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# Ongoing polarization processes in magnetic fluids

***Abstract**. The article deals about magnetic fluids based on a transformer oil and about behaviour of these fluids under influence of static magnetic field represented by time-current characteristics. The measurement is dependent from orientation of actuating magnetic field. This behaviour mainly shows the effect of nanoparticles structuring during exposition of specimen by magnetic field. These particles also changes polarisation processes in fluid. It is also showed in article influence of nanoparticles concentration contained in fluid.*

**Keywords**: magnetic fluid, polarization processes, dielectric spectroscopy, transformer oil, magnetite

## Introduction

Ferrofluid is liquid, which consist from carrier fluid and ferromagnetic nanoparticles coated by surface active substance. Respect particles size, ferrofluids are colloidal liquids. Common size of magnetite nanoparticles is from 2 to 20 nm. As mentioned, these particles are coated by surface active substance – surfactant. In our case takes the role of surfactant oleic acid, which is monounsaturated omega-9 fatty acid. Molecules of oleic acid are made from polar hydrophilic head and long unipolar hydrophobic chain. Main function of surfactant is to prevent from clustering. Particles which were created from many nanoparticles would be too heavy to stay dispersed in volume of liquid by Brownian motion. In case of usage ferrofluid as replacement of transformer oil is important to note that the settled particles can cause inhomogeneity in power transformer insulation system.

The wide possibilities of ferrofluid application are based on fact, that these fluids can be positioned inside technical device by acting external magnetic field. Most common use of ferrofluids today is as airtight and lubricating seals in rotary shafts. This is based on fact, that gradient of magnetic field keeps the magnetic fluid in correct position, even in case of pressure differences between the two separated compartments. [1]

## Magnetic fluid in electric power engineering devices

The transformer oil performs two functions in power transformers. Insulating, thus transformer oil prevents the flow of current between separate components as windings, core, vessel etc. Second function is usage as cooling medium, consequently conduct heat out of windings and core to walls of vessel. Subsequently is this heat dissipated into surrounding of vessel. [1]

Another point of view is usage of transformer oil as impregnation of oil – paper insulation system. It should be noted, that size of nanoparticles of $Fe_3O_4$ isn't limited only by presence of phenomenon of particles coupling caused by negotiation of Van der Waals force, but also with problem of penetration of paper in these systems. Viscosity of these fluids must not be too dense, because too dense magnetic fluid will not get into every layer of oil – paper insulation system.

Positive influence of application magnetic fluid instead of conventional transformer oil is lower temperature of windings and higher capacity to sustain overvoltage, and present better resistance at degradation in time due to humidity compared to classic oil [2]. This fact brings smaller dimensions of power transformers and less amount of cooling liquid.

The better heat transfer from windings is caused by presence of phenomenon named thermomagnetic conductivity. Condition for this phenomenon is presence of temperature gradient and magnetic field. In case of usage in power transformer are conditions for thermomagnetic convection satisfied. The source of temperature gradient is heat produced by AC current in windings. Thus heat generated by winding and core of transformer creates in arena inhomogeneous magnetic field temperature gradient.

## Parameter of magneto dielectric anisotropy

In thesis, which are aimed to magneto dielectric phenomena is published definition of anisotropy parameter g(B) [3],[4] which is related to permitivity:

$$g(B) = -\frac{\varepsilon_{II}(B) - \varepsilon(0)}{\varepsilon_{\perp}(B) - \varepsilon(0)} \tag{1}$$

Where $\varepsilon_{||}(B)$ and $\varepsilon_{\perp}(B)$ are dielectric constants for different orientations of magnetic induction vector. This parameter is one of possibilities, how to specify influence of presence and positioning of magnetic nanoparticles to measured parameters.

## Investigation of polarisation processes in magnetic fluid by dielectric spectroscopy

One of the non-destructive methods of diagnostics of high voltage insulation system in general is dielectric spectroscopy. This method is based on measurement of current in time and frequency domain. Stability of microstructure and composition of the insulating material is changing due to degradation processes. As a result of these changes is changing behaviour of insulation material from view of polarization processes. Based on this fact, is possible to characterize degree of degradation of specimen. Our sample can be mentioned as a capacitor with pair of electrodes and dielectrics between them. Thus after connecting voltage to our specimen current starts flow thru dielectric. In case of ideal dielectric the current hasn't real component. But in practice is real component of current caused by processes of polarization and conductivity. These processes are dependent on kind of dielectric in which they are occurs. Based on existence independent Debye's polarization processes and Maxwell – Wagner equivalent model is possible to formulate total polarization current as:

(2) $$i_c = \frac{U}{R_i} + \sum_{i=1}^{n} I_{m_i}.e^{-\frac{t}{\tau_i}}$$

This equation can be used if for measurement is used electric field with intensity approx. $10^5$ $Vm^{-1}$. The macroscopic view is descripted by current $i_c$ which represents mutually independent polarization processes in magnetic fluid. U is applied voltage on the specimen, $R_i$ is DC insulation resistance after infinite long time, $I_{mi}$ is amplitude of i – th component of Debye's elementary current, $\tau_i$ is relaxation time constant of i – th component.

Usage of dielectric spectroscopy for examination of structuralisation processes and processes of creating clusters of $Fe_3O_4$ nanoparticles is suitable because of measurement time provides sufficient view of ongoing polarization processes. It's possible to recognize these processes by increase of polarization current. It should be noted, that magnitude of current is changing by acting of magnetic field with different vector orientation. Also by usage of this method for diagnostic magnetic fluids it's necessary to apply external magnetic field before start of measurement. Because structuralisation of particles takes a short time (approx. 60 s).

## Measurement circuit

For measuring of test specimens is necessary to prepare test bench which allows various setup of acting external stationary magnetic field. In our case, is external magnetic field provided by pair of NdFeB magnets with magnetic induction 40 mT. Specimen was place in vessel with volume approx. 100 ml which is made from PTFE. For measurement of i(t) characteristics was used electrode system consisting of pair of parallel cylindrical electrodes with diameter 20 mm made from copper. The gap between electrodes was set to 1 mm because of creating electric field with sufficient intensity E.

By reason of comparison is indispensable use for measurement specimens with different concentration of magnetic nanoparticles. For confirmation of ongoing phenomena we use fluids with different concentration based on same carrier fluid.

Therefore for measurement we use two specimens. Both of them are made on common inhibited transformer oil as carrier fluid. Likewise as surfactant is used oleic acid. For measurement of anisotropy is helpful to use two different concentrations. Except magnetic fluids were measurements realised also on pure transformer oil.

Magnetic properties of specimens are described by magnetic induction and are represent as 35 Gs and 70 Gs. Nanoparticles of both fluids are coated by oleic acid.

Measurement was realised by measurement circuit which is shown on fig. 1. As the metering instrument was used programmable electrometer Keithley 617 and the time of measurement was 1000 s. Acquired data was processed by Agilent HP VEE software.

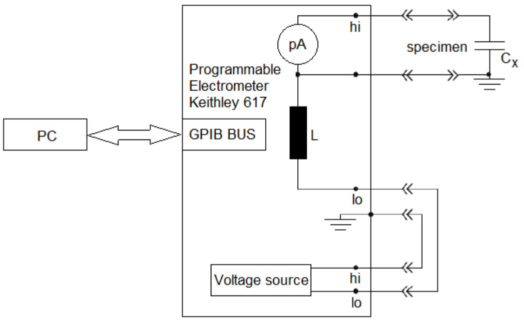

Fig.1. Circuit configuration for measurement

## Experiment

As first experiment was realised measurement of pure transformer oil. As is shown on fig. 2, decreasing current of both samples doesn't have significant deflection in measured i(t) characteristics. The curve A, marked by red is carrier fluid of our specimens. Curve B is another common transformer oil. This curve is showed only for comparison.

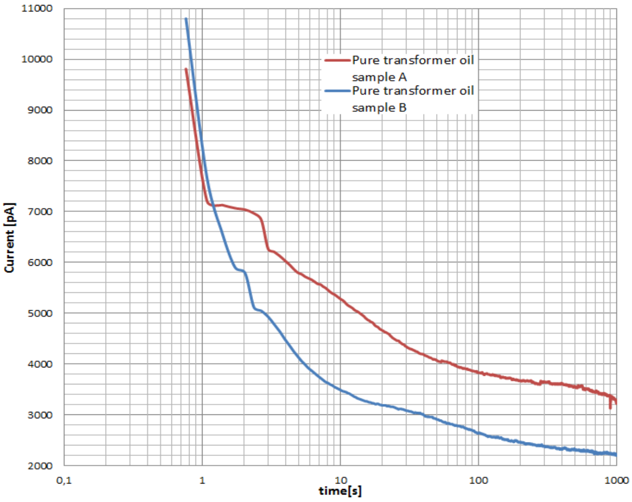

Fig.2. I(t)characteristics of pure transformer oil sample A and B

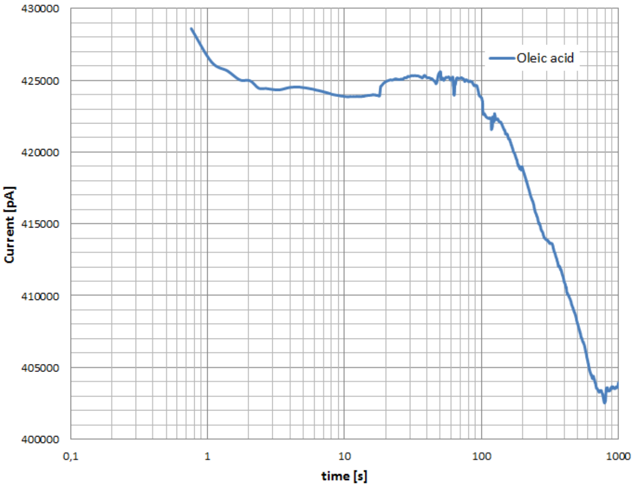

Fig. 3 I(t)characteristics of pure oleic acid

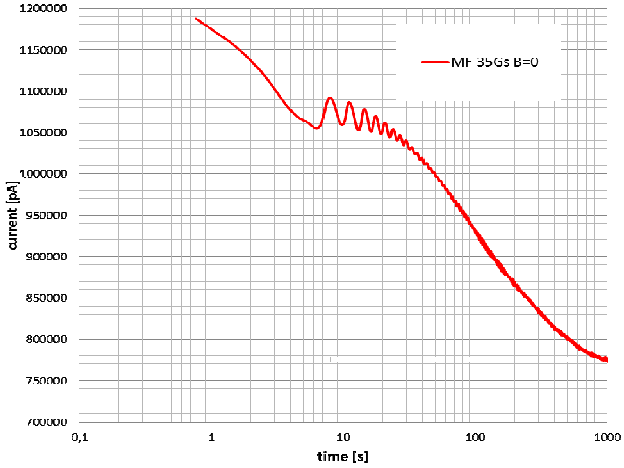

Fig. 4 I(t)characteristics of magnetic fluid 35 Gs without external magnetic field

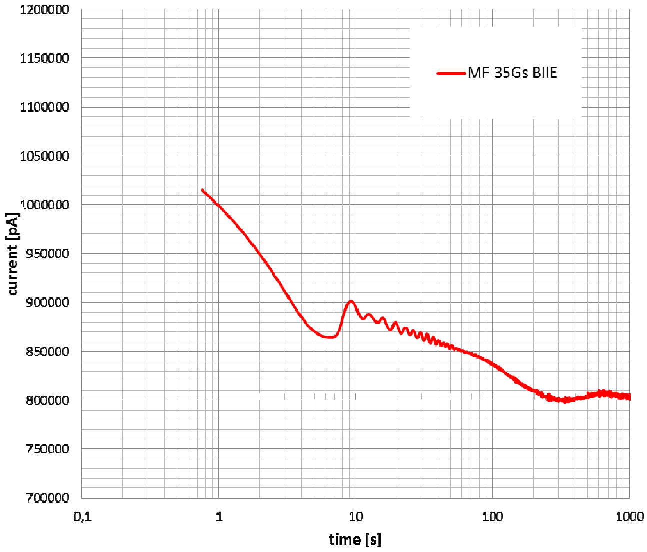

Fig. 5 I(t)characteristics of magnetic fluid 35 Gs with parallel external magnetic field

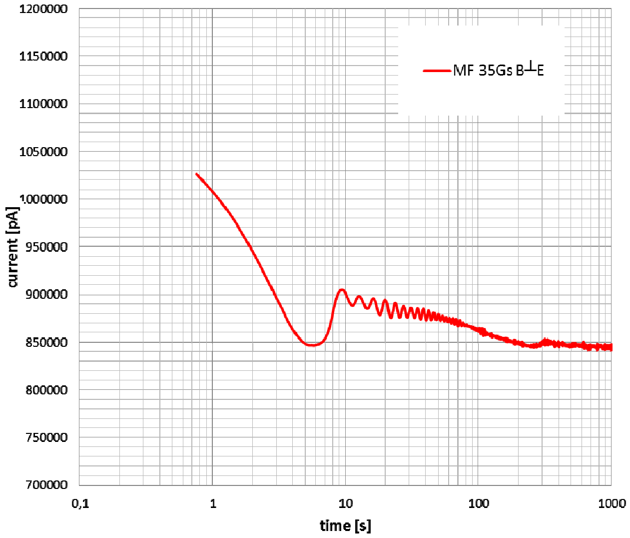

Fig. 6 I(t)characteristics of magnetic fluid 35 Gs with perpendicular external magnetic field

On figure 3 is showed i(t) characteristic of pure oleic acid. This figure is important by reason of understanding individual contribution of oleic acid to measured current in magnetic fluid. Common concentration of oleic acid in magnetic fluid can be approx. 10%, thus influence of presence is relatively small.

The first measured sample of magnetic fluid was sample with magnetic induction 35 Gs. On these characteristics can be observed influence of acting external magnetic field. Without this field is magnitude of current highest. This phenomenon is probably caused by chaotic arrangement of nanoparticles, which are dispersed in liquid volume by interacting solvent and Brownian motion. After application of external magnetic field, nanoparticles starts creating long chains in direction of acting magnetic field. These chains can be long approx. 100 - 300 µm [1]. These chains can together create a strong structure, which can important affects capacitance of specimen and therefore also charging current.

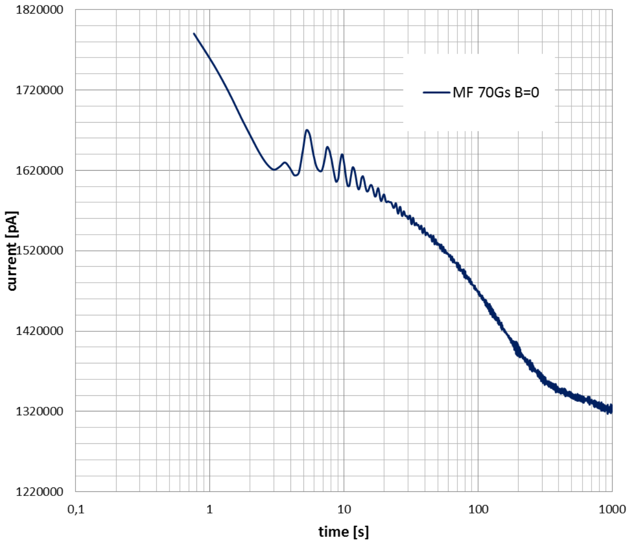

Fig. 7 I(t)characteristics of magnetic fluid 70 Gs without external magnetic field

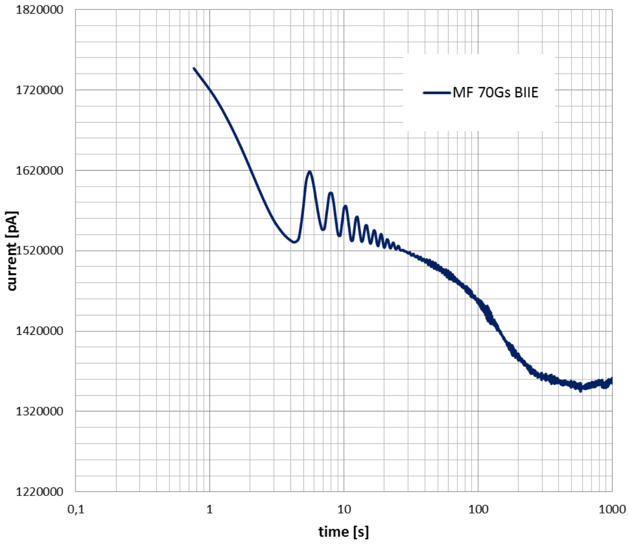

Fig. 7 I(t)characteristics of magnetic fluid 70 Gs with parallel external magnetic field

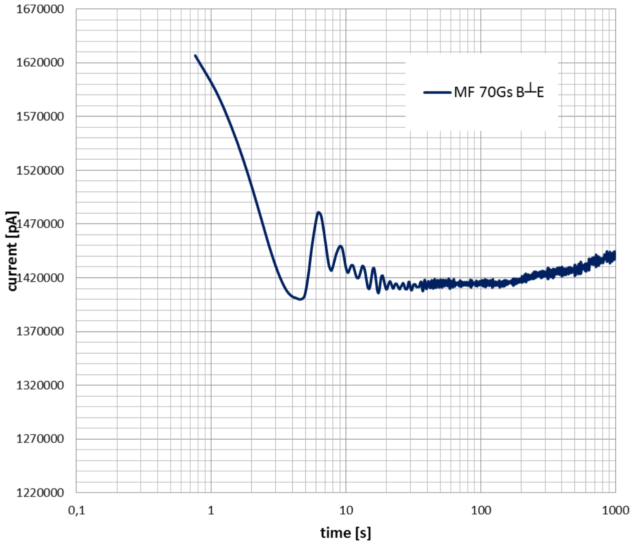

Fig. 8 I(t)characteristics of magnetic fluid 70 Gs with perpendicular external magnetic field

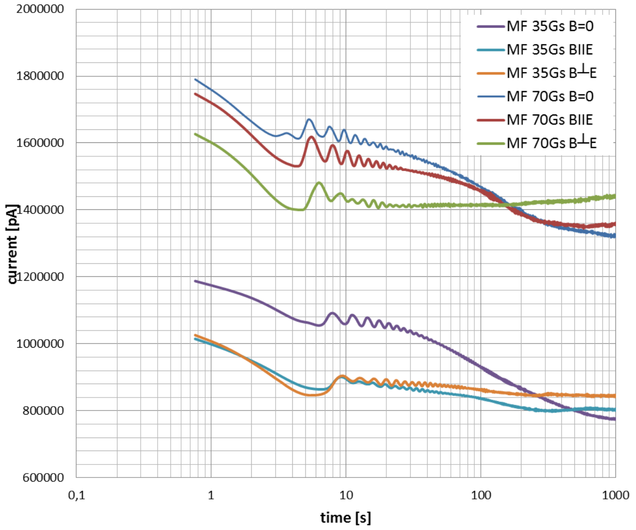

Fig. 9 Comparison of I(t)characteristics of magnetic fluid 35 Gs and 70 Gs

Next measured magnetic fluid was built on same carrier fluid but with double content of $Fe_3O_4$ particles. It caused that current i(t) is increased approx. 1.5 times.

The change of concentration involves not only change of magnitude of current, but also time of start of these peaks. In figures 4 – 6 is given time of start of this phenomenon. It should be noted, that this time is same for every orientation of external magnetic field. Based on fact, that these effect occurs at short time after start of measurement, we can therefore assume only influence of nanoparticles presence. Influence of long chains occurrence can be expected right after presence of initial peaks in time which is approx. 100 s for our sample. In this part of characteristic can be observed oscillations, which are affected by long chains. But these oscillations have lower amplitude like peaks before clustering.

## Conclusion

Aim of this paper was to investigate influence of arrangement of acting external magnetic field to anisotropy of i(t) characteristics of tested magnetic fluids. For confirmation of results were used two different concentrations of magnetic fluids (described as 35 Gs and 70 Gs). As is showed on figure 9, concentration affected only magnitude of measured current, but not the trend of these curves. It means that nanoparticles behaviour is same in every tested fluid. But concentration isn't affecting only magnitude, but also time of occurrence significant growth of current. These are cyclically repeating with damped amplitude. This phenomenon is probably caused by independent nanoparticles or with clusters which occurs in fluid after certain time of acting of magnetic field. Every peaks and Plato's represents some specific polarisation process, which are caused probably by structure of these colloidal fluid.

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