Magstrom white paper

How are issues from magnetic unbalance handled?
How does active magnetic balancing work?

Airgap variations are not in and of themselves problematic unless the rotor and stator comes into contact. However, because the airgap length determines the magnetic flux density between the rotor and stator that in term determines forces and, some of the, losses in the electrical machine. Thus removing the magnetic unbalance removes the issues related with airgap variations.

Means to alleviate unbalanced magnetic pull

Electrical machines are designed to withstand the unbalanced magnetic pull occurring due to airgap variations and rotor/stator irregularities that are naturally occurring in the electrical machines at hand. The issue being the forces, the vibrations, or the displacement that is a result of an unbalanced magnetic pull and the stiffness of the construction. In order to improve the situation mechanical balancing and alignment is always performed. This reduce the issues, but they cannot compensate a deformed component. There are, however, certain design features, and natural phenomena that reduce the forces between the rotor and the stator and they are mentioned below. The passive features, saturation, damper bars and parallel stator circuits has the potential to reduce the forces but not remove them completely. The only means to completely remove the forces, and the extra losses, is to use active magnetic balancing.

Saturation

Saturation is the natural phenomena that materials have a limit in how much the inherent magnetization can be polarized. Depending on the magnetic flux, density saturation will be more or less pronounced.

Although saturation is known to reduce the unbalanced magnetic pull, it is not something that is actively used for this purpose because it results in increased losses. The damping effect of saturation will only substantially reduce the forces and issues for very large airgap irregularities. For smaller values the saturation does not reduce the unbalanced magnetic pull to any large degree.

Damper bars

Damper bars are copper or brass bars that are installed on the pole surface and short circuited with a connection ring.

Damper bars are known to reduce the unbalanced magnetic pull forces occurring between the rotor and the stator. The reduction can be substantial, but at the cost of extra losses in the damper bars themselves and the appearance of a tangential force. The reduction of the force will be for both the total force between the rotor and stator and on the local force the stator experience at the pole passing frequency. Thus, damper bars will reduce the force, which in turn can cause vibrations and extra losses. Damper bars are not actively controlling the UMP so they should be denoted as a passive solution.

Damper bars are frequently installed in generators in order to introduce damping when connecting multiple generators to a load or grid. Synchronous motors directly connected to the grid use the damper bars to start the machine (make it spin). Without the damper bars, there are larger torsional oscillations when a generator is synchronized to the grid. Damper bars also serve to protect the field winding in directly online driven motors and generators during stator faults.

The inclusion of damper bars also has negative side effects, especially in synchronous motors damper bars are prone to cracking due to the large currents and high temperatures they experience during startup. A cracked or broken damper bar can potentially enter the airgap with detrimental results. A machine with damper bars will also require a higher rotor field current in order to compensate for the reduced permeability of the magnetic material leading to higher losses in the machine. However, a converter driven machine would not face the same thermal loading of the damper bars and issues would be similar to a hydropower generator where cracking is not that common as in motors.

Parallel stator circuits

Some electrical machines are built with parallel stator circuits to reduce the current loading in the stator. In an electrical machine with parallel circuits and dynamic eccentricities it is true that unbalanced magnetic pull will be reduced compared to a single circuit machine.

However, for a static eccentricity, this is not always true, and the situation can even cause unwanted phenomena. The circuits (depending on how they are placed in relation to the eccentricity) might not reduce the total force at all, and it may even *induce* oscillating forces at exactly the pole passing frequency[1]. It can also happen that the total force is reduced but a force component at the pole passing frequency arises which can be substantial. Because parallel stator circuits do not actively control UMP, they would not be an active, but merely a passive measure.

Active control

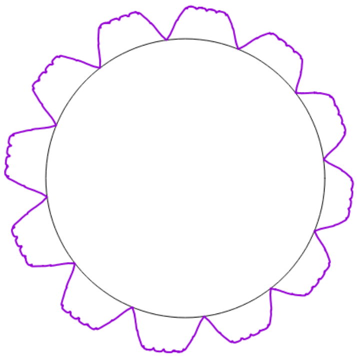
Recent development in power electronic has enabled new innovations[2] and led to the possibility to actively control the unbalanced magnetic pull. The split-rotor concept enables control of segments of rotor poles to ensure the magnetic field is symmetric along the airgap. The system smooths the magnetic field in the airgap irrespectively of the physical airgap length. When controlling the field in the airgap actively it is possible to remove certain so-called space harmonics in the airgap magnetic flux density originating from e.g., shape deviations in the rotor and stator. Controlling the magnetic flux density also means controlling the unbalanced magnetic pull and the vibration inducing forces. This method is not state of the art and represents an emerging technology, but has been demonstrated in pilot projects.

How does the magnetic balancing work?

The objective of a magnetic balancing system is to take a flux density like in the figure below (larger on the left compared to on the right),

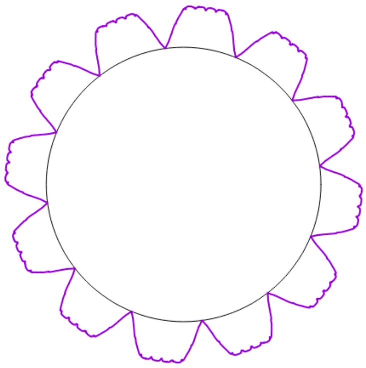
[1] **M. Wallin, M. Ranlöf, and U. Lundin**, **"***Reduction of unbalanced magnetic pull in synchronous machines due to parallel circuits",* IEEE Trans. Magn. 47, 4827 - 4833 (Jun 2011)

[2] **J.J. Perez, C.J.D. Abrahamsson, U. Lundin,** *"Demonstration of active compensation of unbalanced magnetic pull in synchronous machines"*, CIGRE Science & Engineering, 8, 98 - 107 (June 2017)



Absolute value of the airgap magnetic flux density, in a machine with eccentricity. The small arigap is to the right.

and make it as uniform as possible (shown below)



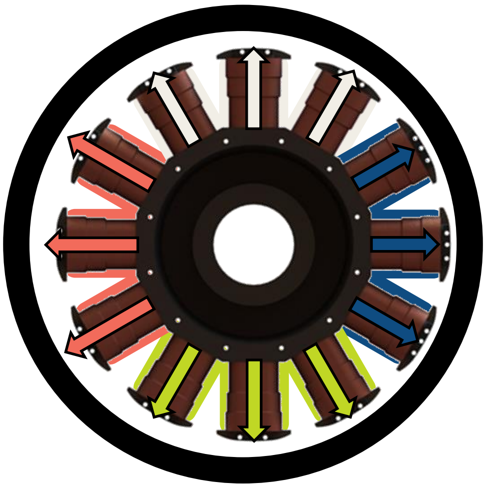
A uniform airgap magnetic flux density that does not produce detrimental forces and losses.

If the electrical machine is magnetically balanced the unwanted forces are removed together with the issues of the forces and uneven flux density (the extra losses and THD).

The physical distance between the rotor and the stator cannot be changed in real time. But the detrimental forces and losses are a result of the unbalanced magnetic field and the magnetic field between the rotor and stator is a result of the physical airgap, the material properties and the **field current** that runs around the electromagnets on the rotor. This means that by controlling the field current to be slightly different in different parts of the rotor the magnetic field will become more or less perfect. This requires modern power electronics that can control currents very fast.

Sensors measure the present magnetic state of unit and analyze the static and dynamic magnetic strength of the individual rotor poles. This information is processed in a dedicated microcontroller which also calculates the needed current for each pole, or groups of several poles. The power electronics ensure that each pole, or segment of a few poles, gets the needed additional current.

Connections are made between the pole interconnectors for the groups of poles and

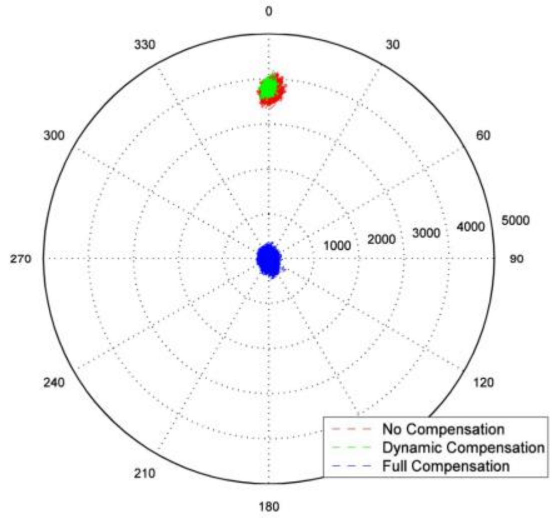


dedicated power electronic hardware.

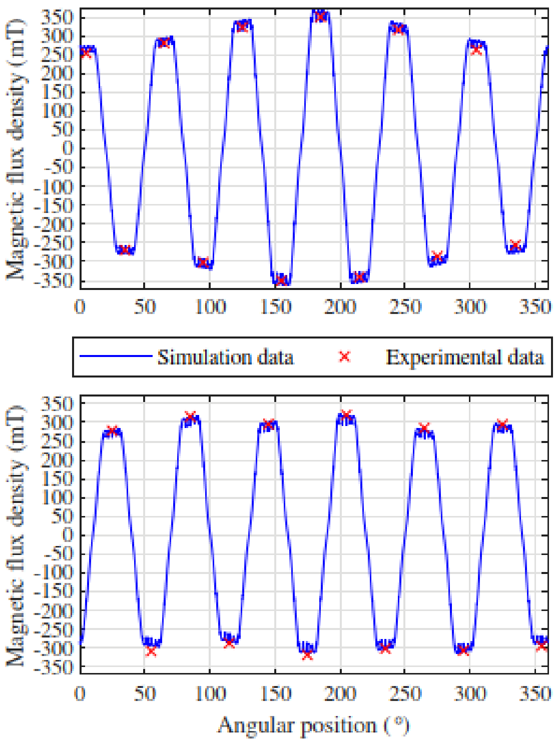
The magnetic balancing system active on a 12 pole salient pole generator which has some eccentricity (small airgap to the right). By reducing the current in the blue segment and increasing the current in the red segment magnetic balance is obtained.

As the rotor spins the field current is adapted to the position of the rotor and the shape irregularity of the airgap.

By equalizing the magnetic field in the airgap, the large unbalanced magnetic forces between the rotor and stator are neutralized, and the machine presents an almost perfect round and concentric rotor and stator magnetic field.



Forces measured between the rotor and an eccentrically placed stator of a smaller generator without any compensation (red), with compensation for rotor defects (green) and full compensation of stator defects (green).



Airgap flux density. The top picture shows the eccentric case (simulated and measured) without magnetic balancing, and the lower picture shows the same with magnetic balancing.