Application of Force Enhancement with Ferrofluids in a Linear Stepping Motor Model

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Introduction

Already simple estimations with a magnetic circuit predict a remarkable force amplification in linear or rotating electric machines filling the airgap between acting magnets (stator and rotor in rotating machines). More detailed estimations are presented here using the method of orthogonal expansion. The measurements are compared with these theoretical results.

Process model of a linear electric machine

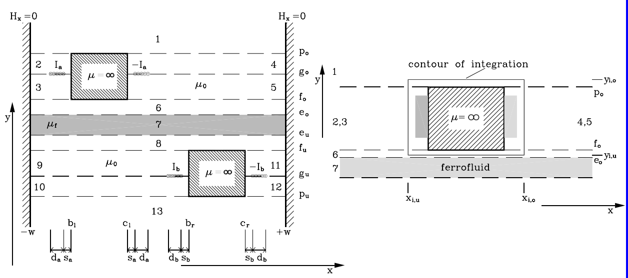


Fig. 1: Geometry of the linear electric machine, their division into subspaces (left) and the contour integral for calculating the force using the Maxwell tensions (right). The coils are composed with stacked current layers. The continuity of fields between the subspaces are guaranteed by fulfilling boundary conditions.

Ansatz function for the vector potential in subspace 3

$$A_{z,3}(x,y) = \sum_{j=1}^{n_3} \cos(k_{3,j}[x-b_l])$$
$$\{\exp(k_{3,j}[y-g_o])A_{3,j} + \exp(-k_{3,j}[y-f_o])A_{3,j}\} \ ,$$
$$k_{3,j} = 0.5(2j-1)\pi/(-w-b_l)$$

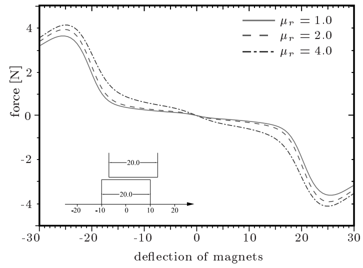
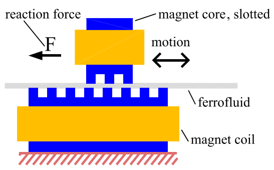


Fig. 2: Lateral force between the two magnets for three values of μ_r, evaluated with the application of Maxwell tensions from the magnetic field calculated with orthogonal expansion.

Measurement of a linear electric machine

Principle of measurement

The reaction forces (transverse forces) of two lateral shifted electromagnets are measured. This is a linear static simulation of a DC electric machine. The force is measured with a piezoelectric force sensor. The horizontal smooth movability guarantees the precision of measurement.



Static DC linear electric machine simulator

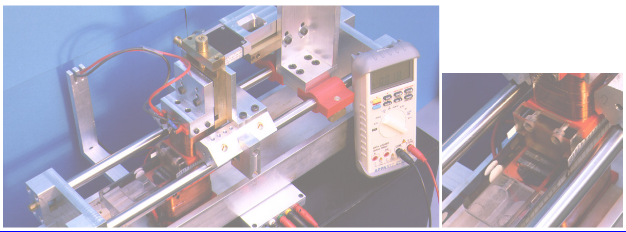


Fig. 3: View of the static model as a whole (left) and the fluid bath with the grooved electromagnets (right).

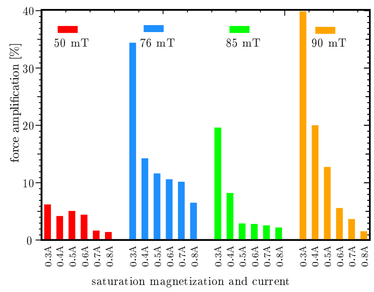


Fig. 4: Relative force amplification at the position of the force maximum between the electromagnets for a smooth magnet core, gap width: 1 mm.

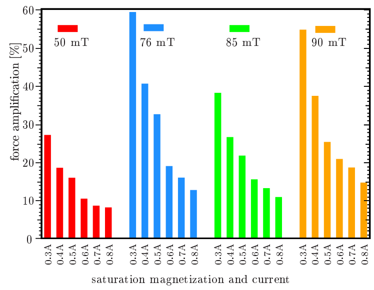


Fig. 5: Relative force amplification at the position of the force maximum between the electromagnets for a smooth magnet core, gap width: 2 mm.

Conclusion and prospects

The force amplification in electric machines using ferrofluids has been proved theoretically and experimentally. The result is a significant improve of effectiveness for electric drives. The increased force is especially interesting for the holding moment, which is a crucial performance figure in stepping motors. Moreover for traction engines the starting torque is an important parameter. Here the ferrofluid develops his capabilities particularly since rotational friction, which lowers the force amplification, is totally absent. Alltogether the use of magnetic fluids in electric machines offers a wide variety of applications.

The next step is to transfer this satisfying results on rotating machines. To overcome the difficulty of enclosing the fluid a ferrofluid based seal is an interesting option.