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DETECTING MAGNETIC DEPOSIT IN OIL

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The paper deals with experimental detection of tiny magnetic particles deposited in oil. An iron powder magnetized using stationary magnetic field simulates the magnetic particles. The powder is sprinkled in oil and a fluxgate magnetometer is utilized to measure its remanent magnetic field. Several variables are altered during the experiments and their influences on the measured data are summarized. It is revealed, that even the measured values of the magnetic field intensity are in order of units of Am^{-1}, the fluxgate sensors are sufficiently sensitive to detect such weak magnetic field.

Keywords: maintenance, condition based monitoring, rotating machines, wear magnetic deposit, fluxgate magnetometer

1 INTRODUCTION

Condition based monitoring is becoming key element in maintenance of various structural components in many industrial fields. Primary intention of the maintenance is to assure failure-free service of monitored structures under required level of safety. Especially those structures whose failure can cause considerable ecological and/or economical losses are needed to be monitored and periodically inspected. The secondary effect of the periodical maintenance is the possibility to elongate the life-span of material/structure over an originally planned limit based on the continuous monitoring. It helps to increase the utilization of base materials and energies. Nevertheless, the data gained by the periodical in-service monitoring and the evaluated results can be used for feed-back analyses of used materials and their constructions what is helpful to deepen and gradually complete theoretical knowledge and practical experiences during the design, development and optimization of new facilities. Consequently, the periodical monitoring plays an important role within global priorities on the environment protection and on savings of primary energy sources and raw materials.

It is well known that lubricants such as oil are commonly used to minimize wear in operating machine parts such as transmissions, gearboxes, hydraulic systems, engines, electric machines, etc., [1]. However, in spite of lubrication, particles wear from rubbing and bearing surfaces and deposit in the lubricant. It has long been recognized that knowledge about the amount and form of these wear particles can give valuable information concerning the condition of the machine, [1], [2]. The highly stressed parts in modern machines are usually made of cast iron or steel; the wear particles from surfaces of these parts contain iron and thus they are strongly magnetic.

The paper deals with experiments aimed in detection of wear magnetic particles deposited in oil. The fluxgate magnetometer is utilized for the measurements.

2 EXPERIMENTAL SETUP

An iron powder simulates tiny magnetic particles. Four iron powders with different grain sizes of 50, 75, 150 and 360 μm are used for the experiments.

The iron powders are magnetized in air hole of a magnetizing coil using a circuit shown in Fig. 1. The magnetizing coil is driven with DC current. Value of the exciting current is adjusted using a standard auto-transformer connected to the distribution net of 230 V and 50 Hz. Output of the autotransformer is connected to a bridge diode rectifier that drives the magnetizing coil.

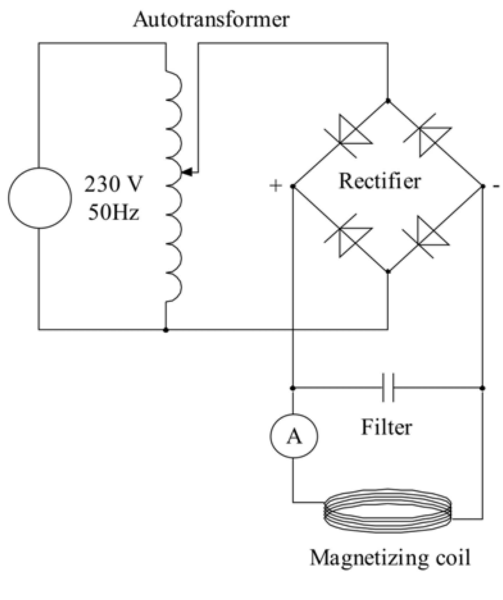

Fig. 1. Configuration of the magnetizing circuit

The magnetizing coil is an air coil wound in the circumferential direction. The detailed picture of the magnetizing coil is shown in Fig. 2. The coil has 7000 turns and its resistance and inductance are 688 Ω and 2 H, respectively.

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The magnetic field intensity in the centre of the coil can be calculated based on:

$$H = \frac{NI}{2w} \ln \frac{\sqrt{R^2 + (h/2)^2} + R}{\sqrt{(R-w)^2 + (h/2)^2} + R - w}$$

where N is the number of turns, I is the value of driving current in [A], $w = 0.02$ m is the width of coil winding, $R = 0.055$ m is the outer radius of coil winding, $h = 0.02$ m is the height of coil winding. For the given parameters, the dependence of the magnetic field intensity in the centre of the coil on the exciting current is approximately given by: $H = 77\times10^3 I$ (A/m).

The magnetic field intensity decreases of 6.7 % at the edge of the coil along its axis for a given value of the current.

Fig. 2. Magnetizing coil

Preliminary experiments without oil showed that the magnetic field from iron powder saturates when the exciting current is approximately 250 mA. Four values of the current are therefore used for driving the coil to magnetize the iron powders: 100, 200, 300, 400 mA.

The iron powders are magnetized as follows. A certain amount of one powder (5g) is put in a tube that is positioned in the centre of the coil as shown in Fig. 2. At first, the coil is driven with an adequate AC current. The AC magnetic field is used to stabilize magnetization processes, because it is well known that the magnetization process in ferromagnetic materials is supposed to be stable after 20 cycles.

The transient disconnection process after the AC pre-magnetization brings uncertainty in the remanent magnetization of the powder. Therefore, the coil is then driven with the corresponding DC current to magnetize the powder. Fluxgate sensors are utilized to measure the remanent magnetic field of the iron powders. The fluxgate magnetometer is based on what is referred to as the magnetic saturation circuit, [3]. Principal layout of the magnetometer is shown in Fig. 3. Two parallel bars of a ferromagnetic material are placed closely together. The susceptibility of the two bars is large enough so that even the Earth's relatively weak magnetic field can produce near magnetic saturation in the bars. Each bar is wound with a primary coil, but the direction in which the coil is wrapped around the bars is reversed.

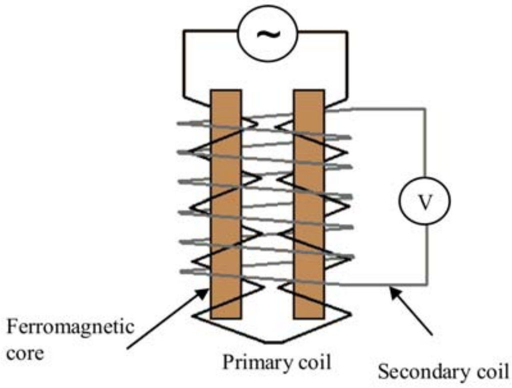

Fig. 3. Layout of fluxgate magnetometer [3]

An alternating current is passed through the primary coils causing a large, artificial, and varying magnetic field in each coil.

This produces induced magnetic fields in the two cores that have the same strengths but opposite orientations, at any given time during the current cycle. If the cores are in an external magnetic field, one component of the external field will be parallel to the core axes. As the current in the primary coil increases, the magnetic field in one core will be parallel to the external field and so reinforced by it. The other will be in opposition to the external field and so smaller. The field will reach saturation in one core at a time different from the other core and fall below saturation, as the current decreases, at a different time. This difference is sufficient to induce a measurable voltage in a secondary coil that is proportional to the strength of the magnetic field in the direction of the cores.

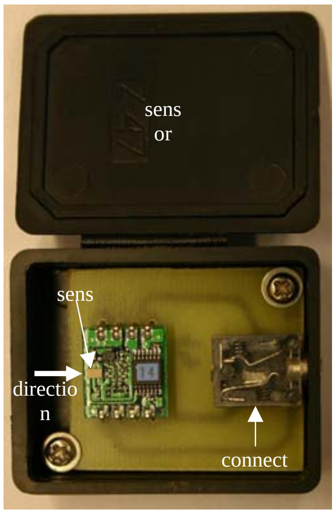

Fig. 4. Photo of the fluxgate sensor

Picture of the fluxgate sensor used in the experiments is shown in Fig. 4. The output of the sensor is in range from 0 to +5 V DC. When no external field is applied, the output of the sensor equals to +2.5 V. The output voltage decreases or increases depending on the orientation of the applied external field. Measured intensity of the external magnetic field of 79.6 Am^{-1} corresponds to a value of 1 V in the output DC voltage.

It should be noted that a value of the Earth magnetic field intensity in the place of measurement (Žilina, Slovakia) is 38.9 Am^{-1} while its vertical component is 35.3 Am^{-1} and the horizontal component has a value of 16.1 Am^{-1}, [4]. All the measurements are taken in the vertical direction. The measured output voltage due to the Earth's magnetic field is approximately 0.459 V what corresponds to the magnetic field intensity of 36.5 Am^{-1}.

Figure 5 shows the experimental set-up. The fluxgate sensor is driven by a DC source DF1730SB3A with a voltage of +5 V. The output voltage of the sensor is measured by a voltmeter METEX M-3870D. The sensor is oriented in vertical direction and attached by an arm to a stage. Position of the sensor is fixed to minimize variation of the sensor output voltage due to the Earth's magnetic field.

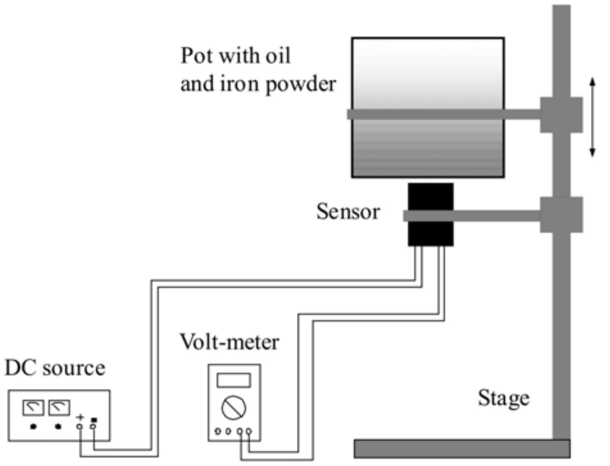

Fig. 5. Experimental set-up

A plastic pot is attached by another arm to the stage. The pot is positioned over the sensor. The minimum distance between the sensor itself and the iron powder deposit is 13 mm due to the pot thickness (1 mm) and due to the distance between the sensor and the surface of its case (12 mm). The remanent magnetic field of the iron powder is measured from the bottom of the pot where the magnetic particles deposit in oil. The pot is filled with 100 ml of a standard type of gear oil. Because the measurements are taken from the bottom of the pot, amount of the oil in the pot does not play any role. Magnetized iron powder is added to the pot with the oil during the measurements in a step of 5 g from 0 to 50 g. The following section summarizes the gained results.

3 MEASUREMENT RESULTS

Three variables are changed during the experiments:

- grain size of the iron powder (50, 75, 150, 360 μm);
- magnetizing current (100, 200, 300, 400 mA),
- mass of the iron powder in 100 ml of the oil (from 0 to 50 g with a step of 5 g).

Following plots summarize the gained results according to those variables. All the measured values of the sensor output voltage are converted into the corresponding values of the magnetic field intensity. The measured reference value of the Earth magnetic field intensity is subtracted from the processed data.

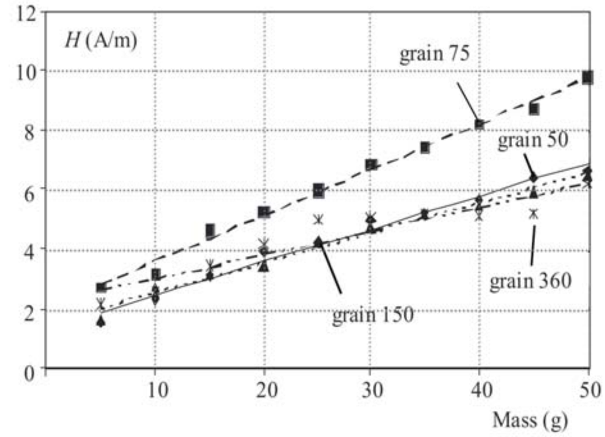

Fig. 6. Dependence of the magnetic field intensity *H* on the *mass* of the powder, magnetizing current I = 100 mA

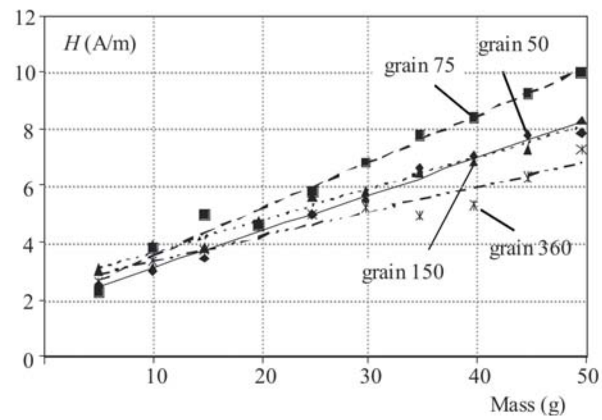

Fig. 7. Dependence of the magnetic field intensity *H* on the *mass* of the powder, magnetizing current I = 200 mA

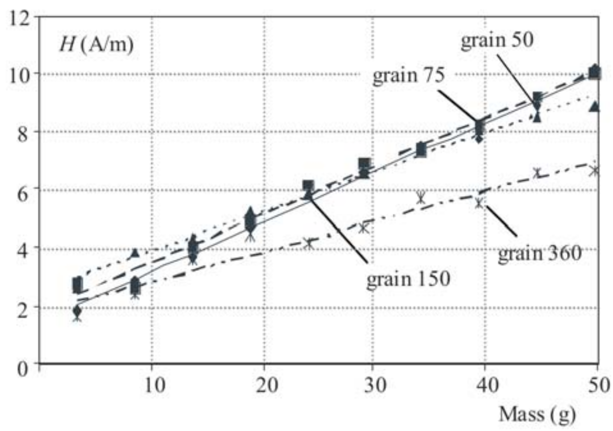

Fig. 8. Dependence of the magnetic field intensity *H* on the *mass* of the powder, magnetizing current I = 300 mA

Dependences of the magnetic field intensity on the mass of the powder in oil are illustrated in Fig. 6 to Fig. 9.

One plot displays the measured data (points) for one value of the magnetizing current and for the four grain's sizes of the iron powder. It can be seen, that the dependence of the magnetic field on the mass of the powder with one size of the grain exhibits almost linear relation within the investigated range. Linear interpolations of the measured points are shown in the figures. As it can be observed, parameters of the interpolated lines depend on the grain size of the iron powder as well as on the magnetizing current.

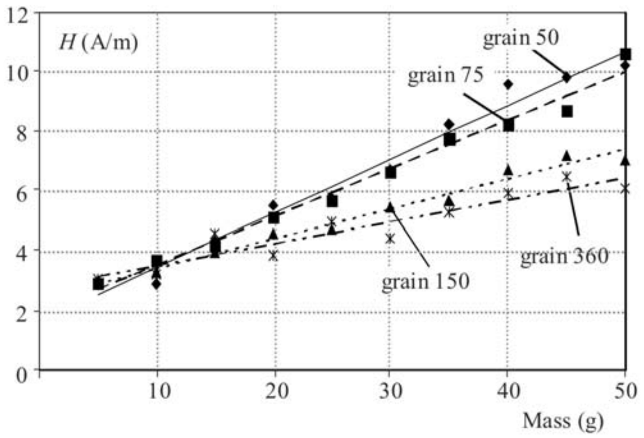

Fig. 9. Dependence of the magnetic field intensity *H* on the mass of the powder, magnetizing current I = 400 mA

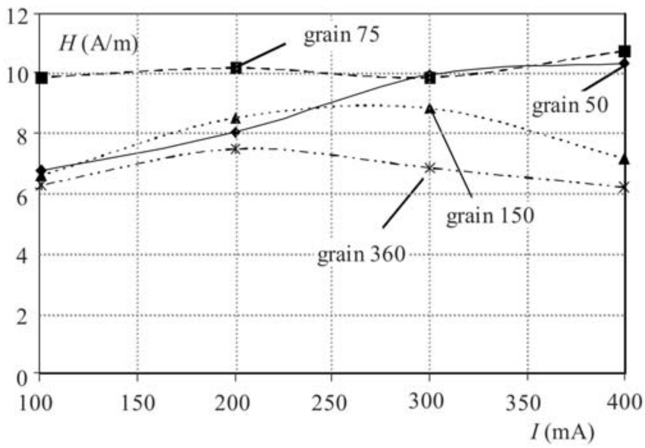

Fig. 10. Dependence of the magnetic field intensity *H* on the magnetizing current *I*, the mass of the powder is 50 g

The dependences of the magnetic field intensity on the magnetizing current for the four different iron powders are shown in Fig. 10. Only data gained for the final concentration of the substance (50 g of powder in 100 ml of the oil) are shown in this figure. It can be seen that the remanent magnetic field of the iron powder deposit in oil somehow depend on the powder magnetizing conditions as well as on the powder grain size. However, it is quite difficult to find clear relation between those variables due to the fact that the sedimentation of the iron powder in oil is quite difficult coupled process. The measured values of the magnetic field intensity depend on how the grains orientate themselves during the sedimentation in each particular case.

4 CONCLUSION

The paper dealt with detecting tiny magnetic particles in oil. Iron powder magnetized using the stationary magnetic field was used to simulate the particles. Fluxgate magnetometer was employed to measure the remanent magnetic field of the iron powder deposit in oil. The measured values of the remanent magnetic field are in range from 0 to 11 $\mathrm{Am^{-1}}$. In comparison, vertical component of the Earth magnetic field intensity in the place of measurement is approximately 35 $\mathrm{Am^{-1}}$. The measured values of the magnetic field are quite low; however, the fluxgate sensors are sufficiently sensitive for detection tiny magnetic particles in oil.

Several variables were altered during the experiments to investigate their influences on the measured data. Almost linear relationship between the measured field intensity and the concentration of the iron powder in oil was observed within the investigated range. However, the measured values depend also on the grain size of the iron powder as well as on the magnetizing conditions. It is quite difficult to find clear relation between those variables due to a complicated process of the sedimentation. Large amount of experiments and their statistical evaluation should be done to understand the process and to find relationships between the variables.

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