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Automatic Measurement Station for Ferrite Materials Testing

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The paper presents automatic and modular measurement station for the magnetic materials testing. It allows for measurements of magnetic hysteresis loops under various regimes (sine, triangle or arbitrary magnetizing field, sine or triangle magnetic flux density) and relative permeability curves. The modular nature of the system allows for measurements of magnetic parameters under additional external influences, such as temperature and stress. The system is currently used for measurements of ferrite materials parameters.

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1. Introduction

Many modern electronic devices are made using inductive elements. Often, the magnetic cores in these elements are made of iron oxides, such as ferrites. Selection of the right core is essential for the proper work of a device, for example switching mode power supplies, filters, chokes and transformers. Each type of material is used for different application, and the core parameters need to be examined. For this purpose an automated measurement station designed for ferrite magnetic cores testing was made.

2. System setup

System works under control of PC with National Instrument LabVIEW software for measurement systems management. The core of the system consists of high resolution U/I converter and fluxmeter controlled by a PC with National Instruments Data Acquisition Device.

The system is a classical hysteresis graph, which generates alternating magnetic field in the sample and measures its response, which is the change of the material's magnetization. The stand allows for conducting series of measurements, with variable magnetizing fields parameters such as amplitude, frequency, and shape. The shape used varies depending on the sample's application. Using iteration method, the station also allows for generating linear and sinusoidal magnetic flux in the samples, which ensures lower losses compared to using linear and sinusoidal magnetizing field [1]. This in turn allows for true magnetic parameters measurements, without the eddy current disruption. Key parameters which result from such measurement are relative permeability curve μ, power losses P_h, coercivity H_c, saturation flux density B_s and magnetic remanence B_r changes in the function of various parameters.

The system also allows for measurements under variable compressing force using external press and integrated force sensor, as well as under variable temperature in −40 °C–+200 °Crange, using additional PolyScience cryostat. Figure 1 presents the block diagram of the system, whereas Fig. 2 presents the measurement system.

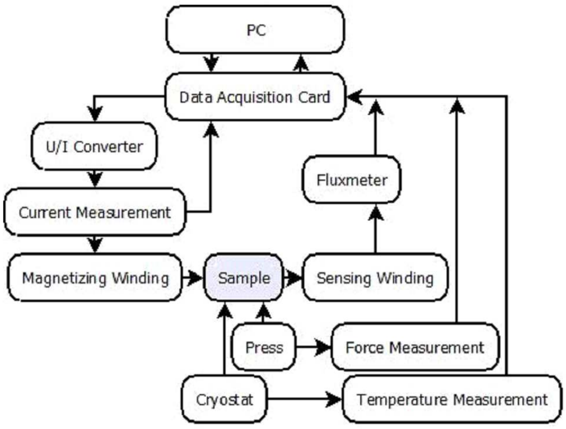

Fig. 1. Block diagram of the measurement system.

Detailed information about each module is presented in Table I. Each of the modules can be easily replaced with another device, e.g. custom made fluxmeter.

The system also features:

- Automated acquisition of hysteresis loops with variable parameters (e.g. frequency, shape and amplitude of magnetizing field)
- Computations for hysteresis loop parameters (e.g. inductance vs. current and frequency)
- Demagnetization of sample between measurements

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TABLE I

Detailed information about system modules.

Module	Device name	Additional information
U/I converter	KEPCO BOP 36-6M	max. current ±6A max. voltage ±36 V
Data Acquisition Device	National Instruments NI PCI 6221	max. voltage: ±10V 16-bit 250 kS/s ADC 16-bit DAC
fluxmeter	LakeShore Model 480	DC range 0–300 mV s DC accuracy ±10 μV s
cryostat	PolyScience AD07R-40-A12E	temp. range –40 °C–200 °C temp. stability ±0.01 °C
force sensor	ZEPWN CL 14	force range 20 kN accuracy 0.1%

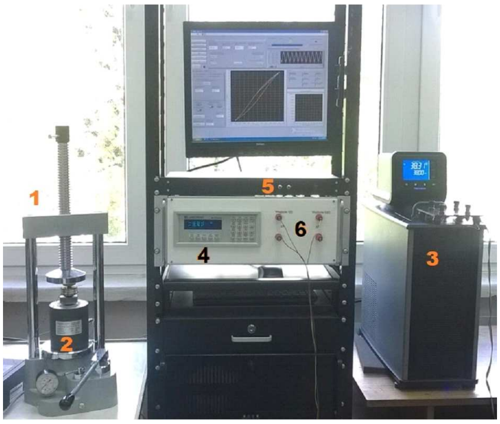

Fig. 2. Measurement system (1 — press, 2 — force sensor, 3 — cryostat, 4 — fluxmeter, 5 — U/I converter, 6 — connectors).

- Averaging of user defined number of hysteresis loops into one full loop
- Software and hardware fluxmeter drift compensation
- Centering of the loop by maximum B or H, or by H_c and B_r
- Temperature measurement
- Force measurement
- Saving measurement data to text and image files

3. Measurement process

The system features several options for magnetizing waveform shape:

- Sinusoidal magnetizing field
- Triangle magnetizing field
- Sinusoidal flux density
- Triangle flux density
- Demagnetizing waveform
- Custom waveform (generated by user with LabVIEW's waveform tools)

To measure, the software is performing generation of driving current signal and acquisition of voltage signal from fluxmeter basing on the following procedure:

- Computation of magnetizing waveform
- Generation of voltage driving signal (NI DAQ)
- U/I conversion
- Reading voltage signals from fluxmeter (NI DAQ)
- Capture peaks (fluxmeter)

Signal generated for demagnetization of sample follows the formula (1):

$$I(t) = I_0 \sin\left(2\pi f t\right) \mathrm{e}^{(-\frac{t}{\tau})}, \tag{1}$$

where $I(t)$ — current value, I_0 — maximum current value, f — frequency, t — time, τ — time constant. The exact value of time constant and frequency depends on sample's magnetic remanence and coercivity field values, and differs greatly for hard and soft magnetic materials.

The sinusoidal/triangle flux density response is achieved using iteration method. In the first iteration, the sample is magnetized using specially developed function, which speeds up the iteration process and lowers losses in the coil as opposed to using other waveforms in the first iteration. The function has the following Eq. (2) on each quarter of period:

$$H(t) = \frac{A \tan(b\omega t)}{\tan(b\frac{\pi}{2})}, \tag{2}$$

where $H(t)$ — magnetizing field waveform in quarter of period, A — amplitude of magnetizing field, b — slope parameter, ω — angular frequency, t — time. The slope parameter b is in the range from 0 to 1 and determines how much the generated waveform is similar to a perfect tangent. Using value of 0.1 generates a near perfect triangle waveform, while optimal values for measurement are in the range of 0.9 to 0.97.

The second quarter is then reflected with respect to the Y axis to obtain continuous function, and the third and fourth quarter are a reflection of first and second with respect to the X axis. Figure 3 presents an exemplary result of the first iteration using the function.

In the next iterations the function $H(B)$ obtained in previous iterations is fitted to a polynomial from which the $H(t)$ giving sine/triangle $B(t)$ is obtained. Order of the polynomial was obtained experimentally, the best results were obtained using order of 25. The sample is then magnetized with the new $H(t)$ function. Typically after 2–4 iterations (depending on the type of sample) the form factor of $B(t)$ vs. ideal triangle or sine function

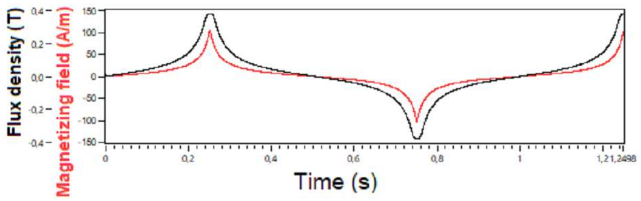

Fig. 3. Magnetizing current and sample response on first iteration.

is less than 0.1% and root mean square (RMS) error is less than 5% [2].

Magnetic losses depend heavily on the rate of magnetic flux density change $\mathrm{d}B/\mathrm{d}t$ [3]. Using triangle magnetic flux density allows for measurement with greatly diminished losses, which ensure true magnetic parameters measurement and low heat dissipation in the sample, while measuring with sine magnetic flux density allows for measurement in accordance with the norms [4, 5]. Figures 4 and 5 present obtained $H(t)$ and $B(t)$ waveforms for sine $B(t)$ and sine $H(t)$ measurements. The resulting power loss ($\int H\,\mathrm{d}B$) is much lower using sine $B(t)$ in comparison to sine $H(t)$.

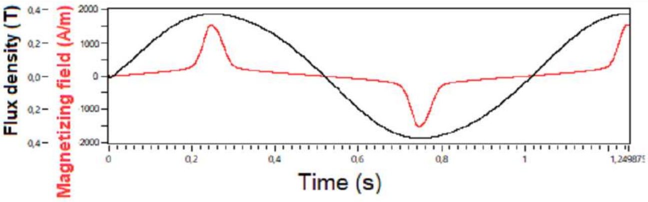

Fig. 4. Measurement results for sine $B(t)$.

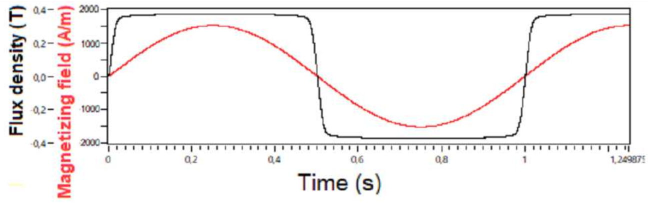

Fig. 5. Measurement results for sine $H(t)$.

Generation of sine $B(t)$ is also possible by magnetizing the coil in constant voltage mode instead of constant current mode, but a number of requirements, such as very low impedance of power supply and measurement resistor, as well as high number of magnetizing turns, must be fulfilled [4]. Using iteration method, these requirements can be omitted.

The measurement station allows the following measurement series:

- Variable magnetizing field amplitude (constant frequency)
- Variable frequency (constant magnetizing field's amplitude)
- Quasi-static series (constant $\mathrm{d}H/\mathrm{d}t$, variable amplitude)
- Variable temperature series
- Variable force series

4. Exemplary results

A sample with 3E6 (3E10-M) — high permeability material core optimized for use in wideband transformers as well as EMI-suppression filters made by Ferroxcube was chosen for measurement. The obtained hysteresis loop for 3E6 core is presented in Fig. 6, $H_m = 1000$ A/m, saturation flux density $B_s \approx 400$ mT, magnetic remanence $B_r = 55$ mT, coercivity $H_c = 1.5$ A/m, relative permeability 25000.

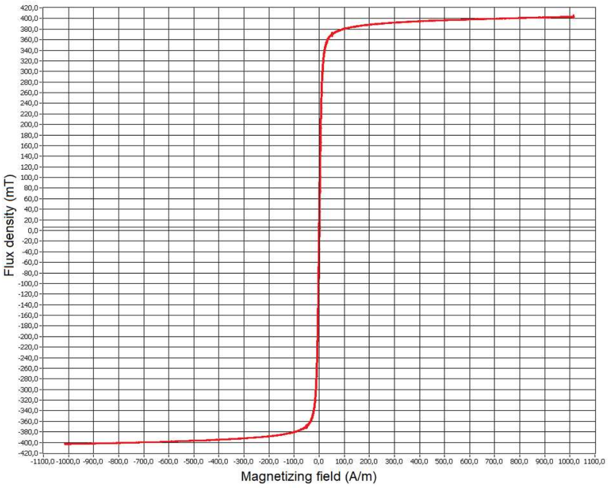

Fig. 6. BH loop for 3E6 core.

5. Comparison

The system was compared with Pentalab HB-PL30 magnetic measurement system. An F-3001 ferrite core was tested on Pentalab system and on the new system using the same parameters:

- Sinusoidal H waveform
- Magnetizing field amplitude 215 A/m
- Frequency 1 Hz

The results are presented in Fig. 7 and Table II.

The results indicate that the old system that was used previously produced unsymmetrical hysteresis loops. The number of measurement points was limited to 129, while the new system allows for as much as 10000 pts, so the resolution and accuracy was greatly increased. The differences in coercivity field and magnetic remanence are mainly caused by the asymmetry in the loops measured by HB-PL30 system.

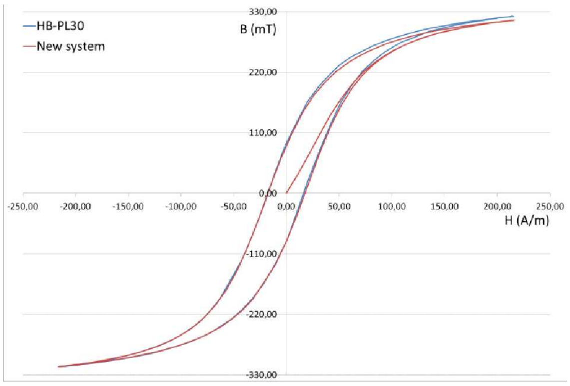

Fig. 7. Comparison between systems.

TABLE II

Comparison results

System	H_m	H_c	B_m	B_r	μ_r
	[A/m]		[mT]		
HB-PL30	215	16.79	318.7	89.6	1179
new system	216	17.82	314.1	87.9	1156.8
% difference	0.4%	5.8%	1.5%	1.9%	1.9%

The new system also features automatic drift compensation, both hardware and software-wise, sinusoidal and triangle B waveforms, and other options, which were previously unavailable in Pentalab system.

6. Conclusions

The main intention of this research was to design the test station which allows for obtaining of full magnetic characteristics of soft magnetic materials, such as ferrites, under the influence of various parameters, with accordance to norms of magnetic measurements [6, 7].

The station allows for magnetizing current generation of 6 A amplitude with resolution of 0.2 mA (maximum load 6 Ω) and frequency up to 1 kHz (depends on inductance of magnetizing coil). Temperature of the measurement can range from −40 °C to +200 °C. Force range of measurement reaches up to 20 kN.

The modular design allows for quick modification of utilized devices, for example with interchangeable U/I converters and fluxmeters.

Acknowledgments

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