Testing the nanocrystalline cores

1. Measurement of the quasi-static hysteresis

The measurement system was developed for testing toroidal samples prepared from ultra-soft magnetic materials (Hc < 1 A/m). Nevertheless, the equipment can be used for taking the hysteresis loop of semi-hard magnetic materials as well (Hc < 10 kA/m) due to the Kepco type DC power supply (I_{max} = 50 A). The measurement system is shown in Fig. 1.

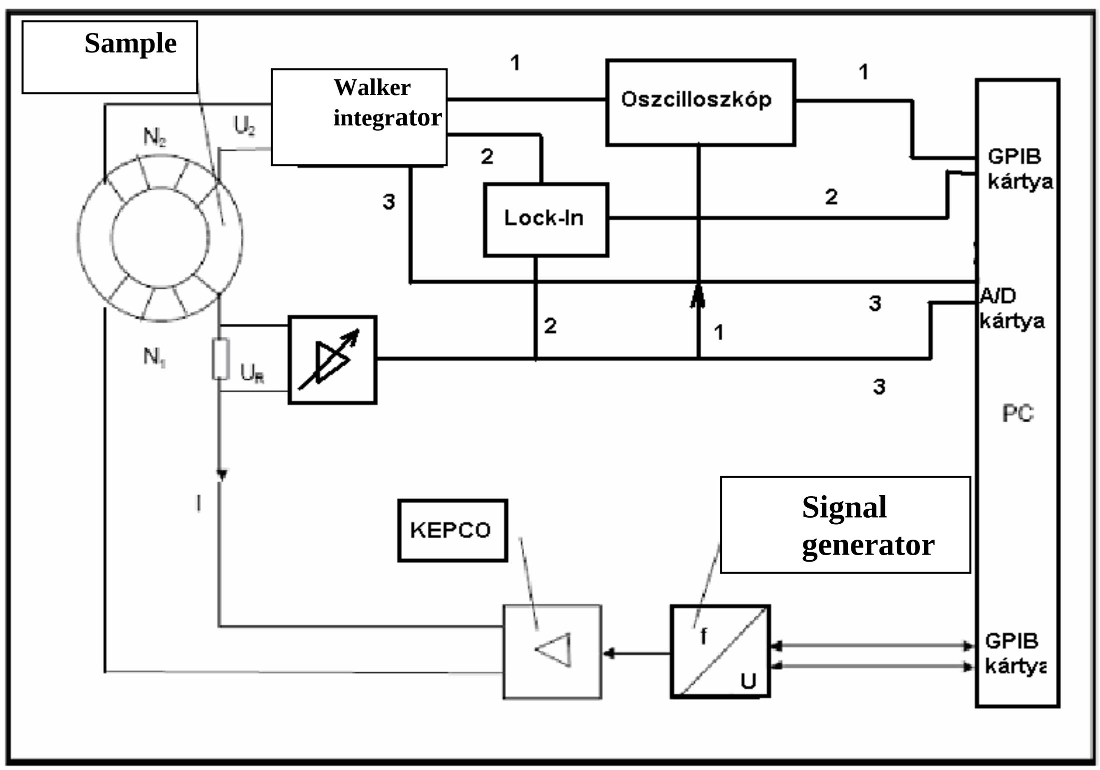

Fig.1. Measurement system to measure, compute, plot and display the quasi-DC hysteresis loop characteristics.

For the toroidal samples we use the less number of exciting and detecting coil windings. For the ultra-soft magnetic materials (Finemet type nanocrystalline, zero-lambda amorphous, etc) it is sufficient a linear conductor through the centre of the toroid (one turn exciting coil).

1.a. The "hardware" of the measuring system.

For toroidal samples the slowly varying exciting field can be calculated with eq.1, where the current is measured through the potential drop, U_H, on a measuring resistance, R, connected in series with the exciting coil, I = U_H/R:

$$H = \frac{N_1 \cdot I}{l} = \frac{N_1}{l \cdot R} \cdot U_H \; [A/m] \qquad (1)$$

The length of the magnetic path and cross section, S, are calculated by eq.2 and eq.3, respectively:

$$l = \frac{d_i + d_o}{2} \pi \; [m] - \qquad (2)$$

$$S = \frac{m}{l \rho} \; [m^2] \qquad (3)$$

The induced signal, Ui, is given by the eq. (4) as a function of cross section, S , measuring frequence, f, and the number of secondary turns, N2:

$$U_i = -N_2 \cdot S \cdot f \cdot \frac{dB}{dt} \; [V] \qquad (4)$$

This signal is integrated by the Walker integrator yielding the magnetic induction, B in Tesla:

$$B(t) = \frac{1}{N_2 \cdot S \cdot f} \int U_i(t)\, dt \; [T] \qquad (4)$$

In our case N1 = 1 and N2 is varying between 10-100. The larger the N2 the smaller is the drift of the integrator.

In order to generate the waveform of the exciting current we have the following possibilities:

1. The built in waveform generator of Kepco power supply. This provides limited number waveforms only.
2. The Agilent function generator provides the possibility of generating various wave forms and it is used also as a DA converter to command the Kepco power supply by any kind of computer composed wave forms.

1.b The “software of the measuring system.

The sampling resolution and frequency of the H and B values depend on the detecting unit:

1. The resolution of the lock-in is the best (1 mV between -10 and +10 V) but the sampling frequency (28 kHz) is the lowest comparing to the oscilloscope and AD card. The sampling interval can be varied between 35 μsec and 0.1 sec and 32 000 point/cycle can be maximal recorded.

2. The resolution of the oscilloscope is 20 mV/256, but only 1000/cycle can be recorded with a sampling frequency of 1 MHz.

3. The sensitivity of the AD card is 2.5 V/4096 and the sampling frequency is 150 kHz.

The 3 AD converters (see the 1, 2 and 3 routes on the fig. 1) can be optimised for different measuring tasks: For real quasi DC measurements (very low frequencies, below 0.01 Hz) the AD converter of the lock-in is the best. At larger frequencies the AD converter of the oscilloscope can be used exploiting the fact that the measurement can be monitored and checked before processing the measured data.

Correspondingly, 3 different software was prepared in DELPHY language and adapted to the 3 different AD converters

The common feature of all the 3 software’s are :

I. Excitation
II. Measuring the flux
III. Drawing the hysteresis loop.

The detecting equipments are very sensitive to the variation of temperature, this is why constant temperature should be kept during the measurements. The parasitic thermoelectric potential drops and the noise of the amplifier causes a drift which can be corrected by the software.

The flow diagram of the measurement is shown in Fig.2.

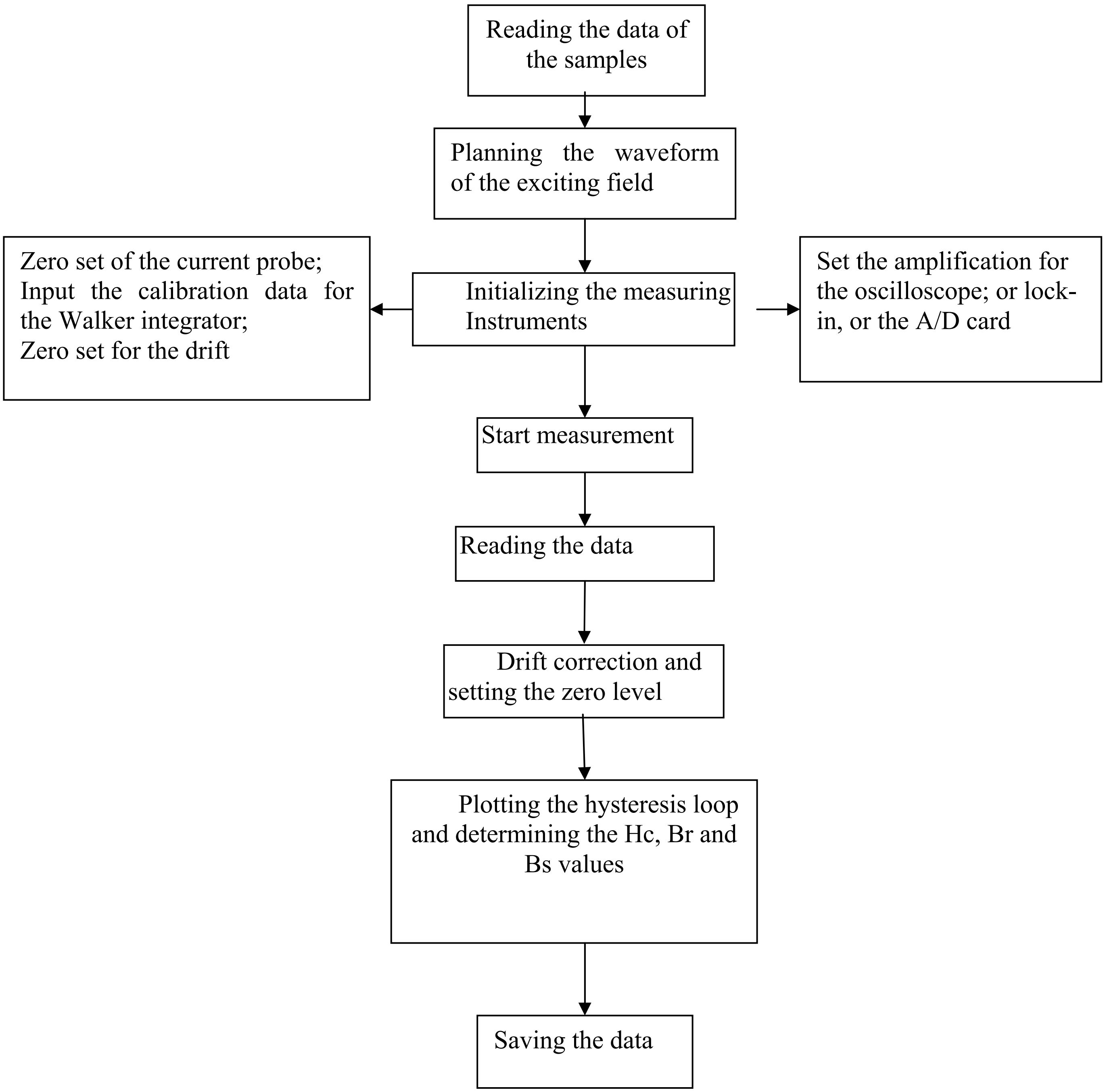

Fig. 2. : Flow diagram for the quasi DC hysteresis loop measurements

3. **Measuring setup for frequency dependence of permeability**

Sheme of the measuring system is shown in Fig.3:

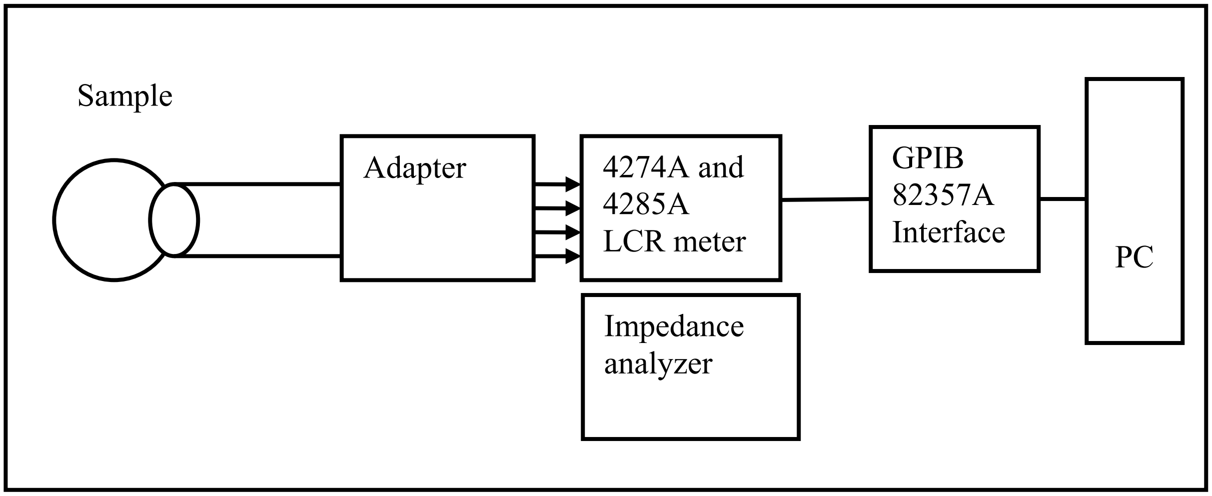

Fig.3. Measuring system for the permeability spectra

The impedance analyser (Hewlett-Packard 4274A és Agilent 4285A) provides the equivalent Ls induction and Rs resistance

$$L = \mu_0 . \mu' \frac{S * N^2}{l} \text{ (H)}$$

$$\mu'' = \mu' * \frac{R}{L * \omega}$$

where

L: inductance in Henry, R resistance in Ohm
μ_0: permeability of vacuum = $4\pi.10^{-7}$ Vs/Am
μ': real part of the permeability
S: cross section (m^2)
N: number of turns
l: magnetic path length (m)
ω: frequency

Using the measured data one can determine the quality factor, Q as a function of frequency:

$$Q = \frac{\mu'}{\mu''} = \frac{\omega L}{R}$$

Some representative measurements

In Fig. 4 the quasi-DC hysteresis loop is shown for a toroidal sample prepared from a Finemet type nanocrystalline ribbon after a ROUND type heat treatment (540 ^{o}C/1h). The first magnetization (virgin) curve was obtained after a careful demagnetization of the sample.

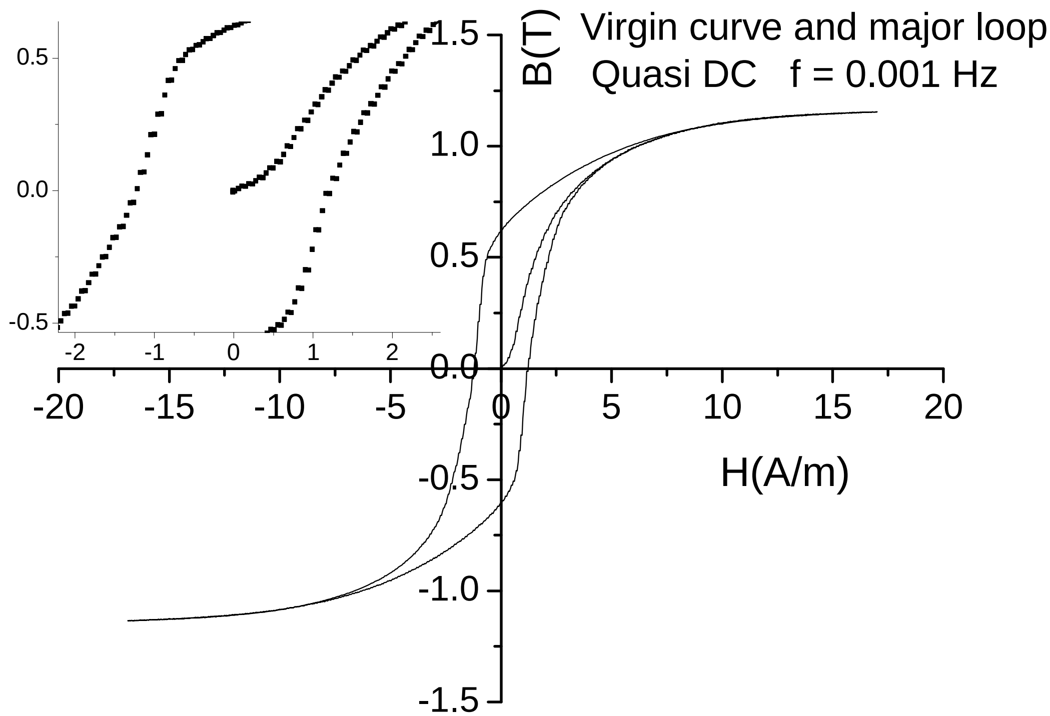

Fig. 4. ROUND type hysteresis lop for a toroidal Finemet sample. In the inset the resolution of the measurement is shown.

The permeability spectra for the same sample is shown in the Fig.5.

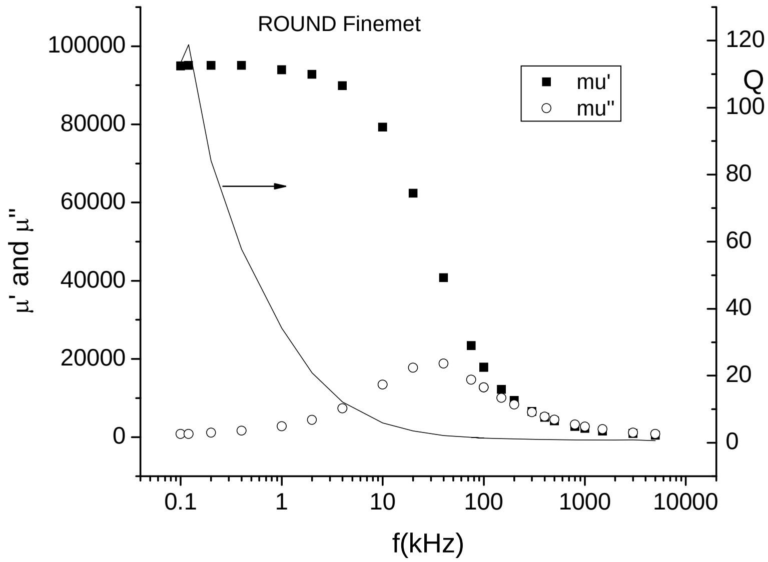

Fig. 5. The frequency dependence of the complex permeability and of the quality factor for a ROUND type Finemet sample

The eddy current frequency limit is ~ 40 kHz, which corresponds to the frequency whre the imaginary ppart of the permeability has a maximum. The quality factor drops down to unity above 10 kHz.

The result of a heterogeneous heat treatment can be recognized from the "WASP" shape of the hysteresis loop which is partial flattening at small fields due to an inhomogeneosly induced transversal anisotropyn (see Fig.6.)

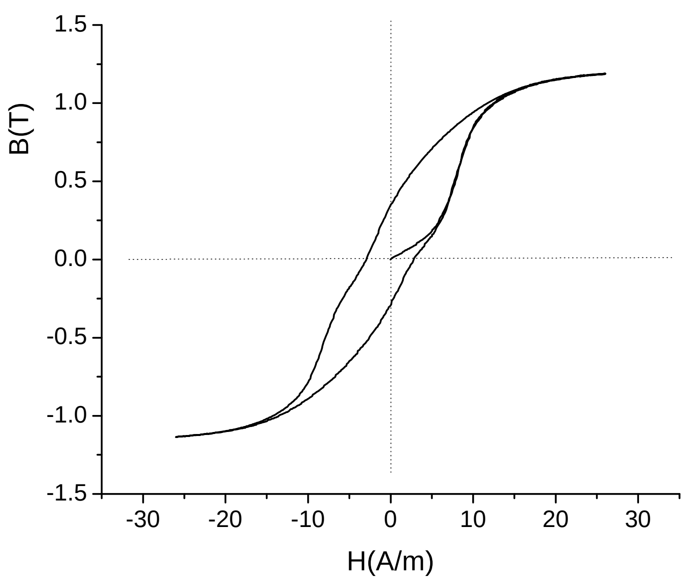

Fig.6. Result of partially induced transversal anisotropy: a WASP type hysteresis loop.

The heterogeneity of the heat treatment varies from sample to sample as can be seen on the permeability spectra as well in Fig.7. For small exciting fields the permeability is decreased compared to the ROUND type homogeneous core and the eddy current frequency limit is shifted to higher values. The heterogeneity appears in the scatter of the data for the samples marked with #1 and #2.

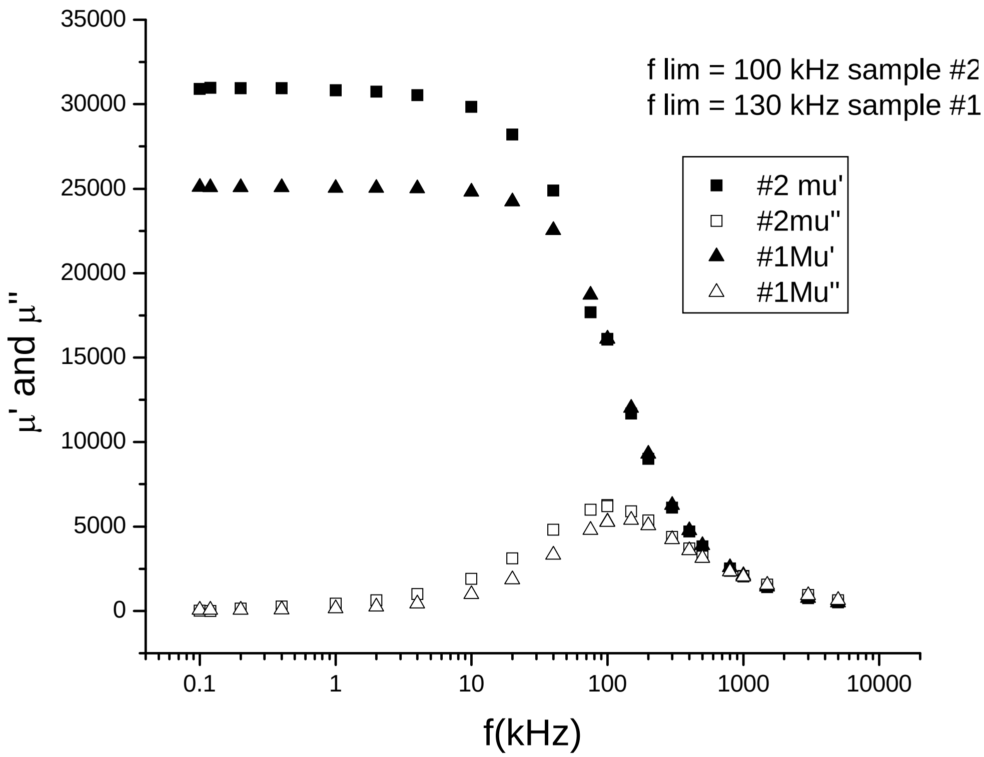

Fig. 7 The permeability spectra for samples having partial induced transversal anisotropy.