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Extraction of Barkhausen noise from the measured raw signal in high-frequency regimes

Dalibor Blažek[a], Miroslav Neslušan[b,*], Martin Mičica[a,c], Jaromír Pištora[d]

[a] IT4 Innovations National Supercomputing Center, VŠB-TU Ostrava, Studentská 6231/1B, 70833 Ostrava-Poruba, Czech Republic
[b] Faculty of Mechanical Engineering, University of Žilina, Univerzitná 1, 010 26 Žilina, Slovak Republic
[c] Institut d'Electronique, de Microélectronique et de Nanotechnologie, Lille 1 University, France
[d] Nanotechnology Centre, VŠB-TU Ostrava, 17. listopadu 15, 70833 Ostrava-Poruba, Czech Republic

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ABSTRACT

This paper deals with extraction of pure Barkhausen noise from the raw signals received in high-frequency regimes. The raw Barkhausen noise signals measured in high-frequency regimes contain components which cannot be attributed to the interaction of Bloch Walls with pinning sites and stress states such as the thermal noise of the sensor and the mechanical vibrations of the sensor-exciting core. Due to the variable ratios of thermal noise to Barkhausen noise as well as distortion of the signal due to vibrations, the raw signal as received and the pure Barkhausen noise signal can differ remarkably, thus making signal interpretation a debatable issue. For this reason, the post-processing method of the measured signal is presented here. In addition, the properties of μScan 500 device are analysed in detail.

1. Introduction

Barkhausen noise (BN) originates from the irreversible and discontinuous Bloch Walls (BWs) motion in ferromagnetic materials during the cyclic magnetization of an inspected surface. BWs tend to be pinned in their positions and their discontinuous and irreversible motion occurs when the strength of the magnetic field attains the critical value equal to the pinning strength of the structure. BN is a function of both the microstructural features and the stress state, which affect BN in a synergistic manner. However, the microstructure mainly affects the pinning strength and the free path of BWs movement whereas the stress state affects the domain and the corresponding BWs alignment.

BN techniques were widely studied and BN signals and extracted BN features (such as rms value, peak position, peak height, noise power spectrum and shape of BN envelopes [1–11]) were correlated to a variety of microstructural features such as dislocations, grain size and grain boundaries, precipitates, and secondary phases as well as the stress state. BN techniques have found a high industrial relevance mainly for monitoring surfaces after grinding of shot-peening. However, BN methods have not yet been standardized due to the variety of applied devices and the corresponding variability in magnetizing frequencies and voltages as well as detection coils (their shape and frequency responses), which in turn result in the remarkable differences in received BN signals [12].

Aspects of magnetizing frequency were previously studied by Moorthy et al. [13], who adopted low - (0.4 Hz), medium - (20 Hz), and high - (125 Hz) frequency techniques mainly to reveal grinding burn (surface over-tempering) and its extent beneath the surface based on the correlation between BN values and BN envelopes (obtained at the different magnetizing frequencies) and the residual stress state assessed by via X-ray diffraction. The detailed investigation of the influence of the amplitude of magnetic field strength and the frequency response of the pick-up coil (4–32 kHz) on the shape of BN profile and frequency has been done by Vashista and Moorthy [12]. Dhar and Atherton [14] also revealed that BN activity, BN pulse – height distribution and flux density are strongly affected by the magnetizing parameters; especially magnetizing frequency. Stupakov et al. [15] discussed influence of the construction of the BN pick-up coil, BN signal sampling and filtering within the variable magnetizing frequencies. Tiitto and Säynäjäkangas [16] reported that the nature of BN changes continuously with increasing magnetizing frequency and explain this phenomenon in terms of the clustering of elementary transitions.

Increasing the magnetizing frequency increases the opposition to the rapid change of magnetization due to eddy current generation. As the magnetization frequency increases, the skin

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* Corresponding author.
E-mail addresses: dalibor.blazek@vsb.cz (D. Blažek), miroslav.neslusan@fstroj.uniza.sk (M. Neslušan), martin.micica@vsb.cz (M. Mičica), jaromir.pistora@vsb.cz (J. Pištora).

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depth decreases. Eq. (1) indicates that the skin depth δ is frequency-dependent

$$\delta = \sqrt{2/\omega\mu\sigma} \tag{1}$$

where ω is angular speed ($\omega = 2\pi f$), μ is magnetic permeability, and σ is electric conductance. Eq. (1) supposes the presence of a medium having constant conductivity and permeability, whereas the real surfaces obtained after, for example, grinding or shot-peening contain stresses and microstructure gradients, which mean in turn that conductivity and permeability are a function of the depth beneath the surface.

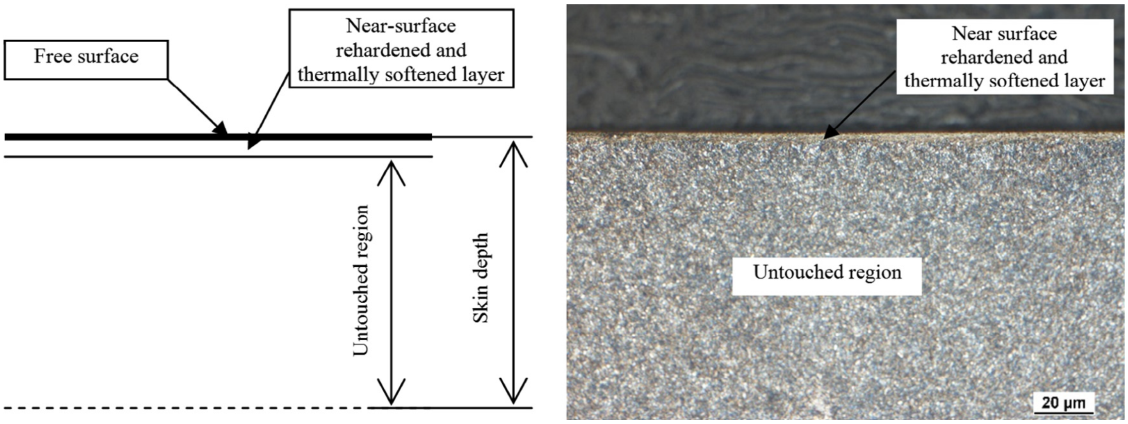
Calculated skin depths express usually the thickness of the excitation magnetic field penetration. However, calculation based on Eq. (1) indicates that the calculated skin depth is far from the BN-sensitive layer thickness due to the strong attenuation of electromagnetic pulses during their propagation towards the free surface. Although BN pulses are generated in deep regions (beneath the true skin depth) they cannot be detected on the free surfaces. The true skin depth should be considered as a layer from which BN pulses can be received on the free surface. It is worth to mention, that the low frequency components of the received BN signal reach farther than the high components and may originate from deeper regions within skin depth whereas the high frequency components originates from the near surface region. On the other hand, pulse – height distribution is a function of magnetizing frequency [16]. Such behaviour can be employed to link the different frequency components of BN signal with the different layers beneath the surface. For instance, Kypris, Nlebedim and Jiles [11,17] proposed the model by incorporating frequency and depth dependence components to provide a framework for assessment stress variation along depth by the use of BN technique.

Moreover, the nonlinear hysteretic response of the material itself is a frequency dependent and the experimental results in dynamic conditions differs from the quasi-static one [18]. The low-frequency techniques are more often employed for material characterizations, where BN pulses are studied as a function of BWs interaction with microstructural features after the different regimes of heat and mechanical treatment, whereas high-frequency systems are mostly adopted for monitoring of the near or subsurface layers of the surfaces after grinding, shot-peening, and so on.

Moorthy et al. [13] reported that low- and medium-frequency measurements are more sensitive to deeper extents of thermal softening induced by grinding. However, measurements reported in [19] proved than BN measurements at magnetizing frequencies in the range of 125–225 Hz are also sensitive to the extent of thermal softening after grinding. Saturation of BN values versus thickness of the heat-affected zone occurs when the thickness of the thermally affected zone exceeds 100 μm. Grinding operations can suffer from over-tempering or over-heating of the surface, which in turn cause early crack initiation and premature failure of parts. The thickness of over-tempered (thermally softened) layers can vary in the range of several micrometers up to several hundreds of micrometers depending on the grinding condition, coolant feeding, grinding wheel wear, and so on. For this reason, BN measurements within a quite wide range of magnetizing frequencies (in the range of 0.1 up to 225 Hz) can be successfully suggested for sensitive and reliable monitoring of grinding operations.

Nowadays, many grinding operations are replaced by hard-turning or hard-milling cycles in a variety of applications [20,21]. The surfaces produced by these operations differ remarkably from the surfaces produced by grinding due to the considerably different mechanism of chip separation and kinematics of the machining cycle compared to the grinding process. Due to the very short period during which the hard-milled surface is exposed to severe plastic deformation at elevated temperatures, hard-turned and-milled surfaces usually exhibit only limited thermally affected zones of only a few micrometers in thickness beneath the white rehardened layer of comparable thickness in the near-surface region [22,23]. Thus, BN signals obtained at the magnetizing frequency of 125 Hz, the frequency usually used for detection of ground surfaces, give only limited information about BWs interaction with pinning sites and stress from the near-surface layer altered by the machining process itself, whereas most of the received BN pulses originate from the untouched structure in the deeper regions within the skin depth (see Fig. 1) [23]. It is well known that for successful application of the BN technique it is essential to achieve the required skin depth of the magnetic field for that specific application. For this reason, higher magnetizing frequencies are needed to reduce the signal of background pulses from deeper regions. It may seem that one could simply use a high-pass filter on the measured Barkhausen signal to receive only emissions near the surface, instead of exciting less volume. However there are situations at which the use of high-pass filter is counterproductive. For example, we have measured the BN on the macroscopic steel samples, where the thin surface layer has been altered by the machining (the altered layer has anisotropic properties while the bulk material remains isotropic) with the goal to find a frequency window at which the BN anisotropy would be strongest. It turned out, that the obtained anisotropy was highest at lower frequencies.

StressTech RollScan 300 or μScan 500 are commercially available devices that are widely employed in many industrial applica-



(a) Brief sketch (b) Micrograph

Fig. 1. Hard-milled surface versus skin depth at low magnetizing frequency.