ULTRASONIC WELDING PROCESS AND EQUIPMENT FOR CONSTRUCTION OF ELECTRON-TUBE MOUNTS

Second Quarterly Progress Report
For the Period
October 1 through December 31, 1962

Contract No. DA-36-039-sc86741
Order No. 19063-PP-62-8181

Placed by
Industrial Preparedness Activity
United States Army Electronics
Material Agency

AEROPROJECTS INCORPORATED
West Chester, Pennsylvania

ULTRASONIC WELDING PROCESS AND EQUIPMENT FOR CONSTRUCTION OF ELECTRON-TUBE MOUNTS

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The object of this program is to design and construct prototype welding equipments and their associated accessories to perform by ultrasonic techniques the welding operations required in the assembly of electron tubes under Specifications SCS-114A and SCIPPR-15.

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Report Prepared by: [signature]

Report Approved by: [signature]

ABSTRACT

Results of welding eighty-two combinations of materials and geometries are presented. An evaluation program for all successfully welded combinations has been established. Progress in the effort to use ultrasonic welding in the manufacture of three specific electron tubes is reported.

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PURPOSES

The objectives of this Production Engineering Measure (PEM) are to:

1. Demonstrate the capability limits of ultrasonic welding to join combinations of metallic materials of interest to the electron-tube industry. This part of the work will be limited in that it will not continue exhaustive attempts to weld those combinations which might prove particularly difficult to join.

2. Analyze the welding requirements for three specific electron tubes. The three tube types selected are the Type 6080WB, 5814WB and 6205. These were selected by the U. S. Army Electronics Materiel Agency because they are widely used in military equipment, and have a record of failures due to improperly welded joints.

3. Prepare fixturing and tooling for the specific electron tubes, so that ultrasonic welding may be used in the manufacturing process.

4. Weld the parts required to assemble electron-tube mounts for the three tube types, and evaluate.

5. Build production ultrasonic welding equipment which will enable an electron-tube manufacturer to make the welded connections in a broad range of electron-tube types.

6. Install the ultrasonic welding equipment in a production company, and produce on a pilot basis with that company's personnel, a limited lot size of each of the three tubes for subsequent evaluation in accordance with applicable military specifications.

NARRATIVE AND DATA

WELDING STUDY

The welding study was directed toward the accomplishment of the following objectives: (a) demonstration of the capability of ultrasonic welding to join 51 metal combinations in wire to flat sheet material (b) define tooling requirements and material surface preparation necessary to accomplish satisfactory welds in these combinations (c) development of an evaluation method for the welds that is sufficiently determinate to indicate successful application of ultrasonic welding to production manufacturing.

Figure 1 indicates a total of 91 weld specimens to be attempted (in two wire sizes for a total of 182) and incorporates the 51 similar and dissimilar metal combinations required to be ultrasonically welded under the program. Although welding was done on all of these 182 combinations during the period of this report, only 82 successful selected combinations (41 x 2) are shown by shaded blocks in the Figure. These combinations represent a group wherein satisfactory joint efficiencies had been obtained in both fine and heavy wire weldments in the same material combination. Joint efficiency (in percent) is calculated from the failure load of the specimen divided by the failure load of the unwelded wire multiplied by 100. Whenever a welded combination was obtained which could be considered satisfactory for practical purposes, no additional improvement was sought. Additional study of surface preparation, welding parameters, and fixturing will improve tensile-shear strengths, reduce strength variations, and decrease deformation, and there is little doubt that all of the combinations are satisfactorily weldable for the end uses here under consideration.

Effort was expended in literature research, and contacts with technical sources during this report provided assistance in joining various of the difficult-to-weld combinations. Published data relevant to the welding of refractory metals are generally inadequate, and information covering manufacturing or processing techniques difficult to secure. Technical cooperation in these areas has, however, been obtained from the General Electric Company in Cleveland, Ohio during a visit there on December 11, 1962, but a complete report thereon is being withheld until a later report.

1. Material Procurement

The material initially ordered for use in the program has been received. In many cases it was necessary to search for satisfactory substitutes, due to difficulties encountered in the condition of the material, and the presence of contaminants therein. For instance, molybdenum free from contaminants was unobtainable. It is contemplated that a discussion of these difficulties, together with their impact upon the work and with pertinent solutions, will be included in the next report.

2. Tooling

a) Fine-Wire Tooling

A typical welding tip used on the 100-watt and the 20-watt (used for reasons explained subsequently) ultrasonic welding machines is shown in Figure 2. A hardened-steel welding-pin tip is brazed into the end of the contoured shank which is attached to the transducer-coupler assembly by a threaded stud. Both ends of the pin tip are ground to a spherical radius. The welding of wires is sometimes facilitated by the placement of a semi-cylindrical groove in the end of the tip, which not only assists in the locating of the workpieces, but also reduces wire deformation and the level of energy required. The groove is usually parallel to the axis of the exponential shank because in the transverse position the wire tends to roll during welding.

Other pin-tip configurations, for application to relatively inaccessible places, can be designed and readily manufactured. Critical aspects of such fabrication include the problem of physical strength, to prevent breakage when required power is applied, and the avoidance of resonance in a mode which will not permit welding. It is important in the design of tips that the resonant frequency of the entire system be not changed so that the system will deliver power in accordance with system calibration.

For fixturing, two spring-loaded clamps (Figure 3) firmly fasten the coupons to the welding anvil. In all cases, this arrangement met all welding requirements for fine wires.

On the 100-watt and 20-watt welding machines, the level of ultrasonic energy is low compared to the thickness of the coupons, and is not sufficient to penetrate the heavy coupon and affect the anvil tip. Thus, for the fine-wire weldments, anvil tip materials were not a consideration.

b) Heavy-Wire Tooling

Difficulties were experienced with the first welding fixture for the 4-kw spotwelder (described in the First Quarterly Progress Report), and its performance was regarded as unsatisfactory. It was found that the eccentric clamping lever did not permit adequate latitude in welding a sufficient number of wires to the same coupon, nor did it hold coupons securely enough. In addition, the restraining lips (phenolic laminate-Micarta) deteriorated in use, necessitating the substitution of metal lips. In an effort to overcome the fact that the adjustable base complied at the frequency of the applied ultrasonic energy, slots were cut into the periphery of the flanges thereof, with the view of altering its natural frequency. Despite the achievement of a reduction in vibratory response, the action remained inadequate, and a Micarta base was substituted for the steel base, to avoid resonant vibrations. However, this base pulled the copper anvil flange out of position, preventing good contact between the copper anvil and its support. Subsequently, the adjustable base was eliminated, and no problems were experienced.

A welding fixture was evolved to surmount the limitations of the previously used designs, and is shown in Figure 4.

Several materials were used for anvil tips in the heavy-wire-to-coupon welding, and their performance is indicated in the table below. It will be noted that tip life and anvil life are related to the physical properties of materials to be welded. All anvil tips were made to the configuration shown in Figure 5.

Type of Tip	Condition	Performance of Tip Material
Astroloy, cast	As-cast	Satisfactory, but the tip spalled. Tip is not reclaimable.
Astroloy, fabricated from rolled-plate stock	As-received	Very Good
Type M-2 Tool Steel	Heat-treated	Good

Sonotrode tips of various materials and geometries were used. A heat-treated Inconel-X sonotrode tip (Figure 6A) gave satisfactory results on soft-metal wires.

Cast Astroloy, in the "as-cast" condition with a 3-inch spherical-radius tip (Figure 6B) cracked and chipped.

Sonotrode tips made from extruded Astroloy* stock and forged Udimet 700** bar stock (heat-treated by Aeroprojects) proved to be quite satisfactory. They are shown in Figure 6C. Longer than standard tips (as an economy measure to permit regrinding) produced high stresses at the brazed joint between the reed and the tip, due to a high bending moment and to greater stiffness. Since the brazed fillet showed evidences of cracking,

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* A superalloy developed originally by General Electric Company. Currently manufactured by Wyman Gordon Co.

** A superalloy developed and manufactured by Special Metals Incorporated.

modifications were made to the tip, to decrease stresses by reducing the degree of stiffness. The modified geometry is shown in Figure 6D. Proving satisfactory after this change, tips of this type were used initially for all heavy-wire combinations. Regrinding to restore surface contour and condition had no adverse effect on tip performance. It should be noted parenthetically here that there is presently no yardstick which can be universally applied in determining the extent of tool life. Under conditions of operation there is a degree of tool abuse existent. There is evidence to indicate, however, that when optimum welding conditions have been established, long tool life may be expected. For instance, production reports show the making of over 1 million welds in aluminum, about 12,000 in beryllium copper, without any tip maintenance.

Sonotrode tips made from Astroloy and Udimet 700 in heat-treated condition with 3-inch spherical radius and grooved as shown in Figure 7, were used for welding material combinations considered either partly satisfactory or impossible to be joined with an ungrooved spherical-radius tip. These tips were also used for welding soft wires to hard coupons when excessive wire deformation occurred. The grooved tip reduced deformation and produced higher joint efficiency, and in some instances produced joints which could not be made with the plain, spherical-radius tip. For welding hard, brittle wires, in materials such as molybdenum and tungsten, which cracked due to the high deformation associated with a spherical tip, a tip groove provided restraint and virtually eliminated wire cracking. The groove is parallel to the direction of vibration.

The grooved tip is useful also in reducing the notch produced at the joint (Figure 8) by spherical-radius tips. Figure 9 compares the results of welding gold wires to nickel plate by spherical-radius tips, and by grooved tips. It has been determined that the groove width should be about 0.005 inch larger than the diameter of the wire.

The performance of Astroloy and Udimet 700 sonotrode tips was superior to that of Inconel-X alloy tips, possibly due to the superior high-temperature properties of the former alloys. When used on hard metals and alloys, Inconel-X tips may crack and chip at the work-interface. Such cracks as occur are usually deep, to the end that such tips cannot be salvaged by grinding. Astroloy and Udimet 700 tips offer much higher resistance to cracking than Inconel-X tips, and do not chip. Moreover, cracks in the Astroloy and Udimet 700 tips are usually shallow, and the tips can ordinarily be reclaimed by grinding to a depth of 0.020 inch to 0.030 inch. Regrinding may be continued as required until no material structural strength remains.

Despite the superior weldment characteristics from the grooved tip, it is not uncommonly preferable to use a standard spherical-radius tip because of the economies which can be effected. Tip damage is more readily discernible, regrinding or redressing is easier, and positioning of weldment components is less critical.

3. Welding

Of the number of generally controllable variables in the ultrasonic welding process (sonotrode-tip radius, anvil radius, clamping force, power, and time) only the last three of these are readily adjustable by the operator.

In most applications, the anvil tip is flat. The passive anvil is essentially non-compliant, thus concentrating the vibratory energy in the weldment. The sonotrode-tip spherical radius contacting the work (such as shown on Figure 7) is governed by the thickness and the properties of the material being welded. Although welding has been accomplished with a range of tip radii, experience with flat material has shown that the tip radius should ordinarily be between 50 and 100 times the thickness of the material adjacent to the sonotrode tip (1).

The clamping force, power, and weld interval (or time) are under the immediate control of the operator. These are adjusted to near optimum values for each combination of materials being welded. Equations have been derived from which estimates of the energy (and therefore power and time) required to make a weld can be deduced (1). To date, no straightforward analytical method for determining clamping force has been determined, and its value is established empirically.

There does exist a clamping force for which the energy required to produce a weld is minimum. This clamping force is important in that if welding is attempted at a clamping force setting much different (greater or less) than this optimum value, more energy will be required to make a satisfactory weld, and much more heating of the weldment will result (1).

The level of power delivered by the power source to the welder controls the amplitude of the vibration of the sonotrode tip and, hence, the magnitude of the dynamic stresses at the weld interface between the parts being welded. A certain minimum value of cyclic stress must be achieved before welding will occur. Thus, there is a lower limit, or "threshold", for the amount of applied power, which must be exceeded.

Finally, the length of the pulse of ultrasonic power determines the energy supplied to the weld. The product of the power (watts) multiplied by the time (seconds) is the amount of energy (watt-seconds) actually utilized. The thickness and hardness of the parts being welded primarily determine the energy required to create welds. Other factors also govern the energy requirement, but generally as either thickness or hardness of the parts increases, the energy required for welding also increases (1).

Previous experimental data are useful in determining machine settings which will be reasonably satisfactory. Probably the most practical and the most reliable method to determine correct welding machine settings for power, clamping force, and weld time is to ascertain the threshold curve (4).

A typical threshold curve is shown in Figure 10. There is an optimum clamping force at which bonding of a given material combination is accomplished with least vibratory energy. To produce a threshold curve as shown in Figure 10, the procedure is first to select a weld time interval that appears reasonable on the basis of previous experience or available data. Second, select a power setting that appears reasonable on the same basis. Then make welds progressively, increasing the clamping force only from a low value by modest steps through some high value. At the low values essentially no bonding will be observed, as can be determined by manual peeling of the weldment and observing if, or if not, a nugget is pulled from one of the pieces. But at some level of clamping force bonding will be observed, and bonding will continue as clamping force is increased to some point where no further bonding will occur. If no bonding whatever is observed, it can be assumed that the power setting is too low and/or the weld time interval is too short. By repeating the above procedure at several power and/or time settings, when the bond or no-bond formation is noted on suitable graph paper with the ordinate stepped off in increments of power and the abscissa stepped off in increments of clamping force, it is straightforward to quickly observe the envelope of power-clamping force relationship at any fixed weld time interval, inside of which bonding occurs and outside of which no bonding occurs.

The proper clamping force will be the value at which the threshold curve is minimum. The proper power setting will be somewhat higher than the minimum value indicated by the threshold curve, so as to be within the "good bond" envelope.

As previously pointed out, the total energy utilized is the product of power and weld time. Excessive weld time causes surface damage and sometimes cracking. Thus, as a general rule, welding should be carried out with the shortest practical weld time interval and at a proper power level indicated by the threshold curve.

To conserve material, a maximum number of wires was welded to one coupon. The positioning of these welds was dictated by considerations of space required both for tool application and test procedures. Specially designed welding fixtures and tensile-testing machine jaws were devised (Figure 11), as reported in the First Quarterly Progress Report.

a. Fine-Wire Welding

Ultrasonic welding of fine wires requires close control of the power level and the clamping force. For most fine-wire-to-tab combinations, the 100-watt, 40-kc welding machine was satisfactory. For extra-fine, soft wires, such as 0.0003-inch gold, the 20-watt, 60-kc welding machine had to be used, as referenced under fine-wire tooling. On the 100-watt unit, the clamping force is applied by a mechanical spring through a range of zero to 15 pounds. The necessary precision of this clamping force exceeds the capability of the 100-watt welder used for some of the fine, soft wires.

Additionally, control of power with the 100-watt welder was also insufficiently precise at the low values required for the welding of extra-fine, soft wires. With the 20-watt welder, clamping force is applied by adjustable counter-weights providing a range from zero to 250 grams with a variation in any particular setting of ± 1 gram. Power is also more accurately controllable in the low range with the 20-watt unit. The 100-watt unit was pictured in the previous report. The 20-watt unit is shown in Figure 12.

Because of the number of specimens to be welded, and the difficulty in handling the fine wires, it was decided to locate and hold the fine wires during welding by the use of tweezers and a microscope, rather than by a clamping and locating fixture. A 60-power Bausch & Lomb binocular stereo zoom microscope was used. Similar instruments are in general use throughout the electronic industry to assist with problems of this nature.

Figure 13 shows the handling technique used for hard and soft wires. One end portion of the wire was to be subjected to tensile-shear testing. The use of tweezers to hold and position the wire during welding exerted some tension against the holding force of the welding tip at the weld point. Such tension was not critical with the harder wires and did not affect weld or wire strength. On soft wires, however, such as gold, silver, and copper, the tension weakened the wire at the edge of the weld, giving unreliable tensile-shear values. Accordingly, tweezer handling of soft wires was restricted to that section of the wire not used for tensile-shear testing.

Extreme care was necessary in lowering the welding tip onto the wire, to avoid flattening the wire prior to welding. Such deformation reduces joint strength, and changes the welding conditions.

When welding very fine wires with a standard spherical-radius tip, the wire must be placed almost exactly under the center of the radius. Should the wire lie eccentrically under the tip, a poor joint will result, because the tip would have greater contact with the tab than with the wire, or the wire will roll during the weld pulse.

A semi-cylindrical groove in the tip helps to locate the wire, but it does not appear practical to use a grooved tip for wires less than about 0.0005-inch diameter. Grooved tips do make stronger welds with some materials such as gold, copper, nickel and tungsten.

Specifics of the tip design contribute to weld quality. To optimize these details, it would be necessary to study the effect of such specifics as the length, depth, and radius of the groove in the tips, or of various spherical radii on the standard tips.

The joining of hard wires to hard coupons caused tip deterioration and pitting. Consequently, some of the tips required frequent honing and redressing. Tip wear is drastically reduced when the machine is operated constantly at the optimum machine settings.

It is important that the joint area on the coupon be smooth, flat, and reasonably parallel to the anvil surface. It is necessary to occasionally burnish the coupon to insure smoothness and flatness by using the tweezer ends or by moving the welding tip approximately 1 mil to each side of the weld area. Titanium and molybdenum required such attention. Burnishing had little effect on tungsten because of its high hardness.

Materials with a rough surface texture are unsuitable for fine-wire bonding without additional surface preparation. In the procurement of materials, no surface conditions were specified, and several of the materials, e.g., tungsten and molybdenum, had a rough texture. In the present case, auxiliary surface preparation, such as surface grinding and electroetching, was required to insure a surface condition appropriate for fine-wire bonding.

"White room" conditions should be used in the bonding of very low-strength fine wires such as gold and copper. Particles of foreign matter on the coupon or wire were found equal to or larger than the wire diameter. In these instances, the materials should be located so that clean areas are used.

Most wires were welded in the "as-received" condition. The coupons were wiped with acetone. The fine copper wire could not be welded satisfactorily until it was cleaned by dipping into a 50 percent solution of nitric acid (HNO_3) for two or three seconds, and then flushed with water.

b. Heavy-Wire Welding

All heavy-wire weldments were made using a laboratory model of the 4-kw ultrasonic welder. Tooling and techniques previously described were used to make the weldments.

4. Weld Evaluation

a. Evaluation Program

Pertinent military specifications and electron-tube industry practices were reviewed with representatives of Chatham Electronics and the U. S. Army Electronics Materiel Agency. The following comments are provided by way of background and general information for the specifics of the several tests outlined in later paragraphs.

a) Shock, vibration, and fatigue are the primary mechanical test exposures for electron tubes.

b) Specific details of test specifications vary according to the electron-tube type. Each test is conducted on a separate group of electron tubes and not sequentially on the same tube. The ability of the electron tube to withstand test exposure is usually determined by a comparison of electrical measurements, such as transconductance and noise, which are made both before and after testing. A change in electrical characteristics usually results from deformation of tube components or by particles being shaken loose. Such particles generally result from weld spatter (not present from ultrasonic welds). Such particles are jarred loose during tests. Tests are made upon completed electron tubes because the glass envelope supports the electron tube mount.

c) Tests are not made under low temperature or temperature cycling conditions. In many cases tests are conducted when the tube heaters or filaments are hot with electrical current as normal in operation. Heaters and cathodes are prone to failure because of their lack of strength at elevated temperatures. They not uncommonly fail by breaking or by distorting beyond usable limits, rather than by failing at the weld. Standard shock and vibration test equipment permits only room temperature and heated tests as just mentioned.

d) Gas filled electron tubes are first evacuated to very low pressure prior to the introduction of atmosphere. The atmosphere in both gas filled and vacuum tubes is inert and has no effect on weld performance. Completed electron tubes are tested for reasons other than the effect of vacuum or gas on the mechanical assembly.

Vibration tests at varying frequency are made to determine failures because of resonance in the completed tubes. After such exposure, evaluation is electrical. X-ray examination is not used or stipulated to evaluate weld quality.

Chatham Electronics is preparing a quotation to cover the fixturing and the work necessary for shock and vibration tests of specimens welded by Aeroprojects.

b. Strength Testing

Handling of the fine-wire weldments is difficult. Wires of .0015-inch diameter and smaller often fail before, during, or after welding from looping and kinking. For tensile-shear testing, small pieces of masking tape should be affixed to the free ends of the wires, and the weldments so manipulated that the weight of the tape keeps the wire in tension at all times.

Care must be exercised to prevent the masking tape from sticking to surfaces other than the wire (such as the fixture), because the welded assembly can not then be removed without breaking. As a safeguard, the wire ends can be sandwiched between a small square of paper and a smaller piece of tape so that no free edges of the tape are exposed.

Figure 14 shows the testing of these fine wire weldments in an inverted position. This technique is utilized where the parent metal strength of the wire is measured in pounds (the load cell of the Instron machine does not support the weight of the coupon and fixture when the gram scale was used.)

No particular difficulties are encountered in tensile-shear testing the heavy-wire weldments. The jaw arrangement for tensile-shear testing the heavy wire-coupon assemblies is shown in Figure 11. Note the several welds per coupon.

The tensile-shear data obtained for the combinations here reported are tabulated in Tables 1 and 2, together with the computed values of joint efficiency, strength variation, and other pertinent data.

c. Metallurgical Evaluation

Metallographic procedures for the preparation of dissimilar metal junctions of this configuration are complex, requiring extraordinary manipulative skill to ensure that the specimen represents accurately the structure and character of the bond. Since each material combination presents individual problems of preparation and interpretation, a complete discussion of the metallographic evaluation will be withheld until all combinations have been examined.

WELD-EVALUATION PROGRAM FOR WIRE-TO-COUPON WELDMENTS

I Basic Data

1. .060-inch diameter wire weldments

   A. Tensile-shear test of a minimum of three specimens.

      1. Compute average, range, and variation of strengths.
      2. Compare average tensile-shear strength with ultimate tensile strength of wire, and compute joint efficiency.

   B. Examine external weld surface for defects.

   C. Microsection one specimen.

      1. Examine from 30X to 500X.
      2. Photograph for report purposes at approximately 30X and 250X.

      (Note: Transverse and longitudinal sections are being taken. Photos are of transverse and longitudinal sections.)

2. .0003-inch diameter wire range weldments

   A. Same as 1A

   B. Same as 1B

   C. Microsection one specimen whenever -

      (a) during welding it is evident from external inspection that such examination would be valuable,
      (b) a successful small-wire weld has been obtained in a combination where a large-wire configuration has not been successfully joined.

      1. Examine to 1000X.
      2. Photograph for report purposes at a suitable magnification.

II Shock Test

1. Expose 3 specimens of each successfully welded combination obtained under the Basic Data evaluation to the Shock Test described under Test Specifications.

   a. Test exposures are to be made at room temperature.
   b. Test exposures are to be made without special atmospheres.

2. Tensile-shear test all surviving welds.

III Vibration and Fatigue Tests

1. Expose 3 specimens of each successfully welded combination obtained under the Basic Data evaluation to the Fatigue Test described under Test Specifications.

   a. Test exposures are to be made at room temperature.
   b. Test exposures are to be made without special atmospheres.

2. Examine specimens after 60 seconds exposure in Z plane, and note failures. Resume exposure for 32 hours.
3. Expose specimens for 32 hours in Y plane.
4. Examine specimens after 60 seconds exposure in X plane, and note failures. Resume exposure for 32 hours.
5. Tensile-shear test all surviving welds.

TEST-EXPOSURE SPECIFICATIONS FOR WIRE-TO-COUPON WELDMENTS

In all the tests, the coupons will be clamped to the fixtures so that the wire is unrestricted. Applicable test specimen dimensions and test planes are shown in Figure 15.

Shock Test

The shock test shall be conducted on a high-impact shock machine for electronic devices. Each weldment shall be subjected to a total of 21 hammer blows of 30° (450 G) angular displacement; that is, seven blows in each of the positions X, Y and Z in any sequence.

Fatigue Test

The weldments shall be rigidly mounted on a table vibrating with simple harmonic motion at a frequency of 25 $\pm$ 2 cps with an amplitude of 0.040 $\pm$ 0.005 inch (total excursion 0.080 $\pm$ 0.005 inch). The weldments shall be vibrated for a total of 96 hours, 32 hours in each of the three positions X, Y and Z.

ELECTRON-TUBE STUDY

At the beginning of the report period, a contract was executed with Chatham Electronics providing for technical service, electron-tube parts, and the electron-tube evaluation specified for the last phase of the program.

The major effort during this report period was associated with the welding study.

Electron tube Type 6080WB was studied and the assembly sequence thereof revised to facilitate accessibility for the ultrasonic welding tooling. The new sequence, shown in Table 4, was approved by Chatham. Design work on the tooling for this tube has been initiated.

The contact area between the sonotrode tip and the workpiece is normally within the area of the tip diameter. To reach some of the weld areas in the 6080WB electron tube, it was necessary to design a tip, shown in Figure 16, which will have the contact area outside the diameter of the tip. Several of these tips will have to be designed with the contact surface of each contoured to suit the specific joint geometry. The experimental tip was evaluated on flat material with good results.

Test welds, using the 100-watt welder, were made between the tungsten heater wire and the nickel heater connectors so that the nickel tubing previously welded to the tungsten heater wire could be eliminated. However, satisfactory welds were not obtained as the hard tungsten wire embedded into the nickel without forming a true bond.

All junctions on the Type 6205 electron tube were attempted with the 100-watt welder. These welds were evaluated together with Chatham, and it would appear that only the cathode tab can be welded with this machine. It should be possible to make all other welds on the 600-watt welder. It was not possible to weld the stem lead to the plate, as the plate material (identified as Alclad iron) crumbled during welding. Further investigation will be made into this problem.

No work was done on electron tube Type 5814WB.

CHATHAM ELECTRONICS CORRELATIVE ACTIVITY

Chatham Electronics performed advisory services during Phase 1 of the program.

Conferences were held at the Chatham plant, and their assistance was enlisted in various areas of the work: (a) Establishing specialized refinements to sequential production operations in electron-tube manufacture. (b) Detailing representative historical aspects of weld failures in electron tubes. (c) Isolating difficulties encountered in molybdenum and tungsten. (d) Establishing weld evaluation procedures and undertaking preliminary evaluation of some ultrasonically welded parts. (e) Supplying electron-tube components and samples.

Currently, Chatham is preparing a quotation covering fixturing and work necessary to subject specimens ultrasonically welded by Aeroprojects to shock and vibration exposures.

In the later phases of the program, Chatham will more specifically direct its efforts to the evaluation of ultrasonic welding applicable to electron-tube manufacture.

CONCLUSIONS

Junctions in most of the desired combinations have already been successfully effected, demonstrating conclusively that ultrasonic welding produces satisfactory welds in a wide range of material combinations of interest to the electron-tube industry. The effect of tooling and surface preparation on welding has been indicated. Generally, surface preparation is less critical than that required for resistance welding. However, in some materials, such as tungsten and molybdenum, surface condition and contaminations are significant.

It will be possible without recourse to substantial research to ultrasonically weld nearly all of the required junctures in the three specific electron tubes. Assembly sequencing of the electron tubes can be varied to minimize accessibility problems.

PROGRAM FOR THE NEXT REPORTING PERIOD

Welding the remaining combinations will be completed. All successfully welded combinations will be subjected to the test exposures outlined, and subsequently evaluated. Junctures for the three electron tubes will be welded.

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2. 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.

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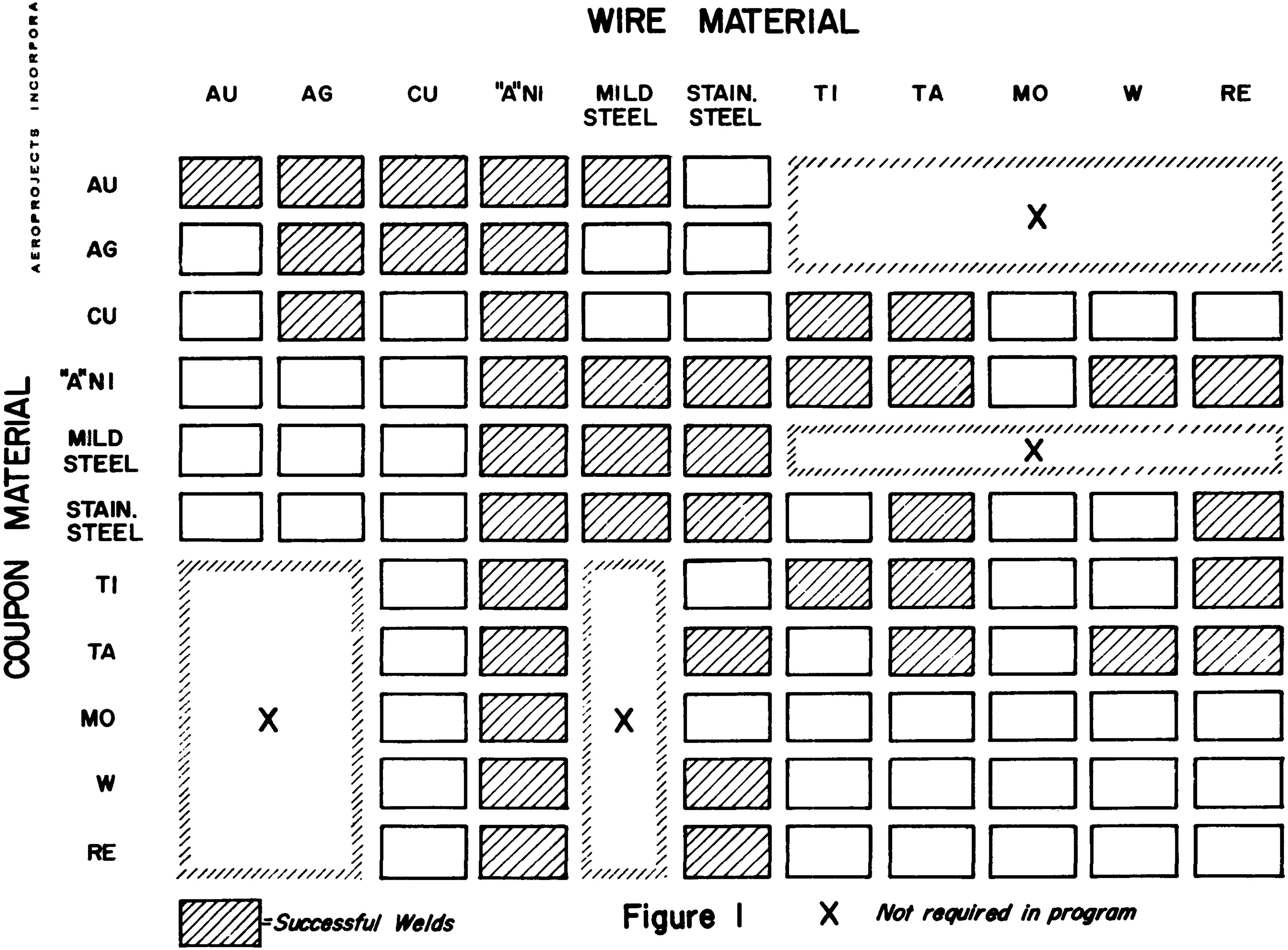


Figure I

SUCCESSFULLY WELDED COMBINATIONS OF FINE AND HEAVY WIRE TO COUPON

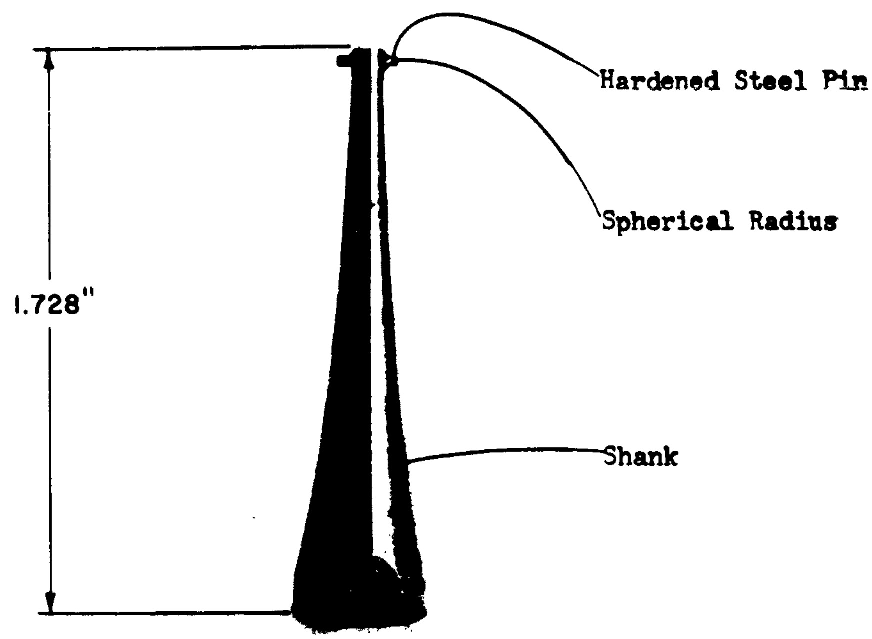


Figure 2

TYPICAL WELDING TIP USED ON THE 100-WATT
AND 20-WATT ULTRASONIC WELDING MACHINES

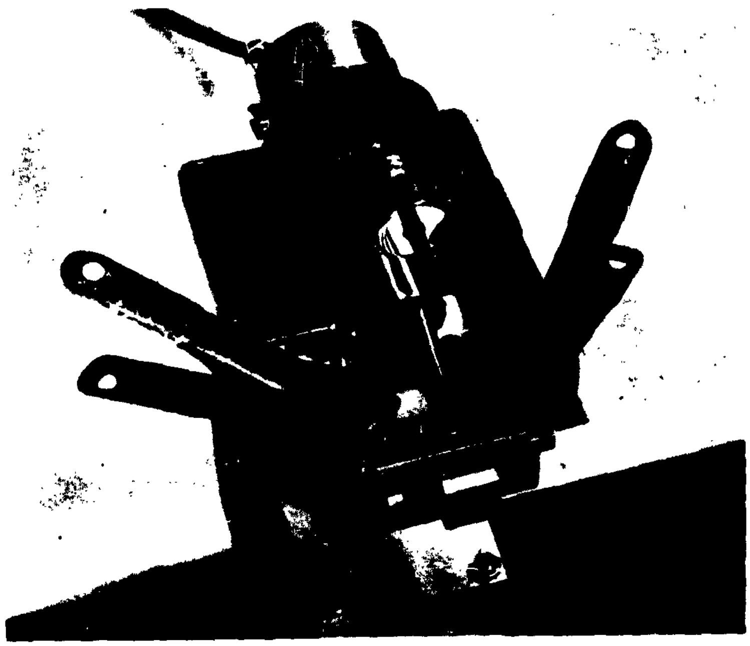


Figure 3

FIXTURING FOR THE 20-WATT WELDER (PICTURED)
AND 100-WATT WELDER

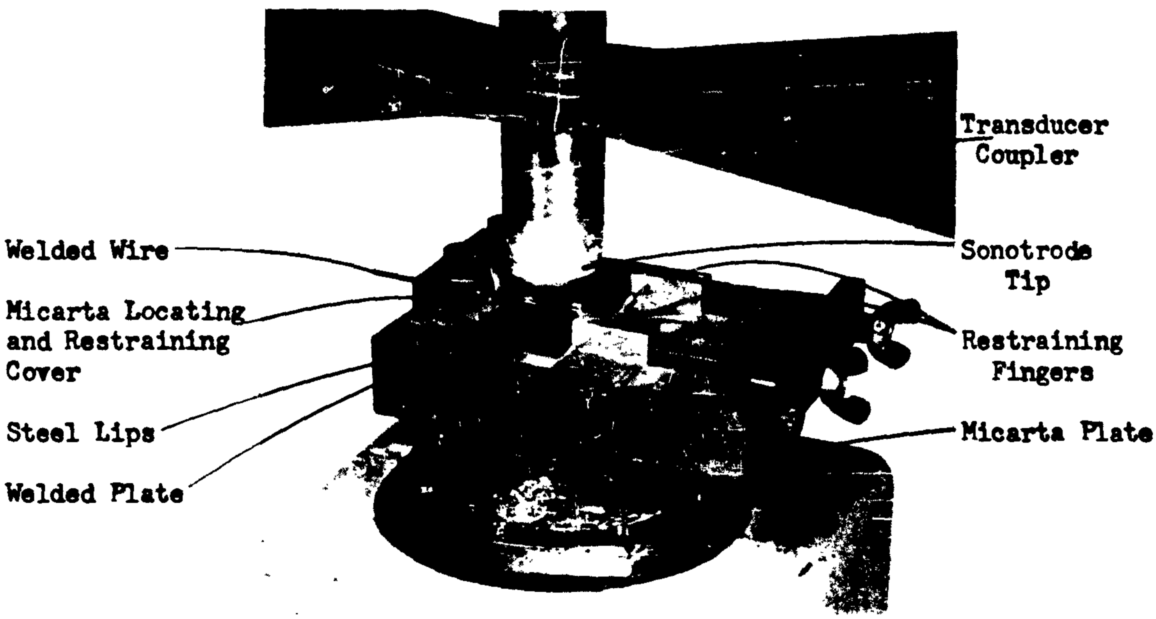


Figure 4

MODIFIED WELDING FIXTURE INSTALLED ON 4-KW SPOT WELDER

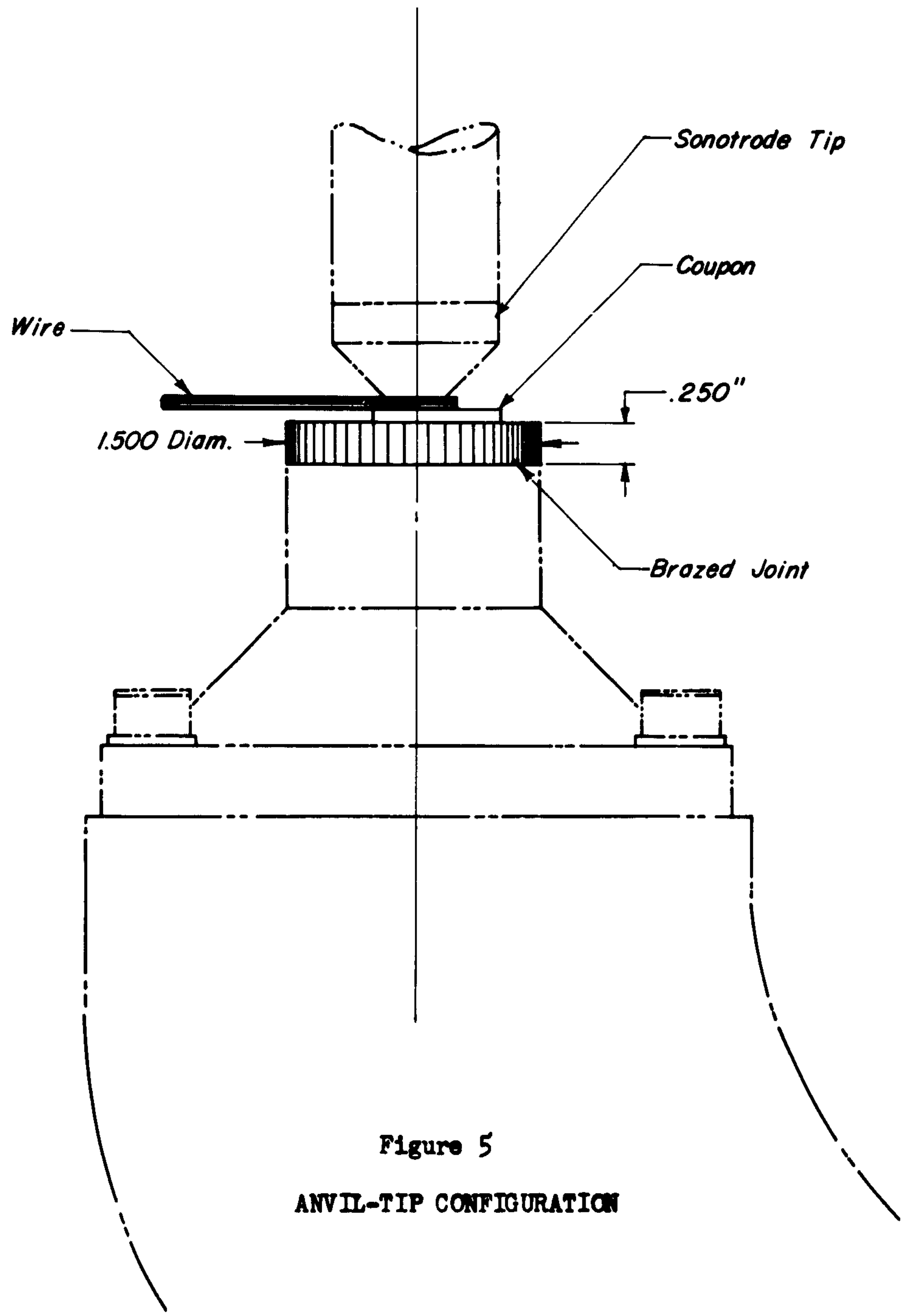


Figure 5

ANVIL-TIP CONFIGURATION

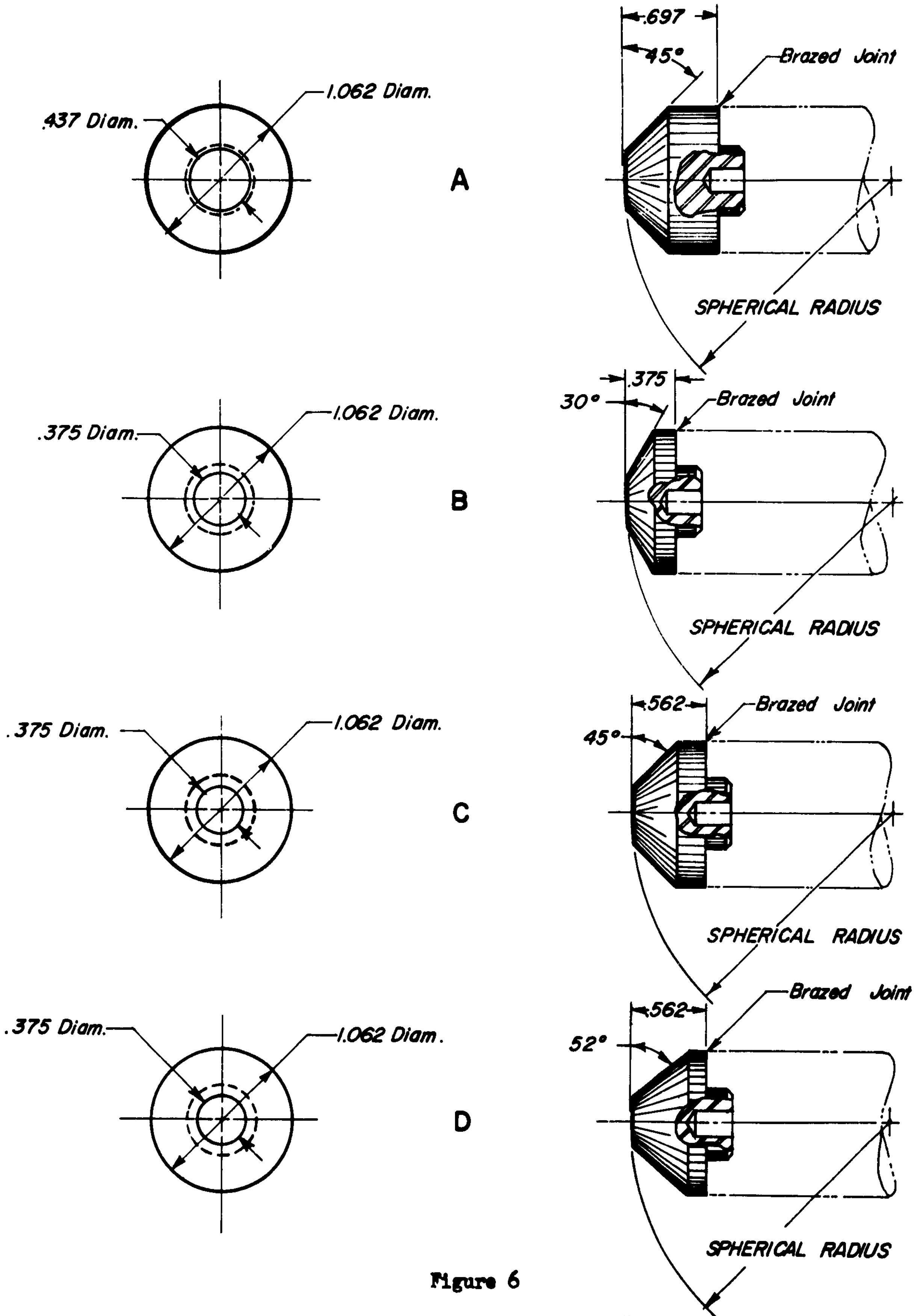


Figure 6

SPHERICAL-RADIUS SONOTRODE TIPS

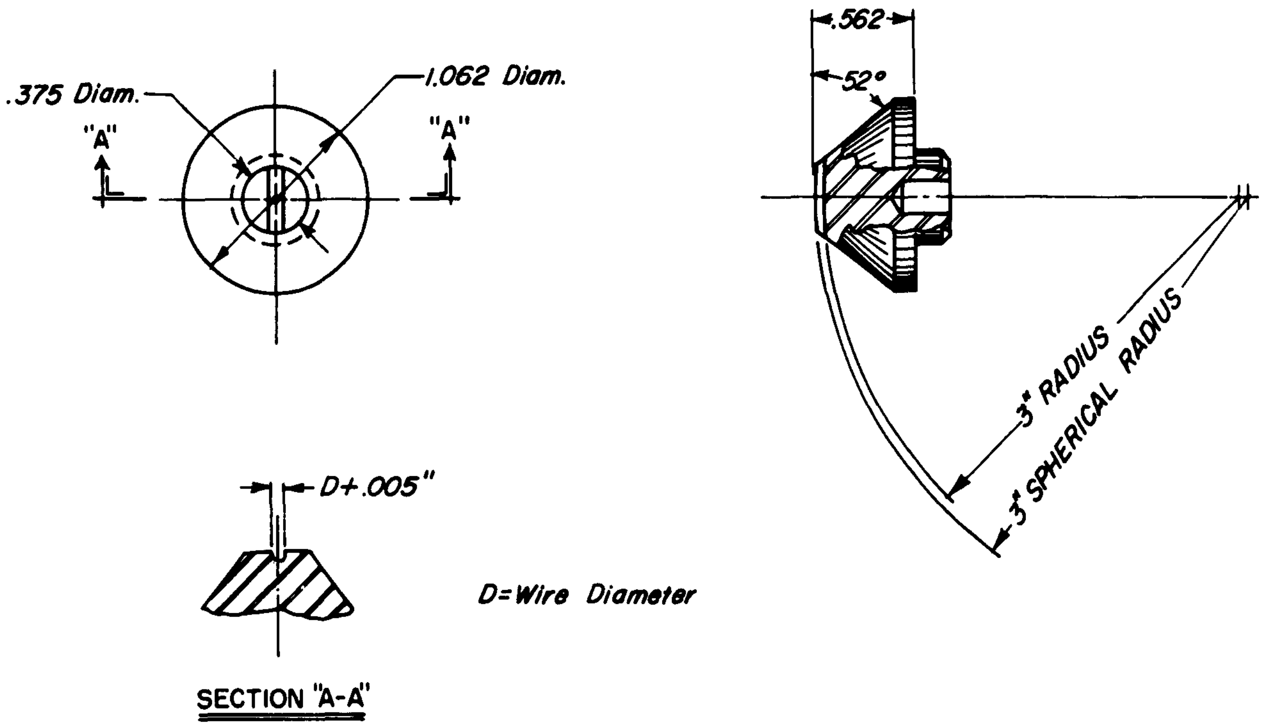


Figure 7

3-INCH GROOVED SPHERICAL-RADIUS SONOTRODE TIP

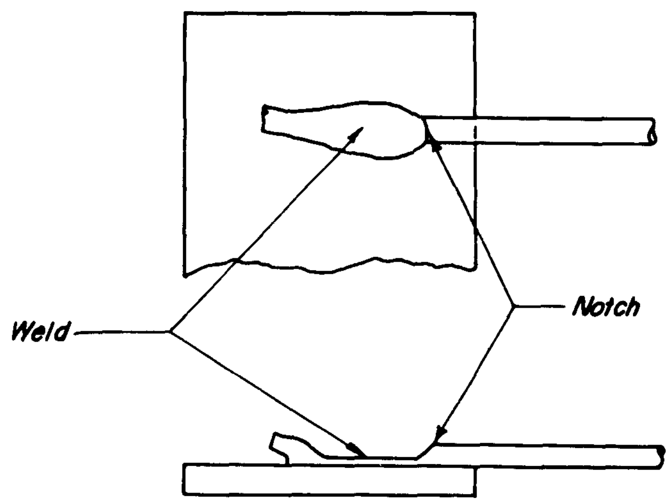


Figure 8

NOTCH PRODUCED AT JOINT BY SPHERICAL-RADIUS TIP

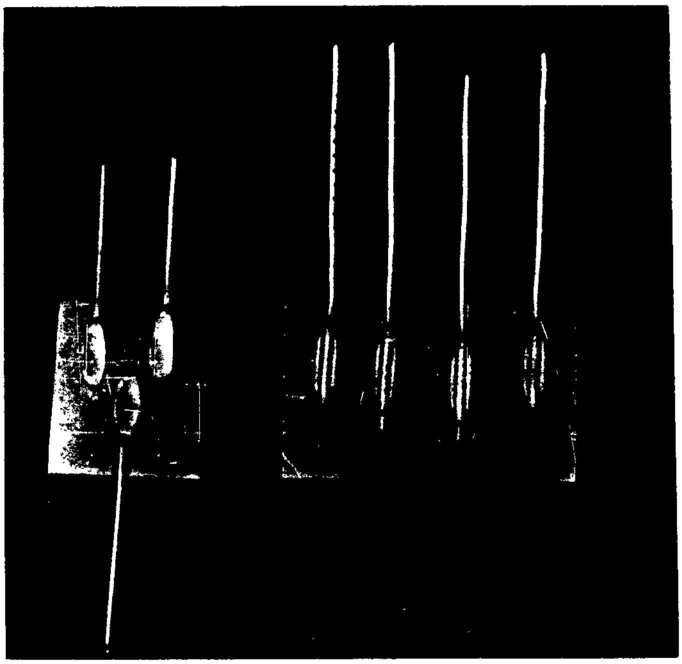


Figure 9

GOLD WIRE (0.060 INCH) WELDED TO NICKEL PLATE (0.060 INCH)

Left: Welds Made with Ungrooved
3-Inch Spherical-Radius Tip

Right: Made with Grooved Tip

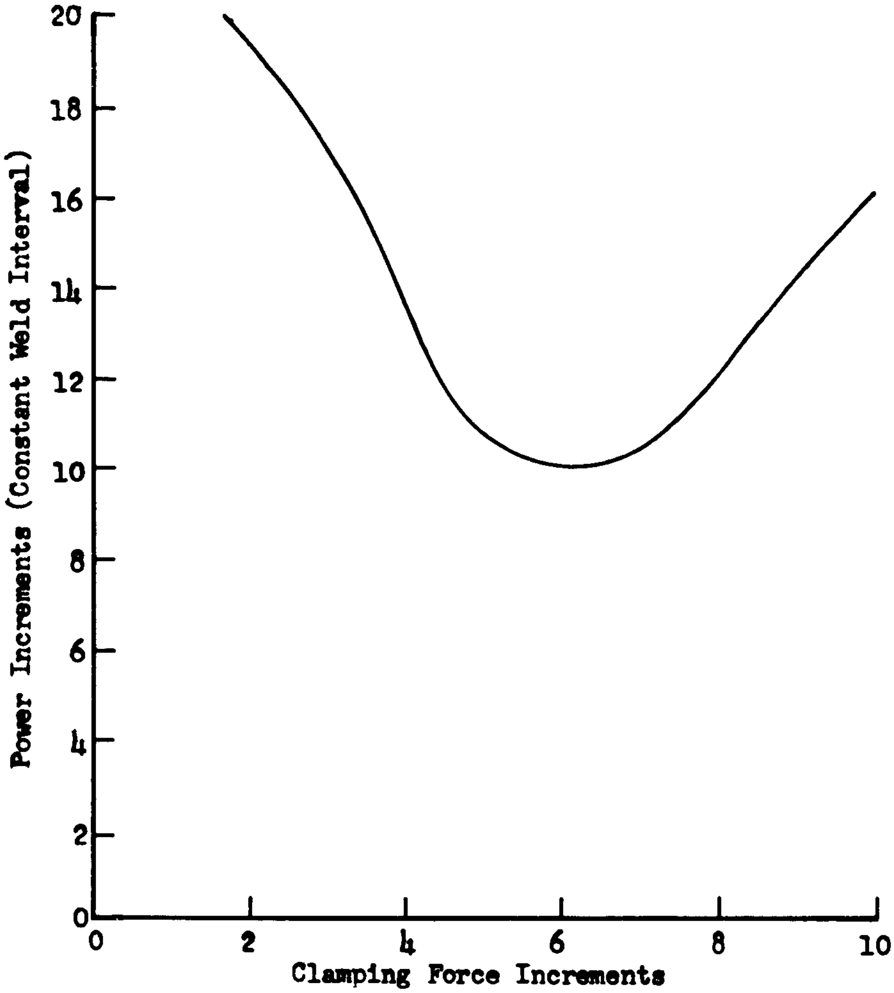


Figure 10

THRESHOLD CURVE

(Welds produced at conditions above curve are satisfactory. Those below curve are unsatisfactory.)

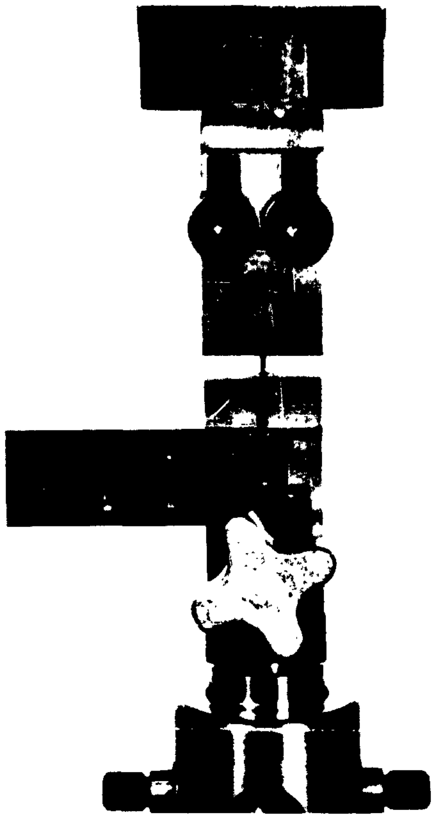


Figure 11

JAW ARRANGEMENT PERMITS TENSILE-SHEAR TESTING
OF SIDE-BY-SIDE ULTRASONIC WELDS
OF 0.060-INCH DIAMETER WIRE TO THE SAME COUPON

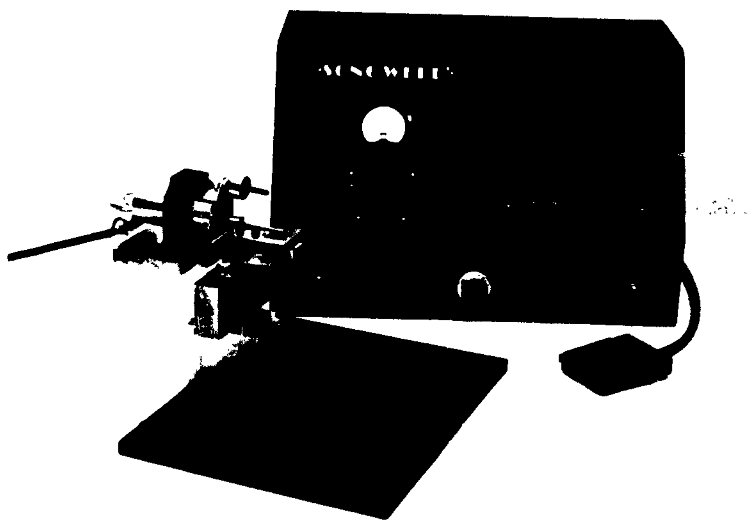


Figure 12

COMMERCIAL ULTRASONIC 20-WATT WELDER

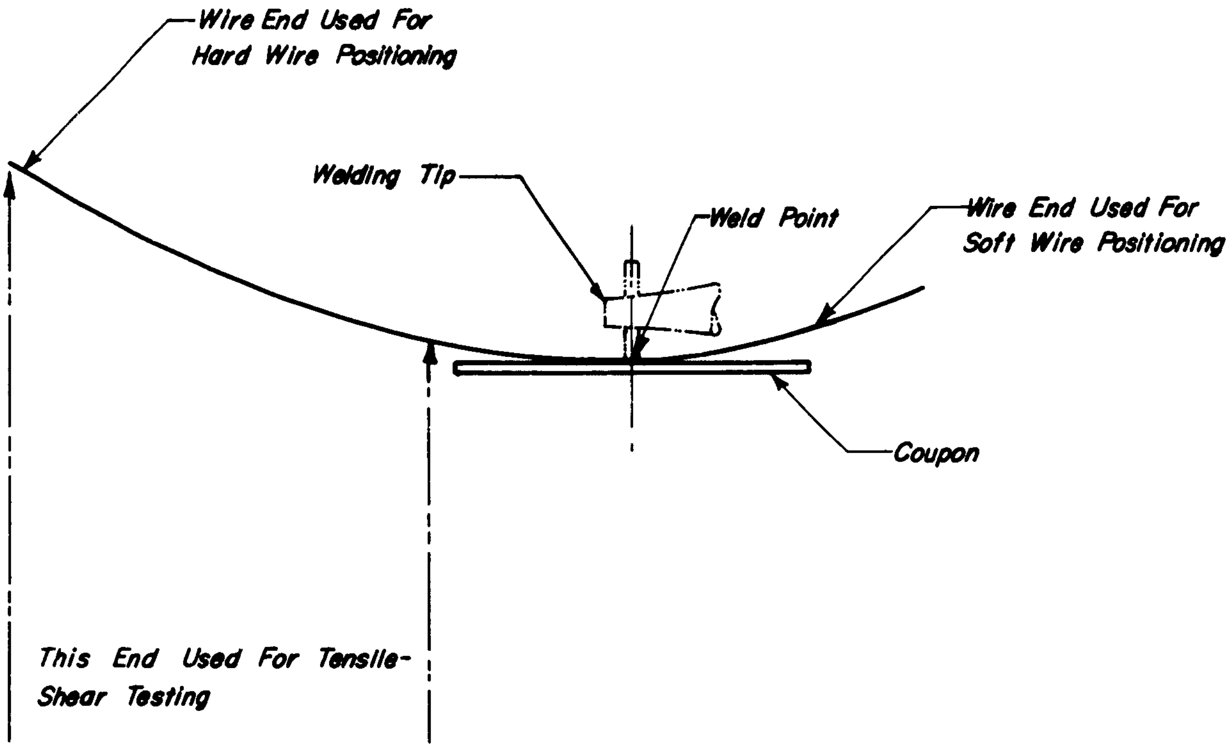
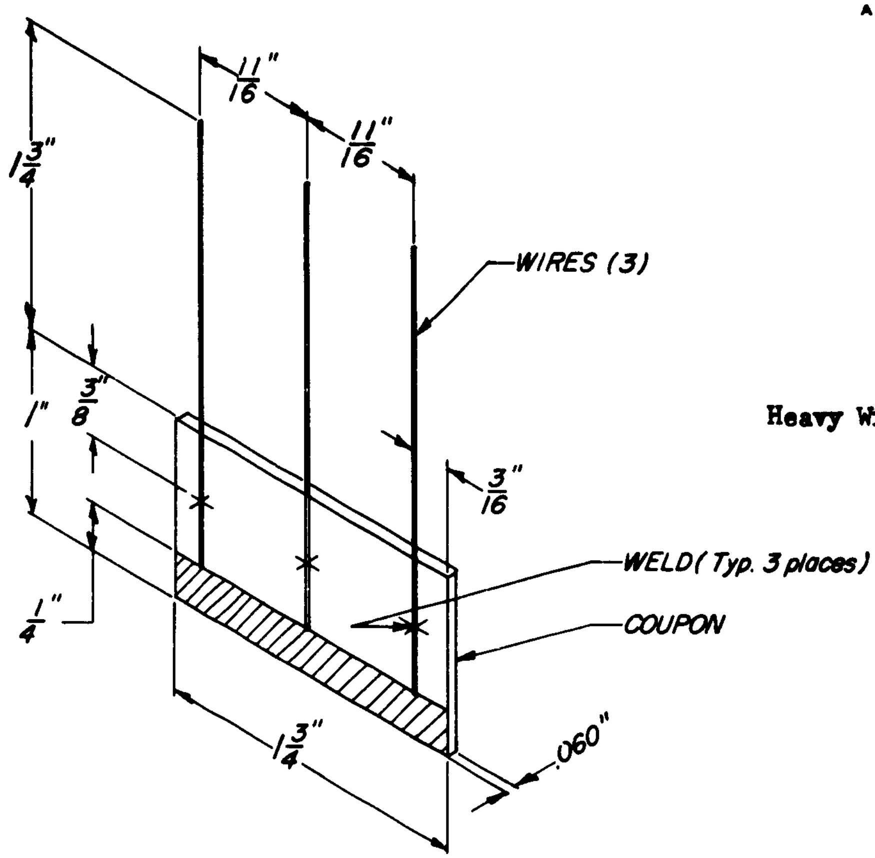


Figure 13

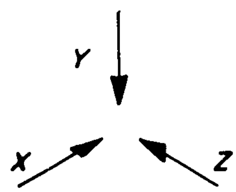
WIRE-END HANDLING TECHNIQUE
FOR HARD AND SOFT WIRES

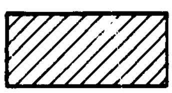
Figure 14

UPSIDE DOWN POSITION OF JAW ARRANGEMENT
USED FOR TENSILE-SHEAR TESTING OF
HIGH-STRENGTH WIRE-TO-COUPON WELDS



Heavy Wire to Coupon





Area available for clamping in test fixture.

Fine Wire to Coupon

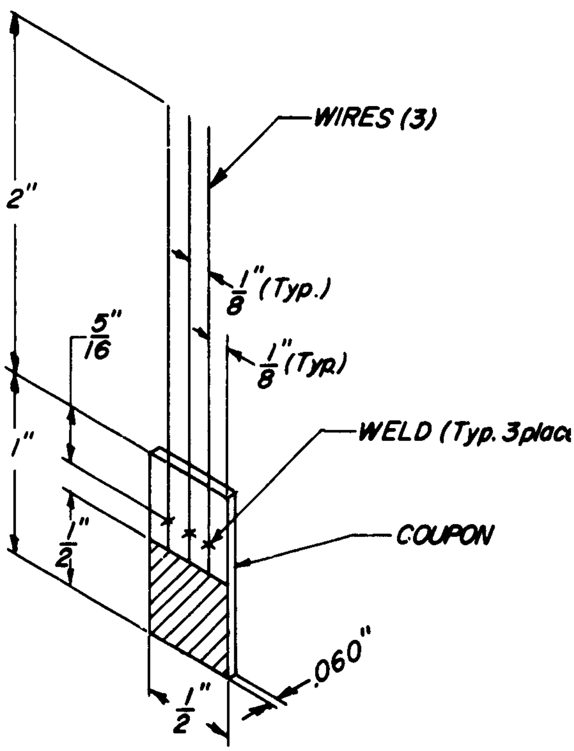


Figure 15

SPECIFICATION FOR WELD SPECIMENS AND TEST PLANES

Figure 16

SONOTRODE TIP FOR 600-WATT WELDER

[redacted]

Table 1

TEST RESULTS OF FINE-WIRE-TO-COUPON JUNCTURES

Weld Combination Materials		Joint Efficiency	Tensile-Shear Strengths		Variation**	Welder Used	Welding
Wire	Coupon	(percent) #	(2) Base Wire*	(1) Welded Wire*		(Watts)	Comments
Gold	Gold	96	2.7 gm	2.6 gm	0.538	20	a,h,k
Silver	Silver	100		22.3 gm	0.076		c
	Gold	100+	22.3 gm	22.4	0.009	100	c
	Copper	94		20.96 gm	0.124		c
Copper	Silver	70	6.15 gm	4.3 gm	0.581	20	c,h
	Gold	92	6.15 gm	5.7 gm	0.035	20	b,e,h
"A" Nickel	Titanium	95		6 gm	0.133		b,e,g,h
	Tungsten	98		6.18	0.056		a,h
	Tantalum	92		5.8	0.155		a,h
	St. Steel	94		5.9	0.203		b,h
	Mild Steel	92		5.82	0.01		h
	Silver	92	6.3 gm	5.81	0.043		c,d,h
	Rhenium	92		5.78	0.104		b,h,j
	"A" Nickel	98		6.2	0		b,d,e,h
	Molybdenum	93		5.85	0.196		b,f,h
	Gold	90		5.69	0.084		c,d,h
	Copper	95		6.01 gm	0.05		b,d,h
Mild Steel	St. Steel	92		0.24 lb	0.083		a,g,h
	Mild Steel	83		0.22	0.348		b,g,h
	"A" Nickel	98	0.26 lb	0.25	0.078		b,e,h
	Gold	81		0.211 lb	0.450	100	d,h
St. Steel	St. Steel	79		0.263 lb	0.114		g,j
	Mild Steel	70		0.231	0.952		g,j
	"A" Nickel	96	0.333 lb	0.32	0.093		e,j
	Rhenium	93		0.31	0.064		a,h
	Tantalum	88		0.295	0.338		g,j
	Tungsten	76		0.256 lb	0.058		g
Titanium	"A" Nickel	81		42.9 gm	0.263		b,h
	Copper	96	52.5 gm	50.4	0.124		b,e,h
	Titanium	98		51.6 gm	0.096		g,h
Tantalum	Titanium	100+		0.493 lb	0.010		g
	Tantalum	89		0.43	0.302		g
	"A" Nickel	87	0.48 lb	0.42	[illegible]		[illegible]

	"A" Nickel	[illegible]		[illegible]	[illegible]		[illegible]
Titanium	Copper	96	52.5 gm	50.4	0.124		b,e,h
	Titanium	98		51.6 gm	0.096		g,h
	Titanium	100+		0.493 lb	0.010		g
	Tantalum	89		0.43	0.302		g
Tantalum	"A" Nickel	87	0.48 lb	0.42	0.214		c,e
	St. Steel	100+		0.51	0.078		b,f,h
	Copper	96		0.46 lb	0.141		e,j
Tungsten	"A" Nickel	93	16.3 gm	15.23 gm	0.164		e,g,h
	Tantalum	88	16.3 gm	14.35 gm	0		g,h
	St. Steel	83		1.85 lb	0.864		b,e,j
Rhenium	"A" Nickel	100+	2.23 lb	2.46	0.191		d,j
	Titanium	100+		2.55	0.245		g,j
	Tantalum	64		1.43 lb	0.391		j

WELDING COMMENTS

a) Wire flattened excessively.
b) Wire flattened moderately.
c) Wire flattened slightly.
d) Complete imbedding of wire into coupon.
e) Partial imbedding of wire into coupon.
f) Slight imbedding of wire into coupon.
g) Tip or tweezers were used to burnish the weld area on the coupon, thereby providing a smooth, flat surface.
h) Tip was used to make small reference mark on the coupon to insure exact wire location.
j) Occasionally, the wire broke outside of the joint area during the welding pulse.
k) A slight change of welding parameters proved critical for 0.003-inch gold wire.

* Average of three specimens.

** Variation = $\frac{\text{highest shear-strength value - lowest shear-strength value}}{\text{average of individual shear strengths}}$

= $\frac{\text{Col. (2)}}{\text{Col. (1)}} \times 100$

[redacted]

Table 2

TEST RESULTS OF HEAVY-WIRE-TO-COUPON JUNCTURES

Weld Combination Materials: Wire	Weld Combination Materials: Coupon	Joint Efficiency (percent)	Tensile-Shear Strengths: Base Wire* (lbs)	Tensile-Shear Strengths: Welded Wire* (lbs)	Variation**	Welding Comments	Metallography and Comments
Gold	Gold	100+	53	54	0.019	c	
Silver	Silver	93		73.7	0.0135	b,e	
	Gold	100+	76	79	0	b,g,k,m	
	Copper	100+		80	0.05	c,i,m	Appendix A #1
Copper	Silver	95	114	107.7	0.009	b,e,s	Appendix A #2
	Gold	100+	114	119	0	b,g	
"A" Nickel	Titanium	94		148.7	0.08	d,m,r	
	Tungsten***	100		165	0	b,w	
	Tantalum	98		155.8	0.025	s,aa,bb,cc	Appendix A #3
	St. Steel	97		155	0.006	r,s	
	Mild Steel	73		116	0.0603	l	
	Silver	90	159	152.3	0.0065	b,e,q,z	Appendix A #4
	Rhenium	78		124	0.217	d,g,gg	
	Nickel	99		158.7	0.057	c,v	
	Molybdenum	100		164	0.012	t	
	Gold	95		152	0.223	p	Appendix A #5
	Copper	100+		160	0.088	b,j	Appendix A #6
Mild Steel	St. Steel	100+		160	0	b,g	
	Mild Steel	100	157	157	0.0317	b	Appendix A #7
	Nickel	100		157	0.0312	b,v	
	Gold	97		153	0.026	p	
St. Steel	St. Steel	100+		280	0.05	a	
	Mild Steel	95		255	0.0231	b	Appendix A #8
	Nickel	92	268	248	0.0645	c	Appendix A #9
	Rhenium	94		253	0.0276	c	
	Tantalum	89		239	0.625	d,f,h,s	
	Tungsten***	93		250	0.096	c,w	
Titanium	Nickel	94		242	0.045	c,m	
	Copper	100+	256	264	0.95	u,x	
	Titanium	100		257	0.0194	c,u	
Tantalum	Titanium	100		150	0.02	c,p	
	Tantalum	100	151	161.3	0.062	aa,bb,cc,dd	
	Nickel	94		142	0.035	b	Appendix A #10

Titanium	Copper	100+	256	264	0.95	u,x	
	Titanium	100	⊥	257	0.0194	c,u	
Tantalum	Titanium	100	⊤	150	0.02	c,p	
	Tantalum	100	151	161.3	0.062	aa,bb,cc,dd	
	Nickel	94	⊥	142	0.035	b	Appendix A #10
	St. Steel	100+	145	152	0.052	a	Appendix A #11
	Copper	91	151	138	0.32	h,o	
Tungsten	Nickel***	85	660	491.7	0.132	ee,ff	Appendix A #12
	Tantalum***	72	660	431	0.498	f,s,	Appendix A #13
Rhenium	St. Steel	100+	360	364	0.033	b	
	Nickel	100	360	370	0.0567	b	
	Titanium	100	343	343	0.0758	c	
	Tantalum	72	360	258.4	0.0321	s,aa,bb,cc	

All combinations were welded on 4kw spot welder.

a) Excellent weldability.
b) Very good weldability.
c) Good weldability.
d) Satisfactory weldability.
e) Low rate of variation.
f) High rate of variation.
g) No variation.
h) Improved variation possible through further study.
i) Acceptable amount of wire deformation.
j) Small amount of wire deformation.
k) Wire deformation could be decreased by manipulation of welding parameters.
l) High power and grooved tip should be used to decrease wire deformation and notch and to increase tensile-shear.
m) Use of grooved tip would reduce wire deformation.
n) Longer tip radius would decrease wire deformation.
o) Etching and/or flattening of wire might improve joint.
p) Wire required flattening before welding.
q) To remove strain hardening, flattened wire had to be stress relieved annealed before welding.
r) No reliable weld possible with spherical-radius tip.
s) Grooved tip would improve weldability.
t) Electroetched sheet and grooved tip produce good weldability.
u) Grooved tip mandatory.
v) Larger spherical-tip radius or grooved tip would decrease weld-line notch.
w) Grinding and electroetching of sheet and use of grooved tip are mandatory.
x) Welding without grooved tip produces cutting through plate.
y) Abraded sheet and wire offers very good weldability.
z) Excessive imbedding proved objectionable. Flattened wire could be used on thin sheet.
aa) Size of details (small parts) may cause resonance problems.
bb) Either damping or changing the natural frequency, or both, would help.
cc) Better joint is produced without removal of surface film from tab.
dd) Very good weldability without abrading sheet or wire.
ee) Removal of surface film needed to improve variation and reduce wire cracking.
ff) Grooved tip might also reduce wire cracking and spalling through restraint.
gg) Excessive wire deformation might be improved by use of harder Ni wire.

* Average of three specimens.

** Variation = $\frac{\text{highest shear-strength value} - \text{lowest shear-strength value}}{\text{average of individual shear strengths}}$

*** After surface preparation of base wire.

Table 3

WELDMENT MATERIALS DESCRIPTION

	Material	Gage (inch)	Condition
Coupons (1 x 3 inches)	Gold	0.060	Annealed
	Silver	0.060	
	Copper	0.055	
	"A" Nickel	0.060	
	Mild Steel(AISI 1010)	0.060	
	Stainless Steel(AISI 304)	0.060	
	Titanium	0.068	
	Tantalum	0.063	Annealed
	Molybdenum	0.060	Stress-relieved
	Tungsten	0.063	Stress-relieved
	Rhenium	0.060	Annealed
Fine Wires	Gold	0.0003	Hard
	Silver	0.0015	99.99% pure - 20% elongation
	Copper	0.0005	Hard
	"A" Nickel	0.0005	Hard
	Mild Steel(AISI 1010)	0.0015	Low Carbon
	Stainless Steel(AISI 304)	0.001	Hard
	Titanium	0.001	Hard
	Tantalum	0.003	14% Stretch
	Tungsten	0.0003	Etched
	Rhenium	0.005	
Heavy Wires	Gold	0.060	Annealed
	Silver	0.060	
	Copper	0.064	
	"A" Nickel	0.060	
	Mild Steel(AISI 1010)	0.062	
	Stainless Steel(AISI 304)	0.0625	
	Titanium	0.063	
	Tantalum	0.062	Annealed
	Tungsten	0.064 to 0.066	Stress-relieved
	Rhenium	0.060	Annealed

This table lists only those materials reported in Tables 1 and 2.

Table 4

TUBE TYPE 6080WB

ASSEMBLY SEQUENCE FOR ULTRASONIC WELDING

Sequence No.	*Old No.	Component	to	Component	Remarks
1	1	Cathode Tab		Cathode Sleeve	
2	2	Cathode Tab		Itself	
3	7	Anode Eyelet		Anode Support	
4	6	Grid Eyelet		Grid	
5	5	Anode Connector		Anode Support	
6	11	Anode Connector		Anode Support	
7	3	Grid Connector		Grid	
8	9	Heater		RH and LH Heater Connector	Note 1
9	4	Grid Connector		Grid	
10	15	Snubber		Snubber Support	
11	10	Grid Radiator		Grid	Note 2
12	12	Stem Leads		Heater Connector Grid Connector Anode Connector	Note 3
13	13 14	Cathode Connector Cathode Connector		Stem Lead Snubber Support	
14	18	Splash Spacer Support		Snubber Support	Note 4
15	16	Top Cathode Connector Top Cathode Connector		Snubber Support Cathode Tab	
16	17	Getter		Snubber Support	Note 5

* These numbers refer to key numbers in Description of Welding Junctures presented in the First Quarterly Report.

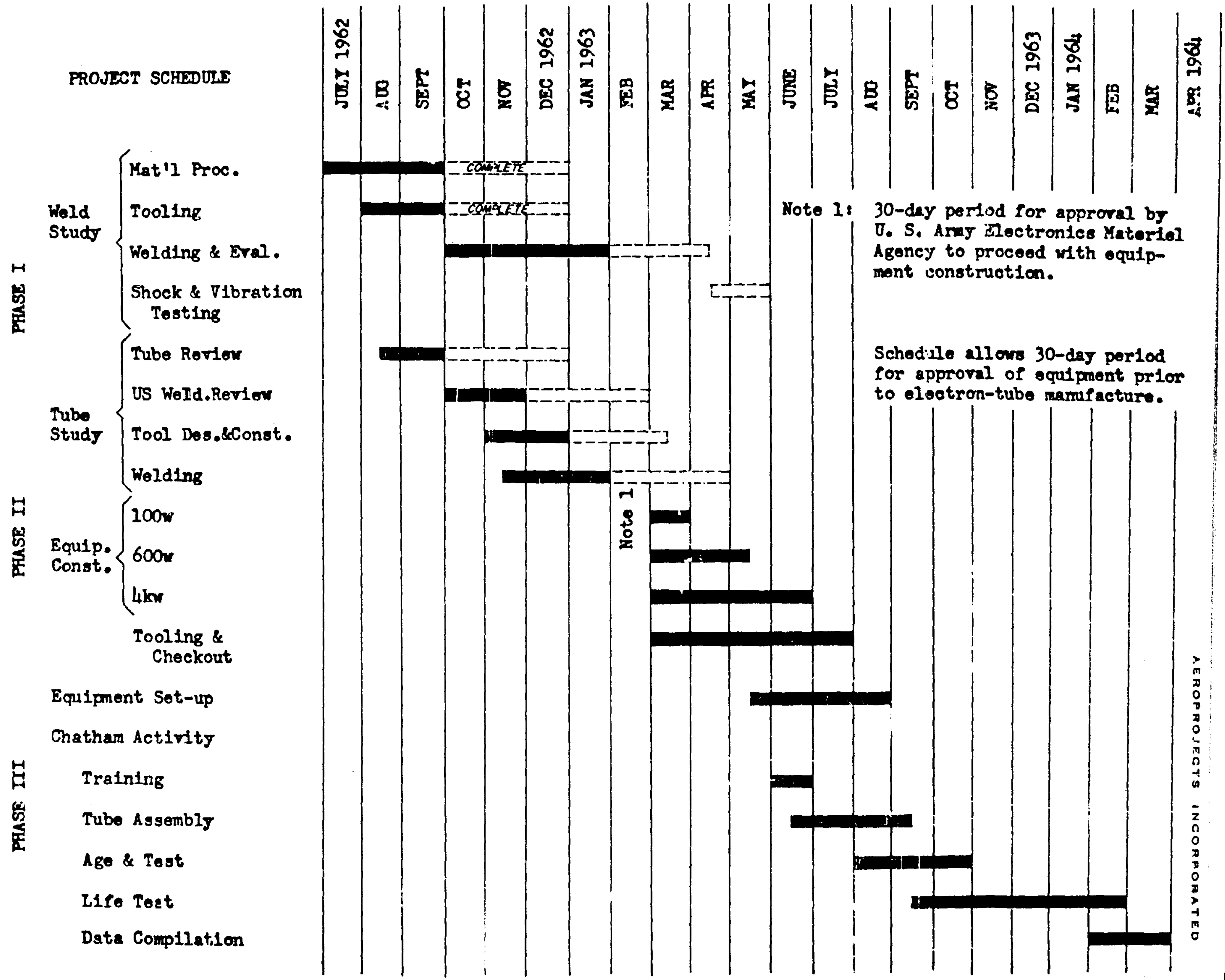
Note 1. Tungsten heater wire together with the nickel sleeve may be welded directly to the nickel heater connector, thereby eliminating the heater sleeve to heater welding juncture Key #8 as a separate operation.

Note 2. These joints will be resistance welded. Ultrasonic welding can join these materials and geometries, but accessibility is limited beyond a practical solution for tooling or tube redesign.

Note 3. The heater connectors will be formed to attach to the outside of the stem leads, rather than to the inside to facilitate ultrasonic welding. A small hand tool may be required.

Note 4. The splash spacer supports will be assembled on the snubber supports so that the welding will occur on the outside, rather than the inside of the splash spacer to facilitate accessibility for ultrasonic welding.

Note 5. The weld required between the getter and the snubber support is a crossed-wire weld. Welds will be attempted, although no activity in the program has provided a basis for ultrasonically welding this geometrical configuration.


PROJECT SCHEDULE
JULY 1962
AUG
SEPT
OCT
NOV
DEC 1962
JAN 1963
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC 1963
JAN 1964
FEB
MAR
APR 1964
PHASE I
Weld Study
Mat'l Proc.
Tooling
Welding & Eval.
Shock & Vibration Testing
Tube Study
Tube Review
US Weld.Review
Tool Des.&Const.
Welding
PHASE II
Equip. Const.
100w
600w
4kw
Tooling & Checkout
PHASE III
Equipment Set-up
Chatham Activity
Training
Tube Assembly
Age & Test
Life Test
Data Compilation
COMPLETE
COMPLETE
Note 1
Note 1: 30-day period for approval by U. S. Army Electronics Materiel Agency to proceed with equipment construction.
Schedule allows 30-day period for approval of equipment prior to electron-tube manufacture.

IDENTIFICATION OF TECHNICAL PERSONNEL

Personnel not previously reported who made technical contributions, and the manhours of work performed by all personnel during this report period.

Nicholas Maropis, Physicist

B. A. in Physics and Mathematics from Washington and Jefferson College, 1949, with graduate studies in various aspects of physics, including spectroscopy, microwave techniques, and mathematics. His experience includes both practical engineering background with General Motors and with the U. S. Air Force, and in college-level teaching. Included are 3 years' experience with the Naval Ordnance Laboratory in the application of instrumentation to high-speed shock phenomena.

Mr. Maropis is responsible for ultrasonic transducer development.

William B. Devine, Director of Publications

A. B. in English from the University of Pennsylvania, 1936. For the past 25 years Mr. Devine has been active in the fields of technical and industrial communications, marketing, advertising, and public relations, serving in executive capacities to the level of executive vice-president with several leading corporations.

Mr. Devine is a member of Phi Beta Kappa, and Pi Gamma Mu, national honorary social sciences fraternity. He has been associated with Aeroprojects for the past 7 years as marketing and writing consultant, and has recently joined the Corporation staff as Director of Publications. His duties include active supervision of the editorial function.

TECHNICAL MAN-HOURS EXPENDED DURING THIS REPORT PERIOD

NAME	PROJECT POSITION	HOURS EXPENDED THIS REPORT PERIOD
W. N. Rosenberg	Project Supervisor	176
J. Koziarski	Director Welding Lab	436
J. G. Thomas	Metallurgist	332
G. Sekula	Junior Engineer	393-1/2
A. L. Fuchs	Chief Design Engineer	37
C. DePrisco	Chief Electronics Engineer	3
W. B. Devine	Director of Publications	76
N. Maropis	Physicist	6

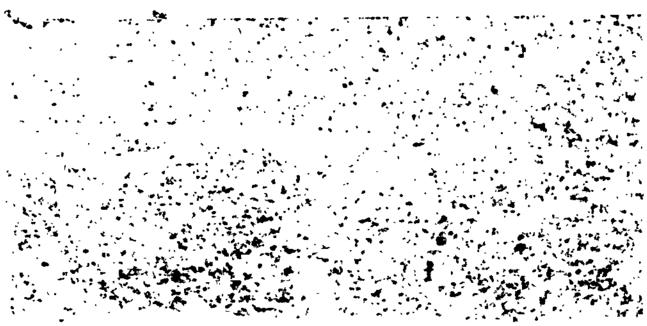
APPENDIX A

METALLOGRAPHY

Etchant: $NH_4OH + H_2O_2$
(Silver unetched)

Combination Number 1: Silver (Wire) 0.060 gage to Copper (Coupon) 0.055

Longitudinal



Magnification: 52X

Magnification: 250X

Transverse

Magnification: 63X
Reduced to 3/4 Size

Magnification: 250X

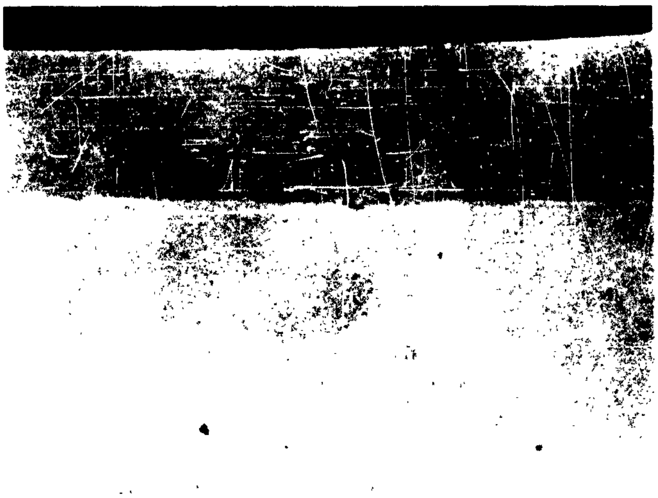
Comments: The joint shows a high degree of interpenetration and interfacial flow. Bond quality is uneven, but satisfactory bonding was achieved along the center of the wire-sheet contact surface. The longitudinal section illustrates only a small portion of the weld zone.

METALLOGRAPHY

Etchant: Unetched

Combination Number 2: Copper (Wire) 0.064 to Silver (Coupon) 0.060 gage

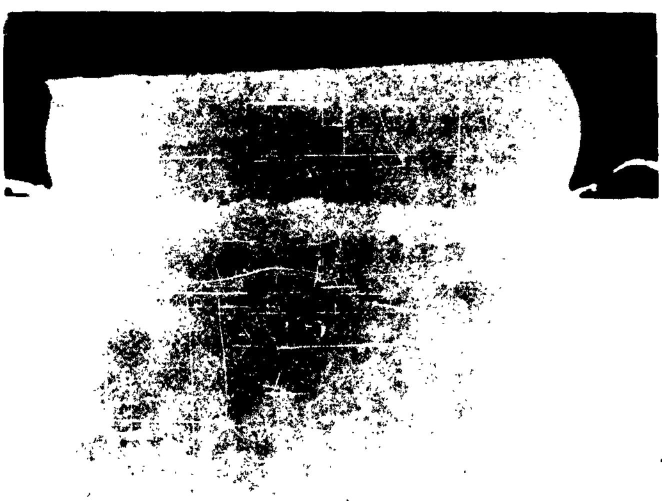
Longitudinal



Magnification: 36X

Magnification: 250X

Transverse



Magnification: 36X
Reduced to 3/4 Size

Magnification: 250X

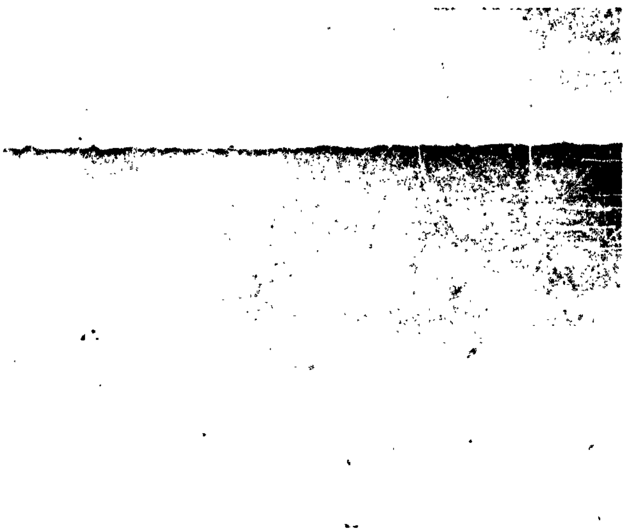
Comments: The edge-to-edge integrity of the joint and the degree of interpenetration of the mating surfaces exemplify a high degree of bond quality. No voids or unbonded areas were observed in these sections. Eccentric contact of the welding tip and wire resulted in deep indentation into the silver sheet along one edge (see lower left photomicrograph).

METALLOGRAPHY

Etchant: Unetched

Combination: Nickel to Tantalum
Number 3 (Wire) (Coupon)
0.060 gage 0.063

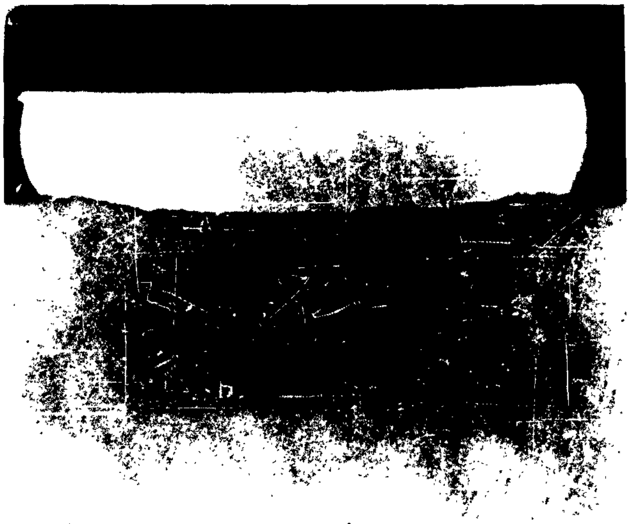
Longitudinal



Magnification: 36X

Magnification: 250X

Transverse



Magnification: 36X
Reduced to 3/4 Size

Magnification: 250X

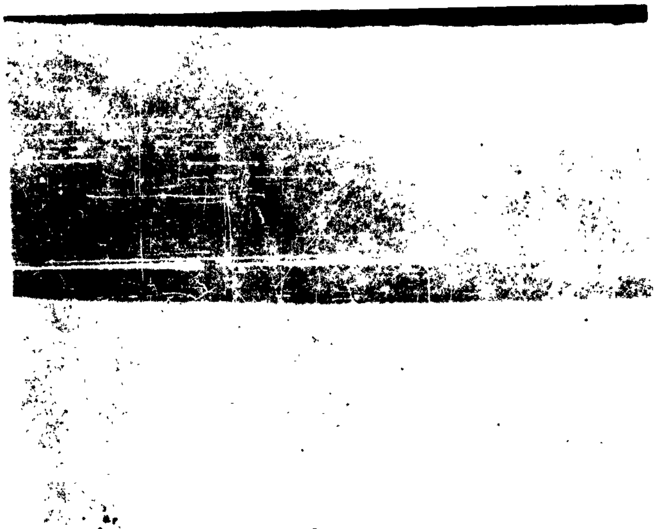
Comments: Only a few scattered unjoined areas were observed. As a whole, the joint exhibits good interpenetration and integrity of the mating surfaces.

METALLOGRAPHY

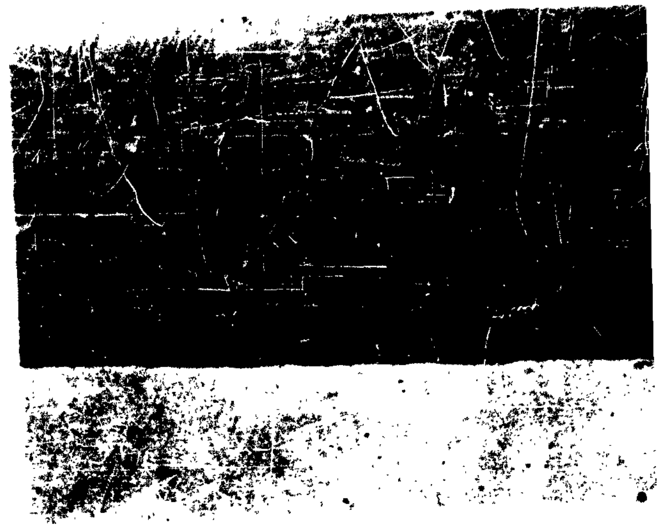
Etchant: Unetched

Combination: Nickel to Silver
Number 4 (Wire) (Coupon)
0.060 gage 0.060

Longitudinal

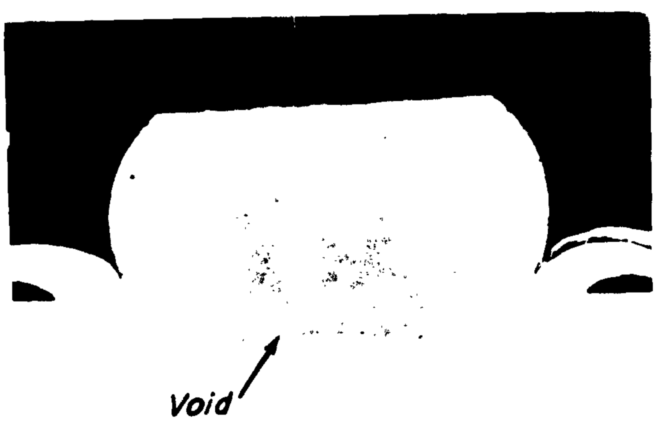


Magnification: 40X



Magnification: 250X

Transverse



Magnification: 40X
Reduced to 3/4 Size

Magnification: 250X

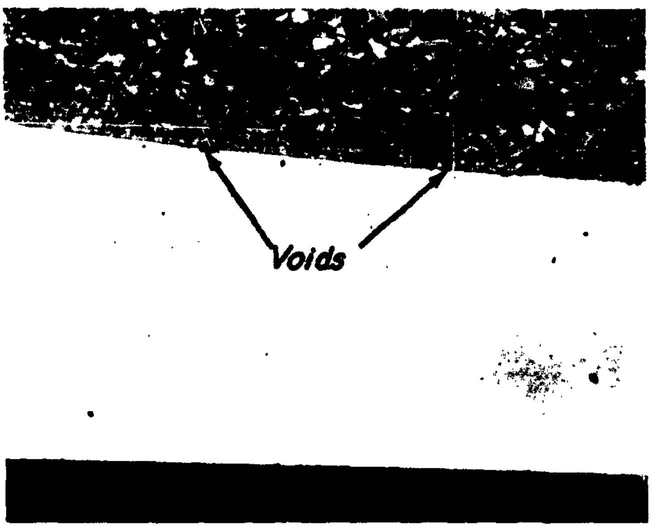
Comments: Bonding quality varies. The non-uniform deformation of the wire effected an unbonded area in the center. Edge bonding is satisfactory although numerous small voids are evident. The longitudinal section, taken along the edge of the wire, shows uniformly good bond quality.

METALLOGRAPHY

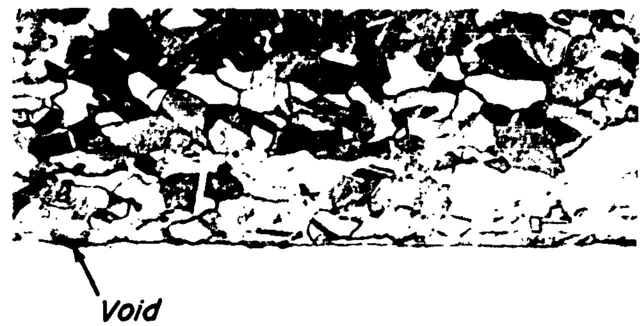
Etchant: KCN + $Na_2S_2O_8$
(Gold unetched)

Combination: Nickel (Wire) 0.060 to Gold (Coupon) 0.060 gage
Number 5

Longitudinal



Magnification: 36X



Magnification: 250X

Transverse

Magnification: 36X

Magnification: 250X

Comments: Several small voids are present at the interface, but in general, joint integrity is good. The lack of appreciable interpenetration is to be expected with metals of different hardness. The edges of the flattened wire are not bonded.

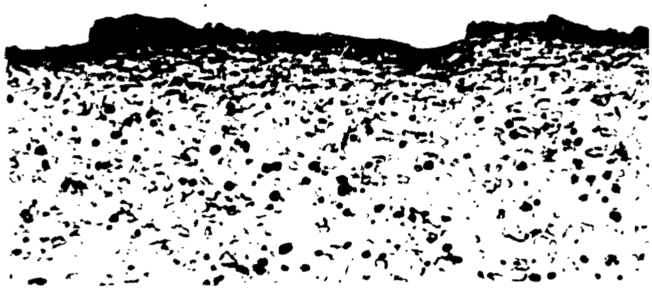
METALLOGRAPHY

Etchant: $NH_4OH + H_2O_2$
(Nickel unetched)

Combination: Nickel to Copper
Number 6 (Wire) (Coupon)
0.060 gage 0.055

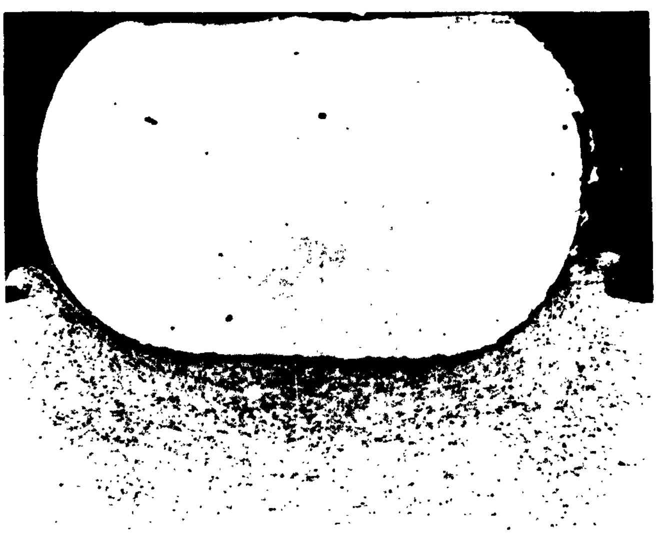
Longitudinal

Magnification: 52X



Magnification: 250X

Transverse



Magnification: 52X
Reduced to 3/4 Size

Magnification: 250X

Comments: This joint displays excellent bonding characteristics. External deformation is small. The weld interface contains good interpenetration along with associated turbulent flow, uniformity of bond quality, and absence of imperfection such as voids or unbonded areas. The weld edge shows minimum crevasse formation.

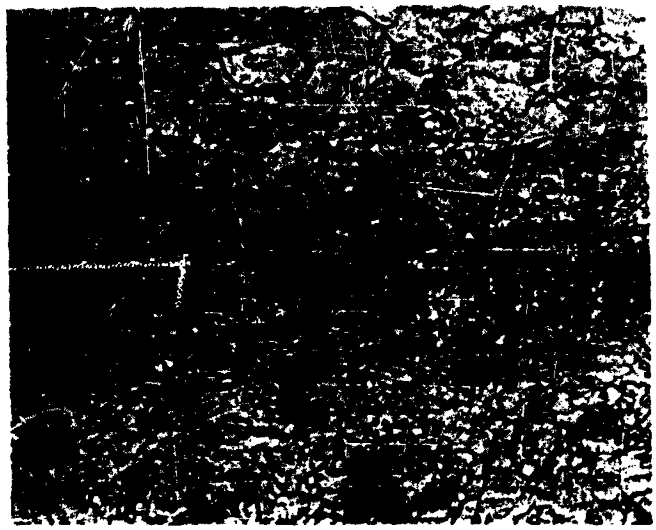
METALLOGRAPHY

Etchant: 1% Nital

Combination: Mild Steel to Mild Steel
Number 7 (Wire) (Coupon)
0.062 gage 0.060

Longitudinal

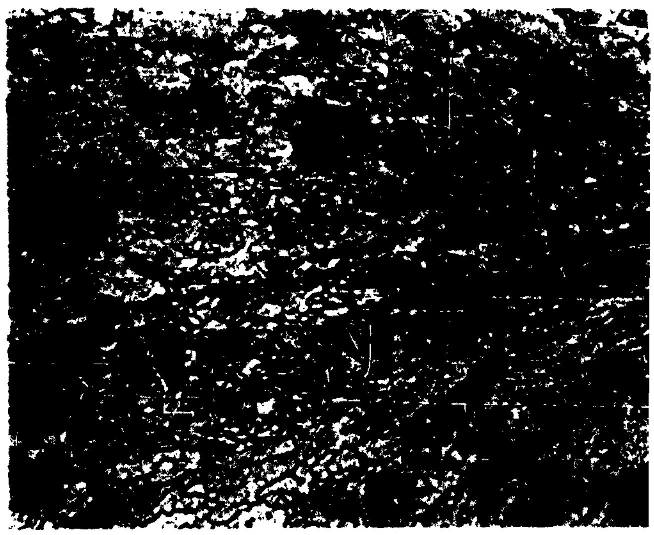
Magnification: 36X



Magnification: 250X

Transverse

Magnification: 36X
Reduced to 3/4 Size



Magnification: 250X

Comments: Thermal effects are quite apparent. Sub-grain formation and recrystallization have occurred on the surface of the wire and along the bond interface. The recrystallized grains tend to assume a square block-like outline in the longitudinal section. The interface contains clusters of surface debris and small voids.

METALLOGRAPHY

Etchant: 1% Nital
(Stainless steel unetched)

Combination: Number 8
Stainless Steel (Wire) 0.0625 gage to Mild Steel (Coupon) 0.060

Longitudinal

Magnification: 36X

Magnification: 250X

Transverse

Magnification: 36X
Reduced to 3/4 Size

Magnification: 250X

Comments: This joint exhibits very good bond characteristics. The sub-grain formation and/or recrystallization hold evidence to the thermal effects in the carbon steel.

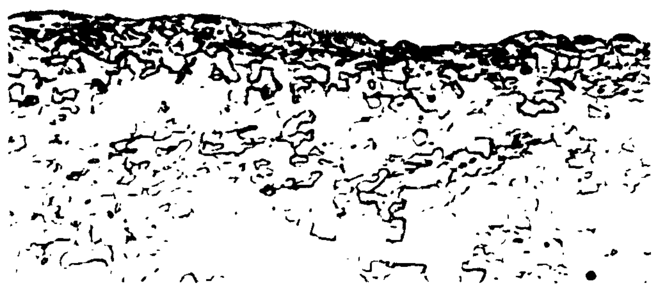
METALLOGRAPHY

Etchant: KCN + $Na_2S_2O_8$
(Stainless steel unetched)

Combination: Stainless Steel (Wire) 0.0625 to Nickel (Coupon) 0.060 gage
Number 9

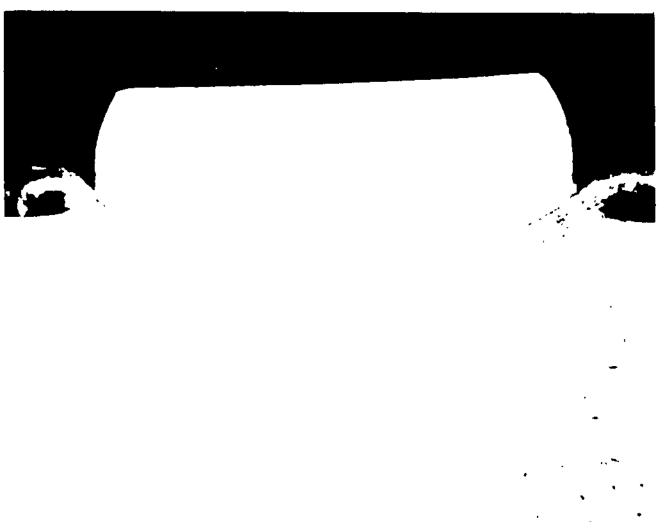
Longitudinal

Magnification: 36X

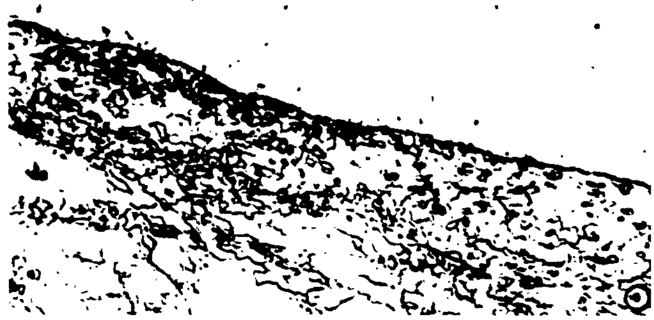


Magnification: 250X

Transverse



Magnification: 36X
Reduced to 3/4 Size



Magnification: 250X

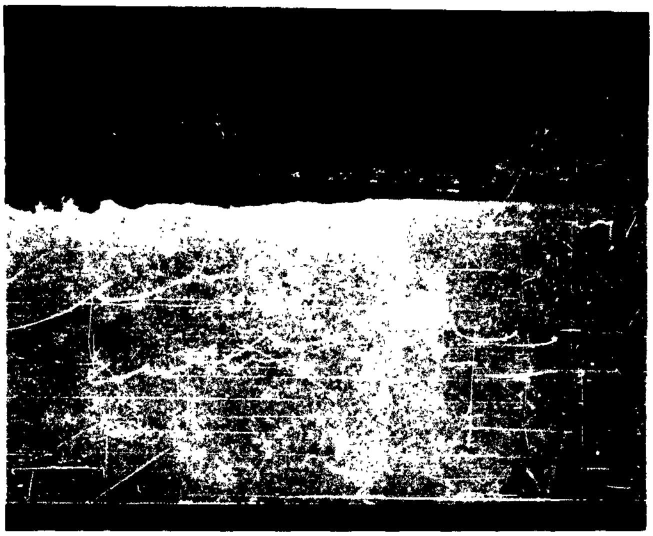
Comments: Satisfactory weld characteristics are evident. Mutual interpenetration of the faying surfaces and absence of voids or non-bond areas indicate the integrity of the joint. Note the flow and expulsion of the nickel sheet and recrystallization structure adjacent to the weld interface.

METALLOGRAPHY

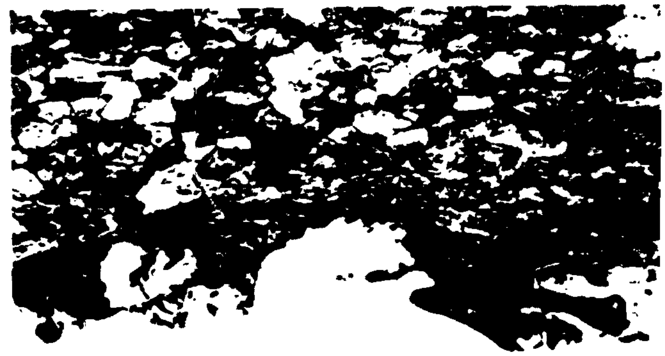
Etchant: HF + HNO_3 + Lactic Acid
(Nickel unetched)

Combination: Tantalum (Wire) to Nickel (Coupon)
Number 10
0.062 gage 0.060

Longitudinal

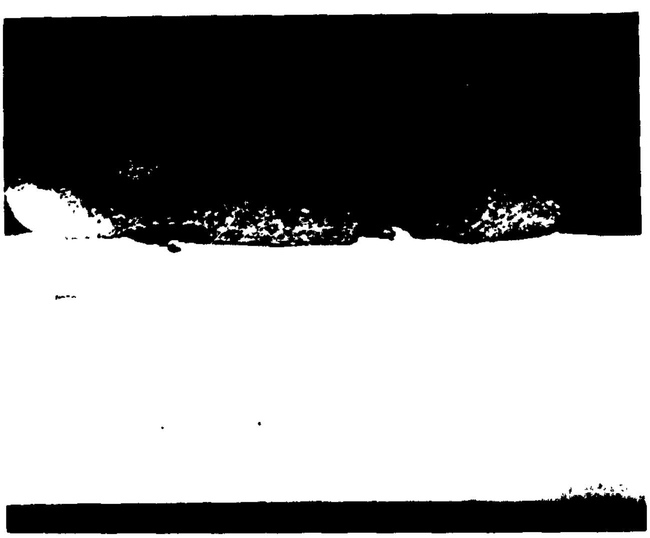


Magnification: 36X



Magnification: 250X

Transverse



Magnification: 36X
Reduced to 3/4 Size

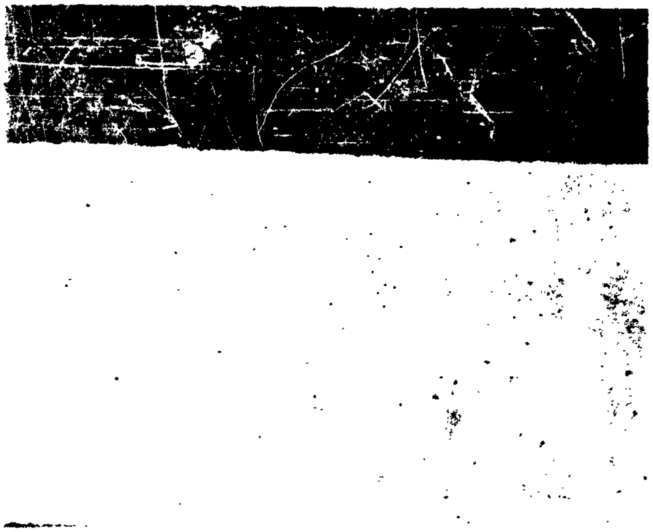
Magnification: 250X

Comments: Uniform bonding throughout the entire contact area has not occurred, but excellent local bond areas are present. The darkly-etched regions of the wire delineate the heat pattern developed during welding.

METALLOGRAPHY

Etchant: Unetched	Combination: Number 11	Tantalum (Wire) 0.062	to gage	Stainless Steel (Coupon) 0.060

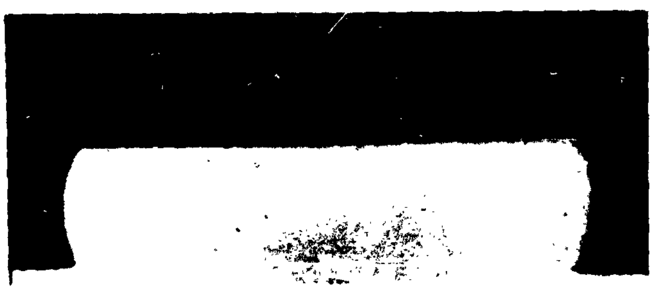
Longitudinal



Magnification: 36X

Magnification: 250X

Transverse



Magnification: 36X
Reduced to 3/4 Size

Magnification: 250X

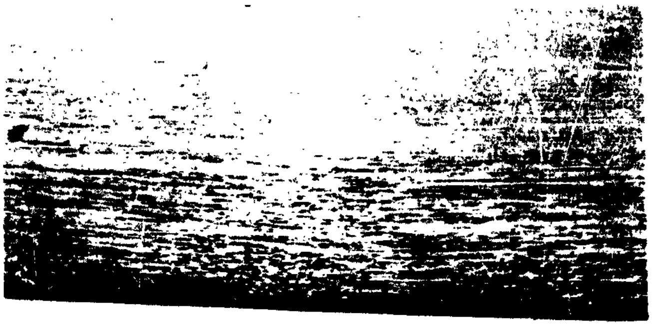
Comments: Small voids and clusters of accumulated oxide decorate the interface; elsewhere, integrity is excellent. Some of the interfacial debris may be non-metallic inclusions within the stainless steel. No positive identification is available.

METALLOGRAPHY

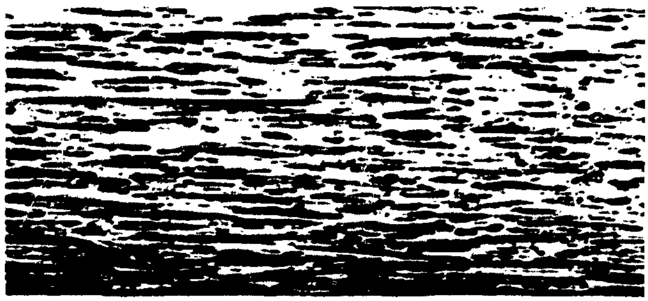
Etchant: KOH + $K_3Fe(CN)_6$
(Nickel unetched)

Combination: Tungsten to Nickel
Number 12 (Wire) (Coupon)
0.064 to 0.066 gage 0.060

Longitudinal



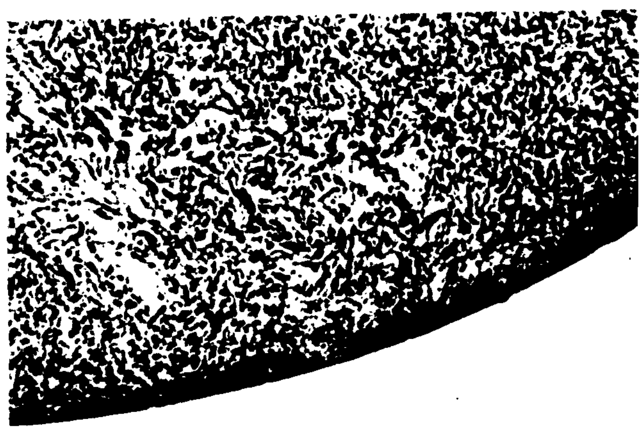
Magnification: 48.5X



Magnification: 250X

Transverse

Magnification: 48.5X



Magnification: 250X

Comments: Very good integrity of the mating surfaces is demonstrated. However, evaluation of bond quality must be deferred because of polishing relief at the interface. Note cracking and spalling of tungsten wire.

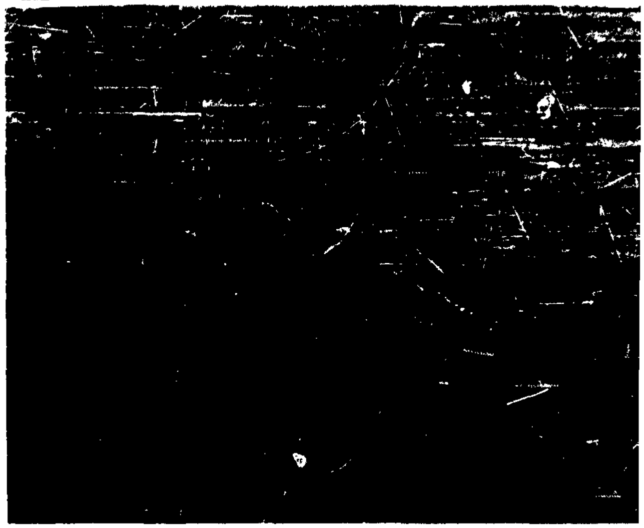
METALLOGRAPHY

Etchant: KOH + $K_3Fe(CN)_6$ (Tantalum unetched)

Combination: Tungsten (Wire) to Tantalum (Coupon)
Number 13 0.064 to 0.066 gage 0.063

Longitudinal

Magnification: 55X



Magnification: 250X

Transverse

Magnification: 55X
Reduced to 3/4 Size

Magnification: 250X

Comments: Metallographically, bond quality proved difficult to determine because of the interface relief. No large voids were observed; the surfaces appeared to be in intimate contact. Note the crack in the tungsten wire.

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