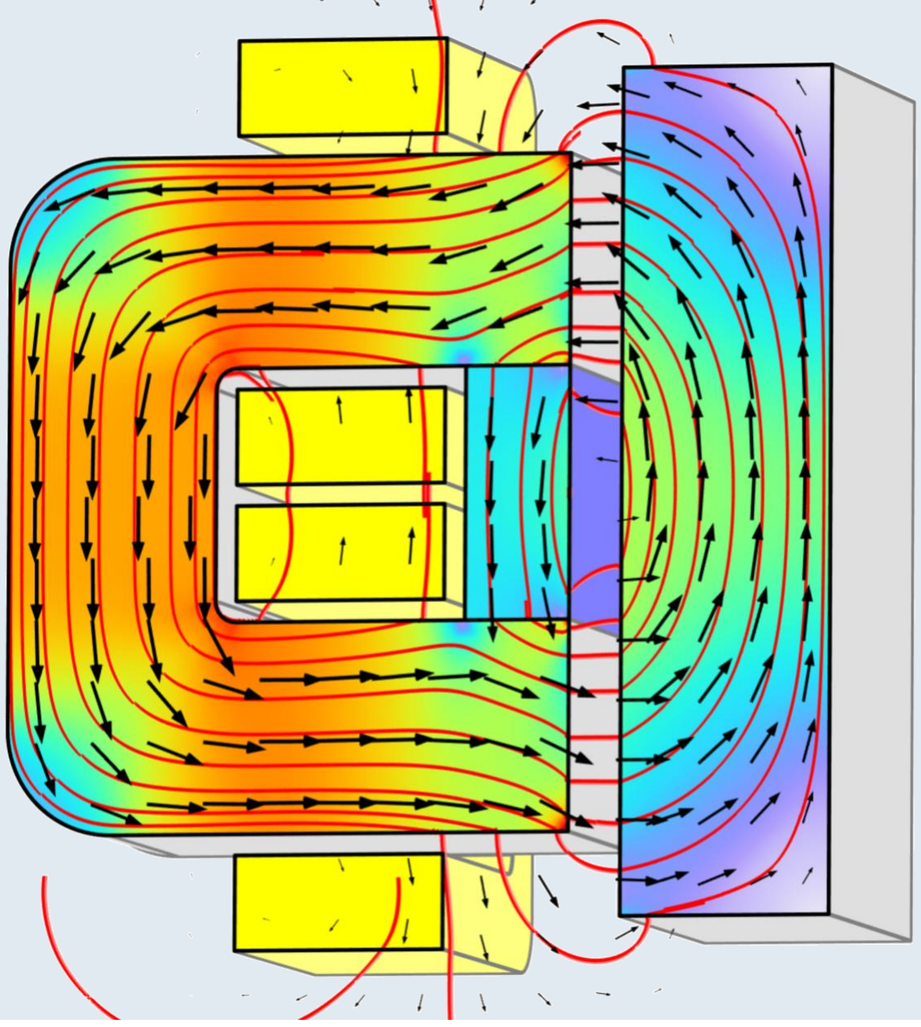

Boosting the efficiency of reluctance actuators with permanent magnets

Use of a permanent magnet to suppress the onset of magnetic saturation in a reluctance actuator

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Introduction and goal

Electromagnetic actuators are an important actuation tool to achieve positioning precision on the nanometer scale. In this realm Lorentz actuators are mostly used, due to their linear dependence between actuation force and applied current. The ever-growing demand to increase the force efficiency of actuators leads towards more detailed investigations of reluctance actuation.

Overall, we find that a Lorentz actuator is limited by dissipation, while a reluctance actuator is limited by magnetic saturation.

To suppress this magnetic saturation effect of a reluctance actuator, a permanent magnet is placed anti-parallel to the flux path which leads to an increase of the force efficiency for this current direction. This principle is schematically depicted in Figure 1[a].

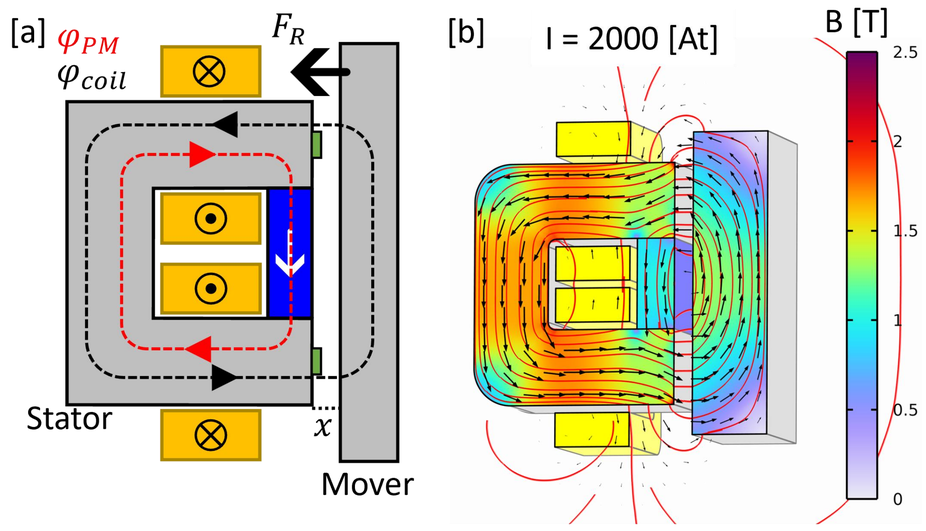

Figure 1. [a] Schematic working principle of the reluctance actuator with a permanent magnet in parallel. [b] Simulation results at $I = 2000\ [At]$.

Methodology

We model the 3D actuator geometry to evaluate the flux paths and magnetic field strength in the actuator as function of current [1]. Here, we implement the electromagnetic fields interface and use the Ampere's law node to setup the permanent magnet and the BH-curve for the carbon steel to include magnetic saturation.

We then visualize the flux paths and optimize the design to reduce flux leaking depending on the airgap. We utilize the force calculation node to determine the force on the mover for different permanent magnet geometries and strengths. Only a quarter of the geometry is evaluated to reduce the computational time.

Results

The simulation results are shown in Figure 1 [b]. For a current of $I = 2000\ [At]$ the stator is not saturated yet ($< 2\ [T]$), if a permanent magnet is added. The force output as a function of current is shown in Figure 2. In blue the quadratic behavior for a reluctance actuator without saturation is shown and in orange with saturation. The results for the additional permanent magnet are depicted in black and becomes asymmetric. For a negative current magnetic saturation sets in earlier, which results in a lowering of the output force, but for a positive current a force efficiency increase of 45% is reached.

The actuator design with a permanent magnet implements a preferred directionality of the current. To conclude, we can increase the actuator efficiency successfully by adding a permanent magnet to the design.

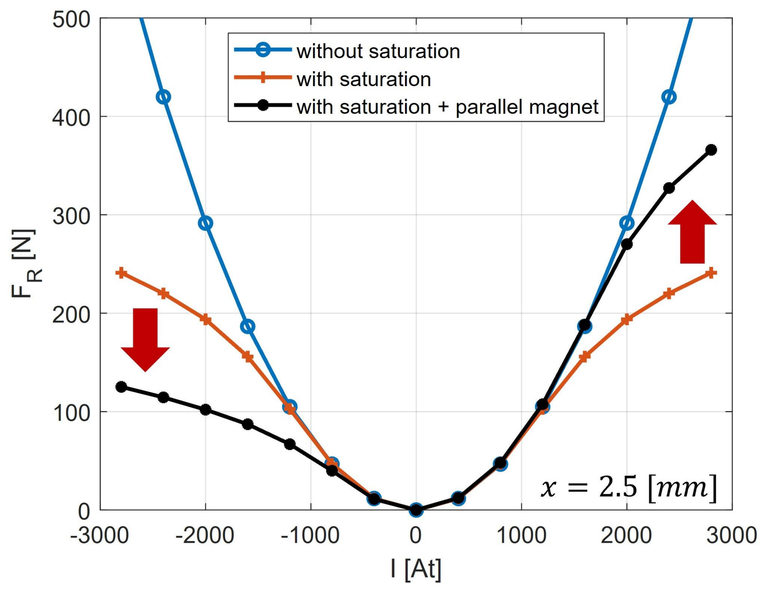

Figure 2. Force output as a function of current for a reluctance actuator without saturation (blue) and with saturation (orange). The force curve shifts when a permanent magnet is added (black).

REFERENCES

[1] COMSOL Multiphysics® v. 6.3, www.comsol.com

For more information see Mikroniek article: 'Increasing force efficiency, reducing dissipation' from February 2025.

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