Boosting The Actuator Efficiency Of Reluctance Actuators With Permanent Magnets

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Abstract

Electromagnetic actuators are an important actuation tool to achieve positioning precision on the nanometre 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 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.

In order to suppress this saturation effect of a reluctance actuator, a permanent magnet is placed in parallel to the flux path which leads to an increase of the force efficiency. This is schematically depicted in Figure 1a. The c-shaped stator and the rectangular mover are shown in grey and are made from carbon steel. Two coils are wound around the legs of the c-shaped stator and are connected in series. Applying a current to the coils generates a magnetic flux φ_coil (black dashed arrows) to run through the mover and stator, which pulls the mover towards the stator.

Additionally a permanent magnet is placed (illustrated in blue), which generates a flux path φ_PM as indicated by the red dashed line. This flux path stays within the c-shaped stator and - at a first glance - does not contribute to the reluctance force. The flux of this permanent magnet is anti-parallel, however, to the flux generated by the coils and suppresses the effect of magnetic saturation.

We use COMSOL Multiphysics software [1] to evaluate the flux paths and magnetic field strength in the actuator as function of current. Here, we implement the electromagnetic fields interface on our 3D geometry and use the Amperes 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.

The simulation results are shown in Figure 1b. For a current of 2000 [At] the stator is not saturated yet, if a permanent magnet is added. The force output as a function of current is shown in Figure 1c. In blue the quadratic behaviour 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.

Since the reluctance actuator can only pull regardless of the current direction, 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.

Figures used in the abstract

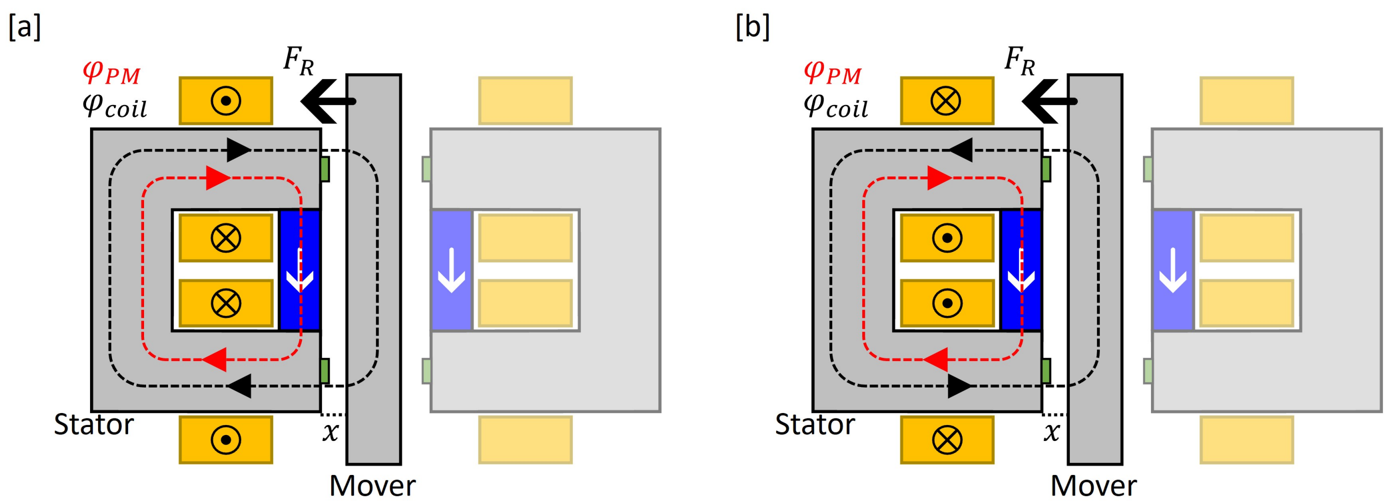

Figure 1 : Reluctance actuator with a permanent magnet placed parallel to the mover. The flux of the coil (black) and the permanent magnet (red) are parallel [a] or anti-parallel [b].

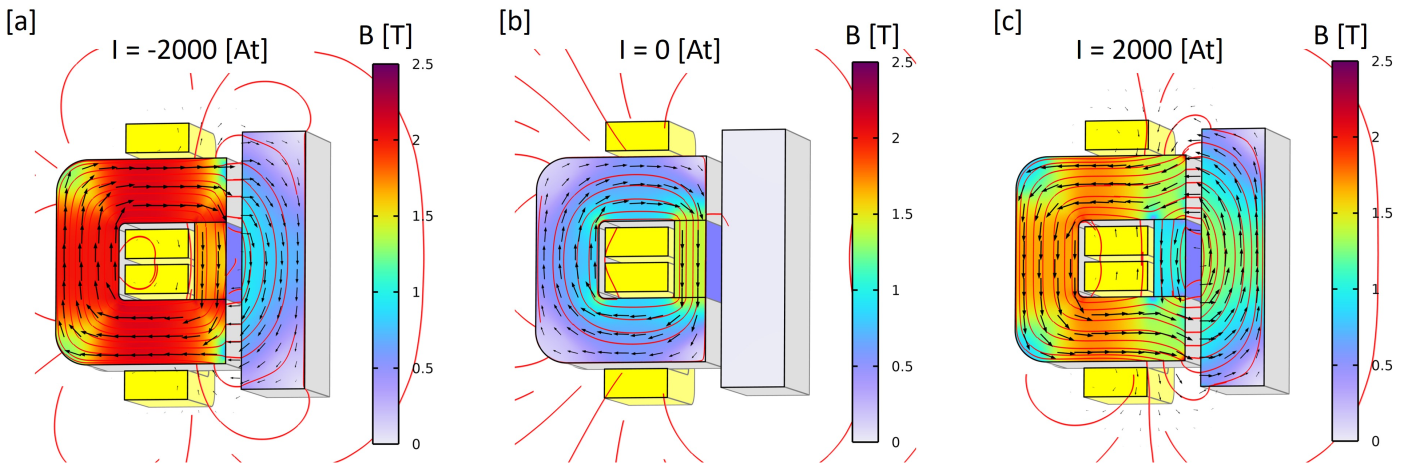

Figure 2 : Simulation results from COMSOL for different currents. [a] The stator is saturated. [b] No current is applied, which results in no force. [c] The stator is not (yet) saturated.

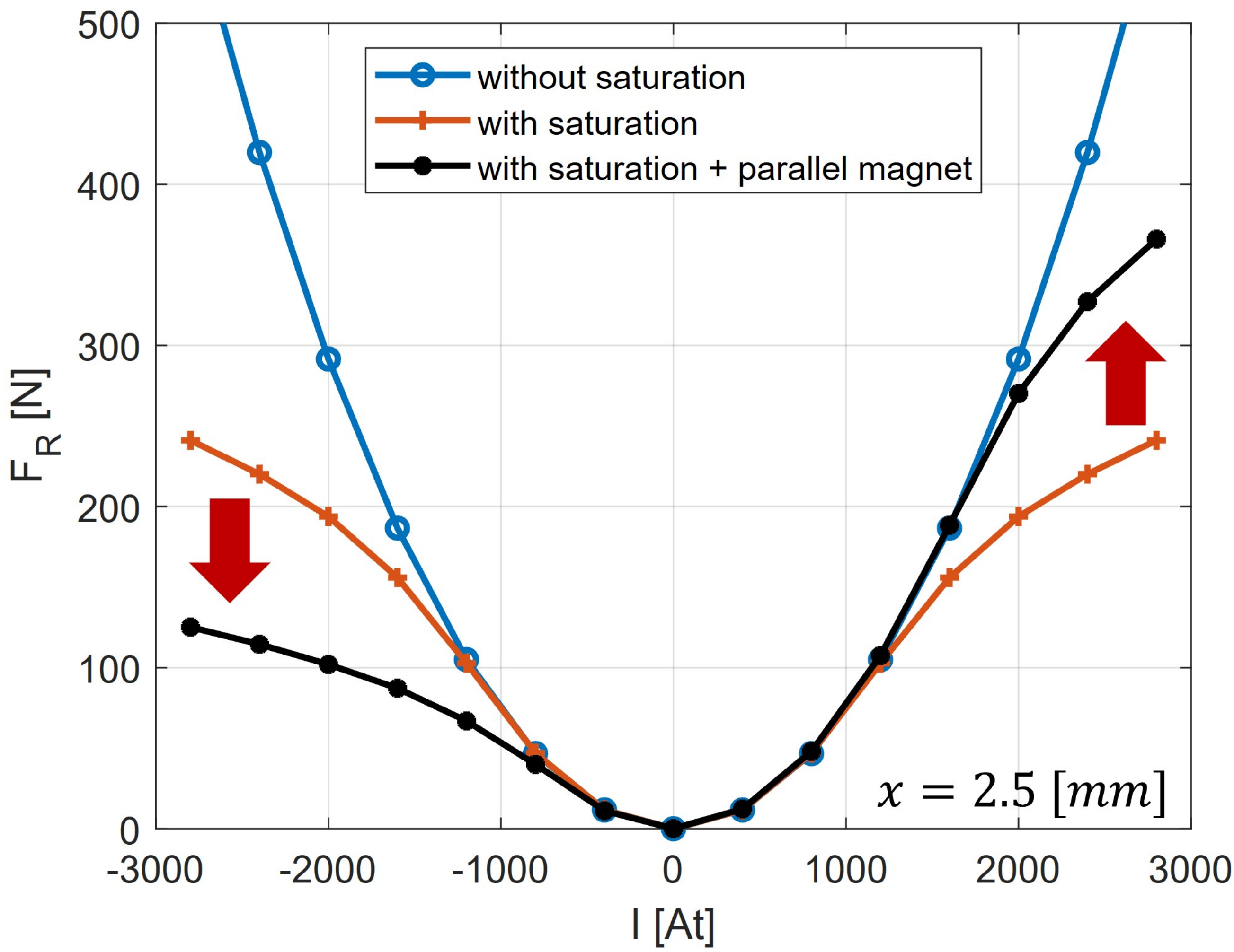

Figure 3 : Force output as a function of current for a reluctance actuator without saturation (blue), with saturation (orange), and with an added permanent magnet (black).