Identification and Robust Control for Motor Commutation

Identification and Robust Control for Motor Commutation

Max van Meer[1], Gert Witvoet[1,2] and Tom Oomen[1,3]
[1]Eindhoven University of Technology, Eindhoven, the Netherlands
[2]TNO, Delft, the Netherlands
[3]Delft University of Technology, Delft, the Netherlands
m.v.meer@tue.nl

TU/e

iMOCO4E

BACKGROUND

Switched Reluctance Motors (SRMs, Fig. 1) provide

- power-efficient actuation,
- with mechanically simple designs,
- at the expense of increased control complexity.

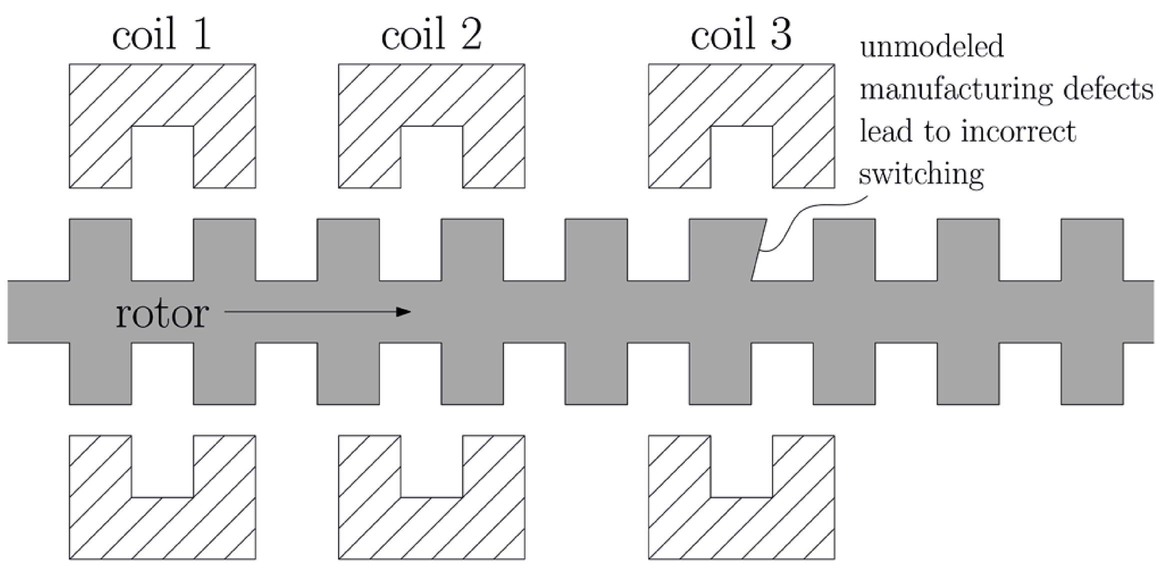

Figure 1
Working principle of SRMs. Sequentially applying currents to the coils attracts rotor teeth, generating torque.

Imperfect switching leads to torque ripple. Two solutions:

- Identification of the torque-current-angle relation
- Robust commutation design for accurate control

NONLINEAR IDENTIFICATION OF SRMs

$$T(\phi, i) = \sum_{c=1}^{n_c} \frac{1}{2} \frac{\mathrm{d}L_c(\phi)}{\mathrm{d}\phi} i_c^2, \qquad (1)$$

Inductances L_c, angle ϕ, and currents i_c affect the torque T.

Problem: How to identify $g = ½\, dL/d\phi$ from only ϕ and i_c, when no torque sensor is available?

Solution: experiment design + Bayesian identification

1. Closed-loop experiments to learn torque
2. Bayesian identification to obtain a model g (Fig. 2)

Results:

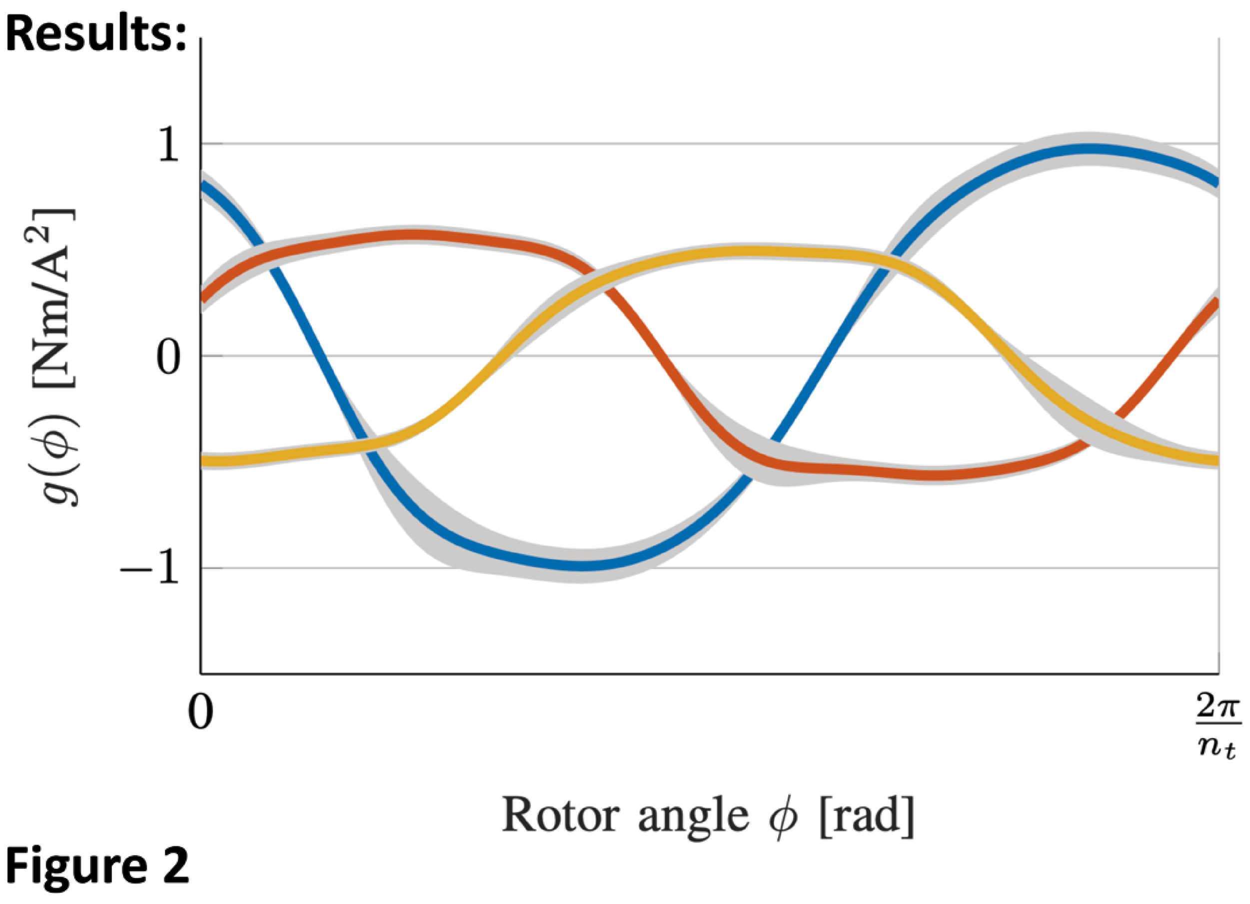

Figure 2
Experimental results. Even without a torque sensor, an accurate model of the SRM is obtained, as well as an expression of the model uncertainty K_θ.

ROBUST COMMUTATION DESIGN FOR CONTROL OF SRMs

Commutation is used to invert SRM dynamics g:

→ Currents $i^{\circ 2} = f(\phi)T^*$ should produce torque $g(\phi)i^{\circ 2} = T = T^*$

→ *Design $f(\phi)$ such that $g(\phi) f(\phi) = 1$*

Previous work: design $f(\phi)$ based on known $g(\phi)$[1]

Problem: g is uncertain and varies per tooth.
Inverting an uncertain model gives torque ripple! (Fig. 3)

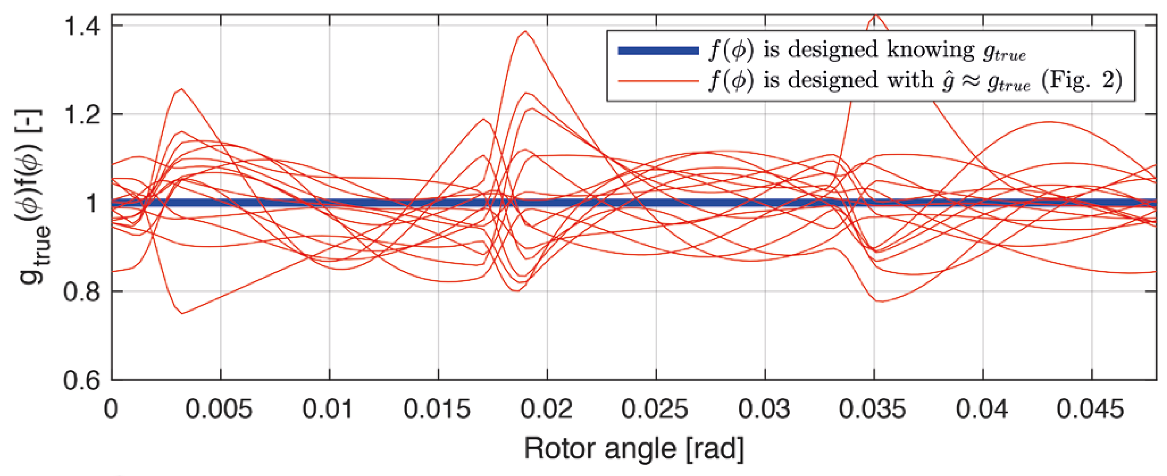

Figure 3
When SRM dynamics are known, perfect inversion is possible (blue). However, a little model uncertainty (Fig. 2) leads to a large torque error when inverted naively (red)!

Solution: design $f(\phi)$ to be robust to uncertainty in $g(\phi)$!

$$\begin{aligned} \min_\alpha \quad & \mathbb{E}\left[\|g(\phi,\theta)f(\phi,\alpha) - 1\|_2^2\right] \\ \text{subject to} \quad & f(\phi,\alpha) \geq 0, \\ & g(\phi,\hat{\theta})f(\phi,\alpha) = 1, \\ & \theta \sim \mathcal{N}(\hat{\theta}, K_\theta). \end{aligned} \qquad (2)$$

→ solve using convex optimization (Fig. 3)

Results:

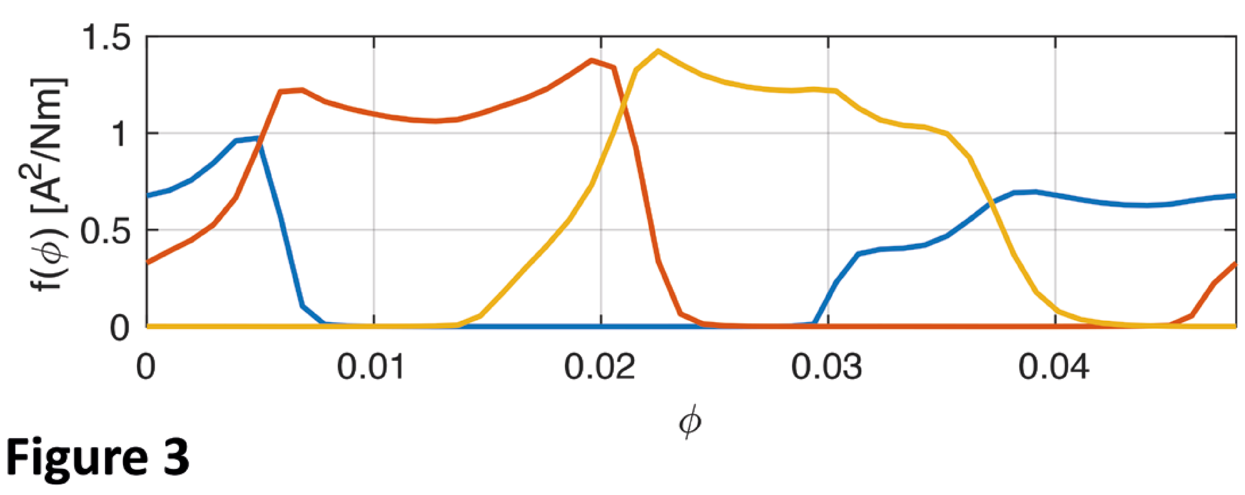

Figure 3
The solution to (2) leads to current waveforms with large overlap, leading to careful switches that induce limited torque ripple when the switching moments are uncertain.

Simulation results: 50% better tracking performance!

Conclusion: motor commutation is improved by data-driven identification of the nonlinear dynamics and subsequent design of robust commutation functions.

References

[1] van Meer, M., Witvoet, G., & Oomen, T. (2022). Optimal Commutation for Switched Reluctance Motors using Gaussian Process Regression. *IFAC-PapersOnLine*, *55*(37), 302–307.