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Low current transformer utilizing Co-based amorphous alloys

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Metal oxide surge arresters have been widely used for protection of power system networks against overvoltages due to atmospheric discharges or malfunction of devices connected to the network. During its operation a surge arrester structure is degradated, what can be observed as an increase of a surge arrester leakage current. Paper presents an implementation of a new, high-permeability, $Co_{64}Fe_4Ni_1Si_{15}B_{14}$ amorphous alloy as a current transformer for monitoring of a leakage current in low voltage surge arresters. The characteristics of the current transformer for different loads have been measured in the system using very sensitive current-voltage converter. Experimental results confirmed that low current transformer utilizing $Co_{64}Fe_4Ni_1Si_{15}B_{14}$amorphous alloy in annealed state gives a possibility to measure a leakage current about several μA with operating frequency 50Hz. Moreover, the results indicate, that the leakage current waveforms have a different shape than a pure sine wave voltage applied to the surge arrester enabling an evaluation of the device nonlinearity as a measure of its degradation by means of a resistive component of the leakage current.

Index Terms— **amorphous magnetic materials, current transformer, surge arresters, leakage current measurement.**

I. Introduction

METAL OXIDE (mostly zinc oxide) varistors are ceramic devices widely used in surge arresters to sense and limit transient voltage surges for protection of power system networks against overvoltages due to atmospheric discharges or malfunction of devices connected to the network. Surge arresters mostly have not been in service much in excess of about 10 years, so if any degradation due to age is to occur this should not be evident at early stage of their exploitation. Therefore stability becomes one of the most important property of performance for ZnO varistors, but degradation may limit performance.
The degradation is usually accompanied by reductions in grain boundary potential barrier heights because of defects near these boundaries [1]. During its operation a surge arrester structure is ageing, what can be observed as an increase of a surge arrester leakage current [2]. The leakage current is passing through the arrester while it is working, and it leads to the insulation degradation of the arrester's insulation properties. Therefore the leakage current may be measured as an indicator for real-time assessment of a device degradation degree.

Several non-destructive diagnostic techniques have been proposed to diagnose accurately condition assessment of ZnO surge arresters, including the standard 1mA reference voltage, lightning impulse discharge residual voltage, voltage response, polarization or depolarization current, return voltage and leakage current measurements. It has been shown that the degradation mainly affects the prebreakdown region of the varistor V-I curve and therefore results in an increase of leakage currents.

It should be indicated that a lower limit of the leakage current for a low voltage surge arrester (below 1 kV) can be as low as about a few μA. Therefore an application of commonly used current transformers is significantly limited. For this reason an evaluation of the surge arrester ageing level requires a current transformer with novel, high permeability magnetic materials. A model of such a transformer is presented in the paper.

II. Core for current transformer

For measurements of low-level leakage currents for surge arresters, high initial permeability cores for current transformers are necessary. Such high permeability exhibit permalloy-type materials [3]. However permalloy-type materials are extremely stress-sensitive [4]. As a result even small stresses from external forces, applied accidentally during the montage of the core or during its exploitation, may lead to significant changes of core's characteristics. As a result reliability and accuracy of permalloy-based cores for current transformers is significantly limited, especially in the industrial environment.

Cobalt-based soft amorphous magnetic alloys, such as $Co_{64}Fe_4Ni_1Si_{15}B_{14}$ amorphous alloy, seems to be very good alternative for permalloy-based alloys in low current transformers applications. Due to the lack of crystalline structure and lack of magnetocrystalline anisotropy, amorphous alloys exhibit a high initial permeability [5], especially after reduction of residual stresses during thermal annealing. Moreover such alloys exhibit a high stress strength [6] and are more rust resistive than crystalline alloys [7]. In addition cobalt-based amorphous alloys are less stress sensitive than permalloys, especially for lower values of stresses [8, 9]. As a result $Co_{64}Fe_4Ni_1Si_{15}B_{14}$ amorphous alloy seems to be suitable as a core for current transformer for monitoring of current leakage for real-time assessment of a surge arrester degradation degree.

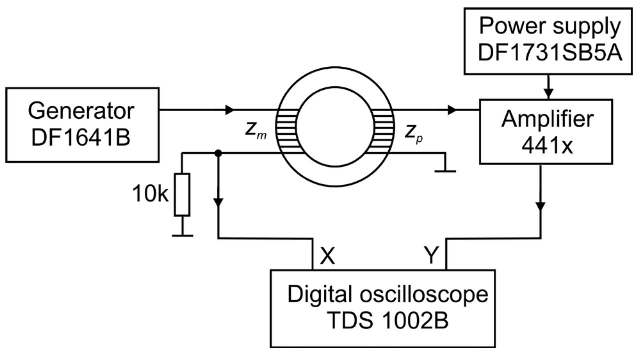
For investigation ring-shaped core made of $Co_{64}Fe_4Ni_1Si_{15}B_{14}$ amorphous alloy was produced. This core has outside diameter 32 mm, inside diameter 25 mm and has 8 mm height. Core was annealed in 365°C for one hour in argon atmosphere to reduce value of residual stresses in the sample and increase its permeability. After annealing core was winded with z_m = 10 turns of magnetizing winding (also for low current measurements) and z_p = 110 turns of sensing winding.

III. Method of measuremnts of core's characteristics

Measuring setup for testing of the characteristics of ring-shaped cores for low current transformers is presented in figure 1. Magnetizing winding is driven from Wien-bridge based voltage generator DF1641B. Due to 10 kΩ resistor, the voltage generator act as a low current source in the range from 10 µA to 1 mA.

Sensing winding of the core is connected with specialized amplifier utilizing low-noise JFET amplifiers. This amplifier amplifies the measuring signal 441 times. Finally, the amplified signal was registered by digitally controlled oscilloscope TDS1002B and transmitted to PC for further processing. It should be highlighted, that measuring setup was carefully shielded against high-frequency noise. Moreover analog signal based generator and linear control power supply was applied to reduce high-frequency noise, generated by digitally controlled equipment in the system.

a)



b)

Fig. 1. Measuring setup for testing of the characteristics of ring-shaped cores for low current transformers: a) schematic block diagram (z_m – magnetizing winding, z_p – measuring winding), b) view of the setup (shielding cover removed)

A measuring signal acquired by the digital oscilloscope TDS1002B was processed using the MATLAB software. Due to the fact, that driving signal was sinusoidal only sinusoidal signal measured on sensing winding was expected. It is caused by the fact, that for lower values of magnetizing field, a magnetization process is connected with domain wall bending (so called Rayleigh region of hysteresis loop [10]). For this reason, especially for dynamic magnetization process, other harmonics in the output signal can be neglected. As a result, during the processing, sinusoidal curve was fitted to measuring signal using least-squares error method [11]. This method was much more effective than digital filtering.

IV. Results of core's tests

Figure 2 presents the dependence of the shape of dynamic hysteresis loop *B(H)* on the value of the amplitude of magnetizing field. It should be indicated, that for magnetizing field frequency f = 200 Hz, the hysteresis loop *B(H)* is nearly linear, what confirms, that in the case of $Co_{64}Fe_4Ni_1Si_{15}B_{14}$ amorphous alloy, permeability may be treated as constant for magnetizing field H up to 5 mA/m.

On the base of *B(H)* hysteresis loops presented in figure 1 it was determined, that initial permeability μ_i was equal 1882 for $Co_{64}Fe_4Ni_1Si_{15}B_{14}$ amorphous alloy annealed in 365°C for 1 hour. With this linear approximation of *B(H)* hysteresis loops, the approximation error is not higher than 6% of the amplitude of flux density B.

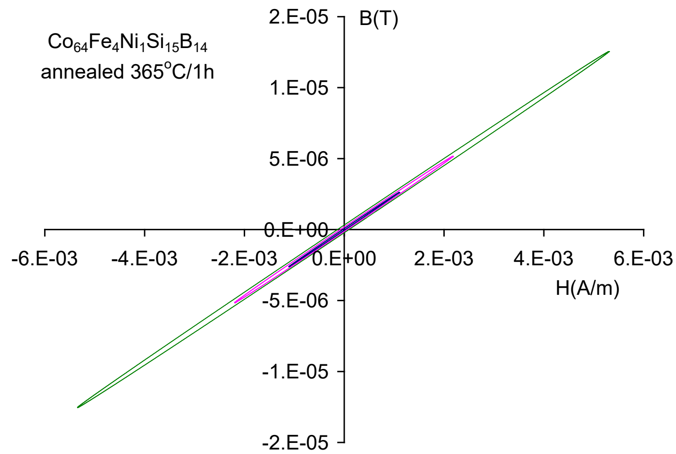


Fig. 2. Magnetizing field amplitude dependence of the dynamic hysteresis loop *B*(*H*) for $Co_{64}Fe_4Ni_1Si_{15}B_{14}$ amorphous alloy (magnetizing field frequency $f = 200$ Hz)

Figure 3 presents the frequency dependence of the shape of *B(H)* hysteresis loops for $Co_{64}Fe_4Ni_1Si_{15}B_{14}$ amorphous alloy annealed in 365°C for 1 hour. Also in such a case the hysteresis loop may be approximated by the line determined by initial relative permeability $\mu_i = 1882$. For such approximation, the maximal error is smaller than 4% of the amplitude of flux density *B*.

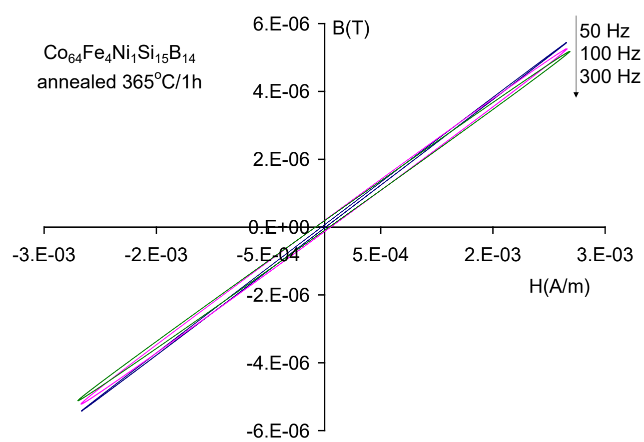
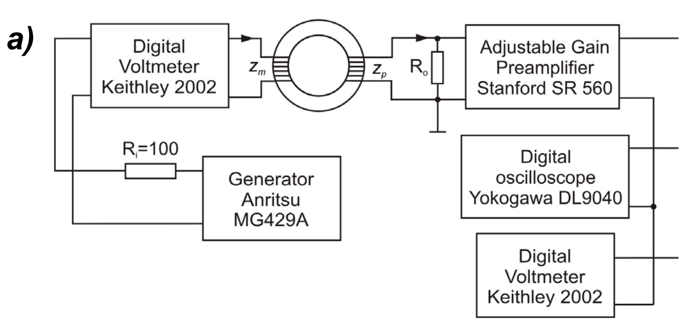


Fig. 3. Frequency dependence of the shape of *B*(*H*) dynamic hysteresis loops for $Co_{64}Fe_4Ni_1Si_{15}B_{14}$ amorphous alloy

Presented results indicate that for magnetizing fields up to 5 mA/m, in the frequency range from 50 Hz to 300 Hz, hysteresis loop of $Co_{64}Fe_4Ni_1Si_{15}B_{14}$ amorphous alloy annealed in 365°C for 1 hour may be linearly approximated with assumption of relative magnetic permeability $\mu_i = 1882$.

V. Method of testing of developed current transducer

Schematic diagram of the setup for testing of the characteristics of current transformers for measurements of surge arresters leakages is presented in figure 4.



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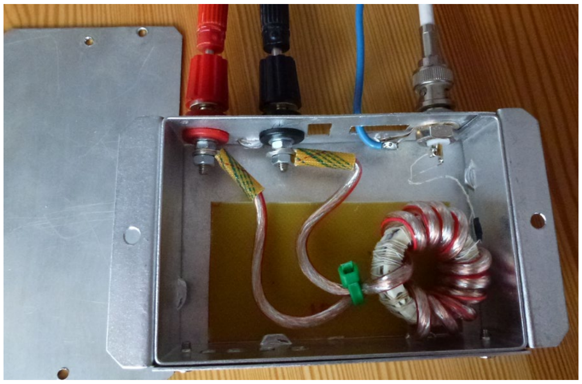

Fig. 4. Current transformer setup for testing the surge arresters leakages: a) schematic block diagram, b) view of the winded and shielded inductive core in the setup (shielding cover removed)

A low-noise very sensitive SR 560 preamplifier was used to make possible a precise measurement of a measuring winding Z_p current. To reduce the value of noise generated by external sources, current transformers operate with resistance R_0 connected to its output. In such a case measurement is related to the output current, which is more resistant on clutters in industrial environment.

VI. Results of current transducer testing

Frequency dependence of the output signal from the current transformer (utilizing the core made of $Co_{64}Fe_4Ni_1Si_{15}B_{14}$ amorphous alloy annealed in 365ºC for 1 hour) is presented in figure 5. In the presented case value of measuring resistor R_0 was 100 Ω, whereas current transformer was driven by sine voltage with amplitude U_i = 200mV.

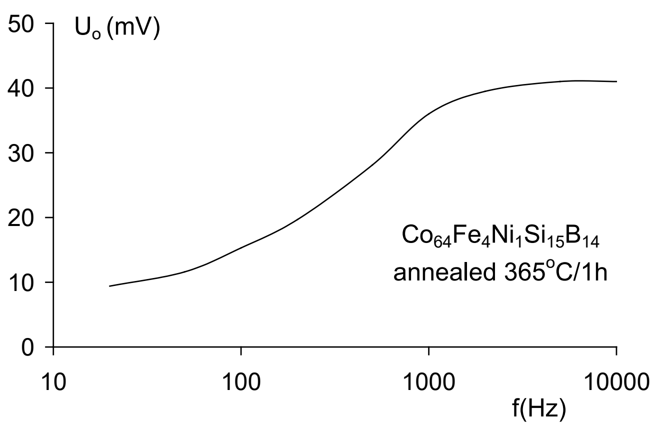

Fig. 5. Frequency dependence of a value of output signal U_0 for driving voltage amplitude U_i = 200 mV and measuring resistor R_0 = 100 Ω

Figure 6 presents the dependence of U_o versus U_i characteristics on a value of the load resistor R_0. Measurements were carried out for the frequency f = 50 Hz.

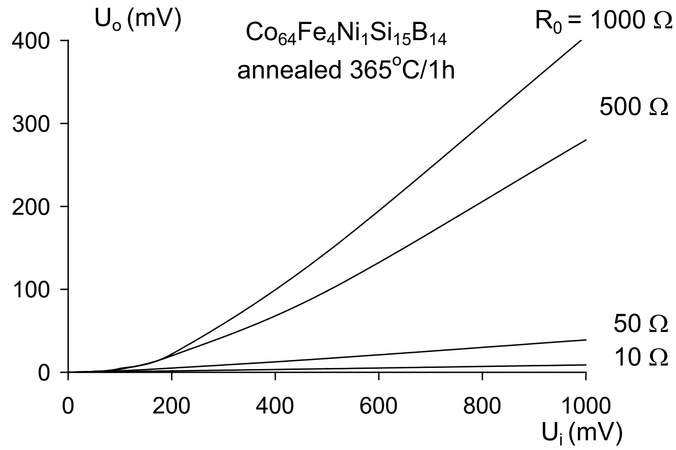

Fig. 6. Dependence of $U_o\,(U_i)$ characteristics on a value of output resistor R_0 (frequency f = 50 Hz)

Presented results indicate, that developed current transformer (utilizing $Co_{64}Fe_4Ni_1Si_{15}B_{14}$ amorphous alloy annealed in 365°C for 1 hour) can operate effectively for frequencies up to 1kHz. Moreover the most highest sensitivity of current transformer is reached for highest value of output resistor R_0.

Varistors applied in low-voltage surge arresters (up to 1 kV) produced by ABB Przasnysz (type LOVOS, see figure 7), Apator (type ASA) and Dehn (type DG MOD 275) were tested using the presented transformer.

Exemplary results of the field tests on surge arrester type LOVOS-10/280 (ABB) are presented in figure 8. For voltage driving surge arrester 280 V with amplitude up to about 500V (channel 1), leakage current (channel 2) amplitude was calculated as up to 500 µA. Moreover, leakage characteristic of measured surge arresters is strongly non-linear. It was observed, that highest values of leakage current were measured for narrow range of voltage nearly amplitude of voltage on the surge arrester.

Fig. 7. Selected varistor measured specimens: a) disc-shaped ZnO structures after being fired (top row) and with metalized contacts (bottom row), left 280 V, middle 440 V, right 660V, b) surge arresters with these varistors

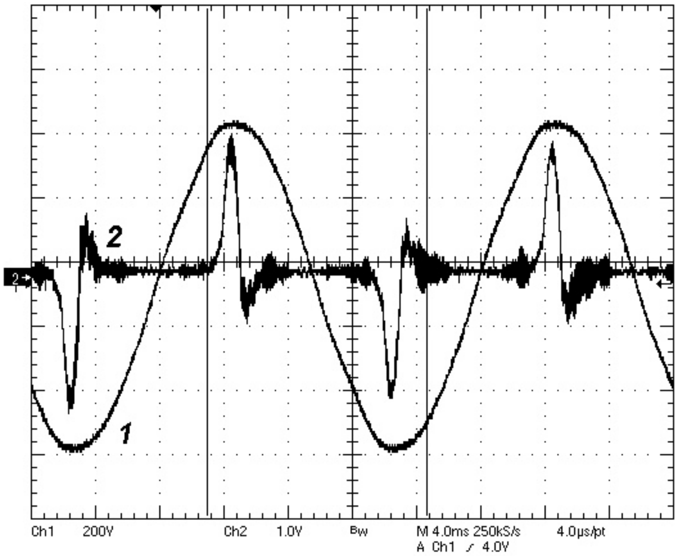

Fig. 8. Results of measurements of current leakage on surge arrester type LOVOS-10/280 (ABB): 1 – voltage on surge arrester, 2 – leakage current curve

VII. Conclusion

Results presented in the paper indicates, that $Co_{64}Fe_4Ni_1Si_{15}B_{14}$ amorphous alloy annealed in 365°C for 1 hour may be effectively applied as a core of low current transducer for measurements of leakage on the surge arresters. Such core is more resistant on stresses applied during its exploitation and as a result is more suitable for industrial environment.

Presented experiments confirmed, that for magnetizing field H up to 5 mA/m, in the range of the frequency f from 50Hz to 300 Hz, dependence of flux density B in the core on magnetizing field H is nearly linear. For these conditions magnetic permeability μ is equal 1882, with linearization error below 6%.

Presented results of the field tests confirmed, that developed low current transformer gives possibility of measurements of leakage current from low-voltage (up to 1 kV) surge arresters. Moreover it was indicated, that leakage characteristic of the surge arrester is strongly non-linear.

Acknowledgment

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