COMPONENT PERFORMANCE ADVANTAGES REALIZED THROUGH THERMOPLASTIC ENCAPSULATION

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Abstract: **Thermoplastic encapsulation of electrical and electromechanical devices continues to yield improvements in cost, performance, and environmental sealing. The use of an injection molding process enables traditional advantages of part consolidation and cost reduction via integration of mounting components, termination features, and total cycle times of 20 to 60 seconds. With the use of recently introduced thermally conductive thermoplastics, advances are being realized in thermal dissipation, particulate emissions, the reduction of both structural and audible vibration, and electrical circuit encapsulation. This paper will review these developments.**

Key words: Thermal, noise, vibration, particulate, cost reduction, motor, eccentricity, component integration

I. INTRODUCTION

Engineering plastics have over time continued to replace metals and other materials in the electrical industry. The inherent design flexibility of the materials allows greater part integration and lower system costs in manufacturing operations. The injection molding process brings advantages in costs, quality, and performance, particularly for high volume manufacturing.

Recent advances in materials, design, and processing have increased the focus on system integration in coil wound devices. This has been particularly evident in motor components, where thermal dissipation, tight dimensional control, and reduced costs are all driving factors.

Traditional motor design has focussed on designs which are either open systems (covered only with a thin layer of varnish) or potted with a two part thermoset epoxy system. In these cases the material covering the wires provides primarily an insulating function. The use of thermoplastics is continuing to provide necessary insulation while also allowing three dimensional functionality that provides more robust, compact, and efficient design.

Recent developments have shown that by modification of material properties and characteristics, and by tightly controlling processing conditions, one can significantly effect both the magnitude and variability of critical motor characteristics such as eccentricity, vibration, TIR, and particulate emissions.

Maximum cost and performance benefits are achieved when utilizing the design freedom of thermoplastics to enable new configurations which simplify the total system. Examples of this would be in the use of strip laminations or segmented laminations.

In this paper, recent work will be reviewed which demonstrates the design, material, and processing considerations for effective application of thermoplastic encapsulation techniques to a variety of motor components.

II. DISCUSSION

A. Alternative Construction Techniques

When utilizing thermoplastic encapsulation, full advantage should be taken of the capabilities of the process. Unlike a potting process, thermoplastic can take the place of structural parts of the motor. Both connection and mounting features can generally be molded into the part, eliminating extra components and their associated costs, stack up tolerances, and potential failure sites. Mounting bearings directly off of an encapsulated stator allows significant reductions in the allowable air gap, due to stack up tolerance reduction.

The following concept demonstrates how encapsulation can be utilized for significant manufacturing and performance improvements. Market demand continues to increase for motors with high power density. In stators with high slot fill and small tooth openings, challenges exist with winding speed, yield rates, and ability to maximize slot fill. Strip laminations can be used to advantage.

Winding speed and yield rates are improved by being able to utilize a strip lamination, as seen in Figure 1. Instead of using a difficult and slow needle winding operation, parts can now be wound on a flat strip with a conventional fly winder with multiple spools. The strip is then roll formed as shown in Figure 2, into the geometry shown in Figure 3.

At this point the strip is placed into an injection mold for the encapsulation process. It is critical that the ends of the strip are closed and kept together in a precise and repeatable manner. Side actions on the injection mold are utilized to press the ends together, and plastic is then injection molded around the entire assembly to lock the laminations together and produce a unitized stator. The stator geometry and dimensions must be maintained over time and over a range of temperatures. Ceramic reinforced thermoplastics are now available with CLTE (Coefficient of Linear Thermal Expansion) values approaching that of steel, insuring that the position of the rolled strip, and specifically the strip ends, is maintained. Again, terminations (pins, flying leads, or flex circuit) are molded in during the encapsulation process.

Additional advantages to this method include:

- Reduction in lamination scrap
- Improvement in magnetics due to uniform grain orientation

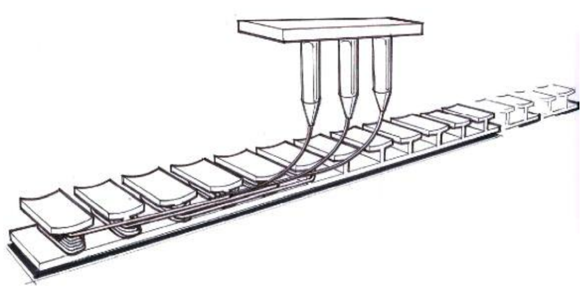

Figure 1. Fly winding of strip lamination

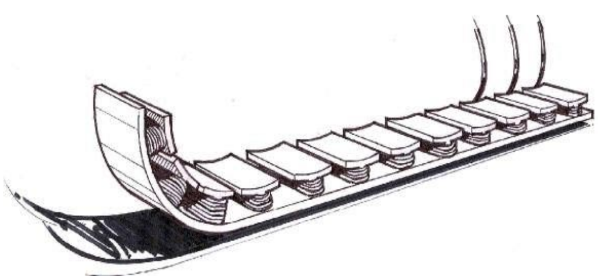

Figure 2. Roll forming of strip lamination

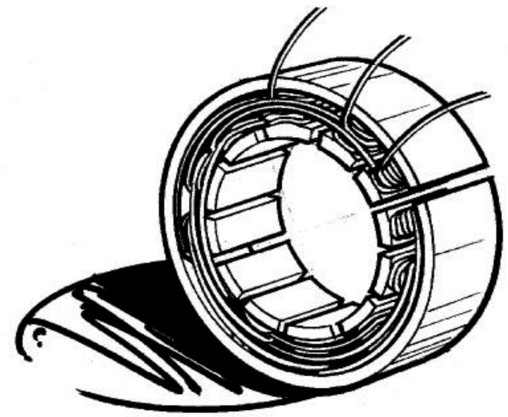

Figure 3. Strip lam prior to encapsulation

Another approach to maximize motor performance is the use of segmented stators. Again, thermoplastic enapsulation can be utilized to bring significant manufacturing and performance advantages to this type of motor. As with strip lams, this approach allows very high slot fill, beyond that achievable with conventional stators and winding techniques. Segments can be individual or may contain multiple slots; the example shown in Figure 4 is a twelve slot motor, with two interior slots and two slots fromed by the mating arc segments.

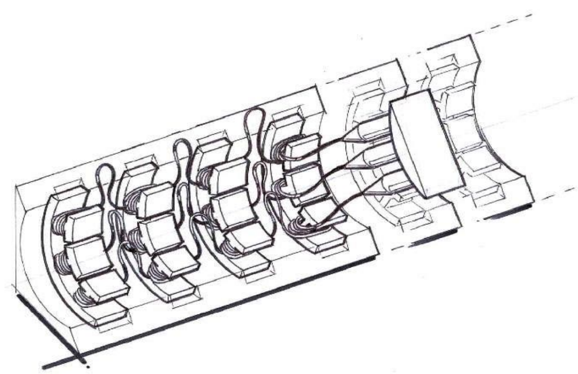

Figure 4. Stator segment during winding

In this example, the arc segments are positioned in a fixture for winding. Again, fly winding is used so that multiple poles can be wound simultaneously. Sufficient wire is left between arc segments, such that the segments can be removed from the winding fixture and oriented into the final geometry, as shown in Figure 5.

These segments are then placed into an injection mold for encapsulation. Either the mold geometry or side actions are used to align the segments in their final position. Thermoplastic is injected into the mold, locking the segments together and simultaneously forming mounting and connection features. A low CLTE material insures that steel positioning is maintained over a range of time and temperatures.

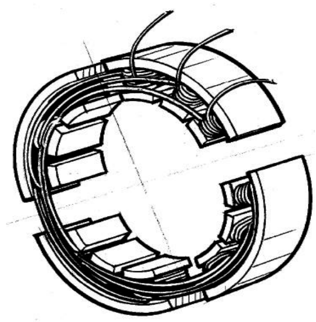

Figure 5. Alignment of stator segments

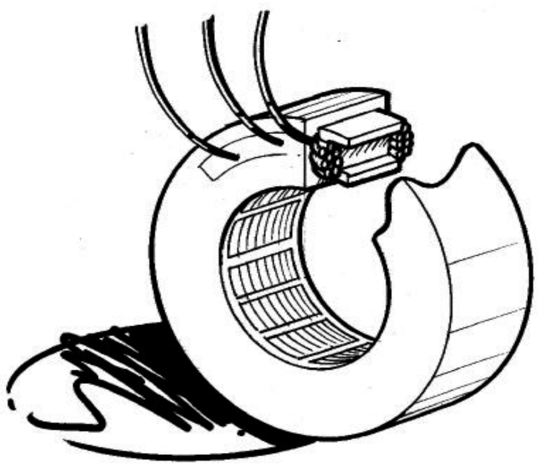

Figure 6. Encapsulated segmented stator

B. Vibration Reduction

Initial work in this area was done with the high volume, high speed spindle motors found in computer hard drives. The stators are traditionally open systems which are attached to an aluminum baseplate and spin at speeds in excess of 10,000 rpm. Industry sources often state that data can be put on a hard drive four times more densely than it can be read. Vibration reduction is thus an area of intense focus, as this reduction can lead directly to increases in data capacity. Improvements in dampening and eccentricity lead to reduce vibration; work in these two areas is covered under sections C and D of the Discussion section. This knowledge can be translated into industrial motor applications.

C. Noise Reduction

The acoustic characteristics of a specific motor system can be significantly affected by encapsulating the stator. Encapsulation alters the structure of the system, and an understanding of how to work with and control encapsulant geometry and material properties is critical to designing a system with the desired acoustic performance.

Experimentation has shown that the use of injection molding to encapsulate the stator provides significant advantages in attenuation of noise and of the frequencies of concern. Thermoplastic resins using various base resins and filler levels have been evaluated to provide dampening of specific harmonic ranges.

Figure 7 shows the effect of different materials when used to encapsulate a stator for a specific high speed spindle motor. The control illustrates the case of an unencapsulated stator, and is seen in the dotted line in the middle of the chart. As predicted, the noise generated varies with frequency and encapsulant material.

Softer materials such as the two elastomeric materials are seen to be very effective at dampening vibration. These materials exhibit flexural modulus values at room temperature of 10,000 to 90,000 psi. The data does show a higher cumulative noise magnitude, however, due to resonance with the base plate at lower frequencies.

The cumulative noise level, across the entire frequency range, is lowest with stiff materials such as LCP and long glass fiber reinforced materials, as shown. It is seen that these materials reduce the reaction to driving of the baseplate, avoiding the resonance issues seen in this example with the softer materials.

The demonstrated ability to influence system noise and vibration opens up a new capability to modify the thermoplastic encapsulating materials in order to account for the harmonics of a specific motor. As suggested in Figure 7, below, it is important to carefully match both the design of the system geometry and the critical material characteristics in order to maximize dampening and avoid harmonic reactions. Testing has shown that ceramic filled resins have higher loss factors than other filler systems, such as glass, and that LCP tends to also provide a higher loss factor than other base resins.

Noise reductions also can occur given the reduction in air rush which occurs when the stator is encapsulated in such a way as to provide a smooth bore.

In transformers, noise reduction takes place as the thermoplastic locks the laminations together and helps eliminate the “buzz” often seen as these plates vibrate.

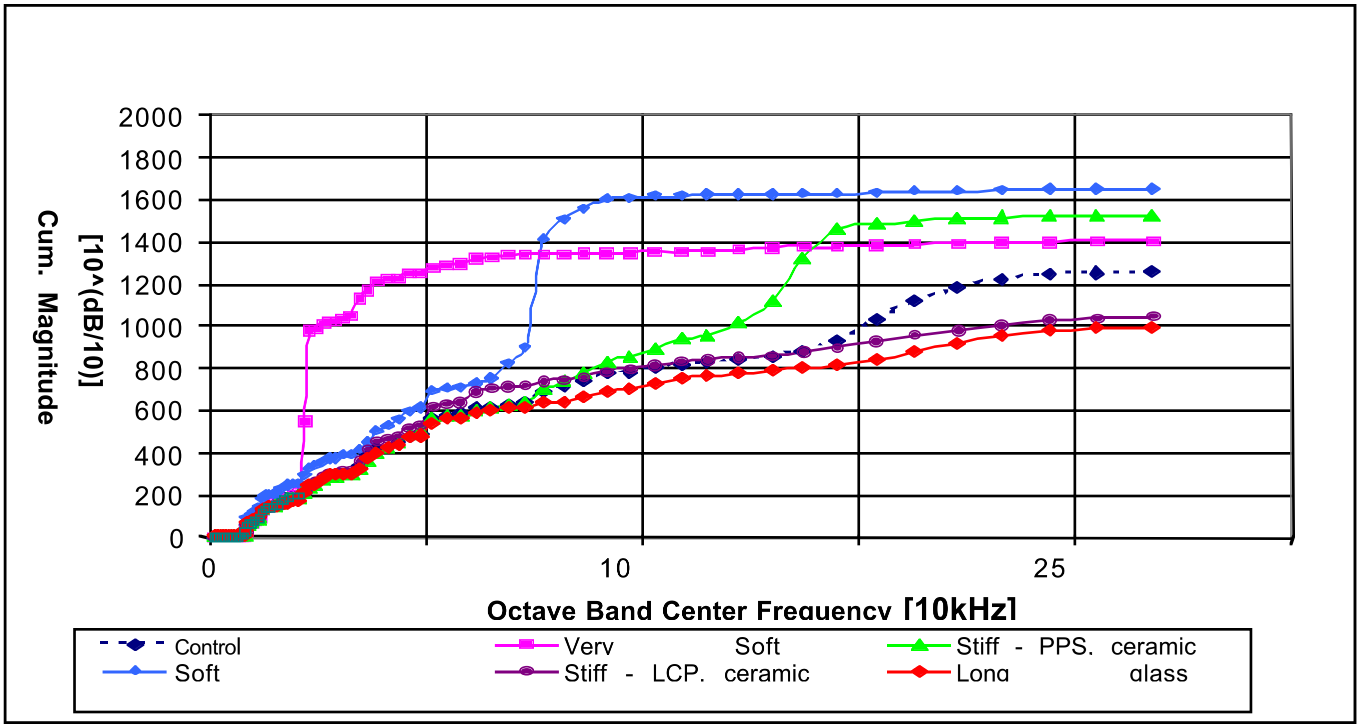

Figure 7. Cumaltive noise magnitude vs. frequency

D. Design Factors Influencing Noise and Vibration

A critical factor in the performance, noise, and vibration of small, high speed motors is control of tilt, eccentricity, and height of the stator. Current methods of manufacture for high speed spindle motors such as found in Hard Disk Drive motors attach the stator to the baseplate using either a press fit or adhesive bond.

In particular, eccentricity of the stator and the tilt of the stator relative to the magnets are significant contributing factors to the high levels of noise and vibration spoken to above. These two factors contribute significantly to the first and second order harmonics of a system.

The height of the stator is critical as it effects the flux and power of the motor. Variations in height will increase or decrease the force upon the bearings, resulting in changes in noise generated and bearing life.

In these HDD motors, the stator poles are located on the outside of the stator. With these components, a unique approach has been developed to reduce stator eccentricity. The stator is encapsulated with thermoplastic via an injection molding process. However, instead of affixing the stator directly to the baseplate or locating the stator off a snug fit on a core pin in the injection molding tool, in this case the stator is allowed to float free when loaded into the mold. As can be appreciated, by eliminating the metal-to-metal interface energy transmission can be manipulated.

In this configuration plastic flows around the inside of the stator, between the stator and a central boss. The isostatic pressure of the molten plastic is used to uniformly position the stator. Recent work has shown that using this manufacturing method instead of a conventional press fit or adhesive bonded configuration, eccentricity can be reduced from 75 microns to approximately 30 microns.

A critical factor in the design is to encapsulate with plastic in such a way as to eliminate all metal-to-metal contact. The plastic serves the purpose of isolating the stator from the rest of the system; even a small area of metal-to-metal contact allows energy to be transmitted between the stator and adjacent baseplate.

E. Processing Effects on Noise and Vibration

In the injection molding process, the injection and packing pressures have a major effect on a number of part variables, particularly stiffness and material shrinkage, which in turn effect the noise and vibration characteristics of the system. The fundamental principle is that a stiffer material shifts the resonant frequencies higher. Subtle changes in the pressure applied to plastic in the mold cavity will effect the stiffness of the material and thus the resonance structure of the device.

When encapsulating motor components in order to reduce noise and vibration, testing has shown that it is critical to achieve extremely tight control of the cavity pressure seen inside the mold cavity. This pressure is traditionally controlled by holding the machine settings to be very repeatable.

A significant challenge with traditional injection molding is that the polymerization process used in chemical manufacture inherently gives a range of molecular weight, even for the most consistent products available. With thermoplastics, material viscosity is related to molecular weight, hence variations in melt viscosity, due to molecular weight, dryness, etc, translate into variability in the amount of pressure applied to the cavity. This pressure variability is magnified due to pressure losses which occur in the runner system prior to the mold cavity.

For control of noise and vibration, our work has shown that it is essential to utilize in-mold pressure sensing, controlling the process using the actual pressure seen by the components being encapsulated. This method adjusts the machine parameters as necessary to maintain a consistent cavity pressure each shot.

F. Thermal Rise Reduction

As motors are reduced in size, thermal rise becomes an increasing concern. Prior commercial applications have shown that significant thermal rise reductions can be achieved even while encapsulating coil wound devices with traditional engineering thermoplastics. The lower thermal conductivity of traditional thermoplastics (0.1 to 0.3 W/m K) is still significantly better than that of air.

These thermally conductive materials can be manufactured with a broad range of base resins. A major recent break through is the development by LNP Engineering Plastics of a set of thermally conductive versions of the elastomeric materials discussed in Section B. This opens up new possibilities in vibration isolation and electronics encapsulation.

III. CONCLUSIONS

Significant performance, manufacturing, and cost advantages are being opened up with the continued implementation of thermoplastic encapsulated systems. New possibilities for component and system design exist due to:

- Ceramic reinforced materials – Opening up new possibilities due to unmatched performance in heat transfer and dimensional consistency
- Innovative design methods that not only integrate components but provide performance improvements specific to the concerns of motor designers.
- Improved understanding of the relationship between thermoplastic material properties and acoustic effects in motor design.
- Improved control of the injection molding process, as seen from the perspective of encapsulated electrical/electronic components

John Hanrahan received his BS in mechanical engineering from Rensselaer Polytechnic Institute (RPI). His professional career includes positions in technical service, design engineering, application development, and marketing with the engineering thermoplastics businesses of GE Plastics, DuPont, and Honeywell (formerly AlliedSignal), both in the US and in Asia. He is President of Encap Technologies, Inc., an engineering consultancy which designs and prototypes thermoplastic encapsulation systems for electro-mechanical devices.

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