Magstrom white paper

Issues with airgap shape irregularities, sensitive machines and how to observe it

In this part we discuss machine designs that are more prone and sensitive to airgap variations, the resulting issues and how to detect them.

Designs prone to airgap issues

All electrical machines will have some form of airgap irregularity. The critical question to answer is whether the mechanical design can handle the resulting magnetic forces or not. Smaller electrical machines, and fast spinning ones, tend to have solid construction elements in the rotor: solid rotor spiders, and solid poles. These units typically handle airgap irregularities better than larger units but may still be affected over time.

Units with **large diameters** tend to have welded constructions and machine elements that are joined together instead of being machined from a single piece. Also placement matters – e.g. horizontal bulb units can have very large airgap irregularity due to the gravitational pull. Some designs optimized to handle thermal expansion and foundation movement are also causing headaches for plant owners. Units with **sliding stator feet**, **floating rotor rings or rims** or **segmented stators** which are not built in place but manufactured in a workshop and bolted together, experience the negative effects of the magnetic forces quicker, and some form of airgap monitoring system is recommended. The monitoring system observes trends in the airgap and alerts if they become too big.

Another reason for a magnetically unbalanced unit are rotor pole short circuits. A pole interturn short-circuit results in a lower magnetomotive force (MMF) from that particular pole (a less strong electromagnet). The reduced field strength from the defect pole rotates together with the rotor and causes an oscillating force on the stator at the rotational frequency.

The airgap is usually measured when the unit is cold, not magnetized (electromagnets turned off) and not during full rotation. During operation and thermal expansion, the low level of eccentricity under stationary conditions is typically not maintained, and it might be substantially higher. This behavior is expected and included in the design of large electrical machinery.

There are different designs and means to handle the changing airgap during thermal loading and rotation. For small electrical machines with rigid structures the airgap can be of the order of 1 mm. For large diameter machines, it is typically of the order of 10-30 mm. A large airgap will be more forgiving when it comes to airgap irregularities but also decreases the efficiency of the electrical machine. To be able to observe the airgap during all modes of operation, sensors are installed.

The magnetic forces between the rotor and the stator act to decrease the stator diameter even further. On the rotor, the centrifugal forces and the magnetic forces would both want to increase the rotor diameter. Therefore, the airgap is typically different from the nominal one during full rotation and when the rotor is magnetized.

Airgap monitoring

In order to quantify shape deviations and deduce if there are static or dynamic forces in play that cause vibrations, the best way is to measure the airgap at several locations. One method is to measure the distance between the rotor and stator with a capacitive sensor. This is commonly applied in larger electrical machines.

Another method is to measure the magnetic field strength at multiple positions since that directly couples with the local force that affects the rotor and stator. Magnetic flux density sensors do not capture the geometrical size of the airgap directly, but indirectly. A local variation in the airgap affects the magnetic flux density, which in turn is measured.

From the information of the variation of magnetic flux density the resulting magnetic forces can directly be calculated. Additionally, direct measurement of magnetic flux is the only way to conclusively detect rotor pole short circuits and other magnetic defects. Another drawback with capacitive sensors is that they are larger than magnetic flux density sensors and can cover several cooling ducts, thus locally reduce the cooling of the machine.

Issues that can be caused by irregular airgaps

A variety of issues can arise from airgap irregularities. The issues can be classified as either:

- Thermal
- Mechanical
- Electromagnetic
- Audible

Which phenomena is more pronounced depends on what type of irregularity the considered machine has; rotor or stator, static or dynamic or a combination thereof. Quite often the phenomena are related, e.g. an electromagnetic issue can lead to excessive heating.

Since some issues caused by airgap irregularities can also be caused by other mechanisms as well, it can be tempting to attribute problems to other causes than to airgap irregularities. If no direct measurements of magnetic flux exist, it may be wrongly assumed that a unit does not have issues with airgap irregularities, but still rotor components crack and damper bars break.

Typical issues resulting from airgap irregularities are:

- Vibrations (but quite often none) & Noise,
- Large journal bearing losses,
- Large losses in the damper bars,
- Hot spots, or hot regions in the stator laminates,
- Loose rotor poles,
- Rotor spider/rim material fatigue and cracks in the rotor.

These conditions are generally observed either by vibration monitoring and or generator inspection, but a vibration monitoring system does not observe losses and static forces. In order to conclusively attribute the issues to an irregular airgap, sensor that directly measure the flux in the airgap are required.