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INVESTIGATION OF ULTRASONIC WELDING  
OF REFRACTORY METALS AND ALLOYS

May 1963

Prepared under Navy Bureau of Naval Weapons  
Contract No. NOW 63-0125-c

Bimonthly Progress Report No. 4  
16 February 1963 through 15 April 1963

**AEROPROJECTS INCORPORATED**  
WEST CHESTER, PENNSYLVANIA

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ABSTRACT

A laboratory-type 4-kilowatt spot-welding machine was instrumented for power-force programming. Preliminary investigations using this improved technique were carried out in the welding of 2024-T3 bare aluminum, AISI 304 stainless steel, and Inconel X alloys. Efforts to procure adequate quality refractory metals were continued.

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INVESTIGATION OF ULTRASONIC WELDING  
OF REFRACTORY METALS AND ALLOYS

Ultrasonic welding involves the introduction of relatively high vibratory stresses into an intended weld zone. The magnitude of such stresses depends upon the level of power delivered to the weldment, and the properties and thickness of the materials being joined. The required clamping force is also influenced by the weldment materials, and is adjusted to a value which provides the most efficient transmission of vibratory energy into the intended weld area.

The magnitude of both power and clamping force for the satisfactory welding of a combination of materials are determined experimentally. Previously, the applied power and clamping force have been of fixed preset value during the weld interval. However, standing-wave-ratio measurements, which provide a measure of the actual power delivered to the weld zone while welding under these preset conditions, gave evidence that delivered power varied during the formation of the weld.\* These SWR measurements suggest that the weld interval involves two stages. The first is an induction period during which some slippage of the sonotrode tip may occur in the establishment of coupling of the sonotrode to the weldment, and leads to the second stage, which appears to be the actual interval of weld formation, and during which the vibratory energy is effectively utilized. The programming of power and clamping force permits control of the delivered power, to the end of more efficient welding, control of temperature rise in the weldment, and minimization of certain undesirable weld characteristics.

During this report period a laboratory-type 4-kilowatt ultrasonic spot-welding machine was instrumented for power-force programming experiments. 2024-T3 aluminum, AISI 304 stainless steel, and Inconel X were welded with power-force programming.

Power-Force Programming Monitoring Instrumentation

The equipment described in prior Progress Reports No. 1, 2, and 3 operated successfully. The block diagram shown in Figure 1 illustrates the detection and recording scheme used for the measurement of power, force, and displacement.

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\* Jones, J. B., N. Maropis, J. G. Thomas, and D. Bancroft, "Fundamentals of Ultrasonic Welding, Phase II." Research Report 60-91, Navy Contract N0a(s) 59-6070-c, December 1960.



A. Power

Power is monitored by sampling the control signal from a resistive divider, applying it to an amplifier-rectifier unit, and recording the signal on a strip-chart recorder.

B. Force

The SR-4 strain gages used for measuring force are mounted on the hydraulic cylinder of the welding machine. The signal from the gages is fed through a strain analyzer circuit and recorded on a strip-chart oscillograph.

C. Displacement

A high-quality ceramic phonograph cartridge and stylus assembly (Astatic Corporation No. 51-2) is used to sense the displacement amplitude. The cartridge is shock-mounted on the welder with the stylus in contact with the sonotrode tip. The magnitude of the output signal is proportional to the displacement, and is amplified and recorded on a strip-chart instrument in the same manner as power and force.

Power-Force Programming Experiments

Initial investigation of the effects of programming power and clamping force was carried out with 2024-T3 aluminum, type 304 stainless steel (annealed), and Inconel X. Standard welding machine settings which have historically yielded satisfactory welds are shown in Table 1.

With these standard machine settings as a base, and employing limited data on power delivery variations during the weld interval (1, 2), four programs for force and/or power were selected for exploration and are shown as A, B, C and D of Figure 2.

For each program, the total weld interval T is the time established for non-programmed welding of the material under consideration.

- 
- (1) Jones, J. B., N. Maropis, J. G. Thomas, and D. Bancroft, "Fundamentals of Ultrasonic Welding, Phase I." Research Report 59-105, Navy Contract NOas 58-108-c, May 1959.
  - (2) Jones, J. B., N. Maropis, J. G. Thomas, and D. Bancroft, "Fundamentals of Ultrasonic Welding, Phase II." Research Report 60-91, Navy Contract NOa(s) 59-6070-c, December 1960.

Five weldments were made with each material, using each of the four programs in random order, for a total of twenty welds in each material. The 0.063-inch 2024-T3 bare aluminum with 1100-H18 aluminum foil interleaf could not be programmed above the power capacity of the machine, since the standard welding machine power setting required to produce a satisfactory weld with this material was 4200 watts. Thus the step involving an increase in power above the standard power setting  $\Delta P2^*$  was omitted.

Simultaneous force, power, and displacement strip-chart oscillograms were obtained for each programmed weld. Intermittent standard control welds were made and evaluated by tensile-shear tests to ensure that the performance of the welder was normal throughout the test series. Oscillograms obtained while welding the type 304 stainless steel specimens are shown in Figure 3. Comparison of the oscillograms to the preset program patterns (Figure 2) indicates that the welding conditions respond to the control signals.

Power and force calibrations were checked at regular intervals. The displacement calibration was spot-checked by comparing typical oscillograms from the control welds with previously obtained calibration reference charts.

Evaluations of weldments made under the above conditions were based upon tensile-shear strength, deformation measurements, and metallographic examination. Weld quality was determined by tensile-shear testing three weldments of the 0.063 alloy, and four weldments of the 0.040 aluminum alloy, stainless steel and Inconel X series. All remaining specimens were examined micrographically. Deformation studies consisted of micrometer weldment thickness measurements at the weld zone and at unwelded areas of the specimens.

Tables II and III contain a summary of the welding machine settings, the energy (in watt-seconds) delivered for each pattern, and the tensile-shear strength of each weld obtained from each pattern.

The data were reviewed with regard to differences in weld quality based on shear-strength, and to ascertain if such observed differences seemed to have genuine significance or merely reflected random variation. The small number of specimens precludes hard conclusions at this time. However, the results (shown in Table IV) indicate the general effects of power-force programming on weld strength, and they will be useful in giving direction to subsequent program selection. Broadly, it appears that average weld strengths under PFP conditions can be higher, and strength variations lower.

---

\* P. = Power level normally required to produce satisfactory welds without power-force programming.

In general, it appears that no significant difference existed between patterns A and B or between patterns C and D, but that the difference between group A B and group CD is probably real.

Deformation measurements did not reveal any specimen differences directly attributable to power-force programming.

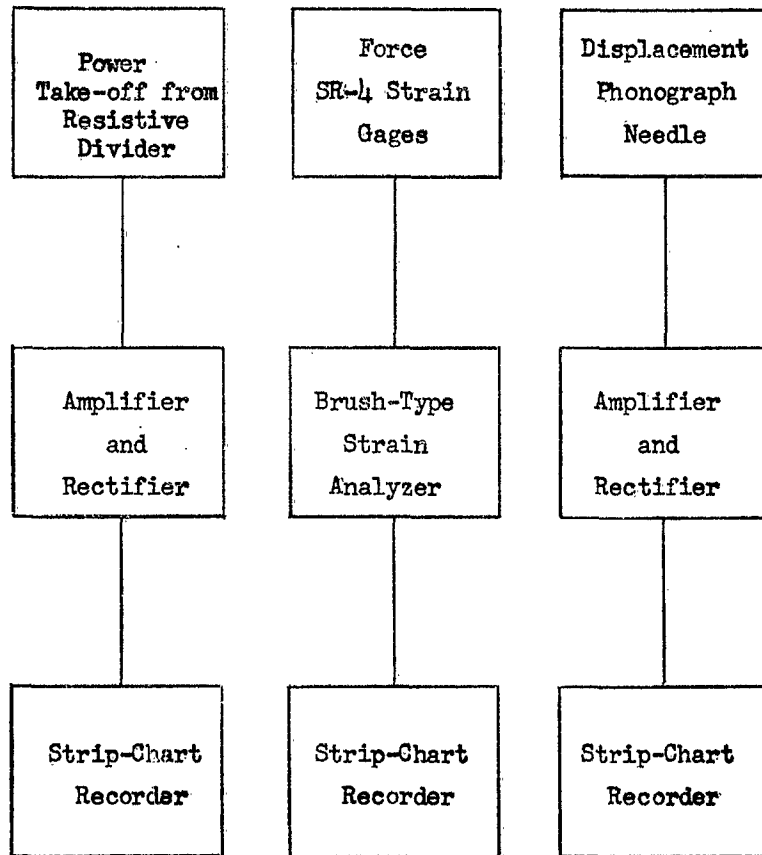
Metallurgical studies disclosed a difference for the various PFP patterns, but the differences are not consistent among the four materials used in the investigations.

#### Future Work

1. Modifications including provision for a more linear variation in the output power with respect to the programmed power level, alleviation of degradation of the strain gages, and reduction in extraneous pick-up which distorts recorded signals are necessary, and will be initiated during the next report period.
2. Effort to obtain refractory welding materials of adequate quality is continuing.
3. Further exploration of PFP effects will be carried out.

Figure 1

SCHEMATIC OF POWER-FORCE PROGRAMMING SYSTEM SENSING ELEMENTS



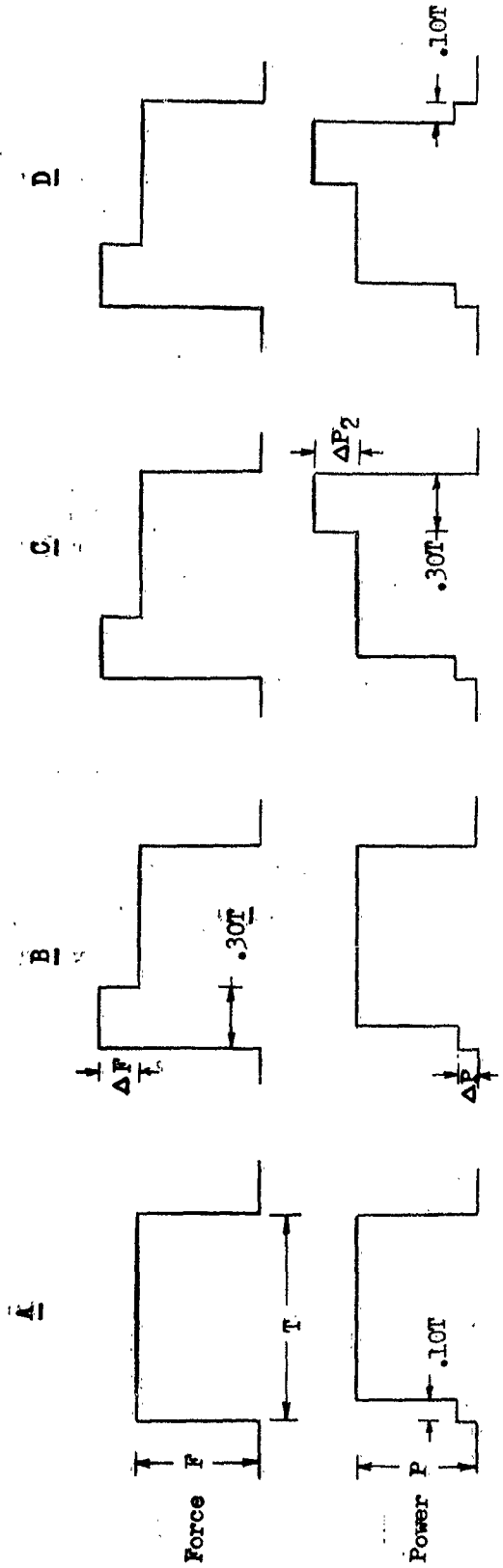
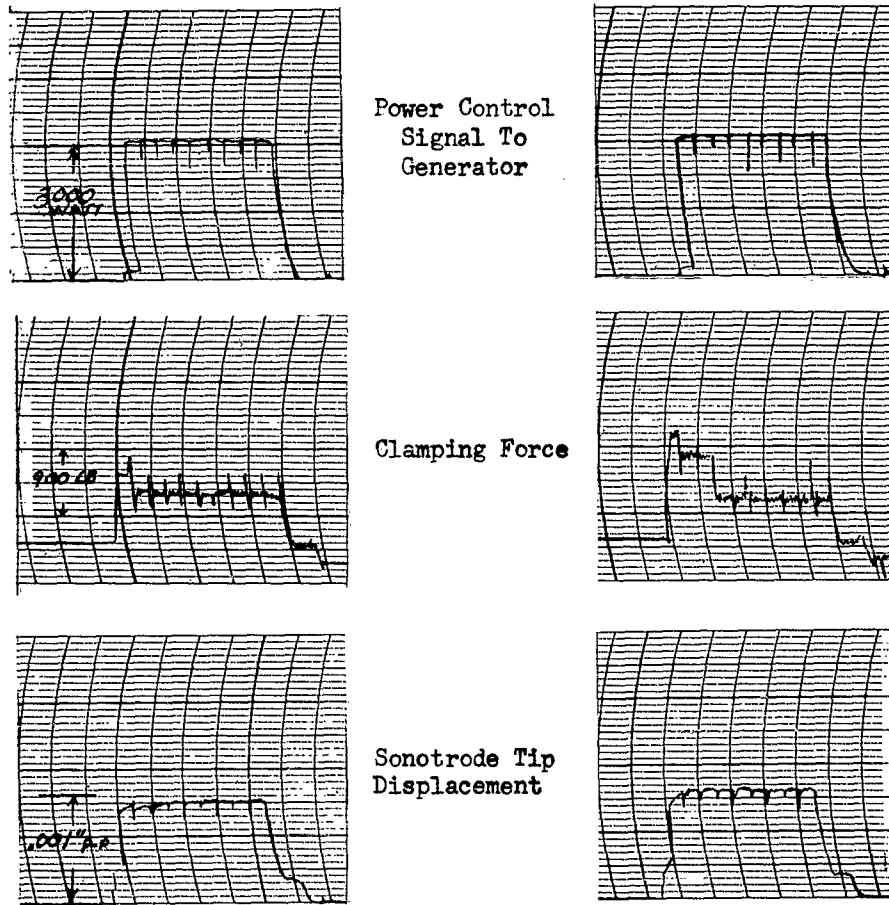


Figure 2

POWER AND FORCE PROGRAMMING PATTERNS AND CORRESPONDING  
 POWER, FORCE, AND TIME VALUES FOR MATERIALS INVESTIGATED

Material	Gage Inch	Total Weld Interval T-secs	Clamping Force		Ultrasonic Power to Transducer		
			F-lbs	ΔF-lbs	P-watts	ΔP <sub>2</sub> -watts	
2024-T3 Bare Aluminum	0.050	1.5	1000	200*	160	3200	1000
2024-T3 Bare Aluminum	0.063						
1100-H18 Interleaf Aluminum	0.001	1.5	1150	50	160	4200	0
Type 304 Stainless Steel	0.031	1.0	690	210	150	3100	1000
Inconel X	0.016	1.5	275	105	210	1800	500

\* Maximum Clamping Force Available on Machine is 1200 pounds.

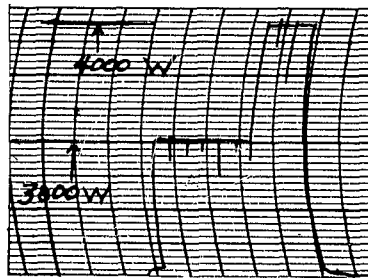


Pattern A

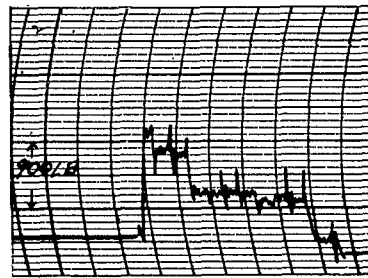
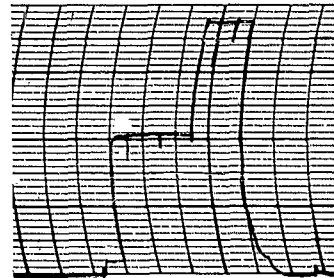
Pattern B

Figure 3

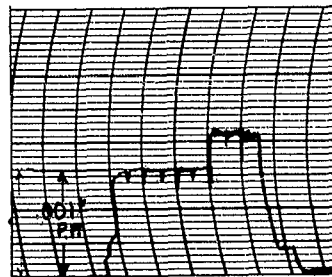
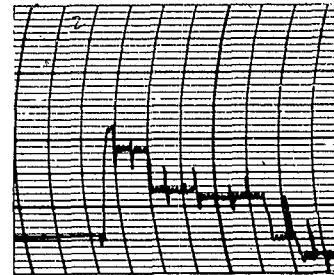
OSCILLOGRAMS FOR PROGRAMMED PATTERNS A AND B FOR POWER,  
 CLAMPING FORCE, AND SONOTRODE TIP DISPLACEMENT  
 WHILE WELDING 0.031-INCH THICK TYPE 304 STAINLESS STEEL



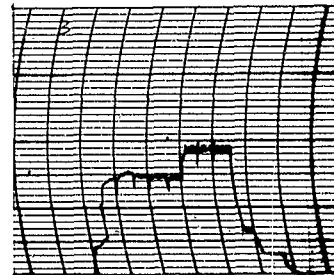
Power Control  
Signal To  
Generator



Clamping Force



Sonotrode Tip  
Displacement



Pattern C

Pattern D

Figure 3

OSCILLOGRAMS FOR PROGRAMMED PATTERNS C AND D FOR POWER,  
CLAMPING FORCE, AND SONOTRODE TIP DISPLACEMENT  
WHILE WELDING 0.031-INCH THICK TYPE 304 STAINLESS STEEL

Table I  
 STANDARD WELDING MACHINE SETTINGS FOR VARIOUS MATERIALS

Material	Gage, (inch)	Power, (watts)	Clamping Force (pounds)	Weld Time, (seconds)
2024-T3 Bare Aluminum	0.040	2400	800	1.5
2024-T3 Bare Aluminum	0.050	3600	900	1.5
2024-T3 Bare Aluminum with 0.001-inch thick 1100-H18 aluminum interleaf	0.063	4200	1150	1.5
Type 304 Stainless Steel	0.031	3000	550	1.0
Inconel X	0.016	1800	300	1.0



Table II

EXPERIMENTAL WELDING WITH POWER-FORCE PROGRAMMING

PPF Pattern	Welder Settings			Applied Energy (watt-sec)	Individual Tensile-Shear Strength (pounds)
	Power, (watts)	Clamping Force, (pounds)	Weld Interval, (seconds)		
<u>0.063-inch 2024-T3 Bare Aluminum, 0.001-inch 1100-H18 Foil</u>					
A	160	1150	.15	5690	1060
	4200	1150	1.35		900
					790
B	160	1200	.15	5690	1025
	4200	1200	.30		1340
	4200	1150	1.05		1010
C					
D	160	1200	.15	5090	1230
	4200	1200	.30		1080
	4200	1150	.90		1030
	160	1150	.15		
<u>0.050-inch 2024-T3 Bare Aluminum</u>					
A	160	1000	.15	4340	555
	3200	1000	1.35		965
					300
B	160	1150	.15	4340	540
	3200	1150	.30		400
	3200	1000	1.05		595
C	160	1150	.15	4790	1545
	3200	1150	.30		825
	3200	1000	.60		1265
	4200	1000	.45		
D	160	1150	.15	4340	1255
	3200	1150	.30		1360
	3200	1000	.45		1390
	4200	1000	.45		
	160	1000	.15		

Table III

EXPERIMENTAL WELDING WITH POWER-FORCE PROGRAMMING

PPF Pattern	Welder Settings			Applied Energy (watt-sec)	Individual Tensile-Shear Strength (pounds)
	Power, (watts)	Clamping Force, (pounds)	Weld Interval, (seconds)		
<u>0.016-inch Inconel X</u>					
A	210	275	.15	2450	480
	1800	275	1.35		500 460 490
B	210	380	.15	2450	520
	1800	380	.30		480
	1800	275	1.05		490 450
C	210	380	.15	2690	560
	1800	380	.30		495
	1800	275	.60		500
	2300	275	.45		520
D	210	380	.15	2450	560
	1800	380	.30		510
	1800	275	.45		560
	2300	275	.45		495
	210	275	.15		
<u>0.031-inch Type 304 Stainless Steel, 2B Finish</u>					
A	150	690	.10	2810	780
	3100	690	.90		865 780
B	150	900	.10	2810	860
	3100	900	.20		790
	3100	690	.70		850 630
C	150	900	.10	3105	860
	3100	900	.20		920
	3100	690	.40		875
	4100	690	.30		895
D	150	900	.10	2810	915
	3100	900	.20		920
	3100	690	.30		825
	4100	690	.30		990
	150	690	.10		

Table IV

STATISTICAL ANALYSIS TO ESTABLISH WHETHER A SIGNIFICANT  
 DIFFERENCE IN STRENGTH IS OBTAINED BY PFP

Material	Gage, (inch)	PFP Pattern	Mean $\mu$ (pounds)	No. of Samples (n)	(Test for Significance) Comparison with		
					A P	B P	C P
2024-T3 Bare Aluminum	0.050	A	616	3			
		B	517	3	.274		
		C	1217	3	<.001	<.001	
		D	1335	3	<.001	<.001	.26
2024-T3 Bare Aluminum with Foil	0.063	A	917	3			
		B	1125	3	.001		
		C	-				
		D	1113	3	<.003	>.42	
Inconel X	0.016	A	483	4			
		B	485	4	.42		
		C	519	4	<.001	<.023	
		D	531	4	<.001	<.005	>.242
304 Stainless Steel	0.031	A	808	3			
		B	783	4	.159		
		C	883	4	<.001	.050	
		D	913	4	<.001	.014	>.050

A probability of .050 shows a significant difference.

Ref. - Lacey, O. L., Statistical Methods in Experimentation, McMillan Company,  
 Chap. 9, 1957.

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