Sensorless Field-Oriented Control and Position Estimation

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Reducing reliance on rare earth metals and cutting costs has become a significant priority for automotive supplier BorgWarner Sweden AB. In line with this objective, BorgWarner aims to explore the implementation of a sensorless field-oriented control (FOC) solution for their in-house developed and produced Brushless Direct Current Motor (BLDC). By reducing the need for physical sensors, such as neodymium magnets and magnetic angle sensors, BorgWarner hopes to achieve greater robustness and cost-effectiveness in their electrical motor systems.

To achieve the goal of eliminating the neodymium magnet and magnetic angle sensor setup, this master thesis investigates the possibilities of estimating the rotor position of the BLDC motor from standstill up to high speeds. Two distinct methods are employed to accomplish this estimation.

At medium and high speeds, the back electromotive force (BEMF) proves to be a valuable tool for determining the rotor position. Since BEMF is directly proportional to the rotational speed, it can be used for estimation purposes. However, in this study, an alternative approach is adopted to estimate the rotor position. Instead of relying solely on BEMF, the magnetic flux, which aligns with the rotor, is utilized along with a Phase-Locked Loop (PLL). This approach is preferred due to issues such as unwanted noise and signal offset present in the BEMF, which lead to an unreliable angle estimation.

To estimate the rotor position at standstill and low speeds, the high-frequency induced voltage signals and the motor's characteristics are utilized. By analyzing the high-frequency current response to the high-frequency injection, the rotor position can be obtained. However, it should be noted that the high-frequency injection method encounters limitations in the presence of a load, leading to suboptimal performance.

Comparing the two methods, the magnetic flux based PLL implementation emerges as the most reliable approach for medium and high speeds. The sensorless FOC proves to be more resilient to loads than the sensored FOC at high speeds, for instance, from 1000 rpm, the sensorless FOC showcases a better load capacity, at some cases up to 200 %.

The high-frequency injection method, which relies on saliency characteristics, shows promise in estimating the rotor position at standstill and low speeds. However, this method encounters limitations in the presence of a load, resulting in compromised performance.

In conclusion, the best method for medium and high speed was the magnetic flux method along with PLL. The high-frequency injection method proved the ability to estimate the rotor position at standstill and low speeds, but need a further development to resolve the poor performance issue.

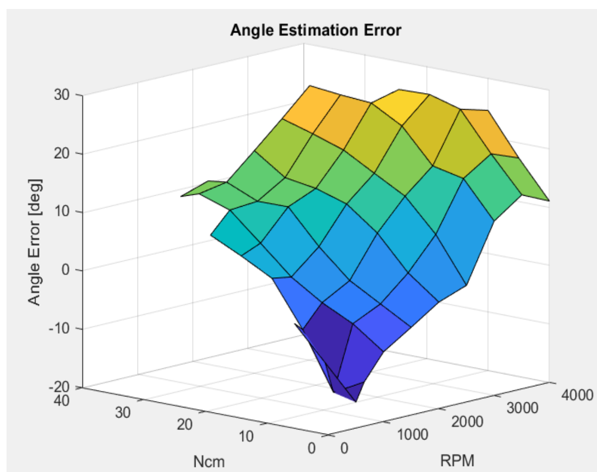

Figure 1: Angle estimation error from the calculated magnetic flux rotor position estimation.