Product Data

Subject: **Insulation Systems — Epoxy Versus Porcelain**

TABLE OF CONTENTS:

INTRODUCTION

Since Thomas Edison's time, porcelain has been the standard of the electrical industry for post or stand-off type insulators. Early houses were wired with knob and tube type wiring where the knobs were made of unglazed porcelain. Switchboard builders used glazed and unglazed stand-off insulators to separate and support bus bar systems. In recent years switchboard builders have changed to polymeric insulators due to poor delivery, fragility, and cost of porcelain. It is now fairly common practice in 5 KV motor starting equipment to use polyester or polyurethane insulators instead of porcelain. In the early 1950's, epoxy was introduced and in the early 1960's it was used not only as a material for stand-off or pin type insulators, but current carrying conductors were being cast into it. The polymers of today are the insulation systems of tomorrow with epoxies rapidly becoming the standard for medium and high voltage systems.

The experimentation stage, or the field testing stage, has been carried on since 1951 and has been highly successful. With this history of success and the inclusion of Electromagnetic Industries into the Square D family, we decided to ignore porcelain as an insulation system for our metal-clad and metal-enclosed switchgear. In order to do this, however, we had to develop an insulation system which we felt was, in every respect, superior to porcelain and one that we could produce with our own technologies.

In this paper I will try to present a new language, present a history of development, present summaries of test data performed by various second parties, present claims of epoxy's superiority and acceptability, present Square D's expertise and test results, and summarize the superior attributes of epoxy over porcelain.

DEFINITIONS

CYCLOALIPHATIC DIGLYCIDYL ESTERS:

This terminology describes a circular chain of totally saturated carbon molecules commonly referred to as epoxy resins of the non-aromatic variety. This is the type of epoxy resin Electromagnetic Industries use in their instrument transformers for both indoor and outdoor applications. The material was first introduced as a product in Germany in 1963 in the form of post insulators. Instrument transformers were first cast into this material in about 1966.

BISPHENOL A EPOXY RESINS:

Bisphenol resins are aromatic compounds and are made of straight chain unsaturated carbon molecules. These epoxy resins were first introduced in 1953 and have since been used in making indoor electrical insulators and bushings. They were tried outdoors in many different applications up through 1965 but with very poor results. They are affected by sunlight (ultra-violet), and weathering (moisture, contaminants, and wind abrasion).

POLYMERS:

Polyesters, polystyrenes, polycarbonates, polyethylenes, polypropylenes, polyvinyl chlorides, and aliphatic hydrocarbons (epoxies).

WEATHERING:[1]

The elements of weathering are radiation - both solar and thermal, oxidation, hydrolisis, chemical degradation, and hydrostatic pressure.

SOLAR RADIATION:[1]

Ultra-violet light is absorbed by polymers such as polyesters, polycarbonates, polyvinyl chlorides, and to a lesser extent by bisphenol epoxy (cycloaliphatic resins are not affected at all). Ultra-violet light causes breakdown damage of the carbon chains and ultimate arc tracking.

OXIDATION:[1]

The oxidation process forms peroxides in polymers with single chain molecules. The aliphatic hydrocarbons have circular chains with practically no sensitivity to oxidation.

HYDROLYSIS:[1]

The action of rain, sleet and snow is hydrolysis and will raise the level of damage to polymers when exposed to radiation, oxidation and other chain breaking influences.

CHEMICAL DEGRADATION:

Ozone, sulphurdioxide, hydrogen sulfide, and nitrogen oxide, are ever present gases in industrially contaminated environments. These gases will combine under weathering conditions to form acid and alkaline solutions to attack insulation surfaces. Ceramic insulation (Porcelain) is only marginally affected by these deleterious agents. Polymer insulators are quite susceptible except for cycloaliphatic hydrocarbons due to their highly stable chemically circular chain linkage.

PYROLYSIS:[1]

This is the formation of an electrical conducting path at an interface in epoxy or polyester insulators. It is caused by localized electrical leakage or by an electrical flashover which results in the pyrolysis of the interface. The polymer in the system has then been oxidized. As the pyrolysis continues, a conducting deposit of carbon is left behind. The exception to this is cycloaliphatic epoxy resins. Pyrolysis of this polymer results in gaseous products only.

[1] Technical report Owens/Corning Fiberglass & Company "The Elements of Weathering and Tracking in Polymeric Electrical Insulation."

TRACKING (PYROLYSIS) SEQUENCE:[1]

1. Electrical leakage
2. Ionization
3. Noise
4. Corona (internal)
5. Corona discharge (visual)
6. Thermal degradation
7. Oxidation
8. Carbon deposition
9. Track extension

The tracking or organic insulations can happen under protective environments without the previously defined weathering factors being present. The damage mechanism in this case is partial discharge (corona) in internal and external voids in the moldings. Most polyester glass compounds we at Square D are familiar with are molded from liquids or powders. The liquid is poured into molds or in sheets which are then formed into shapes. The powder is compressed in a heated molding press into the desired shapes. All of these processes leave internal air voids and are subsequently subject to partial discharge if used in the presence of voltage stresses above about 1000 volts. Cycloaliphatic epoxy resins mixed and poured under extreme vacuum conditions (1mm of mercury or less) eliminates air bubbles (possible air voids) and subsequent partial discharge.

ELECTRICAL LEAKAGE:[1]

Polymeric insulation in electrical circuits carrying only a few kilovolts per inch under dry conditions will have surface leakage currents across the insulation in the microampere range. Under wet conditions the leakage increases to the milliampere range until at some value flashover occurs and the tracking sequence proceeds.

IONIZATION:[1]

The previously discussed voids which occur in polymeric insulation materials will have the gas in these voids ionized when the insulation is subjected to high dielectric stress. This ionization in the internal voids is called partial discharge and will increase in intensity as the surrounding material also becomes ionized, until a breakdown finally occurs.

CORONA:[1]

The next step in the tracking sequence is corona. As the voltage stress on the insulation goes higher and higher, the ionization appears on the surface and becomes visible. The visible ionization (corona) causes surface degradation and subsequent tracking.

THERMAL DEGRADATION AND OXIDATION:[1]

As stated, electrical leakage caused by corona generates heat at the point of ionization. This heat builds up in the polymeric material until a chemical change takes place (example: oxidation).

CARBON DEPOSITION:[1]

If the polymer is oxidized and burns, the residue is pure carbon and the condition becomes self-destructive.

TRACK EXTENSION:

After the tracking sequence has advanced through thermal degradation to carbon deposition, continuing damage causes track extension.

ALIPHATIC POLYCARBOXYLIC ANHYDRIDE ACID HARDENER:

Derivatives of this are used along with various fillers to make weather resistant electrical insulators from cycloaliphatic epoxy resins. Resin alone will not make epoxy parts. As with the epoxies you buy from your local hardware, hardners are required. That's where the similarity stops, because epoxy in insulation systems require different fillers to give different properties.

HISTORY AND FIELD TESTING

PROGRESS:[1]

An Owens/Corning paper, written in 1972, reported on epoxy materials put on weathering tests in 1965, 1966, and 1967. During these years, today's epoxy compounds were just being developed for practical uses. The samples used in these tests, although performing well, did not stand up to weathering the way a porcelain substitute (cycloaliphatic epoxy) should. Since 1966, there has been rapid progress in polymer insulation development for outdoor applications and applications where severe tracking conditions exist. These polymers combined cycloaliphatic diglycidal ester resins with hydratedalumina filler compounds. The product of oxidation of these compounds is a gas, therefore, little or no carbon deposits are left behind to propagate tracking. Some weathering and thermal damage does still occur but can be taken into account in the product design.

Since 1964, process improvements have been made in mixing, curing, testing and mold designs which expand the scope of products. Testing theory and practice has become more definitive with researchers conducting studies on surface phenomena, salt contamination, artificial fog, and long term corona effects. Others are investigating weather shed design, termination methods for strain insulators, and processes for composite casting. While much of the work in this field has been aimed at medium to high voltage insulators, a substantial part of the knowhow developed by this research can and has been translated into improved weathering resistance for outdoor applications. Likewise, the advances in processing will and has resulted in composite castings with superior mechanical strength and homogenous, void-free interiors.

This history would not be complete without field installation examples from around the world. These installation examples used the latest technology in vacuum casting with mixtures of the newest compounds available.

CIBA-GEIGY:

Ciba-Geigy, a Swiss company, was one of the two (2) inventors of the epoxies having developed them in Switzerland. They announced their discovery almost simultaneously with Shell Oil Company in the United States. Ciba-Geigy now manufactures cycloaliphatic epoxy resin systems for electrical bushings, insulators, and composite castings. They have done much experimentation in outdoor insulators and first put them on test in 1961. In 1961, Ciba installed at a Swiss utility, cycloaliphatic rods and subjected them to a continuous voltage of 16 KV. The rods were 200 millimeters long and 50 millimeters in diameter. The surrounding atmosphere was heavily laden with foundry gases. The fill in the rods was silica flour. Up to January, 1974, there were no signs of tracking or appreciable erosion, although the surface had become roughened.

In 1963, Ciba installed 110 KV suspension insulators (three in series) and subjected them to a continuous voltage of 330 KV. Two of the three chains under test were sandblasted prior to starting the test. Neither the sandblasting nor the contaminated atmosphere bothered any of the three chains. They are still functioning without any sign of tracking.

30 KV post insulators tested at a utility near Manchester, England, beginning in 1967, show only slight erosion on the underneath surface of the skirts and no signs of tracking.

Post insulators of every variety and shape have been tested at voltages from 15 KV through 245 KV throughout the world in all kinds of contaminated atmospheres. To date no failures have occurred which were caused by any of the previously mentioned causes of tracking in polymer insulation.

BAYER:

Bayer (a German Company - they also make aspirin), like Ciba-Geigy, developed epoxy resins for companies like Messwandler-Bau. They have documented many of their findings and I will quote from some of their information.

In 1966, Bayer installed 110 KV post insulators in various locations throughout Europe. They were subjected to environments, such as coal dust, high humidity, aluminum foundry dust, ultra-violet rays (installed on top of mountains), and seaport salt laden air. As of January 19, 1974, there were no signs of leakage current damage, but there was a rough texture to the surface of some of the insulators. All insulators are still functioning without any electrical problems.

In 1969, suspension insulators applied to 110 KV lines were installed in Germany in industrial locations. Again as of 1974, there were no signs of leakage. These suspension insulators had the cycloaliphatic epoxy resin reinforced with fiberglass fillers.

Bayer installed, in Bavaria on a 110 KV transmission line, suspension insulators reinforced with fiberglass and alumina fillers. These were installed in June, 1969, and as of January, 1974, there were no signs of malfunctioning. There was a slight darkening of the surface due to foreign deposits which is periodically removed by rain. These suspension insulators were approximately 10 feet long.

In 1966, a German transformer manufacturer, Westerwald, used Bayer technology and compounds to make 20 KV instrument transformers for outdoor pole mounting. These were installed in January, 1967, on the shores of the Baltic Sea. As of 1974, the units looked the same as they did the day they were installed.

MESSWANDLER-BAU GMBH BAMBERG GERMANY:

This company, using Ciba resins, first cast transformers in 1951. These, of course, were not with today's technology nor today's chemical compounds, but it does show that this is not a new industry which grew up last year because of someone's invention the year before. Messwandler has cast current transformers with epoxy resins up through 60 KV where the casting itself weighed over 500 lbs. The complete casting of the transformer core and coil eliminates the necessity for an additional housing. It is a weatherproof and fungusproof device.

In 1967, Messwandler-Bau built sixteen 60 KV current transformers which were installed in Heilbronn, Germany, near a salt mine. Heilbronn is a heavy industry city. As of January, 1974, the transformers were in good condition and looked like new. This type of data goes on and on. It is no wonder that both in France and Germany, 95% of the insulators, either of the stand-off variety or the strain-suspension variety, are made from cycloaliphatic epoxy resins and only 5% are still made of porcelain.

APPLICATIONS OF CAST EPOXY RESINS IN POWER CIRCUIT BREAKERS:[2]

Several interesting points were brought out in this paper.

The statement was made that cycloaliphatic epoxy resins are self-cleaning. When a spark over occurs on these epoxy castings, a gaseous material is liberated and this does not adhere to the surface. The material that is liberated is $Al_2O_3H_2O$. This material is non-toxic and is used as a mild abrasive in some toothpastes. How non-toxic can you get?

The authors further state by varying the quantity of filler, an epoxy system can be formulated that will encapsulate any materials normally used in power circuit breaker manufacture without any problems due to different coefficient of expansion between dissimilar materials. This is the same information Ciba-Geigy and Messwandler-Bau discovered in 1966 and now in 1975, it was rediscovered by Westinghouse.

The question was asked of the authors if they had made hydrostatic burst tests on their epoxy resins and how did this compare with similar tests made on porcelain type bushings? In reply, they stated the values at which comparable porcelain parts burst were roughly equivilant to the point of bursting of the epoxy parts. However, the big difference lies in that the porcelain pieces burst into many small fragments like shrapnel. When the epoxy parts fail (by cracking), they still maintain their basic structure. In most cases, the authors felt the epoxy parts would still maintain the mechanical system even after a hydrostatic failure. Also, the epoxy parts are not as susceptible to mechanical failure due to thermal shock or point loading as are porcelain parts. This last statement was verified by cantilever and vibration tests on assembled epoxy and porcelain bushings.

Westinghouse has been a strong advocate of porcelain in their 15 KV metal-clad switchgear, they have even named it Porceline switchgear. They are now changing their higher voltage oil and SF_6 circuit breakers from porcelain to epoxy insulation systems. In their article, which is printed in

[2] IEEE Winter Meeting 1974-75. Paper presented by J.P. Burkhardt and C.F. Hoffman, Westinghouse Electric Corporation.

[3] Insulation/Circuits Magazine, October, 1974. Article by C.F. Hoffman and J.P. Burkhardt of Westinghouse Electric, Pittsburgh, Pennsylvania

Insulation/Circuits Magazine, October, 1974, they imply they were the first to use alumina trihydrate as a filler in cycloaliphatic epoxy resins. Both of these items were used in insulators, bushings, and instrument transformer castings as far back as '65 (power transformer castings 1966).

Westinghouse goes on to say they have had cycloaliphatic resins on flat sample pieces placed outdoors for their weathering research. They are subjecting these samples to 1.6 KV per inch and have had them under test for 4½ years with only a slight chalking of the epoxy surface. The next application Westinghouse used cycloaliphatic epoxy for was to replace the porcelain on the 262 KV to 765 KV rated live tank gas filled breakers. When porcelain was used, it required a chemical coating resistant to arced SF_6 gas.

In a previous article by Hoffman and Burkhardt, they wrote about replacing porcelain with epoxy in the oil circuit breaker bushings and subjecting these to hydrostatic burst tests. When both porcelain and epoxy were subjected to arcing, temperature cycling, and mechanical life tests, the epoxy showed no reduction in burst strength and proved equal or superior to porcelain in all cases. During the impulse tests, some of the porcelain parts cracked.

Since all of the internal insulators and bushings were replaced by epoxy in both the gas and oil circuit breakers, the next step was to replace the outdoor porcelain with epoxy. This was done and found that the epoxy bushings were able to withstand higher 60 Hz voltages during wet tests than conventional porcelain (this was partly attributable to the simplified shed design which was able to be designed into the epoxy and could not be designed into the porcelain). The epoxy bushings passed all tests in accordance with requirements of ANSI $C76.1_4$. The point of expressing these facts on Westinghouse advances is to show that we are not the only manufacturer who sees the advantages, both to ourselves and to the ultimate customer of epoxy over porcelain.

Until the discovery of cycloaliphatic reaction resins with completely saturated carbonhydrogen ring structures (called cycloaliphats) the outdoor application of epoxy was not possible. With the appearance of the cycloaliphatic resin, the ultra-violet withstand, the weathering withstand, and resistance to arcing and leakage currents in spite of foreign deposits was increased to the point of being equivilant or superior to porcelain.

Plastics, including cycloaliphatics, to a certain extent, show a reduction of their initial mechanical properties down to a determinable final set of mechanical properties compared to the ceramic insulators which have a constant set of mechanical properties over a period of 20 years. It is important then that the designer of the insulators or castings know what the properties of the epoxy will be at the end of this 20 year life expectancy. This will enable him to design his equipment with the same mechanical safety factors as with ceramic insulating materials. This loss of mechanical properties in epoxy resins is minimized when they are not subjected to outdoor environmental problems, as proved by Owens/Corning Fiberglass test results (tests conducted from 1966 to 1972 on bisphenol epoxies).

TESTING

VOLTAGE ENDURANCE OF EPOXY RESINS:[4]

This paper reported results of endurance tests, outdoor performance tests, and partial discharge tests. The summary states: for significant results for partial discharge measurement, it is extremely important that proper quality control be maintained throughout the testing operation. It further states: "On the basis of the test results run by the Technical Research Center of Finland, it can be concluded that the selection of correct cycloaliphatic resin compounds combined with careful design and quality control will give reliable devices for outdoor use even in heavily polluted areas".

Many different cycloaliphatic resins were tested with various fillers and hardeners. These tests were conducted on flat pieces of material which had voltages up to 30 KV applied through electrodes pressing against each side of the pieces. Impulse voltages of 30 KV were applied at repeated intervals. The impulse voltages had steep wave fronts of the magnitude of 1000 kilovolts per microsecond. These pulses were applied at 5 minute intervals and the results range from a life

[4]A paper presented to Cigre (This European organization functions similarly to IEEE) and presented by engineers from the Technical Research Center of Finland. The date of this paper was August 21-29, 1974.

of 1600 hours through 22,000 hours depending on the filler, hardener, accelerator, etc. The problem with an accelerated life test of this nature is, there is no reference to expected operating life under normal operating conditions. It strictly points out the relative merits of the different resins with different hardeners and fillers when subjected to high impulse voltages to stimulate aging under accelerated conditions.

The conclusion on the tests for voltage endurance indicated that high stress is liable to deteriorate epoxy resin insulation. Partial discharge acts as a warning signal, but purely routine partial discharge tests will not guarantee the quality of epoxy resin products. Routine tests might find the inception voltage and extinction voltage to be very high for a product just off the line; but later the inception voltage level could diminish to less than the rated voltage, in which case it often leads to a rapid breakdown. Partial discharge measuring instruments should be left connected in the circuit while the voltage is being raised and lowered. Electromagnetic Industries performs partial discharge tests in this manner and require that no more than 10 microvolts be present at 130% of the rated line to ground voltage. Since EI's test equipment will measure as low as 2.5 microvolts (2.5 microvolts total including outside noise — an unshielded test laboratory would have 15 microvolts or greater ambient noise), their procedure requires that there be no additional measurable partial discharge at the working voltage of the equipment under test.

Certain outdoor utility station tests were run in Finland and the results are quite impressive. The phonomena studied was tracking, erosion of the insulator surface, pollution on the insulators (which causes flash overs) and surface discharges. All of these were measured continuously and evaluated at the end of the tests.

The test at Vaasa was on 24 KV rated insulators and was conducted over a 10 year period. The first samples were made of aromatic resins. It was found silicone grease protected the resins but eventually caused heavy erosion unless the surface was cleaned and re-greased regularly. If the surfaces were protected by shelter from the rain and the sunshine, the samples were undamaged throughout the test period. Cycloaliphatic insulators were placed on test in 1965 and some have been coated regularly with an artificial mixture of pollution. The sun's rays caused a slight erosion to occur in test samples in the form of bleaching and roughening of the surface. No serious erosion or tracking occurred on any cycloaliphatic samples. Silicone grease was tried on some samples but damaged the resin due to dirt accumulation. Aging tests on the samples were not altered significantly by either wet or dry testing at withstand voltages.

The tests at Kikkola, Finland, were even more interesting. This is a utility outdoor switching yard located on the seashore. There is a large fossil fuel power plant, a sulphur smelting works, a zinc works, and a sulphuric acid works all in close proxomity to the test station. Porcelain insulators have to be greased regularly to avoid flash over. The cycloaliphatic resin insulators have not been cleaned since the tests began in January, 1969 (examined for this paper in January, 1974). Surface resistance is measured every few months and the results are interesting. Surface resistance in new insulators is very high to start with but rapidly diminishes with use. Within a few years it reaches its limit value, 50 to 250 kilohms at which point pollution and self-cleaning are in equilibrium, and there it stays. The measurement is performed after a thorough wetting of the surface of the sample. The stabilization point is an extremely important factor in designing outdoor insulators.

For general interest, polyurethane insulators were installed in the same test station under the same conditions. They were destroyed 4 to 7 months after installation. Polyurethane is being experimented with by electrical equipment manufacturers in this country and may shortly appear in some of their products. The polyurethane is cheaper, the molding process is simpler, and the molding and curing time is extremely short, all compared to cycloaliphatic epoxy; but the life is also short. Polyurethane used as a 600V insulation system is quite acceptable.

In conjunction with this paper , short term tests were also run. These tests were run according to procedures outlined by the International Electro-Technical Commission (IEC) Subcommittee — #15A on Short Time Tests. The procedures are covered by paper #15A (Secretariat) 23 dated January, 1973. The scope of the tests was for a method to cover the evaluation of electrical insulating materials for use under severe ambient conditions by measurement of the relative tracking and erosion resistance. The tests were run for a period of 360 minutes or until failure of the material. It was interesting to note the cycloaliphatic resin Electromagnetic Industries uses in their instrument transformers passed the 360 minute time limit, without failure. Porcelain also passed, polyurethane went 29 minutes, bisphenol (aromatic) epoxy went 2 minutes, cycloaliphatic resins with alumina hydrate as a filler had the longest life.

A merry-go-round test was also performed by mounting test rods on a rotating disc which was inclined at about a 15 degree angle from horizontal. The disc rotated once a minute through a bath of salt water and ultra-violet light. The test voltage was 10,000 volts and the test was considered complete on a sample when flash over occured. The results are interesting in that the formula Electromagnetic Industries uses for their transformers lasted 1250 hours to failure while porcelain lasted only 1051 hours. The rods with pure alumina hydrate as a filler instead of a combination of alumina hydrate and silica flour were taken off test — **they did not fail!** One point of comment should be brought out in that epoxy resins with pure alumina hydrate filler are more brittle than those that contain some portion of silica flour. The conclusion of all the tests run by the Technical Research Center of Finland and presented to Cigre are:[4]

1. The outdoor tests indicated that certain insulators made of cycloaliphatic epoxy resins are reliable even under the harshest conditions.
2. Resin insulators require much less maintenance than porcelain ones.
3. Under conditions in which porcelain insulators have to be cleaned and greased regularly, cycloaliphatic resin insulators need no maintenance whatever.
4. For faultless performance the manufacturer need only take sufficient care in selecting the basic resin, hardener, and additives and in designing the shape of the insulator and in careful discharge testing to discover any manufacturing problems.

ONTARIO HYDRO:[5]

Mr. Kirtz has been experimenting with electrical insulating materials at Ontario Hydro since 1961. He published his first paper, which was IEEE Publication 66 dated June, 1963, on Insulating Materials and Various Test Results. At that time one of the epoxies he tested, which had alumina hydrate fill, was still on his endurance wheel test after 1500 hours. He states in his conclusion that the life acceleration factor for his endurance wheel test is in the order of 50 to 500. This epoxy sample, tested for 1500 hours, would have a minimum projected life of 9 years and a maximum projected life of 90 years (ideal conditions would have to prevail). The irregularity was caused by the differing amounts of rain on the various materials. All of these epoxies tested at that time were of the bisphenol (aromatic) variety.

It wasn't until 1969 that he published the IEEE paper referred to above. This paper was a comparison between the bisphenol and the cycloaliphatic epoxies. His test results showed hydrated alumina filled cycloaliphatic outrated all other materials on tests for track resistant properties. On his tracking endurance wheel test some of the epoxy formulation have gone as high as 1000 hours with erosion but no tracking. In one of the cases the cycloaliphatic sample went 2100 hours with erosion and high leakage but no tracking (12 to 120 years). With his test procedure he states procelain alone has not tracked, but porcelain covered with silicone grease (which is a common practice with many utilities) failed in under 2 hours. Subsequent correspondence with Mr. Kirtz has verified that Ontario Hydro are now willing to put into outdoor service, directly exposed to high voltage stresses such materials as teflon, silicone rubber and hydrated alumina filled cycloaliphatic epoxy. The criteria is 1000 hours without failure on his tracking endurance wheel test.

EPOXY ADVANTAGES

BAYER:[6]

Bayer has listed — from testing experiences — advantages of epoxy resin insulators over ceramic type insulators. They are:

HIGH BENDING STRENGTH — Porcelain has a very low bending strength compared to equal cross sections of epoxy.

HIGH TENSILE STRENGTH — Cemented insertes will pull out and crack porcelain under high tensile loading conditions not affecting inserts in epoxy.

[5] IEEE Publication 69C33-E1 dated September 8, 1969, presented by Mr. M. Kirtz, Senior Dielectrics Engineer, Stations and Underground Sections Electrical Research Department, Ontario, Hydro, Toronto, Ontario, Canada.

[6] Bayer Bulletin on Lekutherm printed January 5, 1974.

HIGH SHOCK STRENGTH — Porcelain will explode if shocked beyond it's capacity, whereas epoxy will simply crack and retain it's grip on whatever is embedded into it.

LOW SPECIFIC WEIGHT — Epoxy can be cast in thin walled sections and have equivalent or greater strength than solidly case porcelain of the same shape.

HIGH ARC RESISTANCE — There are many varieties of epoxy, but the cycloaliphatic varieties with alumina filler and the proper hardeners have resistance to arc tracking superior to porcelain.

HIGH DIELECTRIC STRENGTH — Dielectric strength depends on the fillers used in the epoxies. Alumina fillers make epoxy superior to porcelain.

SMALL SHRINKAGE — This is controlled by the type of fillers used with cycloaliphatic epoxies. It is difficult to control in large porcelain moldings.

CLOSE TOLERANCES — Porcelain molding tolerances are in the neighborhood of plus or minus 5-10% while epoxy casting tolerances can be held to .001 inch.

WIDE RANGE OF SHAPES — Porcelains range of shapes and sizes are quite limited. Their shapes must have thick sections for strength, and manufacturing restrictions determine limitations of certain porcelain dimensions.

METAL INSERT CASTING — Current carrying conductors (bus bar) can be cast into epoxies with similar coefficients of expansion, whereas nothing can be cast into porcelain. The inserts in porcelain are cemented in place and must be large in order to eliminate the possibility of expansion which would crack the porcelain.

As far back as 1964, Bayer was working closely with several German transformer manufacturers utilizing these epoxy traits to vacuum cast power and distribution transformers in epoxy resins. Several of these transformer manufacturers have successfully marketed epoxy resin encapsulated transformers since 1966. These manufacturers are now casting transformers with ratings through 35 KV and 10,000 KVA.

SQUARE D COMPANY

ELECTROMAGNETIC INDUSTRIES:[7]

By vacuum casting their transformers, partial discharge problems and ultimate breakdown of their transformers are eliminated. Each transformer Electromagnetic Industries produces is carefully tested for partial discharge. The criteria used is that the allowable partial discharge at 1.3, 1.73, and 2.25 times the rated working voltage on a transformer must not be greater than 10, 60, and 160 microvolts respectively when using the Nema #107 circuit. The partial discharge voltages during testing are recorded when the voltage is decreased from 75% of the maximum applied or induced voltage level. These measurements are recorded throughout the voltage lowering process until extinction voltage occurs. The extinction voltage must be greater than the working voltage to assure that partial discharge will not continue after normal voltage is re-established. One important fact to remember is they are the only manufacturer who conducts a 100% testing program on all instrument transformers above 600 volts. With EI's experience in vacuum casting transformers, they have been designated to vacuum cast the bussing insulation system for Solenarc switchgear. Much experimentation and testing was carried out to determine the best formula of cycloaliphatic epoxy resins and alumina hydrate filler to give life under stress conditions equal to or greater than the life of porcelain.

SQUARE D, MIDDLETOWN:[8]

One of the tests conducted was to determine the tracking characteristics of the material used. Three 1" diameter bars of cycloaliphatic epoxy resins with alumina hydrate fillers were track

[7] Electromagnetic Industries, Inc., a subsidiary of Square D Company, has manufactured vacuum cast instrument transformers cast in cycloaliphatic epoxy resins since 1971.

[8] Manufacturing location of Solenarc switchgear.

tested at 600 volts A.C., 100 volts A.C., and 1500 volts A.C. The test procedure used test probes initiated an arc and caused degredation of the surface of the material. The test probes were then drawn apart at a steady rate of speed. The distance tracked (when the stuck arc extinguished) was measured for each of the test voltages. The average volts per inch computed from the track length at the three voltages was calculated. The three samples averaged 4800 volts per inch for sample A, 6266 for sample B, and 8000 for sample C. This is phenomenal material! Three porcelain samples were also tested at 1500 volts and all three samples tracked at a distance of 7/16 of an inch which would give a 3400 volt per inch result. This tracking test is extremely difficult and surpasses any of the previously described tracking tests in severity. This is the only test where the arc is struck, the material burns, and the arc is sustained as long as possible. All the other tests were arcing tests initiated by a voltage pulse.

SUMMARY

For ready reference, the many advantages of cycloaliphatic epoxy resins for use in insulators, bushings, and combination assemblies with current carrying inserts are listed below.

MECHANICAL:

Higher bending strength
Higher tensile strength
Higher shock strength
Lower specific weight
Small shrinkage
Closer tolerance molding capacity
Wider range of shapes
Ability to mold electrical conductor inserts
Lower maintenance characteristics
Predictable ultimate mechanical strength

ELECTRICAL:

Higher dielectric strength
Higher arc tracking resistance
Condensor screen bushing casting ability

CHEMICAL:

Resistant to oxidation
Resistant to ultra-violet light
Impervious to atmospheric contaminants and gases
Unaffected by the elements
Fungusproof
Harmless residues during operation

D. W. Selby