JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 10, No. 7, July 2008, p. 1847 - 1852

# Magnetic measurements of soft magnetic materials and hysteresis modelling using LabVIEW programs

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The paper presents some experiments that have been carried out on toroidal cores on which two coils have been wound. In the primary coil a current of the desired waveform was introduced, and at the terminals of secondary coil another voltage proportional to the time derivative of the magnetic flux density was acquired. At the terminals of a resistance inserted in primary circuit, is acquired a voltage, proportional to the supply current and respectively with the magnetic field strength. From acquired voltages it was possible, after a certain arithmetic calculus, to draw the hysteresis cycle. After measurements it was made a modelling of major hysteresis cycle using lines and circle segments. For comparison the measured hysteresis cycle and simulated one are plotted on the same graph.

(Received April 1, 2008; accepted June 30, 2008)

*Keywords:* Solid core, Sheet core, Primary coil, Secondary coil, Hysteresis.

## 1. Introduction

For magnetic materials one of the most important characteristics is the hysteresis cycle. For this reason we tried to obtain the major hysteresis loop, the minor hysteresis loop, and the reversal curve of the first kind [1] – [5].

The experimental setup contain a Data Acquisition Board - DAQ NI PCI-6052E, 16 bit, 333 kS/s, from National Instruments, which is placed in a PCI slot of a computer. This DAQ made for high accuracy measurement, has the resolution of 16 bits, and can acquire up to 333000 samples per second. The DAQ has one connector which contains input/output terminals. The range of measurements can vary between -10V and 10V.

On the output connector of the Data Acquisition Board an adaptor for BNC inputs/outputs from National Instruments NI BNC 2090, is included.

A Bipolar Power Supply is used to amplify the output signal from DAQ via NI BNC 2090, and to inject into the primary circuit the desired waveform current. The Bipolar Power Supply PBX 20-20 is produced by KIKUSUI and it can operate in all four quadrants. The Voltage limits are -20 V to 20 V, and the current limits are -20 A to +20 A. The PBX 20-20 is able to perform high speed changes in polarity, with rise and fall times of maximum 50 µs. It can be operated in two modes: constant voltage operating mode, and constant current operating mode. In our system, this bipolar power supply is used only as an amplifier for the output signal generated by the data acquisition board DAQ, and it operates in constant current control or constant voltage control.

The voltage $U_s$ is supplied by PBX to the primary circuit. This voltage gives rise to a current that passes through the primary coil and a high accuracy manganin resistor. From this resistor, a voltage $U_n$ proportional to the magnetic field strength $H$, is acquired by DAQ. From the secondary circuit another voltage $U_x$ is acquired, which is proportional to the time derivative of the magnetic induction $B$

A LabVIEW program is installed in the computer, in the PCI slot of which the DAQ is inserted, which controls the Data Acquisition Board and performs the calculus required to obtain the hysteresis cycles.

## 2. LabVIEW program

This program uses virtual instrumentations for several purposes. The different virtual instruments can be connected and the results can be obtained and visualized on virtual oscilloscopes.

The program which we have prepared contains two distinct parts: one which generates and acquires data from or to DAQ, and one which makes the calculus in order to obtain the magnetic field strength $H$ and magnetic induction $B$ starting from the two voltages acquired by the DAQ.

The needed input data are the resistance $R_n$, numbers of turns of the primary coil $w_1$ and the secondary coil $w_2$, the cross-section surface of the toroidal core $S$ and the medium length of the core $l$.

For the first part, it is necessary to specify the period, number of samples, number of samples per period, for the calculation of the buffer size and sampling frequency.

In this first part, there are several virtual instruments for analogue input and output. The most important are AI Config and AO Config, which make the bound between the LabVIEW program, and Data Acquisition Board.

The desired voltage for the primary circuit can have a sinusoidal waveform or can have another waveform, which can be obtained by means of a MatLab Program, or another program, which have as a result a text file. This text file contains a column vector, which contains the instantaneous values of the desired waveform.

From the output of the first block, which is a *case structure,* the *buffer size*, *sampling frequency* and desired waveform was obtained. The blocks AO Config, AO Write, AO Start, AO Clear are Intermediate Analog Output Virtual Instruments, which command the DAQ to generate the desired waveform at its output channel Dac1out.

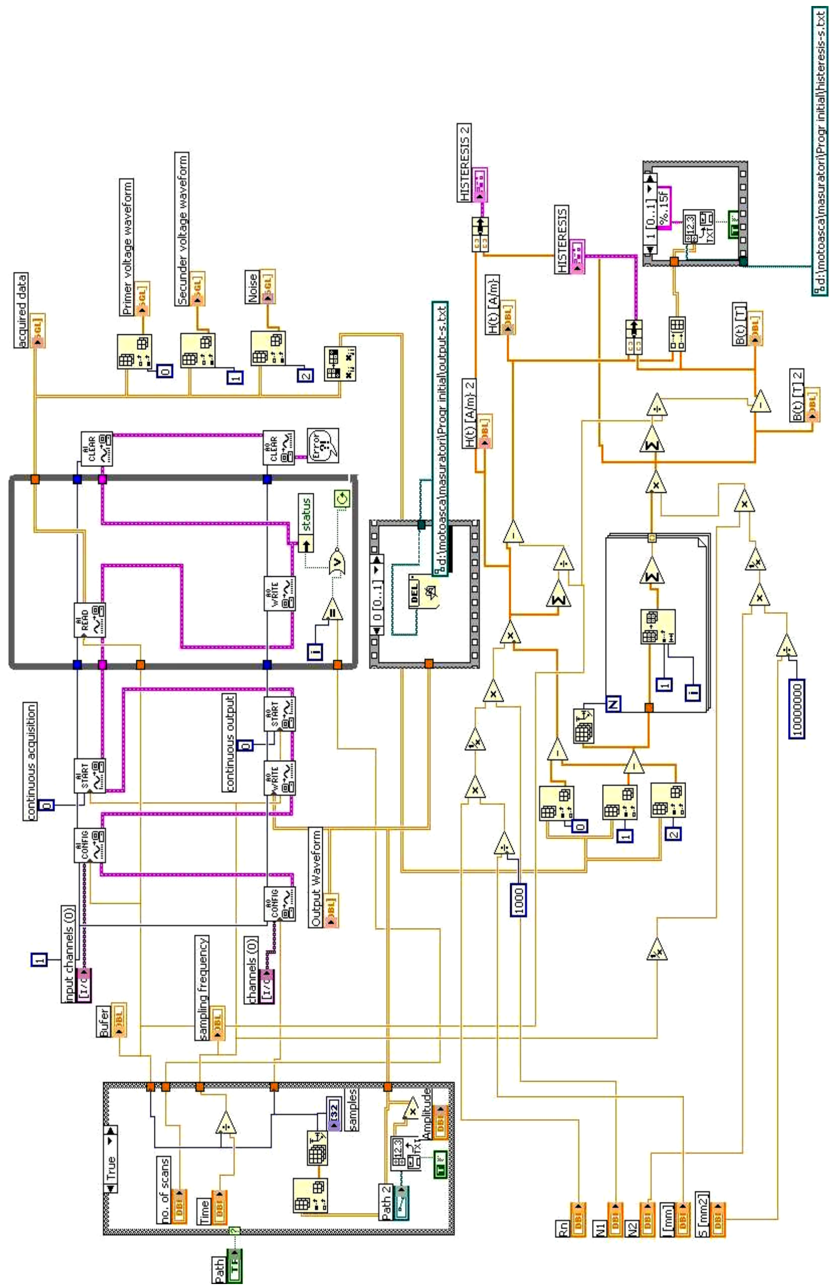

*Fig. 1. LabVIEW program.*

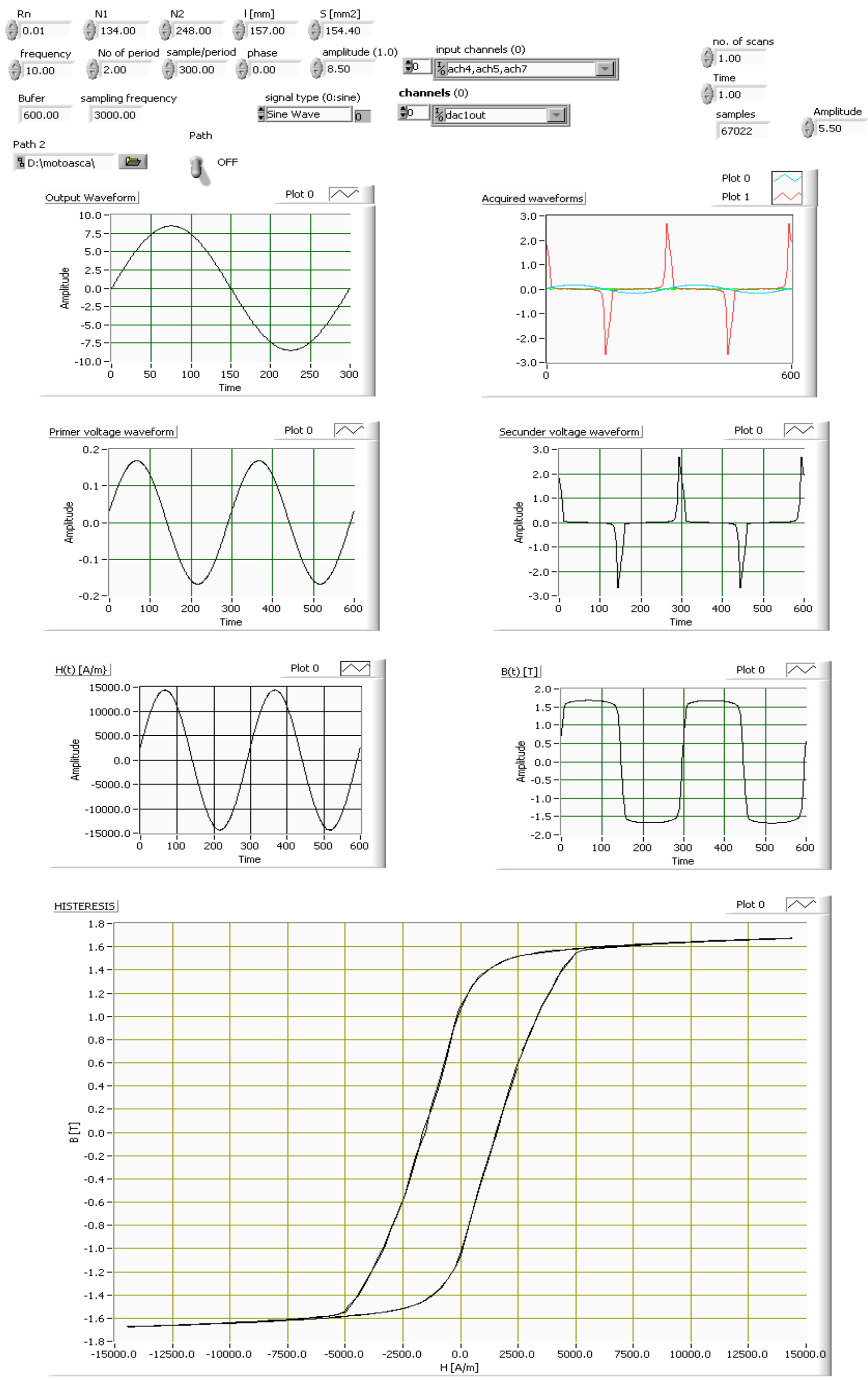


Fig.2. *There are plotted several curves obtained as explained above for sinusoidal primary voltage waveform. (Each necessary explanation is written over the corresponding item)*

The Blocks AI Config, AI Start, AI Read and AI Clear are Intermediate Analog Input Virtual Instruments, which command acquisition of the voltages $U_n$, $U_x$ and noises for one channel, by DAQ, from three channels: ach4, ach5 and ach7. The acquired waveforms are plotted on the virtual graphs (oscilloscopes).

In the second part of the LabVIEW program, an arithmetic calculus is performed in order to obtain from $U_n$

the magnetic field strength $H$ and from $U_x$ to achieve magnetic induction $B$.

The relations who give the magnetic field strength $H$ are well-known from the magnetic circuital law [6]:

$$\oint_{\Gamma} \boldsymbol{H}\,\mathrm{d}\boldsymbol{l} = \int_{S_\Gamma} \boldsymbol{J}\cdot\mathrm{d}\boldsymbol{S} + \int_{S_\Gamma} \frac{\partial \boldsymbol{D}}{\partial \mathrm{t}}\cdot\mathrm{d}\boldsymbol{S}\,, \quad (1)$$

from which it can be written, knowing that

$$\int_{S_\Gamma} \boldsymbol{J}\cdot\mathrm{d}\boldsymbol{S} = wi\,, \quad (2)$$

where $i = U_n / R_n$ and the mean length of the core $l$:

$$H = \frac{w\cdot U_n}{R_n\cdot l}\,, \quad (3)$$

where $w = w_1$ the number of turns for the primary coil.

From the law of electromagnetic induction, but replacing in it, the electromotive force by the corresponding voltage, it follows:

$$U_x = w\frac{\mathrm{d}\phi}{\mathrm{d}t} \quad (4)$$

where $w = w_2$ is the number of turns of the secondary coil, and $\phi$ is the *magnetic flux-linkage*.

Using the flux-turn it results that:

$$\phi = \mathrm{B}\cdot\mathrm{S}\,, \quad (5)$$

Now, the expression of the secondary voltage acquired from the terminals of the secondary coil, can be written:

$$U_x = w_2\,\frac{\mathrm{d}(\boldsymbol{B}\cdot\boldsymbol{S})}{\mathrm{d}t}\,. \quad (6)$$

And from the last relation, one can obtain magnetic induction $B$:

$$B = \frac{1}{w_2\cdot\mathrm{S}}\int_T U_x\,\mathrm{d}t\,. \quad (7)$$

## 3. Hysteresis modeling using lines and arcs of circles

For modeling of the hysteresis cycle is proposed an analytical method which uses lines and arcs of circle for modeling the branches of the major hysteresis cycle. First it is plotted the descending branch and after that by an inversion is obtained the ascending branch of hysteresis loop. The facility of this model is that it requires a small amount of data for inputs, and the hysteresis cycle obtained is very near to the real one.

For the descending branch there was considered several reference points and between them is an arc of circle or a line.

For this reason the reference points considered as is shown in Fig. 4 was:

- the saturation points
- point 2 in first quadrant where two arcs of circle are joined
- the remanent magnetic induction
- the coercive field strength
- point 6 in third quadrant where two arcs of circle are joined
- slope of the tangent to the descendent branch of the hysteresis cycle in the positive saturation point.

Finally the input data are reduced at only 9 dates (5 points and a slope at saturation point), considering that the cycle is symmetrical with the respect to the origin of coordinate axis.

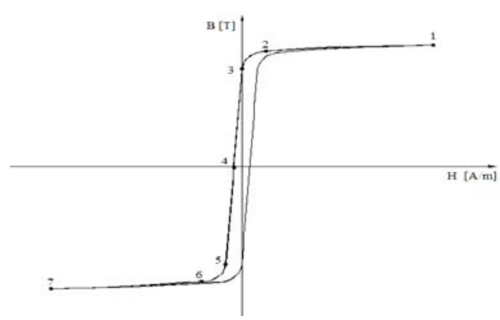


*Fig. 3. Explanation of modelling program using lines and segments of arcs*

In figure 4 is presented front panel of LabVIEW modelling program with a graph which contains the measured hysteresis cycle and the simulated one.

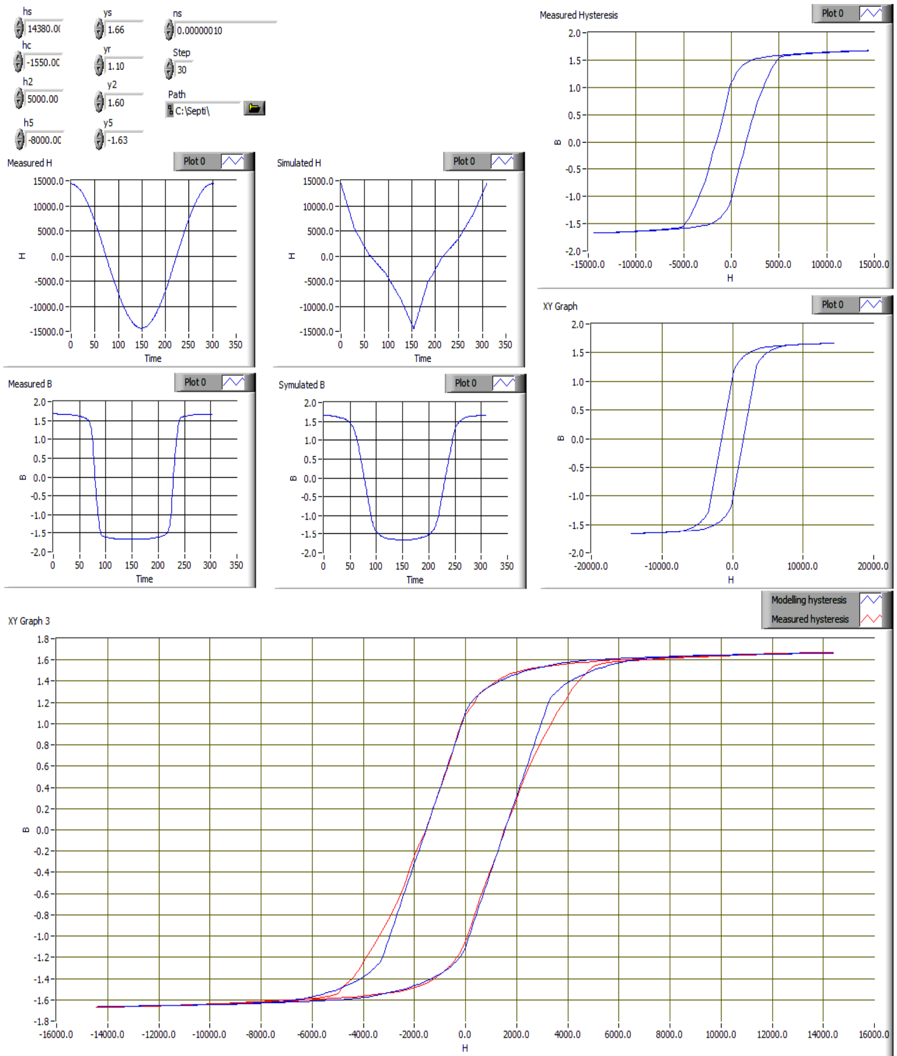


*Fig. 4. Front panel of LabVIEW modelling program*

The measured hysteresis cycle was stored in a file and the program extracts the data and plots them in another three graphs like before. The hysteresis cycles are overposed on another graph to show the difference between them.

## 4. Conclusion

The measurements reveal the major hysteresis loop and the reversal curves (returning curves or transition curves of the first kind), useful in the study of magnetic materials. Any kind of magnetic materials can be measured using this Data Acquisition Board and LabView program.

The modelling program can be used in order to obtain a major hysteresis loop for soft and hard magnetic materials starting from a small amount of input data founded in many catalogue data sheet of materials producers.

The program can be improved more by adding other program lines which can construct the returning curves of the first kind, or minor hysteresis loops, starting from major hysteresis loop using inverse mapping functions, which will be presented in other papers.

Using an error minimization recursive function, the modelling program can be coupled with measurement one in order to obtain the best position for point 2 and 6 for the best fitting between measured and modelling hysteresis cycles.

**Acknowledgement**

We acknowledge to the Department of Broadband Infocommunications and Electro-magnetic Theory, from Budapest University of Technology and Economics and especially Professor Amalia IVANYI, head of group of Electromagnetic Theory, for their kind support for realize these experiments in their laboratory, and for guidance along these experiments.

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