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Concept of a new type of electric machines using ferrofluids

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Abstract

The rapid development of ferrofluids in recent times allows to improve electric machines with these materials. They can be used to reduce the magnetic resistance in the airgap between the mutually moved magnet system in every motor, especially the stator and the rotor in a rotating system. In particular, for slowly moving or rotating machines, they offer a great advantage.

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Keywords: Orthogonal expansion; Magnetostatics; Ferrofluid; Electric machines

1. Introduction

Magnetic fluids, which are a suspension of magnetic nano-particles in a carrier fluid, covered with a tensid layer to prevent clustering, have super-paramagnetic properties. This high permeability can be used in several applications, since the improvement in chemical technology during the last years provides fluids with high saturation magnetization, relatively low viscosity and, above all, long-term stability. One option of technical application, which is treated in this paper, is the force or torque amplification in linear or rotating electric machines by filling the fluid in the gap between stator and rotor. Thus the magnetic resistance of the airgap is reduced.

The very promising theoretical results for both linear and rotating machines have to be proved by experiments. Besides the pure amplification effect, many other effects are involved in running a real motor. Therefore, it is necessary to point out the limits and technological difficulties of this invention.

2. Construction of a ferrofluid supported linear electric machine

In Fig. 1, the principle of measurement for flat magnet surfaces, representing a continuous electric

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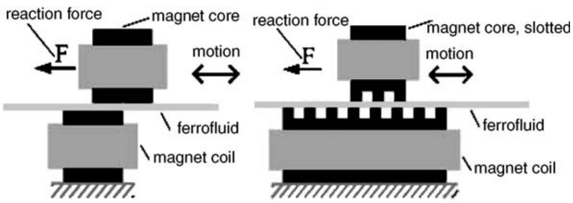

Fig. 1. Principle of measurement for a simple linear machine (left) and for a stepping motor (right).

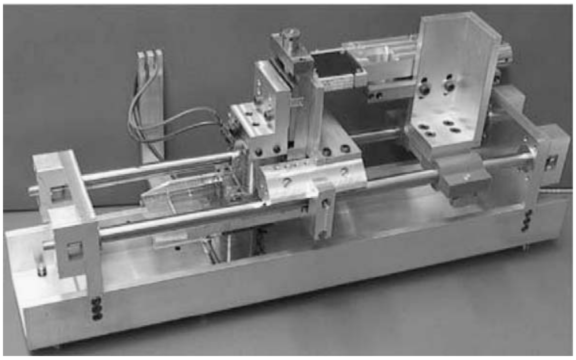

Fig. 2. Photo of the ferrofluid supported linear machine equipped for measuring lateral forces.

drive (left), and for grooved magnet surfaces, simulating a stepping motor (right), can be seen. The reaction forces (lateral forces) of two horizontally moved electromagnets are measured.

Fig. 2 shows a photo of the linear electric machine, where the major parts are depicted. The lower electromagnet is fixed. The upper one moves on ball bearings on polished steel round rods. This reduces the force due to rolling friction down to a maximum of 0.03 N. The forces are measured with a DMS-based force sensor by a computer-aided measuring system. This DMS-based force sensor can be seen in the background.

The following demands are fulfilled by the measurement set-up:

- the forces which are acting between the lateral moved electromagnets, can be measured,
- precise adjustment of the gap width between the two magnetic poles is achievable,
- balancing out of the whole apparatus to avoid effects of gravity is feasible,
- reproducible adjustability of the upper electromagnet to minimize the measuring error of force and nevertheless keeping a constant width of the gap between the two magnets is possible,
- reliable enclosement of the ferrofluid between the magnetic poles is within reach.

3. Construction of a ferrofluid supported rotating electric machine

For testing a rotating machine, a commercial asynchronous motor has been modified as shown in Fig. 3. The following demands have to be considered:

- the hollow space outside the gap between stator and rotor has to be minimized to reduce the needed quantity of ferrofluid,
- rotation as well as magnetic and electric functionality must not be influenced.

The undesirable hollow spaces in the construction of the electric machine are filled with epoxy resin, which is capsulated with aluminium sheets to prevent dissolving by organic fluids. Thus a minimum of consumption of ferrofluid is guaranteed. An influx and an outlet for the fluid are

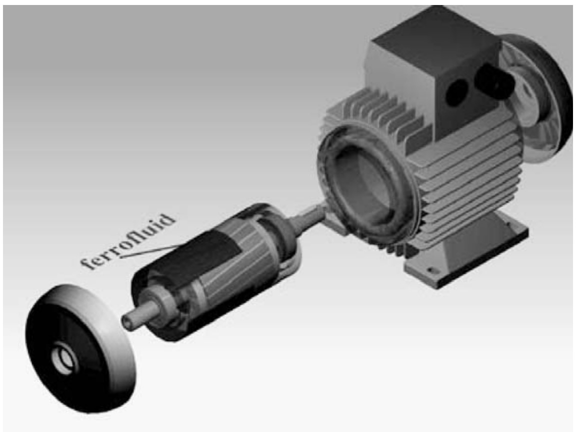

Fig. 3. Rotating electric induction machine equipped for operation with ferrofluids.

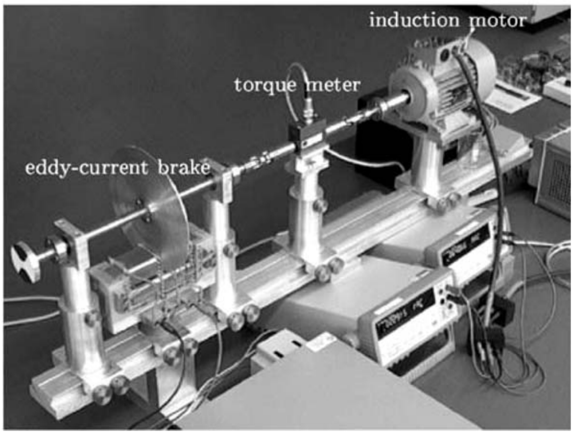

Fig. 4. Experimental set-up to measure the parameters (torque, rotational speed, voltages, currents) for the rotating asynchronous motor.

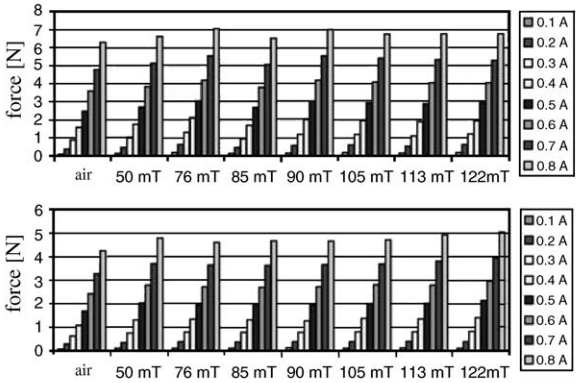

Fig. 5. Bar graphs for the lateral forces for the airgap and 7 different ferrofluids in the gap measured at several magnet coil currents; gap width of 0.5 mm (upper) and 1.0 mm (lower).

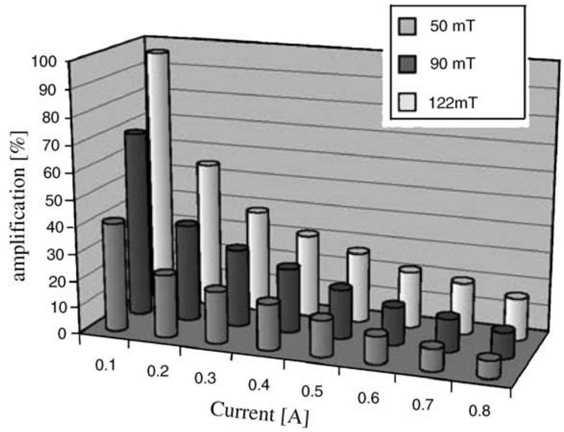

Fig. 6. Bar chart of the amplification of force for three-different ferrofluids in the gap relative to the airgap measured with several magnet coil currents; 0.5 mm gap width.

mounted. A weak spot for sealing the motor is the rotating axis. The best solution in this experimental stage is to collect the fluid coming out from there and refill it.

The rotational speed in the measuring set depicted in Fig. 4 is controlled by a frequency converter. An eddy-current brake gives a mechanical load. From the current provided to the brake, the produced torque can be calculated [5]. A strain gauge-based torque meter, which records also the rotational speed, measures the torque acting on the motor.

4. Experimental results for the linear electric machine

Experiments have been carried out for a variety of fluids. Each type of ferrofluid is characterized in Fig. 5 with its saturation magnetization. Fluids with lower saturation magnetization are available on the market, the better ones are produced in laboratories at an experimental stage.

In Fig. 5, one sees two bar graphs for the lateral forces between the two magnets for air in the gap as well as seven different fluids and for several exciting magnet coil currents. The left graph is for a gap width of 0.5 mm, the right one for 1.0 mm.

Fig. 6 shows the amplification of lateral force related to the air-filled gap for three different fluids versus the exciting current for a gap width of 0.5 mm, Fig. 7 shows the same for a gap width of 1.0 mm.

The results allow the following conclusions:

- a remarkable force amplification is given,
- as expected wider the gap, larger the effect because of the greater influence of the changed magnetic resistance,
- for a lower coil current, which means a less magnetic field in the gap, the amplification effect rises,

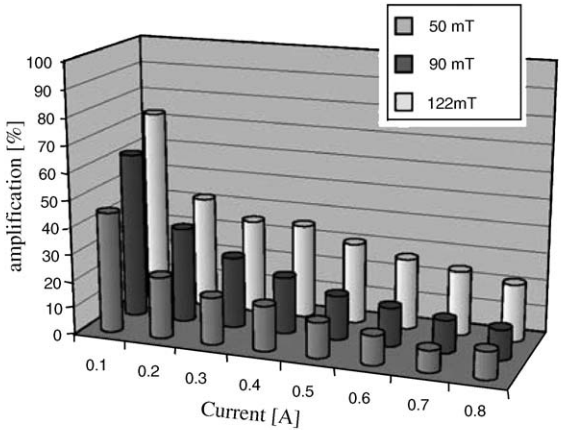

Fig. 7. Bar chart of the amplification of force for three-different ferrofluids in the gap relative to the airgap measured with several magnet coil currents; 1.0 mm gap width.

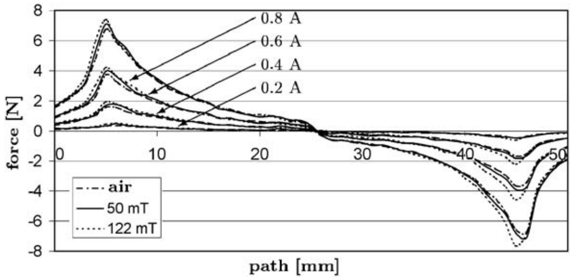

Fig. 8. Lateral force versus path length for the flat-surfaced magnets.

- the behaviour of the fluids under test is very individual, which means that besides the saturation magnetization, other properties such as viscosity and shape of the magnetic particles are also important.

Fig. 8 gives some examples of the lateral force along the measured path for four different exciting coil currents and the gap filled with air and two different fluids. Here the flat-surfaced magnets are used as in Figs. 5–7.

In Fig. 9, the lateral force along the measured path for grooved surfaced magnets is taken using air and two different fluids. At every step a remarkable increase of the maximum force can be seen. This gain of force makes clear the

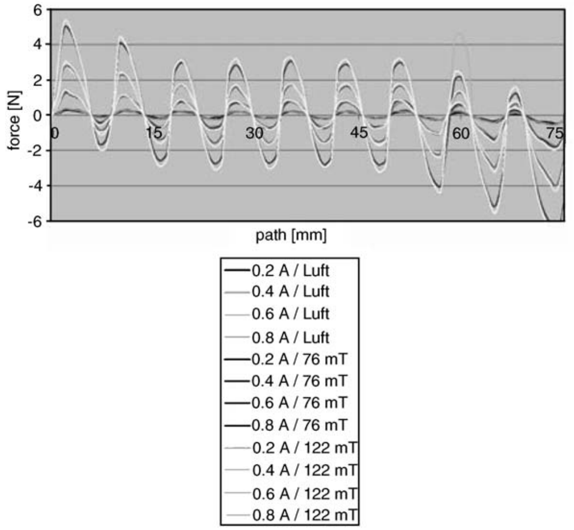

Fig. 9. Lateral force versus path length for the grooved-surfaced magnets.

importance of the effect with regard to the holding torque in stepping machines. This point indicates the most probable area of employment of ferrofluids in electric machines, because, due to the low linear or rotating velocities in applications of stepping motors, friction is negligible.

5. Experimental results for the rotating electric machine

Two types of ferrofluids were tested at low rotational speeds, because at higher speeds the additional friction will be predominant. In Fig. 10, the efficiency of the induction motor is depicted versus the measured torque load for three rotational speeds with air and a kerosene-based fluid of 122 mT saturation magnetization in the gap. In Fig. 11, the same is done for a water-based fluid with 57 mT.

Fig. 12 shows the increase of efficiency in the induction motor for three different rotational speeds and the 122 mT ferrofluid. Here the influence of the rotational speed is evident.

With more technological effort, the upper limit of the rotational speed, at which the force amplification will predominate the friction, can

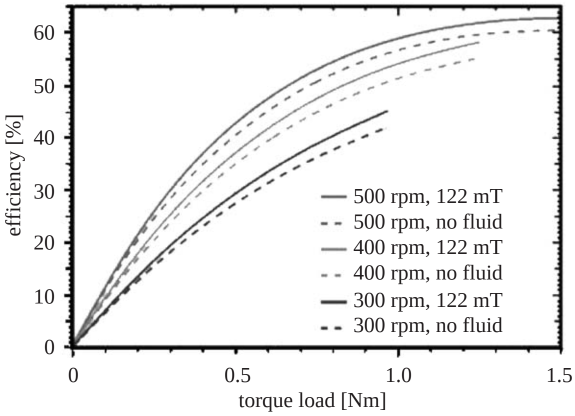

Fig. 10. Efficiency of the induction motor for three different rotational speeds and a 122 mT saturation magnetization ferrofluid as well as air in the gap.

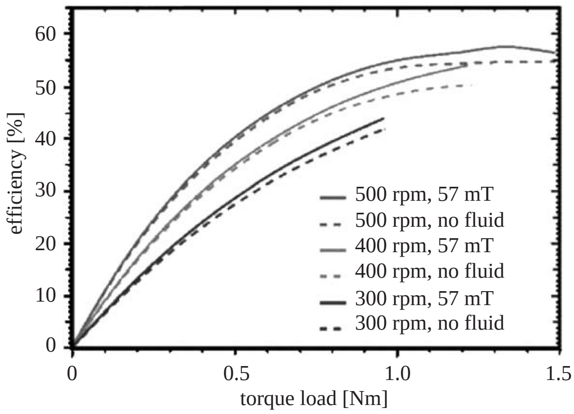

Fig. 11. Efficiency of the induction motor for three different rotational speeds and a 57 mT saturation magnetization ferrofluid as well as air in the gap.

be raised as theoretical investigations applying the Couette flow have proved [1].

6. Summary

The results of the measurements both for linear and rotating electric machines promise a high

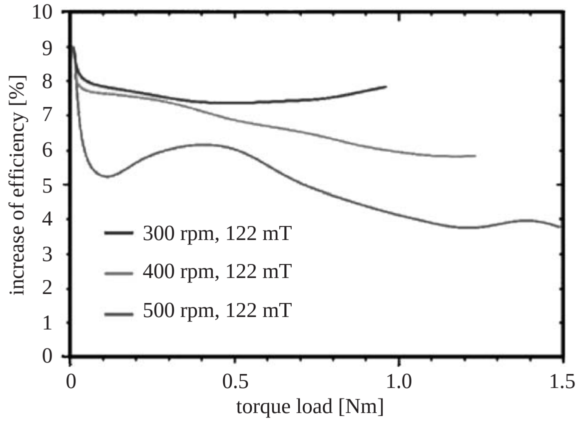

Fig. 12. Increase of efficiency for three different rotational speeds and a ferrofluid with 122 mT saturation magnetization.

relevance of ferrofluid application for building more efficient electric motors in the future. For technical applications, a standardization of ferrofluids is desirable. Some technological effort is necessary to guarantee a reliable enclosement of the fluids. Innovative fluids, e.g. based on cobalt particles with a higher saturation magnetization and lower viscosity as well as excellent stability will be very promising.

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Further reading

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