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# IMPACT OF MODIFIED ENDINGS ON NOISE CHARACTERISTICS OF Fe-BASED GLASS-COATED MICROWIRES

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Amorphous glass-coated bistable microwires are characterized by unique magnetic properties usable in a wide range of technical applications. Almost all of them are based on the measurement of the switching field, at which the remagnetization process of the microwire occurs and the magnitude of which is influenced by the measured physical quantity, as for example tensile stress or temperature. The domain wall generation and the remagnetization of the microwire is a complicated thermodynamic and structural process accompanied with an uncertainty, which is observable as the switching field noise. This noise is then often a limiting factor of the microwires' sensoric application possibilities. The article deals with the influence of the microwire ending structure on its noise characteristics. Noise of microwires with cut endings and also with chemically modified endings was analyzed. The initial experiments show a significant decrease of the switching field noise of microwires with chemically modified endings.

Keywords: microwire, noise, structural analysis

## INTRODUCTION

Magnetically bistable microwires are characterized by a rectangular hysteresis loop, resulting from the existence of the core-shell domain structure. Remagnetization of the bistable microwire usually takes place through a single large Barkhausen jump associated with the propagation of a single domain wall along the axially magnetized core of the microwire. The theoretical assumption, also supported by experiments, is a fact that the domain wall is created at one end of the microwire due to the minimization of magnetostatic energy. The creation and propagation of the domain wall are complex thermo-dynamical processes that are also responsible for noise of the microwire switching field [1, 2 and 3]. In the presented paper the influence of the microwire endings' treatment on the microwire noise characteristics is analysed.

## THEORY

Magnetic bistability of the microwire is caused by the positive magnetostriction of the metallic material, resulting from the mechanical interaction of the metallic central part of the microwire with the glass coating, originating in the technological processes of manufacturing - rapid quenching of microwire. Additionally the different coefficients of thermal expansion of the metallic material and of the coating cause tensile stresses generated during the rapid quenching of the microwire. Microwires are manufactured several kilometers long, and for their utilization in sensorics they have to be divided into shorter pieces. Mechanical cutting into smaller pieces results in local interference of mechanical stresses generated during the manufacturing process. This is the cause of local disruption of homogeneous tensile stresses created during the microwire manufacturing, which can results into deviations of magnetic properties, mainly in the switching field noise in the separated pieces of microwire.

As it has already been said earlier, the creation of the domain wall occurs at the end of the microwire, so it depends on the previous treatment of the microwire ending. Chemical modification of the microwire material is one of the ways of treating of the microwire ending. It can be performed partially, by removing the damaged part of the glass material, or completely removing the core and coating of the microwire ending.  If chemical modification on the material of microwire ending is applied, no additional mechanical tensions are generated. Neither cracks nor other mechanical defects will occur. The ending of the microwire sleeplessly merges into a full cross-section, thereby enabling a continuous and symmetrical distribution of internal tensions within the microwire. This process is fully controllable and repeatable, which enables formation of equal endings of all the separated parts of the microwire.

For the purpose of measuring the noise characteristics of the microwire, the external noise has to be separated. Fig. 1 illustrates a centred time recording of a signal from the microwire, representing a switching field. The signal analysis shows the inherence of stochastic and deterministic components, as a superposition of the external interference and internal noise.

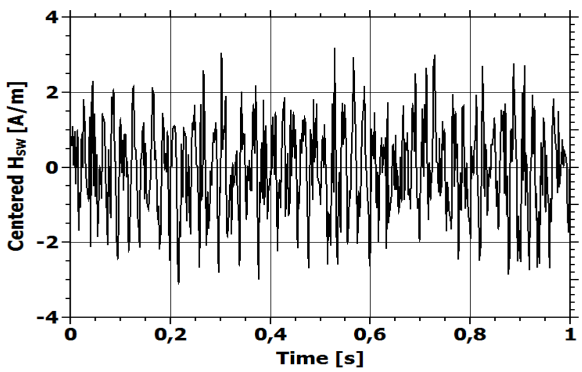


**Fig. 1.** Time record of $H_{SW}$ noise from microwire sensor

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To separate the internal noise characteristics from the external interference, measurements were performed on two samples, X and Y, positioned parallelly in a homogenous external magnetic field and triangular excitation field [4]. Variance of the switching field for sample X is given by expression

$$\mathrm{var}(X) = \sigma_X^2 = \frac{1}{N}\sum_{i=1}^{N}\left(x_i - \overline{X}\right)^2 , \qquad (1)$$

where $x_i$ represents switching field in $i$-th step of the measurement. This variance contains all the noise components, both external and internal ones. Covariance between samples X and Y will determine the correlated, *ie* the external component of the noise as described as follows

$$\mathrm{cov}(XY) = \sigma_{XY} = \frac{1}{N}\sum_{i=1}^{N}\left(x_i - \overline{X}\right)\left(y_i - \overline{Y}\right). \qquad (2)$$

Standard deviation of the internal noise for samples X and Y is then given by

$$\sigma_X\left(H_{SW}\right) = \sqrt{\sigma_X^2 - \sigma_{XY}} , \qquad (3)$$

$$\sigma_Y\left(H_{SW}\right) = \sqrt{\sigma_Y^2 - \sigma_{XY}} . \qquad (4)$$

As during our previous researches proved various noise characteristics of microwires in the positive and negative sides of their magnetization characteristics, the standard deviation of each side of magnetization characteristics will be determined individually. This procedure results in obtaining two values of the standard deviation of the internal noise for each of the measured microwires. The first one represents the noise of the switching field in the positive direction of magnetization, whilst the second one in the negative direction with reference to the triangular excitation field.

## EXPERIMENT

Measurements were performed using the improved induction method, when the microwire is positioned in the excitation field with triangular characteristics [4,5]. For the purpose of the experiment, microwires of chemical composition $Fe_{42.5}Ni_{35}Si_{7.5}B_{15}$ marked as N37 were selected [5,6]. Three groups of microwire samples differing by the way of treating the microwire endings were formed. All samples were a priory divided by cutting using sharp surgeon scissors. The first group involved four microwires 2 cm in length, which were only cut off. This group served as a reference and no additional modification was applied. The example of microwires with cut endings is shown in the following picture.

Continuous measurement was subsequently graphically evaluated using a histogram and the mean value of the standard deviation of the switching field.

The second group contained four microwires 3 cm in length, with glass coating removed by way of etching in an 38 % solution of Hydrofluoric acid for a period of 30 min. The centre of the microwire was masked by a layer of wax, 2 cm long and the endings of the microwire were subjected to acid treatment. The etching process resulted in a continuous transition of the glass coating endings towards the core of the microwire as seen in Fig. 4

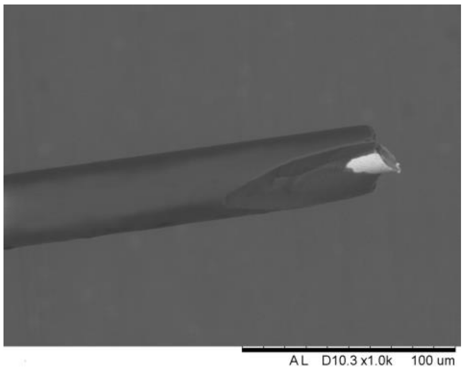


**Fig. 2.** Photography of microwire with cut ending

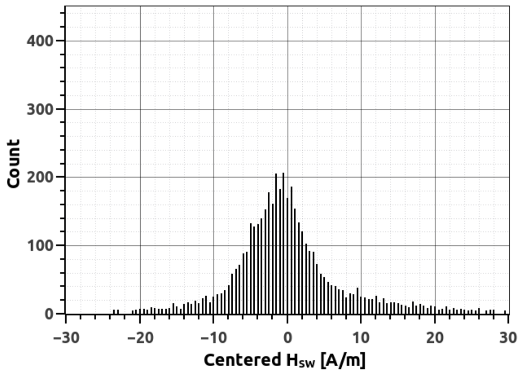


**Fig. 3.** Histogram of $H_{SW}$ noise measured on the first series of samples with cut endings

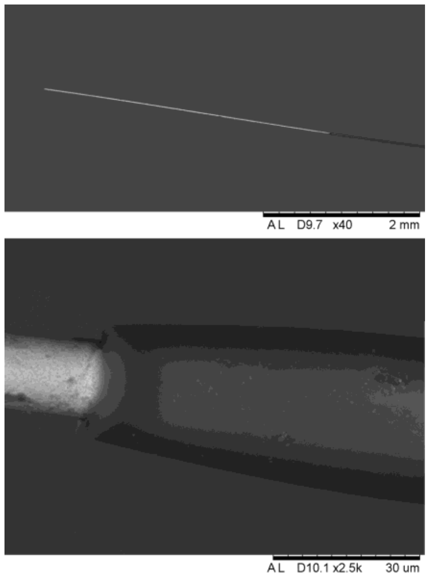


**Fig. 4.** Photography of microwire with glass r emoved from the microwire ending by Hydrofluoric acid etching (top) and detail of glass coat end (bottom)

Similarly to the first group, the measurement results are summed up in the following histogram.

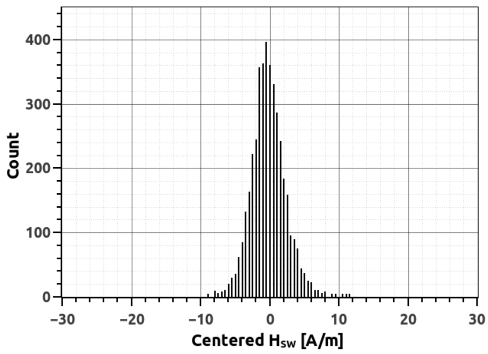


**Fig. 5.** Histogram of $H_{SW}$ noise measured on the second series of samples, the Hydrofluoric acid etched microwire endings

The third group consisted of four microwires 3 cm in length, which were also masked in their centers using wax at a length of 2 cm. Step one involved etching off the glass coating in an 38 % solution of Hydrofluoric acid for a period of 30 min. followed by etching of the core of the microwire in a 32 % solution of Hydrochloric acid for 30 min. The result of this treatment is illustrated in Fig. 6.

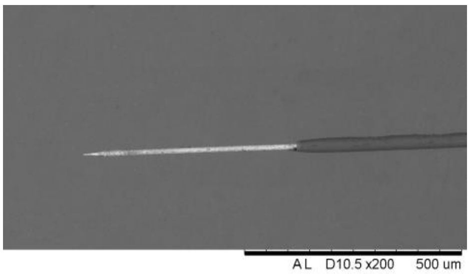


**Fig. 6.** Photography of microwire with glass removed from the microwire ending by Hydrofluoric acid etching and core removed by Hydrochloric acid etching

The histogram describing the noise characteristics of this group of samples is in Fig.7.

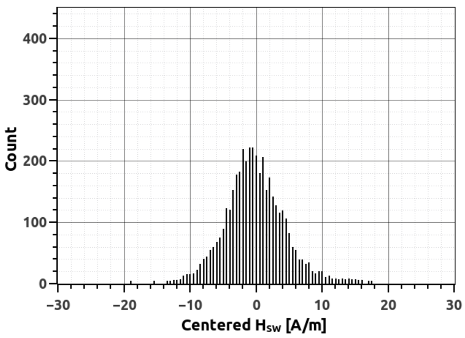


**Fig. 7.** Histogram of $H_{SW}$ noise measured on the third series of samples, the Hydrofluoric acid and Hydrochloric acid etched microwire endings

Each group of microwires was separated into pairs, which were fixed on a base, thus, making up parallel pairs of sensors. The couples were subjected to measurements as described in the theoretical part of this paper.

## CONCLUSION

Performed measurements proved the assumptions that the way how the microwire endings are modified influence the noise characteristics of the investigated samples significantly. The referential group of microwire samples with cut endings achieved the mean value of standard deviation of the switching field at 6.51 A/m, the third group is demonstrating a slight improvement at a mean value of the standard deviation of 4.18 A/m. The smallest noise characteristics were achieved by the second group exhibiting mean standard deviation of 2.33 A/m.

Research has pointed out the need for further investigations of microwire endings in terms of their utilization possibilities in sensoric applications. It is necessary to verify the presented methodology also for microwires of different chemical composition and to evaluate larger statistical files. It would also be suitable to try other methods of dividing microwires, *eg* by means of a laser or water beams *etc*. Mass-scale use of sensors based on microwires is significantly conditioned by this research, as the noises characteristics of sensors are the basic limiting factor of the further utilization of microwires in technical applications.

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