

Development
of
ULTRASONIC WELDING EQUIPMENT
for
REFRACTORY METALS

by
Nicholas Maropis

54823

AEROPROJECTS INCORPORATED

West Chester, Pennsylvania

Contract: AF 33(600)-43026

ASD Project No. 7-888

Interim Technical Progress Report

October through December 1963

Design, development, and construction of the 25-kilowatt spot-type welding machine has continued. Emphasis was placed on performance evaluations of both the modified 3.3-kilowatt tension-shell ceramic transducer and the single-element example of the overhung-coupler geometry with its present mechanically replaceable welding tip. Motor-alternator power source liaison was conducted, and control system components were incorporated into the welder frame.

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AFSC Aeronautical Systems Division
United States Air Force
Wright-Patterson Air Force Base, Ohio

ABSTRACT-SUMMARY
Interim Technical Progress Report

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DEVELOPMENT
OF
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FOR
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Nicholas Maropis
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[Design, development, and construction of the 25-kilowatt spot-type welding machine has continued. Emphasis was placed on performance evaluations of both the modified tension-shell ceramic transducer and the single-element example of the overhung-coupler geometry with its present mechanically replaceable welding tip.] Liaison efforts associated with expediting delivery of the motor-alternator power source were conducted, and control system components were incorporated into the welder frame. *1 to p9 →*

The four-wafer unbonded ceramic transducer was driven at its design power (a maximum of 3.4 kilowatts) without the former arc-over difficulties, and there was no evidence of untoward unit or circuitry failure. Thermal characteristics of the device proved to be adequate, calorimetric tests demonstrated electromechanical conversion efficiencies of from 52 to 69 percent, and under actual welding conditions the transducer's efficiency was at least twice that of a conventional magnetostrictive transducer.

[Welding tip design problems were noted, and exploration of acoustical coupling features is proceeding while fabrication of modified coupling members is in progress.] *and RUC 4-2-64*

from p9

FOREWORD

This Interim Technical Progress Report covers the work performed under Contract AF 33(600)-43026 from October 1, 1963 through December 31, 1963. It is published for technical information only and does not necessarily represent the recommendations, conclusions, or approval of the Air Force.

This contract with Aeroprojects Incorporated of West Chester, Pennsylvania, was initiated under ASD Manufacturing Technology Project 7-888, "Development of Ultrasonic Welding Equipment for Refractory Metals." It was administered under the direction of Fred Miller of the Fabrication Branch (ASRCTF), Manufacturing Technology Laboratory, AFSC Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

This project is under the direction of J. Byron Jones, with Nicholas Maropis serving as Project Engineer. Others associated with the program are Carmine F. DePrisco, Chief Electronics Engineer; John G. Thomas, Metallurgist; Janet Devine, Physicist; Jozef Kozlarski, Ultrasonic Welding Laboratory Director; and W. C. Elmore, Consultant. This document has been given the Aeroprojects internal report number of RR-64-9, and is an interim report. Information reported herein is preliminary, and subject to further analysis and modification as the work progresses.

The methods used to demonstrate a process or technique on a laboratory scale are usually inadequate for use in production operations. The objective of the Air Force Manufacturing Methods Program is to develop, on a timely basis, manufacturing processes, techniques and equipment for use in economical production of USAF materials and components. The program encompasses the following technical areas:

Rolled Sheet	Powder
Forgings	Component Fabrication
Extrusions	Joining
Castings	Forming
Fiber	Material Removal
Fuels and Lubricants	Solid-State Devices
Ceramics and Graphites	Passive Devices
Nonmetallic Structural Materials	Thermionic Devices

Your comments are solicited on the potential utilization of the information contained herein as applied to your present or future production programs. Suggestions concerning additional Manufacturing Methods development required on this or other subjects will be appreciated. Direct any reply concerning the above matter to the attention of Mr. W. W. Dismuke, ASRKRA.

PUBLICATION REVIEW

Approved by:


V. Byron Jones

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DEVELOPMENT
OF
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Phase II

INTRODUCTION

Since ultrasonic welding was first demonstrated as a practical method for joining thin gages of aluminum and other common metals and alloys, the equipment capability has been continuously extended to joining materials of increasing thickness as well as newer metals and alloys that are difficult or impossible to weld by other techniques. The aerospace need for high-temperature, corrosion-resistant, refractory metals and alloys has emphasized the need for ultrasonic welding machines of greater capability than are now available.

The objective of this program is to design, assemble, and evaluate heavy-duty ultrasonic welding equipment for joining refractory materials and superalloys in thicknesses up to 0.10 inch, and to develop necessary techniques for producing reliable welds in these materials. The accomplishment of this objective is divided into three phases: Phase I is concerned with establishing feasibility, defining problem areas, and delineating appropriate solutions thereto. Phase II embraces the development of the required equipment and techniques. Under Phase III, the performance characteristics of the ultrasonic welding equipment will be demonstrated.

Under Phase I, completed prior to the current reporting period (1)*, the feasibility of producing ultrasonic welds in both monometallic and bimetallic combinations of Cb(D-31), Mo-0.5Ti, Inconel X-750, PH15-7Mo stainless steel, René 41, and tungsten was demonstrated. By extrapolating the weldable gage capability of 4-kilowatt and 8-kilowatt ultrasonic spot-type welders, and utilizing a previously developed first-approximation criterion for the energy required to weld materials of various hardnesses and thicknesses, the electrical power input to the transducer necessary to join the above materials in gages up to 0.10 inch was estimated as approximately 25 kilowatts.

* Numbers in parentheses refer to List of References at end of report.

Also under Phase I, problems involved in the production of heavy-duty ultrasonic welding equipment were delineated, a systematic approach to solving these problems was outlined, and requirements for the requisite heavy-duty spot-welding equipment were defined. Basic concepts involved in such machines were investigated, and spot-type welders for high-power operation were studied in considerable detail. Theoretical and experimental information was evolved to support the design requirements for this type of machine.

A survey of the "state of the technology" of transducer materials and coupler materials, supplemented by laboratory investigations, evinced that the transducer-coupling system for the heavy-duty equipment should preferably utilize lead-zirconate-titanate ceramic transducers, and coupling members made of aluminum-bronze, K Monel, or beryllium-copper. The requisite vibratory power can be delivered to the weld zone by means of an opposition-drive transducer-coupling system.

Ultrasonic welding of the refractory metals during the course of this program, and subsequent work involving refractory metals on concurrent programs, have indicated the suitability of Astroloy and Udimet 700 alloys as tip materials.

Preliminary studies showed that the transducer-coupling systems could be driven by either a motor-alternator or an electronic generator providing about 25 kilowatts of 15-kilocycle electrical power. If the motor-alternator were selected, solid-state elements would be considered to meet the switching requirements.

The work initiated under Phase II has the following objectives:

1. Develop the necessary methods, techniques, and equipment to ultrasonically join the selected materials.
2. Design and construct ultrasonic joining unit(s) in accordance with the approach outlined in Phase I.
3. Develop methods and techniques to demonstrate the capability of the equipment developed under Phase II to join the selected materials.

This report describes the work accomplished during the period from October 1 through December 31, 1963. Special attention was given to evaluation of primary equipment elements required in the 25-kilowatt ultrasonic spot-type welding equipment, including testing of the modified tension-shell ceramic transducer and of a single-element portion of the projected acoustical coupling system, plus incorporation of control components into the welder frame. The third item above, equipment capability studies, cannot be pursued until after equipment assembly has been completed.

I. MATERIAL INVESTIGATIONS

"THE OBJECT OF PHASE II IS TO DEVELOP THE NECESSARY METHODS, TECHNIQUES, AND EQUIPMENT TO ULTRASONICALLY JOIN THE SELECTED MATERIALS."

Materials investigations requisite to fulfillment of Phase II were essentially completed prior to this report, and no further work in this area is anticipated until the 25-kilowatt welder is operating. The current status of these investigations is reiterated briefly below.

WELDMENT MATERIALS

The necessity for using high-quality materials in the ultrasonic welding of high-temperature and refractory metals and alloys has been indicated throughout this program, as well as in other related programs. Suitable materials of known metallurgical history, although of indeterminate quality, have been obtained (3) for welding investigations with the 25-kilowatt welder. These materials include columbium D-31 alloy, Inconel X-750, Molybdenum-0.5% titanium, PH 15-7 Mo stainless steel, René 41, and tungsten, all in the stress-relieved or annealed condition, in sheet gages up to 0.10 inch. 7113

TIP MATERIALS AND GEOMETRY

In extended experiments with welding-tip materials, both Astroloy and Udimet-700 have demonstrated good welding performance and long service life. These alloys have similar chemical compositions, similar mechanical properties, and essentially identical metallurgical structures. Sufficient stock is on hand for the fabrication of tips for the 25-kilowatt welding machine from both of these materials. 7113

Investigations of welding-tip geometry have established that tips having spherical radii of 0.85, 1.75, 3.7, and 6.0 inches should effectively weld the entire range of sheet thicknesses from 0.005 to 0.10 inch. 6 p 3

II. EQUIPMENT DEVELOPMENT

"THE CONTRACTOR SHALL DESIGN AND CONSTRUCT AN
ULTRASONIC JOINING UNIT IN ACCORDANCE WITH THE
APPROACH OUTLINED IN PHASE I."

Work has continued on evaluation of components for the 25-kilowatt ultrasonic spot-type welding machine. Various problem areas have been and are being investigated, while substantial progress has been made toward completion of the structure assemblage.

TRANSDUCER

As noted earlier (4), tests have shown that the tension-shell ceramic transducer should provide a suitable system to employ in ultrasonic spot-type welding. The envelope or armored design enables practical usage of the ceramic's relatively high natural electromechanical conversion efficiency, advantageous features having been provided which also minimize fragility and high voltage hazards, and facilitate incorporation of requisite cooling. Early models for operation at intermediate power levels (2 and 3.3 kilowatts, respectively) showed actual conversion efficiencies of up to 92 percent, although they operated successfully up to only about one-half of design power on a rigorous continuous-duty basis. With the two-wafer 3.3-kilowatt unit, for example, continuous power could be applied up to 1600 watts, but arcing occurred at higher powers.

The previous report (5) discussed not only the various factors tending to adversely affect full-power operation, but also the rationale for and details of several design modifications, which were undertaken in order to furnish an efficient system that is non-heat-power limited up to its design power capacity.

During the current report period, and as explained at some length below, such modification of the 3.3-kilowatt transducer was completed, and observations were made of the model's electrical and thermal characteristics, power delivery into the acoustical calorimeter, and performance under actual welding conditions. The device was successfully driven at its design power (a maximum of 3.4 kilowatts) without the former arc-over difficulties, and there was no evidence of untoward unit or circuitry failure.

The modified 3.3-kilowatt transducer comprised four ceramic wafers separated by metallic washers containing air-cooling channels, making a total of eight interfaces instead of the four in the original two-wafer design. The two additional wafers (and their associated washers) were used for purposes of alleviating the heat problem. Lowering the driving

voltage and matching coil requirements was also effected by reducing the requisite power density to less than 3 watts/cc/kc.

Preparations prior to assembly included the making of new metal* spacers and conditioning of the ceramic** wafers to provide more nearly lineal thermal expansion characteristics. Metal washer diameter was increased so as to give a heat-dissipation area approximately 40 percent greater than that of the ceramic-edge surface area. Following the suggestion of Clevite Corporation (5), the ceramic wafers were heat-cycled for about one hour at from 150 to 200°C.

This particular unit was unbonded for purposes of ready disassembly and inspection of components, i.e., in lieu of bonding, metal washer fabrication involved provision for two parallel silver-surfaced plates having cooling channels machined on one side of each plate, for a total of three more interfaces. With the machined channel sides abutting, compressive bias stress held the 11-interface unit together. In the final assembly, the number of interfaces will be reduced by making each spacer in one piece, and the components may be bonded with high-strength epoxy resins or by diffusion techniques.

In a study of the thermal characteristics of the device, it was ascertained that the cooling air supply was inadequate to prevent overheating of the ceramic wafers, within the design power range, for reasonable spot-welding duty cycles. Infrared radiometer temperature sensing of the washers was used to obtain this information, the radiometer having its output connected to a strip-chart recorder and viewing the metal washer edges (which had been previously coated with Alsamite flat-black high-emissivity paint) through holes in the tension sleeve. So that actual temperatures could be more accurately detected, the radiometer's output had been calibrated, by relating its output while viewing another similarly painted surface to "known" temperatures obtained via an imbedded thermocouple.

Data on the transducer assembly's electromechanical conversion efficiency were obtained by means of a direct calorimetric technique (2,3), which affords a reproducible test load for performing transducer evaluations. The assembly was attached to an acoustical coupling member (in much the same manner as it would be attached in an ultrasonic welder), and the coupling member was connected directly into a lead-block energy absorber, with a cooling coil serving to carry away the heat resulting from vibratory energy degradation in the lead billet. By operating the calorimeter at a level approximating the acoustical test value, it was possible to determine the calculated acoustical energy delivered to the calorimeter and measured in the usual mass rate of water flow and temperature rise data.

* Invar-36, a low-thermal-expansion-coefficient nickel-iron alloy made by Carpenter Steel Company.

**PZT-4 lead-zirconate-titanate, Clevite Corporation.

In this test, the ceramic transducer assembly was operated: (a) continuously at 1200 watts to provide data for comparison with those obtained previously, and (b) under simulated pulsed-power welding conditions wherein duty cycles of 25 percent (1 second on and 3 seconds off) and 50 percent (1 second on and 1 second off) were used at power levels up to 2400 watts. Short (2-minute) continuous-power tests were conducted at the 3000- and 3400-watt levels. From these it was learned that the system was functional at the upper limit of design power as well.

Conversion efficiencies realized with the four-wafer unit ranged from 52 to 69 percent, as against 75 to 92 percent for the two-wafer design. Allowing for the above-mentioned unbonded and extra-interface aspects, adequate confirmation appears to have been obtained that the 60 percent conversion efficiency projected (1) for the final prototype design is straightforwardly practical of attainment.

For trial under actual spot-type welding conditions, the ceramic transducer assembly was substituted (by screw-attachment) for the conventional nickel-stack transducer in a standard 2-kilowatt ultrasonic welder. The minimum power input required to produce high-strength welds was determined, using materials on which substantial welding background information was available, namely, 0.032- and 0.040-inch 2024-T3 bare aluminum alloy.

With the 0.032-inch sheet and previously standard conditions of 700 pounds clamping force and 1.5 seconds weld time, at a power level of 850 watts input to the ceramic assembly, the resulting weldments exhibited shear strengths of 700-800 pounds (as measured on an Instron tensile testing machine, Model TT-C-L). These results appeared to confirm the efficiency of the ceramic (electrostrictive) assembly at about twice that of the nickel (magnetostrictive) transducer, inasmuch as the latter system required approximately 1700 watts power input for the same weld strengths (same clamping force and weld interval).

The same conclusion was drawn after somewhat more extensive welding tests with the 0.040-inch alloy, using 1100 watts power input to the ceramic assembly (under previously standard conditions of 850 pounds clamping force and 1.5 seconds weld time). With these machine settings, the welds had tension-shear strengths of 900-950 pounds, whereas equivalent-strength welds made with the magnetostrictive transducer array at the same clamping force and weld time had required a power level of 2400 watts.

TRANSDUCER-COUPLING SYSTEMS

The single transducer-coupling system heretofore reported as having been fabricated, which embodied a scaled-down version of the overhung-coupler geometry (5) projected for use on the final 25-kilowatt welder, was assembled with provision for mechanically removable welding tips. Subsequent powering, together with detailed microphone probing measurements

and actual welding experiments, was resorted to in order to establish acoustical performance characteristics. Energy loss was observable in the area of the tip-coupler joint, as evidenced by displacement of the tip's welding surface from the coupler's vibratory axis. A brazed-on tip may eventually be used, unless current efforts are successful which involve modifying the tip and tip holder by further recessment into the coupler so as to reduce the eccentricity of the tip with reference to the axis of the coupler. While the required additional systems are in process of design, exploration of the single system's characteristics is continuing with the view to final isolation of additional factors having potential bearing on welder performance, such as the generation of modes of vibration which may be undesirable in the end item.

POWER SOURCE

Liaison efforts have continued with respect to obtaining delivery of the 25-kilowatt motor-alternator power source, the major components of which are the 100-horsepower electric motor, the differential variable-speed transmission, a 1-2 speed-matching transmission, and the 5560-rpm alternator. Delivery of the completed assembly to our plant is now scheduled for about February 10, 1964.

Technical difficulties delayed acceptance of the speed-matching transmission after its delivery by Foote Brothers Gear & Machine Corporation (Chicago, Illinois) to Bogue Electric Company (Paterson, New Jersey). Because this step-up gearing incorporated (by unannounced vendor change) an oil cooler extending below the motor-alternator base level, it was also necessary to modify the supporting structure being fabricated to our design by Wiedeman Machine Company (King of Prussia, Pennsylvania).

Starting characteristics of a motor-drive system are governed by total inertia I , and acceleration time t , as given below (6,7):

$$I = W R^2 \quad (a)$$

and

$$t = \frac{I (RPM_2 - RPM_1)}{308 T_{av}} \quad (b)$$

where: W = weight (in pounds)
 R = radius of gyration (in feet)
 t = time to accelerate from RPM_1 to RPM_2
 T_{av} = average torque developed by the motor for acceleration of the inertia over the speed range.

Motor-alternator specifications had included, for the speed-matching transmission, an input rotational inertia value of 161 lb/ft² and a ratio of input to output of 1:2. As measured by Bogue Electric Company, alternator inertia without the 1:2 transmission was 40.1 lb/ft². With the transmission there would be 160.4 lb/ft² plus the gearing transmission inertia. However, as delivered by Foote Brothers, the ratio was 1:2.0217, possibly explaining the rotational inertia figure change to 164 lb/ft² plus gear inertia. Therefore, at a given input speed the output speed would be 1.085 percent greater than specified. The effect of this change on acceleration time required to reach operating speed cannot be determined until the sub-assembly is coupled to the transmission-motor assembly, but a sufficient range is believed to have been incorporated into the transmission to accommodate the difference.

This matter was reviewed during a visit of our personnel to Bogue Electric Company on December 26, 1963. It was decided to accept the step-up gear box on condition that the added inertia will not adversely affect the acceleration time of the complete assembly. During this visit, the alternator was inspected and tested while operating at design power into a resistive load. The "no load" voltage out of the alternator was found to be 265 volts, as against the 250 volts rms specification, but the 15-volt difference was within the safety factor range provided in the 250-volt figure. Acceptable operation having been noted, it was arranged that shipment of the components would be made as soon as possible for coupling to the differential variable-speed transmission and mounting onto the supporting structure.

MACHINE STRUCTURE

The force system's hydraulic components (except for the servo valve) having been frame-mounted, tested, and found to operate satisfactorily (5), work during this report period centered around the control systems for the welder. Those control components governing basic welding machine functions were installed on the left panel, while the auxiliary units (such as the oscilloscope and the power-force programming controls, which are normally used only during set-up procedures) were removed from the front panels and relocated to the right side of the machine. Such locale differentiation for the controls should facilitate the production-type operations for which the welder is designed.

LIST OF REFERENCES

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6. Standard Handbook for Electrical Engineers, McGraw-Hill Book Co. (1949) 7-92.
7. Libby, C. C., Motor Selection and Application, McGraw-Hill Book Co. (1960).

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Attn: Mr. C. W. Kniffin (RDRAE-F)	1	Southwest Research Institute
Andrews Air Force Base, Maryland		Attn: Glenn Damewood, Dir. Applied
		8500 Culebra Road Physics Dept.
1 Aeronautical Systems Division		San Antonio 6, Texas
Attn: ASRKCB		
Wright-Patterson Air Force Base, Ohio	1	Union Ultra-sonics Corporation
		Attn: John Zotos, Chief Project Scientist
2 Aeronautical Systems Division		111 Penn Street
Attn: Metals & Ceramics Lab (ASRCM)		Quincy 69, Massachusetts
Wright-Patterson Air Force Base, Ohio		
1 Aeronautical Systems Division	1	Vought Aeronautics Division
Attn: Applications Lab (ASRCE, Mr. Teres)		Chance-Vought Aircraft, Inc.
Wright-Patterson Air Force Base, Ohio		Attn: George Gasper, Mfg. Engr. Mgr.
		P. O. Box 5909
		Dallas, Texas
2 Aeronautical Systems Division		
Attn: Flight Dynamics Lab	1	Vought Aeronautics Division
Structures Branch (ASRMDS)		Chance-Vought Aircraft, Inc.
Wright-Patterson Air Force Base, Ohio		Attn: Chief Librarian, Eng. Library
		Dallas, Texas
1 Battelle Memorial Institute		
Defense Metals Information Center	1	Vought Aeronautics Division
Attn: Mr. C. S. Dumont		Chance-Vought Aircraft, Inc.
505 King Avenue		Attn: J. A. Millsap, Chief Engr.
Columbus, Ohio		Manufacturing Research Dev.
		P. O. Box 5907
1 Ballistic Missile Systems Division		Dallas, Texas
Attn: Industrial Resources		
P. O. Box 262	1	G. C. Marshall Space Flight Center
AF Unit Post Office		National Aeronautics & Space Administration
Inglewood, California		Attn: William A. Wilson
		Chief, MR & D Branch
1 Chief, Bureau of Naval Weapons (PID-2)		Huntsville, Alabama
Department of the Navy		
Washington 25, D. C.	2	Langley Research Center
		National Aeronautics & Space Administration
1 Frankford Arsenal		Attn: Technical Director
Research Institute 1010 (110-1)		Langley, Virginia
Attn: Mr. E. R. Rechel, Deputy Director		
Philadelphia 37, Pa.	1	Scientific & Technical Information Facility
		P. O. Box 5700
1 Solar Aircraft Company		Bethesda, Maryland 20014
Attn: Engineering Library		
2200 Pacific Highway	1	Engelhard Industries
San Diego, California		384 W. First Street
		Attn: Bill Smith
		Dayton 2, Ohio