U. S. NAVAL AIR DEVELOPMENT CENTER

JOHNSVILLE, PENNSYLVANIA

Aeronautical Electronic and Electrical Laboratory

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PHASE REPORT
EVALUATION OF WELDED CONNECTIONS FOR
AIRBORNE ELECTRONIC EQUIPMENT

WEPTASK NO. RAV41J001/2021/R008-01-001
Problem No. 23 (RAV44J035)

SUMMARY

The evaluation of welded connections that may replace soldered connections in airborne electronic equipment revealed the need to enlarge the scope of the evaluation and indicated the areas where additional work is required.

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Ref: (a) BUWEPS ltr RAAV-4423/45 of 7 Feb 1961
(b) Spec No. MIL-E-5400, "Electronic Equipment, Aircraft, General Spec for"
(c) The Martin Company Report No. OR-1378-A, "Electronic System Integration, A Value Analysis and Cost Comparison," of Jan 1961
(d) Sippican Corporation Report No. FA-A202234-B, "Failure Rate of Welded Joints in Polaris FBM Guidance Computer," of 1 May 1961

INTRODUCTION

WEPTASK No. RAV41J001/2021/R008-01-001, Problem No. 23 (RAV44J035), established by reference (a), requested the U. S. Naval Air Development Center (NAVAIRDEVCEN) to investigate and evaluate welded connections that may be used in place of soldered connections in airborne electronic equipment. At the present time there exists, under Specification No. MIL-E-5400, reference (b), control of the general technical requirements and some construction controls for electronic equipment used in aircraft.

This report represents the preliminary results of a NAVAIRDEVCEN investigation of welded connections and the results of investigations made by several manufacturers engaged in the production of welded assemblies and welding equipment. It will be necessary to further evaluate many series of welds to determine the materials that are weldable, the most desirable dimensions, the types of electrodes, etc, so that the true value of the welded connection in airborne electronic equipment may be adequately determined.

EVALUATION AND DISCUSSION

Nondestructive Tests of Welded Connections

At present, an absolute nondestructive test for welded connections does not exist. Through many series of welds, it is possible to predict the optimum welding machine settings of pressure versus energy for each particular weld. This is accomplished by inspecting each weld visually to determine if any burning or splitting of the connection occurs. The connection is then destroyed by the use of a tensile testing machine, and the strength at which the connection failed is recorded. Figure 1 shows how this data can be used to develop an isostrength diagram for a particular welding problem. In conjunction with this, metallurgical studies and microphotographs are made on similar welds so that absolute proof can be established as to the consistency of the weld. To obtain good welds repeatedly, the welding program must be established in this manner, and operators and inspectors properly trained. It is also necessary that the welding machines be checked regularly and that operators be prohibited from making adjustments.

One method of nondestructive testing has been established, but it is purely a mechanical test and cannot be considered conclusive. With the use of a calibrated spring, a tensile test may be made on the welded connection to insure that the connection does adhere to the minimum tensile strength as determined by the isostrength diagram requirements. Although this test indicates the strength of the weld, it does not insure that a good metallurgical bond has been obtained between the two metals.

Research is presently being conducted on nondestructive test methods. An ideal device would be a system within the welding machine to detect defective welds immediately, reject the weld, and correct the machine settings before continuing to another weld. The possibility of using r-f induction methods or ultrasonic inspection is being considered and investigated, but present indications reveal that such systems will not be developed for at least two years.

Weldable Materials

A number of materials can be welded successfully. The most common and most easily welded material is nickel, and it is used extensively as interconnecting leads and input and output leads in welded assemblies. Other materials which are easily welded include: gold-flashed Kovar (gold-plated nickel-iron-cobalt), copper, Dumet (copper-clad nickel-iron), nickel-coated copper ribbon, Alloy 42 (nickel-iron), and Alloy 180 (nickel-copper). In the case of welding to tinned-copper leads, the use of nickel coated copper ribbon gives the best results. Success has also been achieved by stripping the tinned coating and welding directly to the copper. However, as stated previously, there is considerable effort to determine the materials which can be welded and the conditions necessary to achieve consistent welds.

Several assemblies have been designed and constructed at the laboratory. Examples of these are shown in figures 2 and 3. The components are standard types and, with the exception of the transistors and diodes, have tinned-copper leads; nickel ribbon was used for interconnections. Although there were no destructive tests made on the weld joints, the welds appeared to be acceptable by visual inspection. The input and output leads in figure 2 are brass pins (Elco Corporation). Tinned-copper leads were used on the module in figure 3.

Lead Diameters

The lead dimensions which can be welded primarily depend upon the capabilities of the welding machine. In the laboratory, the welding unit employed is a WELDMATIC, capable of a maximum output energy of 80 w/sec at a pressure of 10 lb. No effort was made to answer the question on the basis of this particular welder because there are other welders in use which have higher discharge capacities. The most desirable diameters to be used in welded electronic packages are in the range from 0.01 to 0.032 in. These dimensions include all the standard components necessary to complete an assembly, and all can be welded readily using an 80 w/sec, 10-lb pressure welder.

Cleaning of Leads

It has been found that minor cleaning of leads may be necessary, although it does not appear to be a critical factor. Comparison of leads welded without cleaning and those welded after cleaning with trichlorethlyene showed no difference in the final weld. As stated before, it may be necessary to strip the tinned coating from copper leads to obtain a proper weld. Care should be taken to make the weld as soon as possible after stripping to prevent oxidation from forming on the copper. Should this occur, however, it is then necessary to use a dilute acid dip to remove the oxidation. In any case, cleaning of leads should be accomplished by chemical rather than mechanical methods.

Lead Lengths

The length of the lead has no affect on the welded connection. However, in the construction of an assembly, it is desirable to have the leads extend above the body of the package before encapsulation. This allows electrical tests to be performed without danger of injury to the welded connection or the components. At the time of encapsulation of an assembly, the leads must be trimmed before the module is placed into the encapsulation mold.

Component Injury

There is some danger of injury to the component in the welding process, depending upon the type of welder employed. With the d-c discharge type, it is physically possible to weld directly at the body of the component and not destroy any of its electrical or mechanical characteristics. This is due to the fact that the heat is instantaneous (1-2 ms) and occurs only at the point of contact with the welding electrodes and the leads being welded. Close proximity is illustrated in figures 2 and 3. The a-c type welder operates on the principle of preheating the welding area before welding, making the weld, and then slowly cooling the welded connection. The preheating process must be closely controlled to insure that no significant heat, particularly in the case of semiconductors, reaches the junction and damages or destroys the component.

In the construction of a welded assembly, the possibility exists of establishing loop currents within the wiring matrix because of the welding electrodes coming in contact with leads other than those being welded. This is more critical in using the a-c type welders than the d-c discharge type. This danger can be reduced by one or a combination of the following three methods:

1. Coating or covering of the body of the welding electrodes with an insulating material to prevent erroneous contact.

2. Design of the assembly to allow sufficient spacing for the electrodes to contact only the desired connection.

3. Tailored design of the electrodes.

At times, however, none of these methods may be used and, in such cases, extreme care is the only remedy.

Cost Analysis

The cost of producing a welded assembly appears to be slightly higher than the cost of producing a prime quality printed board. The increased cost is due largely to the design work that is more complex for a welded assembly than for a printed board. Equipment and material for both types of construction are comparable in cost and do not contribute to the differences. In a cost analysis by the Martin Company of Orlands, Florida, reference (c), the total unit cost per printed board was $36.46 as compared to $73.32 per complete welded assembly. Discussions with welded assembly manufacturers did not reveal any conclusive proof, but it is reported that the cost of welded assemblies is now competitive with prime quality printed circuit boards.

Reliability and Consistency of Welded Connections

The main factor in producing reliable welds consistently is the ability of the component manufacturer to maintain good quality control on the lead materials and dimensions. Once a weld schedule has been established, the welding operation itself is routine and can be performed by virtually any individual. Studies published by the Sippican Corporation, reference (d), indicate a reliability figure of 0.006×10^{-6} failures per operating hour in systems designed for the Polaris Fleet Ballistic Missile Guidance Computer. There were a total of three failures in 84,700 welds. To maintain this reliability in welded assemblies, the tolerances on the components themselves should be closely controlled. Due to intensive training programs instituted by individual welded assembly manufacturers, welding inspectors have been able to detect visually 92 to 100 percent of the defective welds.

Related Information

One problem intimately related to, but not directly involved in, the welding technique is that of interconnection of assemblies. While it is possible to obtain reliable interconnections, a simplified, reliable, connection device, capable of withstanding the aircraft environment, does not appear to be available. Solution of this problem would promote increased use of welded assemblies and facilitate maintenance of systems utilizing welded assemblies.

CONCLUSIONS

Summarizing the answers to the specific questions of the problem assignment:

1. At the present time an absolute nondestructive test for welded connections does not exist.

2. Many materials are weldable, but all require determination and control of optimum energy and pressure to insure that a good metallic bond has been obtained in the welded connector.

3. The most desirable lead diameters are in the range from 0.010 to 0.032 in.

4. Minor cleaning of leads may be necessary but is not critical. If performed, cleaning should be accomplished by chemical methods and not by mechanical methods.

5. The length of the component lead has no affect on the welded connection.

6. There is some danger of component injury, but this can be practically eliminated by correct choice of equipment and the use of intelligent design procedures and techniques.

7. The overall cost per unit of welded modules appears to be slightly higher than printed circuit boards. Other advantages of welded modules, which tend to offset their higher cost, include higher component density, expendable packaging, rapid construction, increased structural strength, and increased reliability.

While the above answers do not completely satisfy the problem assignment requirements, they more clearly define the problem and indicate the areas wherein additional work is required.

Private industry has made great advances since the conception of the welded connection at the Instrumentation Laboratory at Massachusetts Institute of Technology. These advances have been in the use of welded connections in electronic equipment and in the institution of more rigid standards of component manufacture. The latter improvement is of great value in itself.

Once a welded assembly has been encapsulated, it cannot be repaired, therefore it is essential that all components meet the required specifications as stated by the purchaser. When component manufacturers become more aware of the problem, as manufacturers of systems are now doing, greater reliability can be expected from welded assemblies and the resulting electronic equipment.

Future activity on the problem assignment will be concentrated on the following:

1. Evaluation of methods used in the establishment of weld schedules and isostrength diagrams. These evaluations will include a wide variety of lead materials and verification of weld quality by microphotography.

2. Further study of methods of performing nondestructive testing of welds.

3. Study of interconnection methods and devices.

Upon completion of these activities sufficient information will be available to permit the documentation of welding controls.

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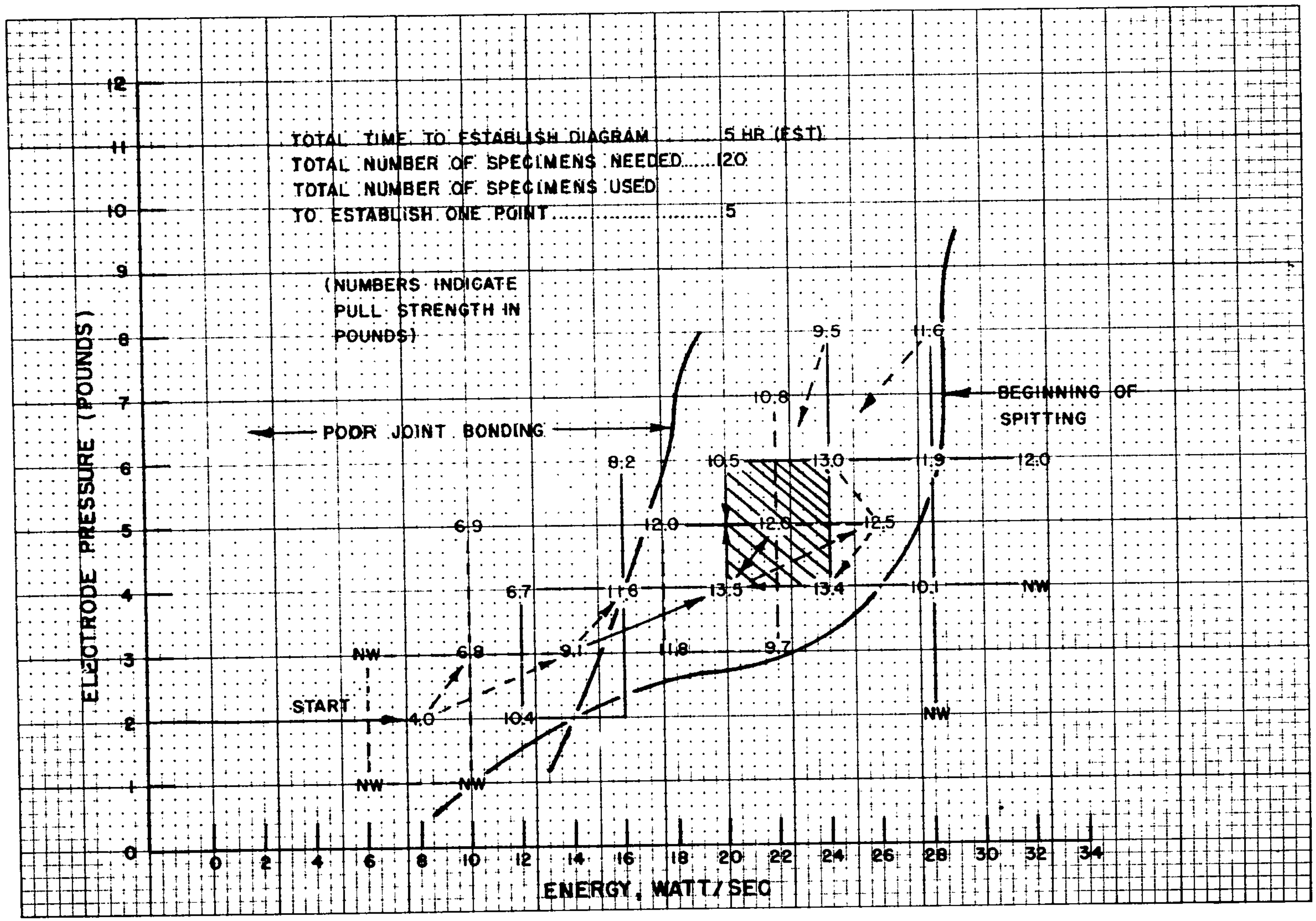

FIGURE 1 - Bond Strength Diagram Used in Conjunction with an Isostrength Diagram to Determine the Most Desirable Parameters to Produce a Good Weld

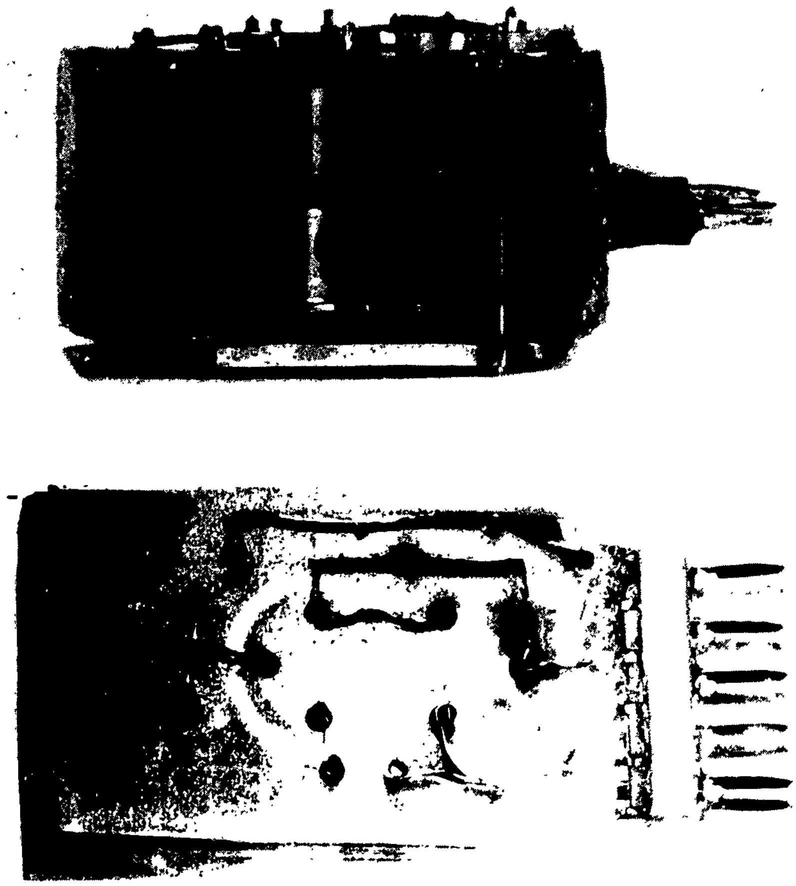

FIGURE 2 - Partially Encapsulated Welded Module with Brass Connecting Pins

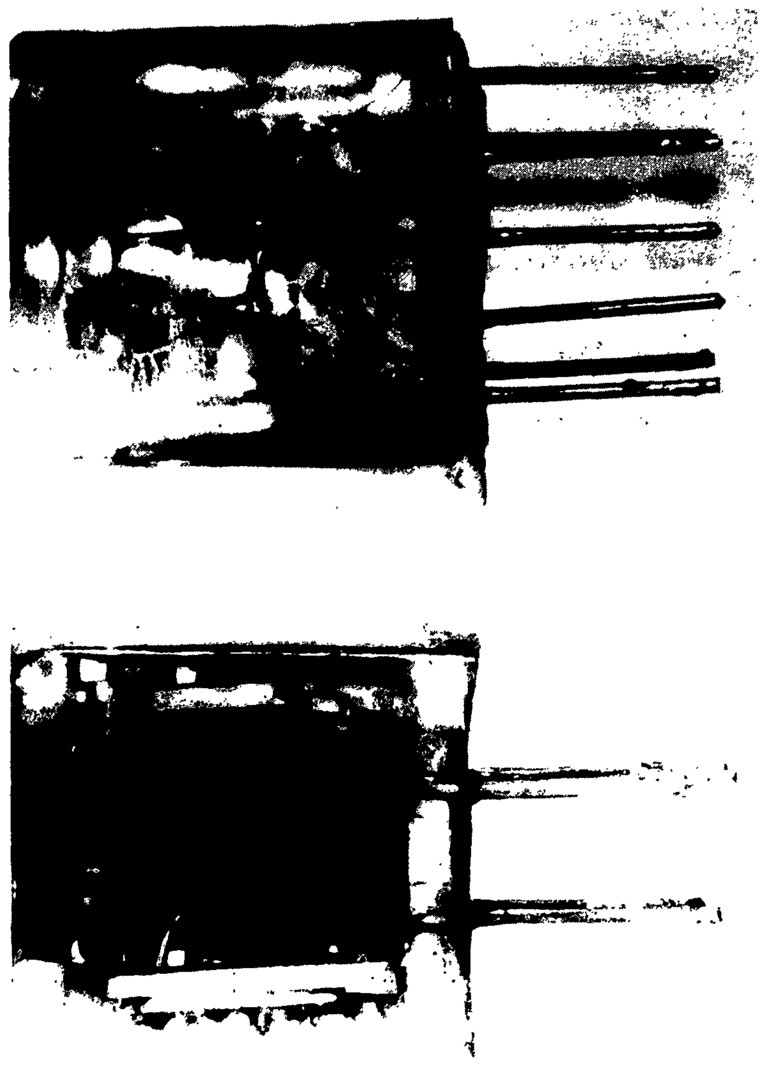

FIGURE 3 - Completely Encapsulated Welded Module with Tinned Copper Connecting Leads