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A METHOD FOR ENCAPSULATING HIGH VOLTAGE POWER TRANSFORMERS

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SUMMARY

Voltage breakdowns become a major concern in reducing the size of High-Voltage power converter transformers. Even the smallest of voids can provide a path for corona discharge which can cause a dielectric breakdown leading to a transformer failure. A method of encapsulating small high voltage transformers has been developed. The method virtually eliminates voids in the impregnation material, provides an exceptional dielectric between windings and provides a mechanically rugged package. The encapsulation material is a CTBN modified mica filled epoxy. The method requires heat/vacuum to impregnate the coil and heat/pressure to cure the encapsulant.

The transformer package utilizes a Diallyl Phthalate (DAP) contact assembly in which a coated core/coil assembly is mounted and soldered. This assembly is then loaded into an RTV mold and the encapsulation process begins.

PURPOSE

The purpose for writing and presenting this paper is to document a proven process that has evolved over the past 5 years, and to present to the industry a method which reduces stresses on the core, eliminates cracking of the epoxy and provides the insulation necessary for small high voltage transformers.

Sandia National Laboratories, Albuquerque NM, Allied Signal Inc., Kansas City Division, and General Electric Neutron Devices, Largo Florida, have all participated in the development of the process and have approved the method for production. General Electric is in production on a family of these small high voltage transformers, having successfully manufactured over 1000 units using this approved method.

TRANSFORMER APPLICATION

The transformer is used in a flyback converter to charge a 2.0μ F capacitor to 3.3 k V from a nominal 28 V source. See schematic figure 1.

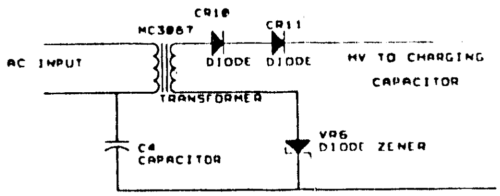


figure 1.

TRANSFORMER DESIGN

For the stated application, the design is as follows:

- POT CORE - MAG. INC. PART NUMBER G42616-25
- BOBBIN - SINGLE SECTION DELRIN

- PRIMARY - 24 TURNS OF 28 AWG HEAVY POLYESTER INSULATED COPPER WIRE
- INTER WINDING INSULATION - 3 TURNS OF 1 MIL. KRAFT PAPER
- SECONDARY - 765 TURNS OF 38 AWG HEAVY POLYESTER INSULATED COPPER WIRE
- LAYER INSULATION - 4 TURNS OF 1 MIL. KRAFT PAPER
- INSULATION OVER SECONDARY- 5 TURNS OF 1 MIL. KRAFT PAPER
- HIGH VOLTAGE LEAD - 25 AWG STRANDED TINED COPPER, TEFLON INSULATION WITH POLYOLEFIN SHRINK SLEEVING

ASSEMBLY PROCEDURE

1. WIND TRANSFORMER
2. PLACE COIL ASSEMBLY INTO CORE AND BOND CORE HALVES TOGETHER USING EPOXY ADHESIVE ON THE OUTER PERIMETER OF THE CORE SEAM
3. BOND CORE/COIL ASSEMBLY ONTO DAP CONTACT ASSEMBLY AND FILL CENTER HOLE OF CORE USING FILLED POLYSULFIDE
4. CURE
5. LOAD TRANSFORMER ASSEMBLY INTO RTV MOLD
6. ENCAPSULATE
7. CURE
8. DEMOLD AND REMOVE SPRUE
9. TEMPERATURE CYCLE
10. INSPECT, VISUAL 10X
11. TEST
12. INSPECT, VISUAL 10X

ENCAPSULATION PROCEDURE

A. MOLD PREPARATION

Clean molds using alcohol or acetone to remove any contamination and load transformer assembly into mold. Place molds in a vacuum oven at a temperature of 110°C with a maximum pressure of 25 mm Hg absolute for 2 to 4 hours.
Break vacuum with nitrogen and reduce temperature to 70°C. The units shall be stabilized at this temperature either under a nitrogen atmosphere or in a vacuum oven at a maximum pressure of 25 mm Hg absolute after which the vacuum shall be broken with nitrogen.

B. ENCAPSULANT FORMULATION

DESCRIPTION	PARTS BY WEIGHT
EPOXY RESIN EPON 828 SHELL CORP.	60
FILLER DRIED, GROUND, MICA, 4X	40
CURING AGENT Z SHELL CORP.	12
WHITE COLOR PASTE FOR EPOXY RESINS	3.6

WARNING:
Adequate ventilation must be provided during the handling of the resins and hardeners to prevent excessive exposure

to their vapors. Accidental ingestion or skin contact should be avoided. If skin contact does occur, immediately wash with soap and water.

C. MIXING PROCEDURE

Preheat epoxy resin to 66°C minimum prior to mixing. The mica filler must be dried prior to mixing. An acceptable method for drying the mica is, pour mica onto a shallow pan (not over two inches deep) and place pan in a convection oven for 4 hours minimum at a temperature of 107°C.

Combine the epoxy resin, filler and color paste in a container whose diameter is approximately equal to its height and whose volume is at least four times the volume of the mixed compound. Heat the combined mixture to 80°C and add the curing agent which shall be at room temperature. Mix until material is uniform throughout. The temperature of the mixed material shall be at 65°C minimum when the units are poured. Immediately after mixing, evacuate at a pressure of 0.5 to 3.0 mm Hg absolute for a minimum of 1 minute after the initial foam rise collapses.

The preloaded, preheated molds shall be placed in a 71°C preheated vacuum oven and then evacuated to a pressure of 0.5 to 3.0 mm Hg absolute. Maintain this reduced pressure for at least 2 minutes to degas the components. The temperature of the vacuum oven may vary +/- 15°C during the vacuum and encapsulating process. After degassing is completed, and while under this reduced pressure, the warm, deaerated resin shall be introduced into the mold. During the filling operation, the absolute pressure shall be no greater than 15 mm Hg. After the mold has been filled, the reduced pressure of 0.5 to 3.0 mm Hg shall be maintained for at least 3 minutes after foam collapses. Allow pressure to return to atmospheric. The maximum allowable time between addition of curing agent and completion of evacuation is 25 minutes.

D. ENCAPSULANT CURE

Cure for 2 hours minimum at 79°C in a pressure chamber under a minimum positive nitrogen pressure of 30 psi with no circulation, followed by 16 hours minimum at 93°C in a circulating air oven.

POST ENCAPSULATION

Demold and remove sprue. Temperature cycle units in a circulating air oven 5 times from room temperature to -55°C to 125°C back to room, 4 hours per cycle (1 hour hold at temperature, 1 hour transition time). This procedure is performed to stabilize internal stresses at the use temperature.

TEST REQUIREMENTS

A. ENVIRONMENTAL

MECHANICAL SHOCK - SHOCK AMPLITUDE 3500G, 2.0 m SEC. DURATION, 3 MUTUALLY PERPENDICULAR AXES, 3 SHOCKS IN EACH DIRECTION FOR A TOTAL OF 18 SHOCKS.

SINSUODIAL VIBRATION - FREQUENCY RANGE(HZ) 10-2000-10, TRAVERSE TIME 0.5 oct/MIN, DISPLACEMENT 0.2 INCH, TEST TIME 1 CYCLE

RANDOM VIBRATION - 3 MUTUALLY PERPENDICULAR AXES, 20 MIN PER AXIS, COMPLEX POWER SPECTRAL DENSITY FROM 5 HZ TO 2000 HZ AT G LEVEL'S OF .001 G^2/HZ TO .4G^2/HZ

STEADY STATE ACCELERATION - 3 MUTUALLY PERPENDICULAR AXES FORCE 100g, DURATION 10 SECONDS

TEMPERATURE SHOCK - 3 CYCLES, -55°C TO 100°C, EACH CYCLE 1/2 SINE FOR 60 MIN. WITH A 5 MIN. MAX. TRAVERSE TIME

B. ELECTRICAL

Electrical tests consist of DC Resistance, Secondary Inductance, Capacitance, Turns Ratio, Polarity, Insulation Resistance and Induced Voltage (Corona Test). Induced voltage testing consists of applying a sinusoidal voltage of 106 VRMS across the primary winding at a frequency which results in or near minimum current. The amplitude of the applied voltage shall have a rise and fall time of 4 seconds maximum and a steady state holding time of 9 to 12 seconds. There shall no corona in excess of 1.0 volt peak, on the output of the secondary.

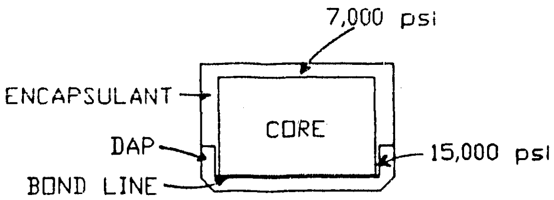
PRELIMINARY RESULTS

A group of 158 transformers were encapsulated using the stated encapsulation procedure. Visual inspection on units removed from the molds showed no irregularities. The units were then machined to the proper height and temperature cycled. Visual inspection at this point found 6 units with cracks on the top surface and 67 units with various magnitudes of separation between the DAP contact assembly and the epoxy encapsulant. Environmental and Electrical testing proceeded, in that order, with no functional failures noted. Visual inspection at this point showed some cracks and the epoxy/DAP separations had grown in size. An additional 7 units with separations were found.

STRESS ANALYSIS
see figure 2.

Stress analysis of the encapsulated package are as follows:

1. Failure stress of encapsulant = 7000 psi
2. Stresses on top surface of core in encapsulant are > 7000 psi
3. Stresses between core and DAP near pins = 15,000 psi
4. Failure stress of DAP near epoxy DAP Bond = 3000 psi



STRESS IN MICA FILLED EPOXY @ -55°C

figure 2.

Generally the failures (cracks and separations) can be linked to one overriding condition, there is a large difference in coefficient of thermal expansion (CTE) between the ferrite core and the mica-filled epoxy encapsulant. From the stress analysis it is evident that the mismatch in CTE is the primary contributor to failures during thermal cycling.

PROCESS AND MATERIALS MODIFICATIONS

Sandia Materials Specialist recommended a rubber toughened epoxy formulation be used to minimize cracking. The Epon 828 was modified with carboxyl terminated butadiene nitril (CTBN) which is a rubber modifier.[1]

Several methods to mechanically decouple the ferrite core from the epoxy encapsulant have been examined. The only successful method uses a syntactic polysulfide with a 3.3% fill of phenolic microballoons, as a means of mechanically decoupling the core from the encapsulant.

The DAP contact assembly which has a failure stress, near the bond line, of 3,000 psi has also been examined and modified to improve its bondability. Improvements to the DAP contact assembly are: 1. The bond surface is now a textured surface which provides more surface to bond to. 2. Specifications were revised calling out a specific suppliers formulation which limits the mold release agent. 3. Bake out assembly at 150°C for 24 hours and plasma clean prior to assembly.

MODIFIED PROCEDURE

A group of 150 transformers were manufactured using the following modified procedures:

1. WIND TRANSFORMER
2. ATTACH HV LEAD
3. ASSEMBLE COIL IN CORE AND BOND CORE HALVES
4. CURE
5. COAT CORE - TOP, BOTTOM AND SIDES USING SYNTACTIC POLYSULFIDE WITH A 3.3% FILL OF PHENOLIC MICROBALLOONS (APPROX. 10 MIL COATING)
6. BOND CORE TO DAP CONTACT ASSEMBLY USING POLYSULFIDE AND FILL CENTER HOLE OF CORE WITH POLYSULFIDE
7. CURE
8. SOLDER
9. ASSEMBLE TRANSFORMER INTO RTV MOLD
10. PREHEAT
11. ENCAPSULATE (SAME PROCEDURE AS BEFORE)
12. CURE
13. DEMOLD AND REMOVE SPRUE
14. TEMPERATURE CYCLE
15. INSPECT, VISUAL, 10X
16. TEST
17. INSPECT, VISUAL, 10X

The same encapsulation material was used with the exception of the Epon 828, which was replaced with CTBN modified Epon 828. Same Encapsulant formulation as before.

FINAL RESULTS

Of the 150 transformers started, 2 units failed electrical inductance test. No units exhibited any type of visual defect. Units were subjected to an additional 150 temperature cycles -55°C to + 90°C with no additional failures of any type. Stress analysis of the modified package show stresses in the encapsulant are significantly reduced. The highest stress point is off the corners of the core where it is difficult to coat with filled polysulfide. Stresses at the corners are approximately 2,600 psi at -55°C. Rubber modifier to EPON 828 encapsulant increased its failure stress to approximately 10,000 psi. Changes to the DAP contact assembly slightly improved its bond strength. Experimentation is continuing in this area. Twenty units have been cross sectioned revealing exceptional impregnation.

FUTURE ACTIVITY

A method of encapsulation which eliminates the DAP contact assembly is being evaluated. This method uses a hard mold and by use of a locating pin through the hole of the core, the transformer assembly is centered in the mold cavity. The same core preparation and encapsulation formulation as above is used. Preliminary results, on a group of 14 transformers, demonstrate exceptional impregnation, no surface defects and are electrically identical.

CONCLUSION

This modified method for encapsulating high voltage transformers has been developed and placed in production. Currently greater than 1,000 units have been manufactured using the new method with no rejects due to cracks or separations. The biggest improvement is in the addition of a stress relief medium between the core and encapsulant.

ACKNOWLEDGEMENTS

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[1] Sayre, J. A.; Assink, R.A.; Lagasse, R. R. Polymer Journal, 1981, 22, 87.

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