

Identification and Robust Control for Motor Commutation

Citation for published version (APA):

van Meer, M., Witvoet, G., & Oomen, T. A. E. (2023). *Identification and Robust Control for Motor Commutation*. Poster session presented at 5th DSPE Conference on Precision Mechatronics, Sint Michielsgestel, Netherlands.

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Document status and date:

Published: 01/01/2023

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
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- The final published version features the final layout of the paper including the volume, issue and page numbers.

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Identification and Robust Control for Motor Commutation

Max van Meer¹, Gert Witvoet^{1,2} and Tom Oomen^{1,3}

¹Eindhoven University of Technology, Eindhoven, the Netherlands

²TNO, Delft, the Netherlands

³Delft University of Technology, Delft, the Netherlands

m.v.meer@tue.nl



BACKGROUND

Switched Reluctance Motors (SRMs, Fig. 1) provide

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

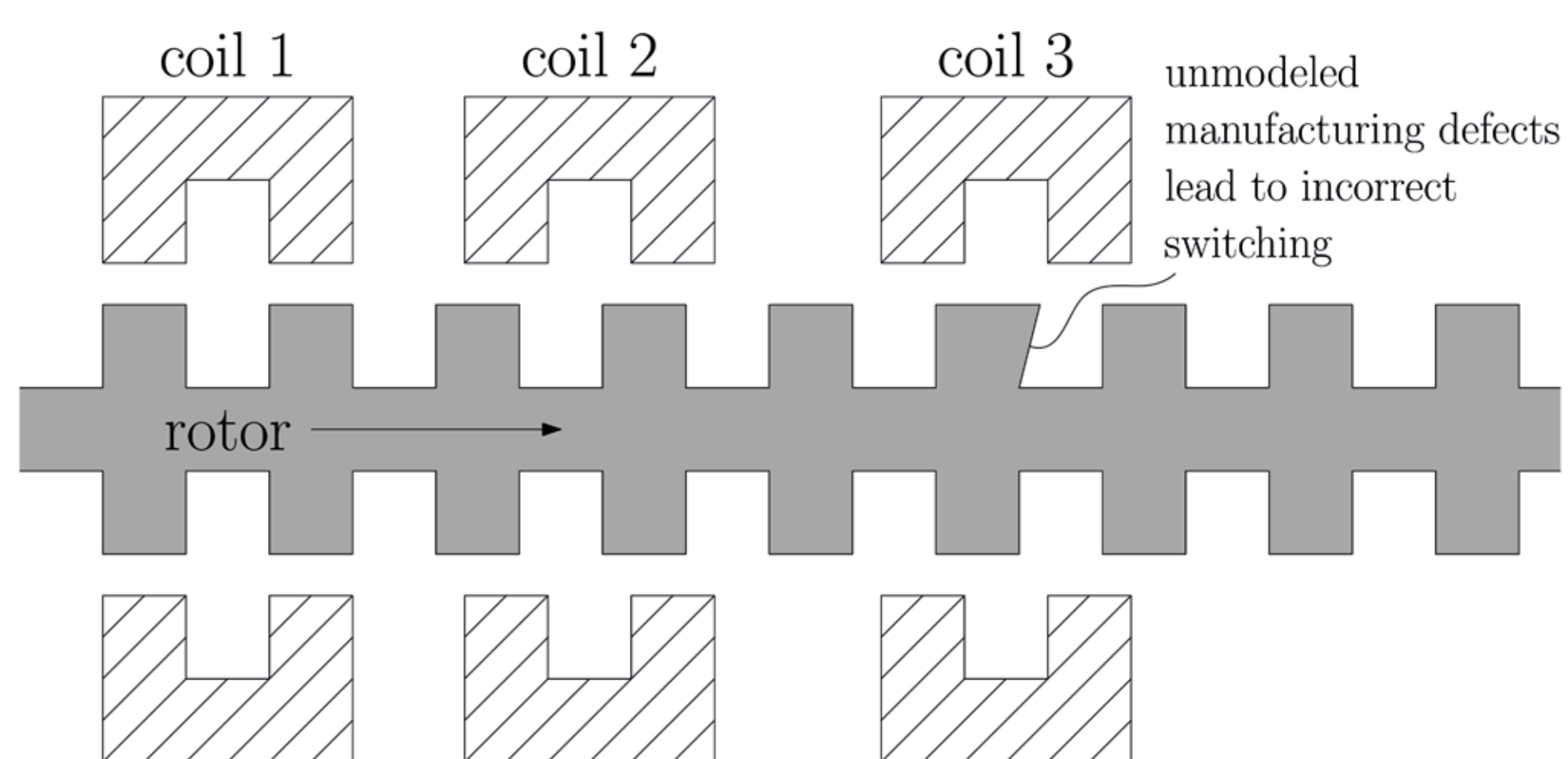


Figure 1

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

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

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

Problem: How to identify $g = \frac{1}{2} dL/d\phi$ from only ϕ and i_c , when no torque sensor is available?

Solution: experiment design + Bayesian identification

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

Results:

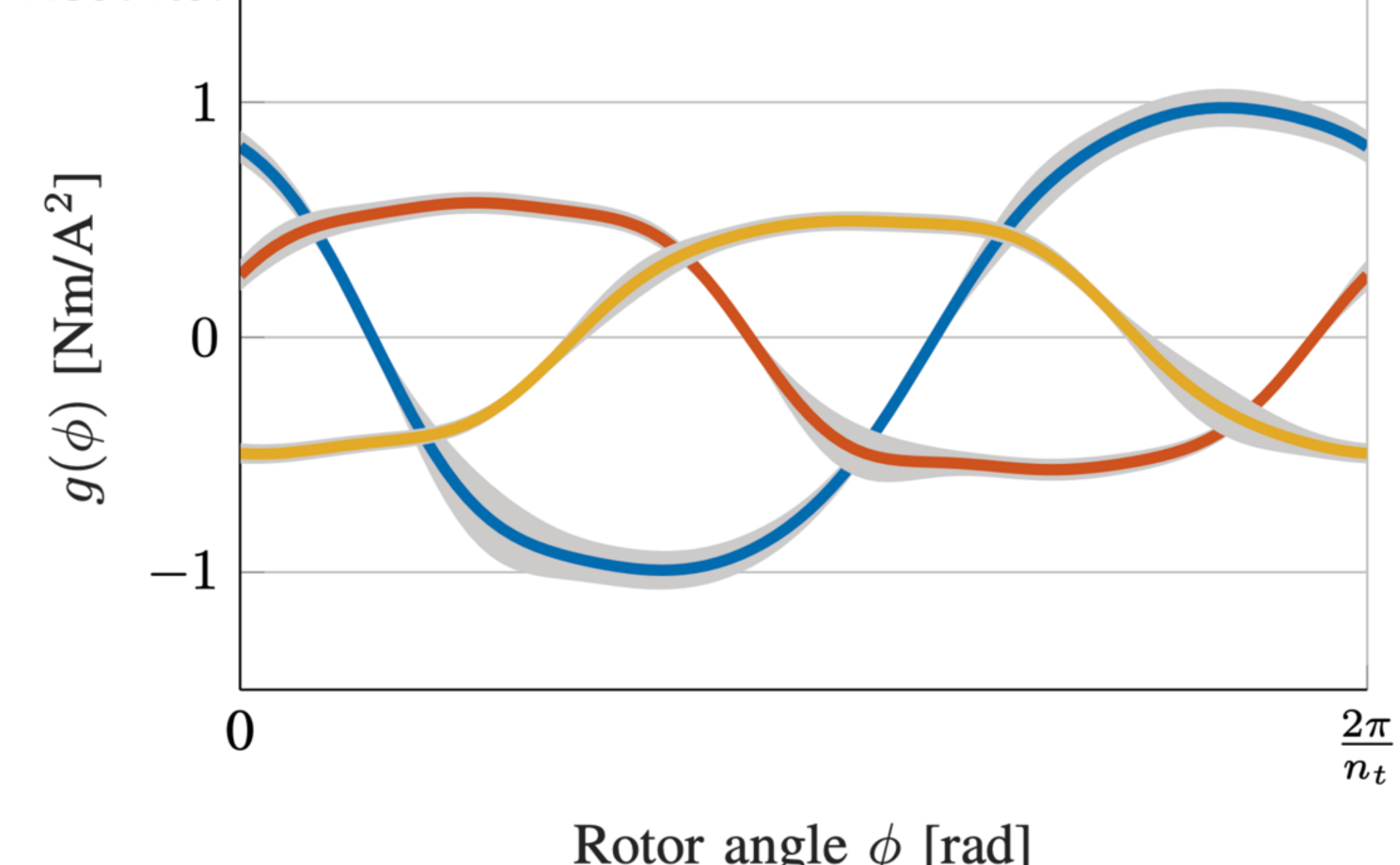


Figure 2

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 $i^2 = f(\phi)T^*$ should produce torque $g(\phi)i^2 = T = T^*$

→ 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)

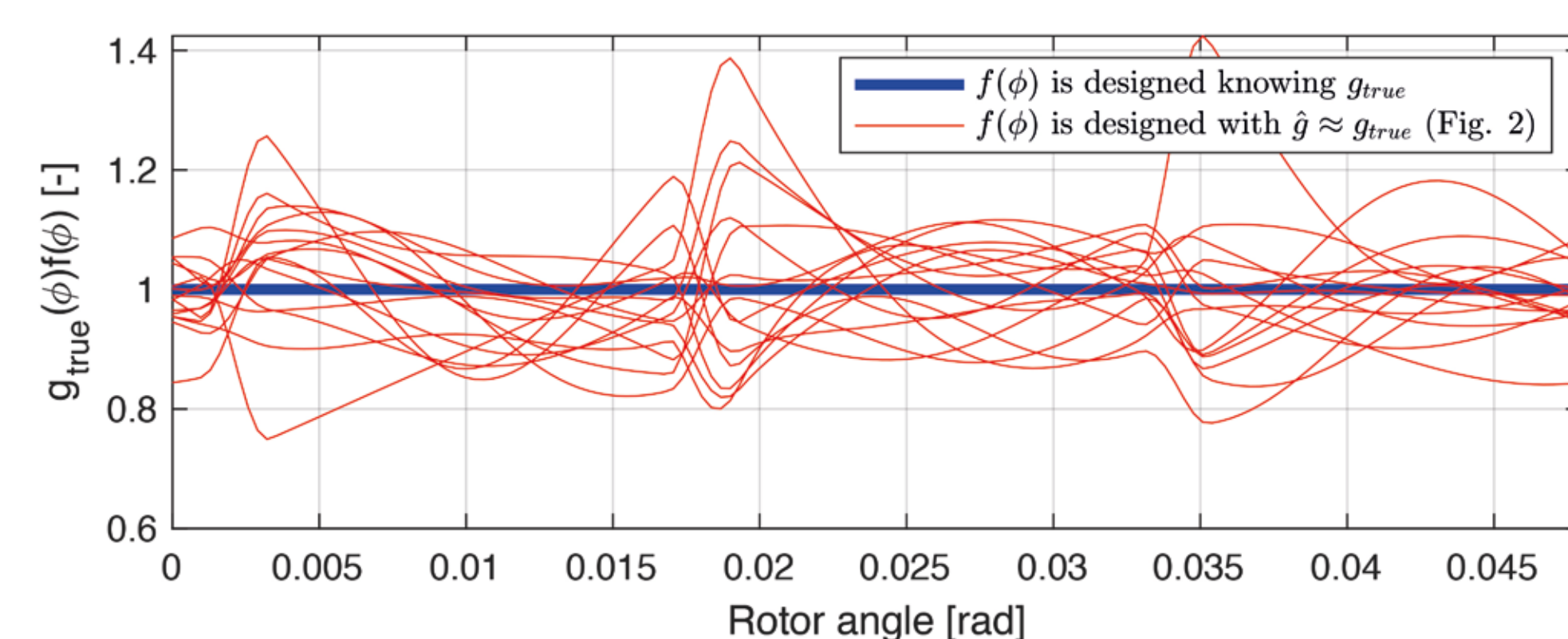


Figure 3

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 $g(\phi)$!

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

→ solve using convex optimization (Fig. 3)

Results:

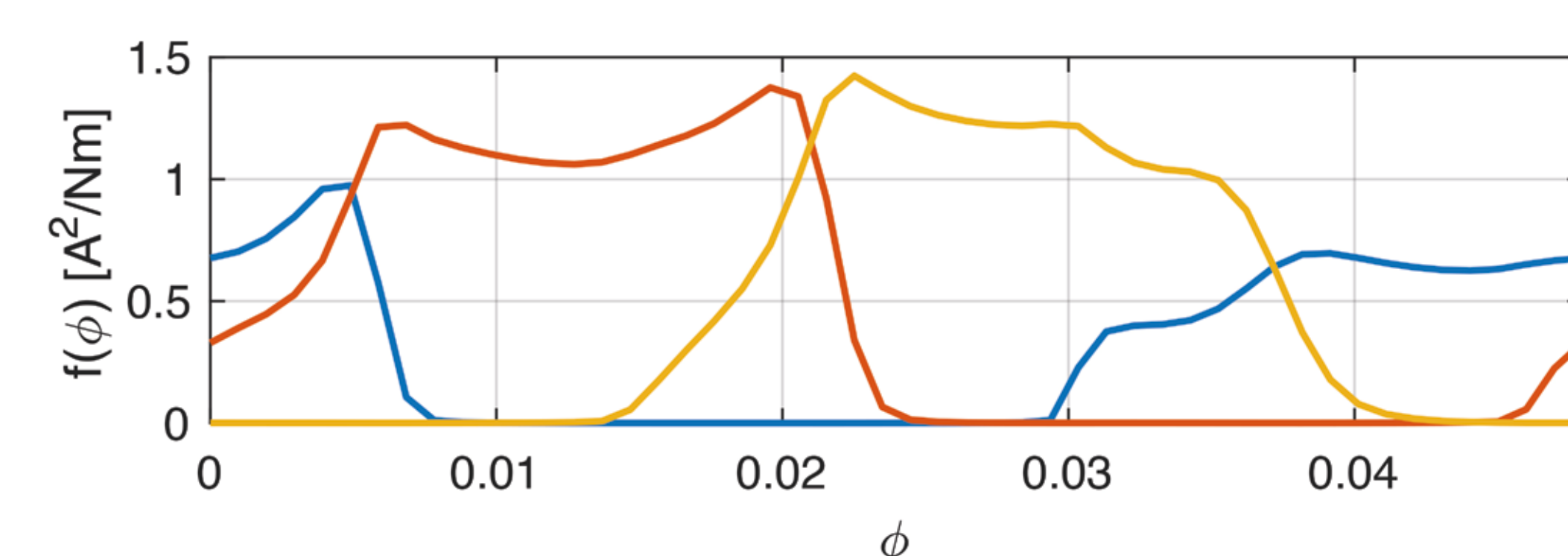


Figure 3

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.