Technical note

CONTROL METHODS FOR QUIET OPERATION OF PERMANENT MAGNET SYNCHRONOUS MOTORS

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INTRODUCTION

Noise and vibration production in electric motors is predominantly driven by pulsating torque. Though methods are available to isolate the pulsating torque from creating unwanted noise or vibrations, this research considers methods that act at the source and minimise pulsating torque.

Smooth torque production in electric motors usually requires careful motor design and manufacture. High precision manufacturing increases costs and the challenge is to make motors cheaply that have the smoothness and quietness of more expensive items.

One method to minimise design and manufacture restrictions in Permanent Magnet Synchronous Motors (PMSM) is to measure each motor's imperfections as it leaves the production line. This information can then be used to calculate specific current waveforms to compensate for these imperfections and allow quiet operation from an otherwise noisy motor. Current feedback control is used to ensure that these current waveforms are followed in operation.

The success of this method relies heavily on accurate measurement of the motor imperfections responsible for the pulsating torque. Without this accurate measurement, compensation and quiet operation is not possible.

The key objectives of this research were to:

- identify critical motor imperfections responsible for creating pulsating torque.
- develop a new method to accurately measure these imperfections.
- implement previously published current control methods using the new imperfection information to minimise pulsating torque.

MOTOR IMPERFECTIONS

Motor noise originates from pulsating torque. The main motor imperfections responsible for creating pulsating torque are cogging torque and current measurement error (offset and gain) [1].

Cogging Torque

Cogging torque in a PMSM is caused by the magnets on the rotor tending to align with the steel teeth on the stator rather than with the copper windings. Careful motor design (magnet arc adjustment, skewed magnets) can eliminate cogging torque. However, in practice, manufacturing errors (magnet placement, eccentricity and material property variation) will always lead to some cogging torque.

For one motor studied, Islam, Mir and Sebastian [2] suggested that if a magnet is misplaced from its "perfect" position by 1°, then the magnitude of the cogging torque can be increased by over three times.

Current

Current measurement error is normally considered as a combination of an offset and a gain error (i.e. the assumption is made that the output remains linear).

Chen, Namuduri and Mir [3] calculated that in the worst case, a 1% error in offset could lead to a 4% error in torque ripple and a 1% scaling error between sensors in different phases could lead to a 2.3% torque ripple.

EXPERIMENTAL SETUP

To ensure accurate torque measurement, a test setup was designed using finite element modal analysis to avoid any resonant frequencies in the measurement range. To verify the analysis, the system was analysed using an impact hammer and accelerometer. This testing confirmed that the first resonant frequency was at 700Hz, well above the upper measurement limit of 150Hz. The final test setup is shown in figure 1.

ACCURATE MEASUREMENT

Traditionally, motor imperfections (cogging and current errors) have been measured independently. Our research showed that a more effective method of measuring motor imperfections was to split up the total motor noise into individual components. This pulsating torque decoupling (PTD) approach was done by applying a least squares minimisation between the electromagnetic torque generated by the current and the measured torque. The cogging torque, which should be independent of current was then the residual, or remaining torque not explained by the electromagnetic torque.

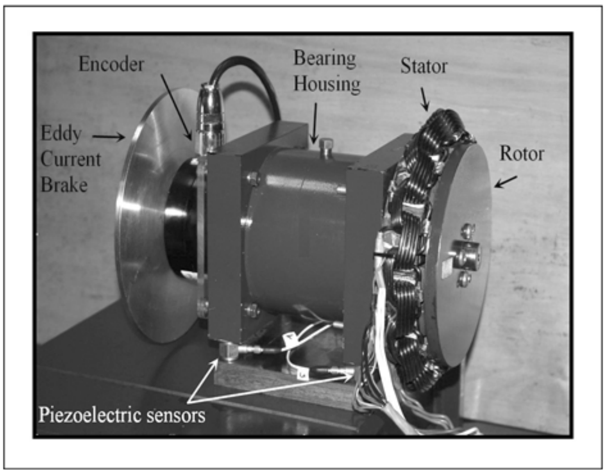

Figure 1. Charles Darwin University Motor Test Setup

The first pane in figure 2 shows the original pulsating torque. The second pane demonstrates how the torque can be split up into the “Xy” component that is due to the current errors and the “z” component that is predominantly the cogging torque. Some of the “z” component cannot be explained by cogging torque and this is shown in the third pane.

More detailed analysis is presented in [4].

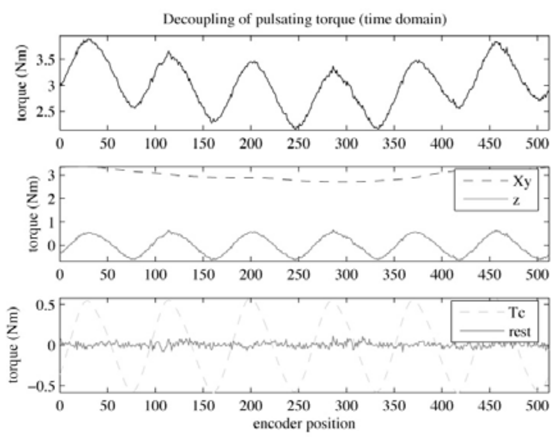

Figure 2. Torque decoupling (time domain)

RESULTS

For the test motor considered, the pulsating torque levels were calculated as the root mean squared (RMS) value of pulsating torque divided by the rated torque of the motor. A standard sinusoidal current was used as a baseline and resulted in 8 - 9% pulsating torque.

To see the potential improvement, five published methods for minimizing pulsating torque were compared. For each method, the performance was evaluated using information about motor imperfections determined by (1) traditional methods of measurement and (2) the PTD method.

Figure 3 shows that while there was a small variation between methods, the source of imperfection information was a much larger determinant for the total pulsating torque. The use of traditional methods, resulted in 3-4% pulsating torque while when the PTD method was used, the best method was capable of reducing the pulsating torque to less than 1% of rated torque.

This result demonstrated that if the motor imperfections can be adequately determined, an otherwise noisy motor can be made to run smoothly and quietly.

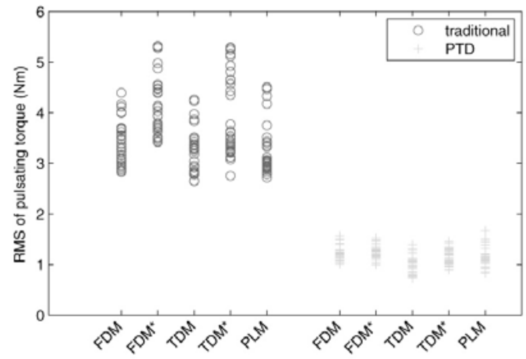

Figure 3. Pulsating torque method comparision

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