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Experiments with a ferrofluid-supported linear electric motor

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Inserting ferrofluids in the gap between the acting magnets of electrical machines will enlarge the forces or torques by reducing the magnetic resistance of the gap. Based on this effect, the efficiency of linear and rotating electric drives can be improved. The experimental setup to measure this force amplification in the case of a linear electric drive and the results are presented. Copyright © 2004 John Wiley & Sons, Ltd.

KEYWORDS: ferrofluids; electric machines

INTRODUCTION

Amongst the great variety of applications of magnetic fluids[1] force magnification is one of the most promising. The first research object in this direction was an artificial heart support system.[2] Electric motors, linear or rotating, have an airgap between the acting magnets, e.g. stator and rotor in a rotating machine. In terms of magnetic circuit theory,[3] the airgap can be understood as a high magnetic resistance. Filling the airgap with a magnetic fluid, which means that the μ_r is increased, lowers the magnetic resistance of the gap and thus that of the whole circuit built up of stator, airgap and rotor. In terms of field theory,[4] the magnetic flux and, as a result, the field strength are enlarged. Both interpretations lead to higher forces, or torque in the case of rotating machines, acting between the magnets. The experimental investigation of this effect are treated in the following.

PRINCIPLE OF MEASUREMENT

The aim of the measurements carried out here is to show the magnification effect by using ferrofluids under neglect of side effects.[5]

Figure 1 (left) shows a photograph of the static simulation of a DC electric machine. The fluid bath between the two magnets, here those with a grooved surface to simulate a stepping motor, can be seen in Fig. 1 (right).

The principle of measurement is depicted in Fig. 2 for a flat magnet surface (left) and for grooved surfaces as a simulation of a stepping motor (right). The reaction (transverse) forces of two laterally shifted electromagnets are measured.

The measurement setup fulfills the following demands:

- Measurability of the forces acting between the laterally moved electromagnets.
- Smooth adjustability of the upper electromagnet to minimize the measuring error of force while keeping a constant width of the gap between the two magnets.
- Adjustment of horizontal position of the whole apparatus to eliminate the effects of gravity.
- Reliable containment of the ferrofluid between the magnetic poles.
- Precise adjustment of the gap width between the magnetic poles.

The upper electromagnet moves on ball bearings on polished round steel rods. This reduces the force due to rolling friction down to a maximum of 0.03 N. The forces are measured with a force sensor controlled by a computer-aided measuring system.

MEASUREMENT RESULTS

Figure 3 presents the curves measured of lateral forces versus the deflection of the two magnets towards one another for air and two different fluids in the gap for three different

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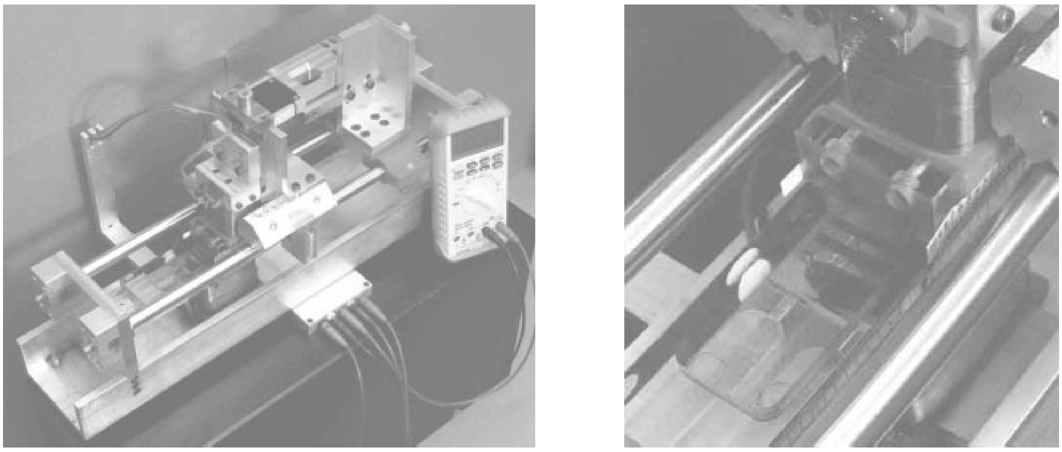

Figure 1. A linear static simulation of an electric motor with a force measurement module (left) and the fluid bath with the lower and the upper electromagnets as a detail of the static motor simulation (right).

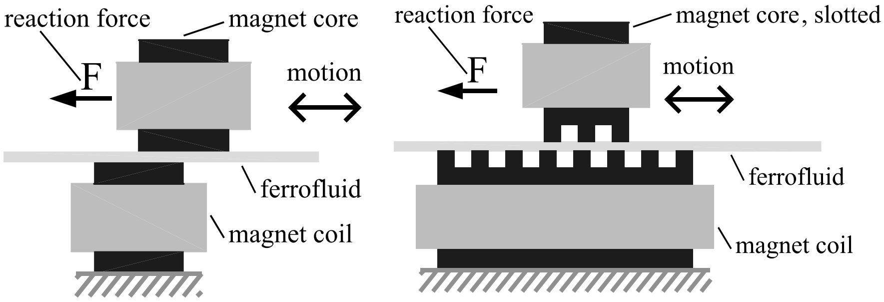

Figure 2. Principle of measurement for a linear electric motor simulation with magnets with flat surfaces (left) and with grooved surfaces (right), which describes a stepping motor.

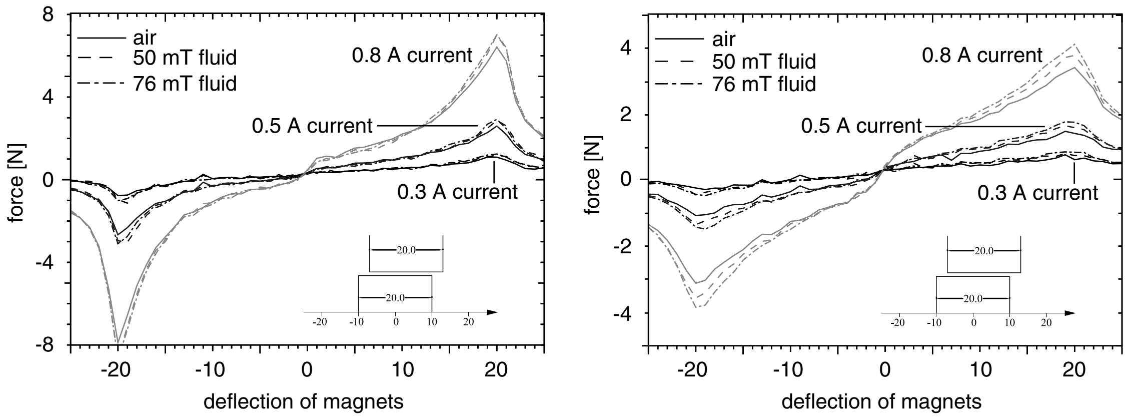

Figure 3. Lateral force between the linearly moved magnets versus the lateral deflection for air, two different ferrofluids and three currents for a gap width of 0.5 mm (left) and for a gap width of 1.5 mm (right).

coil currents with gap widths of 0.5 mm (left) and 1.5 mm (right).

Figure 4 depicts the maxima of the lateral forces between the two electromagnets for four fluids with different saturation magnetizations and several exciting coil currents, which means a varied magnetic field strength. On the left one sees the absolute values of the force; on the right is the gain of force related to the case of using an air-filled gap. The results shown in Fig. 4 are for an airgap width of 1 mm; Fig. 5 shows the same measurement values for a width of 2 mm.

The results of the measurement can be interpreted as follows:

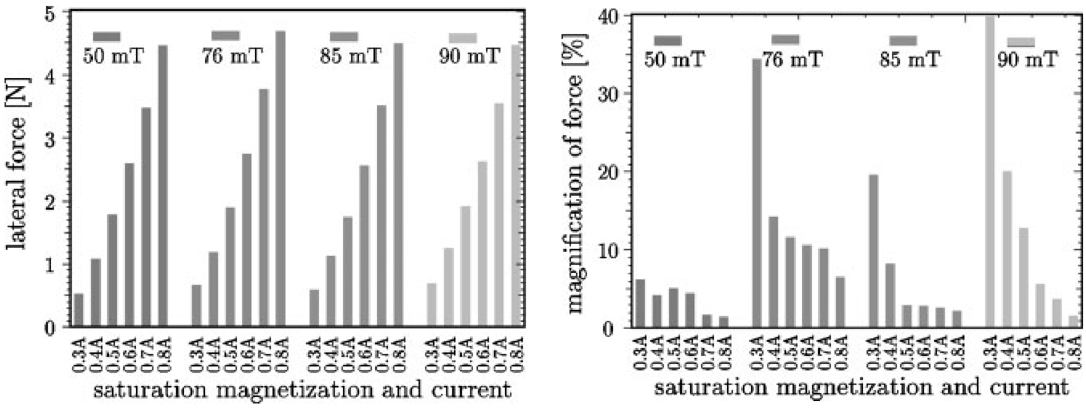

Figure 4. Lateral force at the position of the maximum force between the two electromagnets for flat magnets (left) and relative force amplification belonging to it (right); gap width: 1 mm.

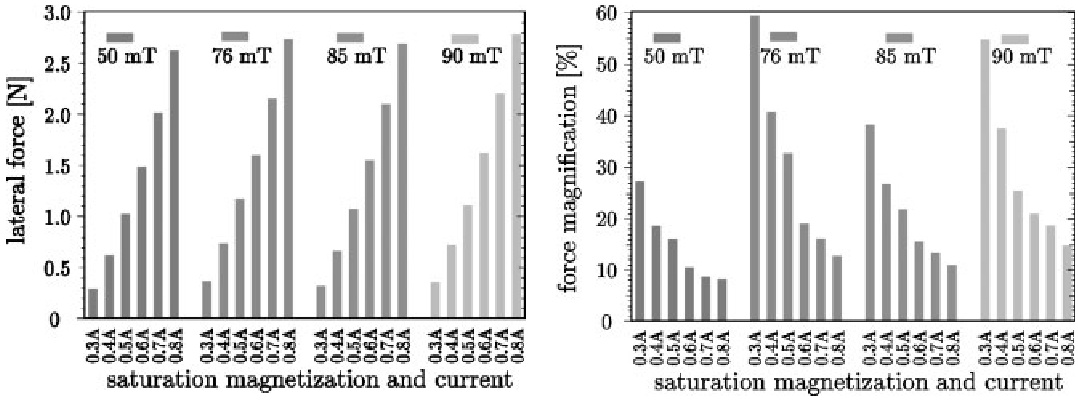

Figure 5. Lateral force at the position of the maximum force between the two electromagnets for flat magnets (left) and relative force amplification belonging to it (right); gap width: 2 mm.

- For wider gaps the magnification of force is more significant.
- A high viscosity of magnetofluids with a high saturation magnetization reduces the movability of the magnets and thus limits the measurement precision.
- The mechanical influences due to the viscosity prevent a significant increase of the force magnification using ferrofluids with a high magnetization, as long as the proportion of saturation magnetization to the viscosity is not improved noticeably.
- Containment of the ferrofluid carrying volume is essential to avoid vaporization of the ferrofluid carrier liquid.

CONCLUSIONS

The results of the measurements show a significant magnification when ferrofluids are employed in the airgap of electrical machines. For low currents, which means low field strength and thus unsatisfied magnetization, the effect is especially strong. The results obtained here can be extended to rotating electric machines. Effective containment of the ferrofluid carrying volume is essential. Appropriate systems have to be developed. A promising possibility is a ferrofluid-based seal. Furthermore, in cooperation with suppliers of ferrofluids, a lower viscosity of the fluids should be aimed for.

Acknowledgements

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