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MINIATURE CORE ASSEMBLY FABRICATION
AND TEST PROCESSES

PDO 6989248, Final Report

H. F. Jordan, Project Leader

Published August 1976

MASTER

Prepared for the United States Energy
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**Kansas City
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Project Leader:
H. F. Jordan
Department 845

PDO 6989248
Final Report

Technical Communications

**Kansas City
Division**

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MINIATURE CORE ASSEMBLY FABRICATION AND TEST PROCESSES

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Prepared by H. F. Jordan under PDO 6989248

A fabrication technology has been developed to permit rapid and reliable fabrication of ferrite core assemblies that use small diameter copper wire. A method was devised for matching magnetic characteristics of ferrite cores using a computerized data system.

WPC-plb

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SUMMARY

Progress was made toward developing a fabrication technology for producing a miniature memory core assembly and matching the magnetic characteristics of production quantities of the multi-purpose ferrite cores used in the assembly.

A number of sample core assemblies were fabricated to evaluate processing steps. As a result of the work, the following fabrication techniques were developed.

- The use of a copper-loaded solder such as Savbit Alloy 1 was found to help solve the copper dissolution problem common with small diameter copper wires.
- Low solder temperatures were determined important to the control of copper dissolution of the wire.
- Wire breakage and insulation abrasion problems were reduced by deburring and coating the cores.
- Fixturing was devised to minimize wire breakage during the manual core winding.
- Double-sided adhesive tape proved to be excellent for positioning the fine wires during soldering and for temporarily affixing the cores to the carriers.

In addition, a test technique was devised to provide for computerized core matching using a time-based digital characterization of the core's magnetic capabilities.

DISCUSSION

SCOPE AND PURPOSE

This study was undertaken to determine a fabrication technology for the production of a ferrite core assembly used in a next-assembly operation. The project also had a goal of developing a process which permitted the rapid matching of magnetic characteristics of the multi-aperture cores used in the assembly.

ACTIVITY

The core assembly (Figure 1) is assembled with the parts shown in Figure 2. Core apertures are wound and tested first. Two wound cores are assembled on a carrier consisting of a phenolic board with brass pins pressed in holes located around the edges. Windings on the core pair are soldered to the pins and tested for continuity. A second board is then pressed on the pins to form a carrier for the second pair of wound cores. These core windings are soldered to the pins and continuity is again verified.

Several assemblies were fabricated to evaluate the processes necessary to successfully manufacture them on a production basis.

The use of small wire in the core windings indicated potential problems. AWG 44 and AWG 48 magnetic copper wire 0.001 inch (0.0254 mm) in diameter is specified for use on the cores. Two of the 0.020 inch diameter (0.508 mm) apertures each contain three windings with a total of 44 turns of wire. Two other apertures contain 20 turns each and the largest aperture contains a 50 turn winding. Wire breakage and insulation damage were projected to be special problem areas. As a result, the following areas were isolated for special investigation:

- Solder selection,
- Insulation abrasion,
- Core winding, and
- Core-carrier assembly.

In addition, effort was directed toward developing methods for rapidly and efficiently ensuring that the ferrite cores used in the assembly are magnetically matched.

Figure 1. Completed Core Assembly

Solder Selection

Copper and other metals are known to dissolve in molten solders. In the case of this core assembly, the dissolution of the 0.0012 inch diameter (0.0305 mm) copper wire is of concern because a small amount of dissolution could result in functional failure or a low reliability connection.

A review of the literature on solder dissolution of copper and other metals (Appendix) revealed that copper dissolution rate is a function of five factors:

- The types and ratios of metals used in the solders;

Figure 2. Carriers and Cores
Used in Core Assembly

- The physical movement or lack of it of the solder relative to the copper surface (solder transport);
- The copper and copper compound concentrations in the solder;
- The temperatures involved (rate increase is approximately exponential with absolute temperature); and
- The size and configuration of the copper wire.

This information provided the basis for an evaluation of the dissolution of small diameter copper wire using special solders.

Three solders were evaluated. Silver solder was evaluated as a result of the desirable results obtained earlier at high temperatures (reported in Bendix report BDX-613-1015). Solder containing copper (Savbit Alloy 1) was evaluated, and common 63Sn-37Pb solder was evaluated for comparison purposes.

Short lengths (approximately 0.50 inch (12.7 mm)) of stripped 0.002 inch diameter (0.0508 mm) AWG 44 wire were immersed for various lengths of time in solder baths controlled at 100°F above the melting point of the solders used. This is the lowest temperature recommended for good wetting action; the low temperatures were used to minimize the dissolution rate of the copper. It should be noted that the relative merits of the solders evaluated would differ radically at elevated temperatures.

Bath temperatures were monitored using a Technique Associates Pyrometer Model 9B. Each sample of wire was coated with Kester 1015 flux before immersion. The samples were encapsulated, cross-sectioned, and microphotographed for measurement purposes. The results are plotted in Figure 3.

Savbit Alloy 1 proved superior. It was used in the fabrication of the evaluated assemblies and was found to compare favorably with typical tin-lead solder in ease of application. A laboratory analysis of Savbit Alloy 1 showed that it contains 50.2 percent tin, 47.9 percent lead, and 1.9 percent copper. The copper content is recognized as the major reason for the superior dissolution characteristics. It serves to lower the effective diffusion rate of copper at the joint interface (Appendix).

Wire Breakage and Insulation Abrasion

Core assembly specifications provide that the smallest apertures (0.020 inch diameter (0.508 mm)) contain 18 AWG 44 and 26 AWG 48 wire turns. As individual wires bend around the aperture there is a tendency for two things to happen: the wire may scrape the edge of the ferrite core and break or short to another turn, and it will tend to extend into and fill the center rather than follow the rectangular cross section of the core material. The filling aperture will then become difficult to thread wire through. The second tendency is difficult to control because it is a function of the low tension (21 and 8 grams) permissible with the small wire.

Both problems can be minimized with appropriate processing of the core edges. When the core edges are radiused and coated to prevent scraping of the insulation, the insulation may be used in a single thickness to take advantage of an approximately 10 percent decrease in wire diameter. Radiusing the core edges is also preferable to attempting to add additional insulation.

Several groups of 5 to 10 cores each were processed differently to determine the best method of removing sharp edges from the cores. The best results came with the use of a barrel-finishing centrifuge known as a Harperizer (Model 2VM-13). The Harperizer

Figure 3. Results of Solder Dissolution Tests

was preferable because its dual rotation capability removes material quickly. The drum containing the parts spins on its own axis and that axis revolves around a second axis outside the drum. A radial acceleration of 15 gs is sustained without immobilizing the parts on the drum surface.

The best results were obtained by Harperizing the ferrite cores for 15 minutes using a Number 24 fused aluminum oxide. The aluminum oxide was screened to eliminate particles that could lodge in the small apertures and it was mixed with water and a 120 grit (0.005 inch) (0.127 mm) abrasive compound. Using larger oxide particles resulted in a disproportionate amount of wear on the outer edges of the cores. Smaller particles lengthened the process time. Particles either slightly larger or slightly smaller than the smallest aperture appeared to function best.

Unprocessed and Harperized cores were encapsulated, cross-sectioned, and microphotographed for comparison purposes. Figure 4 illustrates the change observed in the use of the recommended process.

One concern which arose was the potential loss of core material as a result of the process and the accompanying loss of magnetic capability. A sample of 10 cores was processed for double the recommended 15 minutes and magnetic performance was monitored before and after Harperizing. Peak secondary voltage for the

UNPROCESSED CORE, MINOR APERTURE (50X)

PROCESSED CORE, MINOR APERTURE (50X)

Figure 4. Processed Versus Unprocessed
Core Cross Sections

same input current was measured. Test results, plotted in Figures 5 and 6, show a significant 10 percent reduction in magnetic capability. It is apparent that the 15 minute Harperizing recommended will result in a decrease of approximately 5 percent of the total magnetic flux capability.

A 0.0012 inch thick (0.0305 mm) coating of Parylene was applied to the cores as additional protection against scraping the wire insulation. Parylene is particularly suitable because it can be applied in a thin film of uniform thickness on an irregular surface. The material is applied as a monomer gas which polymerizes on contact with the core surface. Deposition from the vapor phase monomer is uniform over edges, points, and internal areas. It deposits without any of the stresses that might cause magnetostriction of the ferrite. The thickness of the coating also limits forces applied by the coating over a temperature range. Thicknesses significantly smaller than 0.0012 inch (0.0305 mm) are within the process capability.

Cores that had received the recommended processing (Harperizing and Parylene coating) as well as non-processed cores were wound with wire. Wire breakages occurring during winding were recorded for each core. The results (Table 1) indicate that wire breakage in processed cores is significantly reduced. It may be noted that initial breakage of processed cores reflects a learning curve.

Core Winding

Winding the fine wire was considered a challenge because of the probability of wire breakage and the difficulty of manually threading the many turns through the smaller 0.020 inch diameter (0.508 mm) apertures.

During the study, approximately 26 cores were wound. One person did all the winding and developed an expertise that permitted the completion of approximately two cores per day.

Ease of fabrication dictated that low magnification be used in the core winding operation. A 2X glass with a 4-inch diameter (101.6 mm) lens and peripheral lighting typically available in the assembly area was found adequate.

An inexpensive fixture was constructed (Figure 7) which offered easy hand access around the core, had a provision for taping the wire ends of completed windings out of the way, and offered a degree of flexibility to minimize wire breakage. Horizontal and vertical deflections of 0.10 and 0.0625 inch (2.54 and 1.59 mm) were measured for a force of 8 grams (allowable tension of AWG 48 wire). Actual use of the fixture proved that it provided the access, convenience, and flexibility intended.

Figure 5. Sense Voltage Using Unprocessed Cores

Figure 6. Sense Voltage Using Harperized Cores

Figure 7. Core Winding Fixture

Table 1. Wire Breakage in Processed and Unprocessed Cores

Core Number	Breakages Processed	Unprocessed
13	5	
12	2	
11	2	
14	0	
1	0	
30		3
9	0	
104	0	
100		5
29		3
16	1	
17	1	
81		7
88		3
80	0	
86	0	
10	0	
103	0	
101	0	
102	1	
107	0	
109		5

A winding sequence was determined which best served the needs of the assembly. The 9-turn windings were wound before the two 13-turn windings because the last 13-turn winding uses a continuation of the wire used in the first 13-turn winding. The wire crossover thus bisects the aperture. Applying the 9-turn windings first avoids the difficult operation of threading the wire through a part of the aperture.

Testing was necessary to ensure that the intended number of turns was wound through the C and E apertures prior to subsequent soldering. The number of turns and windings, and the mental concentration required to avoid breakage, were considered sufficient reasons to assume a possibility of an incorrect number of turns on the part of the individual doing the winding. A fixture was constructed with wire clip connections arranged in a circle to make connection more convenient.

Turns-ratio testing was performed with the TE3108, a tester readily available. It consists of an oscillator, a turns-ratio bridge, and a null detector. Ratio testing was performed at 20 kilohertz with the input and winding ratios listed in Figure 8. Typical readings are listed for reference. The results indicate that the available equipment is capable of providing meaningful test results.

Core-Carrier Assembly

Several problems associated with the assembly of the core to the carrier were predictable.

- It was initially recognized that wire placement would be difficult because of the small wire.
- A temporary core attachment would be helpful because the core might have to be removed.
- Solder operations require a temperature control device to assure control of copper dissolution and prevent production of unreliable connections.
- Rework of the first carrier level is unadvisable after the second carrier level is assembled.

Double sided adhesive tape was used to control wire placement (Figure 1). This proved effective and allowed the operator to position one or more wires precisely on a pin and solder them. The tape also held soldered wires on the upper carrier while upper carrier wires were being soldered. Actual assembly work involving 24 cores produced 1 broken wire.

Tape was also used for initial attachment of the core to the carrier to provide for easy removal if an electrical defect or broken wire should require it. Pin-to-pin winding continuity was checked and results indicated correct connections. One assembly level malfunctioned when tested in conjunction with next-assembly circuitry. The failed level was a first carrier level which makes inspection difficult until the assembly can be destructively tested after useful next-assembly tests have been performed. On the positive side, 11 of 12 carriers, or 23 of 24 cores, were wound and connected satisfactorily.

Soldering was done with a low temperature soldering iron to minimize the heat used to flow the Savbit Alloy 1 solder and retard copper dissolution (Appendix). Initial results on the first assembly were poor with considerable difficulty experienced as a result of poor wetting on the brass pins. All the pins were subsequently plated with 0.00025 inch (6.35 μ m) of gold and

Figure 8. TE3108 Ratio Test Results

solder wetting was satisfactory just above the solder melting temperature.

As was noted elsewhere, copper dissolution has been empirically determined to be an exponential function of absolute temperature. A method of controlling temperature and temperature-time is available in the various solder machines. A TTC Solder Controller and Solder Machine with provisions for controlling heat amplitude and duration was used on one assembly. The heating element was

positioned on top of the pins and the maximum time setting (10 seconds) was used with the lowest heat which would flow the solder. The surface on the top of the pin was small for reliable heat transfer. However, the solder machine is the preferable method for making solder connections where, as in this instance, significant dissolution of the copper wire is a possibility and where a suitable heat element interface is available. Pin redesign could provide a reliable contact area.

Core Matching

Use of the miniature core assembly at the next-assembly level depends upon core-to-core matching of the magnetomotive characteristics of core apertures. Apertures C and E (Figure 8) are required by design function to be matched on a core pair basis. An effort was made to find an automated method of matching these apertures to avoid time-consuming and imprecise visual matching of individual waveforms.

The requirement that the cores have matched magnetomotive characteristics can be restated in this application as a requirement that flux linkage in the apertures be matched for similar levels of drive current. A measurement of, and therefore a comparison of, flux linkage is available in terms of an output voltage comparison over a time interval ($v = Nd\phi/dt$) if equivalent inputs are used.

This fact is illustrated in Figure 9 where equal amplitude voltages are not equivalent representations of the same input current because they relate to different current drive levels. Stated another way, aperture matching may be accomplished through a comparison of output voltage amplitudes using similar input currents and a time base relationship identifying times for comparison when similar amplitudes were applied in each aperture.

In the case where the output is to be digitized, input current levels can be used to trigger digital amplitude measurement devices for comparison measurements. The validity of such discrete comparisons was explored using photographs with the time base relationship identified.

A test setup (Figure 10) was used to obtain B-H and sense voltage waveforms, where B relates to the flux level developed in the core for an input magnetizing force of H ampere turns. Similar current levels are identified in the B-H and sense voltages displayed in Figure 11 through the use of intensity modulation of the oscilloscope wave forms.

Times T1, T2, T3, and T4 (Figure 11) identify points of interest. T1 relates to the input current level or time where aperture flux is increasing at a non-linear rate. T2 and T3 identify the

Figure 9. Equivalent Voltage Amplitude for Different B-H Characteristics

GR1308 SET ON
10 kHz 70 V RMS

H-P 214A SETTINGS:
20 V PULSE AMP
NEG PULSE OUTPUT
EXT TRIG MODE
PULSE POSITION 0-1
PULSE WIDTH 0.05 μ s

555 OSCILLOSCOPE *USED AS AMPLIFIERS
UPPER BEAM 2 V/cm
LOWER BEAM ("0" PLUG-IN)
 $Z_i = 1 \text{ M}\Omega$
 $Z_f = 0.0001 \text{ }\mu\text{F}$
TIME BASE: A-1.0 μs ; B-10.0 μs

Figure 10. Test Circuit for Measuring Different Portions of B-H Loops

SENSE VOLTAGE: $1 \mu\text{s/cm}$ HORIZONTALLY
 0.02 V/cm VERTICALLY

Figure 11. B-H and Sense Voltage
 Waveforms for Core 10
 Aperture

period of almost constant rate of increase in magnetic flux. T4 identifies the current level or time when the flux rate increase is tapering off.

It was theorized that a comparison of voltages at T1, T2, T3, and T4 would provide a satisfactory method of comparing aperture characteristics for the purpose of matching cores.

Similar measurements were made on nine other cores and digital readings were extracted from the waveforms (Figure 12). This information was used in a computer comparison program set up to identify matched cores. The program summed the square of the differences and computed a matrix of values. It then identified the nearest fit, next nearest fit, and so on. The matrix and printout of fit are shown in Figure 13 and Table 2.

The validity of the results was checked by direct aperture comparison. A common input was threaded through the matched apertures and the output of the series-connected sense windings was photographed for the bucking mode of connection (that is, a zero output represents a perfect match). These difference outputs, shown in Figures 14 and 15, verify that mismatch does increase in the sequence of selection. The results indicate that the technique does provide for matching.

CORE 9

CORE 29

CORE 66

Figure 12. B-H and Sense Voltage Waveforms
for Cores 9, 29, 66, 100, 103,
104, 105, 106, and 108

CORE 100

CORE 103

CORE 104

Figure 12 Continued. B-H and Sense Voltage Waveforms for Cores 9, 29, 66, 100, 103, 104, 105, 106, and 108

CORE 105

CORE 106

CORE 108

Figure 12 Continued. B-H and Sense Voltage Waveforms for Cores 9, 29, 66, 100, 103, 104, 105, 106, and 108

SERIAL NUMBER	100	108	10	9	103	106	105	104	29	66
100	0.000	0.308	0.130	0.255	0.345	0.322	0.125	0.428	0.015	0.095
108	0.308	0.000	0.732	0.218	0.187	1.035	0.432	0.435	0.332	0.092
10	0.130	0.732	0.000	0.365	0.605	0.397	0.355	0.512	0.125	0.355
9	0.255	0.218	0.365	0.000	0.270	1.092	0.595	0.142	0.275	0.165
103	0.345	0.187	0.605	0.270	0.000	0.913	0.415	0.532	0.305	0.165
106	0.322	1.035	0.397	1.092	0.913	0.000	0.142	1.445	0.272	0.572
105	0.125	0.432	0.355	0.595	0.415	0.142	0.000	0.962	0.085	0.170
104	0.428	0.435	0.512	0.142	0.532	1.445	0.962	0.000	0.527	0.452
29	0.015	0.332	0.125	0.275	0.305	0.272	0.085	0.527	0.000	0.085
66	0.095	0.092	0.355	0.165	0.165	0.572	0.170	0.452	0.085	0.000

Figure 13. Core Match Matrix of Difference Results

Should this core assembly become a production item, it is suggested that a limit be imposed on point-to-point mismatches and that cores failing to match within a given number of comparisons be scrapped for incompatibility.

ACCOMPLISHMENTS

The use of a copper-loaded solder such as Savbit Alloy 1 and a method of controlling the solder temperature and time were found to eliminate the copper dissolution problem associated with soldering extremely fine wire.

Wire breakage and insulation abrasion were both reduced through the elimination of the sharp edges of the cores. A combination of Harperizing (tumble deburring) and coating with Parylene was found to be an effective method of eliminating the sharp edges.

A fixture was developed which permits a degree of flexibility to minimize wire breakage and provides easy hand access to the core during winding, and also has a provision for taping the wire ends of completed windings out of the way.

Winding efficiency was found to be improved by winding the two 9-turn windings first and then winding the two 13-turn windings. This winding pattern eliminates the necessity of threading the

Table 2. Matched Core
Apertures

Serial Numbers	Difference Result
100 and 29	0.015
108 and 66	0.092
106 and 105	0.142
9 and 104	0.142
10 and 103	0.605

wire through half the aperture. Ratio testing using the existing TE3108 was determined to be adequate to check the number of turns in an aperture winding.

Double sided adhesive tape was found to be excellent for positioning wires on the carrier prior to soldering and also for temporarily attaching the cores to the carrier. Operator assembly time and wire breakage were both reduced as a result of using the tape.

The tedious job of magnetically matching cores was speeded up by providing for digital data and the identification of matched cores through the use of a computerized program.

FUTURE WORK

No future work is planned on this project at this time. However, some future development work will be required if the core assembly is made a production item.

CORES 29 AND 100

CORES 105 AND 106

SENSE VOLTAGE: $1 \mu\text{s}/\text{cm}$ HORIZONTALLY
 $0.02 \text{ V}/\text{cm}$ VERTICALLY

Figure 14. Sense Voltage Difference for
 Cores 29 and 100 and 105 and
 106

CORES 9 AND 104

CORES 10 AND 103

SENSE VOLTAGE $1 \mu\text{s}/\text{cm}$ HORIZONTALLY
 $0.02 \text{ V}/\text{cm}$ VERTICALLY

Figure 15. Sense Voltage Difference for
 Cores 9 and 104 and 10 and 13

Appendix

LITERATURE SEARCH ON COPPER/METAL DISSOLUTION

A review of the literature on copper/metal dissolution pointed up the fact that it is a complex subject. Articles dealing with the subject date back to 1897 when A. A. Noyes and W. R. Whitney (*F. Physical Chemistry*, 23, 689) speculated that it was the result of atomic diffusion from the solute interface.

Subsequent work by Berthond (*J. Chem Phys.* 10, 633, 1912) points up that the dissolution rate is influenced by several factors, with material movement among them. In a solder-to application such as this one, the solder is considered to penetrate the copper on an atomic scale, alloying and then forming intermetallic compounds Cu_3Sn and Cu_6Sn_5 (Howard H. Manko, *Solders and Soldering*, New York: McGraw Hill, 1964). Copper and these intermetallics diffuse in the direction of lower concentration and are considered to continue to disperse at a rate that depends on both transport and diffusion processes.

In the wire-to-pin soldering of interest in this application, the diffusion process is considered predominate in the dissolution of the copper. If convection or other means of physical displacement are significant the rate of dissolution can increase appreciably. In fact, reaction rate was shown to increase by a factor of four in R. E. Beal's evaluations ("Solder Joints in Printed Circuits," *Circuits Manufacturing*, November 1969, p 26). This points up that a big variance could be experienced in the quality of connections if a large safety margin is not provided.

Another factor significantly affecting rate is the difference in concentration of copper across the reaction interface. This is evident in the following mathematical representation of dissolution by Berthond where $C_{\text{sat}} - C_{\infty}$ is a multiplication factor.

$$j = \frac{K}{1 + (KA/D)} (C_{\text{sat}} - C_{\infty})$$

where

K is the surface reaction constant,

D is the diffusion coefficient,

A is $\frac{(C_{\text{sat}} - C_{\infty})}{VC_{\text{sat}}}$

V is volume,

C is the bulk concentration of copper and copper compounds, and C_{sat} is the saturation concentration of copper and copper compounds.

Dissolution rates were empirically found by Bader ("Dissolution of Au, Ag, Pt, Cu, and Ni in Molten Tin-Lead Solder," *Welding Journal*, December 1969) to also vary exponentially with temperature. His results fit the equation

$$r = Ae^{-BT}$$

where

r is the rate of dissolution

A is an empirical constant,

B is an empirical constant, and

T is the absolute temperature in evaluation where sections of 0.030 inch diameter wire were immersed in a solder bath.

Bader concluded that wire diameter decreased radially in a linear manner with time for a given temperature. The results were noted to conflict near the X-Y intercept where wire diameter in the range of particular interest to this project is involved. Beal made the observation that material dissolved at a rate proportional to the square root of time in evaluations involving 0.001 and 0.002 inch thick brass. It appears probable that the rate of dimensional change may be a function of material configuration and size.

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