

TEMPERATURE MAGNETIC HYSTERESIS OF NICKEL  
NEAR THE CURIE TEMPERATURE

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Temperature magnetic hysteresis of high purity nickel is investigated near the Curie temperature. The impedance of a coil wound on a toroidal sample on temperature is measured. The paper presents the results measurement and analysis of the data obtained.

INTRODUCTION

Temperature magnetic hysteresis (TMH) is the irreversibility of a change of the characteristic parameters of magnetic materials during heating and cooling in a constant magnetic field /1/. It can be expressed by a general relation:

$$\oint (pdT)_{H=\text{const}} = C$$

where  $p$  represents magnetization, magnetic permeability or magnetic susceptibility. Although TMH is a phenomenon that occurs in almost all investigations of magnetic phase transitions and which, therefore, influences measurement results it has been relatively little investigated. There is no theory of TMH. It is explained on the basis of fragmentarily determined dependences of individual quantities determining the summary process of magnetization on temperature /2,3/. One of the problems related to TMH is definition of phase transition temperature and determination of the absolute values of magnetic parameters of polycrystalline samples for which TMH plays a significant role. Results of the investigation of TMH influence on definition of the Curie temperature ( $T_C$ ) for nickel are given in this paper.

EXPERIMENT

Investigation of TMH for nickel is performed by means of a simple measuring system of which the block-diagram is shown in Fig. 1. The experiment consists of the coil impedance measurement. The coil

coil is wound on a toroidal sample. The sample of small mass (1,73 g) is made out of high purity nickel (99,99%), with the external diameter of 10 mm, the internal diameter of 4,82 mm and the thickness of 3,4 mm. The coil has 30 windings.

Measuring circuit is supplied with alternating current of the frequency of 15 kHz. The impedance ( $Z$ ) is determined directly by measuring the voltage and intensity of current (using digital voltmeter  $V$  and ampermeter  $A$  shown in Fig. 1). During one experiment the intensity of magnetizing current is kept constant by adjusting the change

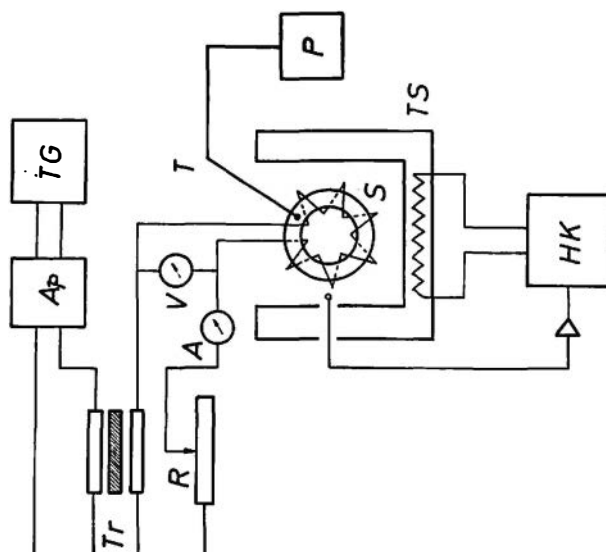


Fig.1. TG-power supply (15 kHz), Ap-amplifier, Tr-transformer, R-variable resistor, T-thermocouple, P-potentiometer, S-coil with sample, TS-thermostat, HK-heating control.

able resistance ( $R$ ). In that way the amplitude of magnetizing field remains constant in spite of the change of the impedance of the sample coil ( $S$ ) with the change of temperature. The experiments are performed at two maximal intensities of magnetizing field  $H_1=1,68$  mOe ( $=0,134$  A/m) and  $H_2=16,8$  mOe ( $=1,34$  A/m).

The sample with a coil is placed in a thermostate (TS) with automatic regulation of temperature. Temperature is measured by the thermocouple iron - constantan (T) by application of potentiometric method (potentiometer P). Measurement is performed "point by point" upon

achievement of the stationary conditions in the temperature interval of  $25^{\circ}$  near the Curie temperature.

#### RESULTS OF MEASUREMENT

Results of the measurement of the impedance ( $Z$ ) of the coil with Ni - core on temperature are shown in Figs. 2 and 3. Both figures show the presence of TMH and the same regularity: formation of a closed loop near the Curie temperature ( $T_c = 360^{\circ}\text{C}$ ).

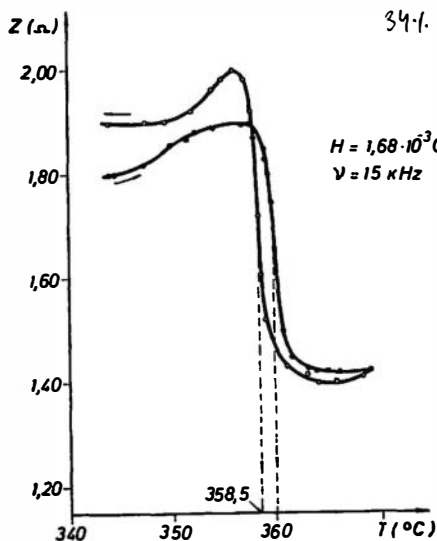


Fig. 2.

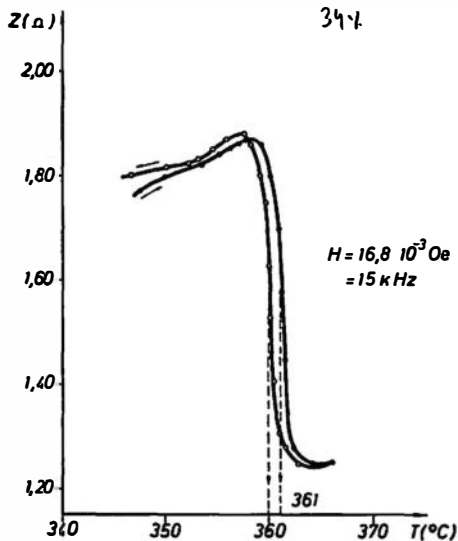


Fig. 3.

In connection with the measurements performed the significance of the measured quantity ( $Z$ ) with respect to the material investigated should be explained. This problem is discussed in detail in /4/ in relation to the investigation of strong magnet near the temperature of phase transitions. The coil impedance is determined by its inductance proportional to magnetic permeability ( $\mu$ ), and, to a lesser extent, by a resistance associated with losses in the magnetic material /5/. Due to that, the curves  $Z(T)$  have the shape similar to that of  $\mu(T)$  curves /4,6/. On the basis of the above stated, it follows that curves  $Z(T)$  give the resulting effect of all processes

that cause TMH in a polycrystalline magnet. This means that the causes of TMH cannot be explained only on the basis of such measurements, what in fact is not the aim of this paper.

Although nickel has been investigated to a great extent, so far as we could determine, the TMH for this material is described in a very few papers /7,8/. The previous investigations were performed by measurement of magnetization in a wide range of temperatures but with small density of points so that the details in a narrow temperature interval near the Curie temperature cannot be established on the basis of these measurements. Due to that, our investigations of TMH for nickel are the first ones of the kind.

#### RESULT ANALYSIS

Experimental results presented in Figs. 1 and 2 show that TMH influences definition of the Curie temperature ( $T_c$ ). If  $T_c$  is defined by the position of inflection point on the curve  $Z(T)$ , as is done for diffuse phase transitions of polycrystalline materials /9/, than the heating and cooling curve have different values. The values for  $T_c$  obtained in this manner are given in Table 1.

Table 1

|                        |                                     |                                     |
|------------------------|-------------------------------------|-------------------------------------|
| maximal field strength | H=1,68 mOe                          | H=16,8 mOe                          |
| heating curve          | $T_c = 360,0 \pm 0,5^\circ\text{C}$ | $T_c = 361,0 \pm 0,5^\circ\text{C}$ |
| cooling curve          | $T_c = 358,5 \pm 0,5^\circ\text{C}$ | $T_c = 360,0 \pm 0,5^\circ\text{C}$ |
| mean value             | $T_c = 359,2^\circ\text{C}$         | $T_c = 360,5^\circ\text{C}$         |

These values show the effect of TMH on a determination of  $T_c$  using this technique. This is the effect to be taken into consideration in magnetic measurements. At the same time these values show the influence of magnetic field on  $T_c$  although the experiments are performed in very weak magnetic fields. As could have been expected /6/, the phase transition temperature increases in a stronger field. The values obtained are above the temperature of  $T_c = 358,58^\circ$  obtained by calorimetric measurements based on magnetic heat capacity determination /10/.

#### CONCLUSION

The measurements performed show that TMH condition certain indefiniteness in the position of  $T_c$  and that, on the basis of magnetic measurements, the mean value of the heating and cooling curve must

be accepted as a value of  $T_c$ .

It is necessary to noticed that in our experiments very weak magnetizing fields are used. But, the examples for very large changes of magnetic parameters near the room temperature in magnetizing fields of some mOe are known (for example, /11.-14./ and earlier measurements described in /15/). The effect of the weak magnetizing field, observed in our experiments, probably can be explained by high purity of the used sample, i.e. by the influence of this purity on the domain structure and consequently on the magnetizing process. Influence of H on TMH indicates that it would be interesting to investigate the dependence of TMH hysteresis loop width near  $T_c$  on the intensity of magnetic field. These measurements shall soon be performed.

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