



A *BRITHINEE ELECTRIC* WHITE PAPER

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**BELT AND SUSPENDERS**  
September 21, 2006

## BELT AND SUSPENDERS

As old-fashioned as it may sound, Brithinee Electric is a “belt and suspenders” kind of company. Some say we over-engineer our repairs; we might agree, but we understand that the cost for a premature motor failure, shorter generator life, or excessive power consumption is many times higher than the small premium cost to provide Brithinee Quality. We think “over-engineering” makes good financial sense.

Adding a belt, when you’re wearing suspenders, illustrates the extra care we take in selecting materials, training our people, and serving our clients. We are ultra-conservative and ultra-cautious when it comes to conducting our business and doing your motor repair. That extends to the types of materials we use, the methods we employ in doing your repair, how we hire and treat our employees, our vendors, and our customers.

We have devoted many hours to selecting only the best materials to use in repairing your motor. We continue to look for new, better products to use to make the repaired motor more reliable. We are meticulous in installing extra thermal protection and more insulation in our repaired motors than many shops and manufacturers do - belt and suspenders.

Our repair staff checks and double checks all the test results, measurements and calculations involved in each repair. We keep detailed records both on paper and in our computer files of “as found and as left” measurements, test data, pictures of the motor and all pertinent data. Our computer records go back to 1989 and our paper records date back to 1969 - more belt and suspenders to be sure.

We search diligently for only the best and most experienced motor winders, machinists and mechanics. Not only do we look for people with good motor repair skills but we look for people who have the same dedication to quality we emphasize. Many of our employees have worked at other shops and to a man, they say the methods and materials we use in our repair process are better and more comprehensive than any they have used before. We won’t cut corners when it comes to repairing your motor. That goes along with our belt and suspenders approach to repair.

This dedication to quality is what we have built our business around. We don’t tolerate two standards of quality at Brithinee Electric. Before the Brithinee name goes on a repaired motor, we must be certain it is the best repair we can produce. We are our own severest critics. If it isn’t good enough to pass our standards, we won’t deliver it.

We realize that the cost of the repair is only a very small part of the whole cost of having a motor fail. You, the customer, bear the cost of having a process or line down as well as the cost of removing the old motor and reinstalling the repaired one. That's why we feel we must make that repaired motor as reliable as we possibly can so you can get your line or process back in operation as quickly as possible and feel certain it will continue to operate reliably.

And we know too, as shown in an independent industry study, you, the customer, won't stand for shoddy workmanship. We call it the "one strike law". One bad experience with a repaired motor and you tend to look for another repair shop. The easiest way to keep that from happening is to give you the best repair possible and that's what Brithinee Electric strives to do every single time.

We constantly work to provide a safe, clean, pleasant workplace for our employees. We believe if our employees are happy, they will produce better work. Our concern extends to the environment as well. Brithinee Electric has worked with the state and local environmental agencies to promote clean air, clean water and clean land. After all, we live here too.

We believe strongly in building relationships not only with our customers but with our vendors. We feel that having long-term relationships with our vendors brings us dividends when it comes to getting the best products and prices they have to offer. Working with us for many years, these vendors have come to know what we want and how we work. They know that we want only the best and that's what they give us.

When it comes to customers, we have built relationships with many of them that extend back 25 years and more. These relationships have been built on mutual trust and the concept of working together to solve problems. We feel if a customer has a motor problem, we share that problem and want to share in finding the solution.

Belt and suspenders may be rather old-fashioned but they do describe how we treat our customers - each and every time. We have been in business since 1963 and plan to be in business for many more years so we have to deliver quality - each and every time. You demand that and we do too. If that's old-fashioned, then snap our suspenders!

## NOMEX

Advanced thermal technology was born more than 30 years ago when DuPont scientists created a fiber with an extraordinary combination of high-performance heat- and flame-resistant properties, as well as superior textile characteristics. DuPont's family of NOMEX® fiber products provides outstanding heat and flame resistance.

NOMEX® is also used for electrical insulation in where its inherent dielectric strength, mechanical toughness and thermal stability provide high reliability in the most demanding applications.

NOMEX® has the right balance of properties for use in transformers, motors, generators and other electrical equipment. This unique balance of properties has been providing reliability to manufacturers for over 35 years.

NOMEX® is a synthetic aromatic polyamide polymer that provides high levels of electrical, chemical and mechanical integrity when converted into its various sheet forms. Used properly, NOMEX® paper products can extend the life of electrical equipment, reduce premature failures and repairs, and act as a safeguard in unforeseen electrical stress situations.

NOMEX® paper products have characteristics which make them ideally suited for electrical insulation applications. These characteristics may vary slightly in the different forms and types of NOMEX®.

NOMEX® papers find numerous applications in motors and generators.

NOMEX® is used in all types of rotating equipment from AC and DC to random and form-wound, in sizes from miniature servo motors to 13.6kV industrial drives and 150MW steam-turbine generators. The use of NOMEX® papers provides significant advantages to users of motors and generators.

### **Better thermal protection**

Use of NOMEX® for ground insulation can prevent premature motor failure and equipment downtime. This is because NOMEX® does not shrink, become brittle, soften or melt during short-term exposure to temperatures as high as 300°C and maintains good insulating properties continuously at 220°C for 10 years. Motors may encounter temperatures considerably above their design ratings due to:

- Overloads, caused by reduced speeds or stalled rotors
- Restricted cooling (especially in dirty environments)
- Reduced line voltage or unbalanced phases
- Frequent starts and stops
- Unusually high ambient temperatures

Because of its superior thermal properties, NOMEX® can enhance motor

performance and reliability.

### **Boosted mechanical toughness**

The strength and resilience of NOMEX® papers help extend rotating equipment life in severe operating conditions. These conditions include severe shock and vibration seen in steel mill drives and railway traction motors, as well as the abrasion caused by thermal expansion and centrifugal forces in standby gas-turbine generators.

The flexibility and formability of NOMEX® Type 410 and 414 NOMEX® papers—0.18 to 0.38 mm (7 to 15 mil)—facilitates their insertion as slot liners. Their resilience holds them in the slot.

The stiffness of thick grades of NOMEX® papers—0.51 to 0.76 mm (20 to 30 mil)—makes them especially useful as slot wedges, topsticks and midsticks. Thicker NOMEX® papers are routinely hot-formed into permanent shapes such as slot wedges and V-ring segments.

The high dielectric strength and cut-through resistance of NOMEX® papers may permit replacement of thicker materials, thereby gaining additional space in the slot.

### **Reduced slot liner damage**

The tear resistance of NOMEX® papers reduces slot liner damage during winding and shaping of the coils in random-wound motors. Under more severe conditions, two- and three-ply laminates of NOMEX®-MYLAR®-NOMEX® and NOMEX®-KAPTON®-NOMEX® can be counted on to provide a superior slot insulation barrier.

### **How important is insulation material selection when repairing a motor?**

It's vital. The insulation material may mean the difference between delivering superior performance during overloads, or not being able to stand up to the heat, which can lead to premature equipment failures.

- NOMEX® has the right balance of properties for use in motors, generators, transformers and other electrical equipment.
- NOMEX® brand paper products have an ideal combination of performance characteristics, including high levels of electrical, chemical and mechanical integrity, which make them well suited for electrical insulation applications. Used properly,
- NOMEX® paper products may prolong the life of electrical equipment, help reduce premature failures and repairs, and may act as a safeguard in unforeseen electrical stress situations.

### **What is the Motor Repair Alliance Program?**

The Motor Repair Alliance Program is a new and exciting coalition DuPont is forming with the most innovative and forward-thinking motor repair shops across the country. In addition to maintaining high standards of performance and quality and exceptional levels of customer service, members of the Motor Repair Alliance Program use insulation products made of DuPont™ NOMEX® in the motors they rewind.

### **Why do they use insulation products of NOMEX®?**

Members of the Motor Repair Alliance Program use insulation materials of DuPont™ NOMEX® for many reasons. NOMEX® products are available in a broad range of shapes and sizes in temperature classes ranging from 130oC to 220oC, so they meet diverse performance, cost and design needs. They provide exceptional and consistent performance for a wide variety of applications and comply with demanding quality and production standards. Insulation materials of DuPont™ NOMEX® also offer superior safety margins in case of overloads and temperature peaks, so they can help improve motor reliability and life span. Finally, NOMEX® may help extend equipment life by reducing premature failures, overall downtime and maintenance costs.

NOMEX® papers and pressboards are made entirely of synthetic aromatic polyamide polymer in two forms:

1. **Floc:** short fibers that provide mechanical strength.
2. **Fibrids:** microscopic filmy particles that provide dielectric strength and act as a binder.

The floc and fibrids are combined to form sheet structures by specialized paper-making methods. During each process the fibrids join to form filmy webs between the fibers. In most cases, the paper sheet is then densified—or calendered—at high temperature and pressure to permanently lock the components together and produce a relatively impermeable structure with high levels of electrical and mechanical integrity.

### **What effect does moisture have on NOMEX® brand insulation?**

NOMEX® paper is hygroscopic and will reach equilibrium at room temperature at a moisture content equivalent to approximately 10% of the surrounding relative humidity (i.e., 5% moisture content at 50% RH). With increased moisture content, some mechanical properties (such as elongation) actually go up, and most stay within 20% of the dry value under conditions up to 95% RH. Dimensional change occurs with moisture content, with the largest effect being in the Z (or thickness) direction. Electrical properties change very little even in an environment at 95% RH. There is no need for concern as long as the paper is allowed to breathe freely. If used in a sealed system, however, it is recommended that the NOMEX® paper be dried prior to further processing.

**Conductivity or Resistivity** (inversely related terms): Measures the current-carrying ability of an insulating material—as if treating the insulating material as a conductor. Measured by ASTM D-257.

**Corona or Partial Discharge**—Low-level passage of high-voltage current through a gas, usually air, due to ionization. In air, corona creates highly active ozone, which can cause severe chemical damage to materials nearby. May be audible (a hiss) and visible (a blue glow).

**Corona Resistance or Voltage Endurance** (similar terms)—Ability of the insulating material to withstand damage caused by voltages (usually high) applied in use.

**Dielectric Strength**—Voltage required to puncture the material. May be direct current or alternating current (DC or AC), at many test conditions. Often measured by ASTM Standard D-149.

**Dielectric Constant or Permittivity** (similar terms)—Measures the capacity of the material to store energy. Generally, the lower the better, since it also determines how much AC leakage current can flow through the material and how voltage stress is distributed in an insulation system. Often measured by ASTM D-150.

**Dissipation Factor**—Relates to energy that is lost in the insulating material due to AC current flow (capacitive current). Usually measured by ASTM D-150.

**Impulse Dielectric Strength**—Ability to resist a very short pulse of

## OTHER TERMS

**Breaking Elongation**—Amount the material will stretch under tensile stress before yielding and breaking under tension. Measured by ASTM D-828.

**Calender**—To pass paper between rollers at high temperatures and high pressures to increase density, properties and surface smoothness. Usually done to high-quality papers.

**Initial Tear Resistance**—Ability of the material to resist tearing when a force is applied to tear a well-cut edge of the material. Usually tested by ASTM D-1004.

**Power Frequency**—Frequency of the sine-wave power in Hertz (written Hz) (formerly cycles per second). Usually 60 Hz in the United States and parts of Asia, 50 Hz in Europe and parts of Asia, etc.

**Harmonics**—Multiples of the power frequency, e.g., 120 Hz, 180 Hz, 600 Hz, on a 60 Hz power system. The higher the harmonic content, the higher the rate of

damage to the equipment if corona (partial discharge) occurs.

**Tear Propagation Strength**—Measures the ease with which a cut or tear that already exists can be further extended. Usually measured by TAPPI Test T-414, the Elmendorf Test.

**Tensile Strength**—The ability of the insulating material to resist straight-line pulling forces without breaking. Usually measured by ASTM D-828.

**Thermal Conductivity**—Measures the speed with which heat is transmitted through the material. The higher the thermal conductivity of the insulation, the easier it is to cool the electrical equipment by transferring heat to other parts of the machine or to the air. Usually measured by ASTM D-1674.

### Temperature Conversions & Dimension Conversions

Degrees C	Degrees F	inches	mm	mils
100	212	.002	.051	2
110	230	.003	.076	3
120	248	.004	.102	4
130	266	.005	.127	5
140	284	.006	.152	6
150	302	.007	.178	7
160	320	.008	.203	8
170	338	.009	.229	9
180	356	.010	.254	10
190	374	.015	.381	15
200	392	.020	.508	20
210	410	.025	.635	25
220	428	.030	.762	30
230	446	.050	1.27	50
240	464	.100	2.54	100
250	482	.200	5.08	200
260	500	.300	7.62	300
		.400	10.2	400

An electric motor's insulation system separates electrical components from each other, preventing short circuits and thus, winding burnout and failure. Insulation's major enemy is heat, so it's important to be sure to keep the motor within temperature limits.

There is a rule of thumb that says a 10 degree Celsius (1299 degrees Fahrenheit) rise reduces the insulation's useful life by half, while a 10 degree Celsius (50 degrees Fahrenheit) decrease doubles the insulation's life. This implies that if you can keep a motor cool enough, the winding will last forever, which ignores factors like moisture, vibration, chemicals and abrasives in the air that also attack insulation systems.

The real issue is at what temperature the motor windings are designed to operate for a long and predictable insulation life—20,000 hours or more. NEMA, the National Electrical Manufacturers Association, sets temperature standards based on thermal classes, the most common being A, B, F and H. The accompanying table provides a summary.

Insulation Classes & Their Thermal Ratings	
Insulation Class	Maximum Winding Temperature
A	105° C (221° F)
B*	130° C (266° F)
F*	155° C (311° F)
H	180° C (356° F)

**\*Most common classes for industrial-duty motors**  
Table shows highest allowable stator winding temperatures for long insulation life. Temperatures are total, starting with a maximum ambient of 40° C (104° F).

Class B or Class F insulation systems are usually used in today's industrial-duty NEMA "T frame" motors. Many manufacturers also design their motors to operate cooler than their thermal class might allow. For example, a motor might have Class F insulation but a Class B temperature rise. This gives an extra thermal margin. Class H insulation systems are seldom found in general-purpose motors, but rather in special designs for very heavy-duty use, high ambient temperature or high altitudes.

Class A insulation, while not used on today's industrial-duty motors, was standard on industrial "U frame" motors built in the 1960s and earlier. Because Class A insulation has such a low temperature rating, older motors were required to have far lower maximum temperatures. This accounts for the perception among many long-time motor users that modern motors "run hot." In fact, they do compared with older motors, but modern insulation systems are so much better that the reliability and durability of new motors are equal to or better than older-design motors. Plus, better insulation systems have allowed motor manufacturers to put more horsepower in a smaller package.

### Determining Correct Operation

Though many people believe they can judge a motor's operating characteristics by feeling its surface, that really isn't a very effective method. Design ratings for temperature apply to the hottest spot within the motor's windings, not how much of that heat is transferred to the motor's surface. Unless you have intimate knowledge of a specific motor model's design—including benchmark lab readings of heat runs that show "normal" surface temperatures for that specific model in exact locations on the frame—a motor's "skin temperature" provides little if any evidence of what's going on inside. This is true even if temperature measurement methods far more sophisticated than the human touch are used. In addition, for safety reasons, it is unwise to touch operating motors anyway.

Specifying motors with inherent overload protectors, thermostats or resistive temperature devices, or installing similar protection in motor controls, can help ensure that a motor is taken off-line before winding damage occurs. Motor

protection of one sort or another is advisable in almost any application. A common and reliable field test for motor heating involves checking the motor's amp draw with a clamp-style ammeter. Use this to confirm that actual amps are less than or equal to the nameplate rating. A precise test for winding temperature is the resistance method. This involves careful measurements with sensitive equipment, calculations and several hours of time. Procedures to conduct such tests can be found in technical manuals. Or contact your motor manufacturer.

### **Common Sense Precautions**

Sometimes a motor overheats because of a manufacturing or design defect. But far more often, overheating can be traced to misapplication. Overloading is the leading cause. This could take the form of using an undersized motor, a situation that may become more common as concern for energy efficiency puts the emphasis on eliminating oversized motors. Use an 80% loading as your guide. Most electric motors reach their peak efficiency at that load, and a comfortable overload margin remains.

Other common causes of overloading include a load seizing up or misalignment of power transmission linkages. Plus, unanticipated changes in environment, aging of equipment, misuse and other factors can subject the motor to stresses for which it was not intended.

Environmental conditions that can result in motor overheating include high ambients (especially look at the near vicinity of the motor for any heat-generating device) and high altitudes, (above 3,300 feet (1005.84m), where the "thin" air has less cooling potential). You might have to derate a motor under these conditions, probably choosing the next size up. Another environmental concern is dirt and fibers, which can clog ventilation openings, coat heat dissipating surfaces and cause a variety of mechanical problems.

Power supply problems are another overheating cause. Low voltage will result in the motor drawing higher current to deliver the same horsepower, and the higher current means higher winding temperatures. A 10% drop in voltage could cause nearly that much greater temperature rise. Excessive or sustained high voltage will saturate a motor's core and lead to overheating as well. In three-phase motors, phase imbalances can result in high currents and excessive heat, the extreme being the complete loss of voltage in one phase (called single phasing), which, if correct protection is not in place, will result in motor burnout.

Often overlooked as a cause of overheating is the number of start/stop cycles. It's not uncommon for a motor at starting to draw five times or more the current it does while running. This accelerates heating dramatically. Though various provisions are made relative to loading and off-time, NEMA identifies the number of allowable starts and starting intervals in MG10, Table 2-3. You can also refer to the EASA brochure "How to Get the most from your Electric Motors", Table 3.

Finally, pay special attention when applying adjustable-speed inverter drives, especially if you are introducing an inverter in a system of older motors. Some additional heating to the motor windings will inevitably occur because of the inverter's "synthesized" AC wave form. A greater cooling concern involves operating for an extended time at low motor RPM, which reduces the flow of cooling air.

Modern inverter-duty motors have higher insulation ratings to help alleviate this concern, and the robust insulation systems used in most of today's general-purpose industrial motors are adequate for many applications as well. In some cases, however, secondary cooling such as a special blower may be required.

Maintenance experts agree that excessive heat causes rapid deterioration of motor winding insulation. The common rule states that insulation life is cut in half for every 10 C of additional heat to the windings. As an example, if a motor that would normally last 20 years in regular service is running 40 C above rated temperature, the motor would have a life of about 1 year.

Leading standardization organizations have concluded that 30 percent of motor failures are attributed to insulation failure and 60 percent of these are caused by overheating. Articles have been published stating that a significant cause of bearing deterioration is overheating. There are typically five main reasons for overheating—overload, poor power condition, high effective service factor, frequent stops and starts, and environmental reasons.

## INSULATION MATERIALS

There are a variety of insulation materials used in both the manufacture and the repair of an electric motor. These include phase barriers, slot cells and top sticks. These insulation materials may mean the difference between delivering superior performance during overloads, or not being able to stand up to the stresses, which can lead to premature equipment failure.

### What Do Insulation Materials Do?

Insulation materials perform four distinctly different functions - they provide **electrical separation**, protect against **high temperatures**, withstand **mechanical stresses** and protect against the **environmental** effects of moisture in an operating motor.

Insulation material like slot cells and top sticks separate the copper magnet wire from the surrounding core iron. Without this insulation, you must depend solely on the wire insulation itself to keep a motor from shorting to ground. In the same way, the phase barriers separate the coils of magnet wire from each other and keep them from shorting out, resulting in winding burnout and motor failure.

An operating motor generates heat, which in turn can cause rapid deterioration in the insulation materials and the magnet wire insulation itself. **The common rule of thumb is that the insulation life is cut in half for every 10°C of additional heat to the windings.**

In order to categorize these thermal issues, NEMA, the National Electrical Manufacturers Association, has set temperature standards for insulation materials based on thermal classes. Thermal classes A, B, F and H are the ones you see most often and they are rated as follows:

Insulation Classes & Their Thermal Ratings	
Insulation Class	Maximum Winding Temperature
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*\*Most common classes for industrial-duty motors  
Table shows highest allowable stator winding temperatures for long insulation life. Temperatures are total, starting with a maximum ambient of 40° C (104° F).*

Class B or Class F insulation systems are usually used in today's industrial-duty NEMA "T frame" motors. Many manufacturers also design their motors to operate cooler than their thermal class might allow. For example, a motor might have Class F insulation but a Class B temperature rise. This gives an extra thermal

margin. Class H insulation systems are seldom found in general-purpose motors, but rather in special designs for very heavy-duty use, high ambient temperature or high altitudes.

Class A insulation, while not used on today's industrial-duty motors, was standard on industrial "U frame" motors built in the 1960s and earlier. Because Class A insulation has such a low temperature rating, older motors were required to operate at far lower maximum temperatures. This accounts for the perception among many long-time motor users that modern motors "run hot." In fact, they do compared with older motors, but modern insulation systems are so much better that the reliability and durability of new motors are equal to or better than older-design motors.

In addition to providing electrical insulation and withstanding higher and higher temperatures, the insulation material should be able to absorb the insulating resin or varnish, which when properly cured, will become rock-hard. This absorption property is called saturability. The end turns of the windings receive the most mechanical stress during operation. The more varnish the insulation materials in that area can absorb, the stronger the windings become thus making them better able to withstand the mechanical stresses of a rotor turning at 1800 or 3600 RPM.

In addition this saturability plays a big role when the motor is run using a variable frequency drive. When a VFD is used to power a motor, the windings must be completely impregnated with resin to eliminate air pockets (voids). This raises the threshold voltage at which partial discharge and corona occur.

One primary cause of premature motor failure is the onset of electrical discharge activity (corona) within the motor winding itself. Corona - also referred to as partial discharge - causes corrosion of the magnet wire insulation from the production of ozone and nitrous oxides in the voids between conductors

Two conditions are necessary to produce a partial discharge in the void of a winding. The first is high peak voltage across the void in the winding insulation. (This high peak voltage occurs thousands of times per second based on the VFD.) The second condition is the presence of an initiatory electron. This is an electron that has been struck by radiation such as gamma or X-rays. Laboratory observations show these two conditions occur simultaneously perhaps once per second whereas the high peak voltages occur thousands of times per second based on the VFD setting.

When these two conditions are present, the resulting partial discharge is similar to the static discharge you experience during very dry weather when you walk across a carpet and receive a shock when you touch a metal doorknob. The spark that results, while it isn't harmful to your hand if it occurs once or twice, could hurt you if it occurred many, many times. That is the also true of the partial discharge in a winding. If partial discharge occurs often enough, it can actually eat away at

the film coating on the magnet wire insulation. The more insulating varnish the insulation materials can absorb, the fewer voids will be left to be attacked by partial discharge.

The voltage at which partial discharge (threshold) begins is called partial discharge inception voltage (PDIV). When the PDIV is exceeded and maintained, the insulation thickness is reduced allowing the partial discharge intensity to increase, thereby accelerating the attack on the insulation itself. Thus the higher this threshold, the better.

Moisture in the windings sounds the death knell to an electrical motor. This moisture can come in the form of a flood of water or a mist or fog. Regardless of how it is formed, once moisture is allowed access to the windings, it can cause shorting and motor failure. The insulation materials play a vital role in preventing this moisture from forming an electrical current across the windings. Considering the rigorous electrical, thermal, mechanical and environmental stresses placed on motor windings during use, the winding insulation materials are essential in providing an added measure of durability to the rewound motor.

### **The Evolution of Insulation Materials**

The first insulation was almost always naturally occurring materials like mica, cotton, wool, silk, flax and asbestos. Often these natural materials had serious temperature limitations, which required that motor operating temperatures, electrical, mechanical and environmental stresses be kept to a minimum because the insulation just couldn't handle the increased requirements. In other cases, natural materials like asbestos presented serious environmental and health risks which weren't recognized years ago.

As man-made fibers were developed, these limitations could be removed due to the greatly improved electrical, thermal, mechanical and environmental capabilities of the new materials. But as motors have evolved, their windings were designed to operate with even higher electrical, thermal, mechanical and environmental stresses than in the past. This places even greater stresses on the motor and its insulation.

The history of synthetic insulation products dates back to 1908 and began with the development of a product known as Bakelite (named after its inventor, Leo H. Baekeland), which was joined in 1927 by polyvinyl chloride, in 1936 by acrylic and in 1938 by polystyrene and nylon. A wide variety of synthetic materials followed in the 1940s and '50s. While these products were relatively unsophisticated as compared to the materials offered today, they opened the door to the development of more and more complex synthetics including DuPont™ Nomex®.

## DuPont™ Nomex®

Nomex® has for many years been known for its superior heat- and flame-resistant properties. It protects so well from heat that firemen wear Nomex® clothing to fight fires and automobile racers wear racing suits containing Nomex® to protect themselves from burning fuel.

Nomex® is also used for electrical insulation where its inherent dielectric strength, thermal stability, mechanical and environmental toughness provide high reliability in the most demanding applications. Used properly, Nomex® insulation materials can extend the life of electrical equipment, reduce premature failures and repairs, and act as a safeguard in unforeseen electrical stress situations.

Use of Nomex® for ground insulation can prevent premature motor failure and equipment downtime. This is because Nomex® does not shrink, become brittle, soften or melt during short-term exposure to temperatures as high as 300°C and maintains good insulating properties continuously at 220°C for 10 years. Motors may encounter temperatures considerably above their design ratings due to overloads caused by reduced speeds or stalled rotors, restricted cooling (especially in dirty environments), reduced line voltage or unbalanced phases, frequent starts and stops and unusually high ambient temperatures, all of which are common in industrial environments. Nomex® provides the best safeguard against motor failure from these thermal conditions.

The strength, resilience and saturability of Nomex® papers help extend rotating equipment life in severe operating conditions. These conditions include severe shock and vibration seen in steel mill drives and railway traction motors, as well as the abrasion caused by thermal expansion and centrifugal forces in standby gas-turbine generators.

Since Nomex® products are available in a broad range of shapes and sizes in temperature classes ranging from 130°C to 220°C, they meet diverse performance and design needs. We have found they provide exceptional and consistent performance for a wide variety of applications and comply with demanding quality and production standards. Insulation materials of DuPont™ Nomex® also offer superior safety margins in case of overloads and temperature peaks, so they can help improve motor reliability and life span. Finally, Nomex® extends equipment life by reducing premature failures, overall downtime and maintenance costs.

## The Brithinee Difference

Most repair facilities have some Nomex® materials on their shelves and probably use them for some rewind applications. In the 1970s, Brithinee Electric decided to standardize on DuPont™ Nomex® insulation papers for all our rewinds. Then in 1993 we adopted Quad-Coat wire into our systems. Since that time, we have experienced nearly zero warranties due to winding material failures. That tells us our choice of DuPont™ Nomex® as well as the type of magnet wire and varnish we use coupled with the winding methods we employ was the right one for our repair customers

While most new NEMA T-frame motors you find today would be manufactured with Class B or Class F windings, Brithinee Electric has standardized on Class H insulation materials, which provide the maximum thermal protection on the market today. DuPont™ Nomex® insulation materials are just one of the building blocks of Brithinee Quality.

## MAGNET WIRE

The wire used in electric motor coils is called “magnet wire”. First, Brithinee Electric uses only copper magnet wire. There are several manufacturers of magnet wire in the U.S. One independent lab that routinely tests various manufacturers’ magnet wire after first removing the film coating has told us that Superior Essex wire regularly tests the best. Hands down. And Superior Essex manufactures all the wire Brithinee Electric uses in its rewinds.

### How Magnet Wire Is Made

The vast majority of the magnet wire Brithinee Electric uses is “round” wire, meaning that a cross-section of that wire is round as opposed to the square or rectangular wire used in other applications. “Round” wire is used to produce “random” or “mush” windings. “Rectangular” wire is used to produce “formed coils”, such as for high voltage machines.

The wire is drawn through a series of precision diamond drawing dies to get the desired finished size before passing through an annealer that both softens and cleans the conductor. After annealing, the wire passes through an enamel bath and then precision metering dies control the amount of enamel coating applied. From there the wire passes through the enameling oven where the solvents are evaporated away and the polymers cured. The amount of enamel applied per pass is very small and it takes several passes through the bath and oven to achieve the desired coverage.

**Why it’s important to you - so important that we put a product label on each rewound motor describing the wire type we used.**

Most motor manufacturers and service centers use “heavy-build” or “double-build” magnet wire, which must withstand voltages of at least 6175 volts for 15 AWG wire. The “Quad-Build” or QuadCoat Essex GP/MR-200<sup>®</sup> wire Brithinee Electric uses in most of our rewinds has twice the enamel coating and can withstand voltages exceeding 20,000 volts.

In addition to the higher withstand voltage; the tougher, thicker film coating suffers less damage during coil making and insertion. Due to the stator slot configurations of some motors, we cannot use QuadCoat wire in every instance and still keep the winding resistance within acceptable limits. In those instances, we use Essex ULTRASHIELD<sup>®</sup> PLUS double-build film-coated wire which has additives in the film, making it “inverter duty”. We’ll get into what that means in a moment.

Since the insulating enamel is applied wet to a round surface, the concentricity or evenness of the film coating is not perfect and variations in the film

thickness can be as high as three or more to one. Think of spraying paint onto a round surface. The thickness of the paint on the topside will be less than that on the bottom. Such is the case with magnet wire too. Although the manufacturer might intend to apply .004” enamel to the wire, in fact, the coating may be as thick as .003” on the bottom but only .001” on the top side.

Superior Essex, the wire manufacturer we choose for 100% of our wire product, keeps the film’s wall thickness variation to less than 1.8 to 1, which means few “thin spots” which can short through.

Essex has developed proprietary, patented enamel insulations for the wire we use. The GP/MR-200<sup>®</sup> wire (General Purpose/Moisture Resistant-200°C Class) has two separate insulations. The basecoat enamel is modified polyester and the topcoat is a polyamideimide with an internal lubricant built in to help the wire wind with less damage. This lubricant also helps the wires “nest” with other turns of wire in the finished coil. In addition Essex applies an external dry lubricant to the wire to make the coil insertion easier and reduce damage to the wire during winding.

Wire pliability is important when winding motors. If the wire easily conforms to the shape we want, there is less chance of damage during winding and the finished coils are easier to insert in the stator. It’s just easier to make a premium motor with soft copper wire which has a tough, durable, slick coating.

The wire is tested on-line during manufacture for film continuity faults in the film insulation where shorting can occur. Where NEMA allows as many as five faults per 100 feet in double-build film coated magnet wire, the QuadCoat wire we use has virtually no faults at all along the entire length of wire.

### **The Affect of Variable Frequency Drives (Inverters) on Magnet Wire**

While the introduction of variable frequency drives (VFDs) brought whole new dimensions of motor starting and speed control, they also brought a whole raft of previously unknown problems to the motor industry.

Even in a perfect environment where the electricity supplied to a motor would be a perfect sine wave, the peak voltage (for a 460 volt system) is 650V. But motors don’t operate in a perfect environment where they see a perfect sine wave. The utility switches power supplies, motors get turned on and off and other disturbances in the power supply occur regularly. These changes result in occasional peak voltages of 1200V, 1500V and sometimes even higher. A steep wavefront of voltage like this can enter at least the first few coils in the stator, often causing damage. How far the surge will penetrate into the windings and how much damage will be done depends on the magnetic configuration of the motor itself.

Now add the VFD and those “occasional” peak voltages of 1200V or 1500V become frequent peaks on the order of 2000V on a 460V circuit. In addition, VFDs, the majority of which are pulse width modulated (PWM), introduce voltage rise times as short as 0.1 microseconds. This very fast pulse rise time combined with many other factors can cause motor windings to fail prematurely.

As important as these fast voltage peaks are, this isn't the primary cause of premature winding failure. That distinction falls to the onset of electrical discharge activity (corona) within the motor winding itself. Corona - also referred to as partial discharge - causes corrosion of the magnet wire insulation from the production of ozone and nitrous oxides in the voids between conductors.

Corona is caused by two factors present in every electric motor. The first is the presence of an initiatory electron or one that has been hit by radiation. Keep in mind that radiation in many forms is all around us. The second is the simultaneous voltage spike we have just discussed. When the initiatory electron and a voltage spike occur simultaneously, corona is created, causing corrosion of the magnet wire insulation and eventual (this may be a very short time) premature failure of the motor.

When these two conditions are present, the resulting partial discharge is similar to the static discharge you experience during very dry weather when you walk across a carpet and receive a shock when you touch a metal doorknob. The spark that results, while it isn't harmful to your hand if it occurs once or twice, could hurt you if it occurred many, many times. That is the also true of the partial discharge in a winding. If partial discharge occurs often enough, it can actually eat away at the film coating on the magnet wire insulation.

The voltage at which this partial discharge begins (*threshold*) is called partial discharge inception voltage (PDIV). When the PDIV is exceeded and maintained, the insulation thickness is reduced allowing the partial discharge intensity to increase, thereby accelerating the attack on the insulation itself. Thus the higher this threshold, the better.

### **What Can be Done?**

There are several things that can be done to mitigate the effects of corona. First, using flexible magnet wire results in better coil conformity where the wire strands nestle closely to each other limiting spaces or voids. The careful formation of these coils is extremely important in reducing voids. One set of wire researchers concluded that the mere forming of the magnet wire into coils reduced the PDIV of the wire itself by 25%. Coil insertion (which is done by hand) into the stator further reduces the PDIV even further so the careful, often time-consuming task of motor winding becomes more of an art.

Second, magnet wire coating plays an important role in withstanding corona activity. PDIV plays an important part in winding motors for corona resistance. Double-build magnet wire has a PDIV near 650V before VPI. The QuadCoat wire Brithinee Electric uses has a PDIV about 40% higher or around 910V before VPI. Thus with double-build wire, you are forced to rely even more heavily on the resin in the impregnation process to keep the winding out of trouble from the corrosive effects of partial discharge. And when you consider that the peak voltages generated by VFDs can be on the order of 2000V, you can see that the wire coating alone doesn't provide all the protection necessary to prevent premature winding failure.

Third, vacuum pressure impregnation (VPI) of the windings with insulating resin forces the resin into the windings to fill any remaining voids. The resin and the VPI process is the last link in successfully winding a motor to resist the effects of corona. We will go into the VPI system and the resin we use in another section.

The QuadCoat wire Brithinee Electric uses, the care we take in coil formation and insertion and the VPI system and resins we have chosen all play important roles in reducing the failure rate of Brithinee Electric windings from what most people would attribute to "voltage spikes". These failures have dropped from perhaps a dozen per year ten years ago to approximately zero today in those windings using quad-build film coated wire by Superior Essex.

#### **What Does This Mean for You?**

It means more uptime. It means you can rest assured your motors rewound by Brithinee Electric using QuadCoat wire by Superior Essex will stand the test of time.

One wind-generator customer of ours, who was accustomed to measuring insulation resistance to ground ("meggering") on machines that were turned off during wet weather found dramatically improved readings on those machines rewound using QuadCoat wire. The result - he could operate those machines far more hours without concern about winding failure.

QuadCoat wire is just one of the building blocks of Brithinee Quality.