OPTIMIZATION OF ELECTROMECHANICAL DEVICES

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ABSTRACT

Electromechanical devices are becoming ever more common in transport industries, aerospace, marine and automotive. Lower maintenance and easier control are part of the driving force in the progression of electric machines.

Weight and noise are two of the concerns facing the designer of electric machines. In a world where sustainable energy is key, efficiency, materials and reusability are strong constraints of the design. Light, silent and efficient are necessary qualities for success.

Choosing the appropriate machine topology (pole/slot combination, type of motor) is only the first step of the design. Through the shape optimization of the motor features such as stator teeth and rotor poles the designer will reduce the weight of the machine. Shape optimization will also help control the electromagnetic forces leading to vibrations and noise generated by motors. Furthermore, the quality of the torque produced by the machine is key to smoother operation of the device. Optimization needs however to match and maintain the electromechanical specifications for the machine.

In this contribution, we consider an existing industrial motor in which the torque ripple developed during operation leads to much vibrations and noise. The industry would accept the noise as a trade-off for low cost of production. However, failures of bearings in this machine lead to costly repair. The failures are traced back to the vibrations of the motor. The cost of replacement makes limiting the vibrations in the motor a design requirement.

In a first set of studies, a shape optimization of the motor features is performed to limit the torque ripples during operations. The motor is driven by a sine drive. Torque ripples are associated to variations of the electromagnetic field in the airgap, more precisely to the harmonic content of BEMF in PM motors. A first idea is that reducing the harmonic content of the BEMF will lead to a lower torque ripple, limiting the vibrations.

In a first optimization, the objective is to lower the total harmonic distortion (THD) of the BEMF developed by the motor. The goal is to obtain a BEMF as sinusoidal as possible. Elements of the shapes of the motor features are the parameters tested. The constraints are the average torque and acceptable saturation of the magnetic components. This optimization yielded reduction of torque ripple from 27% of the average torque for the initial design to only 4% for the optimized design.

To try to reduce the torque ripple further, a new optimization is performed. In this case the objective is the minimisation of the torque ripple itself, the constraints and parameters remaining the same as before. Again, the motor was fed with a sine drive. Through this direct optimization, the torque ripple is further reduced to 1% of the average torque.

These two optimizations lead to modifications of the geometry. This type of optimization is only possible when conducted early in the design. These shape optimisations also lead to lighter and stronger designs. However, when trying to reduce the torque ripple after construction of the motor, reshaping the geometry is not an option anymore.

A possibility is to work on the drive signal fed to the motor. In this case, the shape of the signal is optimized to yield the same average torque with a lower torque ripple content. The goal of the optimisation is the content in torque ripples, the parameter is the shape of the input signal, and the constraints remain the same as before, minimal torque and maximum saturation to respect. Using this optimisation, the torque ripple was reduced to only 1.9% of the average torque, without any change in the geometry of the motor.

The best process for optimization is to include both the vibration analysis and the electromagnetic analysis into the same optimization scheme, bringing the vibration concerns early in the electromechanical design through loose coupling of EM and mechanical tools in the optimization environment.