Zpět

Significance of Magnetizing Voltage on Barkhausen Noise Emission of Hard Milled Surfaces

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This paper deals with the non-destructive evaluation of surface made of hardened roll bearing steel after hard milling via Barkhausen noise technique. The paper discusses significance of magnetization voltage on Barkhausen noise (BN) emission and the corresponding BN features such as Peak Position, FWHM and the shape of BN envelope. BN emission is linked with variable flank wear of cutting tool. Effective value of BN, FWHM and Peak Position derived from the raw BN signal as well as BN envelopes are compared with metallographic observations and theoretical background about magnetic domains reconfiguration when the near surface undergoes severe plastic deformation at elevated temperatures. The results show that magnetization voltage takes significant role in magnitude of BN, shape of BN envelope as well as asymmetry of BN emission during cyclic magnetization.

Keywords: Barkhausen noise, Hard milling, Magnetization voltage

1 Introduction

Cyclic magnetization in a ferromagnetic produces magnetic pulsation as a result of nucleation and reconfiguration of magnetic domains and corresponding motion of Bloch Walls (BW). This motion is usually pinned by precipitates and other lattice defects and result in their discontinuous irreversible movement. Pulsating magnetization is a product of discontinuous BW jumps and well known as Barkhausen noise [1, 2, 3], see Fig. 1. BN techniques are widely employed in the practice mainly for monitoring ground parts and other components loaded near their physical limits. Surface integrity expressed in terms of residual stresses, microhardness or structure transformations is linked with BN values obtained from surface. This technique is mostly adopted for inspection of ground surface since strong correlation between the heat generated in the grinding wheel – workpiece contact associated surface burn (producing thermally softened surface containing low dislocation density and tensile stresses) and the corresponding magnetoelastic responses expressed in BN values [4, 5].

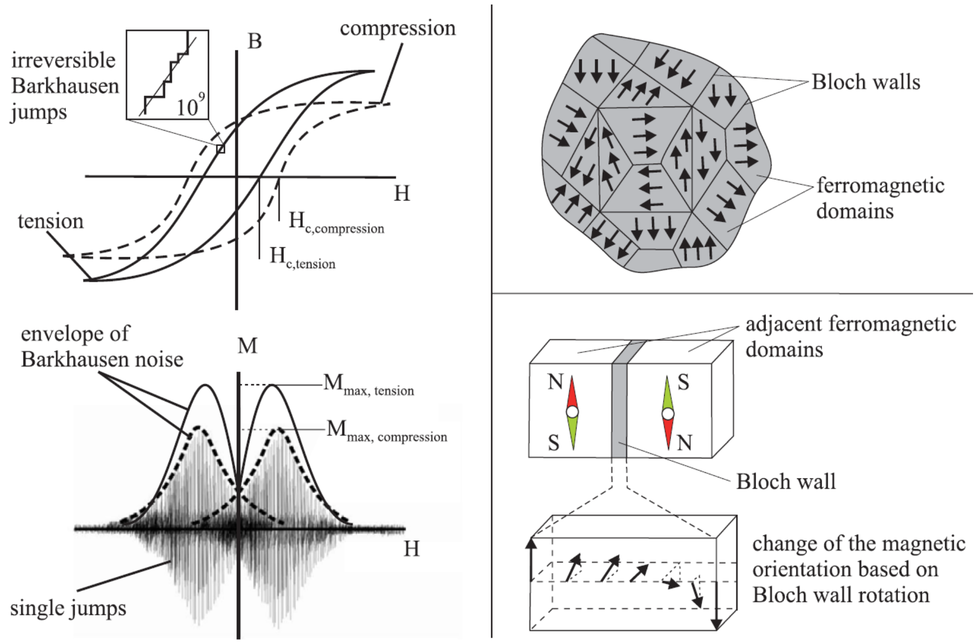


Fig. 1 *Discontinuous changes of hysteresis loop and influence of stress on Barkhausen noise (left side), domain configuration in ferromagnetic material with the detail of Bloch Wall (right side), [2, 3]*

Nowadays, it can be found that hard machining (mainly turning and milling) can substitute grinding operations due to its flexibility and high removal rates. On the other hand, hard turning operations exhibit specific disadvantages such as formation of white layers (WL) induced in the early stages of flank wear or unexpected catastrophic tool failures. It should be also reported that nondestructive monitoring of hard turned or hard milled surfaces based on BN technique has not found industrial relevance due to more complicated relations between received BN and surface integrity. Surface state after hard machining is a function mainly flank wear VB and cutting speed. Operations performed by tool of high VB produces relative thick white layer (WL) as well as the corresponding heat affected zone (HAZ) [6, 7]. On the other hand, grinding cycles produces usually WL free surfaces. However, thickness of HAZ after hard milling is about 1 order lower than that induced by grinding operation. HAZ increases magnitude of BN compared to bulk whereas WL in the near-surface region emits poor BN due to existence of higher volume of retained austenite, compressive stresses and very fine grain [6]. Being so, a concept in which BN technique can be adapted for monitoring hard turned or milled surfaces differs from those employed for monitoring ground surfaces. Conventional attempts to correlated BN signal and the corresponding BN features with microstructure or stress state usually fail. The main problem is linked with the contra indicatory effect of the different surface constituents contributing to BN emission received on the free surface. While HAZ in deeper regions enhances BN emission, the near surface layer containing WL gives quite poor BN. Moreover, complicated stress state can not be easily linked with magnetoelastic responses. It is also worth to mention that ratio between WL and HAZ thickness after hard machining is much higher as opposed to grinding [5]. Moreover, hard machined WL is denser, more uniform with severely strained matrix whereas ground WL retains in their original appearance [8]. For this reason, an alternative concept for monitoring surface after hard turning of milling should be considered. This study is mainly focused on significance of BN system set up, especially magnetizing voltage since the right choice of conditions in which the surface undergoes the cyclic magnetization can be beneficial with regard to obtainable information from BN readings [9, 10]. BN measurement is confronted with metallographic observations and appearance of BN envelopes.

2 Experimental conditions

Experiments were conducted on samples made of bearing steel 100Cr6 of hardness 62 HRC. 10 pieces of dimension 60x43x25mm were prepared for long term test. Cutting process was monitored as a long term test where such aspects as flank wear VB, structure alterations and corresponding surface integrity expressed in magnetoelastic responses (BN) of the hard milled surface were investigated. Cutting and other conditions: milling machine - FA4 AV, dry cutting, cutting tool made of cemented carbides R300-1240E-PM, R300-050Q22 - 12M 262489 of diameter Ø 50mm with 2 inserts of variable flank wear VB (in the range 0,05 to 0,8 mm), a_p = 0,25 mm, v_f = 112 mm.min^{-1}, n = 500 min^{-1}. Flank wear was measured for both cutting inserts and VB values indicated in the paper represents their average value.

BN measurement was performed by the use of RollScan 300 and software package μScan in the frequency range of 10 to 1000 kHz (magnetizing frequency 125 Hz, magnetizing voltage in the range 4 to 16 V). Each BN value was determined by averaging of 10 consecutive BN bursts (5 magnetizing cycles). BN values indicated in the paper represent the effective (rms) value of BN signal. To reveal the microstructure transformations induced by milling 10 mm long pieces were sectioned from the samples and routinely prepared for metallographic observations.

3 Results of experiments

Tool wear

Fig. 4 depicts the different phases of flank wear VB. Hard turning operations are not usually performed with inserts of flank wear VB above 0,4 mm in order to avoid the excessive cutting forces and the corresponding stability of machining. On the other hand, the flank wear is a major factor affecting the thickness of heat affect zone (HAZ) as well as white layer (WL), see Fig. 2 and 3. For this reason, quite large VB were employed to facilitate surface of relative thick HAZ and WL; thus making more remarkable specific aspect of surface integrity investigated via BN.

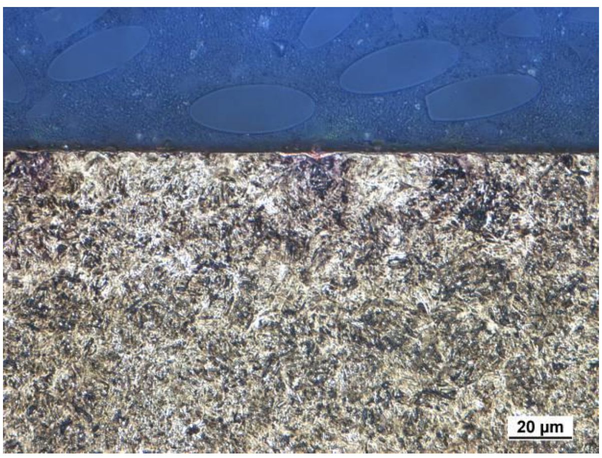


Fig. 2 *Microstructure of the milled surface VB = 0,05 mm, Nital 5% (10s)*

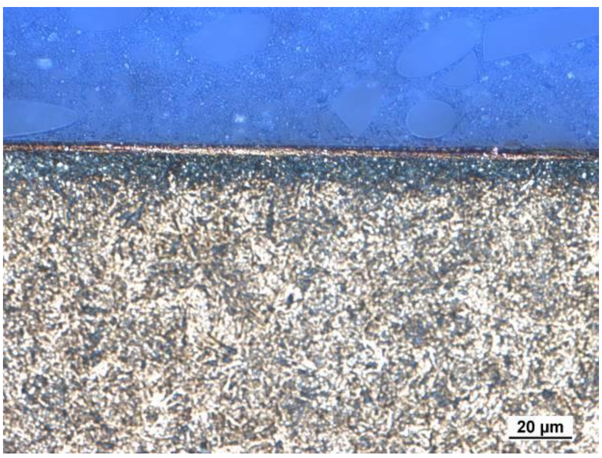
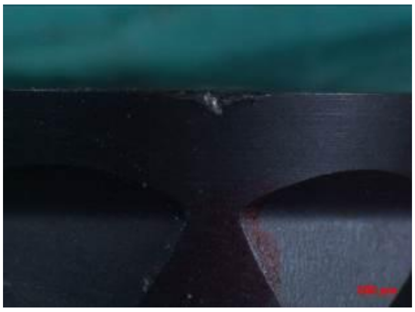
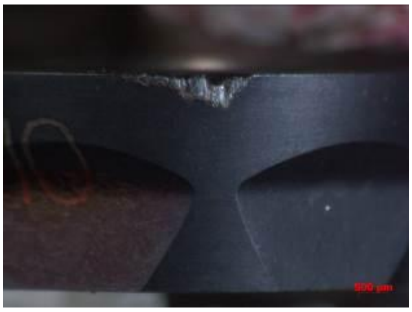


Fig. 3 *Microstructure of the milled surface VB = 0,08 mm, Nital 5% (10s)*

a) sharp cutting insert, VB = 0,05 mm



b) VB= 0,4 mm



c) VB= 0,6 mm

d) VB= 0,8 mm

Fig. 4 *The different phases of flank wear VB*

BN emission

Fig. 5, 6, and 7 illustrate the BN signals, respective their rms values obtained for the different flank wears VB as well as variable magnetization voltages. It is well known that magnetizing voltage is directly proportional of strength of magnetic field during cyclic magnetization. Strength of magnetic field affects BW motion and their interference with lattice imperfections (pinning sites) such as dislocation cells, carbides, secondary phases of grain boundaries. BN at low magnetizing voltages is a product of BW motion and their interference with pinning sites of low pinning strength. On the other hand, BW cannot get over lattice imperfections of high pinning strength. Being so, the low magnetization voltages produces the low BN, see Fig. 7. As the magnetization voltage and the corresponding strength of magnetic field increases the more rich BN emission of higher magnitude can be received. Fig. 7 also demonstrates the strong influence of flank wear VB on BN. As the flank wear becomes more developed BN emission is strongly reduced, see also Fig. 5 and 6. It should be noticed that BN emission obtained from surfaces after hard milling (especially at low VB) is very high. As it was claimed [11, 12], the main reason can be viewed in cutting temperature exceeding the Curie temperature needed to disturb domains configuration of ferromagnetic steel. Domain configuration of the near surface during heating is disturbed and the new domain alignment is configured during rapid cooling. Domains are not randomly but preferentially oriented in the direction of the cutting speed (tangential direction). Except high BN values also strong magnetic anisotropy after hard machining can be detected as it was previously reported [11, 12].

Fig. 7 shows that BN drops down along with the progressive developed VB. Progressive decrease of BN versus VB is linked with the structure transformations in the near surface layer as a region mostly contributing to the BN signal obtained on the free surface. It is well known that surface produced by hard turning or milling consists of WL in the near surface region followed by HAZ in the deeper region. While HAZ is a region producing richer BN due to reduced hardness (and the corresponding lower density of dislocations), coarsening carbides and stresses shifted to the tensile stresses, WL emits quite poor BN emission as a result of higher volume of retained austenite, compressive stresses, very fine grain, high dislocation density and carbon in a supersaturated state [6, 8]. Thickness of HAZ as well as WL gradually increases along with the progressive VB increase. Decreasing BN emission along with the VB indicates that WL takes a major role while significance of HAZ is minor.

WL is a region within the temperature exceeds the austenitizing temperature. Surface rehardening is a product of rapid self – cooling. Thickness of WL is a function of VB. Flank wear land represents the path within the machined surface undergoes the severe plastic deformation at elevated temperatures. Two basic aspects of more developed VB should be discussed as follows:

- more developed VB corresponds with the longer time period within the machined surface undergoes severe plastic deformation at elevated temperatures,
- temperature in the tool – workpiece interface increases with VB due to increasing normal and shear stresses [13].

Both aspects contribute to the thicker WL (as well as HAZ) along with VB because the austenitizing temperatures penetrate deeper beneath the surface. As it was reported, WL is a structure emitting quite poor BN due to compressive stresses and microstructure features interfering with BW. BW in WL is hard to unpin due to high dislocation density, fine grain and higher volume of retained austenite. Being so, the weaker BN signals received for the surface produced by inserts of higher VB corresponds with the shape of BN envelopes (see Fig. 12 and 13) and Peak Positions found on the envelopes, see Fig. 9, 10 and 11.

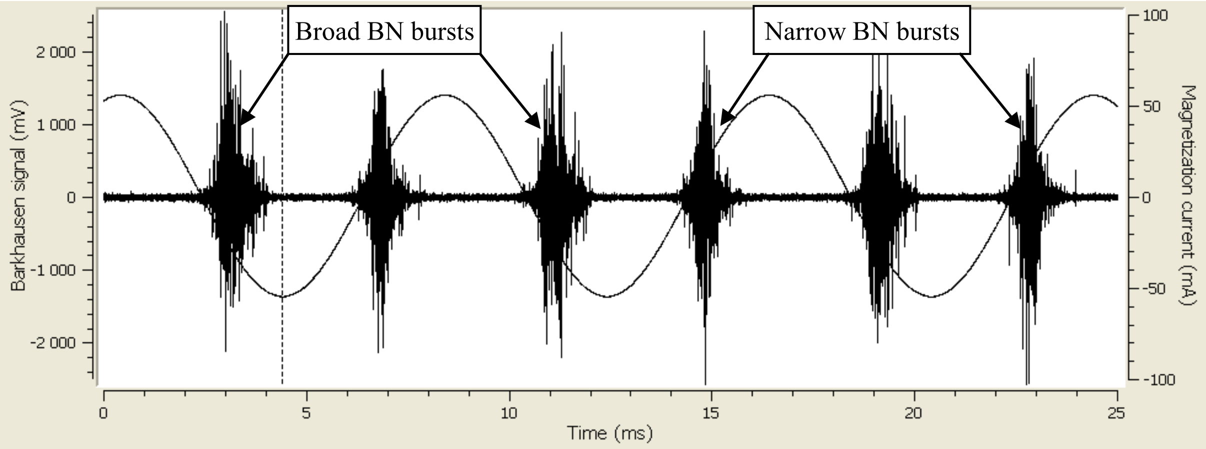


Fig. 5 *The raw BN signal, VB = 0,05 mm, magnetization voltage 4V*

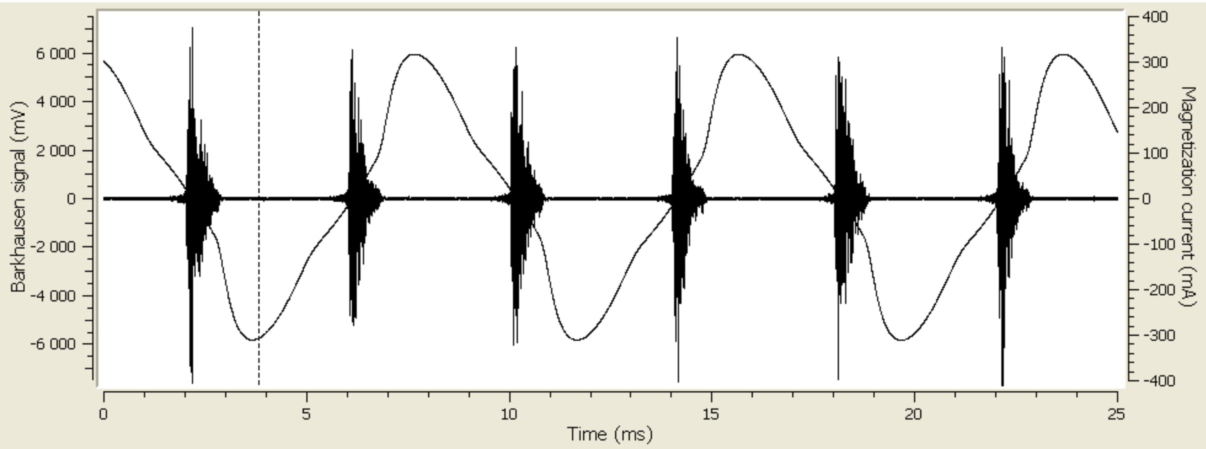


Fig. 6 *The raw BN signal, VB = 0,05 mm, magnetization voltage 16V*

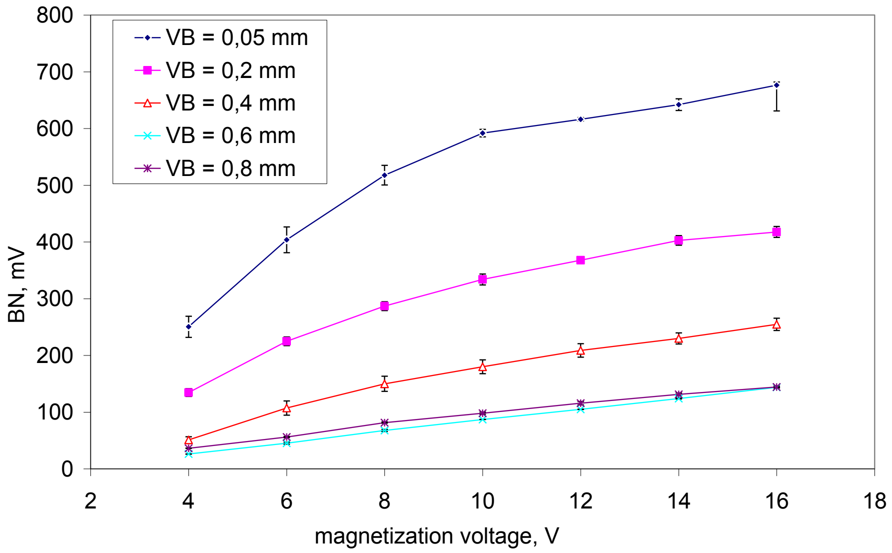


Fig. 7 *BN versus magnetization voltage*

Peak Position

BN envelope, as that illustrated in Fig. 8, can bee used for extraction of such BN features as Peak Position or Full Width at Half Maximum (FWHM), see Fig. 8. Peak Position is strength of magnetic field in which the richest BN emission can be obtained whereas FWHM is the width of the envelope in position of half maximum. The higher Peak Position is the higher pinning strength and the corresponding magnetic field is needed to unpin BW motion. Extraction of both features should be reconsider, especially in the case when the inspected surface contains the typical "sandwich" structure. Such structure usually contain harder surface emitting poor BN followed by deeper region emitting richer BN. In such case BN envelope either gives two peaks on the envelope or the envelope exhibits visible distortion (as that on Fig. 8). Two peaks on the envelope are due to emission of two different structures (for instance rehardened and thermally softened, martensite and bainite, etc.). When the contribution of both structures is more or less balanced, two peaks on the BN envelope occurs. However, when one of these structure components is minor only certain BN distortion can be found. In such cases extracted values of Peak Position (and sometimes FWHM) calculated by MicroScan software should be reconsidered, see Fig. 8 and Fig. 11.

Fig. 9 demonstrates that Peak Position is magnetization voltage dependent quantity. Maximum BN emission is obtained earlier in stronger magnetic fields. For this reason, Peak Position in the magnetization range 4 to 8 V decreases. The following increase is associated with initiation of BN emission from the near surface rehardened layer (WL). It is believed that the near surface region contains hardened layer of higher dislocation density (and the corresponding hardness). However, this layer does not contribute to the BN signal received on the free surface at low magnetization voltages due to its high pinning strength. BW are pinned in their positions since the strength of magnetic field is less the pinning strength of the structure. Being so, inspected surface gives the nearly untouched; BN envelops containing single peak, see Fig. 12a. On the other hand, high magnetizing voltages initiates BW motion in both (harder and softer) layers and shape of BN envelope is altered as mentioned above. Shift of Peak Position to the higher magnetic fields, indicated by MicroScan software is attributed to the occurrence of secondary peak due to BN pulses originating from harder near surface layer. Indicated Peak Position is also function of VB and the corresponding WL thickness.

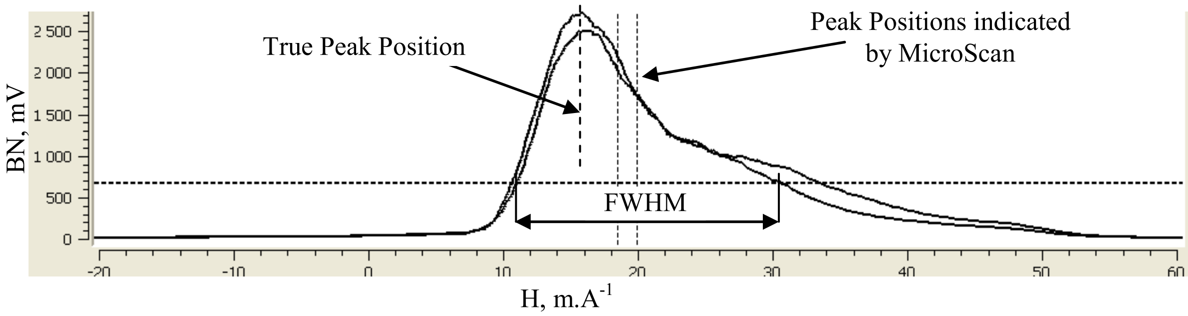


Fig. 8 *BN envelope and corresponding Peak Position and FWHM*

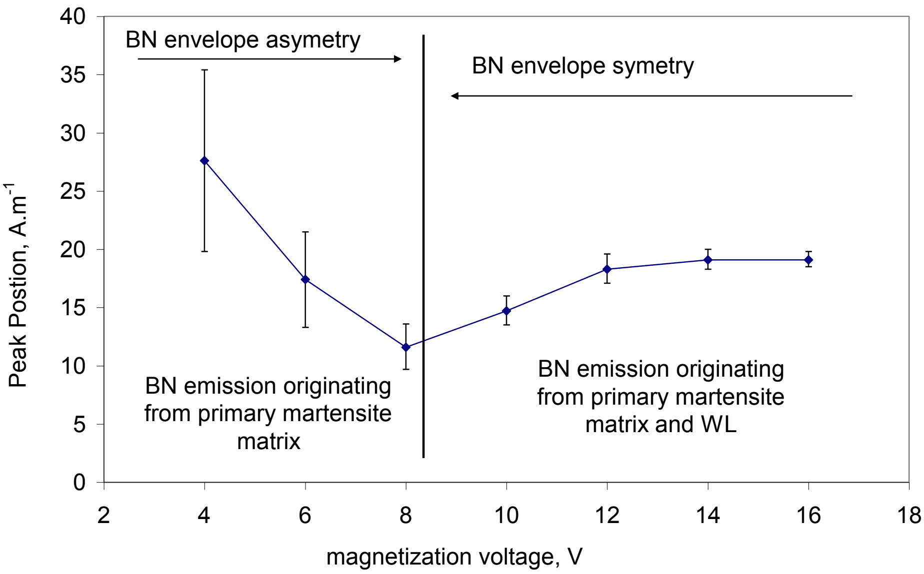


Fig. 9 *Peak Position versus magnetization voltage, VB = 0,05 mm*

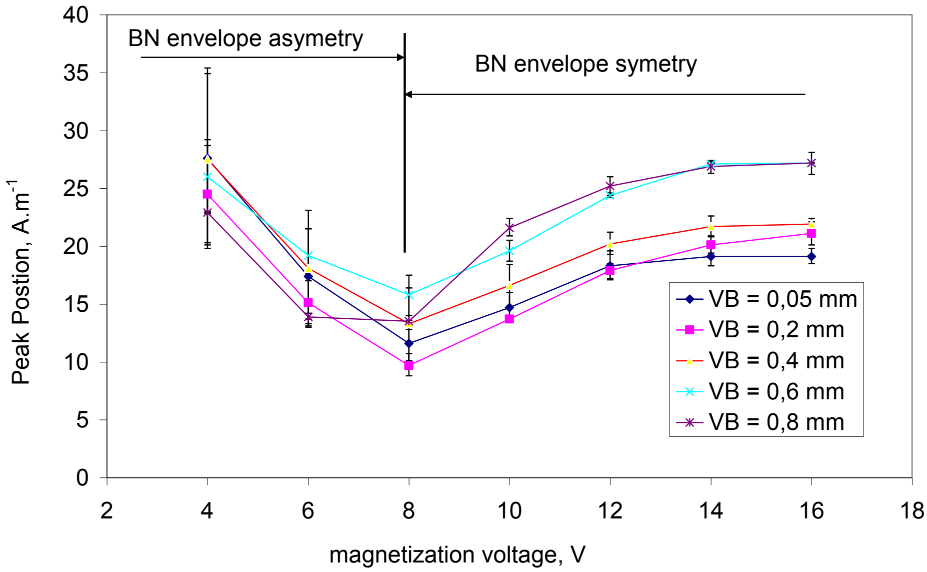


Fig. 10 *Peak Position versus magnetization voltage*

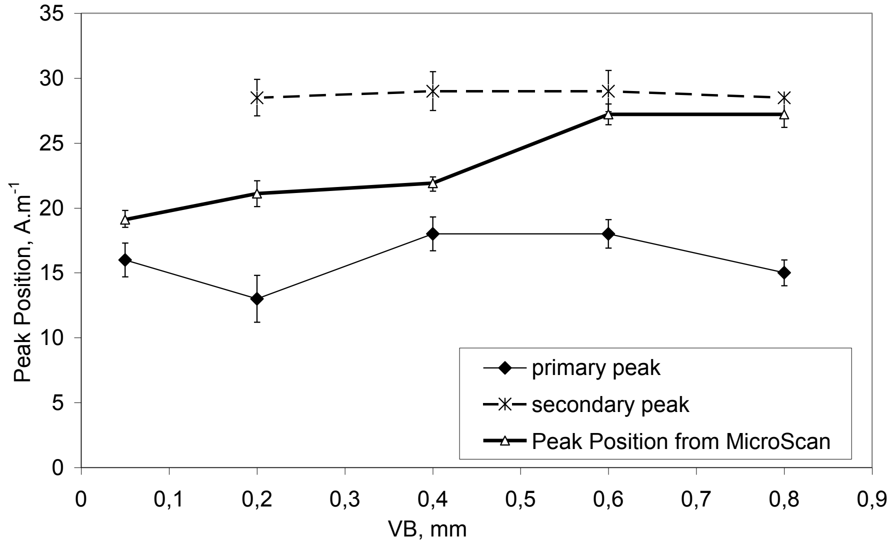
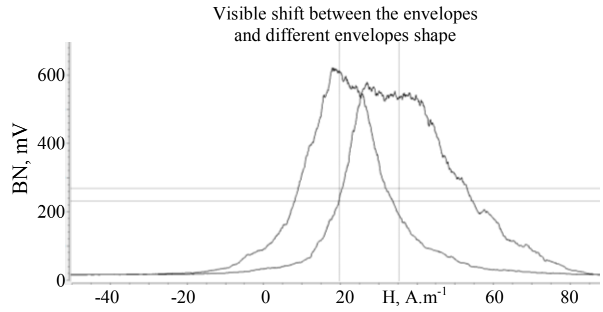


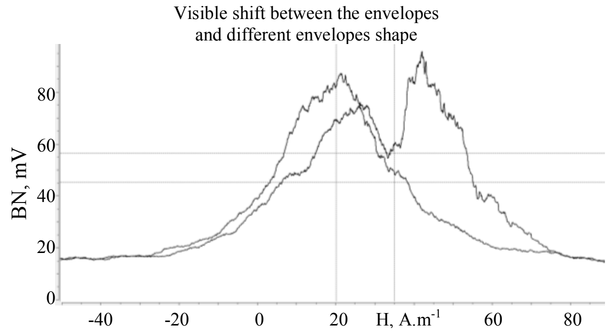
Fig. 11 *Peak Position versus flank wear VB*

Peak Position provided by MicroScan progressively increases along with WL thickness. However, BN envelope exhibits two peaks. First one is originating from heat treatment itself and second one from WL. Secondary peak becomes more apparent along with increasing WL thickness as well as magnetization voltage. Peak Position extracted from MicroScan is positioned between primary and secondary peaks and its position is shifted from primary peak at low VB closer to secondary peak at higher VB, see Fig. 11. Fig. 11 also shows that Peak Position of primary and secondary peaks stays nearly constant with regard to VB. Being so, the variable BN emission is only a function of BN magnitude.

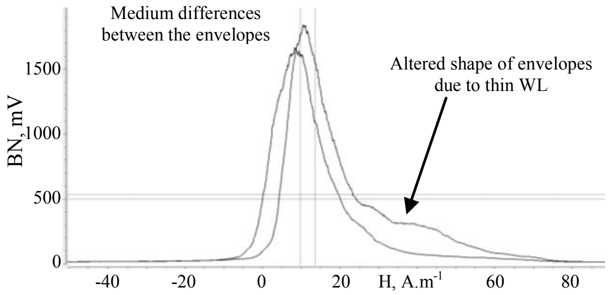
Magnetization voltage affects not only the BN shape but also the symmetry between BN burst (and the corresponding BN envelopes) during one magnetization cycle (ascending and descending part of magnetization curve and the corresponding ascending and descending part of hysteresis loop). Hard milled surface is produced by cutting edge in motion in the direction of cutting speed. As it was discussed above, domains are strongly aligned in the direction of cutting speed. Being so, when the magnetic field is reversed in the direction of cutting speed the surface emits more rich BN emission and lower Peak Positions than that when direction of magnetic field is opposed. In such case strong asymmetry between positive and negative BN envelopes can be found (see Fig. 12a and Fig. 12b) together with the remarkable differences between Peak Positions derived from positive and negative BN envelopes. However, Fig. 10 illustrates that such remarkable differences occurs mainly at low magnetization voltages. As the magnetization voltage increases asymmetry in BN envelopes and the corresponding differences in Peak Positions is decreasing, see Fig. 9, 10 and 12. Asymmetry in BN emission can be also evidenced on the raw BN bursts as those illustrated in Fig. 5. The descending part of magnetizing field produce broad BN bursts whereas ascending part gives more narrow BN bursts. Fig. 5, 6 and 10 also show that BN asymmetry is a function of VB and the corresponding WL thickness and occurs mainly at low VB. As the VB increases degree of asymmetry is decreasing and symmetric BN burst (and the corresponding BN envelopes) occur at lower magnetization voltages. Surface produced by cutting edge of VB = 0,8 mm gives symmetric BN burst at all magnetization voltages, see Fig. 13.



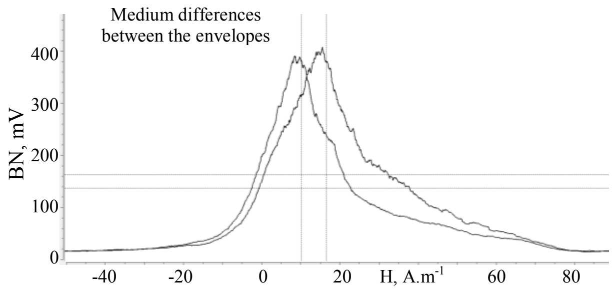
a) magnetization voltage = 4V, VB = 0,05 mm



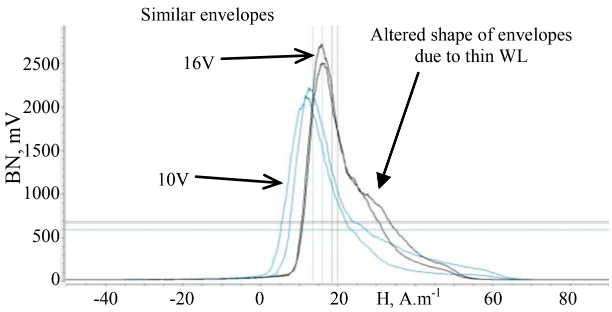
b) magnetization voltage = 4V, VB = 0,4 mm



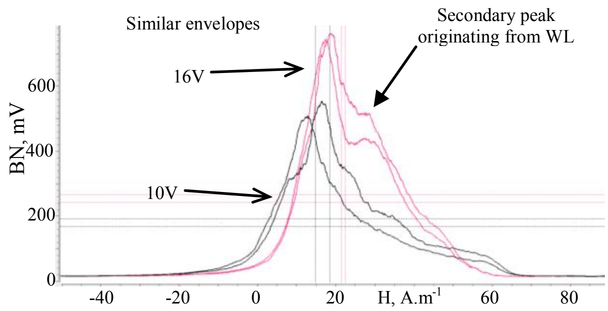
c) magnetization voltage = 8V, VB = 0,05 mm



d) magnetization voltage = 8V, VB = 0,4 mm

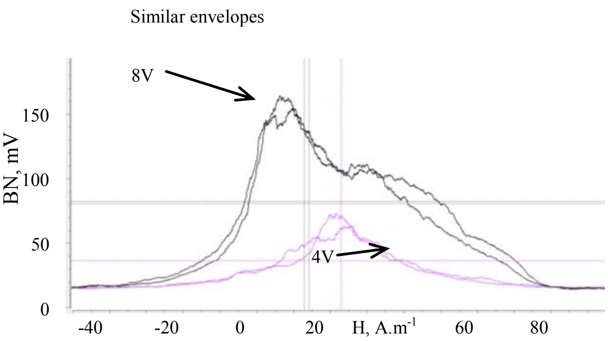


e) magnetization voltage = 10 and 16V, VB = 0,05 mm

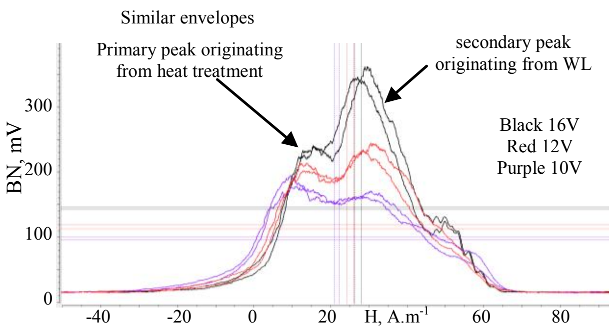


f) magnetization voltage = 10 and 16V, VB = 0,4 mm

Fig. 12 *BN envelopes, VB = 0,05 and 0,4 mm*



a) magnetization voltage = 4 and 8 V



b) magnetization voltage = 10, 12 and 16 V

Fig. 13 *BN envelopes, VB = 0,8 mm*

Except bursts asymmetry, magnetization voltage also affects appearance of secondary peak attributed to the BN emission originating from WL occurring at higher magnetic fields. Fig. 12 and 13 demonstrate that secondary peak becomes more visible along with increasing VB (and corresponding WL thickness) as well as magnetizing voltage. VB = 0,05 mm does not produce dominant secondary peak neither at low nor high magnetizing voltage. VB = 0,4 mm produces minor secondary peak at higher magnetizing voltages whereas VB = 0,8 mm gives balanced primary and secondary peaks at medium magnetizing voltages (10 or 12 V) and dominant secondary peaks at magnetizing voltage 16 V. Being so, it should be concluded that magnetization voltage can make apparent the specific aspect of hard milled surface. While the low magnetizing voltages expose mainly strong magnetic asymmetry of machined surface the high voltages reveal occurrence of WL (height of secondary peak can be linked with the thickness of WL).

FWHM

FWHM feature is the Peak Position depend feature. Fig. 14 illustrates that Peak Position and the corresponding FWHM. FWHM is also WL sensitive BN feature. FWHM progressively decreases as the magnetization voltage increases for low VB (0,05 mm). As soon as the secondary peaks becomes more visible FWHM exhibits gentle increase for medium VB at higher magnetization voltages, see Fig. 14. Such behavior becomes more remarkable and starts at the lower magnetization voltages for VB = 0,6 mm. The most remarkable increase of this BN feature can be found for VB = 0,8 mm. Higher FWHM for surfaces containing thicker WL is attributed to the BN envelope broadening due to growth of secondary peak at higher magnetization fields originating from WL.

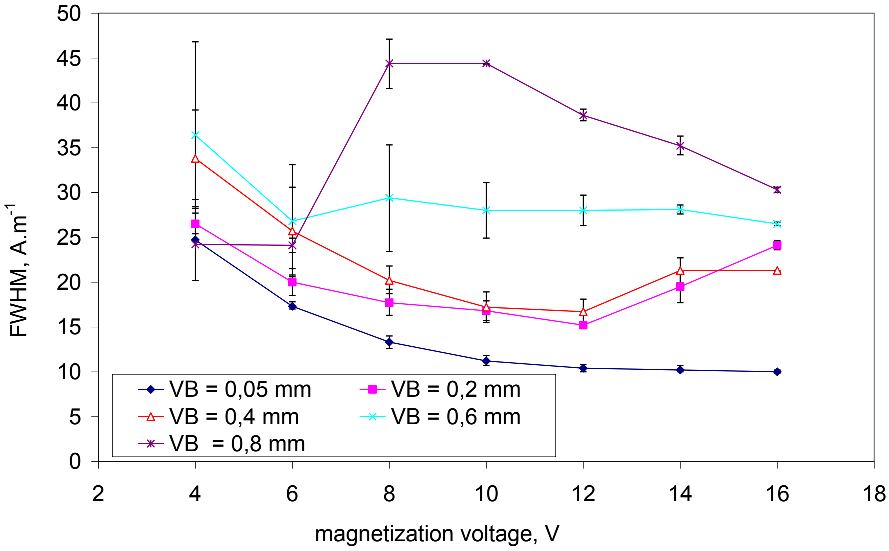


Fig. 14 *FWHM versus magnetization voltage, VB = 0,05 mm*

4 Conclusions

BN technique has found high industrial relevance for detection mainly grinding burn since thermal softening and tensile stresses both contributes to high BN values. Hard milling or turning processes form the different state of surface integrity than that after grinding. WL is usually initiated in the early phases of tool wear; HAZ in the sub-surface region is thin. Furthermore, hard milling cycle produces the surface of specific state of surface integrity as well as of the specific magnetic properties. The paper clearly demonstrates that BN emission and the corresponding BN features are strongly affected by magnetization voltage. While low magnetization voltages make visible mainly strong asymmetry of BN during cyclic magnetization, higher magnetizing voltages reveals existence of WL since the secondary peak growth at the expense of primary peak originating from heat treatment. BN emission of surfaces after hard turning and milling cycles is a function of the workpiece hardness. Strong magnetic anisotropy as well as very high BN values occurs at the different stages of VB when samples of variable hardness are machined. Being so, specific aspects of surface integrity (mainly structure) and the corresponding BN responses need thorough research.

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Abstrakt

Článok: **Vplyv magnetizačného napätia na Barkhausenov šum v povrchoch po tvrdom frézovaní**

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Keywords: **Barkhausenov šum, tvrdé frézovanie, magnetizačné napätie**

Článok sa zaoberá nedeštruktívnym testovaním tvrdo frézovaných povrchov prostredníctvom Barkhausenovho šumu (BN). V článku je analyzovaný význam magnetizačného napätia na BN ako aj BN parametre ako je Peak Position, FWHM a tvar hysteréznych slučiek v závislosti od opotrebenia nástroja. BN hodnoty, FWHM a Peak Position extrahované z BN signálu ako aj BN obálky sú porovnávané v metalografiou a teoretickými poznatkami ohľadne doménového usporiadania povrchu, ktorý je vystavený intenzívnej plastickej deformácii pri vysokýchteplotách.

Zpět