A Novel Approach to Magnetic Fluids Permeability Measurement

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Abstract **This paper deals with problems of permeability measurement of magnetic fluids. The low permeability of magnetic fluids bring certain problems to adequately measure their magnetic properties due to leakage flux, their liquid state makes the process even more difficult. Our approach to measure the permeability and measured properties of several fluids is presented.**

Keywords **Ferrofluids, Magnetic fluids, Magnetorehological fluids, Low permeability measurement**

I. Introduction

Several technical applications using extraordinary properties of magnetic fluids are currently being developed [e.g. 1, 2]. Producers of magnetic fluids usually don´t guarantee – and often even don´t publish – physical characteristics of magnetic fluids and designers of these devices are left on their own measurements. Most important parameters of magnetic fluids are their material-magnetic properties and their magnetoviscous characteristics.

Measurement methods of ferromagnetic solids are described in detail (e.g. [3]), but these methods cannot be used for ferromagnetic liquids. They have these specific magnetic properties:

- very low relative permeability
- their hysteresis properties are negligible
- their magnetic nonlinearity manifests not until rather high magnetization values

The representative property is the magnetic permeability. Different forms of permeability (e.g. reversible permeability, incremental permeability) merge into single property defined by the ratio B/H.

II. Principles of Measurement Approach

It is necessary to arrange the measurement device in a way that the magnetic fluid sample is magnetized by a homogenous magnetic field. From the theory of electromagnetic field (e.g. [4]) it is known that the induction of a toroid coil is

$$L = \mu F(N^2, \text{geometric dimensions}) , \qquad (1)$$

where $\mu = \mu_0\mu_r$ and the function F depends on the number of turns N and on geometrical dimensions of the coil and the fluid sample. If the induction of the coil L_0 without filling the fluid with the magnetic fluid and the induction with the magnetic fluid L_x is measured, the relative permeability of the magnetic fluid is:

$$\mu_r = \frac{L_1}{L_0} . \qquad (2)$$

The next step is to determine the induction of the coil with and without the magnetic fluid in its core. Several means of induction measurement already exist, e.g. see [3]. If a sample of magnetic fluid with known permeability is available, it can be used for the calibration of the measurement as well.

III. Possible Measurement Configurations

Several possible measurement configurations were considered and numerically simulated in order to determine the most suitable one. An amount of generated magnetic leakage flux was observed. Because of the low relative permeabilities of magnetic fluids (about $\mu_r = 2$ for ferrofluids and about $\mu_r = 10$ for magnetorehologic fluids) the magnetic flux inclinates not to pass through the fluid, but to pass through the air or through the container as well. In this point of view, the ideal configuration means that the whole magnetic flux runs through the ferrofluid. A fictional ferrofluid with linear relative permeability μ_r = 2 was used in FEM simulations, magnetorheologic fluids with higher permeabilities would generate even less leakage flux.

A. Anuloid shape of the measured fluid sample

A hollow circlet is filled with measured magnetic fluid. A coil is wired on the anuloid, the induction of this coil is the goal of the measurement. Coils must be winded evenly in order to get a homogenous magnetic field and magnetic flux running only through the measured fluid (see Fig.1. for details). The accuracy of this measurement is high enough, but this configuration has several mostly practical disadvantages, because the maintenance and operation is difficult. If we want to fill the circlet with a fluid, an opening is necessary and it disrupts needed even winding. Most of magnetic fluids use oil as a carrier liquid, dismantling the device could be required for its cleaning before refilling with another type of measured fluid.

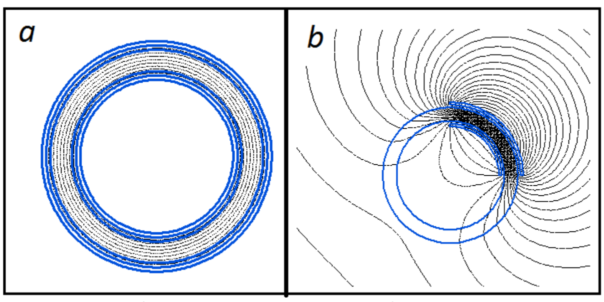

Fig. 1. Results of 2D numerical simulations of circlet measurement configurations and their leakage flux, planar coordinates: a - coil winded evenly on the circlet, homogenous magnetic field; b – incorrect winding, the magnetic field is nonhomogenous

Proposed configuration is suitable mainly for laboratory measurements with high accuracy demands, another configuration for a user requiring a quick operative magnetic fluids permeability test will be proposed.

B. Toroidial shape of measured fluid sample

A hollow glass toroid is filled with measured magnetic fluid. A long coil is evenly winded around the toroid. The induction of resulting coil is compared to the coil without the fluid. As we can see on Fig.2.a, magnetic flux runs not only through the fluid, but through the walls of the container as well. The maintenance and cleaning of this configuration is much easier than in the previous configuration, but a special container for every measured fluid or cleaning the container between single measurements might be required.

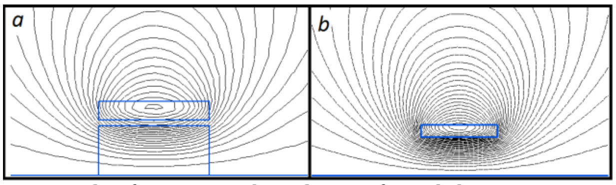

Fig. 2. Results of 2D numerical simulations of toroidial measurement configurations, axisymetrical coordinates: a – a toroidial shape of measured fluid; b – a coil probe submerged in the ferrofluid

C. A coil probe submerged in the magnetic fluid

Now we propose a simplified version of permeability measurement based on the previous described method for possible industrial applications. In practice, a quick but very operative information measurement with lower accuracy requirements is often wanted. Small solenoid is chosen as a probe and immersed into the ferrofluid, the value of induction can be determined using the measurement *RLC* bridge. Submerging and removing the probe is quick, the maintenance and cleaning is very simple.

For a balanced bridge, a measured coil is practically without current and so initialy permeability

$$\mu_{r0} = \lim_{H \to 0} \frac{B}{H} \qquad (3)$$

is measured. The shape of *B-H* characteristics of magnetic fluids is different from the characteristics of other ferromagnetics, the staring permeability is very similar to the permeability in the linear part of the curve. In order to get permeability of higher values of *H*, measured sample should be magnetized before the measurement.

IV. USE OF THE METHOD FOR A QUICK OPERATIVE INDUSTRIAL MEASUREMENT

In our case the Agilent LCR bridge 6243B was used. The range of measure voltages of this bridge wasn´t enough to capture the nonlinearity of the relative permeability on the higher values of the magnetic field caused by the saturation of the ferromagnetic particles, but most of the practical applications of ferrofluids are designed to work in the linear part of the *B-H* characteristics, so this is enough for an operative measurement. This method should allow us to capture these nonlinearities using different bridge or larger coil probe. However, such arrangements would need greater samples of measured fluid. Our measurement details can be seen on Fig. 3., we measured on harmonic voltage with amplitude 100mV and the frequency was 100kHz.

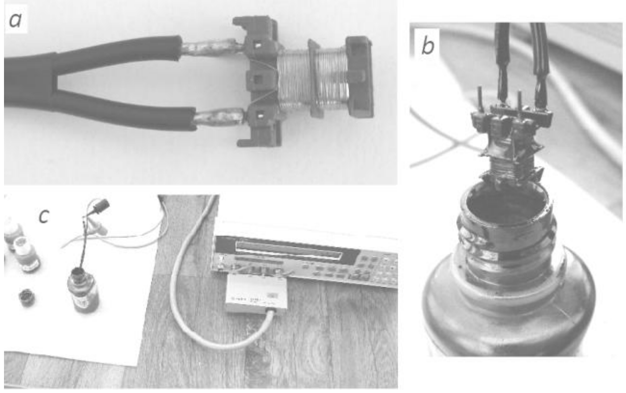

Fig. 3. Quick operative permeability measurement arrangement: a – coil probe; b – coil probe being submerged into the fluid; c – arrangement with the measuring bridge

Initialy permeabilities of several ferrofluids (all of them manufactured by the Ferrotec company) we posses were measured and the results can be seen in the Table I.

TABLE I
PERMEABILITIES OF CERTAIN FERROFLUID SAMPLES

Ferrofluid sample	Relative permeability[-]
EFH1	1,799
EMG607	1,21
EMG707	2,03
EMG1111	1,14

V. MEASUREMENT ERROR

Because of the form of the equation (2), most possible errors are presented both in the numerator and in the denominator and are cancelled out. The measurement error is then given by the error of used measuring bridge, in our case bridge Agilent LCR 6243B.

VI. CONCLUSION

A method for measuring permeabilities of fluids was presented. This method can be used for any fluids, even for ferrofluids with very low permeabilities. A simplified quick but less accurate method for industrial applications is presented as well. Permeability measurement for different values of magnetization, temperature and frequency influences are worth further investigations.

VII. ACKNOWLEDGEMENTS

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