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COMMUNICATIONS

DC compensated permeameter - the accuracy study

Petr Kašpar, Pavel Ripka, Jan Vyhnánek*

We describe D-permeameter originally designed by Trnka and later improved by Fajt and Kaspar and we analyze its precision for the measurement of different soft magnetic materials. The device measures DC hysteresis loops using compensation method, so that H and B can be calculated from the magnetization and compensation currents. The differences from results obtained by other standard methods are below 2%.

K e y w o r d s: permeameter, BH curve measurement

1 Introduction

AC single sheet testers

Single sheet testers serve for the measurement of the magnetic properties of electrical steel in the form of strips and sheets at frequencies of 50 Hz and higher [1]. Single-sheet tester for strips is defined by IEC standard 60404-4. Compensated single-sheet tester was developed by Mikulec [2]. The device is using Rogowski coil as a null indicator, so that it cannot be used for DC measurements. Both magnetization and compensation coils are wound around the specimen. B is measured by the induction coil [3]. Digital version of this instrument solves problems with the stability of two feedback loops - one for keeping the sinewave shape of B, the other for the compensation of magnetomotive force [4].

Permeameters

They serve for the measurement of DC magnetisation characteristics of open soft magnetic samples such as rods, bars and strips. They use magnetic yoke to close the magnetic circuit. IEC standard 60404-4 [5] defines two basic arrangements of uncompensated permeameters with double-C yokes:

- in type A permeameter the magnetizing coil is wound around the specimen and H can be measured by tangential Hall probe or by flat coil [6]
- in type B permeameter the magnetizing coil is wound around the yoke and H is measured by Rogowski-Chattock potentiometer.

In both cases B is measured by induction coil. Type B permeameters are commercially produced [7], [8]. Fig. 1 shows uncompensated permeameter MJR 5 manufactured by Magnet-Physik [8]. The instrument requires two integrators to evaluate H and B. The fundamental problem of uncompensated permeameters is that both B and H vary within the sample volume [9].

Compensated permeameters are of type A and they compensate the drop of the magnetomotive force on the magnetic circuit outside the magnetizing winding. The H in the sample then can be calculated as H$= NI/l$ where N and l are number of turns of the magnetizing coil and l is its length. Classical ballistic compensated permeameters such as Iliovici are considered to be obsolete as they require manual compensation for each measurement point [10].

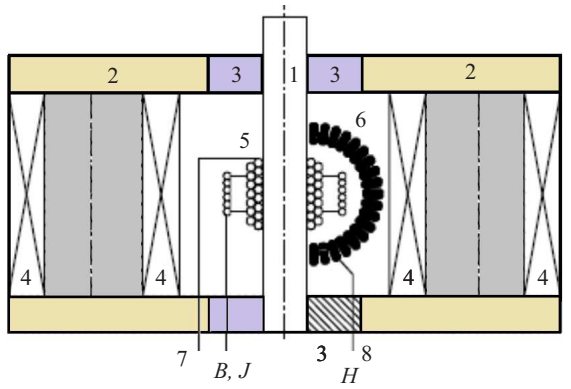

Fig. 1. Uncompensated permeameter MJR 5 by Magnet-Physik (reproduced with permission from [4]): 1 – specimen, 2 – yoke, 3 – exchangeable ploe pieces for bars and sheets, 4 – field generating coils, 5 – J compensating surrounding coil, 6 – potential coil for H measurement, 7 – connecting J - fluxmeter, 8 – connecting H - fluxmeter

2 DC compensated permeameter

In this paper we describe D-permeameter originally designed by Trnka and later improved by Fajt and Kaspar and we analyze its precision for the measurement of different soft magnetic materials.

The instrument (Fig. 2) consists of

- Yoke with compensation winding ck
- Magnetizing solenoid cm
- Fluxgate sensor s
- Feedback compensation electronic box

* Department of Measurement, Faculty of Electrical Engineering , Czech Technical University, Prague, Czech Republic, kaspar@fel.cvut.cz, ripka@fel.cvut.cz, vyhnajan@fel.cvut.cz

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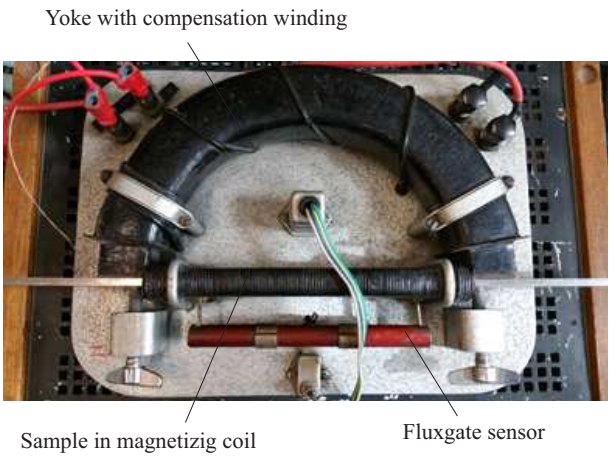

Fig. 2. Compensated Trnka permeameter

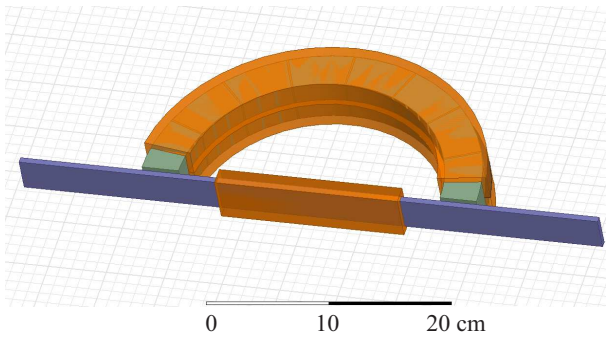

Fig. 3. Digital model of permeameter

D-shaped magnetizing yoke consists of Sendust segments with 7 airgaps. The yoke has practically constant reluctance in the wide range of flux.

The sample is inserted into the magnetizing coil and clamped to the yoke. Then the sample is magnetized by the magnetization current I_m. Magnetic voltage between the ends of the fluxgate sensor is feedback compensated to zero by the compensation current I_k. This in fact compensates for the magnetic voltage drop across the airgaps and magnetic circuit outside the specimen. After fulfilling this condition, the magnetic field intensity H inside the sample can be derived from I_m and flux density B is derived from I_k. This makes the instrument quite handy, as neither B coil nor integrator is required. The hysteresis loop can be measured very slowly, which is necessary for bulk samples.

We have used this permeameter to measure the magnetization characteristics of the steel bar routinely used for grounding. The advantage of the permeameter is that the instrument can measure short segments from long bars without cutting. The cross-section of the bar was 30×5 mm.

Figure 3 shows the 3-D model of yoke with compensation coil and bar sample inside the magnetization coil. FEM model in ANSYS shows the compensation effect: without compensation the flux density within the sample changes by 20 %, Fig. 4, compensation reduces the variation below 0.5 %, Fig. 5. The leakage flux is thus very small.

2 The measurements

Figure 6 shows the magnetization characteristics measured by permeameter (blue trace) and the same loop when B is measured by induction coil and integrator, while H is still measured by permeameter (red trace). The figure shows that the constant for calculation of B from the compensation current probably has about -2.5 % error.

The hysteresis loop measured on steel rod sample was compared to loops measured on the same sample in the yoke and on the ring machined from the same material: the differences were below 2%. In order to achieve good contact with the measured bar, the yoke has splitted central part as shown in Fig. 7. The yoke allows to apply very high H values as shown in Fig. 8. However, if we reduced $H_{\max}$ to the same range as the permeameter, the measured loops had good fit of about 2%.

3 Conclusions

DC D-permeameter is a versatile instrument which can perform fast and precise measurement of DC and low-frequency AC measurements of open samples which can be very long. The samples need not to be cut, and H within the measured section is very homogeneous. B and

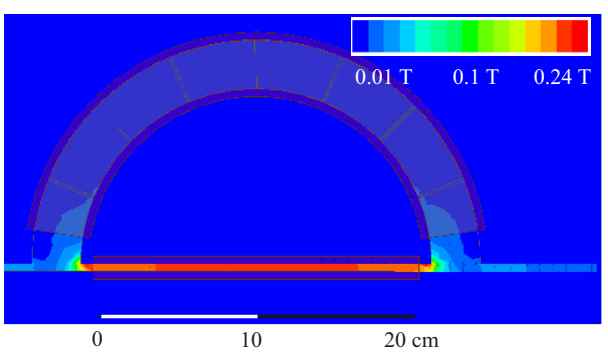

Fig. 4. Field map without compensation

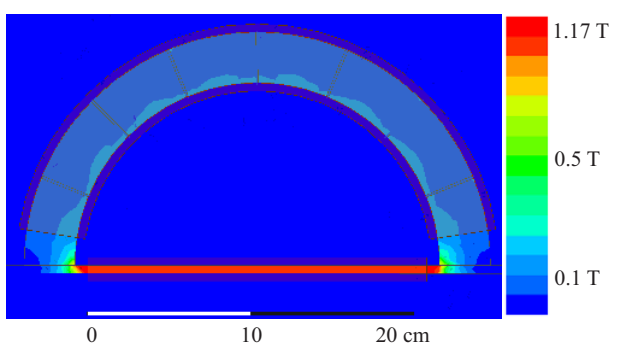

Fig. 5. Field map with compensation

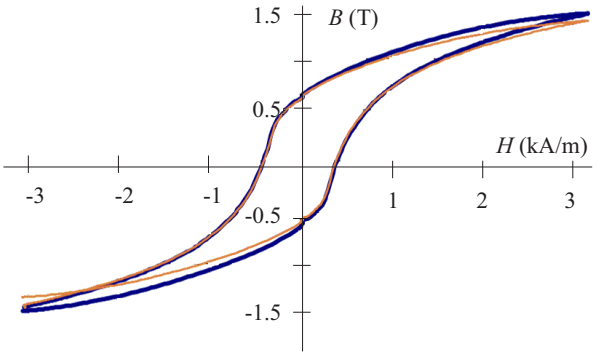

Fig. 6. $B(H)$ loop of soft iron: blue curve B and H measured by permeameter, Red curve measured by coil and integrator, H measured by permeameter

Fig. 7. Detail of the splitted pole

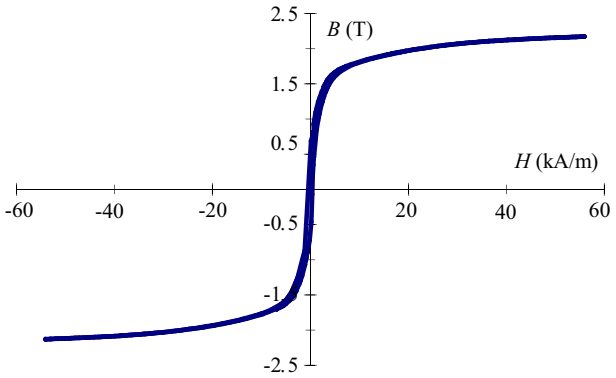

Fig. 8. Hysteresis curve measured in the yoke

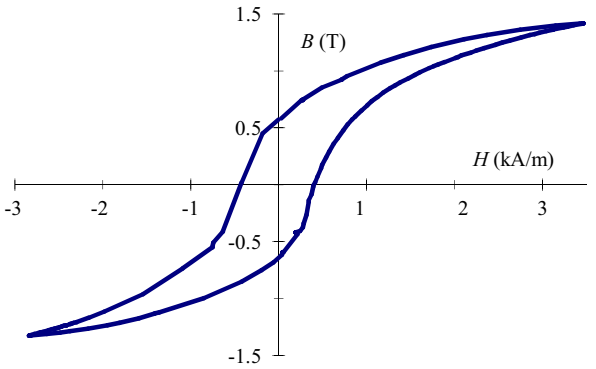

Fig. 9. Hysteresis loop measured in yoke for smaller field amplitude $H_{\max} = 3500$ A/m

H can be conveniently evaluated from the magnetization and compensation currents.

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Petr Kašpar, born in 1955 in the Czech republic, completed his PhD in 1988 and at present he works as an associated professor at CTU.

Jan Vyhnánek, born in 1987 in the Czech republic, graduated from CTU in 2011 with Ing. Title, at present he is a PhD student at CTU.

Pavel Ripka, born in 1959 in the Czech republic, completed his PhD in 1984 and at present he works as a professor at CTU.