STRESS MEASUREMENTS IN MATERIALS AND CONSTRUCTION

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ABSTRACT - The stress level estimation is an important problem in the field on NDT. The paper presents some results from application of ultrasonic and magnetic noise methods for stress assessment in the laboratory”Mechanics, Diagnostics and NDT” in the Institute of mechanics-Bulgarian Academy of Sciences. The paper reports on stated investigation in bolts, rolled carbon steels, assembling dies instruments and pressed joints as well some investigation of the pressing process of the powder metallurgical materials. The results are discussed about reliability and possibilities of its industrial application.

1.INTRODUCTION

The task of tenzometry is the measurement of stress and strains in solid media.
The stress estimation is an important task in the field of non-destructive testing. Many scientists devote an attention of ultrasonic and magnetic noise methods for stress assessments [1-10].
The paper presents some application of ultrasonic methods in bolts, rolled carbon steels, assembling dies instruments and pressed joints as well some investigation of the pressing process of the powder metallurgical materials.

2. DETERMINATION OF STRESSES IN MATERIALS

2.1. ACOUSTIC TENZOMETRY

Acoustic tenzometry is based on the phenomenon of acoustic elasticity, which consists in variation of elastic wave propagation velocity under influence of stresses. According Hooke law dependence between stress and strain has the following

(1) $\sigma = C_1\varepsilon + C_2\varepsilon^2$.

Coefficients of C_1 type are called as elastic constants or elasticity modules, while coefficients of C_1 type are called usually as Murnagan coefficients.
The relation between ultrasonic velocity C, σ and ε is recorded as follows:

(2) $\frac{\Delta C}{C_o} = \varepsilon \frac{C_2}{C_1} \approx \sigma \frac{C_2}{C_1}$

When ΔC is velocity variation, proportional to stress or strain in the tested object, C_o -

velocity when σ =0 and ε =0. The value of velocity variation $\frac{\Delta C}{C_o}$ is in order of 0.01 %.

In the field of plastic strains, velocity remains constant practically. For investigation it is possible to applied different type of waves – surface wave to measure the stresses on the surface layer, longitudinal and transversal waves to measure the stress in site the tested object.

2.1.1. DETERMINATION OF STRESSES IN BOLTS

The determination of ultrasonic stress in the work region of the bolts requires the use of data on the elastic properties of materials, size and shape of bolts, an estimate of the extension the size of the bolts in the process of tightening as well as the temperature control. Figure 1 shows the main dimensions of the bolt.

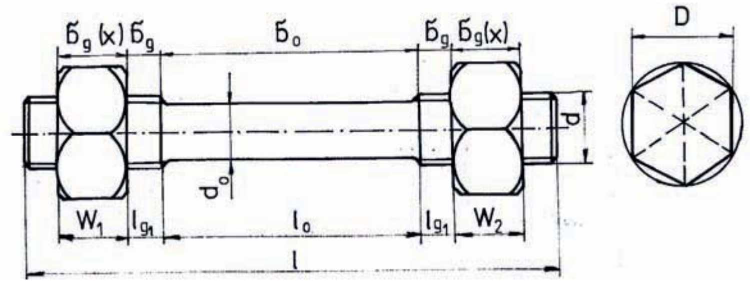

Figure 1.

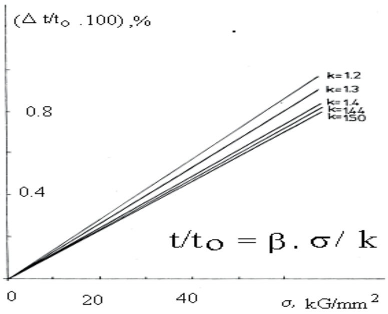

Figure 2.

The ultrasonic pulse-echo phase method is used for measuring the time of propagation of longitudinal waves, which propagate along the axis of the bolts.

The ultrasonic flaw devices type Bolt Mike SM 11, Sonic 136, USD 52 are used.

Mechanical stresses are determined through the dependence

$$(3) \quad \sigma = \frac{k}{\beta}\frac{\Delta t}{t_o} = \frac{k(t(\sigma \neq 0) - t(\sigma = 0)}{t(\sigma = 0)}$$

Where β is the acousto elastic coefficient of the material, k is the shape coefficient of the bolts, Δt is the change of the time of propagation of ultrasonic waves in materials with stress, t_o is the time of ultrasonic wave in unstressed materials ($\sigma = 0$).

The values of k are obtained by tensile testing of the representative bolts with the different length Lo. During the calibration are observed the conditions $l_{\sigma_1} = l_{\sigma_2} = 0$ and $W_1 = W_2$.

The time of propagation of ultrasonic wave and the elongation of the bolts are measured during the loading process.

The computer program is developed to calculate the stress in bolts on the base of the geometrical dimensions of bolts and the propagation time of ultrasonic waves.

Figure 2 shows the typical dependency of $\frac{\Delta t}{t_o}$ for different values of coefficient k.

In Neftochim company, Bulgaria have been tested more than 5000 bolts, mounted in flange connections of pipelines in the system for obtaining a high pressure polyethylene, made by special technology of steel 30NCD16. The acoustoelastic coefficient is β = 1.75.10^{-4} mm^2/kG.

The stress studies of bolts by low frequency vibration methods and tenzometry method show the high reliability and relevance of ultrasonic stress state determination of bolts.

2.1.2. STRESS STATE ESTIMATION IN SURFACE LAYERS IN FERROMAGNETIC MATERIALS

2.1.2.1. ULTRASONIC MEASUREMENT

Stress state estimation is based on the dependence of the relative change in the velocity of ultrasonic surface waves and mechanical stresses.

The theoretical base of the stress estimation is the dependency of the relative change of ultrasonic surface waves and applied mechanical stresses.

(4) $$\Delta C_R = \frac{\Delta C_R(\sigma) - \Delta C_R(\sigma = 0)}{\Delta C_R(\sigma = 0)} = \beta_R . \sigma$$

Where C_R is the velocity of Rayleigh surface wave in materials and β_R is an acoustic elastic coefficient, depending on type of materials and mechanical stresses [2-4].

Numerical and experimental results of the ultrasonic ultrasonic impulses that propagate in a material subjected to bending are presented in [5-7].

An experimental set-up for ultrasonic investigation consists of and computerized ultrasonic instrument allows measuring the time of ultrasonic impulse with accuracy up to 1 ns and 8 bits resolution at sampling rate of 100 MHz [1]. The procedure of the experiment is realized by consecutive loading of metal sheets and registration the ultrasonic wave signal. A triangular shaped cantilever with constant strength, shown in Fig. 3, is subjected to bending loads. The procedures is described in details in [6] . Surface Rayleigh ultrasonic waves are excited by angular transducers with variable angle for the frequencies 4 MHz and 2 MHz. The signal is emitted by transmitter and received by receiver. The signal processing technique is presented in details in [6,7].

The results in [6-7] show that the stress causes the essential change of the ultrasonic surface wave velocity in the main direction of loading.

Figure 3.

The signals of ultrasonic surface wave obtained for unstressed and stressed (strained) specimen are shown in the Fig.4a and 4b in the main and perpendicular loading directions.

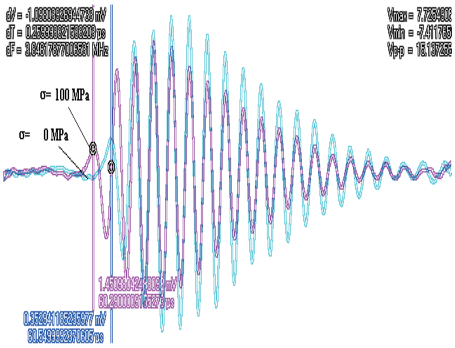

Figure 4a.

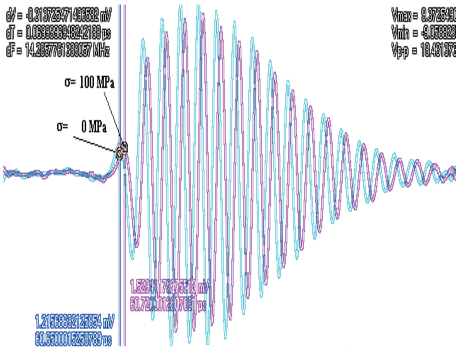

Figure 4b.

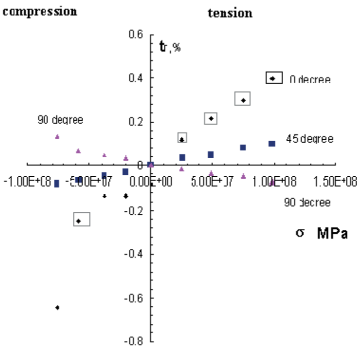

Figure 5.

Figure 6. MULTITEST MC 10

The relative changes of the transmit time of ultrasonic surface waves ($t_r = (t_o - t_s)/t_o$) are presented in fig.5 for the case of tensile and compression in material.

2.2. ALTERNATIVE METHODS FOR MEASURING THE STRESS IN SURFACE LAYERS

2.2.1. THEORETICAL BASE

In the last years some new magnetic methods based on the effect of Barkhausen are applied in the industry.
Mechanical stresses influence on the distribution and the domain wall's motion through the magnetoelastic interaction [8,9]. Compression stresses reduce the intensity of the Barkhausen noise while tension stresses increase it for materials with positive magnetostriction constants.

2.2.2. MAGNETONOISE METHOD. PROCEDURES.

The Barkhausen apparatus consists of device "MULTITEST MC10' - PC, contact magnetic-noise transducer and acoustic piezo-transducer. The informative non-destructive parameters (magnetic-noise voltage Um and magnetic-acoustic voltage Ua) are measured over specimens, saved in device memory and can be graphically presented. Software for data acquisition, treatment and assessment is developed in a MathLab environment [10] .The excitation frequency was set to 80 Hz. The magnetic Barkhausen noise was acquired using adjustable filters up to 100 kHz. The operation and calibration of the "MULTITEST-MC10" device are presented in [10]. The device MULTITEST MC10 is shown in Fig. 6 .
The calibration curves Um-F(σ) and Ua- F(σ) is shown in the figures 7a and 7b.

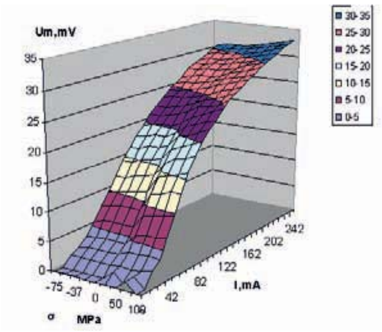

Figure 7a.

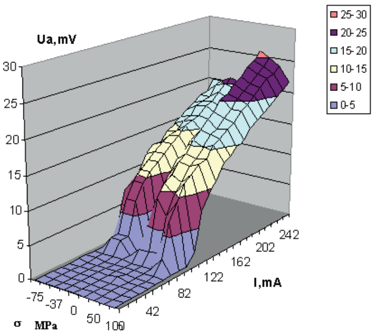

Figure 7b.

The results from calibration show a good possibility for monitoring of the mechanical loads.

3. ACOUSTIC MODEL OF PROPAGATION OF ELASTIC WAVES THROUGH A CONTACT LAYER UNDER PRESSURE

A contact layer is considered formed between the pressing parallel surfaces of two real bodies. The applied pressure is assumed to deform the bodies elastically. Because of the roughness of the contacting surfaces the transmission of the applied pressure through the layer is viewed as realized by numerous single micro contacts. Both elastic and plastic deformations are assumed to develop within the contacting microroughnesses of the layer.
An elastic wave passes through the layer in a normal to the latter direction. Due to the differences in the acoustic properties of the layer and contacting bodies a partial passage and reflection of the wave is observed which, provided the bodies in contact have the same acoustic characteristics obeys the relation [11]

(5) $$R^2 = 1 - D^2 = \frac{(m^2-1)^2}{4m^2 ctg(2\pi' \frac{\sigma\delta f}{C_1}) + (m^2+1)^2}$$

where the notations are used:

$m = \frac{Z_1}{Z_b}$, $Z_1 = \rho_1 C_1$, $Z_b = \rho_b C_b$, $Z_b = C_b(Z_1)$ - acoustic resistance of the body (the layer),

C_b (C_1) - wave propagation velocity in the body (the layer), ρ_b (ρ_1) – density of the body (the layer), δ – current layer thickness, R – amplitude reflection coefficient,
D – amplitude coefficient of transition, f – operating frequency.
The layer is considered as a porous medium under pressure consisting of a statistical aggregate of material particles. With account to known results on elastic waves propagation in porous media [12] the following relations are assumed to apply for some of the characteristics of the porous contact layer, namely

(6) $$C_1 = C_b/(1-ap), \qquad C_{10} = C_b/(1-ap_0)$$
$$\rho_1 = \rho_b/(1-p), \qquad \rho_{10} = \rho_b/(1-p_0)$$

where p is the current porosity of the layer and a is a constant. The index "o" refers to the initial unstressed state of the layer.

According to results presented in [12] the changes of the layer thickness δ follow the relation
(7) δ = δ0 (1 – F (σ)).
The function F (σ), σ being the current compressive stress is determined experimentally for a variety of properties of the media and surfaces in contact. Upon the assumption that the deformation process within the layer follows the mass conservation law, i.e. ρ1δ = ρl0δ0, the expression for the refection coefficient in the case of contact of bodies with the same characteristics takes the form

(8) $$R^2 = \frac{(A^2 - M^2)^2}{4A^2M^2 ctg^2(2\pi\,\delta_o fM/c_b) + (A^2+M^2)^2}$$

where A = 1 – p_0, B = 1 – F(σ), M = B(1 – a) + aA.

Fig.8 shows the results of computation of the values of α for the case of a contact between two real bodies with known characteristics. The agreement with the experimentally obtained data, the latters being presented by the points in 8 demonstrates the applicability of the acoustic model proposed here.

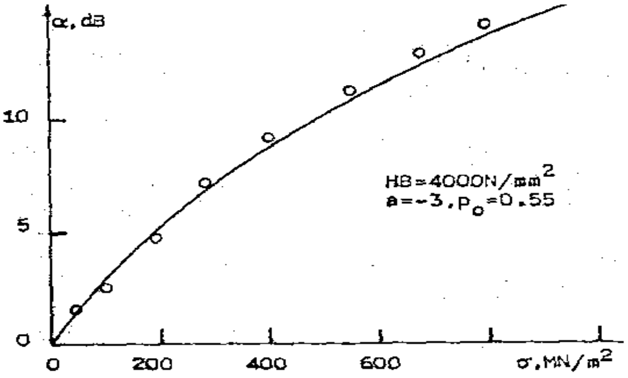

Figure 8.

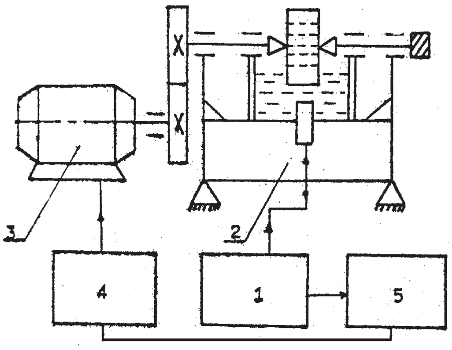

Figure 9.

3.1. APPLICATIONS OF THE ACOUSTIC MODEL. METHOD OF CONTACT STRESSES CONTROL IN ASSEMBLING DIES

A block-diagram of a device for automatic control of assembling dies is shown in fig. 9 where 1 is a ultrasonic defectoscope, 2 is a transducer, 4 is a device synchronizing the electric motor 3 and the circular recorder 5. The amplitude of the signal reflected from the bandage-matrix boundary or, in the case of a multi bandage instruments, from the bandage-bandage boundary is being recorded. The contact stresses are defined by making use of special experimentally constructed etalon curves or by means of the model described above.
Distributions of contact stresses acing inone- and two-bandage instruments are shown in fig. 10 and fig. 11 respectively.

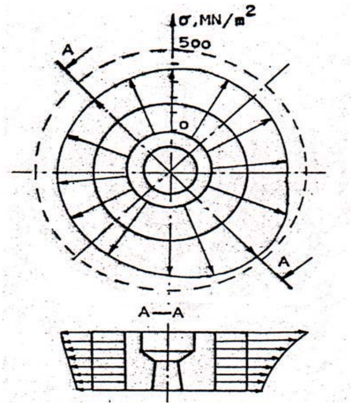

Figure 10.

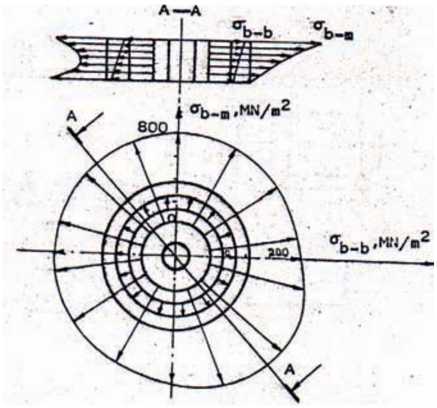

Figure 11.

3.3 METHOD OF INVESTIGATION OF PROCESSES OF PRESSING OF METAL POWDERS IN THE POWDER METALLURGY

A scheme of the experimental installation is shown in fig. 12 where 1,2 is the assembling die, 3-4 are dies designed for transmission of the pressing load over the powder 5 within the instrument, 6 is a ultrasonic transducer, 7 is a defectoscope.
The signal reflected from the matrix-pressed powder boundary is being controlled with account for the partial reflection and passage of the elastic wave at the contact layer on the matrix-bandage boundary. The density of the surface layer of the pressed specimen is determined by means of etalon curves constructed in advance.
Typical dependences of the density ρ^2 ($\rho^{10} = 7.8$ g/cm^2) along the height of a 20 mm high iron powder specimen during the pressing process are shown in fig.13. Curves 1,2,3 and 4 correspond to pressure stresses P = 8633, 17266, 25898 and 34532 N/cm^3. The data thus obtained show good agreement with the theoretical results and demonstrates the applicability of this method in the powder metallurgy.

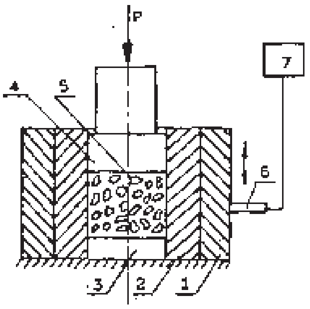

Figure 12.

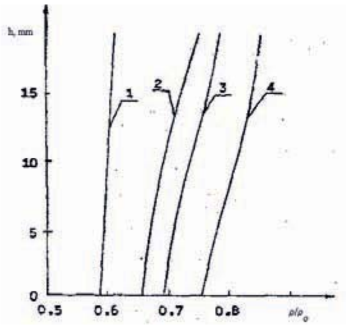

Figure 13.

4. APPLICATION OF STONLEY'S SURFACE WAVE FOR DETERMINATION OF CONTACT PRESSURE IN MECHANICAL CONSTRUCTIONS.

The contact pressure in the boundary between two elastic bodies is controlled successful by means of the longitudinal ultrasonic waves [14-17]. The coefficient of the ultrasonic wave generated perpendicular to formed contact layer between two elastic bodies in investigated. But the accuracy of the measurement of the coefficient of reflection, respectively, of contact pressure, require good made outside cylindrical surface of the press – fit joint and high precision mechanical worked.
For this purpose here are reported of the theoretical and experimental investigation of propagation of Stonley's surface wave between two elastic bodies in condition of mechanical normally loading and it application for evaluation of stress level in contact layer.
The experimental results in [14] show that Rayleigh's surface wave is transformed at the border between two mediums (fig. 14). It is proved, that in the boundary between two elastic mediums when existing contact, can propagate Stonley's surfaces wave. The velocity of Stonley's wave c in case of hard contact is determined from well-known dependence [11].

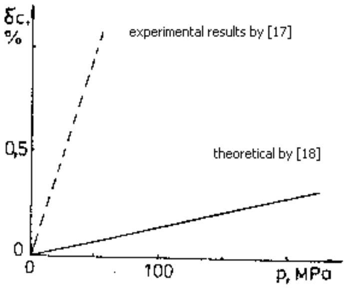

Figure 14a

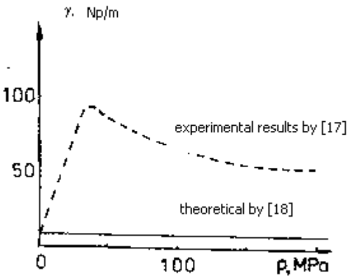

Figure 14b

Fig.14. Dependencies of acoustic characteristics δC (relative variation of the velocity) (a) and γ - attenuation (b) of surface wave on applied contact pressure **p**.

$$R_{(c)} = \left[\frac{C^2}{C_{t1}^2} - g\frac{C^2}{C_{t2}^2} - 2(1-g)\right]^2 - g\frac{C^4}{C_{t1}^2 C_{t2}^2}(r_1 s_2 + r_2 s_1) - \tag{9}$$

$$- r_1 s_1\left[g\frac{C^2}{C_{t2}^2} + 2(1-g)\right]^2 - \left[r_2 s_2\frac{C^2}{C_{t1}^2} - 2(1-g)\right]^2 + 4(1-g)^2 r_1 r_2 s_1 s_2 = 0$$

Where $g = \frac{G_2}{G_1}$, G_i –are shear modules for medium 1 (I = 1) and 2 (I = 2), $G_i = \rho_i C_t^2$ ρ_i C_{ti} C_{li} – mass density of medium ***I*** and velocity of shear and longitudinal waves in mediums 1 and 2, respectively, r_i s_i are determined from dependence $r_i = \sqrt{1 - C^2 / C_{li}{}^2}$ and $s_i = \sqrt{1 - C^2 / C_{ti}{}^2}$ The analysis of (9) presented that there had not been a real decision for mediums with identical acoustical characteristics. Here is proposed physical model, using for theoretical base for the exciting of Stonley's waves between two mediums with identical acoustic characteristics A design of the problem is presented on the fig. 15 a, where 1 and 2 are noted two contacted mediums, 3 – contact layer, formed from roughness of the mediums 1 and 2 from the acoustic medium between them, 4 and 5 – transducer type **MUWB-4-N** for generating and receiving of surfaces ultrasonic waves, propagating to the axis y , 6 – normal transducer, 7 – ultrasonic flaw device. In the layer 3 is created contact pressure **p.** The mediums 1 and 2 have identical acoustic characteristics mass density $\rho_1 = \rho_2$ and velocity $C_{yy1} = C_{yy2} = f_l(p)$ $C_{yz1} = C_{yz2} = f_t(p)$.