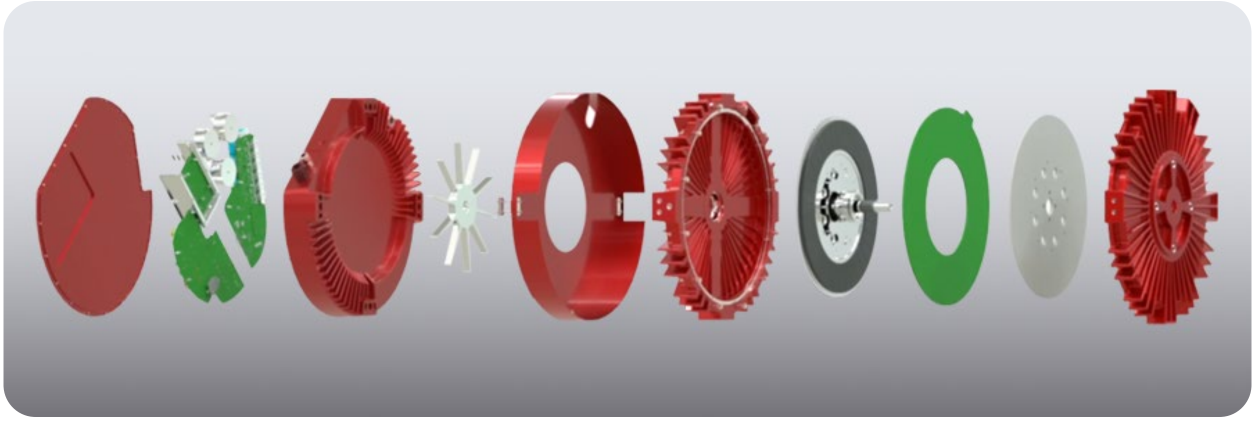
By Cam Witt

Designing Electric Motors for Intrinsic Reliability



In systems that can't quit, electric motor reliability is a critical path to success or costly failure. Even non-critical applications reap important benefits from high-reliability motors—benefits that range from higher return on investment (ROI) to fewer maintenance concerns. Technical system performance, operating costs, support costs, and sustainability all depend on a motor's ability to stand up to its environmental conditions over time.

In a well-designed motor, reliability is essential. That intrinsic reliability is a result of efforts in two distinct realms: motor architecture and predictive analytics. Using the Infinitum motor as an example, in this paper, we'll cover the areas of an electric motor that offer the greatest opportunities for design optimization and how analytics can help mechanical engineers apply precision improvements for greater reliability.

Motor Architecture

A motor's lifespan depends on the condition of stator windings, sliding components, and bearings—the primary failure mechanism of an electric motor.

The mean time between failures (MTBF) on electric motors is directly related to the lifetime of the bearing grease. Opportunities for reliability improvements reveal themselves in each major component of an electric motor:

Bearings

As the leading cause of motor failure, system design centers around ensuring that bearings are kept cool and properly loaded. Exceeding a motor's specifications, such as radial load (i.e., overhang) and axial load (i.e., thrust), can shorten a motor's life by placing additional stress on the bearings. Heat is the most common cause of bearing failure because it degrades bearing grease. A 10° C rise above the recommended operating temperature reduces bearing life by half.

The standard Infinitum motor has steel bearings (balls and race), but hybrid ceramic bearings (steel race, ceramic balls) are available upon request. In both cases, the motor is totally enclosed, and fan cooled (TEFC), with internal impellers for optimal temperature control. Infinitum motors run cooler than conventional induction motors, which means bearing grease lasts longer. All Infinitum motors have an L10 bearing life of 100,000 hours for all orientations.

In the motor development process, Infinitum monitors key motor components using temperature sensors and employs heat sink optimization and other thermal management techniques to achieve cooler operating temperatures. Users can monitor the real-time temperature of key motor components using the motor drive control software available with IEs motors.

Another source of bearing failure is arcing due to shaft voltages. Arcing can cause pitting inside the bearings, resulting in vibrations and premature bearing failure. In an Infinitum motor, bearings are located inside the motor case, and serviceable, drive-end (DE) grounding rings are located outside of the motor case to protect bearings from arcing.

Stator Technology

Conventional electric motors have a laminated iron core with copper coils (i.e., windings). The copper coils are made using specialized forming machines and must be manually inserted, requiring substantial time and labor. Once placed, copper windings are impregnated with an insulating resin that has a high dielectric strength. The purpose of the resin impregnation process is to eliminate air pockets or voids in the insulation. Voids are susceptible to electric discharges and interfere with the heat transfer from the coils to the iron core.
The iron core and copper windings have different thermal expansion coefficients

from one another, so they expand at different rates as motor temperature changes. Expansion and contraction generate thermally induced stresses that can cause cracks in the winding insulation. Cracks are susceptible to electric discharges that can lead to insulation failure.

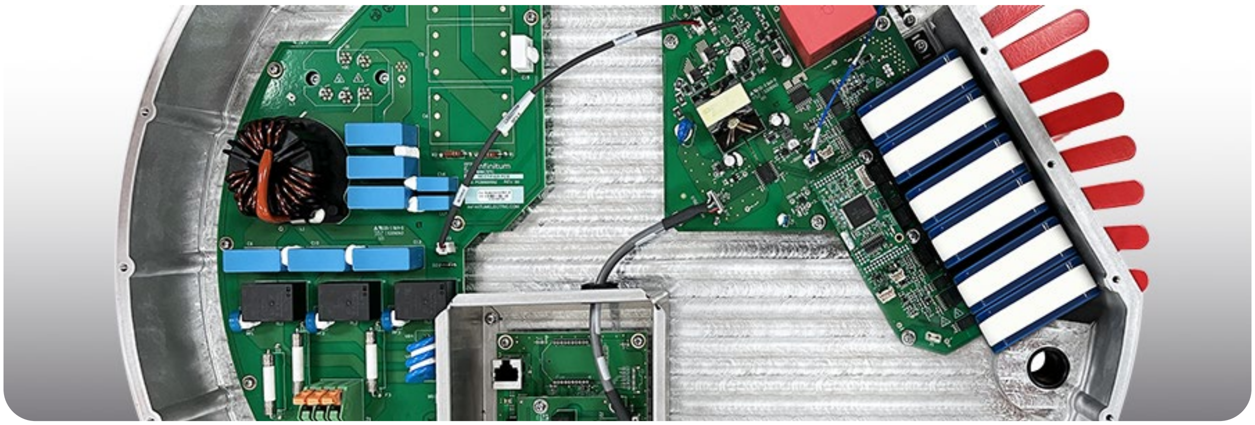
Infinitum motors feature printed circuit board (PCB) stators that use 66 percent less copper than conventional, wire-wound stators. By using a standard, well-proven PCB manufacturing process and common material, like ASTM FR4, Infinitum PCBs can be manufactured world-wide with unparalleled consistency. By design, each layer of copper and glass-epoxy laminate has a similar thermal expansion coefficient, so temperature changes generate a uniform contraction or expansion that prevents thermal cracks. In our recent paper, "Voltage and temperature endurance of printed circuit board (PCB) stators," testing shows that Infinitum's PCB stator life is at least 10 times longer than that of a conventional copper and iron core stator.

Manufacture and Integration of Drive Components

The variable frequency drive (VFD) is integrated into all Infinitum motors. VFDs are tuned by motor family for optimal efficiency. The tuning process optimizes motor system efficiency. Because the VFD is an integrated component, there is less wiring for OEMs, simpler installation, and fewer opportunities for connectivity failures once installed. Beyond a reduction in physical wiring, integration provides seamless connectivity between the motor and drive. Physical proximity reduces electromagnetic interference (EMI) and signal losses on communication links.

Infinitum VFDs undergo extensive electrical resiliency testing to ensure reliability when subjected to electrical transients. All Infinitum VFD components are selected for their high MTBF values and quality.

Strategically positioned heatsinks on the VFD case, right below our silicon carbide metal-oxide-semiconductor field-effect transistors (MOSFETs), maintain low junction temperatures and eliminate the need for liquid cooling, which is prone to failure. Real-time temperature monitoring adds an extra level of insurance via motor drive control software.



Assembly

Infinitum employs robotic assembly equipment to establish highly repeatable processes and ensure precise placement of key components. From a system-level perspective, precision and repeatability result in higher reliability in Infinitum motors.

Predictive Analysis

Another strategy to improve reliability involves predictive modeling. Failure Mode and Effects Analysis (FMEA) is a proactive method to identify where and how a component or system might fail. With that knowledge, engineers can assess the impact of different failure modes, modify components, and/or change processes to reduce the risk of a particular failure occurring.

FMEA can be used in the design and development (DFMEA) as well as the manufacturing process (PFMEA) of electric motors. Design and process FMEA identify opportunities to reduce Risk Priority Numbers (RPNs). RPNs indicate likelihood of failure for a particular component or process by accounting for the severity of the failure and the number of occurrences. A higher RPN value indicates a higher likelihood of failure.

Design Failure Mode and Effect Analysis (DFMEA)

Infinitum uses DFMEA to identify possible weaknesses in motor design, address product malfunctions, and lengthen the product life cycle. For this analysis, RPNs are calculated using MTBF values and a severity, occurrence, and detection scoring rubric. Our statistical results are validated based on aggressive destructive testing using different iterations of Infinitum motors. Run-time testing is another component of the feedback loop. Run-time results are independently analyzed and validated by third-party labs like Austin Reliability Labs (ARL).

Process Failure Mode and Effect Analysis (PFMEA)

As Infinitum ramps up production, process FEMA will enhance long-term reliability by identifying functions and failure modes that negatively impact overall motor manufacturing. Each failure receives a severity ranking determined by its effect. If causality can be determined, the team takes action to reduce the impact.

Highly Accelerated Life Tests (HALT) and Highly Accelerated Stress Screenings (HASS)

Infinitum also performs Highly Accelerated Life Tests (HALT) and Highly Accelerated Stress Screenings (HASS) in on-site temperature chambers and in third-party labs. HALT helps examine thermal cycling from maximum and minimum rated temperatures, revolutions per minute (RPM), static load, and on-off-on cycles. Infinitum disassembles motors after HALT to check for degradation or signs of internal component wear. HASS is a quality assessment to identify weaknesses that may have been caused by the manufacturing processes, so elements of the process can be amended accordingly. By investing time, expertise, and resources throughout design, analysis, and production, Infinitum has built intrinsic reliability into our motors. For more information on how our motors are built, visit our website. There, you'll also find a motor selection tool to help you better understand which Infinitum motor family is best suited for your application.