced good root and face bends from each quadrant.

DATE TRIAL	V. A.	KW. FIELD POWER- STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>2-12</u> 142	<u>70-30</u> 84	<u>20</u>	4		<u>8</u> 3.1	2.6	25 on 7 off 8 on		9/1	Single turn-L 5/8" sq.	5/16	1/4	Brinell hardness 230. 150 mins @ 1400° F. Four face and four root bends were satisfactory. Upset on inside and outside was abrupt.
<u>2-14</u> 143	"	"	"		"	"			"	"	"	"	Carbon Steel. Heat stopped at first 1/16" pushup, off for 6 secs., heat stopped at 3/16" pushup. Upset was gradually rounded. The root bend of quadrant "D" failed at 90 degrees, all other bends were good.
<u>2-14</u> 144	"	"	"		"	"	26 6 8		"	"	"	"	Cr. 2 1/4 150 mins @ 1400° F All bends were good. Pushup was abrupt.
<u>2- 4</u> 145	"	"	"		"	"	"		"	"	"	"	Argon-Cr 2 1/4 150 mins @ 1400° F. All bends were good. Upset in some areas was smoothly rounded.
<u>2-14</u> 146	"	"	"		"	"	"		"	"	"	"	Argon & G. E. Silicone-Cr 2 1/4 150 mins. @ 1400° F. Quadrant "B" root bend failed, other: bends were good.

DATE TRIAL	V. % A. %	KW, % FIELD POWER-- STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>2-17</u> 147	<u>70-30</u> 84	<u>20</u>	4		<u>8</u> 3.1	2.6	26.6		9/1	Single turn - L 5/8 sq.	5/16	1/4	Cr 2-1/4 150 mins. @ 1400 F. Only one root and one face bend were made. Both were satisfactory. Upset was abrupt with splitting around outside periphery.
<u>2-24</u> 148	"	"	"		"	"	"		"	"	"		Croloy 2-1/4 150 mins. at 1400 F. Appearance and results same as #147.
<u>2-24</u> 149	"	"	"		"	"	"		"	"	"		Cr 2-1/4 15 mins. at 1400 F. Max. hardness 39-44. Appearance was similar to #147 and 148 but bend tests failed in the weld at less than 90 degrees.
<u>2-24</u> 150	"	"	"		"	"	"		"	"	"	5/16	Cr 2-1/4 150 mins. at 1400 F. Excessive upset and splitting of edges on outside. Effects of beveled inside were only slightly less inside upset. Root bend was n.g., face bend, o.k.

DATE TRIAL	V, % A, %	KW, % FIELD POWER- STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>2-28</u> 151	<u>64</u>	<u>20</u>	4		<u>8</u> 3.1	2.6	LS#1 off 8		9/1	Single turn - L 5/8 sq.		1/4	Cr 2-1/4 150 mins. @ 1400 F. *L.S. #1 set at 1/16", off 8 secs., L.S. #2 set at 3/16". Upset was not as abrupt as previous welds made at 70 V. but both root and face bends were satis- factory. Max. hardness 29-36.
<u>2-28</u> 152	<u>64</u>	<u>20</u>	"		"	"	"		"	"		"	Cr 2-1/4 30 mins. @ 1400 F. Controls as in #151. Appearance same as #151. Face bend was good and root bend failed. Fusion through wall thickness was incomplete. Max. hardness 37-40.
<u>3-3</u> 153	<u>64</u>	<u>20</u>	"		<u>6</u> 3.1	1.9	"		"	"		"	Cr 2-1/4 45 mins. @ 1400 F. Controls as in #151. Lower forging pressure resulted in more abrupt upset on inside and outside with split and ragged edges on outside periphery. Face bend was good, root bend was brittle failure. Max. hardness 34-40.
<u>3-4</u> 154	<u>84-35</u> 95	<u>30</u> 43	"		<u>8</u> 3.1	2.6	"		"	"		"	No argon. 60 mins. @ 1400 F. Controls as in #151. Max. hardness 30-34. Face and root bend were good. Inside upset was smoothly rounded. Outside upset from rounded to abrupt with some splitting of edges. * Limit Switch

DATE TRIAL	V, A.	KW, FIELD POWER- STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>3-4</u> 155	<u>84-35</u> 95	<u>30</u> 43	10		<u>8</u> 3.1	2.6	17.3		9/1	Single turn 5/8" sq. with L.	5/16	1/4	Argon inside. H.T. 60 mins. @ 1400 F. Max. hardness 32-35. Appearance good and root and face bends were good.
<u>3-4</u> 156	<u>80-34</u> 94	<u>28</u> 42	10		<u>15</u> 3.1	4.8	20.0		"	"	"	7/32	Argon inside. H.T. 150 mins. @ 1400 F. Max. hardness 32-34. Upset was rounded. Face bend was good for 180 degrees and root bend failed at approx. 30 degrees. Incomplete penetration.
<u>3-6</u> 157	<u>35</u> 90	<u>20-40</u> 35		20	<u>18</u> 6.8	2.65	67 total 8 secs off	67	"	Single turn W=1/2 H=3/4 with L.	3/8	3/8	6-3/4 O.D. Croloy. Weld joint was good. Bend tests were made without heat treatment which made it difficult to make true bends but the tests indicated good mechanical strength.

DATE TRIAL	V, % A, %	KW, % FIELD POWER STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>3-11</u> 158	<u>-35</u> 90	<u>20-40</u> 35		20	<u>18</u> 6.2	2.9	67 Tot	67	9/1	Single turn W=1/2 H=3/4 With L	3/8	1/4	6-5/8" O.D. Croloy 2-1/4 Fce. H.T. 1400°F 120 mins. All face bends were good. All root bends failed at from 10 to 30 degrees showing incomplete heat penetration.
<u>3-11</u> 159	"	"		"	"	"	46 On 8 Off 5 On	59	"	"	"	9/32	6-5/8" O.D. Croloy 2-1/4 Induction H.T. 1400°F 150 mins. Penetration was complete and all face and root bends were good.
<u>3-11</u> 160	"	"		"	"	"	47 On 8 Off 3 On	58	"	"	"	7/32	6-5/8" O.D. Croloy 2-1/4 Fce. H.T. 1400°F 120 mins. Quadrant "B" showed a rounded upset inside and out and demonstrated poor fusion. All other quadrants produced good root and face bends.
<u>3-11</u> 161	<u>60-20</u> 77	<u>9</u> 30	8		2.7	2.7	25	25	"	Single Turn W = 5/8 H = 5/8 Turn L.	5/16	5/32	2" Sch. 40 Croloy 2-1/4 Heat stopped at 1/16 pushup. Induc- tion H.T. 1400°F for 2 hrs. Outside showed rounded upset. Inside upset was narrow and abrupt with increased I.D. on either side of upset. Bends n.g.
<u>3-14</u> 162	<u>64-20</u> 80	<u>10</u> 33	8		"	"	21	21	"	"	"	3/16	2" Sch. 40 Croloy 2-1/4 Welding procedure and H.T. as #161. Upset pattern same as #161. Bend test results same as #161.

DATE TRIAL	V, % A, %	KW, % FIELD POWER- STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>3-14</u> 163	<u>66-20</u> 84	<u>12</u> 34	9		<u>2.7</u> 1	2.7	18	18	9/1	Single turn W=5/8 H=5/8 with L	5/16	3/16	2" Sch. 40 Croloy 2-1/4 Welding procedure and H.T. as #161. Upset pattern was similar but with less increase in diam. Root and face bends approached 180 degrees.
<u>3-18</u> 164	<u>-35</u> 87 Constant	<u>20-40</u> 35		20	<u>18</u> 6.2	2.9			9/1	Single turn W=1/2 H=3/4 With L	3/8	9/32	6-5/8 O.D. Croloy 2-1/4 Induction H.T. 1400°F 150 mins. Outside upset was abrupt, inside was smoothly rounded. Each quadrant produced satisfactory root and face bends.

DATE TRIAL	V, % A, %	KW, % FIELD POWER- STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>3-24</u> 165	<u>-35</u> 87	<u>20-40</u> 35		20	<u>18</u> 6.2	2.9	500n 8 Off 8 On		9/1	Single turn L 1/2x3/4	3/8	5/16	6-5/8 O.D. Croloy 2-1/4 Fce. H.T. 2 hrs. @ 1400°F. Inside was smoothly rounded and outside was abrupt upset. Each quadrant produced satisfactory root and face bends
<u>3-24</u> 166	"	"		"	"	"	"		"	"	"	5/16	Same as #165
<u>3-24</u> 167	"	"		"	"	"	"		"	"	"	5/16	Same as #165
<u>3-28</u> 168	"	"		"	"	"	"		"	"	"	5/16	Induction H.T. 2 hrs @ 1400°F. Appearance and results same as #165.

DATE TRIAL	V, A,	KW, FIELD POWER- STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>4-3</u> 169	<u>68-</u>				2.3	2.3			9/1	Single turn- L 5/8 sq.	5/16	5/32	Abrupt upset inside and out. Heat appeared excessive. Face bends withstood 180 degrees and root bend failed at approx. 90 degrees.
<u>4-3</u> 170	<u>66-</u>				"	"			"	"	"	3/32	Power to pump shut off at end of heat cycle. Upset on outside was rounded. Inside upset varied from a rounded contour to a ragged fin. Both root and face bends failed between 90 and 180 degrees.
<u>4-3</u> 171	<u>68-</u>				"	"			"	"	"	5/32	Power to pump shut off at end of heat cycle. Upset on outside varied from rounded to pointed on outside. Inside upset was abrupt and thin. Face bend was good and root bend was n.g.
<u>4-7</u> 172	<u>64-20</u> 80				<u>2.5</u> 1	2.5			9/1	Single turn-L 5/8 sq.	5/16	5/32	Power to pump shut off at 18". Argon at 8 cfh. Rounded upset inside and out. Slightly increased I.D. at either side of upset. One face bend out of 4 was good.
<u>4-7</u> 173	<u>70-</u>				2.8	2.8			"	"	"	"	Power to pump shut off at 1/8" pushup. Upset on outside was abrupt and inside was the same with very slight increase in I.D. on either side of the upset.

DATE TRIAL	V, A,	KW, FIELD POWER- STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>4-11</u> 174	<u>62-20</u>				<u>2.8</u> 1	2.8	22.0	22.0	9/1	Single turn-L 5/8 sq.	5/16	5/32	Power to pump stopped at 1/8". Argon 10 ofh carbon steel. Outside was slightly rounded with very little upset on inside. Bend test ng.
<u>4-11</u> 175	<u>65-20</u>				<u>2.8</u> 1	2.8	19.0	19.0	"	"	"	5/32	Power to pump stopped at 1/8" Argon at 10ofh carbon steel. Upset on outside varied from ragged to rounded. Bend tests n.g.
<u>4-11</u> 176	<u>67-20</u> 80				<u>2.8</u> 1	2.8	18.0	18.0	"	"	"	5/32	Carbon steel. Smoothly rounded upset on inside and out. Appearance was very good. Three bends failed at less than 30 degrees and one at approx. 90 degrees. Amount of upset on inside was slight. Adjusted laminations outward and repeated #176 procedure to make #177.
<u>4-11</u> 177	<u>67-20</u> 80				<u>2.8</u> 1	2.8	18.0	18.0	"	"	"	5/32	Carbon steel. Inside and outside appearance was good. Slightly more upset than #176 was observed. Three of the four bends were good.
<u>4-15</u> 178	<u>66-</u>				"	"	18.0	18.0	"	"	"	5/32	Cr 2-1/4 H.T. 2 hrs. @ 1450°F. Max. hardness 35-37. Appearance similar to #177 and bend test results were identical.

DATE TRIAL	V. A.	KW. FIELD POWER- STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>4-16</u> 179	<u>66-</u>				<u>3.0</u> 1	3.0	14.0	14.0	9/1	Single turn-L 5/8 sq	5/16	3/16	Cr 2-1/4 H.T. 2 hrs. @ 1450°F. Max. hardness 35-38. Increase in pressure produced a more rounded upset and root and face bends failed at approx. 90 degrees.
<u>4-18</u> 180	"				<u>2.5</u> 1	2.5	16.0	16.0	"	"	"	5/32	Cr 2-1/4 H.T. 2 hrs. @ 1450°F. Max. hardness 29-31. Upset was abrupt with splitting edges inside and out. Fusion was completely thru the wall thickness but bend tests broke at edge of heated zone.
<u>4-18</u> 181	<u>62-</u>				"	"	20.0	20.0	"	"	"	5/32	Cr 2-1/4 H.T. 2 hrs. @ 1450°F. Max. hardness 27-33. Appearance similar to #181 except that outside was slightly more rounded. Bend tests withstood 180 degree bends and failed upon further bending as #180.

DATE TRIAL	V, A	KW, FIELD POWER- STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>4-23</u> 182	<u>30</u>				<u>2.5</u> 1	2.5	22.0	22.0	<u>13</u> 1	Single turn - L 5/8 sq.	5/16	5/32	Cr 2-1/4 H.T. 2 hrs. @ 1475 F. Max. hardness 32-35. Specimens produce 180-degree root and face bends. Cracks were obvious even though the bends did not fail.
<u>4-24</u> 183	<u>30</u>				<u>2.7</u> 1	2.7	20.0	20.0	"	"	"	5/32	With iron lamination shielding on both sides of inductor. Upset pattern was similar to previous attempts on .154" wall material. Root and face bends were good. Cr 2-1/4 H.T. 2 hrs. @ 1475 F. Max. hardness 37-41
<u>5-1</u> 184	<u>44-38</u> 60	<u>20</u> 23		5	<u>6.0</u> 1.8	3.3	17.0 on Pushup over- rode 2nd micro sw.		"	"	"	5/32	2.5" O.D. with .250" wall. Croloy 2-1/4 H.T. 1450 F. 2 hrs. Max. hardness 35-44. Weld had good appearance inside and outside. Bend and tranverse tensile tests were good.
<u>5-4</u> 185	"	"		"	<u>6.0</u> 1.8	3.3	16.0 on 5.5 off 8.0 on		"	"	"	3/16	2.5" O.D. with .250" wall. Cr 2-1/4 H.T. 2 hrs. @ 1425 F. Max. hardness 40-44. Appearance good and results comparable to #184.

DATE TRIAL	V, % A, %	KW, % FIELD POWER- STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
5-7 186	44-38 60	20 23		5	6.0 1.8	3.3	19.0 on 5.5 off 6.0 on		13 1	Single turn 5/8" sq. - L		3/16	2.5 O.D. Croloy 2-1/4 Induction H.T. 1 hr. and 45 mins. @ 1525 F. Max. hardness 37-49. Both root and face bends were good but center of bend tests were excessively hard due to ineffective H.T.
5-7 187	44-38 60	20 23		5	"	"	19.0 on 5.5 5.0 on		"	"		"	2.5 O.D. Croloy 2-1/4 Induction H.T. 1400 F---1 hr. 1500 F---1 hr. Max. hardness 38-44. Root and face bends were satisfactory, show noticeably less stiffness at center than #186.
5-13 188	70-	— 35		20- 0	12.0 4.5	2.7	20.0 on 8.0 off 7.0 on		"	"		1/4	4.5 O.D. Croloy 2-1/4 from B1 loop. Insufficient heat in quadrant "A". No bend tests prepared.
5-13 189	70-	— 36		"	11 4.5	2.6	22.0 8.0 38.0		"	"		5/16	4.5 O.D. Croloy 2-1/4 from B1 loop. Induction H.T. 1450 F for 2 hrs. Max. hardness 35-39. 7 bends were satisfactory. The face bend of quad- rant "D" failed. This failure appeared to be a result of a tendency of the hot metal to fold inward during the pushup.

DATE TRIAL	V, A	KW, FIELD POWER- STAT SETTING	KVAR, $\frac{K}{A}$		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>5-15</u> 190	<u>66-</u> 55	<u>20</u> 33		20-0	<u>11.0</u> 4.5	2.6	30.0 on		13/1	Single turn - L 5/8 sq.	5/16	5/16	4.5 O.D. Croloy 2 1/4 from #3 B1 Loop. All Root bends were good. Face bends of quadrants A, C, and D failed. Upset on outside was abrupt and tended to fold in during pushup.
<u>5-16</u> 191	<u>64-60</u> 54	<u>20</u> 32		"	"	"	30 on 6 off 10 on		"	"	"	9/32	4.5 O.D. Croloy 2 1/4 from #3 B1 Loop. Induction H.T. 2 hrs @ 1450° F. Max. hardness 37-41. All root bends were good, three face bends were good, quadrant "D" face bend failed. Bend test results were identical to #189.
<u>5-20</u> 192	<u>62-60</u> 53	<u>20</u> 31		"	"	"	30.0 6 off		"	"	"	1/4	4.5 O.D. Croloy 2 1/4 from #3 B1 Loop. Specimen was not heat treated. Upset was abrupt with folding in of upset on outside and splitting of edges on inside. Heat from first cycle overrode 2nd micro sw. The excessive heat at a lower power setting was a result of operating machine immediately after starting.
<u>5-21</u> 193	<u>63-60</u> 54	<u>20</u> 31		"	"	"			"	"	"	"	4.5 O.D. Croloy 2 1/4 from #3 B1 loop. The four face bends were good and one of the four root bends was good. The other three root bends showed poor fusion across interface.
<u>6-4</u> 194	<u>90</u> 65	<u>50</u> 48	0	0	<u>42.0</u> 16	2.6	47.5 on 6.0 off 17.5 on		10/1	Single turn 5/8 sq.	3/8	7/16	Heat was excessive H.T. 1450° F for 2 hrs. 12" sch 40 Croloy 2 1/4 Micro sw set at 1/16" and 1/4". No bend tests or weld specimens were saved.

DATE TRIAL	V, % A, %	KW, % FIELD POWER- STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
6-6 195	80 60	48 43	0	0	42.0 16	2.6	76.3 on 6.0 off 10.5 on		10/1	Single turn 5/8 sq.	3/8	5/16	Pressure held at 10,000# until inside temperature above 2360°F was reached 42,000 was then added. 12" sch. 40 Croloy 2 1/4. Manually controlled. Quadrants C & D produced satisfactory root and face bends when fce. H.T. @ 1400°F for 2 hrs.
6-10 196	85 60	49 45	0	0	"	"			"	"	"		12" sch. 40 Croloy 2 1/4. Pressure applied throughout Micro switches set at 1/16" and 1/4". Folding in of upset occurred on outside Induction H.T. 1400°F 2 hrs. Max. hardness 33-40. Fusion through wall thickness approximately 50 per cent. Changed recording charts.
6-23 197	85 60	49 45	0	0	"	"	69.0 on 3.0 off 6.0 on		"	Single turn - L 5/8 sq.	"	3/8"	Fusion N.G. Pushup occurred without fusion Max. temp. before 1st micro sw. cutout was 2320°F. Pressure applied throughout #1-msw 3/32" #2 msw 1/4" 12" sch 40.
6-26 198	"	"	0	0	36.0	"	77.0 on 3.0 off 7.0 on		"	"	"	"	Excessive heating on outside with fusion to a depth of only half the wall thickness. Inside region upsets without fusion. 12" sch. 40.

DATE TRIAL	V, A,	KW, FIELD POWER- STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
7-1 199	45	24	0	0	11.0 4.5	2.44	38 on 6 off 8 on		10/1	Single turn - L 5/8 sq.	3/8	1/4	4.5" O.D. Croloy 2 1/4 Max. temp. #1-2340 Min. temp. #2-2220 Max. temp. #3-2350 Δ T at #1 + 10 #2 + 2 #3 + 8 #1 msw. 1/16 #2 msw. 3/16 H.T. 3 hrs. @ 1425°F very smoothly rounded appearance inside and out. Cr - A. thermocouple. Bend tests broke squarely across interface showing no fusion.
7-3 200	45	24	0	0	9.0 4.5	2.0	40.0 on 6.0 off 12.5 on		10/1	Single turn 5/8 sq.	"	3/8	4.5" O.D. Croloy 2 1/4" #1 Msw 1/16" #2 Msw 1/4" Max. temp. 1-2420 Min. temp. 2-2340 Max. temp. 3-2410 Δ T 1-13 2-0 3-4 Upset varied from rounded to abrupt with mostly rounded contour. Only one face bend was good. Max. hardness 33-41.

DATE TRIAL	V, A,	KW, FIELD POWER.. STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
<u>7-7</u> 201	<u>42</u>	<u>22</u>	0	0	<u>12.0</u> 4.5	2.7	50.0 6.0 13.0	on off on	10/1	Single turn 5/8 sq.	3/8	5/16	4.5" O.D. Croloy 2 1/4 #1 msw 1/16" #2 msw 1/4 Max. temp. 1-2400 Min. temp. 2-2280 Max. temp. 3-2400 Δ T 1 2 No ink 3 Upset varied from rounded to abrupt. All face bends good and two root bends were good. The two root bends that failed broke squarely showing poor fusion. Max. hardness 34-36.
<u>7-9</u> 202	<u>44</u>	<u>23+</u>	0	0	"	"	45.0 6.0 13.0	on off off	"	"	"	3/8+	#1 msw 3/32" #2 msw 1/4 Max. temp. 1-2360 Min. temp. 2-2270 Max. temp. 3-2350 Δ T 1-15 2-7 3-15 4.5" O.D. Croloy 2 1/4 Outside upset was ragged and heat appeared excessive. Two face bends and three face bends were good. Upset was abrupt both inside and out.

DATE TRIAL	V. % A. %	KW. % FIELD POWER- STAT SETTING	KVAR, %		FORCE, KIPS JOINT AREA IN. ²	UNIT JOINT PRES., KIPS IN. ²	TIME, SEC.		TRANS. RATIO PRIMARY SEC.	INDUCTOR		PUSH UP, IN SKETCH	REMARKS
			LAG	LEAD			H E A T	P R E S.		TYPE	RAD. CLR., IN.		
203	42	22			11.5 4.5	2.6			10/1	Single turn 5/8" sq.	3/8	11/32	4.5 O.D. with B1 #1 Msw 3/32" #2 Msw 1/4. Pushup stopped at 11/32". Upset was abrupt and all face bends were good. Root bends of quadrants C and D failed.
7-17 204	52-32 63	20 25	0	0	9.0 3.1		22.0	on	"	"	5/16		3"sch 80 Cr 2 1/4 #1 Msw 1/16" #2 Msw 3/16 Max. temp. #1-2420 Min. " 2-* Max. " 3- ΔT 1-10 2-* 3- * #2 Msw did not function. Pushup from #1 overrode #2. Did not make bend tests. Did not save speci- men.
7-18 205	50-30 60	20 27	"	"	8.0 3.1		30.0 5.0 8.0	on off on	"	"	"	9/32	#1 Msw 1/16" #2 Msw 1/4" Max. temp. #1-2240 Min. " 2-2140 Max. " 3-2280 ΔT 1-12 2-4 3-23 No bend tests. Chromel-Alumel thermocouple.

[illegible]

<u>DATE</u> <u>TRIAL</u> V, A, KW, POWER- STAT	KVAR, % <u>LEAD</u> LAG TRANS. RATIO	<u>FORCE</u> AREA UNIT JOINT PRES., KIPS IN. ²	<u>TIME,</u>		<u>INDUCTOR</u>		<u>SIZE</u> <u>O.D.</u> <u>WALL</u> <u>MATERIAL</u>	<u>WELDING</u> <u>TEMP.</u>		<u>HEAT</u> <u>TREAT</u> <u>TYPE</u> <u>TEMP.</u> <u>HRS.</u> HARDNESS	<u>PUSH UP,</u> <u>IN</u> <u>SKETCH</u>	REMARKS
			<u>SEC.</u>		<u>TYPE</u>	<u>RAD.</u> <u>CLR.,</u> <u>IN.</u>		<u>MAX.</u> <u>Dt</u> <u>MIN.</u> <u>Dt</u>	<u>MAX.</u> <u>Dt</u> <u>MIN.</u> <u>Dt</u>			
			H	P								
<u>8-11</u> 209	<u>0</u> 0	<u>8</u> 3.1	24.5	on	Single	5/16	<u>3.5</u> .300 Gr 2-1/4	<u>2390</u> 178	<u>2410</u> 140	<u>Induct.</u> 1400 <u>1.5</u> 41-26	9/32	In addition to H.T. shown one half hour preceeded this @ 1425 F Heating was uneven around periphery and excessive in quadrants B, C, and D. Hardness values were still high and no bend tests were made.
<u>52-32</u> 50	10:1	2.6	3.5	off	turn-L							1500 KW capacitance used for 3" sch. 80 pipe. Inductor changed to use 8.625" O.D. x .375" wall. Capacitance: 1010 KW for effective heating.
<u>20</u> 29			4.0	on	5/8 sq.							
<u>8-18</u> 210	<u>0</u> 0	<u>30</u> 11.3			Single	7/16	<u>8.625</u> .43 Gr 2-1/4			<u>Furnace</u> 1400 <u>2.5</u>	7/16	All face bend were good. One root bend was good, other root bends showed lack of root penetration, broke at interface.
<u>-70</u> 75	10:1	2.65			W=7/8 W=5/8							
<u>8-19</u> 211	"	"	54.0	on	"	"	"	<u>2450</u> 170	<u>2450</u> 130	<u>Induct.</u> 1375 <u>2.0</u>	3/8	Showed improved penetration through wall thick- ness. Only quadrant D root bend failed at interface.
<u>-70</u> 75			3.5	off								
<u>50</u> 35			5.2	on				<u>2400</u> 130				

DATE TRIAL V, % A, % KW, % POWER- STAT	KVAR, % LEAD LAG TRANS. RATIO	FORCE AREA UNIT JOINT PRES., KIPS IN. ²	TIME,		INDUCTOR		SIZE O.D. WALL MATERIAL	WELDING TEMP.		HEAT TREAT TYPE TEMP. HRS. HARDNESS	PUSH UP, IN SKETCH	REMARKS
			SEC.		TYPE	RAD. CLR., IN.		MAX. MAX. Dt Dt MIN. Dt	MAX. MAX. Dt Dt MIN. Dt			
			H	P								
A	E											
T	S.											
8-20 212 —	0 0 —	80.0 11.3 7.1 40.0 11.3 3.5 60.0 11.3 5.3			Single Turn-L W=7/8 H=5/8	5/16	8.625 .43 Cr 2-1/4	No Thermo- couples attached	Induct. 1370 2.0 33-37	1/4	Attempted slow heating and higher pressure to simulate TOCCO procedure. Width of heat band was insufficient and results were as usual with upset inside and out. Hardness traverse was made and used as side bend. It failed abruptly at interface.	
8-21 213 70 held const.	0 0 10:1	5.0 11.3 to 40.0 11.3 .44 to 3.5			Single Turn-L W=7/8 H=5/8	"	"	"	Furnace 1400 1.5 33-37	"	Tried interrupted heating to control temperature. Brought to temp. by visual observation, with- holding heavy pressure until heat was judged O.K. for forging. Argon gas inside. All face bends were good. Quadrant A and B root bends failed abruptly at interface.	
8-21 214 70 held const.	" —	5.0 11.3 to 40.0 11.3			"	"	"	"	Furnace 1400 2.0 24-36	3/32	As #213. Temperature appeared to be lower with obviously less upset. Used Argon. Hardness traverse failed abruptly at interface when given side bend test. No other bend tests were made.	
8-21 215 -70 75 const. 50 35	0 0 10:1	8.0 11.3 .7	120.0		Single Turn-L W=7/8 H=5/8	"	"	2600 2600 70 90 2520 70	Induct. 1370 2.0 29-35	1/8	Temperature of piece was held at a fixed range for a period of slightly over 2 full minutes. A slight ridged upset occurred on outside with very little rounded upset on inside. One root bend was good. All face bends failed at start of bending with brittle fracture at the interface.	

DATE TRIAL V, % A, % KW, % POWER- STAT	KVAR, % LEAD LAG TRANS. RATIO	FORCE AREA UNIT JOINT PRES., KIPS IN. ²	TIME,		INDUCTOR		SIZE O.D. WALL MATERIAL	WELDING TEMP.		HEAT TREAT	PUSH UP, IN SKETCH	REMARKS
			SEC.		TYPE	RAD. CLR., IN.		MAX. Dt	MAX. Dt	TYPE		
			H E A T	P R E S.						TEMP.		
										HRS.		
										HARDNESS		
8-22 216 -70 75 const. 50 35	0 0 10:1	30.0 11.3 2.65	150.0		Single Turn-L W=7/8 H=5/8	5/16	8.625 43 Cr 2-1/4	2600 2600 2000-2570	Induct. 1360 2.0 31-37	1/4	Pushup was attempted when temperature was approx. 2500 F and with induction heat off the pressure would not produce movement. Piece was immediately reheated and with induction heat on, pushup was accomplished. Upset was practically nil for approx. 3/4 of the inside periphery, all upset occurred to the outside. The remaining fourth showed a slight ridged upset on outside with noticeably less than usual upset to the inside. Two root bends were good. All other bends, two root and four face, failed upon start of bending breaking cleanly at the interface.	
8-27 217 -65 70 45 30	"	"	60.0		"	"	"	2640 2640 145 145 2540 45	Induct. 1370 2.0 29-34	3/8	Heat control was as #216 but heat was not discontinued for any appreciable length of time. Upset was smoothly rounded inside and out and macro examination showed evidence of poor fusion across interface. No bend tests were made and specimen was not saved.	
8-28 218 -70 75 50 35	"	40.0 11.3 3.55	75.0		"	"	"	2600 100 —	Induct. 1370 2.0 34-39	1/4	Heat controlled manually. Pressure withheld until heat was judged to be right for forging. Used Argon. Outside appeared to be overheated and drippy. None of the bends (4 root and 4 face) went beyond 40 degrees.	

DATE TRIAL V, % A, % KW, % POWER- STAT	KVAR, % LEAD LAG TRANS. RATIO	FORCE AREA UNIT JOINT PRES., KIPS IN. ²	TIME,		INDUCTOR		SIZE O.D. WALL MATERIAL	WELDING TEMP.		HEAT TREAT TYPE TEMP. HRS. HARDNESS	PUSH UP, IN SKETCH	REMARKS
			SEC.		TYPE	RAD. CLR., IN.		MAX. Dt	MAX. Dt			
9-11 219 -70 75 50 35	0 0 10:1	30.0 11.3 2.65	8.5 4.5 2.5	on off on	Single Turn-L W=7/8 H=5/8	7/16	8.625 .43 Or 2-1/4	2460 80 2530 160	2560 130	Induct. 1375 2.0	3/8	Pres. held at 2,000# during preheating to 2400, and heat was turned off until temp. reached 2460 (coming down) and then automatic controls were used. Preheating time previous to automatic, 70 secs. off time between preheat and automatic controlling, 8 secs. Time column shows only automatic times. Upset around joint was not uniform. One side showed rounded upset, the other was split open with ragged edges. Centering of round was found to be off approx. 1/2". This was corrected for #220. Three root and two face bends were satisfactory.
9-17 220 -70 75 50 35	" " "	" " "	15.0 4.5 8.0	on off on	" " "	" " "	" " "	2450 110 2560 190	2560 140	Induction 1375 2.0 31.33	3/8	Pressure held at 2000# during preheating to 2400 F and heat was turned off until temp. reached 2460 (coming down) and then automatic controls were used. Preheat time previous to automatic, 67 secs. Satisfactory root and face bends were obtained from each quadrant.

DATE TRIAL V, % A, % KW, % POWER- STAT	KVAR, % LEAD LAG TRANS. RATIO	FORCE AREA UNIT JOINT PRES., KIPS IN. ²	TIME,		INDUCTOR		SIZE O.D. WALL MATERIAL	WELDING TEMP.		HEAT TREAT		PUSH UP, IN SKETCH	REMARKS
			SEC.		TYPE	RAD. CLR., IN.		MAX. Dt	MAX. Dt	TYPE TEMP. HRS. HARDNESS			
			H E A T	P R E S.									
<u>9-24</u> 221	<u>0</u> 0	<u>18</u> 6.8		on	Single		<u>6-5/8</u>	No Thermo-	<u>Furnace</u>	<u>5/16</u>	#1 L.S. at 1/16" Upset at joint		
<u>60-46</u>	<u>10</u> 1	2.65		off	Turn-L		<u>11/32</u>	couples	<u>1400</u>		#2 L.S. at 7/32"		
<u>25</u> 30				on	W=1/2 H=3/4		Cr 2-1/4		<u>2.0</u>		was smoothly rounded. Only two face bends were good, all other bend test broke cleanly at inter- face.		
<u>9-26</u> 222	"	"	38.0 4.5 13.0	on	"	"	"	<u>2430</u> 15	<u>2520</u> 95	<u>Induct.</u> 1370 2.0	5/16	#1 L.S. at 1/16" #2 L.S. at 7/32". Upset was more pronounced inside and out. Three face bends and one root bend were good.	
<u>64-50</u> 70								<u>2370</u> 50	25-35				
<u>30</u> 33													
<u>9-30</u> 223	"	"	40.0 4.5 12.0	on	"	"	"	<u>2520</u>	<u>2520</u>	<u>Induct.</u> 1370 2.0	3/8	#1 L.S. at 1/16" #2 L.S. at 7/32". Upset on outside was abrupt with splitting of edges at some points. Only one root bend failed and it showed a clean break at the interfaces.	
<u>65-50</u> 70		Est.		off				<u>2460</u>		<u>26-34</u>			
<u>32</u> 35													
<u>10-1</u> 224	"	"		on	"		"	No Thermo-	<u>Induct.</u>			#1 L.S. at 1/16" #2 L.S. at 7/32"	
<u>65-50</u> 65				off				couples	<u>1370</u>			Duplicate of #223, demonstrated for Barberson personnel. Results were identical.	
<u>30</u> 33									<u>2.0</u>				

DATE TRIAL V, % A, % KW, % POWER- STAT	KVAR, % LEAD LAG TRANS. RATIO	FORCE AREA UNIT JOINT PRES., KIPS IN. ²	TIME,		INDUCTOR		SIZE O.D. WALL MATERIAL	WELDING TEMP.		HEAT TREAT TYPE TEMP. HRS. HARDNESS	PUSH UP, IN SKETCH	REMARKS
			SEC.		TYPE	RAD. CLR., IN.		MAX. Dt	MAX. Dt			
<u>10-6</u> 225 <u>65-50</u> 65 <u>30</u> 33	<u>0</u> 0 <u>10</u> 1	<u>18</u> 6.8 2.65	40.0 on 4.5 off 11.5 on		Single Turn-L W-1/2 H-3/4		<u>6-5/8</u> <u>11/32</u> Cr 2-1/4	<u>2570</u> 150 <u>2570</u> 125	<u>2600</u> 135	<u>Induct.</u> <u>1370</u> <u>2.0</u>	3/8	#1 L.S. at 1/16"+ #2 L.S. at 7/32". Considerable unbalance of heat in piece root bends of quadrants B & C failed. This region appeared relatively cold with smoothly rounded upset. Joint was offset.
<u>10-7</u> 226 <u>55-</u> <u>30</u>	" " "	" " "	62.5 on 4.5 off 20.0 on		"	"	"	<u>2510</u> 170 <u>2490</u> 90	<u>2530</u> 110	<u>Induct.</u> <u>1370</u> <u>2.0</u>	5/16	#1 L.S. at 1/16"+ #2 L.S. at 7/32" Joint had smoothly round contour on outside; cold appearance. Only two face bends were good. Other bends, two face and four root, were typical of cold welds were upset occurred without fusion.

DATE TRIAL V, % A, % KW, % POWER- STAT	KVAR, % LEAD LAG TRANS. RATIO	FORCE AREA UNIT JOINT PRES., KIPS IN. ²	TIME,		INDUCTOR		SIZE O.D. WALL MATERIAL	WELDING TEMP.		HEAT TREAT TYPE TEMP. HRS. HARDNESS	PUSH UP, IN SKETCH	REMARKS
			SEC.		TYPE	RAD. CLR., IN.		MAX. Dt	MAX. Dt			
			H	P								
			E	R								
			A	E				MIN. Dt				
			T	S.								
10-14 227 55-40 70 const. Varied to hold amps const.	0 0 10:1	16.0 6.8 2.65	32.0 4.5 8.0	on off on	Single Turn-L W=1/2 H=3/4	3/8	6.625 11/32 Cr 2-1/4	2400 2600 140 95 2510 90	Induct 1370 F 2.0 25-35		5/16	#1 L.S. @ 1/16+ #2 L.S. @ 7/32 Quadrant A was relatively cold. Quadrants c and d were hot. Upset without fusion occurred at A. Other quadrants were 50% good bends. This was last weld with this inductor. A heavier, wider inductor for this size was fabricated and used for the remainder of the work done on this size.
12-16 228 54-38 70 22 28	0 0 10:1	16.0 6.3 2.65			Single Turn-L h=5/8 w=7/8	5/16	6.625 .280 Cr-21/4	2270 2330 2210	Induction 1370 2.0 40.42		5/16	1200 KVA Capacitance in circuit. Not enough heat. Upset occurred without fusion First trial on new inductor. No bend tests made. Argon was used on this test and all of those following using this inductor.
12-17 229 54-45 90 Const. 25 Varied to hold amps. Const.	10:1	15.0 5.7	23.5 6.0 3.5	on off on	Single Turn-L h=5/8 w=7/8	5/16	6.625 .280 Cr 2-1/4	2320 2430 75 140 2320 100	Induct. 1370 2.0 40-42		1/4	L.S. #1 at 1/16 Temp. was excessive L.S. #2 at 3/16+ during last hr. of H.T. Welding temperature still low. No bend tests. Check theoretical area against actual calculated area and reduced pressure accordingly.
12-18 230	10:1	15.0			Single Turn-L h=5/8 w=7/8	5/16	6.625 .280 Cr 2-1/4	No Thermo- couples				Weld was off centerline Upset occurred without fusion. Side bends broke at interface.

DATE TRIAL V, % A, % KW, % POWER- STAT	KVAR, % LEAD LAG TRANS. RATIO	FORCE AREA UNIT JOINT PRES., KIPS IN. ²	TIME,		INDUCTOR		SIZE O.D. WALL MATERIAL	WELDING TEMP.		HEAT TREAT TYPE TEMP. HRS. HARDNESS	PUSH UP, IN SKETCH	REMARKS
			SEC.		TYPE	RAD. CLR., IN.		MAX. MAX. Dt Dt	MIN. Dt			
			H	P								
			E	R								
A	E											
T	S.											
<u>12-18</u> 231 <u>54-45</u> 90 const. <u>25</u> Varied to hold amps constant	10:1	15.0	27.5	on	Single turn-L h=5/8 w=7/8	5/16	<u>6.625</u> .280 Cr. 2-1/4	<u>2540</u> 65		<u>Induction</u> <u>1370</u> <u>2.0</u> 34-35		LS #1 @ 1/8+. Heat was excessive, some dripping on outside. Bend tests that were taken were good.
<u>12-23</u> 232 <u>54-</u> 80 Const. <u>25</u> Varied to hold amps Const.	<u>0</u> 0 <u>10</u> 1	15.0	40.0 6.0 4.0	on off on	Single turn-L h=5/8 w=7/8	5/16	<u>6.625</u> .280 Cr. 2-1/4	<u>2440</u> 190 <u>2400</u> 100	<u>2480</u> 100	<u>Induction</u> <u>1370</u> <u>20</u> 40-42	5/16	L.S. #1 @ 1/16" L.S. #2 @ 3/16" 7 of 8 bends were good One bend that failed showed poor fusion.
<u>12-29</u> 233 <u>54-</u> 80 Const. <u>25</u> Varied to hold amps constant	<u>0</u> 0 <u>10</u>	15.0	40.0 6.0 4.0	on off on	Single turn-L h=5/8 w=7/8	5/16	<u>6.625</u> .280 Cr. 2-1/4				5/16	The two weld faces moved transverse to one another and temperature record was very erratic. No bend tests were made.

[illegible]

DATE TRIAL V, % A, % KW, % POWER- STAT	KVAR, % LEAD LAG TRANS. RATIO	FORCE AREA UNIT JOINT PRES., KIPS IN. ²	TIME,		INDUCTOR		SIZE O.D. WALL MATERIAL	WELDING TEMP.		HEAT TREAT TYPE TEMP. HRS. HARDNESS	PUSH UP, IN SKETCH	REMARKS
			SEC.		TYPE	RAD. CLR., IN.		MAX.	MAX.			
			H	P				Dt	Dt			
			E	R				MIN.				
A	E							Dt				
T	S.											
<u>1-8</u> 237 80 const.	<u>0</u> 0 10:1	<u>15.0</u> 5.7 2.65	95.0 on 6.0 off 3.5 on	on off on	Single Turn-L h=5/8 w=7/8	3/8	<u>6-5/8</u> <u>11/32</u> Cr 2-1/4	<u>2445</u> <u>2445</u> <u>2410</u>	<u>2445</u>	Induction 1400 F 2.0 26-32	5/16	Δt recorder stuck, no data. Preheat temperature was slightly higher and welding temperature slightly lower, bend test results were practically the same as #236. Seven bend tests were good and one root bend failed at approx. 100 degrees.
<u>25</u> Varied to hold amps. const.												
<u>1-9</u> 238	"	"	72.0 on 6.0 off 3.0 on	on off on	"	"	"	<u>2600</u> 35 <u>2600</u> 70 <u>2560</u> 55	<u>2600</u> 70	Induction 1350 F 2.0 25-35	5/16	This was the same as nos. 236 and 237 except that the preheat period was shorter and the temperature was a little bit higher. Each quadrant was good for root and face bends. The upset at the joint was the same on all three tests, 236, 237 and 238.
<u>1-13</u> 239	"	"			"	"	"	No Data		"	5/16	Procedure and results were same as three tests preceeding.
<u>1-14</u> 240	"	"			"	"	"	"	"	"	"	As above. All bends were flattened till ends met without failure.
<u>2-5</u> 241 <u>24</u> 52 <u>6</u> 18	<u>4</u> 13:1	<u>2.7</u>	28		Single turn with L. 5/8 sq.	1/4	<u>1.900</u> <u>.200</u> Cr 2-1/4			Furnace 1350 2.0	3/16-	L.S. set at 1/16- Initial trial set up on this size produced satisfactory root and face bends with smoothly rounded inside contour.

[illegible]

DATE TRIAL V, % A, % KW, % POWER- STAT	KVAR, % LEAD LAG TRANS. RATIO	FORCE AREA UNIT JOINT PRES., KIPS IN. ²	TIME,		INDUCTOR		SIZE O.D. WALL MATERIAL	WELDING TEMP.		HEAT TREAT		PUSH UP, IN SKETCH	REMARKS
			SEC.		TYPE	RAD. CLR., IN.		MAX. MAX. Dt Dt	MIN. Dt	TYPE TEMP. HRS. HARDNESS			
			H E A T	P R E S.									
<u>3-3</u> 244 80 const.	<u>5</u> 10:1	<u>15.0</u> 5.7 2.65	32.0 6.0 6.0	on off on	Single Turn-L h=5/8 w=7/8		<u>6.625</u> .280 Cr 2-1/4			<u>Furnace</u> <u>1350</u> <u>3.0</u>	<u>5/16</u>	Same welding procedure as regards temp. and pressure controls was used on this weld as on nos. 239 and 240. All 180 degree guided bend tests were good.	
<u>25</u> 35													
<u>3-3</u> 245 80 const.	"	"	"		"		"			"	"	Welding procedure as above. Satisfactory root and face bends were obtained from each quadrant. All sixteen of these bends from these trials no 244 and 245 were flattened with hydraulic force and passing 180 degree bend tests. Only two of the sixteen opened up at the root during this flattening test. See Figures__ and __.	
<u>25</u> 35													
<u>3-4</u> 246 80 const.	"	"	"		"		<u>6.625</u> .280 Cr 1-1/4			"	"	The same welding procedure developed for this size pipe in Croloy 2-1/4 was applied to Croloy 1-1/4. Results were very similar.	
<u>25</u> 35													
<u>3-9</u> 247	<u>5</u> 10:1	<u>15.0</u> 5.7 2.65			Single turn-L h=5/8 w=7/8	3/8	<u>6.625</u> .280 Cr 1-1/4			<u>Furnace</u> <u>1350</u> <u>3.0</u> 28-35	5/16	Specimen weld appeared to be excessively hot on outside and with abrupt upset on inside. The face bends showed evidence of tearing next to the area of upset but none failed to pass 180 degree guided bend test. Three of the root bends failed.	

[illegible]

DATE TRIAL V, % A, % KW, % POWER- STAT	KVAR, % LEAD LAG TRANS. RATIO	FORCE AREA UNIT JOINT PRES., KIPS IN. ²	TIME,		INDUCTOR		SIZE O.D. WALL MATERIAL	WELDING TEMP.		HEAT TREAT		PUSH UP, IN SKETCH	REMARKS
			SEC.		TYPE	RAD. CLR., IN.		MAX. Dt	MAX. Dt	TYPE TEMP. HRS. HARDNESS			
			H	P							E		
<u>3-24</u> 250	0	<u>2.2</u> .8			Single Turn-I W=5/8 H=5/8	1/4	<u>1.900</u> .145 Gr 2-1/4			<u>Furnace</u> <u>1350</u> <u>2.0</u>	1/8	Face bend good root bend n.g. Upset on insdie was a thin ragged flash.	
<u>28-20</u> <u>10</u>	13:1	2.8											
<u>3-24</u> 251	"	<u>2.2</u> .7			"		<u>1.660</u> .140 Gr 2-1/4			"	1/16	Specimen had "cold" appearance. Both face and root bend failed at less than 40 degrees.	
<u>28-20</u> <u>10</u>		3.1											
<u>3-24</u> 252	"	<u>2.2</u> .8			"		<u>1.900</u> .145 Gr 2-1/4			"	1/8	Face and root bend n.g. Upset on outside was rounded. Inside upset was a thin pointed ridge. Inside diameter showed increase, slight belling out. Tears were evident in middle of inside upset.	
<u>28-20</u> <u>10</u>		2.8											
<u>3-25</u> 253	"	<u>2.5</u> .8			"	"	"			"	"	Face bend good, root bend n.g. Halves of specimen were slightly offset. Slight belling out on one side of joint. Outside was rounded upset. Inside upset was slight.	
<u>32-</u> <u>10</u>		3.1											
<u>3-25</u> 254	"	"			"	"	"			"	"	Results as above. Alignment of ends was a little better.	
<u>32-</u> <u>10</u>													

<u>DATE</u> <u>TRIAL</u> V, A, KW, POWER- STAT	KVAR, % LEAD LAG TRANS. RATIO	<u>FORCE</u> <u>AREA</u> UNIT JOINT PRES., KIPS IN. ²	<u>TIME,</u>		<u>INDUCTOR</u>		<u>SIZE</u> O.D. WALL MATERIAL	<u>WELDING</u> <u>TEMP.</u> MAX. MAX. Dt Dt MIN. Dt		<u>HEAT</u> <u>TREAT</u> TYPE TEMP. HRS. HARDNESS		<u>PUSH UP,</u> <u>IN</u> SKETCH	REMARKS
			<u>SEC.</u>		TYPE	RAD. CLR., IN.							
			H E A T	P R E S.									
<u>4-1</u> 255	0	<u>2.5</u> .8	12.0			1/4	<u>1.900</u> .145 Gr 2-1/4			<u>Furnace</u> <u>1350</u> 2.0		1/8	Bend test results n.g. Slight bellling out on inside. Upset was smoothly rounded inside and out.
<u>38-22</u> <u>12</u>	13:1	3.1											
<u>4-1</u> 256	"	"	"			"	"			"		"	Face bend was good. Root bend n.g. Slight bellling out on inside with practically no upset obvious on inside.
<u>38-22</u> <u>12</u>													
<u>4-3</u> 257 <u>39-23</u> <u>12</u>	"	<u>2.5</u> .8	10.5		Single Turn-L W=5/8 H=5/8	"	"			"		"	Face and root bends were goed. Outside was smoothly rounded and inside had a very ridge of upset.
<u>4-3</u> 258 <u>40-24</u> <u>13</u>	"	"	10.0		"	"	"			"		"	Results as above.

DATE TRIAL V, % A, % KW, % POWER- STAT	KVAR, % LEAD LAG TRANS. RATIO	FORCE AREA UNIT JOINT PRES., KIPS IN. ²	TIME,		INDUCTOR		SIZE O.D. WALL MATERIAL	WELDING TEMP.		HEAT TREAT		PUSH UP, IN SKETCH	REMARKS HAMMER DROP, IN.
			SEC.		TYPE	RAD. CLR., IN.		MAX. MAX.		TYPE TEMP. HRS. HARDNESS			
			H	P				Dt	Dt				
			E	R				MIN.	Dt				
A	E												
T	S.												
4-27 259 65-	0 10:1		13.0		Single Turn-L W=5/8 H=5/8	5/16	3.5 .216 Gr 2-1/4			Furnace 1350 2.0	Controlled: .040 Actual: 3/16	36	This procedure produced a very ragged flash at joint both inside. Only one root and one face bend was made, both were good.
4-27 260 65-	"		12.0		"	"	"			"	No control 1/4	18	No stops were used under wedge from this one on. Appearance was as above only more so neither root nor face bend tests were good.
4-27 261 65-	"		10.0		"	"	"			"	3/32	18	No chain. Appearance was much better with smoothly rounded upset inside and out. One face bend was good and others broke cleanly at interface.
4-27 262 65-	"		9.0		"	"	"			"	1/16	18	Upset at joint was practically nothing on inside or outside. Two root bends and two face bends were made. The two root bends passed 180 degree guided bend tests without failing.
4-27 263 65-	"		10.0		"	"	"			"	3/32	18	Duplicate of #261, with chain. Upset pattern was similar and so were bend test results. Root bend was good and face bend n.g.
4-27 264 65-	"		11.0		"	"	"			"	1/8	12	Produced a narrow ridge of upset inside and out. Macro examination showed tearing in upset regions. Neither face nor root bend was good.

DATE TRIAL V, % A, % KW, % POWER- STAT	KVAR, % LEAD LAG TRANS. RATIO	FORCE AREA UNIT JOINT PRES., KIPS IN. ²	TIME,		INDUCTOR		SIZE O.D. WALL MATERIAL	WELDING TEMP.		HEAT TREAT TYPE TEMP. HRS. HARDNESS	PUSH UP, IN SKETCH	REMARKS
			SEC.		TYPE	RAD. CLR., IN.		MAX.	MAX.			
			H	P				Dt	Dt			
			E	R				MIN.				
			A	E				Dt				
			T	S.								
<u>5-5</u> 265 <u>65-</u>	0 13:1	<u>2.5</u> .8 3.1	10.0		Single Turn-L W=5/8 H=5/8	1/4	<u>1.900</u> <u>.145</u> Gr 2-1/4			<u>Furnace</u> <u>1350</u> 2.0	1/8	A setup for this size was made in order to qualify the procedure for making specimens for insetting in actual bismuth loops on a long-period testing program. Root bend was good and face bend failed at approx. 90 degrees.
<u>5-5</u> 266 <u>65-</u>	"	"	"		"	"	"			"	"	Appearance inside and out was exactly like above and bend test results were the same.
<u>5-5</u> 267 <u>65-</u>	"	"	"		"	"	"			"	"	Upset inside and out was just a little more abrupt and both root and face bends were good.
<u>5-7</u> 268 <u>67-</u>	"	"	9.5		"	"	"			"	"	Rate of heating was increased to make upset at joint even more abrupt. This resulted in more tearing upon upset and mechanical properties were n.g. Face bend n.g., root bend OK. Upset on inside was a thin ridge.
<u>5-7</u> 269 <u>67-</u>	"	"	"		"	"	"			"	"	Bend tests n.g. Appearance inside and out was as above.
<u>5-7</u> 270 <u>67-</u>	"	"	"		"	"	"			"	"	Bend tests n.g. Appearance and bend test results as above

APPENDIX B

INDUCTION FORGE WELDING DATA -- FIGURES

107

109

110

111

112

113

114

169

171

170

FACE

ROOT

180

182

181

218

219

1 INCH

221

222

223

244

245

1 INCH

259

262

260

263

261

264