↘ WHITE PAPER ON:

Electronically Controlled and Electronically Protected Motors

Information for end-product manufacturers of motor operated appliances

The foundation

For the past hundred or so years, there have been a few standard variations of motor design. These included the various “flavors” of AC induction motors and a few “flavors” of brushed motors and that was, by and large, it. Over the last hundred years, the materials changed some and the design and fabrication became incrementally more sophisticated but, by and large, the designs were well established.

The last five years has seen a rapid growth in the prevalence of motors that make use of electronics for control (normal operation) or for overtemperature protection (abnormal operation) or both. The most now ubiquitous of these is the electronically commutated motor (ECM). Indeed, electronics has enabled motor design, fabrication and operating efficiency that was previously only dreamed of. In fact, many in the industry are predicting the eventual, if not imminent, demise of conventional induction and brushed motors.

Of course, this doesn’t come without challenges. After all, over the past 100 years, how a capacitor starts a motor or how a thermal motor protector (TMP) operates to limit overtemperatures have been well understood. Today, how a Hall effect sensor and a set of isolated gate bi-polar transistors (IGBTs) combine to turn a rotor or how a combination of software and hardware combine to limit motor overtemperature is certainly less universally understood.

UL has published its new family of motor Standards partly to address these challenges. Though it is well beyond the scope of this single paper to completely address the implications of this new, emerging and very much still evolving, technology on motor safety, let us address the fundamentals.

First, let us define two basic terms as these definitions are found in UL 1004-1.

1. **Operating control** — A device or circuit the operation of which starts or regulates the rotating machine during normal operation.

   and

2. **Protective control** — A device or circuit the operation of which is intended to prevent a hazardous situation during abnormal operation of the machine or equipment. In the context of this Standard, a protective control is one that is relied upon to provide overtemperature protection for a rotating machine.

So we consider that electronic circuits used in motors can perform two broad functions; operation and protection. These two different types of circuits are evaluated and tested in two very different ways.

Operating circuits are evaluated and tested to determine whether or not, under normal conditions of use, the circuit itself will present a risk of fire or electric shock. In contrast, a protective control is both evaluated and tested to appraise this basic level of safety and additionally is evaluated for its **functional safety** (or ability to provide safety functionality).

Functional safety is a term that we hear a lot these days. Most of UL’s evaluations involve the first-described basic level of safety. For example, when UL evaluates and tests a toaster, we are concerned that it not cause a fire and that it not present a risk of electric shock. We don’t much care about the quality of toast that it makes. Surprisingly however, UL has evaluated functional safety of certain products for over a hundred years. Fuses for example must not only not present a risk of fire and/or shock, they are also very carefully evaluated and tested to ensure that they will consistently and predictably open under prescribed conditions of overcurrent.

It is in this fashion that motor overtemperature protective circuits are evaluated. These circuits are evaluated and tested with the motor to ensure that under all normal and reasonably anticipated abnormal conditions of motor operation, the circuit can be relied upon to limit motor winding temperatures to acceptable levels.

How do we do this? Evaluation of electronically controlled and electronically protected motors is, by necessity a multi-disciplinary task (much more about his later). It involves the very same motor safety engineers that you've become accustomed to and worked with these many years as well as control engineers and, in some cases, software engineers. The motor engineers, of course, work from the same UL 1004 Standards that we're familiar with. The control engineers work from an extensive Standard called UL 60730-1, that can be quite intimidating. This 300 plus page monster defies casual reading (or understanding for that matter). The reason is that UL 60730-1 is used to evaluate and test all manner of controls not just motor controls and protective circuits.

The key to navigating and understanding UL 60730-1 is to be found in Table 7.2. You see, UL 60730-1, like its IEC progenitor, is a Standard of declarations. That is, the Standard provides the means to evaluate declarations made by the manufacturer. In and of itself, it is not prescriptive. The "prescriptions" for how UL 60730-1 is applied to motor controls and protective circuits is to be found quite naturally in the motor Standards.

If a circuit is presented as a motor operating (not protective) circuit, the minimum performance levels or how the circuit must be evaluated to comply with the motor requirements are found in Table 7.1, the Motor Control Correlation Table of UL 1004-1. This Table prescribes 11 conditions that correlate to Table 7.2 in UL 60730-1. This then serves as the marching orders or recipe that the control engineers must follow to evaluate a motor operating control.

If the circuit is presented as a protective control, a similar Table, Table 29A.1 is provided in UL 1004-7, UL's Standard for Electronically Protected Motors. These two tables then are the Rosetta Stone, if you will, for decoding UL 60730-1 as it applies to motors.

Of specific interest to end-product manufacturers

One of the potential challenges in evaluating the safety of today's ECM motors is that the motor is often so thoroughly and seamlessly integrated into the end product that it is hard to draw the line at where the motor ends and the end-product begins. Very often, the same control that provides over temperature protection for the motor also controls cycle timing, speed, load sensing interlock monitoring or a myriad of other functions for the end product.

We have seen, evaluated, tested and certified many, many of these designs; more than any other testing or certifying organization. In fact, we wrote the book, the Standard for Electronically Protected Motors, UL 1004-7.

There are just a few secrets to success in evaluating such technologically sophisticated end products:

1. We take a common sense approach to looking at the big picture. A narrow perspective might cause some to conclude that the object, from the motor standpoint, is to prevent overheating of the windings. Not true. Overheating of the windings, in and of itself, does not represent a hazard. The risk of electric shock and/or the risk of fire does. It might seem that the difference is subtle. After all, doesn't overheating of motor windings potentially lead to failure of the insulation and the potential for electric shock or fire? It could but if there are features of the end product that serve to mitigate these risks, those features are factored into our evaluation and test program. For example, if overheating causes failure of the motor insulation system, resulting in the motor shaft becoming electrically live but the end product is designed in such a way that prevents user access to the motor shaft, it is likely that the object of preventing the risk of electric shock has been suitably addressed without incurring lengthy and costly evaluation of the complex motor control circuit. Again, we look at the big picture and we don't test or evaluate simply for the sake of testing and evaluating.
2. We are not only a certifying organization; we are a safety research and Standards writing organization. Our research and many years of supporting experience have enabled us to quantify the levels that define the risk of shock and the risk of fire. Again, the big picture, common sense approach prevails. If your product involves a motor where the levels are less than 15 watts and/or less than 42.4 volts peak or 60 volts DC, then it is very likely that there is no defined risk of electric shock and/or

fire and thus the requirements and tests necessary to evaluate that risk(s) may simply not apply.

3. Products today very often incorporate sophisticated microprocessor based controls that do not simply monitor a single motor operating parameter to ensure safe operation but perhaps many. Often, such controls will monitor motor speed, motor current, back EMF, measure winding temperature directly or any number of similar "schemes". Again, we do not test and evaluate simply for the sake of testing and evaluating. We recognize that certification cost and time to market are important. If your design incorporates redundant safety "schemes", we will sit down with you and your designers and collaboratively decide which one or perhaps two we want to rely upon to address motor overtemperature. If successful, we only test or evaluate those selected schemes. Very often, this strategy shaves significant and important time and cost from the certification experience.

4. Very often, motor manufacturers will redundantly incorporate a conventional thermal motor protector (TMP) into their electronically protected motor. Provided that the combination of the motor and TMP adequately serve to prevent motor overtemperatures, then there is no need to verify the safety functionality of the electronic protection circuit or its firmware. In practice, we know that the circuit will, in all likelihood, operate much faster than the TMP but provided that we have demonstrated that we can depend upon the TMP to reliably limit overtemperatures, there is no need to spend the time, money and effort it would take to evaluate and test the electronic circuit to provide the same functionality.

So what is the overriding point? The point is that we have provided alternatives, we work with you and we look at the big picture. Just as there isn't one way to design and build a motor, there is similarly not just one way to evaluate safety. We have provided numerous alternatives just like those shown here that manufacturers can use to design safety into their products and to avoid unnecessary, costly and time consuming testing. Our motor and control engineers have seen many, many design variations and are prepared to work collaboratively with you; to think out of the box and apply the principles of hazard based safety engineering (HBSE) to the test and evaluation of the latest technology of electronically controlled and electronically protected motors.

What can you expect from the evaluation, test and certification experience?

So far we've simply talked about the nuts and bolts of test and evaluation. Early on we mentioned that each such project is necessarily multi-disciplinary. Indeed, in many cases, we see projects involving a motor, an electronic control or protection circuit, perhaps some processor based firmware, and often the end product that the motor forms a part of (because, increasingly, we see motor controls and protection circuits integrated into appliance controls). Handled badly, this could mean that you would be dealing with 4 different project handlers, 4 different reviewers and perhaps a handful of PDEs thrown in for good measure. Handled badly, this could be quite a confusing and frustrating experience. We have become sophisticated in the art of managing multi-disciplinary projects. What you can expect is that we will bring all of these experts to bear on your project, if necessary, *but that it is likely that you will be provided with a single point of contact*, a single overall "owner" of your project. Almost always, this will be the engineer "highest up the totem pole".

Why is this? When a component, such as a motor, is evaluated to become a Recognized Component motor, it is unknown where that motor will wind up. Once it is a Recognized Component, it could become a motor in a vacuum cleaner, a washing machine, a food processor, a portable tool or a medical blood analyzer. Consequently, since the end use is unknown, we cannot rely upon the end product to take on the burden of mitigating some of the risk. For example, all Recognized Component motors are evaluated and tested to ensure that they do not present a risk of electric shock or fire. As we've explained, in some applications, this may not be necessary at all. If, for example, in a given end product, the motor is completely enclosed and there is no possibility of human contact with the motor or its accessible metal parts, then the simple inaccessibility may suitably mitigate the risk of electric shock. Similarly, if the motor, in the end product, is completely enclosed in a non-combustible enclosure, then the end product may mitigate the risk of fire that is normally addressed by the motor design and construction.

As a result, it makes sense that the project handler for the end product (if the end product is part of the evaluation) look at the big picture and drive the scope of the evaluation and test of the motor to include only what is required to mitigate those risks not addressed by the end product. Similarly, the motor engineer will drive the scope of the control and protective circuit evaluation and test to only address those features that are necessary to provide mitigation of risk. In the end, for projects involving an end product, the end product will generally be Listed, the motor may become an unlisted component of the end product and the control, an unlisted component of the motor. This isn't rocket science but rather is a reflection of how you designed your product in the first place. Your product was undoubtedly designed so that all of the various components contribute their part in making up the whole. All we are doing is applying that philosophy to the safety evaluation process.

So how do we make this happen; how do we ensure that your product safety evaluation is conducted as efficiently and effectively as possible both from a time and cost standpoint.

1. First let me suggest the worst possible way. The worst possible ways is to design and prototype a product and perhaps even design and fabricate some of the production tooling and then drop the prototype or worse a pre-production sample on "UL's desk" and state, "Here, certify this." Let me suggest the obvious. Changes are much more easily and cost effectively made on paper than they are on products or tooling.

2. Remember, UL exists for one purpose only, to work with manufacturers to bring safe products to market. Let me share what our most satisfied and successful customers have learned. They have learned to integrate UL into their product design team and process. Generally, the earlier in the design process that we are brought in, the more successful and time and cost effective the result. Our engineers are not only experienced in UL's motor Standards but they have ready access to UL colleagues who are experts in the hundreds of components and materials that make up a motor. We routinely collaborate with manufacturer's design and production engineers to discuss safety requirements, suggest alternatives and propose solutions.

Get us involved early. Let us work together to bring safe products, *your products*, to market quickly, efficiently and cost effectively. That's what we're here for.

About Underwriters Laboratories

UL is an independent product safety certification organization that has been testing products and writing Standards for Safety for more than a century. UL evaluates more than 19,000 types of products, components, materials and systems from more than 66,000 manufacturers each year. In total, there are more than 20 billion UL Marks appearing on products worldwide. UL's global family of companies and network of service providers includes 68 laboratory, testing and certification facilities serving customers in 102 countries. For more information, visit: **http://www.UL.com/newsroom**.