Testing of Shot Blasting Regimes and Metal Product Surface Hardening Parameters by Barkhausen Effect Method

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In modern engineering the most part of products and structures undergo high static and dynamic loads leading to the increasing of fatigue damages and their future failures in the usage.

The increasing of fatigue strength in the construction and repairing of metal products is achieved by the using of technological operations reducing to the plastic deformation in the metal surface layers. The surface plastic deformation (SPD) makes favourable distribution of the inner stresses along the cross-section of the product which presents the opening of microcracks and considerably increases the fatigue strength. The estimation of the surface layer parameters in metal products after SPD during their production and also in the usage is a very important problem. The solution of this problem can be found in the utilization of non-destructive testing means based on the method of Barkhausen's effect [I,2,3].

The method of Barkhausen's effect has long been recognized for the testing of structural, physical and mechanical properties of ferromagnetic materials [2]. The sense of this method is the remagnitizing of the products by the field of low frequency (0.I-I00 Hz) and the detection by the inductive transducer of magnitization jump changes which are called Barkhausen's jumps (BJ). The elctromotive force of the jumps is determined by reconstruction of ferromagnetic domain texture in its cyclic remagnetising. The dynamics of the texture is connected with the presence of microdefects, nonmagnetic inclusions, internal stresses and different kinds of structural discontinuities. It becomes a physical reason for the opportunity to use the method of Barkhausen's effect for the testing of SPD parameters, which causes the changes of microdeformation discontinities residual stresses and structural phase composition.

The device "AFS" was worked out for the research of the opportunity in using the method of Barkhausen's effect and also for the testing SPD parameters. This device detects different information EMF parameters of Barkhausen's jump currents and average meaning of rectifyable EMF voltage of Barkhausen's jumps during the remagnetizing period, current and average number of EMF outbursts of Barkhausen's jumps in the sepection level during the same period [I,3].

The device block diagram Fig.I includes: remagnetizing unit (RU), primary transducer (PT), measuring unit (MU). The remagnetising unit is used for the feeding of the primary transducer by the linear changing currents with the period T_p and forming of the strobe pulse with θ duration. Triangular form current generator of RU consists of intergrator I, Shmid's flip-flop 2, and power amplifier 3 embraced by the negative back connection in the current with the resistor R. Remagnetizing current frequency is regulated by the changing of the time in the integrator I . The formation circuit of the RU strobe pulse includes threshold element 4 and single-shot multivibrator 5, forming the strobe pulse. The stress changing V_o on the second input of the threshold element 4 makes possible to vary the strobe pulse temporal position t_j on the hysteresis loop of the testing product.

The MU operation principle is in the averaging current signal EMF characteristics from the primary transducer, reinforced by the band-width-duration amplifier 6, on the interval, which is determined by the strobe pulse of the multivibrator 5 . The choice of the measuring parameter is performed by means of the switch "S". In the first position the switch turns on the measuring channel of EMF outbursts of Barkhausen's jumps, consisting of threshold element 7 and analogue key 8 . The threshold element 7 transforms EMF of BJ excessing the C selection level (C is given by the V_c stress) into impulse sequence of equal value and the key 8 opens in the interval of strobe-pulse action of the multivibrator 5 . Changing tj temporary position of strobe-pulse the detection of the bending of current meanings of EMF outbursts of Barkhausen's jumps takes place during the remagnetizing period. In the second position of the switch the block of measuring EMF intensity of BJ turns on. In this block the signal detects, averages, transforms in the digital form and reflects on the indicator IO. During the remagnetizing period strob-pulse in the duration equals the half-cycle of remagnetasing in the realisation of the regime of measuring average EMF characteristics of BJ.

The possibility of wide range remagnetising measuring of testing product as in frequency also in current remagnetizing amplitude is the characteristic property of the device. In the combination with regulated C selection level this property enebles to use the device on the preliminary research and testing stages. The equipment of the device with the set of passing and strapping transducers promotes it.

There are two stages in using this device. Experimental researches are held on the first stage. The analyse of correlation relationships of the characteristics EMF of BJ in different regimes of remagnetizing and measuring with the product control parameters is the aim of these researches. The calibration diagram defining the scale of the device is built on the first stage. On the second stage the device readings are putting in correspondence with the meaning of the testing product parameters.

High strength steels of martensite structure hardened by shot blasting and diamond grinding are the object of the research. The main hardening characteristics are the following: the air pressure in the pistol - "P", the time hardening - "T", the shot blasting diameter "D".

The distributors in the remagnetizing period T_r of average EMF measuring of BJ e (tj) and current meaning of EMF outbursts of BJ in the C selection level in changing the factors of shot blasting are presented in the figures 2,3 . It is evident that

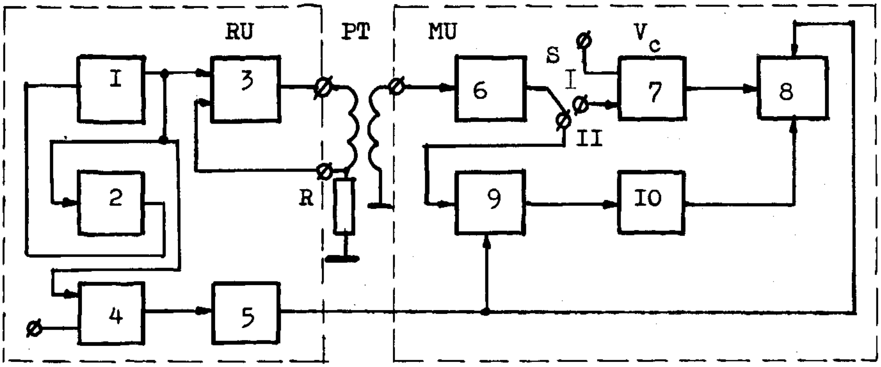

Figure I: "AFS"DEVICEBLOCK - DIAGRAM

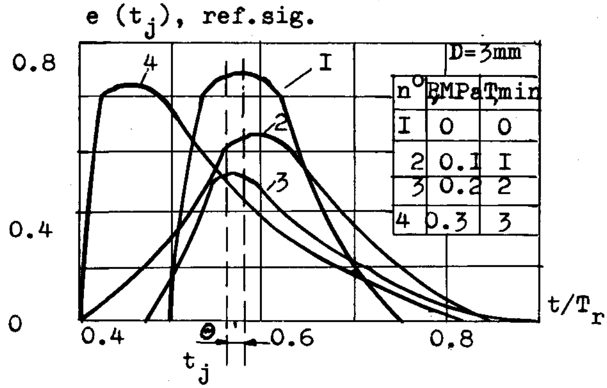

Figure 2: Distribution EMF of BJ $e(t_j)$ for different shot blasting regimes along the remagnatizing period

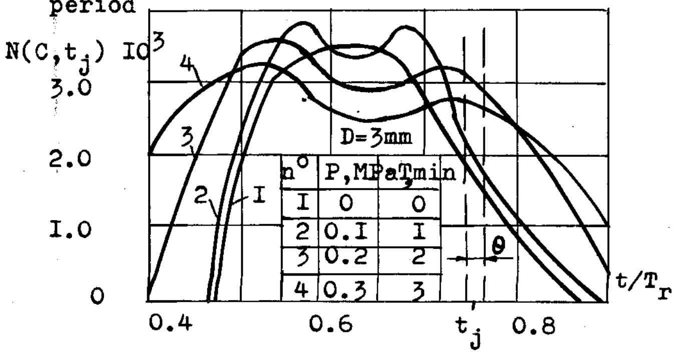

Figure 3: Distribution of EMF outbursts of BJ $N(C,t_j)$ for different shot blasting regimes along the remagnatizing period.

e(t) changes ambiguitily decreases in low hardening degrees and increases in high ones. It should be explained by the fact that at the beginning of hardening the primary influence over EMF of BJ increases the defects of crystal structure and the remained pressing stresses. With the enlarging of hardening degree and travelling inside the metal the maximum meaning of remained stresses, the influence of structural-phasal changes, connected with the milling of the initial structure, increases. The carbides, released in this process, concentrate in the surface layer, which leads to the tendecy of increasing the intendity EMF of BJ.

The above mentioned factors of deformation compete in their influence over EMF of BJ and in large deformations ambiguity creates in curve changes of the figure 2 . At the same time the number of EMF outbursts of BJ is determined by the deformation degree. The average number of signal outbursts increases in spite of the EMF intensity of BJ fall. It confirms the process of initial structure milling of the metals and joined with it the process of domain texture milling in large degrees of hardening [4].

The complex character of informative EMF parameters of BJ changes does not always allow to use average meanings during the remagnitizing period for the testing. The increasing of reliability of the testing can be achieved by using current EMF meanings of BJ $e(t_j)$ and the number of outbursts $N(C, t_j)$ during the selection level. So, on the curves of the Figures 2,3 can be distinguished the parts of dating t_j at which the monotonous dependence $e(t_j)$3 and $N(c,t_j)$ form the degree of hardening is observed.

Inner loading diagram analysis in SPD constructed by X-ray structural analysis method and measuring remained stresses with the help of diffractometer follows that the value of shot-blasting degree from high strength steels estimates by the maximum magnitude G max of remained stresses in the surface layer. The using of current meanings of informative parameters, measured on the hysteresis loop t_j allows to get the dependence with different slope and linearity. From the dependences in the Figure 4 it is evident that the curve 3 has greater sensitivity to G max, corresponding to the "limit" of realization EMF from BJ i.e. the gating section t_j, remoted from the coercitivity force meaning of the product material. At the same time the curve 2 has greater linearity.

The recoverability of inner loading diagram in the surface layer with the help of EMF parameters is of great interest.

The regression analysis of testing high strength steels allows to work out the dependence model of remained stresses G from the depth h of the surface layer and EMF parameters of BJ.

$$G = 185.9-(4.68-4.5\ 10^{-2}h + 3.5\ 10^{-2}\cdot N_{0.45}-4.6\ 10^{-2}N_{0.85})\cdot h - (12.7-0.12\ N_{0.45}+ 2.9\ 10^{-2}N_{0.85})\cdot N_{0.85}-6.16\ 10^{-2}\cdot N^2_{0.45}$$

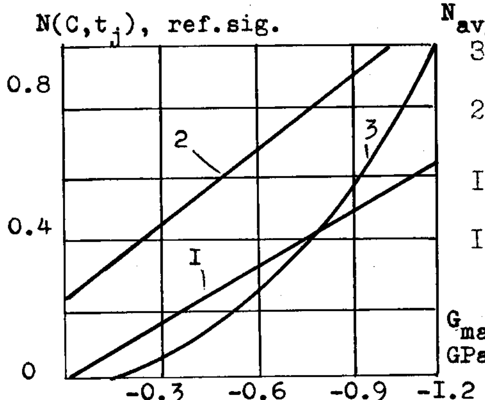

Figure 4: Dependence $N(C,t_j)$ from the maximum remained stresses G_{max}: I - t_j/T_r=0.45; 2-t_j/T_r=0.5; 3-t_g/T_r= 0.85

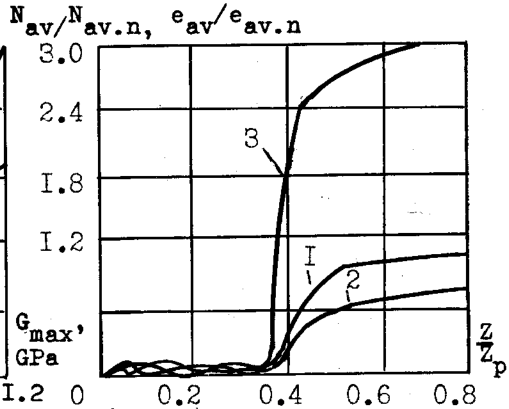

Figure 6: Dependence of EMF parameters of B from the cycling numbers : I - e_{av}; 2 - N_{av}, C = 0.5V; 3 - N_{av}; C= I,0V

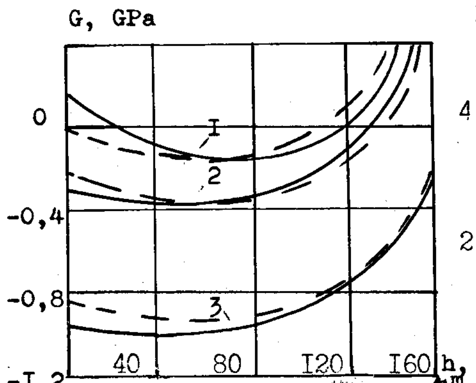

Figure 5: Dependence of remained stresses G from the depth h of the surface layer: I - P=0,IMPa, T=0,5min ; 2 - P= 0.I MPa,T=Imin; 3 - 0.3 MPa, T =I,5 min; D - 3 mm.

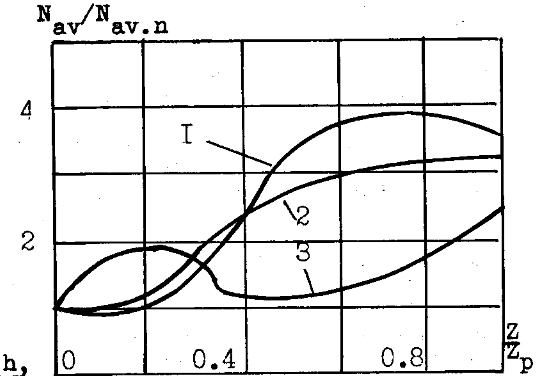

Figure 7 : Influence of SPD over the dependence N_{av}=F(Z) (N_{av_n} - N_{av} for unloaded piece) from the cycling numbers of loading : I - Z_p= I2000; 2 - Z_p= 32000; 3 - Z_p= 27000

To achieve the full adequacy of the model to the experimental readings the meanings of outbursts at the two sections of shot blasting $t_i/Tn = 0.35$ and $t_j/Tn = 0.85$ are taken as arguments. The diagrams of the results are given in the Figure 5, where the calculated curves based on the model are given by the continuity line, and the experimental curves are by the dotted line. The results of the regressive model can be used in the distribution of remained stresses in the depth. Though it demands a great set of statistic readings.

The determination of the fatigue damage degrees, appeared in the products under the action of cyclical changing stresses which are lower than the strength limit as a very important problem in the testing of structures from high strength steels. The decision of this problem is necessary in the changing and repairing of different parts by means of SPD.

The plastic deformation and the dislocation net appears in the metal structure in the cyclic loading. The high localization of the deformation leads to the concentration of stresses and to the formation of small cracks. The process of fatigue takes place in the dangerous cross-section of the product, embracing only surface layers. The interaction of residual and applied stresses leads to the extension of the fatigue damages on the surface and depth of the product. That's the reason of using the Barkhausen's Jumps for the strength properties of metal products [I].

The test results of the cylinder form pieces from the high strength steels are given in the Figure 6. The cylinder loadings were modeled by the rotational bending. The level of working loading is I GPa.

It is evident that the average changes of e_{av} and average number N_{av} of EMF outbursts of BJ from the cycles of loading L ($L = 5I \cdot IO^{-4}$ - the average durability of pieces) are analogue the monotonic increasing can be seen after the section of ambiguity. The ambiguity characteristics in the first stage of loading can be explained by the distribution of remained stresses in their interaction with applied stresses and structural defects with the increasing of pressing stresses in the surface layer of the products. The growth of the dislocation net and the formation of microcracks in the piece is the section of characteristic increase. The further stabilization of Barkhausen effect parameters is connected with the changes of microcracks into the macrocracks and with the changing of remagnatizing conditions.

The appearance of the main crack can be predicted because the readings of the device are greatly increased before its formation. The increasing of the selection level C helps to rise the sensitivity of the device.

The increasing of the fatigue strength of the high strength steel products is achieved by their hardening. The creation of the hardened layers in SPD decelerates the development of the dislocation net. The high level of the remained stresses after the SPD, their distribution and interaction with applied stresses explains the asymmetry of the loading cyclic and the movement of fatigue damages under the surface layer, ie. to the zone of low working stresses. Hardened layer in this case plays the role of the surface frame, which increases the fatigue strength of the product.

The research results of the SPD influence of high strength steel pieces over their fatigue characteristics are given in the Figure 7. The curve I corresponds to the unhardened piece, curve 2 - to the piece hardened by diamond grinding, curve 3 - to the piece, hardened shot blasting. The changes of the EMF parameters of BJ are preserved as for the unhardened and hardened pieces. The maximum meaning $N_{av}/N_{av.n.}$ makes to the sphere of large L that indicates the increasing of fatigue product strength after hardening by diamond grinding. The changing of loading curve 3 for the pieces, hardened by shot blasting, makes difficult to estimate the degree of fatigue damages due to the influence of plastic deformation over the EMF of BJ parameters. To get the unique dependences is necessary to use current EMF characteristics of BJ.

The obtained results are supposed to prove the perspective use of the Barkhausen's effect method for the non-destructive testing of surface hardening parameters and regimes of high strength steel products and forecasting of their properties.

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