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APPLICATION OF BARKHAUSEN NOISE FOR MEASUREMENT OF RESIDUAL STRESSES IN MACHINING

APLIKACE BARKHUSENOVA ŠUMU PŘI MĚŘENÍ ZBYTKOVÝCH NAPĚTÍ PŘI OBRÁBĚNÍ

Abstract

This paper deals with application of Barkhausen noise for measurement of residual stresses after grinding and turning. The results of measurements show that the residual stresses are not homogenous on the machined surface after heat treatment and cutting operations. The different methods give the different character of information about residual stresses induced in the surfaces.

Abstrakt

Příspěvek se zabývá aplikací využití Barkhausenova šumu pro měření zbytkových napětí po broušení a soustružení. Výsledky měření ukazují, že zbytková napětí nejsou homogenní v opracovaných površích po tepelném zpracování a následném obrábění. Různé metody měření umožňují získat podrobnější informace o zbytkových napětích indukovaných v površích.

1 INTRODUCTION

There are many methods applied for measurement of residual stresses induced in the surfaces. Micro magnetic and X – rays methods are non – destructive methods for measurement of these stresses. On the other hand, mechanical method is the destructive method for evaluation stresses. There are some advantages and disadvantages of these methods. And so this paper deals with comparison of the mechanical method and the micro magnetic method for analysis of residual stresses after heat treatment and cutting process. There were applied micro magnetic methods based on Barkhausen noise for evaluation of stresses in this research.

1.1 Barkhausen noise theory

The continuous rotation of magnetic field results into the non continuous magnetization of material. This discontinuity is named as the Barkhausen noise. Coercive force (Hc), magnetic saturation and remanent magnetism are possible to evaluate on the base of hysteresis loop. These parameters can provide information about hardness or stress state of material as is illustrated in Fig. 1 [1]. Fig. 1 illustrates influence of stress on the density of elastic energy. Increasing density of elastic energy leads to change of the shape of domains to minimize the internal energy (in the case of the ferromagnetic materials). This reaction is named as magneto elastic response to the mechanically induced stress. External tensile load results into increasing domains parallel with the magnetization direction and the domains perpendicular to the load are decreasing. The compressive load effect is contrary [1].External magnetization parallel with tensile stress leads to increasing domains parallel with magnetization orientation [2]. Parallel orientation results into more intensive movements of Bloch walls. The compressive stress causes rotation of walls into the direction of the exciting field and eliminates movements of Bloch walls [1].

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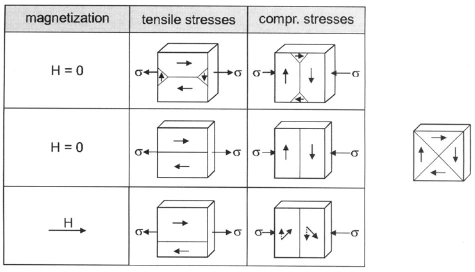

Fig.1 Influence of external factors on orientation of magnetic domains [2]

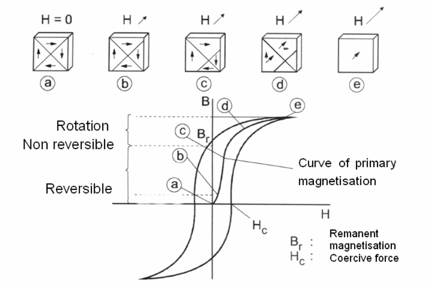

Fig.2 Hysteresis magnetic loop of ferromagnetic materials [2]

This effect can be applied for explanation of the hysteresis loop of ferromagnetic materials (Fig. 2). Increasing excitation leads to rotation of domains to the direction of magnetic flow. Curve (a) is reversible. On the other hand, non reversible magnetization is given by rotation of Bloch walls (b) up to saturation of material (e). Non reversible movements of Bloch wall causes the remanent magnetization *Br*. Elimination of remanent magnetization requires magnetic field of coercive force *Hc*. Existence of stress causes deformation of hysteresis loop (Fig.4a). Bloch walls move under the load of external magnetic field. This movement can be indicated by a small coil as the electric pulse. Movement of Bloch walls is not continuous. There are wall jumps and these jumps are known as Barkhausen noise (Fig.4a and Fig.3) [1].

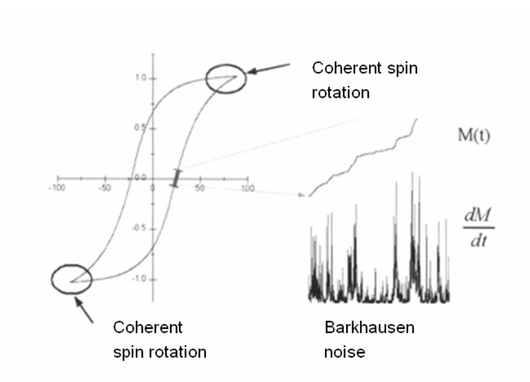

Fig. 3 Hysteresis loop of ferromagnetic material and area of Barkhausen noise inspection [3,4,2,5,6]

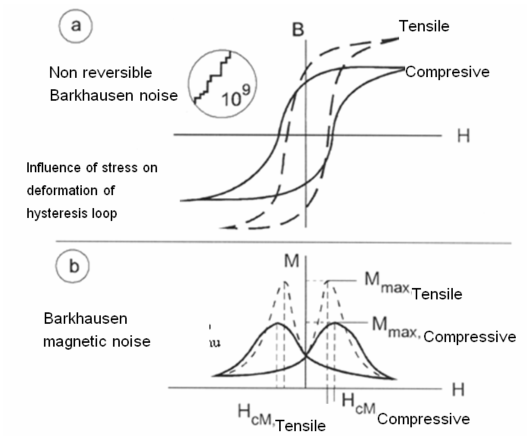

Fig. 4 Deformation of hysteresis loop under the stress (a) and important parameters of Barkhausen noise (b) [3,4,5,6]

Barkhausen noise is damped with increasing depth. The main reason is the damping effect of eddy current influencing electromagnetic fields of moved Bloch walls. Bloch walls rotate under the external load to the orientation of magnetic flow. The compressive stresses decreases intensity of Barkhausen noise and the tensile stresses increase this movement [3,2,7,8] (Fig. 5 a Fig. 6).

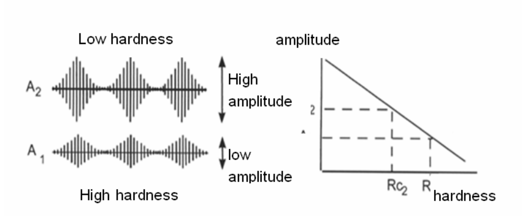

Fig. 5 Influence of hardness on character of Barkhausen noise [3,4,5,6]

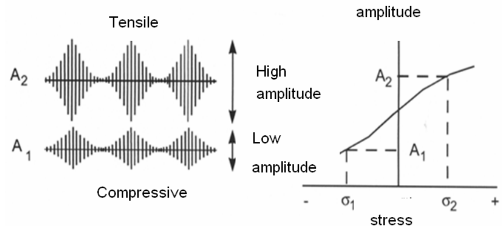

Fig. 6 Influence of stress on character of Barkhausen noise [3,4,5,6]

Hardness of structure influences intensity of Barkhausen noise too, Fig.5. Identification of the different parameters of surfaces should be related to the suitable parameter of Barkhausen noise. Fig.3 illustrates that analysis of Barkhausen noise is realized in the area of Hc. There is the characteristic record of Barkhausen noise in Fig.3. This signal is processed through the conventional mathematic apparatus – generation of envelop curve (Fig.4b). Fig.4a illustrates that stresses can be analyzed not only on the base noise but on the base of the hysteresis loop shape too, respectively its deformation in comparison with its shape without stress load [1].

Mechanical method is the destructive method for evaluation of residual stresses. This method is based on electrochemical etching of surface and measurement of deformation of inspected part. On the base of deformation, properties of material and the next parameters it is possible to calculate residual stresses. There are some advantages and disadvantages of each method and so this paper compare information provides by both methods. Measurement of residual stresses in this paper was carried out on parts after grinding and turning.

2 MEASUREMENT OF RESIDUAL STRESSES

2.1 Measurement of residual stresses after grinding

In first experiment, analysis of residual stresses were carried out on the roll bearing steel 14 209.4 of hardness 62 HRC. Machining was realized on surface grinding machine BPH 20. There were compared 3 different grinding wheels: Al_2O_3, SG and TG (see tab. 2). Cutting condition of surface plunge grinding is in the Tab.1. Residual stresses after machining were measured by the mechanical method and through the Barkhausen noise too.

Tab. 1 Cutting conditions for grinding

a_p [mm]	v_f [m.min^{-1}]	n [min^{-1}]
0,03	8	2520

Tab. 2 Grinding wheels applied in the experiment

5 SG	5 TG	Al_2O_3
01 250x20x76 SG 60 JVX	01 250x20x76 TG 60 JVX	01 250x20x76 38A 60 JVS

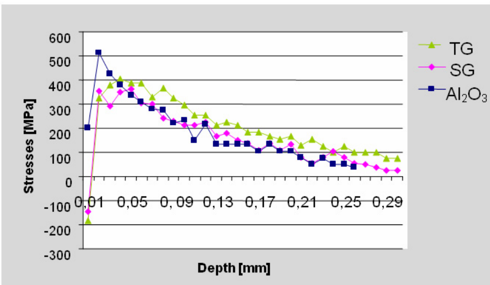

Fig. 7 Residual stresses after surface grinding

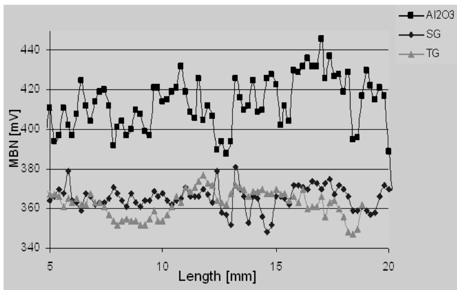

Fig. 8 Residual stresses analyzed through Barkhausen noise

The results of measurements of residual stresses measured by mechanical method (Fig.7) correlates with measurement of stresses measured through Barkhausen noise Fig.8. This method provides information about stress state in the different layers under the surface. Value of MBN in Fig.8 represents the area of Barkhausen noise. This area correlates with residual stresses in the surfaces. This area is increasing with increasing the tensile stresses and is decreasing with increasing compressive stresses. Fig.8 illustrates that the area of Barkhausen noise for surface ground by conventional wheel is higher (about 400) while the surfaces ground by progressive SG and TG wheels are less thermally affected (360). Application of this micro magnetic method for evaluation residual stresses provides information not only about stress state of surface but about distribution of stresses on the surface. There is visible oscillation of stresses on the ground surface. This oscillation is more intensive when application conventional wheel (higher intensity of vibration of grinding process) that that for application progressive wheels.

2.2 Comparison of residual stresses after turning and grinding

The second example of micro magnetic method based on Barkhausen noise is illustrates in the next text. There were analyzed residual stresses on 30 rings of external diameter 49,5 mm, internal diameter 40 mm and width 8 mm. There were carried out the different process of heat treatment processes. Some rings were turned and some ground before the heat treatment. Dimension and profile of these rings were analyzed. The same measurement was carried out after heat treatment. There were realized the different processes of heat treatment with the different structure after heat treatment (martensite of hardness 58, 62 and 65 HRC and bainite of hardness 58 HRC). Turning process was carried out on the lathe SUI 40 with ceramic cutting tool Al_2O_3+TiC (TiN coating). Grinding process were carried out on grinding machine B2uDP2750 with grinding wheel A99 80K 9V 350x20x127. Analysis of stress state was carried on the circumference of rings with interval 45°. Measurement of stresses verifies information that conventional heat treatment on martensite structure induces the tensile stresses on the surface and process of heat treatment of bainite structure (isothermal tempering) induces compressive stresses, Fig.9 [9]. This information was verified by both methods applied for measurement residual stresses.

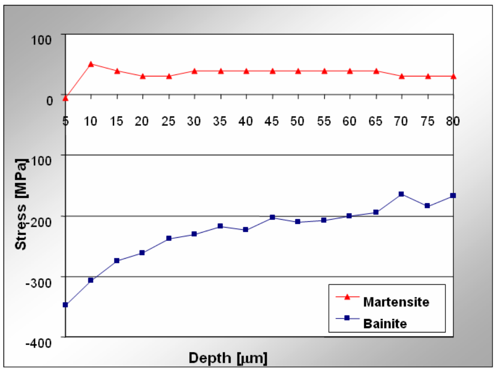

Fig. 9 Residual stresses after heat treatment [9]

Distribution of residual stresses on the ring surface correlates with the profile of rings after heat treatment. On the other hand, this correlation is missing after tempering of these rings (Fig.10 - Fig. 13). Tempering process enables relaxation of stresses after cooling phase of heat treatment. There is significant correlation between distribution of residual stresses and the profile of ring after the cooling phase. This correlation is illustrates on Fig.15. Analysis of this aspect of stress distribution is not possible inspects through the mechanical method because calculated stresses in the different layers give the average value of stress through the circumference the ring. Hardness of rings does not change and distribution of hardness is homogenous considering the circumference of rings. On the other hand, residual stresses are not distributed homogenously. This aspect of heat treatment is illustrated on Fig.14.

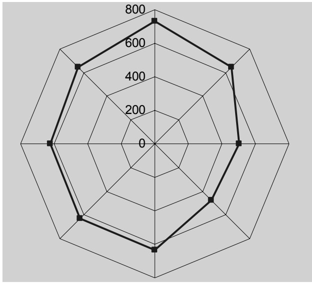

Fig. 10 Distribution of residual stresses on the martensite parts – Barkhausen noise

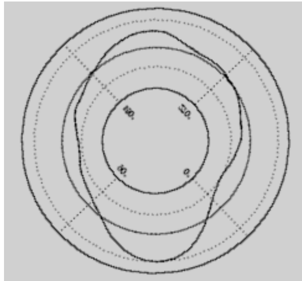

Fig. 11 Profile of machined surface (according Fig.10)

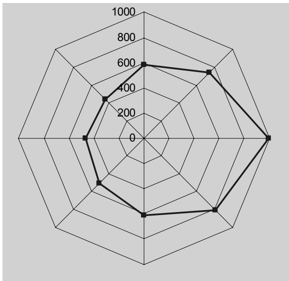

Fig. 12 Distribution of residual stresses on the martensite parts – Barkhausen noise

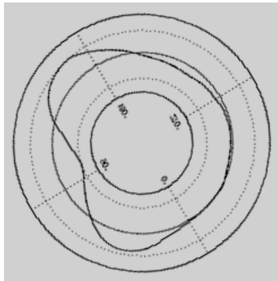

Fig. 13 Profile of machined surface (according Fig.12)

Movement of Bloch wall is eliminated by increasing hardness of structure. This limited movement is illustrates by area and amplitude of the noise envelop curves, *Fig.16*. Residual stresses correlates with area of Barkhausen noise and profile of rings after heat treatment for martensite of hardness 65 HRC.

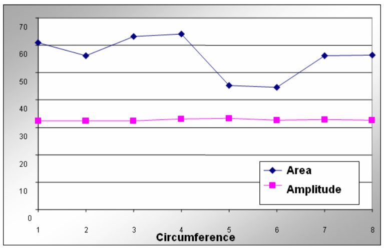

Fig. 14 Parameters of Barkhausen noise area → residual stresses, amplitude → hardness

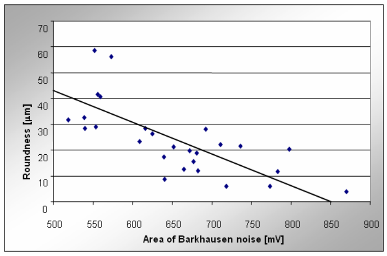

Fig. 15 Relation between roundness and area of Barkhausen noise after heat treatment, martensite 65HRC

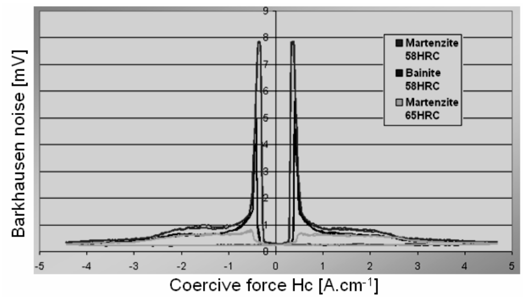

Fig. 16 Envelop curves of Barkhausen noise

Residual stresses after grinding are much more homogenous distributed on the surface that that after turning process (Fig.17, Fig.18). The main reason is stability of cutting process and deformation induced by heat treatment. Grinding process is realized through the repeated passes and spark – out process. On the other hand, turning process is realized per one pass of cutting tool. Vibration of cutting process when turning is related to the deformation after heat treatment. Grinding process is much more stable because of lower cutting depths and lower material removal rates. Moreover, thrust forces are much higher when hard turning that that when grinding process. Thrust forces significantly influences precision of produced parts and distribution of stresses on the machined surface as is illustrated.

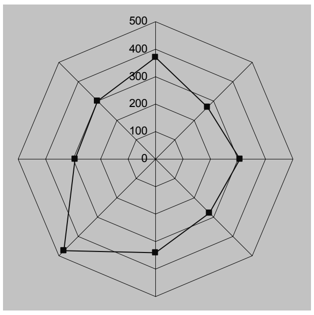

Fig. 17 Distribution of residual stress measured by Barkhausen noise, after turning, bainite 58 HRC

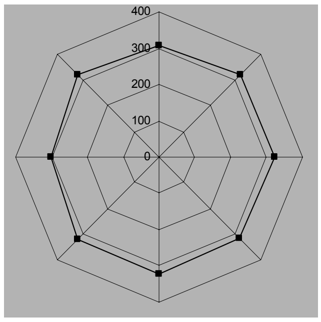

Fig. 18 Distribution of residual stress measured by Barkhausen noise after grinding, bainite 58 HRC

3 CONCLUSION

The results of residual stresses measurement show that each method for evaluation of residual stresses provides the different information. Application of Barkhausen noise provides information about distribution of stresses on the surface. On the other hand, application of conventional mechanical methods provides information about stresses in the different depths under the surface. These stresses are related to the cutting process, cutting conditions, structure of machined materials and heat treatment. Results of experiments illustrate advantages and disadvantages of the higher mentioned methods for evaluation of stress.

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