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Title: A New Reliability Diagnostic for Aged Insulation Systems Based on Cure Monitoring of "Motorettes" of Catalyzed Mica Tapes Wrapped on Aluminum Bars

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A New Reliability Diagnostic for Aged Insulation Systems Based on Cure Monitoring of "Motorettes" of Catalyzed Mica Tapes Wrapped on Aluminum Bars

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Abstract: **A new method to verify and validate the cure of an impregnate used to bond the magnet wire of a random wound stator or transformer was first introduced in 1998. This technique showed promise in saving manufacturing time by accurately determining the cure – ensuring that large production runs could be run more efficiently thus saving time and energy. This technique has now been used to determine the reaction times of catalyzed tapes used on form-wound bars in the VPI process. This technique was used to determine differences in chemical reaction curing rates between different tapes with varying concentrations of catalyst. These tapes can be used together in the same insulation system. This approach may possibly serve to monitor the aging effects on coils over time by subsequently heating to cure process temperature to determine any changes in the leakage current from the original data. This technique calls for more study as to its potential to better understand the long-term cycle-life of electric motors, transformers, and other power carrying devices. The use today of this new technique on form wound bars and its possible use to better understand the long-term aging issues will be discussed in this paper.**

INTRODUCTION

Random wound stators and transformers are processed in thermosetting resins. The curing time of these resins after application to the stator or transformer are not known because of the mass of the stator lamination stack. Most manufacturers ask their resin suppler for guidance in how to best cure these resins. For 100% solid resins any curing information is necessary otherwise the resin's viscosity will not increase and may flow off the stator or transformer (units). This would be unacceptable so most manufacturers will over process to assure their resin is properly cured. This wastes energy by using it inefficiently and spreads to cost over fewer units and raises the cost of energy per unit.

Solvent thinned resins are usually processed by heating just enough to evolve off the solvent until the resin's viscosity is too high to flow. The customer will cure the resin as the electric motor runs in its application. The reason these manufacturers do not cure their resin may be because the lead wire may bond during this curing process or they are trying to reduce any bubbling of the resin. This is done to keep costs as low as possible but leaves the stator mechanically weak, which means the stator can be susceptible to dielectric failure.

About five years ago the authors of this paper introduced a new method to monitor [(1)] the cure of a resin on random wound stators or transformers in production ovens. This method uses an accurate megohmmeter to measure the leakage current at timed intervals through the curing process. The data shows how the viscosity of the resin changes and eventually stabilizes as 100% cure of the resin is reached. This method has been used to determine the cure cycle time of stators and transformer so their curing time can be adjusted to allow for full cure in the shortest time possible. This method has successfully been used to reduce cycle times where they are warranted. This has resulted in time savings and reducing the energy cost per each unit processed.

All of this was done to determine the cure time of random wound stators and round wire transformers. What about higher voltage form wound coils. We had the opportunity to evaluate catalyzed tapes used in a Vipak® like system. Here the tape is a composite of reinforcement, mica paper and a binder to hold the components together and a catalyst to mix and cure the resin. Some of the data will be discussed in this paper.

EXPERIMENTAL RESULTS

Samples of pre-catalyzed tapes were wound around aluminum bars 2 inches wide by ½ inch thick by 12 inches long. The tape was half lapped around the bar and in the center of the bar on top of the insulating tape; a 2 inch wide aluminum foil electrode was wrapped to complete the capacitive section for the test. A small diameter bare copper wire was used as lead wire to connect the foil electrode to the megohmmeter. The lead wire was wound around the aluminum foil to make electrical contact to the foil electrode and the megohmmeter. Originally the aluminum foil was 8 inches wide but was reduced to 2 inches to keep the megohmmeter on scale. This test bar was covered with resin, placed in an oven set at 60°C+ to lower the resin's viscosity to flow into the layers of tape. This test bar was removed from the resin pan and over wrapped with heat shrink polyester tape and then with a layer of Teflon release tape. Figure 1 shows what the final test assembly looks like in an oven.

Figure 1.

A vacuum can be used in processing these test coils. Once the resin and coil has reached temperature the pan with resin and coil can be transferred to a vacuum chamber for approximately a half hour to remove the air. When the vacuum is broken the resin is pushed through the half lapped layers of tape.

Once the insulating tapes have been impregnated, the coil is removed and drained. The coil is covered with a half lapped layer of polyester heat shrink release film tape and a layer of Teflon tape. Care is taken to assure that the connection wire wrapped around the aluminum foil electrode is allowed to come to the surface to make contact with the megohmmeter. The leakage current is measured and then placed in an oven set to 135°C. Once in the oven the leakage current is measured at timed intervals.

The first tape studied was a mica splittings tape where the catalyst concentration varies widely. The variation in catalyst and its effect on the curing time in this layer could be a problem in a cure cycle if a low concentration of catalyst does not allow proper time for the resin in this layer to properly cure. The resin pooling at particle cross over areas causes the variation in catalyst concentration. The number of pools depends on the size and lengths of the mica splittings. On the other end is the effect of the high concentration of catalyst on the cure time of the resin. The first plot shows the curing of a half lapped layer of mica splittings tape with a high concentration of catalyst.

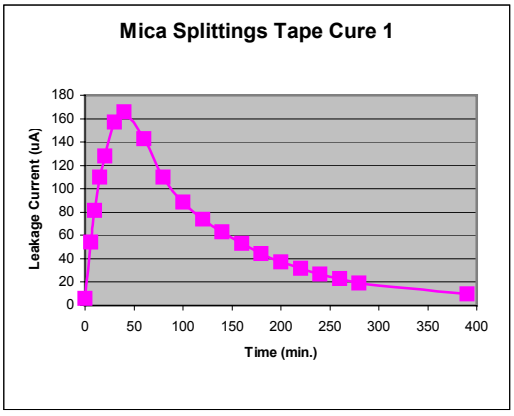

Figure 2.

If two tangents of the slopes showing cure were drawn on the plot, where they cross could be considered onset of cure. In the case of figure 2 the onset of cure is approximately 120 minutes. Figure 3 shows how long the cure can be when the catalyst concentration is low. The onset of cure in this case is approximately 220 minutes. This is a differential of 100 minutes between the two different lots of mica splittings tapes. In some instances, it is possible that the degree of cure could be affected with a wide variation in catalyst content as observed in this data.

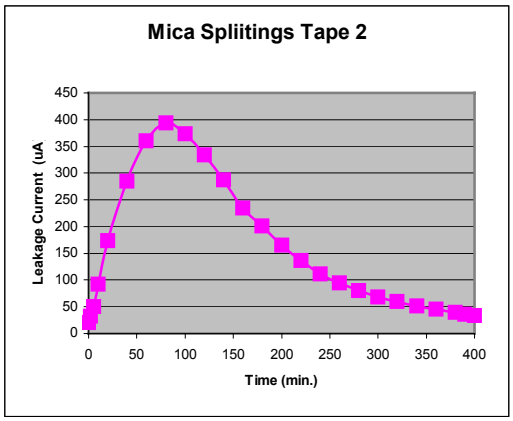

Figure 3.

Since in a long roll of mica splittings tape there will be a wide variation in catalyst content then perhaps the catalyst can be removed from the mica splittings tape and use the catalyst in the tapes above and below the mica splittings tape to cure the resin in the mica splittings tape layers.

A small roll of uncatalyzed mica splittings tape was half lapped over catalyzed tape A. Another layer of tape A was half lapped over the mica splittings tape in a sandwich construction. The coil had a two inch foil electrode and contact wire with the polyester heat shrink film and Teflon release film. Like the previous coils the beginning leakage current was measured and recorded. The taped coil was placed in the oven and the leakage current was measured at timed intervals. Figure 4 shows the curing data.

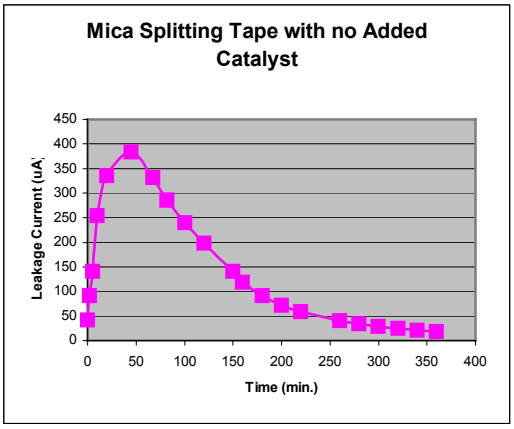

Figure 4.

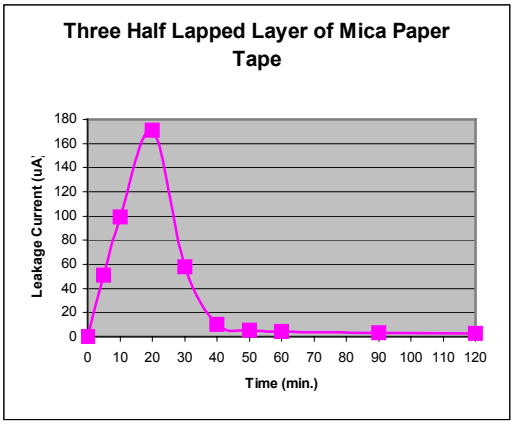

Figure 5.

Figure 4 has an onset of cure of approximately 175 minutes. This cure time is approximately half way between the cure times of the mica splittings tape with high and low catalyst concentration. If the mica splittings tape had its own catalyst added the cure time would be much faster. As you can see this method can be used to evaluate the amount of catalyst used and to adjust the concentration if needed.

To finish the insulation system's cure time study we will determine the cure time of the mica paper tape used. The particulate for mica paper is made by heating mica splittings in a furnace to approximately 550°C to 600°C to shatter the mica splittings into smaller particles. The mica particles are shaken in sieves to control the particle size distribution. This mica is then dispersed in water slurry and made into paper. The porosity depends on the particle size distribution used to manufacture the mica paper. The mica paper is reinforced with a glass or polyester mat or cloth and bound together with a resin to keep the tape together. The binder resin used is usually an epoxy resin and this epoxy resin can be used to hold the catalyst. The other way to apply the catalyst is to disperse it in the tape's matrix. This may allow the catalyst to wash out of the tape during processing.

We half lapped three layers of mica paper tape around the aluminum bar as before and determined the cure time by measuring the leakage current. Figure 5 show the cure time of the mica paper.

The cure time of the catalyzed mica paper tape is much faster than the mica splittings tape, approximately 35 minutes. The developer of this insulation system may have thought that the inner tapes, which would be the mica paper tapes would need to cure faster as the heat penetrated from the outside toward the coil. Since the thermal conductivity of these tapes with resin would be low, it would take time for the heat to rise enough to get the curing reaction of the resin to begin and propagate though the multiple layers of tapes. The large heat sink, the stator stack, will keep the coils below the curing temperature until it rises to the curing temperature. With the slower mica splittings tape it would possibly completely cure until after the mica paper tapes begin curing. This would allow the resin to cure into one very large molecule in each coil. If there is only one molecule of cured resin per coil there would be no interfaces between molecules in a coil and therefore no mechanical weak points. This mechanically weak interface could be susceptible to electrical breakdown and premature failure.

DISCUSSION

This method can be used o properly formulate the insulation system to obtain the best possible final insulation system with highest mechanical integrity. With the best mechanical properties this insulation system will have the best possible dielectric properties, which will exhibit long life. This new test method may have other benefit, which may be more important.

We feel that this method may be a possible diagnostic test method used to determine the integrity or aging characteristics of an insulation system. As the system ages one can test a coil or stator by taking the motor out of service for a short time and heating the stator back to the test temperature, while measuring the leakage current as before. If the leakage current is found to be significantly higher than the previous measurement there must be a reason for this. One would be

contamination from the environment the motor is exposed. The coils could be cleaned and the stator's leakage current re-measured to assure the coils are in excellent condition. If the coils have begun to age significantly then the leakage current will increase at temperature. This could be due to possible formation of cracks in the cured coils or the resin beginning to degrade by chemical bonds cleaving and reducing the molecular weight of the resin. A lower molecular weight would increase the brittleness and allow the resin to possibly initiate cracks in the insulation. These possible failure mechanisms allows the transport of current along these weak points, which causes more heating of the insulation, which would allow the insulation to age at a faster rate. This is a new tool that may become more important as a diagnostic tool.

REFERENCES

1. W. J. Sarjeant; D.R. Speer; R. A. Ripley; 'On-Line Cure Monitoring of Next Generation Motor and Transformer Impregnates'; CEIDP, October 1998.