THE INFLUENSE OF INTERNAL STRESS AND STRUCTURAL STATE IN WIRES ON THE BASIC CHARACTERISTICS OF POHGAMMER'S WAVES

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Initial metal storage is undergoing with considerable plastic deformations due to special features of technological processes during manufacture. These deformations can have various forms, degrees and intensity. The material heats up at difficult deformations. Various types of dislocation substructures are formed; the phase structure of material is also changed. It influences at resistance of material to deformation and destruction.

Therefore, the estimation of wire deformation mode and it's structural condition, quality control, is an actual problem.

Methods and means of nondestructive testing are used for estimation of materials mechanical properties, structural and intense-deformed conditions. It is one of the main directions of nondestructive testing.

The universal method of such estimation does not exist among numerous methods of structural researching and tensometry(mechanical, acoustic, electric, magnetic, optical, neutron-diffractional and others methods). All of them has some advantages and some disadvantages at the same time.

The acoustic method [1] is based on registration of changing speed C (velocity of elastic waves) influence σ due to, is widely used for stress measurement. Relative change of speed $\Delta C/C$ from stress is:

$$\Delta C/C = \beta\sigma = [\beta_1(\lambda,\ \mu) + \beta_2(\lambda,\ \mu,\ l,\ m,\ n)]\sigma; \qquad (1)$$

where β - acoustoelastic factor, which depends on ultrasonic wave types and their directions in relation to a deforming force vector; $\beta_1(\lambda,\ \mu)$ - acoustoelastic factor, which is defined by constants of Llama $\lambda,\ \mu$ - of elasticity of the second order, this factor is caused by geometrical nonlinearity; $\beta_2(\lambda,\ \mu,\ l,\ m,\ n)$ - acoustoelastic factor depending both from constants of Llama, and from - *l, m, n* - Murnagan's constants of third degree elasticity, caused by physical nonlinearity basically.

The maximal absolute acoustoelastic factor value can be at coaxial stress when the direction of a wave and particles displacement coincides with deforming force direction. Speed decreases when stretching deformation takes place; speed increases when compression deformation of compression takes place [2].

Structural factors influence on volumetric (longitudinal and cross-section) wave speed and surface wave speed is mentioned in some research reports [1 - 3]. We have data about size of factors depending on a direction of the enclosed stress, influence of external factors on results acoustic tensometry, ways of use of the received rules for definition of mechanical pressure are available.

Well known [4], that numerous mode of Pohgammer's rod waves (symmetric, antisymmetric, torsion, of zero and greater degrees) can extend in a wire. Use of the specified types of waves in the field of a significant dispersion of speed and existence of several mode leads to distortion, easing of signals and to complexity of their interpretation. Therefore, acoustic method with application of Pohgammer's rod-wave in the field of the minimal dispersion of velocity (small multiplication ***fd***, ***f*** - frequency, ***d*** - diameter of object) to use at researches of the structural and is intense-deformed condition of a wire is expedient [5]. Phase and group velocity of a longitudinal wave of zero order C_{S0} aspire to the general limit at $fd \to 0$ - to rod-velocity of wave. They are defined by expression: $C_0 = \sqrt{E/\rho}$ (***E*** – Yung module, ***r*** - density of environment).

The increase of size of multiplication ***fd*** leads to minor alteration of speed in the field of the minimal dispersion of speed (the dispersion makes no more than 100 m/s on 1 mm·MHz). For example, speed of wave of a rod decreases up to 50 m/s approximately, for diameter of wire of 0,5 mm and on frequency of 1 MHz (***fd*** = 0,5 mm·MHz).

Normal waves in the wires decrease owing to damping in a material of object of the control only:

$$U = U_0 \exp(-\delta r); \tag{3}$$

where ***U*** - impulse of rod wave; ***U₀*** – initial impulse; δ - factor of damping; ***r*** - distance from the center of rod.

Damping of a wave minimally and in direct ratio to frequency in the field of the minimal dispersion. The factor of damping coefficient is equal about 0,15 m^{-1} at diameter of wire of 0,5 mm, at frequency of 1 MHz. It meet to distance $r_e \approx 6{,}7$ m, where the amplitude decreases in ***e*** time. Low damping of a rod-wave and absence of a divergence does frequent repeatedly sounding base, and, hence, to raise accuracy of a research of structure by acoustic method essentially, to provide sensitivity uniform to stress on section of the wire, in difference from volumetric waves.

In rod movement wave occurs symmetrically concerning an axis *z* of the rod. Bias on an axis ***x*** prevails at small multiplications ***fd*** (deformation of a stretching-compression). The amplitude of this bias is constant on section of the rod. Bias in a transversion direction on an axis z less than longitudinal displacement in 10 times approximately. It allows speaking about identical sensitivity on rod wave stress on section of the wire. Small damping and insignificant dispersion of speed do not deform impulses, which extend on object of the control, practically. It also allows to raise accuracy of measurements.

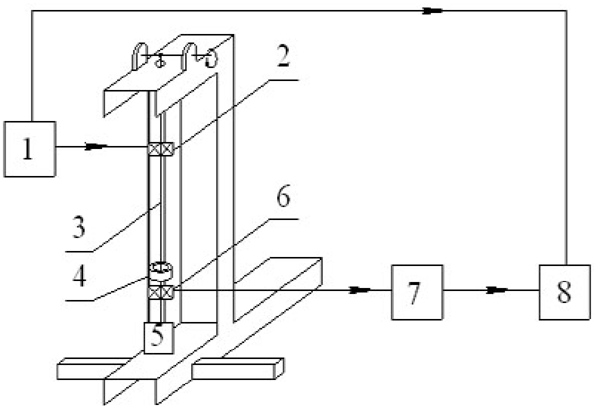


Fig.1. Experimental installation.

Experimental installation for researches of influence of structure and deformations of a wire on parameters of the rod-wave has been developed. The function chart and photo of experimental installation are presented on fig. 1. Short acoustic impulses of symmetric S_0-mode (*f* = 1MHz) are raising in the wire **5** by means a radiator **4** of contactless electromagnetic-acoustic (EMA). The radiator **4** is established on the top plate rigidly fixed on a frame of installation. The Contactless EMA-receiver **6** is located on the bottom plate fixed on a frame of installation. The Contactless EMA-receiver **6** registers impulses after distribution on the wire and transforms acoustic fluctuations to electric signals, which get on a digital oscillograph **8** through the amplifier **7**. Constant magnets **3** serve for adjustment of EMA-converters to the maximal value of the magnetostriction's constant λ_S. The generator of electric impulses **1,** which supply an EMA-radiator **4**, is synchronized with oscillograph's sweep **7**. The control device of loading **2** provides mechanical stress which is supervised by means of a dynamometer **9** with accuracy 0,98N. The EMA-radiator raises S_0-mode in the wire due to Joule's effect (linear magnetostriction), the EMA-receiver registers impulses of S_0-mode due to convertibility magnetostriction-effect.

Speed of a rod wave is defined by means of an echo-pulse method. The sounding base - distance between a radiator and the receiver - is equal 250 mm.

Relative change of speed of rod wave $\Delta C / C_0$ to take account of:

$$\frac{\Delta C}{C_0} = \frac{C - C_0}{C_0} = \frac{L:(t_0 + \Delta t) - L:t_0}{L:t_0} = -\frac{\Delta t}{t_0 + \Delta t}, \tag{4}$$

when $\Delta t = t - t_0$; t_0 и t - time of spreading of a ultrasonic impulse from an EMA-radiator to the EMA-receiver, at absence of loading and at loading.

High accuracy of measurement of speed of distribution of waves (about 0,5 km/s, or 0,01 %) is provided owing to high frequency of digitization of the digital oscillograph of 1 GHz. The casual error of measurements does not exceed 0,02 %.

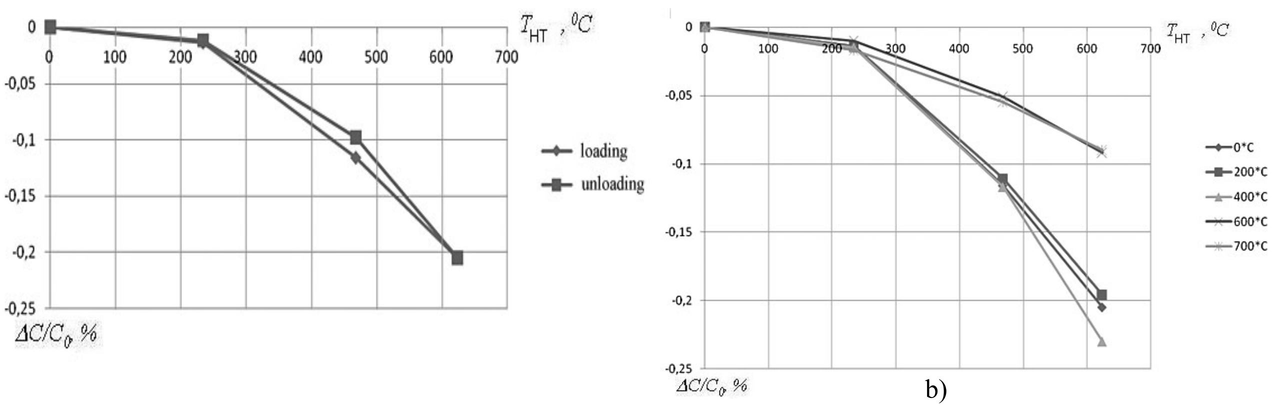
Experiment was being carried out with small longitudinal stretching 19,6 N, or s = 277 N/mm^2, for elimination of axial bends of a wire.

The cold-drawn wire with a high degree of hardening it has been chosen as samples for researches: wire from carbonaceous steel U9A in diameter of 0,5 mm and the wire from constructional spring steel 65G in diameter 0,3 mm and 0,4 mm. Strength of steel U9A is equal 2160 MPa, of steel 65G – 1130 MPa. Small diameter of wire's samples allows to carry out researches in the wide range of mechanical pressure at insignificant efforts.

It is necessary to consider features of distribution of residual stress in the wire at research of objects with the high degree hardening. Which are caused by manufacturing techniques of these objects, and which are defined by size private reduction, by geometry of wiredrawing, by counter-stress, by initial and final in diameters of a wire, and also by a number of other factors.

The results of influence of stretching mechanical stress influence on speed of a rod wave in samples of a wire of steel 65G are presented on fig. 2. The curves were normalized to the speed of a rod wave C_0 in non loaded condition (C_0 = 4971 m/s for G65 ∅0,3 mm; C_0 = 5001 m/s for G65 ∅0,4 mm; C_0 = 5121 m/s for U9A ∅0,5 mm). Reduction of speed of a rod wave with growth of mechanical stress is observed. The elastic hysteresis is absent in the field of investigated stress. The maximal speed change with loading up to 700 MPa is equal to 0,3 % for samples of steel 65G, and 0,6 % of U9A.

For the purpose of balancing and removal of residual stress, the samples had been subjected to a five-minute annealing on t=200°C, 400°C, 600°C and 700°C. The results of researches of annealing influence on change of a rod wave speed for 65G steel are presented on fig. 2. The curves were normalized to a rod wave speed C_0 after annealing in not loaded condition. It is seen that the character of dependences varies after annealing, comes nearer to linear, thus the acoustoelastic factor is increasing. Speeds of ultrasonic waves have increased at removal of high internal stress; this fact proves to be true in work [3].



b)

Fig.2. Relative change of rod wave velocity with loading (a) and temperature heat treatment (b) for samples of G65 0.4mm

Two basic factors - change of EMA-transformation factor and damping of a rod wave during loading - influence on amplitude of a rod wave impulse. The wire structure changes with the applying stretching loadings, as consequence, magnetostriction of material changes, efficiency of EMA-transformation grows with increasing of loadings (fig.2) and with removal of internal stress. The maximum increase of a signal (in 3-4 times) corresponds to the samples, which have passed full annealing.

Efficiency of EMA-transformation falls sharply after annealing. It can be explained by the fact that samples possess a strongly pronounced cross magnetic structure before annealing. Such a structure is connected with a special distribution of the stress arising in the process of wire-drawing, when the most part of size of the sample is compressed in the direction of the wire axis and magnetization vectors of domains is directed perpendicularly to this axis. The cross magnetic structure fails during annealing owing to removal of stress which has created it [6]. This fact is confirmed by the works of other authors [7].

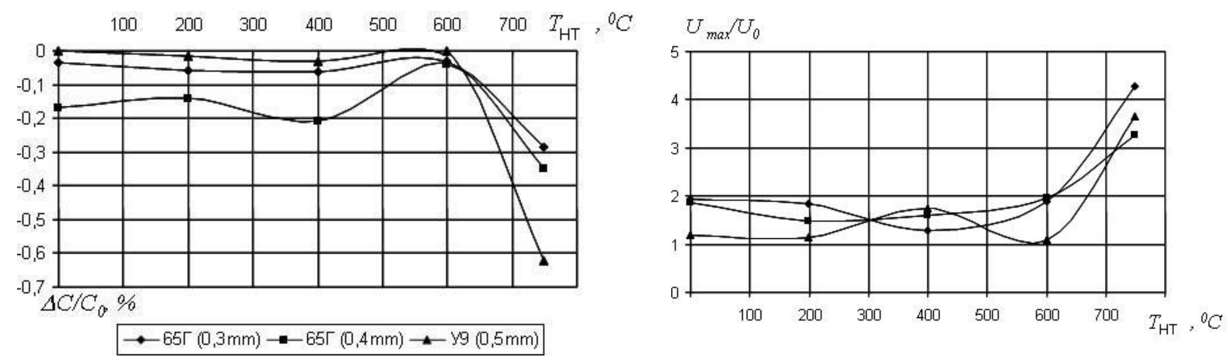
Experimental researches on influence of structure and the is stressed-deformed state of a wire on the basic laws of distribution of Pohgammer's rod wave for a wire from steel 65G (0,3 mm and 0,4 mm in diameter), U9A (0,5 mm in diameter) have been executed. The wire has been investigated in a condition of delivery, after heat treatment with various temperatures, after full heat treatment during increase and reduction of a stress (up to 1000 MPa) including.

Values of acoustoelastic factors of velocity β_{S_0} and of amplitude β_U have been calculated. These factors show effects of reduction of velocity and increase of amplitude of a rod wave at change of tensile stress. Influence of heat treatment on the basic characteristics of Pohgammer's rod waves is shown in figure № 3.

Table 1

Heat treatment, ^{0}C	0	200	400	600	750
Acoustoelastic factors β_{S_0}, TPa^{-1}					
65G (∅0,4 mm)	-270	-230	-230	-92	-234
U9A (∅0,5 mm)	-70	-100	-130	-130	-1200
Velocity of a rod-wave in not tensile stress state C_0, m/s					
65G (∅0,4 mm)	5001	5064	5177	5070	5146
U9A (∅0,5 mm)	5121	5148	5144	5102	5128
Acoustoelastic factors β_U, GPa^{-1}					
65G (∅0,4 mm)	2,99	2,36	2,57	3,13	5,25
U9A (∅0,5 mm)	1,09	1,03	1,59	0,99	3,31

It is expedient to use the Pohgammer's rod wave in the field of the minimal dispersion of speed at researches of the structural and is stressed-deformed states of a wire. Low damping of a rod wave and absence of a divergence allows sounding base to increase repeatedly, and, hence, to essentially raise accuracy of a structure research by acoustic method, to provide sensitivity uniform to pressure on section of a wire, in contrast to volumetric waves. The way of input and reception of acoustic waves by means of contactless electromagnetic-acoustic (EMA) method allows to discharge its influence, which defines accuracy and reproducibility of a structure research by acoustic method.



a) b)

Fig.4. Relative change of velocity (a) and relative growth of amplitude (b) of a rod-wave from temperature heat treatment for wire samples different steel and diameters

The researches of wires of various diameters made of steel 65G and U9A have shown presence of following unequivocal dependences: velocity of a rod wave decreases, if external tensile stress increases; velocity of a rod wave and acoustoelastic factor of velocity increases, if applied stress decreases; amplitude of a rod wave and acoustoelastic factor of amplitude increases, if external tensile stress increases, and if applied pressure decreases.

The effect of acoustoelastic is shown in steel U9A most definitely. The received values of acoustoelastic factors for rod essentially waves surpass known values for volumetric and surface waves.

Experimentally observable results are confirmed by works of other authors in the field of structure researches by magnetic and electromagnetic-acoustic transformations indirectly.

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