ACOUSTIC SPECTROSCOPY OF MAGNETIC FLUID BASED ON TRANSFORMER OIL

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ABSTRACT

The structural changes in a magnetic fluid (formation of clusters) upon the effect of an external magnetic field were studied by acoustic spectroscopy. The properties of magnetic fluid dispersed in inhibited transformer oil ITO 100 have been studied by the analysis of changes in the acoustic wave absorption coefficient. The absorption coefficient of acoustic waves was measured as a function of an external magnetic field in the range of 0–400 mT, parallel to the direction of acoustic wave propagation. The magnetic fluids change their structure under the influence of an external magnetic field and do not return immediately to the initial state after the magnetic field switching off. It is supposed that the cluster of magnetic nanoparticles formed in the fluid subjected to a magnetic field remains after the field has been removed for the some time.

Keywords: *magnetic fluid, acoustic attenuation spectroscopy, clusters, inhibited transformer oil ITO 100*

1. INTRODUCTION

A magnetic fluid is a colloidal suspension of nano-sized magnetic particles covered with a surfactant layer in a carries liquid [1]. Particles of this size are monodomain and interaction between them may lead to their agglomeration and subsequent sedimentation. To avoid these undesired side effects magnetic particles can be coated by a surfactant that produce entropic repulsion. The macroscopic magnetic properties of the magnetic fluid are determined by the orientation of magnetic moments of nano-particles in the external magnetic field. An externally applied magnetic field induces ordering of the magnetic moments of the particles giving rise to magnetization of the sample as a whole and can cause certain amount of colloidal particles to join into quasispherical and clusters as long as hundreds of nanometers or more [2,3]. Magnetic fluids have attracted remarkable magneto-optical properties, such as birefringence, field-dependent transmission and magnetochromatics. Owing to their exceptional physical properties magnetic fluids have recently found wide application in technology and medicine [4]. The heat transfer in electromagnetic devices such transformers can be substantially improved also by using magnetic fluids suspended in transformer oil. The dielectric breakdown strength of transformer oil is strongly influenced by the aggregation effects of magnetic liquid too [5].

One of the useful methods of studying changes in the ferrofluid structure is based on the measurements of changes in acoustic wave absorption $\Delta\alpha$ under the influence of an external magnetic field. The propagation and attenuation of acoustic waves trough suspensions, in which magnetic particles constituting one phase are dispersed in a continuous second phase could be used to characterize properties of magnetic liquids. The interaction between the acoustic waves and the magnetic particles or clusters leads to additional absorption of acoustic wave compared to that in the carried liquid. Acoustic wave propagation in magnetic fluid was studied by several authors both theoretically and experimentally [1,4-6]. In this paper the authors study the changes of the acoustic wave attenuation coefficient as a function of a constant external magnetic field applied at different sweep rate (time). In our type of experiments we used as carried liquid - the inhibited transformer oil ITO 100.

2. METHOD OF MEASUREMNT

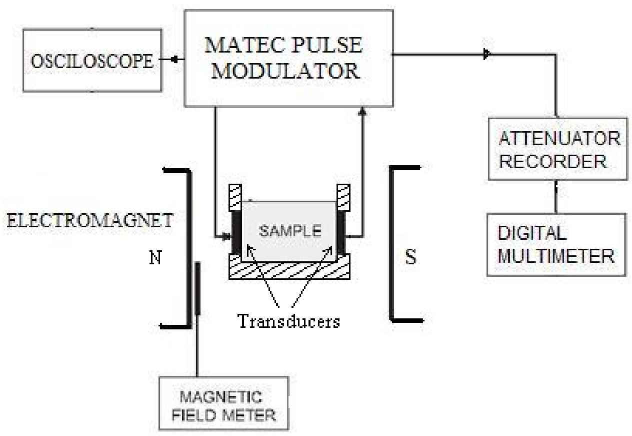

Fig. 1 A block diagram of experimental arrangement

The block diagram of the experimental arrangement is shown in Fig. 1. Measurements of the changes of the absorption coefficient of acoustic wave were carried out by a pulse method using the MATEC Pulse Modulator and Attenuation Recorder [7]. An acoustic pulse propagating in the measuring cell (1.5 x 1 x 1 cm^3) undergoes a multiple reflection from the transducers and its subsequent echoes are recorded. Two selected adjacent pulses following separate paths reach a detector from where signals proportional to their amplitudes are fed to a attenuator recorder. The signal from attenuator recorder, which is proportional to the changes of the acoustic wave absorption coefficient in a given medium was measured by a digital multimeter. The magnetic field changing in small steps 10 mT or 20 mT per every 30 seconds and it was produced in an electromagnet controlled by a current source.

The magnetic fluids used in experiments consisted of magnetite particles ($FeO.Fe_2O_3$), the mean diameter D = 10.6 nm, coated with oleic acid as a surfactant, dispersed in inhibited transformer oil ITO 100. The basic properties of this magnetic fluid, such as the density, saturation magnetization and volume fraction are equal to 1.071 g/cm^3, 8.81 mT and 2 %, respectively. The acoustic velocity in magnetic fluid without magnetic field is c = 1652 m/s (25 ºC).

3. EXPERIMENTAL RESULTS AND DISCUSSION

The measurements were recorded for the acoustic wave of frequencies 5 and 17 MHz, for the direction of acoustic wave propagation parallel to the direction of the external magnetic field **(B || k)**. The magnetic field in the range 0 – 400 mT was changed in steps 10 mT (the whole sweep time - 25 min) and 20 mT (12,5 min) every 30 second. The magnetic field after reach the value of 400 mT and 5-minute pause decreased at the same rate.

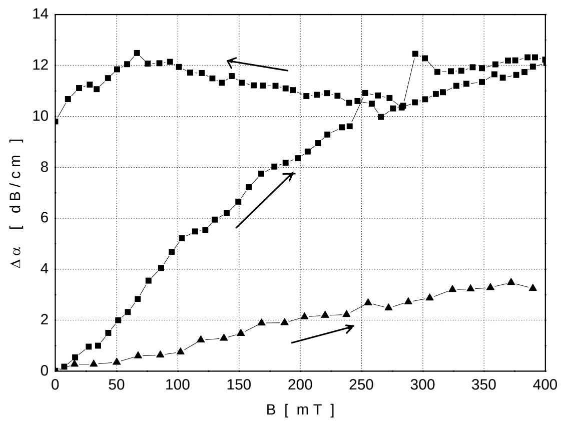

Fig. 2 Changes of the absorption coefficient of acoustic wave for frequency *f* = 17 MHz in the external magnetic field versus the magnetic intensity, when **B** || **k** and for two different values of the steps (■ - 10 mT, ▲ - 20 mT)

Figure 2 presents the changes of the acoustic wave absorption coefficient $\Delta\alpha$ for the acoustic wave of frequency 17 MHz as a function of the magnetic field and for **B** || **k**. These results show a strong influence of the magnetic field on the value of acoustic wave absorption coefficient. With increasing magnetic field, the acoustic wave absorption increases. When the magnetic field is swept at a constant rate, the interactions between the external magnetic field and the magnetic moment of the particle leads to aggregation of particles and more clusters are formed (structures as long as hundreds of nanometers [5]). These effects caused the increase the absorption of acoustic wave with increasing external magnetic field. The character of absorption coefficient changes is different with decreasing magnetic field. The changes of the acoustic wave absorption coefficient show a hysteresis [3,6,8]. This effect can be described by existence of clusters, which lifetimes were longer than time of decrease of the magnetic fluid. The structure does not return to the initial state immediately after the magnetic field has been removed. At rapid increase of magnetic field (20 mT/30 s) the change of acoustic wave absorption coefficient increases more slowly.

Figure 3 presents exemplary results illustrating the changes of the absorption coefficient $\Delta\alpha$ of acoustic wave with frequency 5 MHz as a function of magnetic field and for **B** || **k**. These results again show a strong influence of the increasing magnetic field on the acoustic wave propagation. With increasing magnetic field the acoustic wave absorption increases in opposite to 17 MHz measurement through a maximum. The formation of aggregates in magnetic liquid is indicated at this frequency by the presence of maximum of the absorption coefficient. At value around 240 mT it can be observed a maximum of $\Delta\alpha$, which appear as a result of the additional resonance absorption of the acoustic wave by the spherical clusters (the energy of the wave is transferred to the translation and rotation degree of the freedom of the clusters) [3]. At decreased magnetic field the resonance absorption is shifted to 205 mT. The changes of the acoustic wave absorption coefficient again show a hysteresis as for conditions same as on Fig. 2. The rapid increase of magnetic field (20 mT/30 s) does not show any maximum (Fig. 2 and 3) as well as so evident increase of the acoustic attenuation as at the step 10 mT/30 s.

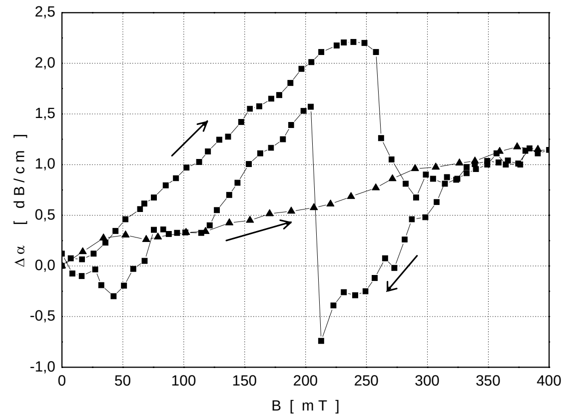

Fig. 3 Changes of the absorption coefficient of ultrasound wave for frequency f = 5 MHz in the external magnetic fluid versus the magnetic intensity, when B || k and for two different values of the steps (■ - 10 mT, ▲ - 20 mT)

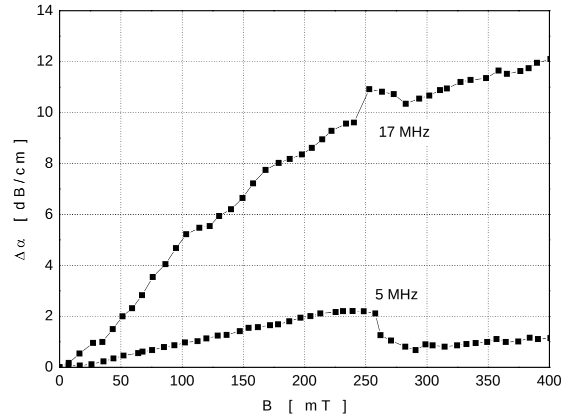

Fig. 4 Experimental data of changes in the ultrasound wave attenuation as a function of the magnetic field for two frequencies of the acoustic waves

The comparison of the changes of absorption coefficient at the frequencies 5 and 17 MHz as a function of the magnetic field at magnetic field step 10 mT are shown in the Fig. 4. From this illustration it is evident that the absorption maximum can be seen also on 17 MHz curve, however the total attenuation at this magnetic field is in this case much higher. It is a result of frequency dependence of acoustic wave attenuation when an acoustic wave propagate through the matter containing particles of particular size.

4. CONCLUSIONS

The acoustic spectroscopy is a very useful tool for investigation of liquids and magnetic fluid in particular. The changes of the acoustic wave absorption coefficient in a magnetic fluid subjected to the influence of an external magnetic field were studied. The acoustic wave attenuation coefficient depends on both the frequency of acoustic wave and the time of the magnetic fluid exposure to the magnetic field. This results from the fact that the magnetic fluid needs a certain time to reach a new state of equilibrium that is formation of clusters. However, the further investigation of the time dependence of acoustic attenuation on the magnetic field at various frequencies and different concentrations of magnetic particles is necessary to understand all processes in this magnetic fluid under magnetic field.

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BIOGRAPHIES

Jozef Kúdelčík was born in January 1975, in Ružomberok, Slovakia. In 1998; he graduated (Mgr.) at the Department of Plasma physics of the Faculty of Mathematic and Physics at UK in Bratislava. He defended his PhD. (2003) in the field of stage of breakdown in the mixtures with SF6. Since 1998; he has been working as a researcher at the Department of Physics at the University of Žilina. His scientific research is focused on discharge mechanism in gases and in dielectric, as water or oil.

Peter Bury received the M.Sc. in experimental physics in 1972 and PhD. In 1982 at the Faculty on Natural Science, Comenius University, Bratislava. Currently he is Professor of Physics of Condensed Matter and Acoustics at Department of Physics, Faculty of Electrical Engineering, Žilina University. The most of his research work was orientated on the study of semiconductors and semiconductors structures using acoustic methods. Formerly he investigated Cr states in GaAs using APR technique, later deep centers in both semiconductor and semiconductor structures using acoustic transient spectroscopy (A-DLTS).