MULTIPARAMETRIC ANALYSIS OF SURFACE INTEGRITY AFTER TURNING THROUGH BARKHAUSEN NOISE IN RELATION TO TOOL WEAR

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This paper deals with application of micromagnetic inspection of surface integrity after turning bearing steel 100Cr6 in dependence on increasing tool wear. This paper indicates influence of tool wear on the selected parameters of Barkhausen noise (RMS value, peak position). The analysis also contains measurement of residual stresses carried out by mechanical method and also analysis of microstructure modifications. The results of experiments show that RMS values of Barkhausen noise decreases with the tool wear as a results of increasing compressive stresses formation in the near surface layers. Moreover the structure transformation occurs in these layers for higher values of flank wear VB.

Keywords
Barkhausen noise, tool wear, residual stress

1. Introduction

Barkhausen noise (BN) techniques have been easily adopted in the industry applications for many years. These methods enable to detect surface integrity expresses in such terms as residual stresses, microhardness or structure transformations. In the ferromagnetic materials Bloch Walls (BW) rotates when the external magnetic field or mechanical load is applied. However this rotation is not continuous because BW are pinned in their positions. Structure defects such as dislocations configuration, precipitates or lattice malformations restrain the free BW movements and so BW movement is in form of jumps when the elastic energy reach the critical values. Magnetoelastic signal can be detected and related to the specific aspects or surface integrity [Sorsa 2012]. Magnetoelastic response strongly depends on such aspects as hardness of structure or stresses induced in the different layers as illustrates Fig. 1 [Theiner 1983]. The physical explanation of the illustrated relations can be found in the literature [Karpuchewsky 2002].

Measuring system is usually based on a sensor with integrated exiting and detecting unit *(Fig. 2)*. Magnetic field is excited through the magnet placed on the inspected surface. Detecting Hall sensor is a small coil receiving the electric pulses as a magnetoelastic response of BW movement. Both units are usually integrated into the one sensor with the contact area about 16 mm^2. Penetration depth of the exiting magnetic field strongly depends on material properties and also the frequency of the exciting magnetic field. The raw BN signal is usually processes and such parameters as RMS value, peak position, coercive force, permeability and other can be easily extracted [Thompson 1994]. An example of multi parametric evaluation of BN signal is shown in Fig. 2. Industrial and also laboratory measurement usually indicate correlation between the specific parameter of surface integrity and RMS value of Barkhausen noise signal. RMS value represent the effective value of the signal dynamic (mixed parameter derived from amplitude and also frequency aspects of a signal), coercive force is resistance of the permanent magnet against demagnetization activated by the external magnetic field. [www.pcs.cz]. Multi parametric approach is connected with many executed parameters of surface integrity and complexity of their mutual relations. Solution of the specific task in the practice requires extracting the suitable parameters from the raw BN signal. A suggested parameter should be sensitive enough from the point of view of investigated parameter.

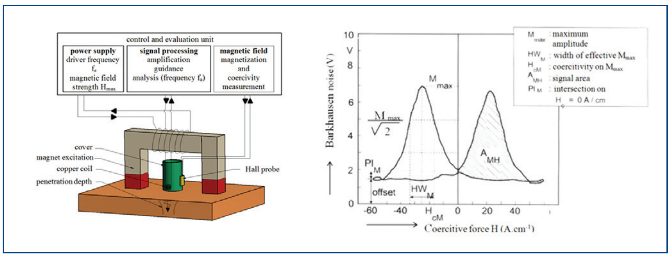

Figure 2. *Brief sketch of BN sensor and parameters extracted from the raw BN signal [Karpuchewsky 2002]*

BN techniques are mostly applied for detection of grinding burn in the automotive, bearing or aerospace industry [Wojtas 1998]. BN techniques can be also adopted for such applications as heat treatment processes [Moorthy, 2001], mechanical hardening of surfaces, welding inspection, magnetic anisotropy [Stupakov 2010] etc. (Fig. 3). Except the finishing operations, optimization of technological processes can be also integrated into the research tasks. The specific tasks in the bearing industry can be also found in the stage before heat treatment. It is easily understood that the different stress state before heat treatment can lead to a different deformation of parts after heat treatment. The different stress state induced of turning operations is connected with the progressive tool wear which significantly change mechanical and thermal load of machined surface. And so this study deals with detection

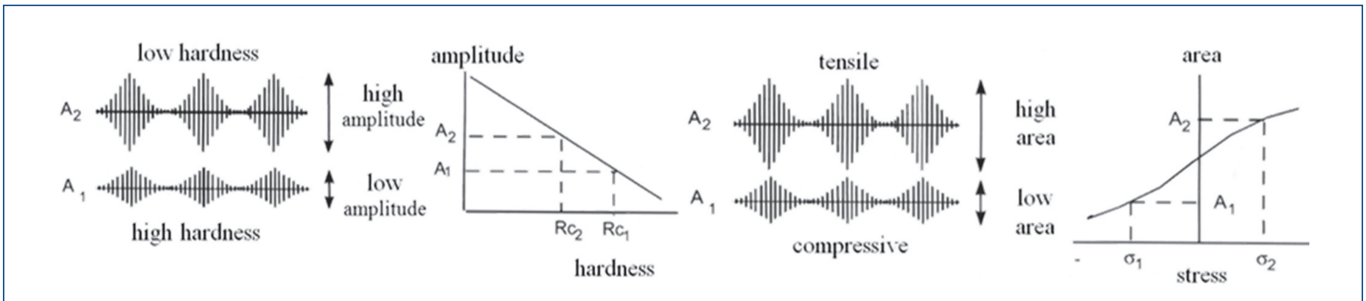

Figure 1. *Influence of stress and hardness on BN [Theiner 2007]*

of surface integrity in relation to the tool wear through the BN techniques and also investigation of other related parameters such as structure transformations, cutting force and residual stress [Blaow 2007]. These additional aspects should be investigated for true interpretation of BN signals.

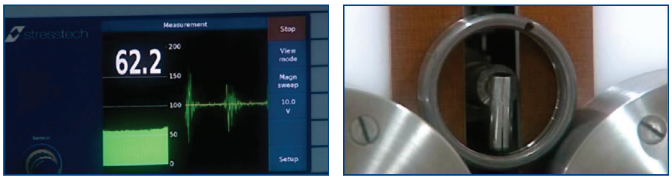

Figure 3. Investigation of bearing ring through BN [www.stresstechgroup.com]

2. Experimental conditions

Experiments were carried out on the roll bearing steel 100Cr6 before heat treatment (27 HRC). Rings of external diameter 52 mm (internal diameter 40 mm) and width 20 mm were located on the shaft as illustrates Fig. 5.
The sharp insert and 4 inserts of the different flank wear VB were used in the experiment as depicts Fig. 4, (2 rings were investigated for each value of tool wear). 4 cutting worn edges were prepared before the test through the long term preliminary stage of experiment.

Cutting and other conditions:
lathe: SUI 40, tool: SNMG 120408E-M 6630, tool holder: DWLNR 2525 M08 KT 804, a_p = 1 mm, f = 0,09 mm, v_c = 100 m.min^{-1}

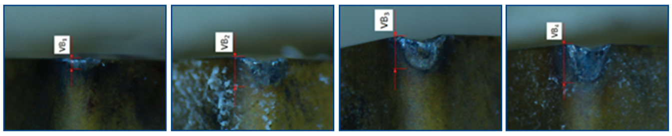

Figure 4. Illustration of tool wear VB: VB1 = 0,2 mm, VB2 = 0,5 mm, VB3 = 0,65 mm, VB4 = 0, 9mm

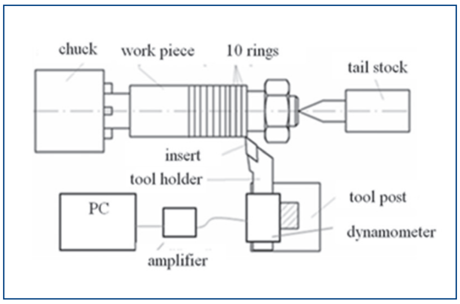

Figure 5. Brief sketch of parts on the shaft

Cutting forces were measured in 3 directions by KISTLER dynamometer (forces analyzed in software DasyLab 3.5). The non-destructive evaluation of surface integrity through the Barkhausen noise was carried out after machining. BN signal were measured in the 8 points on the ring periphery in the direction of cutting speed (device Rollscan 300, multiparametric evaluation of BN in software MicroScan, exciting mag. frequency 125 HZ, mag. voltage 5V, sine shape, analyzed frequency 70 – 200 kHz). After the non-destructive tests the rings were cut off. The small piece was used for metallographic analysis and the rest of ring was used for measurement of residual stress (measured by mechanical method based on electrolytically etching of surface and measurement of the ring deformation).

3. Results of experiments

Fig. 6 shows that cutting forces increases with flank wear VB. The Fig. 6 also depicts that values of cutting forces saturate above VB = 0,65 mm. The most significant increase can be found considering the passive component of cutting force. As it is well known processes in the contact between flank wear and machined surface influences the value of passive force the most of all components and so information about passive force F_p is a strong indication of mechanical (and particularly thermal) load in the tool-workpiece contact. A certain thickness of chip thickness is not transformed into the chip but underflow the cutting edge. The near surface layers of machined surface is exposed to the high thermo mechanical load, its properties are modified.

Fig. 9 illustrates that application of cutting insert under the flank wear VB = 0,65 mm the does not produce surfaces with a visible structure transformation of the near-surface layers. On the other hand, when the flank wear exceed the critical value, structure modifications occur. It should be also noticed that structure transformations are also connected with the passive force saturation.

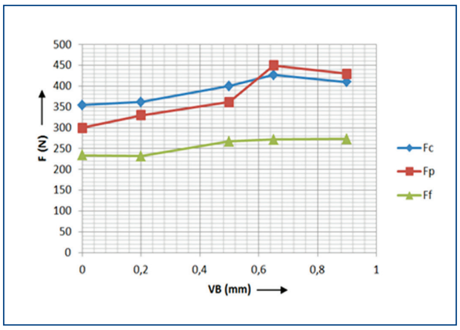

Figure 6. Influence of VB on cutting

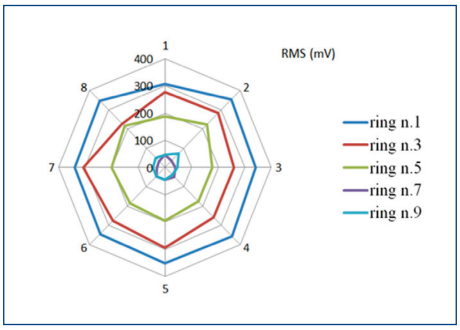

Figure 7. Influence of tool wear forces on RMS values of BN

RMS values of BN strongly correlate with the increasing mechanical load of machined surface. It is assumed that microhardness of surface layers are increasing with the increasing flank wear VB and also associated passive force F_p. Fig. 7 indicates that RMS values decreases with increasing tool wear. Low RMS values of BN are caused by low BW activity. The mechanical load and also associated high mechanical strengthening of the machined surface increasing with flank wear VB activates formation of surface with high dislocation density containing compressive stresses in the near surface layers. Fig. 10 shows that compressive stresses are increasing with flank wear.

Moreover, thickness of layer containing compressive stresses also increases. On the other hand, value of tensile stresses differ only a little while thickness of zone containing tensile stresses is thicker for high values of VB than that for sharp inserts. It is well known that compressive stresses suppress the magnetoelastic response of surfaces while tensile stresses enhance the BW activity. Fig. 10 illustrates that the distribution of residual stresses can be understood as a mixed model with compressive stresses in the near surface layers and tensile stresses in the sub-surface layers. Decreasing RMS values of BN (in relation to increasing VB) indicate that properties of the near-surface layers predominate because despite the thicker zone containing the tensile stresses the RMS values of BN are lower.

Except RMS values of BN the additional parameters can be extracted from the raw BN signal. Fig. 8 shows transformation of Barkhausen noise signal. This transformation can be expressed in such parameters as "peak position" and also "peak average". It was previously investigated that peak position is usually connected with the structure modification of the inspected surface [Moorthy, 2001] as illustrates Fig. 9. Measured values of „peak position" (Fig. 11) and also "peak average" (Fig. 12) correlates with the signals shown in Fig. 8 and also with the transformation of hysteresis loop extracted from the raw magnetic signal (Fig. 13). The progressive shift of the envelope curves, parameters such as „peak position" and "peak average" indicate the rearrangement of magnetic domains and associated modification of BN frequency spectrum. It is assumed that the intensive plastic deformation reallocate BW positions with the smaller magnetic domains areas formed in the structure of near surface. Therefore, BW produces signals with the low amplitudes at higher frequencies.

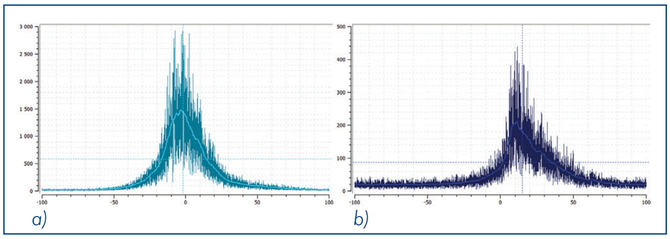

Figure 8. *Envelopes curves for the different flank wear, a) sharp insert, b) VB = 0,9 mm*

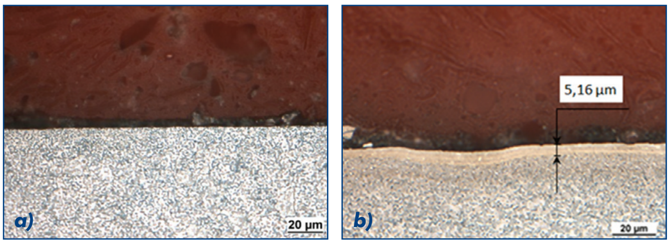

Figure 9. *Micrographs of machined surface - a) sharp insert, b) VB = 0,9 mm*

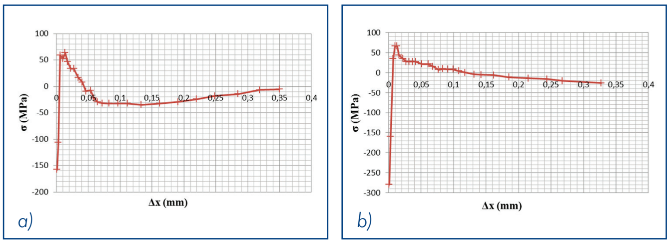

Figure 10. *Residual stresses - a) sharp insert, b) VB = 0,9 mm*

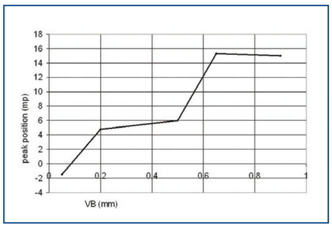

Figure 11. *Influence of flank wear on peak position parameter*

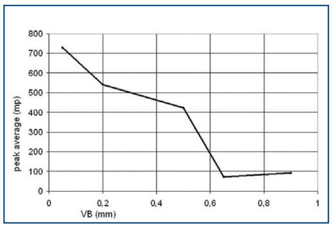

Figure 12. *Influence of flank wear on peak average parameter*

Structure transformation indicates increasing temperature in the contact between cutting tool and machined surface. Fig. 9b indicates that temperature in this contact exceed the recrystallisation temperature and causes the following structure transformation. The visible near-surface transformation was found on the micrographs for flank wears 0,65 and 0,9 mm. Except the visible structure transformation Fig. 9b also indicates variable cutting depths connected with passive force increases and so lower process stability.

Notice: Units of permeability, coercive force and also axes related to the hysteresis loops should be considered in the "mp" units because these parameters are extracted form the dynamic of BN signal. They evaluation do not exactly correspond with the exact physical evaluation and experimental measurement. Therefore the presented values could slightly differ from the real physical values.

Intensive plastic deformation of machined surfaces strongly affects not only mechanical properties of surface layers and their structure, but also related magnetic responses of surfaces. The magnetoelastic response exited by the external magnetic field is strongly eliminated. Except the restricted BW movement is should be considered that the penetration depth of the exciting magnetic field is also reduced. This penetration depth strongly depends on the permeability of a structure [Stupakov 2008] and frequency of an exciting magnetic field. As illustrates Fig.14, permeability of surface significantly decreases with increasing flank wear. Permeability of the structure is derived from the hysteresis loop and such parameters as coercive force (Fig. 15) and remanent magnetism. Permeability represents the slope of hysteresis loop near the coercive force. Fig. 13 show that this slope strongly decreases with the tool wear. The low permeability

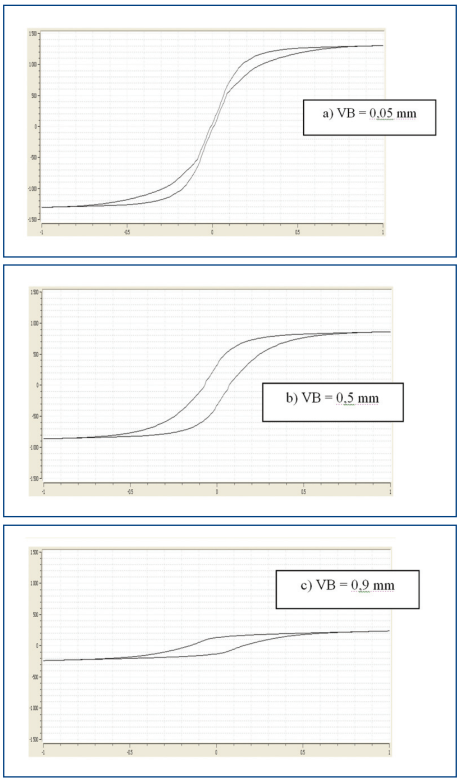

Figure 13. *Influence of flank wear on the shape of hysteresis loop*

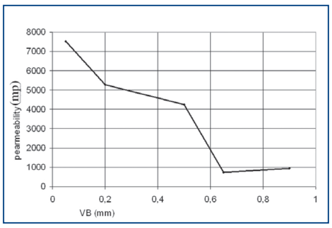

Figure 14. *Influence of flank wear on permeability*

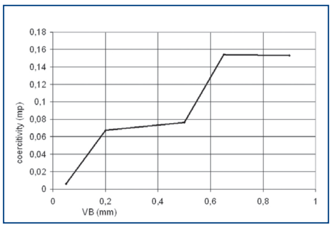

Figure 15. *Influence of flank wear on coercive force*

of structure and connected low penetration depths causes that the deeper layers do not contribute to the total BN signal. BN signal of surfaces machined with the high flank wear consist only the high frequency responses of low magnitudes produced by the highly deformed near surface structures.

4. Conclusion

Study of magnetoelastic emission and also additional aspects of cutting process indicates some conclusions.

- It was experimentally proved that tool wear strongly affect properties of surface layers after turning considering operations performed of the parts before heat treatment.
- Tool wear and associated mechanical and thermal load also affects distribution of residual stresses.
- Despite the constant cutting conditions the surface integrity could vary from the point of view of tool wear.
- Increasing tool wear causes intensive plastic deformation of the machined surfaces and therefore elimination of BW movements and lower BN signals for surfaces machined with the higher flank wear.
- Decreasing penetration depth and permeability of surfaced machined with tool of high wear also reduces intensity of BN signal.

This study illustrates that conventional data processing of BN signal enable to detect variability of surface integrity and so BN technique could be successfully integrated into the manufacturing not only in the final stages of production but also before heat treatment to optimize the consecutive production steps.

The previous research indicated that deformations of parts during heat treatment (especially with thin walls) depend of stress distribution induced by previous machining [Sisak 2010]. This study indicated that BN distribution associated with the stress state correlates with the deformation during the following heat treatment. Solution of this particular task should lead to elimination of deformations induced by heat treatment. This aspect of manufacturing process is very important because parts deformations are closely connected with allowances after heat treatment. Their reduction represents the significant step in time and also economy savings.

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