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An Apparatus for Spot Welding Sheathed Thermocouples to the Inside of Small-Diameter Tubes at Precise Locations

W. E. Baucum
R. E. Dial

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OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
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W. E. Baucum R. E. Dial

ABSTRACT

This report describes equipment and procedures used to spot weld tantalum- or stainless-steel-sheathed thermocouples to the inside diameter of Zircaloy tubing to meet the requirements of the Multirod Burst Test (MRBT) Program at ORNL. Spot welding and oxide cleaning tools were fabricated to remove the oxide coating on the Zircaloy tubing at local areas and spot weld four thermocouples separated circumferentially by 90° at any axial distribution desired. It was found necessary to apply a nickel coating to stainless-steel-sheathed thermocouples to obtain acceptable welds. The material and shape of the inner electrode and resistance between inner and outer electrodes were found to be critical parameters in obtaining acceptable welds.

INTRODUCTION

This report describes an apparatus and method for precisely locating and attaching sheathed thermocouples on the inside of small-diameter Zircaloy tubes. This work was done in support of the Multirod Burst Test (MRBT) Program, which is conducted by Oak Ridge National Laboratory (ORNL) for the Nuclear Regulatory Commission (NRC) as a portion of the Pressurized-Water Reactor Safety Program. Although the apparatus described here was developed specifically for use with Zircaloy tubes, the basic device is applicable to other materials also. However, to use this device for other materials would require the development of parameters and techniques necessary for specific applications.

The MRBT program at ORNL is investigating the deformation behavior of PWR fuel pin simulators that are subjected to controlled pressure and temperature transients representative of a hypothetical loss-of-coolant accident (LOCA). When the stress-temperature combination of the cladding reaches a level that exceeds the yield strength, the cladding balloons and causes a reduction in the coolant flow area. To monitor the cladding temperatures of the fuel pin simulators during this hypothetical event, it is necessary to attach thermocouples on the inside diameter of the Zircaloy cladding so as to leave the outside surface undisturbed.

For these tests, the fuel simulators are electrically heated at 28°C/sec (~50°F/sec) until the surrounding Zircaloy tube (see Fig. 1) bursts at temperatures ranging up to 1204°C (2200°F), depending on the pressure of the helium gas that fills the gap between the fuel simulator and the Zircaloy tube. Four sheathed thermocouples must be spot welded to the ID of the Zircaloy tube at precisely located points (both axially and circumferentially), and the weld strengths must be sufficient to withstand the forces generated by both the sliding of the grooved fuel simulator and the rapid thermal transients that occur during the burst test. For tests above about 980°C (1800°F), tantalum-sheathed thermocouples must be used because of compatibility problems of ordinary materials with Zircaloy. Stainless steel forms a low melting eutectic with Zircaloy above 980°C (1800°F) but is satisfactory at lower temperatures. Since burst tests are conducted at temperatures from about 704°C (1300°F) to about 1204°C (2200°F), both stainless-steel- and tantalum-sheathed thermocouples are used in the assembly of fuel pin simulators.

To fulfill these requirements, a special tool has been designed and fabricated with which a 0.076-cm (0.030-in.) sheathed thermocouple may be spot welded as far as 1.12 m (44 in.) inside a 0.965-cm-ID (0.380-in.) tube at a precisely specified location.

DESCRIPTION OF EQUIPMENT

The spot-welding tool (shown in Fig. 2) consists basically of grooved tubing (over which the Zircaloy tube and thermocouples slide); two electrodes to supply the welding current; and spring-loaded mechanisms to supply the necessary pressure on the electrodes. The grooved tubing consists of two sections of equal diameter (one micarta and one stainless steel) joined end to end with a pin in such a manner that the micarta tube can be easily rotated with respect to the stainless steel tube.

The electrodes are located near the middle of the tool as shown in detail in Fig. 3. Electric power is supplied to the outer electrode by cable through a knife switch, and the inner electrode receives power

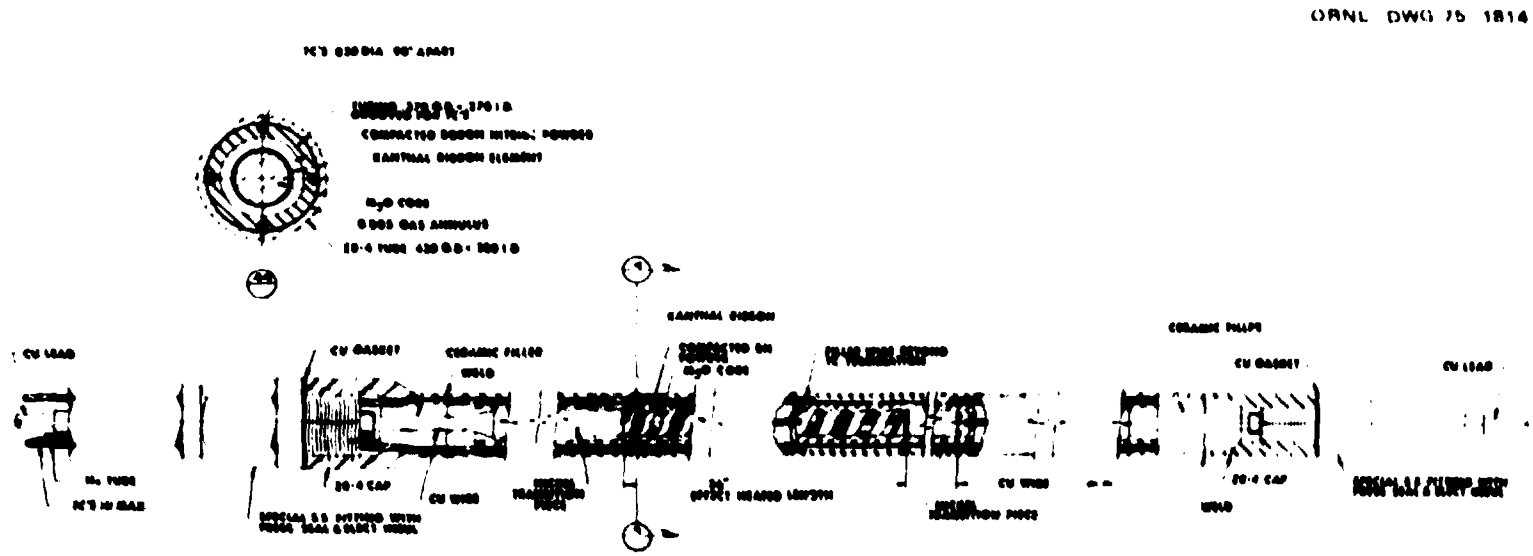

Fig. 1. Multirod burst test fuel pin simulator.

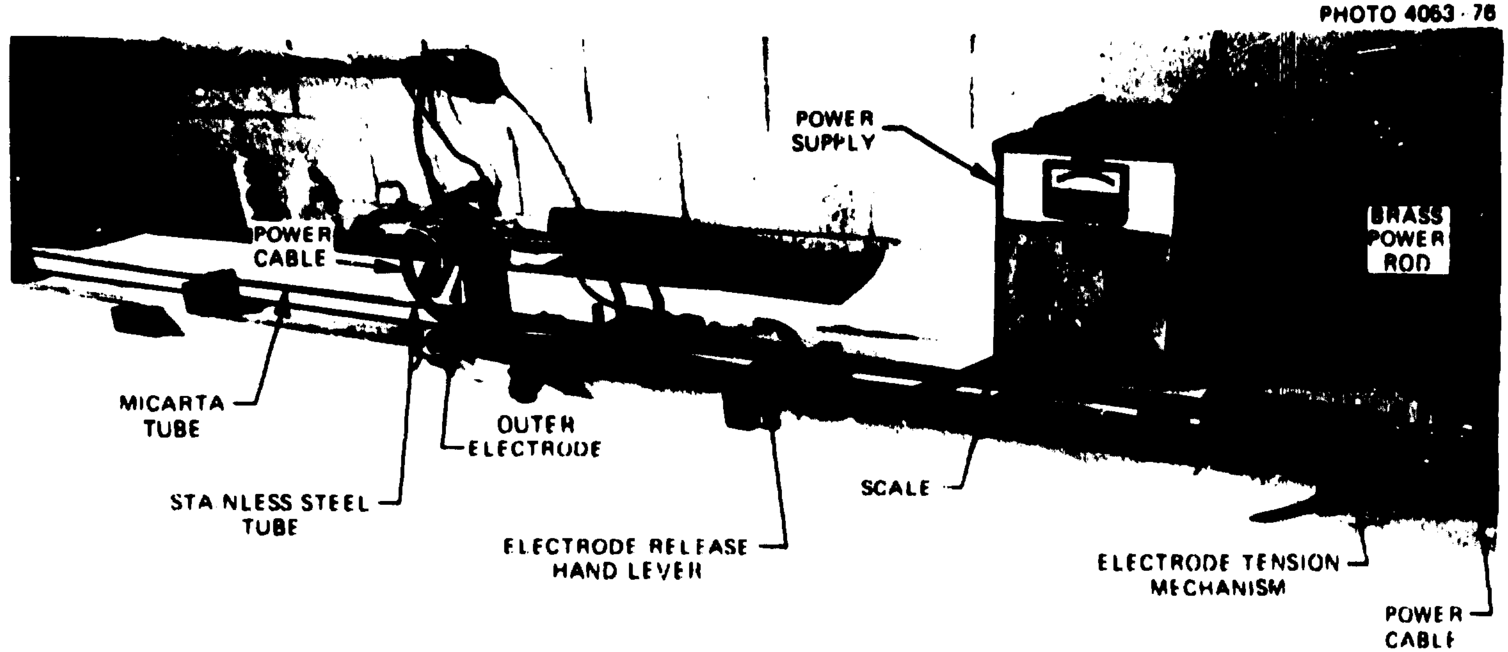

Fig. 2. Spot-welding tool.

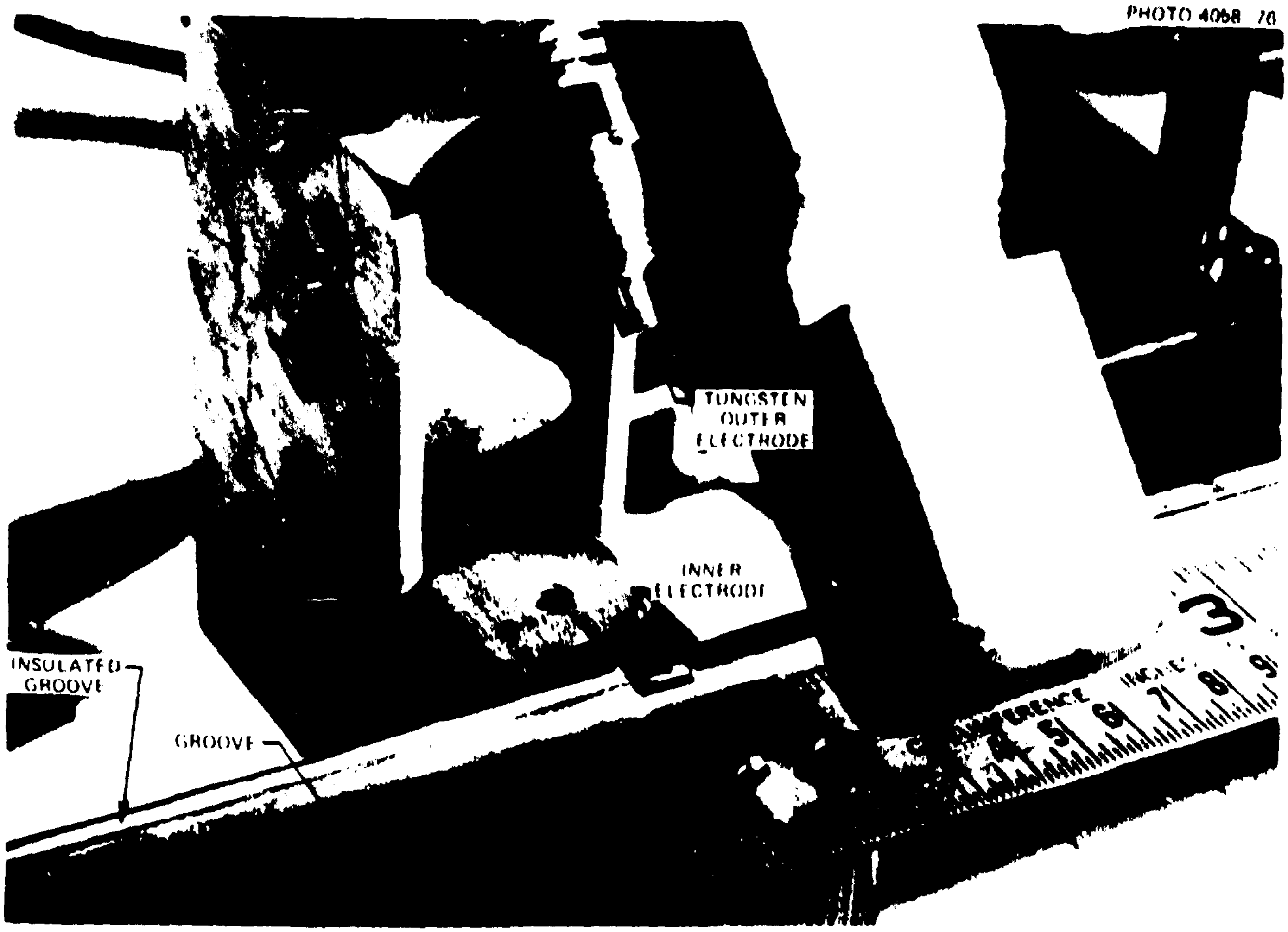

Fig. 3. Inner and outer electrodes of spot-welding tool.

through a copper rod that runs through the center of the stainless steel tube to the electrode tension mechanism mounted on one end of the tool. A separate brass rod acts as a conducter through the axis of the electrode tension mechanism. A cable then connects this rod to the power supply (see Figs. 4 and 5).

To ensure good, reproducible spot welds, the inner electrode must apply a constant force against the thermocouple and Zircaloy tube. Figures 4 and 6 show the means by which this is accomplished. The inner electrode is attached to the tension and power rod, which runs through the stainless steel tube to the electrode lock piece. The spring, compressed between the electrode lock piece and the adjustment screw, then applies force to push the electrode forward onto the Teflon plug. Since both the Teflon plug and the front of the electrode are cut at a 45° angle, the forward force is transformed to an upward force, which pushes the electrode and the thermocouple lying in its groove up through a slotted hole in the stainless steel tube to contact the inside surface of the Zircaloy tube (see Fig. 3). Thus, the electrode is held against the thermocouple, which is held against the Zircaloy tube by the spring tension developed in the electrode tension mechanism. The force with which the thermocouple is held against the tube ID is adjustable by positioning the tension adjustment screw. The electrode lock piece slides in grooves in the case and acts to prevent rotation of the electrode as the adjustment screw is turned.

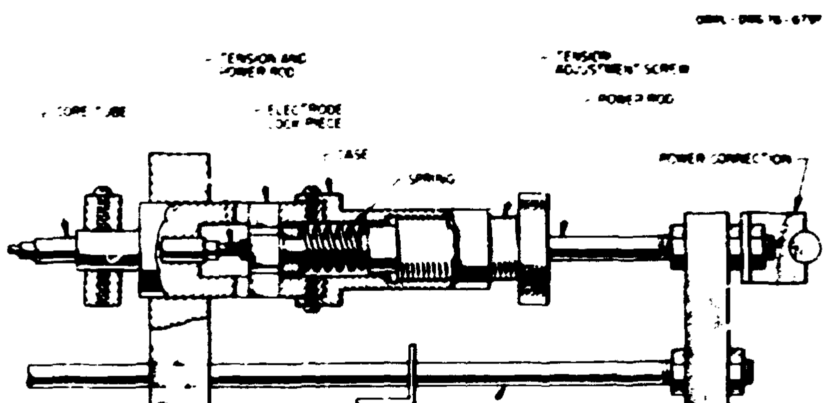

Fig. 4. Electrode tension mechanism.

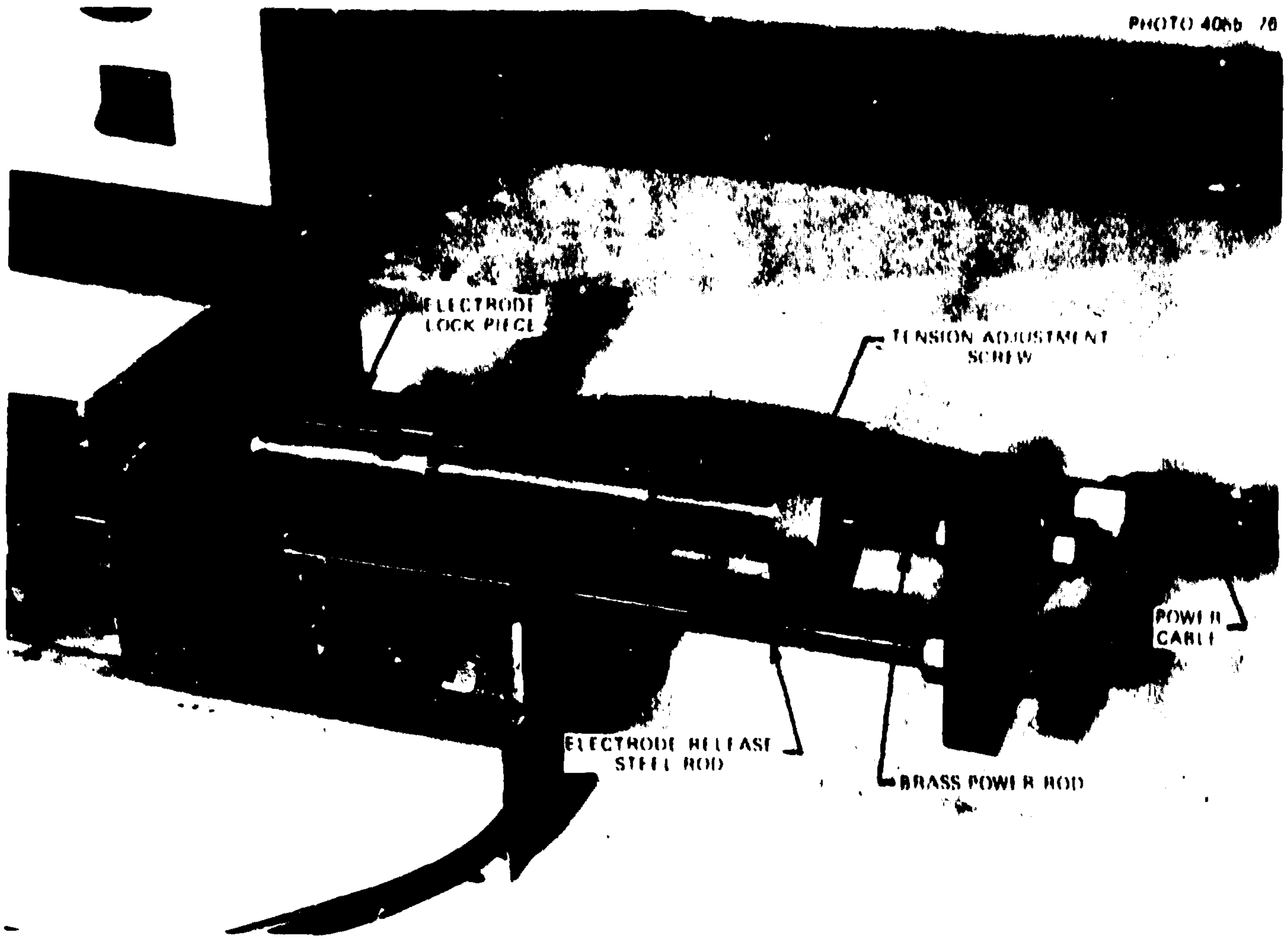

Fig. 5. Electrode tension mechanism.

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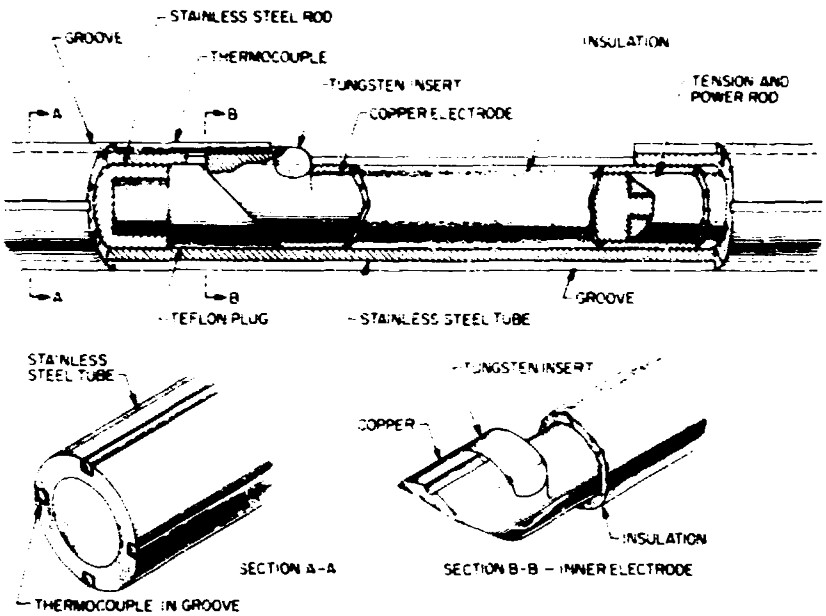

Fig. 6. Diagram of inner electrode mechanism.

The inner electrode (shown in Fig. 6, Section B-B) provides the best welding results of the various configurations and materials tested thus far. The welding surface is copper, which is grooved with a radius approximately equal to that of the thermocouple sheath. The tungsten piece brazed on the back of the welding surface is added to prevent excessive melting of the copper adjacent to the end of the thermocouple where arcing occurs. A further improvement to reduce electrode erosion might be realized by using a copper alloy in place of the copper; however, such a test has not yet been conducted. Electrodes with ungrooved welding surfaces of both tungsten and molybdenum were tried, but excessive sticking of the thermocouples (both tantalum and stainless steel sheathed) to the electrode was experienced. An ungrooved copper electrode works well for the tantalum- but not the stainless-steel-sheathed thermocouples.

The outer electrode mechanism is shown in Fig. 7. The electrode is spring loaded to assure a uniform low contact resistance with the outside surface of the Zircaloy tube. Although copper is probably the best electrode material for spot-welding purposes, it could not be used because in the event of an arc during welding, the copper might splatter onto

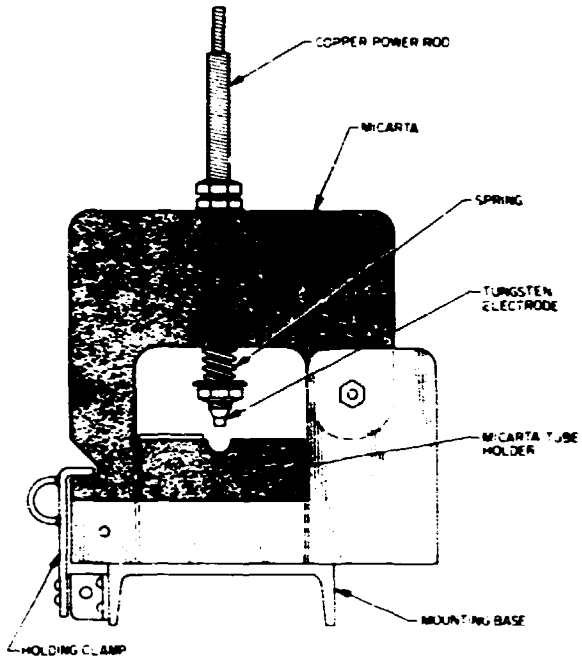

Fig. 7. Diagram of outer electrode mechanism.

the Zircaloy tube and cause eutectic melting during a burst test. Therefore, tungsten, which has a high alloying temperature with Zircaloy (∿1820°C), was brazed onto the copper power rod.

The electrode release mechanism (shown in Fig. 2) is used to move the inner electrode back off the angled Teflon plug and thus down from the Zircaloy tube surface. It consists of a hand lever and a cam that retracts the power rod (see Fig. 4). The power rod then pulls back the inner electrode, releasing the Zircaloy tube and the thermocouple.

The power supply used is a UNITEC model 1-048-03 that is capable of delivering pulses of 0 to 100 Wsec. The pulse duration was measured using a storage oscilloscope and found to be approximately 3 msec.

One problem encountered in the early development of this tool was that some of the welding current was shunted away from the weld area by parallel electrical circuits (at that time, both tubes constituting the tool were of stainless steel). It was intended that the current should flow from the inner electrode to the thermocouple, across the thermocouple-Zircaloy weld interface, to the Zircaloy tube and the outer electrode.

However, some current appeared to flow from the inner electrode down the thermocouple to the stainless steel tube and either directly to the Zircaloy tube or through another attached thermocouple to the Zircaloy tube and outer electrode. The problem was eliminated by changing the left end of the tool as viewed in Fig. 2 from the original stainless steel to micarta and by insulating the thermocouple groove in the stainless steel tube with epoxy in the region (from the electrode to the micarta tube) where contact with the thermocouple was possible. This modification can be seen on the top surface of the left side of the tool in Fig. 3.

To obtain acceptable welds with stainless-steel-sheathed thermocouples, it was found necessary to remove the oxide from the attachment area of the Zircaloy tube.* The tool for removing the oxide was designed and fabricated to scrape off the oxide coating at the precise thermocouple location (see Fig. 8). This oxide-removal tool consists of a stainless steel tube that inserts into the Zircaloy tube and a small abrasive rotating wheel with a mechanism to apply it against the inside surface of the Zircaloy tube at the desired location (see Fig. 9). Also provided is an indexing disk by which the Zircaloy tube may be rotated 360° in precise 90° increments and a metal scale for measuring the axial position of the Zircaloy tube on the tool. As shown in Fig. 9, the abrasive wheel is held in the bottom half of the stainless steel tube by a steel driving rod that runs the length of the tool to the driving wheel for the grinding operation. The grinding wheel assembly is so constructed that retraction of the steel driving rod causes the abrasive wheel to move upward and contact the inner surface of the Zircaloy tube. The driving wheel is then turned by hand to rotate the abrasive wheel which scrapes off the oxide in a local spot ~0.317 cm (1/8 in.) wide by 0.635 cm (1/4 in.) long. By use of the indexing disk for circumferential positioning and the steel scale for axial positioning, specific local spots may be cleaned so that when the Zircaloy tube is moved to the spot-welding tool, thermocouples may be applied precisely to these cleaned spots and welded.

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*The MRBT Program requires that the Zircaloy tubes be lightly oxidized in a steam atmosphere before assembly as a fuel pin simulator.

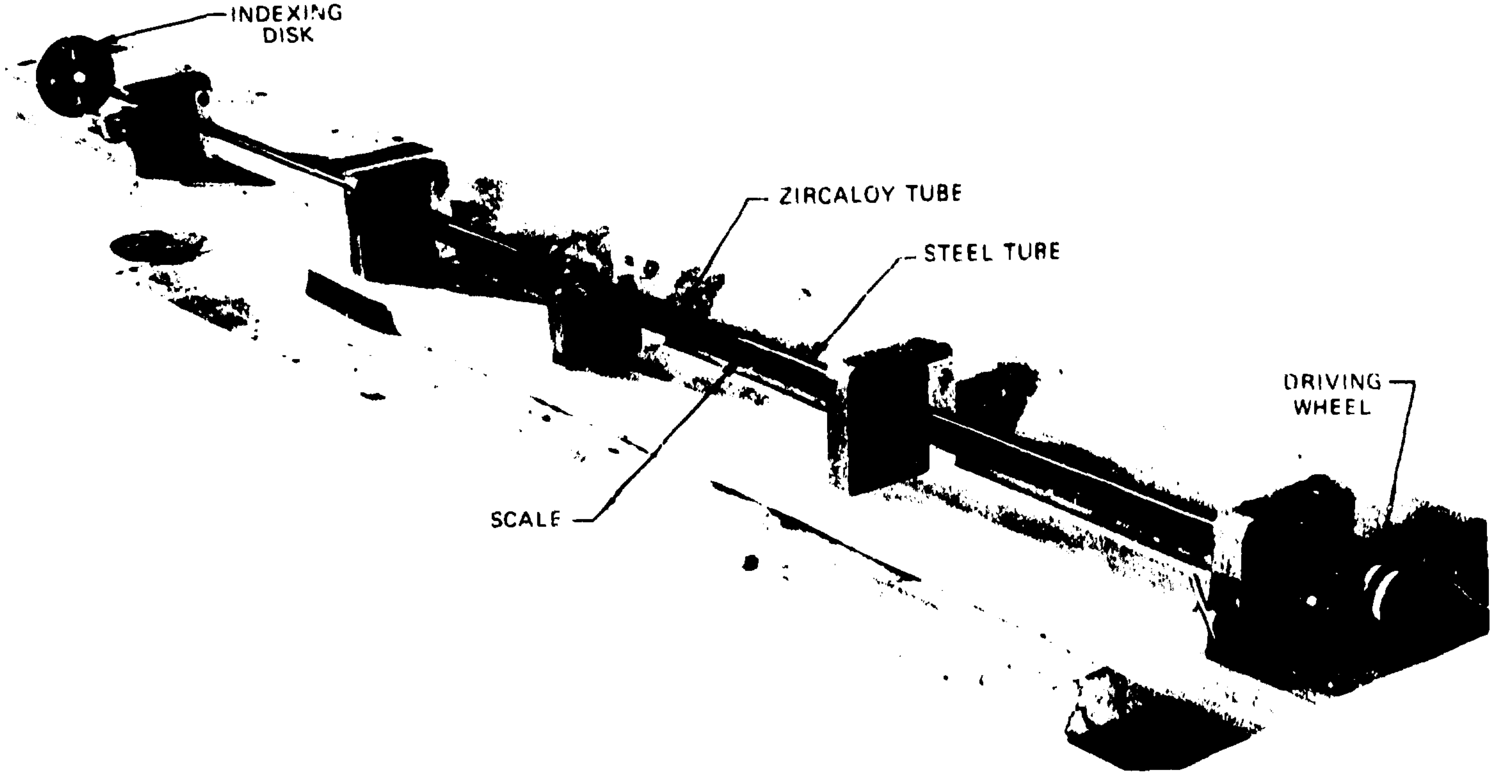

Fig. 8. Oxide-removal tool.

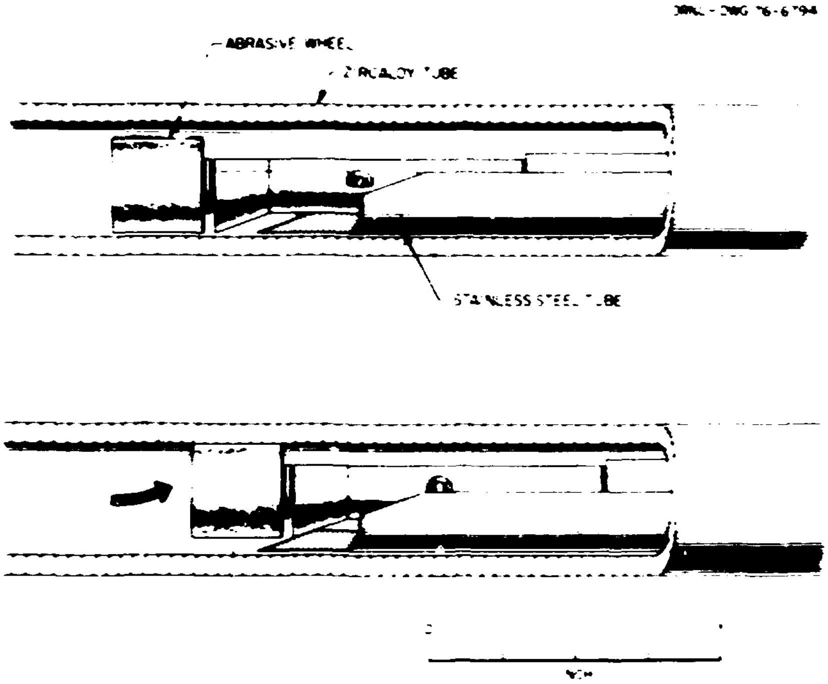

Fig. 9. Diagram of abrasive wheel mechanism.

WELDING PARAMETERS AND OPERATING PROCEDURES

Before attempting to spot weld actual thermocouples into fuel pin simulators, many experiments were conducted using samples of 0.076-cm-diam (0.030-in.) tantalum wire and bulk stainless-steel-sheathed thermocouple lead material welded to small sections of Zircaloy tube. From these experiments it was learned that stainless steel to Zircaloy combinations do not yield spot welds of necessary strength. A search was made for an appropriate intermediate material that is compatible for welding to both stainless steel and Zircaloy and that could be applied to the surface of the stainless steel thermocouple as a thin coating [0.0025 cm thick (0.001 in.)]. The materials investigated included plasma-sprayed tantalum, molybdenum, and vanadium and electroplated platinum, chromium, and nickel. Of these, the only one that produced welds of sufficient strength was nickel; however, these welds were somewhat brittle and the nickel only produced good results when welds were made on clean Zircaloy surfaces. Thus, nickel was chosen as the intermediate material and is plated on the stainless-steel-sheathed thermocouple junction ends. The tantalum-sheathed thermocouples can be welded directly to the Zircaloy without either plating or surface cleaning. Welds of good strength are obtained although some problems are encountered in obtaining good reproducibility. This problem seems to arise from a variable electrical resistance at the tantalum-Zircaloy interface due to the oxide film present on the Zircaloy tube. Experience has shown that a narrow range of resistance is needed at this point to obtain strong welds; a resistance above or below this narrow band results in poor welds. The critical value of resistance was found to be in the range of 0.12 to 0.35 Ω between inner and outer electrodes. Experiments that were performed to determine the optimum welding energy indicated that 50 to 70 Wsec gave best performance for both types of thermocouples.

The procedure used to weld thermocouples into full-length Zircaloy tubes used in the assembly of fuel pin simulators will now be discussed. If the thermocouples to be attached to a particular simulator are specified to be nickel-plated stainless steel, the oxide is first removed from the Zircaloy at the local spots where welds are to be made. This is done by inserting the Zircaloy tube onto the oxide cleaning tool to the proper axial position as measured by the steel scale. The indexing disk is attached to the tube and positioned such that its 0° reference mark is in the 12 o'clock position. A mark is then made on the far end of the Zircaloy tube at this position to serve as the 0° reference mark during future handling of the tube. The tube is clamped in position and the driving wheel and rod pulled back to bring the abrasive wheel into contact with the inner surface of the Zircaloy tube. The driving wheel is manually rotated approximately 1.5 turns to scrape the oxide from the 0° thermocouple location. Since in most simulators it is planned to place four thermocouples 90° apart around the circumference of the tube, the tube is unclamped and sequentially positioned both axially and circumferentially to permit cleaning at the other three locations. No cleaning of the oxide is necessary for the tantalum-sheathed thermocouples since this would reduce the resistance at the tantalum-Zircaloy interface and would result in an inferior weld.

The Zircaloy tube is next placed on the spot-welding tool and positioned so that the thermocouples can be threaded through four grooves in the micarta tube until their ends come to rest at the junction of the micarta and stainless steel tubes. Figure 6 indicates the groove locations. The tube is positioned with the 0° reference mark in the 12 o'clock position. If no reference mark has been previously made, as is the case for tantalum thermocouples, one is established at this time. The Zircaloy tube is pushed back toward the micarta tube end of the spot-welding tool until the electrode and thermocouple in the 0° position are visible, and the thermocouple is moved forward toward the stainless steel tube end of the tool until its tip comes into contact with the tungsten stop (see Fig. 6). The Zircaloy tube is then pushed forward to the proper axial position as indicated by the steel scale, and the inner electrode is released. The outer electrode is brought down and a piece of abrasive paper pulled between it and the Zircaloy tube to remove the oxide at that spot on the outside of the tube. The spring-loaded outer electrode is clamped down and the inner to outer electrode resistance measured. If the resistance is outside the critical range previously discussed, the Zircaloy tube is moved slightly forward and then back to its original position to create a small scratch in the inner wall oxide coating as the thermocouple slides against the tube. This generally brings the resistance into the desired range, but occasionally the procedure must be repeated several times. The power supply is then adjusted to 60-Wsec and pulsed once. The Zircaloy tube and attached thermocouple are then pushed back just past the point where the micarta tube joins the stainless steel tube, and, with the other three thermocouples temporarily held out of the grooves in the stainless steel tube, the Zircaloy tube and thermocouples are rotated by 90°. The 90° thermocouple is then pushed up to the tungsten stop and the whole process repeated until all thermocouples have been welded. At this point, the Zircaloy tube is pushed back onto the micarta tube and the micarta tube separated from the stainless steel tube by removing a joint pin. This removes the Zircaloy tube and thermocouples from the spot-welding tool, leaving the micarta core tube inside to protect the thermocouple spot welds from twisting and flexing. The grooved fuel simulator, having its 0° groove aligned with the 0° mark on the Zircaloy tube, is inserted from one end of the tube and serves to push the micarta core out the upper end as it moves along, accepting the thermocouples into its grooves. After affixing the upper and lower seals, the fuel pin simulator assembly is complete.

CONCLUSION

Both the oxide-cleaning and the spot-welding tools appear to be performing their design tasks relatively well. Both stainless-steel-sheathed (nickel plated on the end) and tantalum-sheathed thermocouples have been successfully welded into fuel pin simulators at the precise locations required and subjected to burst tests where the thermocouples are in helium atmosphere. The temperature data show that both types of thermocouples remain welded to the Zircaloy tube up to the point of tube burst. Also, the deformation of the Zircaloy caused by spot welding does not appear to compromise the tube, since none of the bursts have occurred at the spot-weld sites. One problem is the lack of good reproducibility in weld strength when using the tantalum-sheathed thermocouples. It appears that good weld strength is strongly dependent on obtaining a critical range of electrical resistances at the tantalum-Zircaloy interface. The tools and techniques described in this report are presently in routine use by MRBT program personnel for assembly of fuel pin simulators.