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ON MEASUREMENT OF MAGNETIC PERMEABILITY OF FERROMAGNETIC FLUIDS

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Abstract: This paper contributes to the measurement of the magnetic permeability of magnetic fluids. The measurement of ferromagnetic fluids is difficult due to their liquid state and relatively low values of their magnetic permeabilities. Methods commonly used to measure ferromagnetic properties of ferromagnetic solids usually fail when used for ferromagnetic fluids. Most common mistakes are explained and numerically simulated in the paper. An accurate method for the determination of magnetic properties of fluids is presented.

Key words: ferromagnetic fluid, magnetic fluid, low magnetic permeability measurement.

1. Introduction

Magnetic fluids represent intelligent materials of wide industrial applications (see e.g. [1, 2]). Producers of magnetic fluids usually do not guarantee – and often even do not publish – the physical characteristics of the magnetic fluids and designers of these devices are left on their own measurements. The most important parameters of magnetic fluids are their magnetic properties and magneto-viscous characteristics. Measurement methods for ferromagnetic solids are described in detail (see e.g. [3]), but these methods cannot be used for ferromagnetic fluids. The ferromagnetic fluids possess specific magnetic properties: they have very low relative magnetic permeability, their hysteresis properties are negligible, and their magnetic nonlinearity manifests itself not up to rather high magnetization values.

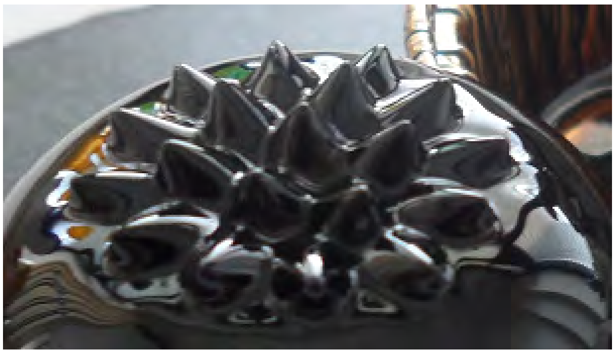


Fig. 1. Typical structure of magnetic fluid under the influence of external magnetic field.

A method for quick industrial measurement of relative magnetic permeability of magnetic fluids was presented by the authors in [4]. This method was improved to be able to measure whole magnetization curves of magnetic fluids.

2. Description of the problem

Most of the methods designed for measuring magnetic solids characteristics require a closed-loop sample of the measured material (e.g. Epstein method). A powering coil generates a magnetic field, the magnetic flux flows through the measured sample, and a signal is measured by a measuring coil. A principal scheme of such an arrangement can be seen in Fig.2.

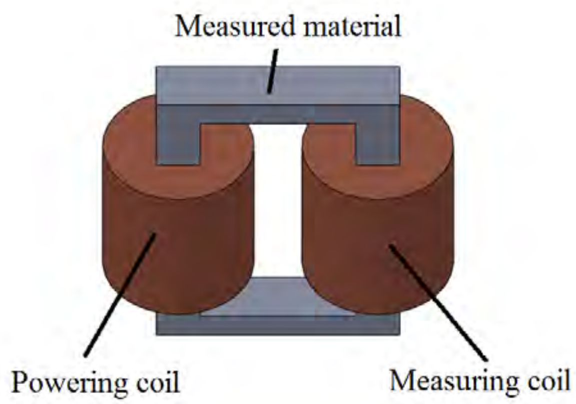


Fig. 2. Principal scheme of classical arrangement for measurement of magnetic permeability of materials.

The magnetic properties of the measured materials can be counted from the measured signal. This can be used for solid ferromagnetic materials with relatively high values of their magnetic permeabilities. An illustrative measurement configuration was numerically simulated with the use of the finite element method in Agros2D software [5], the distribution of the magnetic field in such a configuration can be seen in Fig. 3.

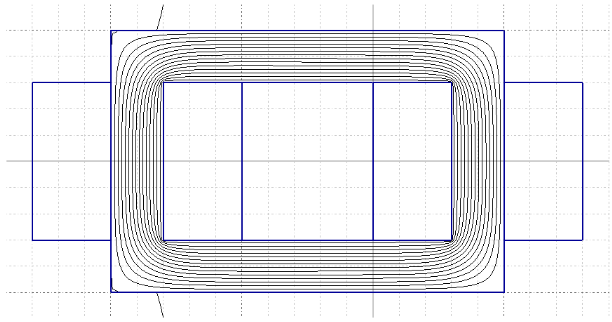


Fig. 3. FEM simulation result representing magnetic field lines in the discussed sample of ferromagnetic material with $\mu_r = 1000$ *(planar coordinates).*

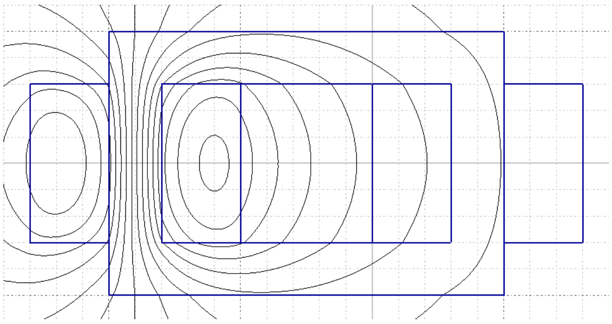


Fig. 4. FEM simulation result representing magnetic field lines located both inside and outside of the investigated sample of magnetic fluid with $\mu_r = 2$ *(planar coordinates).*

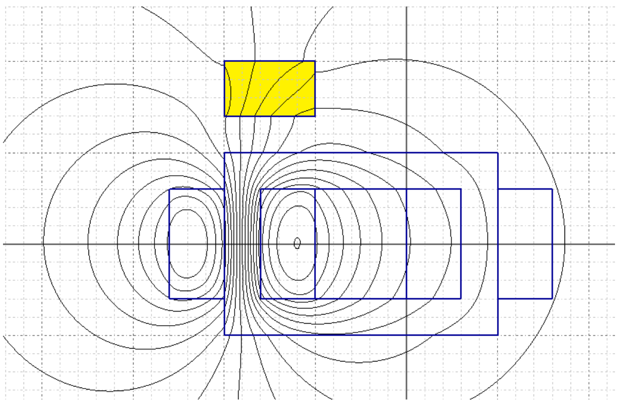


Fig. 5. A closely located ferromagnetic object (coloured, $\mu_r = 1000$*) corrupts the measurement result; FEM simulation result representing magnetic field lines (planar coordinates).*

On the other hand, the magnetic permeability values of commonly used ferrofluids and magnetorheological fluids are very low (depending on the composition of an actual fluid, the value of relative magnetic permeability in range $\mu_r = 1 \sim 10$). As a result of such low values, the magnetic flux does not confine itself inside the investigated sample of the magnetic fluid (see the simulation result in Fig. 4) and thus the data obtained do not correspond to the magnetic propeties of that sample.

Even worse result can be received if a ferromagnetic object is located near to the measuring tool. The magnetic flux then flows through the tool, and its magnetic permeability influences the measured signal.

Based on our practical experience, we can conclude that the common methods used for the measurement of magnetic properties of ferromagnetic solids fail when used for magnetic fluids. The result of such measurements is often $\mu_r = 1$, even if the measured fluid is clearly ferromagnetic. This is caused by the magnetic flux flowing through the surrounding air.

3. Principles of measurement

A measurement transformer was proposed - it consists of two windings (Fig. 6 left), one is powered by alternating current of a known shape, and a voltage is measured acrtoss the other one. Magnetic permeability can be detrminated from these two signals.

Because of low values of magnetic permeability, the whole transformer is immersed in the measured fluid to ensure that the magnetic flux confines itself in the fluid (Fig. 6 right). No other ferromagnetic objects should be located in the nearby area during performing the measurement.

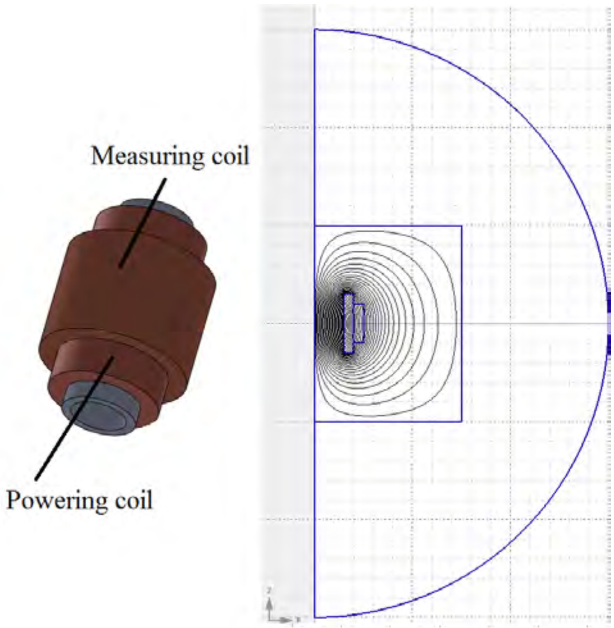


Fig. 6. Proposed measurement probe and FEM simulation result representing magnetic field lines when the probe is immersed in the investigated fluid (axisymmetric coordinates).

The main disadvantage of the proposed measurement configuration is the amount of magnetic fluid required for each measurement. Generally, the lower magnetic permeability of the sample is expected, the more sample is required to ensure that the majority of the magnetic flux is confined to the fluid. The distribution of the magnetic field can be simply checked by means of FEM.

4. Measurement example

A magnetization curve of Ferrotec EFH-1 ferrofluid has been measured. The measurement transformer and the container used for fluids can be seen in Fig. 7.

Fig. 7. Measurement transformer without magnetic fluid.

The powering coil of the measurement transformer was connected to an AC source, the voltage induced in the measuring coil was measured with the use of an oscilliscope and voltmeter.

Fig. 8. Measuring installation.

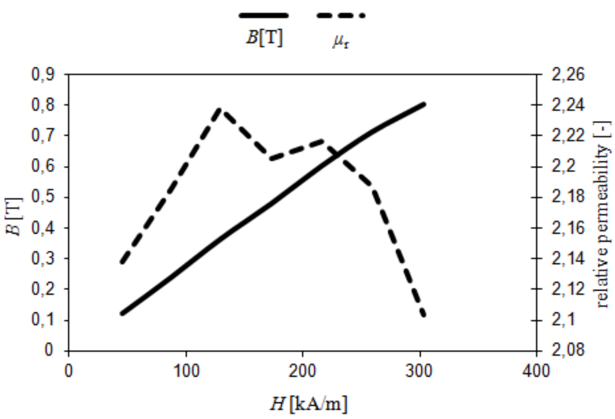


Fig. 9. Example of measured initial magnetization curve of Ferrotec EFH-1 ferrofluid.

The magnetization curve of the measured fluid (Fig. 9) has been calculated using the known relations [3].

The number of turns in each winding limits the values of B/H that may be to received in the course of measuring experiment. More turns mean the possibility to measure the magnetic permeability at higher values of H.

5. Conclusion

Methods developed for measuring permeability of ferromagnetic solids often fail when used for ferromagnetic fluids. Multiple reasons for these failures were shown with the use of FEM simulations.

A method for the measurement of magnetization properties of fluids has been presented. Magnetization curves of magnetic fluids with very low relative magnetic permeability values ($\mu_r < 2$) can be measured using this method.

References

[1] W. Szelag, "Finite element analysis of the magnetorheological fluid brake transients", *COMPEL - The International Journal for Computation and Mathematics in Electrical and Electronic Engineering,* vol. 23, no. 3, pp. 758-766, 2004.

[2] P.Polcar, P.Kropik, and B.Ulrych, "Actuator with erromagnetic plunger working in ferrofluidic fluid", *Przeglad Elektrotechniczny*, vol. 88, no. 7B, pp. 214-216, 2012.

[3] S.Tumkanski, Handbook of Magnetic Measurements, USA: Taylor & Francis, 2011.

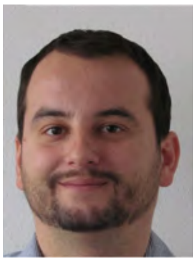
[4] D. Mayer and P. Polcar, "A novel approach to measurement of permeability of magnetic fluids." *Przeglad Elektrotechniczny*, vol. 88, no. 7B, pp. 229-231, 2012.

[5] HPFEM GROUP, *http://hpfem.org*, Nov. 11, 2011.

ВИМІРЮВАННЯ МАГНЕТНОЇ ПРОНИКНОСТІ ФЕРОМАГНЕТНИХ РІДИН

Петр Полцар, Мірослав Кубат

Стаття описує метод вимірювання магнетної проникності феромагнетних рідин. Вимірювання магнетної проникності є ускладненим для феромагнетних рідин через їх агрегатний стан та порівняно низькі значення магнітної проникності. Методи, що використовуються для вимірювання магнетних характеристик феромагнітних твердих тіл не є придатними у випадку феромагнітних рідин. Пояснено причину виникнення похибок та проведено модювання розподілу поля для таких випадків. Запропоновано методику визначення магнітних властивостей рідин, що усуває вказані недоліки.



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