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Tel: 978-562-6017 / Fax: 978-562-7939

Introduction

The need for testing the rotors for the high-speed electric motor is on the rise. The race for better electric drives for EVs, drones, hybrid drive/propulsion systems is accelerating. Many nascent high-performance motors are designed to operate at much higher speeds than the traditional units and require superior durability. Designing and validating the structural integrity, balancing strategy, and durability of the rotor is becoming a relevant concerns.

Challenges in Designing a High-Speed Electric Motor

Optimizing the amount of air gap in a motor is one of the key design concerns for electrical motor engineers. The gap between the rotor and the stator, of course, is a necessary feature to separate the spinning rotor from the stator. Depending on the speed and the size of a motor, the amount of the air gap could range from 0.2~5 mm. The amount of gap must be large enough to accommodate the relative movement between the rotor and the stator due to:

- Manufacturing tolerances
- Movement resulting from the looseness in the support bearings
- The movement caused by shaft/rotor deflection due to unbalance or magnetic pull force
- Growth (or expansion) of the rotor diameter due to centrifugal loads
- Cooling air flow requirement to manage the heat

The undesirable effect of the larger air gap is the high resistance to the magnetic flux, which results in an associated electrical loss. For the higher speed motors, the air gap tends to be larger. Though in some cases a larger air gap is intentionally designed to reduce the “armature reaction”, it is generally desirable to minimize the gap to lessen the magnetic flux resistance and to achieve a better efficiency.

Traditionally, electric motors are designed to operate at relatively low speed (2000-5000rpm).

Nascent high-speed / high-power density motors operate above 15,000 rpm, posing a serious structural engineering cocnerns akin to turbomachine’s.

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The challenge exists for engineers and designers to fully understand the rotor behavior under the high-speed environment and articulate the amount of necessary air gap and optimize the performance of the motor as the competition for developing more efficient and better performing electromagnetic machine intensifies.

Why spin test?

Anything that spins at high speed is subjected to centrifugal (CF) loading. The stress and the deformation behavior of the rotor could very quickly become a complicated problem as the CF load interacts with as the CF load interacts with various features designed into the rotor's structure of the rotor to fashion desired functionalities.

Despite their deceivingly simple appearances, the design of high-speed motor rotors are often complex due to the necessary features it must capture to achieve its functionality. For example, there are several variants of permanent magnet motors we have been asked to spin test. Typically, these rotors have some type of high-strength wrap on its outer diameter to structurally support the magnets from the CF load.

Depending on the material behavior of the wrap under the CF load, and the behavior of the internal construct of the rotor, the growth of the rotor could differ significantly from a numerical model prediction - often surprising the engineers and designers.

Typically, the result of an FEA study gives a clean "even" rotor growth pattern. However, the reality of the rotor growth behavior can be much more complicated as illustrated in the growth measurement data shown in the Figure-1. In real-life, the variations in material properties, positions of the magnet, inherent limitations in manufacturing and assembly accuracies compile into an often uneven and non-uniform rotor growth. The uneven deformation results in unbalance and uneven air gap, that does not only impact the motor efficiency but also which degrades operational quality and durability due to the increase in noise and vibration levels.

Spin test data serves an important role in providing the critical engineering information to the engineers and designers so that they can make necessary design adjustments in the earlier stage of product development. The insights from the test help engineers to fully understand the limitation of the tested design and the implications of the assumptions they made in numerical models.

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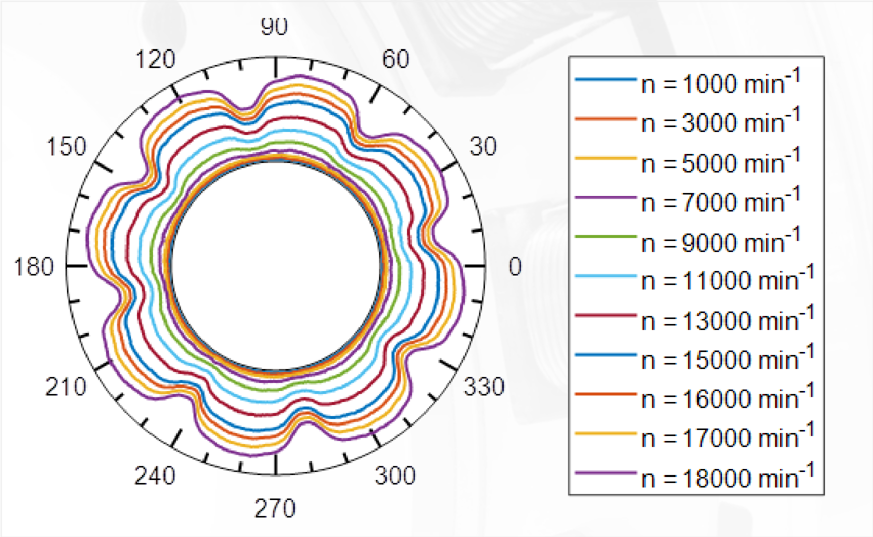

Figure-1: A map of rotor diameter growth at different rpm. The "lobes" in the growth pattern signifies the higher growth areas where the magnets are embedded in the rotor. Note: "Relative growth" value is shown – The runout was isolated from the plot.

Why work with us?

Challenges in designing high-speed electric motors parallel those faced by jet engine customers: The need to understand the rotor stress and growth behavior to accurately to engineer reliable and dependable machines.

One of the important roles TDI has been playing in helping the leading Jet Engine customers is to devise the tests to study and understand the growth of the turbine & compressor disks. The disk growth behavior directly impacts the amount of clearance between the engine casing and the blade tip. Achieving a smaller blade tip clearance results in higher engine efficiency, but the amount of the clearance must be carefully defined by balancing the risk of causing severe rubbing between the blade tip and the casing.

Optimizing the amount of clearance between the blade tip and the casing involves understanding a complex interplay of various factors including, manufacturing tolerances, the amount and the evenness of disk (and blade) growth, thermal expansion, casing deformation (due to the gas pressure and temperature) and more… Through innovative spin testing services, we can provide a piece of the puzzle.

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Test Devices by SCHENCK

The recent merger of Test Devices Inc (TDI) and Schenck Corporation (Schenck) combines the two most advanced spin testing, balancing and high-speed rotor engineering expertise available to serve your needs. Further to the detailed rotor growth test mentioned above, the following variants of spin tests and expert services may also aid in accelerating the design and development of your high-speed motors:

- **Detailed rotor growth mapping:**
  The advanced growth measurement technique was developed by Schenck, is now available also at TDI. The method maps the detailed contour of the high-speed rotors, capturing the accurate variation in the rotor geometry as it deforms under spinning condition.
  See Figure-1 for an example.

- **Burst test & high-speed video imaging:**
  Helps in understanding the failure limit and failure mode of the rotor. In-situ growth measurement and the high-speed video data would help engineers to understand the structural stability of the rotor and its failure mode.

- **Fatigue, LCF test (with RT-CDS & growth mapping):**
  Useful in studying operational cycle fatigue (Low Cycle Fatigue) and durability of the rotor. Test Devices' proprietary Real-time Crack Detection System (RT-CDS) will detect the initiation of the fatigue crack to halt the test to preserve the damaged rotor before it disintegrates. RT-CDS enables customers to know the exact location and the property of the fatigue initiation site, alleviating the need for time-consuming failure investigation work.

- **Heated spin test:**
  Thermal management is one of the key concerns in high-speed motor designs. Operating temperature affects the material strength, as well as the amount of air gap necessary for cooling airflow, and to accommodate the rotor growth due to thermal expansion. Depending on the type of material used to construct the rotors, their behavior could vary dramatically when operated in a room temperature vs. in an elevated temperature condition.

- **The unbalance budgeting:**
  An expert design analysis service to estimate the range of unbalance of a given rotor design. The effect of geometric tolerances of a given part is analyzed and its influence on the unbalance level of the rotor is estimated. By using a mathematical model to simulate the manufacturing process comparing ~10,000 different combinations of the tolerance variations. The output from the analysis provides a probabilistic model of the unbalance in the rotor, which can be used to tune the design to minimize the scatter and avoid surprises in your manufacturing process.