APPLICATION OF MULTI-PARAMETRIC SIGNAL ANALYSIS OF THE BARKHAUSEN EFFECT TO MECHANICAL HARDNESS EVALUATION OF FERROMAGNETIC STEELS

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1. Introduction

The paper presents the results of research on the development of an innovative method for determining the mechanical hardness level of ferromagnetic materials and, in particular, structural steels. This method is based on the measurement of the voltage signal of the Barkhausen effect (BE) and on the multi-parameter analysis of this signal in order to calculate several specific and independent descriptors whose values are unambiguously correlated with the HV hardness level of the magnetized material.

2. Experimental

The BE signal was created and detected by C-core probe, magnetized with sinusoidal 100 Hz wave form. Data of 10 periods of magnetization was registered by AD card 12 bit, filtered within the frequency range from 20 kHz up to 200 kHz. Multi-parametric analysis was performed using LabVIEW software. Tests were run using a set of reference samples of different steel grades. We report here results of measurements for two series of the tempered martensitic samples, labelled as P and X. Set of 7 samples type P is made of P91 grade (X10CRMOVNB9-1). The state 'as delivered' – is labelled as PA while the others (from PB to BG) were quenched from temperatures 1000 ºC or 900 ºC in water or in oil. Their hardness was measured by means of 20HV tester. The set of 5 samples type X are X20CrMoV12.1 grade, air quenched from 1000 ºC and tempered at 750 ºC for different times (from 15 min (XA) to 240 min (XE), respectively, [1]. Hardnes was tested by 30HV tester.

3. Parameter analysis

Parametric analysis of BE voltage signal provides 16 descriptors which can characterize BE signal properties versus the state of tested material. Two types of descriptors related to the magnetic hardness (and thus mechanical hardness) of the samples were used. These are, respectively, the position of the Barkhausen signal envelope maxima and the so-called "BE coercivity field." The first descriptor is determined by measuring the position (on the axis of the magnetizing current intensity) of the signal maximum for increasing and decreasing magnetization. The second descriptor is determined on the assumption that the BE signal is directly related to energy losses in the material. The determination of the pseudo-loop of the BE requires the transformation of the envelope of the BE signal into a signal with similar characteristics to the rate of change of magnetization used for magnetic hysteresis loop measurements - for this purpose, for one half-period the envelope is inverted (change of sign) after which the signal is integrated to obtain a loop on the basis of which the 'coercivity field' is determined. These types of signals are determined for the envelope signal from the full spectrum of the EB signal, as well as for signals with different spectral components. These are signal envelopes for selected frequency ranges of the STFFT transform as well as for selected scales of the continuous wavelet transform (low value scales correspond to high frequency). Both of these parameters for materials with higher magnetic hardness should increase while the dynamics of these changes need not be the same. There is also calculated descriptor using BE pulse count rate for various threshold voltages.

3. Results

There are shown results of the analysis of one from 6 descriptors – labelled as D15, related with STFFT analysis. Figure 1 depicts an example of 3D presentation of the short time FFT like analysis of the sample PB. The Ug quantity it is voltage of current generator, equivalent to 'magnetizing field' intensity.

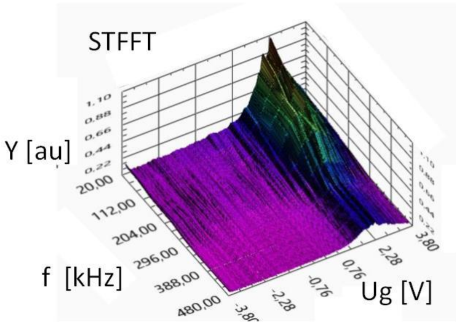

Fig. 1. The STFFT spectrum of the sample PB

Hysteresis loop of the A quantity (Y - intensity of STFFT spectra for low FFT frequency) of the PB sample is shown in Fig. 2.

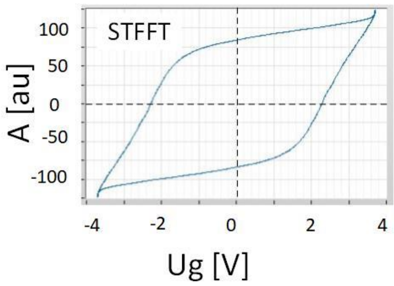

Fig. 2. The STFFT spectrum of the sample PB

Figure 3 presents a set of descriptor D15 values calculated from BE signal analysis for all presented here samples. There are evident two features. Feature 1: all D15 values reveal analogue monotonous like dependence versus HV values, mainly an increase. Feature 2: results of both series correspond very well to this main dependence between D15 and HV. One can also find, that the rate of relative change of the D15 values is much bigger than change of HV value**s**.

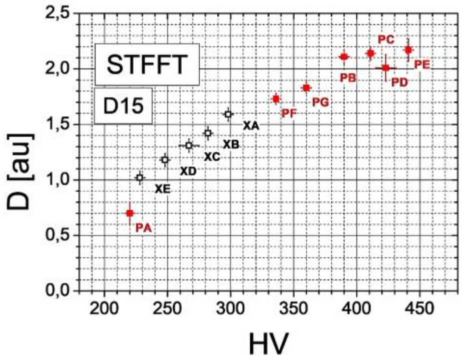

Fig. 3. Descriptor D15 calculated from the STFFT spectrum of the sets of samples P and X

It should be noted, that analog monotonous and strong dependence was found for the other 5 descriptors related to HV feature.

4. Conclusions

The as elaborated results prove that multi-parametric analysis of BE voltage signal provides the set of specific descriptors which are monotonously related to mechanical hardness of the given steel grade. The BE test is a fully non-destructive and takes a few seconds. It enables thus very rapid diagnostics of the mechanical hardness level at a given point on a structural component of relatively arbitrary shape and thickness. Such functional properties are not possessed by available industrial hardness measurement technique. The method is thus especially useful for the monitoring of processes like annealing or PWHT in which the hardness is getting changing strongly and monotonically.

Acknowledgments

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References

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[2] Proprietary system for inspecting the surface condition of ferromagnetic steel products intended for operation in conditions with increased strength; Polish grant **POIR.01.01.01-00-1168/21**