Estimation and Control of Switched Reluctance Motors

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Background

Switched Reluctance Motors (SRMs) are appealing electric actuators due to their mechanical simplicity; however, they experience considerable torque ripple when controlled with model-based methods if the model is not perfectly accurate, see Figures 1 and 2. The torque produced is given by

$$T = \boldsymbol{g}^\top(\phi)\boldsymbol{u}, \tag{1}$$

where ϕ is the rotor angle, and $\boldsymbol{u}$ is a vector of squared currents applied to the phases. The currents to be applied are determined by a commutation function $\boldsymbol{f}$:

$$\boldsymbol{u} = \boldsymbol{f}(\phi)T^*, \tag{2}$$

which must satisfy $\boldsymbol{g}^\top(\phi)\boldsymbol{f}(\phi) = 1$ to achieve a desired torque T^*. This requires an accurate model $\hat{\boldsymbol{g}}$; any model mismatch leads to torque ripple $T \neq T^*$, deteriorating performance.

Identification of Switched Reluctance Motors

In [1], an identification approach of $\hat{\boldsymbol{g}}$ is presented that relies on data of only the currents and rotor angle; no torque sensors are required, reducing the cost. Figure 3 shows that in this way, very accurate models are obtained. These accurate models enable the design of appropriate commutation functions.

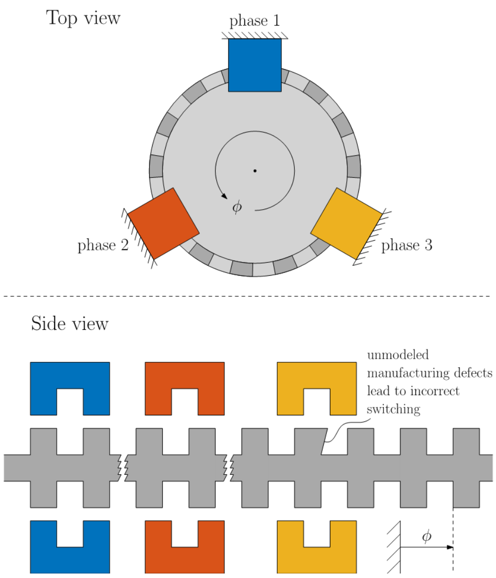

Figure 1: Overview of an SRM. The rotor is located between three stator phases. Energizing a phase with current pulls the nearest rotor tooth, creating torque. Proper timing and control of these currents depend on an accurate model of the SRM.

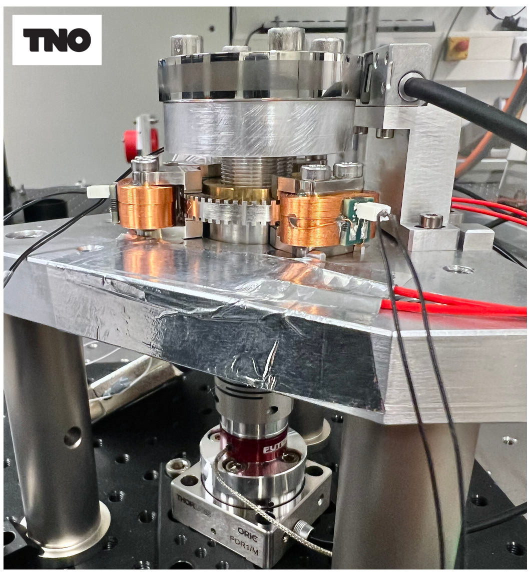

Figure 2: Prototype SRM from TNO. A torque sensor is mounted for validation purposes only; only currents and position are measured during operation.

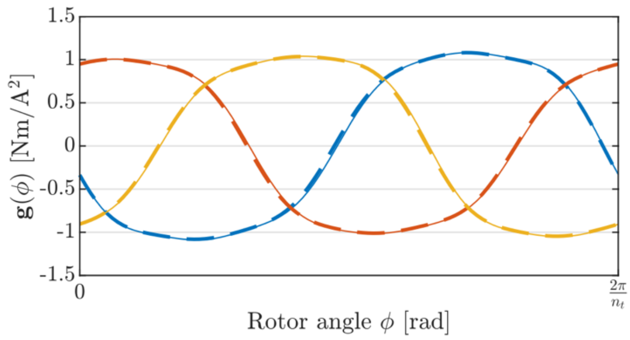

Figure 1: An accurate model (solid) of the true torque-current-angle relation (dashed) is obtained in simulation using only rotor position and current measurements.

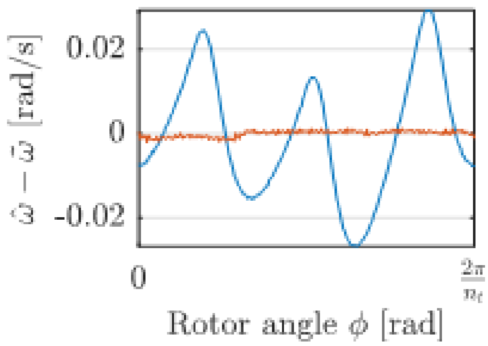

Figure 4: Experimental data showing the mean angular velocity of an SRM before automated commutation (blue) and after 200 iterations of online optimization (red) [3].

Commutation of Switched Reluctance Motors

With an accurate model $\hat{\boldsymbol{g}} \approx \boldsymbol{g}$, torque ripple can be completely eliminated. However, since multiple coils produce torque at any given position, there is additional design freedom in the design of $\boldsymbol{f}$ that can be exploited. In [2], this freedom is exploited to introduce robustness to manufacturing defects in mass production.

Alternatively, the modeling step can be skipped completely. In [3], an automatic approach to commutation design is presented that yields an $\boldsymbol{f}$ using extremum-seeking control, at the cost of a longer experimental time. Figure 4 shows that this approach also achieves accurate tracking.

Conclusion

Torque ripple in Switched Reluctance Motors can be reduced significantly using the presented data-driven approaches to identification and control, even in the absence of torque sensors. This enables opportunities for using SRMS in applications where torque ripple is currently a limiting factor.

References

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