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Use Of Acoustoelasticity Effect With Application Of Laser Sources Of The Ultrasound For Control Of The Stress State Of Railbars Of The Continuous Welded Rails

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Abstract
This article discusses the results of the theoretical and experimental research on the development of methods for controlling the stress state of the welded railbars, on the basis of using the acoustoelasticity effect with laser ultrasound sources. The results of theoretical justification for a choice of this measuring method are given. The barrier places interfering for its wide application are defined, options of their overcoming are offered. In practical part of the article the laboratory findings received when using of the proposed technical solutions regarding the calculation of the welded railbars stress state with application of the acoustoelasticity effect are shown. Additionally, the control procedure of the welded railbars stress state with use of the devices based on application of this effect is offered.

Keywords: Continuous Welded Rails, Railbar, Acoustoelasticity Method, Laser And Ultrasonic Transducer.

Introduction
The continuous welded rails is currently the most advanced construction of the railway tracks. When operating the continuous welded rails gives a significant technical and economic effect due to a number of advantages over a jointed track, among which it is first of all worth mentioning the maintenance costs reduction of the joints, which make up to 80% of the operating expenses at the jointed tracks [1], [2],.

The continuous welded rails is a temperature-stressed structure [1]. Since the railbar fastening does not allow it to be lengthen or shorten when changing its temperature, there are longitudinal compression forces in the railbar (by increasing the temperature of the bar) or stretching (with temperature decreasing). These forces, called as temperature, cause stress that when reaching a certain critical value can initiate the release of the track (compression force) or railbar break (tensile force). Thermal stresses can be calculated based on the known values of Young's modulus, the linear coefficient of thermal expansion of the rail steel, known cross-sectional area of the rail, as well based on the known values of neutral (when longitudinal temperature forces are equal to zero) and the current temperature of the railbar [1]. In addition, with the increasing length of the railbar the nonuniformity of aggregate longitudinal stresses along the railbar length will increase. This can be caused by uneven fixing when laying, by the unevenness of the properties of the surface and geometry of the ballast section, temperature difference of short railbars fixing, welded in a long one, as well as the repair work in some areas of the bar. The distribution of these factors along the length of the railbar and in time has a random character.

Thus, the need to measure the stress on the actual state and the detection of areas with a critical level of stress in the railbars is an important practical problem, the solution of which will ensure the safety of the train services during operation of the continuous welded rails of the temperature-stress type.

Now for the determination of the actual stress in the railbars of the continuous welded rails the control method of the actual temperature of fixing based on the analysis of the motions of a bar measured relatively to "ground" sleepers is standardly approved [2]. However, the need for manual measurements leads to errors related to the human factor, the value of which can reach a hundred per cent, which significantly reduces the accuracy control of the actual stress of the railbars state. Eventually these errors affected the train safety control and make the task of developing other ways of measuring the stress in the railbars is relevant.

One of the possible directions in solving the problem is to develop portable and mobile devices, the principle of which is based on the technology of non-destructive testing of mechanical stresses in the metal structures using acoustoelasticity effect (see, for example: [3], [4], [5], [6], [7], [8], [9]. This effect is a linear relationship between the stresses and the relative change in velocity of ultrasonic waves compared to its original stress-free state. Currently, this method is successfully applied to the determination of the stress state of thin-walled pipes and metal constructions [7], [9]. However, so far there has not been a detailed study of the applicability of this method for the measurement of the stress state of the railbars.

Procedure

i. Theoretical provisions of the procedure.

Dependence of velocity of the ultrasonic waves in the deformed material from the size of the mechanical stress which caused this deformation is called as an acoustoelasticity effect. If in the initial undeformed solid acoustic (elastic) wave is distributed, then local deformation of the body arises in the field of this wave. The stresses caused by this deformation, in the linear approximation are described by Hooke's law:

$$\sigma_{ij} = M_{ijkl}\varepsilon_{kl}, \tag{1}$$

where $\varepsilon_{kl} = \frac{1}{2}\left(\frac{\partial u_k}{\partial x_l} + \frac{\partial u_l}{\partial x_k}\right)$ is the deformation tensor, $u = \{u_1, u_2, u_3\}$ is vector displacement of particles of the body in the field of the wave relative to their equilibrium state, σ_{ij} is arising stress tensor, M_{ijkl} is linear tensor of the elastic modulus of the second order – the so-called stiffness matrix determined by the material properties. From here onwards all indices have the values of 1, 2, 3.

The force components arising due to the stress tensor components σ_{ij} and acting in the direction of x_i on a unit of volume is equal $f_i = \partial\sigma_{ij}/\partial x_j$, coordinate $\{x_i\}$ correspond to points in the initial undeformed state. Without taking into account external forces like gravity the equation of motion of a single volume of the body along the axis x_i is written as:

$$\rho\frac{\partial^2 u_i}{\partial t^2} = \frac{\partial\sigma_{ij}}{\partial x_j}, \tag{2}$$

where ρ is the density of the deformed body. Taking into account Hooke's law (1) equation of the movement (2) can be presented in the form of:

$$\rho\frac{\partial^2 u_i}{\partial t^2} = M_{ijkl}\frac{\partial^2 u_l}{\partial x_j \partial x_k}. \tag{3}$$

Solution of this equation will be for a flat, acoustic wave propagating along a direction specified by a single wave vector of $k = \{d_1, d_2, d_3\}$ (d_i are directional cosines), polarization vector of this wave $p = \{p_1, p_2, p_3\}$. Particle displacement components in this wave is described by

$$u_i = p_i F\left(t - \frac{(kx)}{c}\right), \tag{4}$$

where F(t) is a linear function of the running time $(t-(kx)/c)$, c is a wave phase velocity. Substituting the expression (4) in the equation of motion (3), we get:

and by entering the second rank tensor $G_{il} = M_{ijkl}d_j d_k$, we obtain so-called Christoffel equation [10]:

$$G_{jl}p_l = \rho c^2 p_i. \tag{6}$$

Equation (6) indicates that the polarization vector p is an eigenvector of tensor G_{il} with its own value ρc^2. Thus, to determine the velocity and polarization of the plane waves which can propagate in this material with the stiffness matrix M_{ijkl} along the direction defined by a unit vector k, it is necessary to find the roots of the characteristic equation

$$\left|G_{il} - \rho c^2\delta_{il}\right| = 0. \tag{7}$$

Because the stiffness matrix M_{ijkl} is symmetric, then the tensor G_{il} will be also symmetric and its own values are valid values, and the eigenvectors are orthogonal. Therefore, generally, in anisotropic solid body in the direction of the vector k three plane waves with different speeds can propagate, the polarization vectors of which are mutually orthogonal.

If however a solid body is initially in a state of stress, then in the description of propagation of the elastic waves it is necessary to consider a non-zero starting offset of the material particles, which caused the already existing static deformation. Therefore, the equation (2) and (3) should be written in the Lagrangian coordinates $\{X_i\}$ for points of the deformed solid body. If the amplitude of elastic waves propagating is considered small, the equation (5) is converted to a generalized equation of Christoffel, which within the framework of the theory of finite deformation of the elastic body is usually written in the form [11], [12]:

$$\left[\overline{M}_{ijkl}d_i d_l + (\sigma'_{il}d_i d_l - \rho c^2)\delta_{jk}\right]p_k = 0, \tag{8}$$

where

$$\overline{M}_{ijkl} = \frac{\rho}{\rho_0}\left(M_{mnpq} + N_{mnpqrs}E_{rs}\right)\frac{\partial X_i}{\partial x_m}\frac{\partial X_j}{\partial x_n}\frac{\partial X_k}{\partial x_p}\frac{\partial X_l}{\partial x_q}, \tag{9}$$

ρ_o, ρ is density of the undeformed and subject to initial static deformation of a solid body, σ'_{il} is tensor of the initial static stresses, M_{mnpq} is previously entered linear tensor of the elastic modulus of the second order, N_{mnpqrs} is nonlinear tensor of elastic moduli of the third order, $E_{rs} = S_{rsij}\sigma'_{ij}$ –

tensor of the linear static deformations, S_{rsij} is compliance tensor. In the expression (9) taken into account as the physical transformation of the elasticity modules due to the non-linearity and geometrical – by coordinates transformation.
Generally it isn't possible to find the analytical solution of the equation (8), however if media is isotropic in the allocated directions in which tension works and acoustic waves extend, the analytical decision exists. In particular, for longitudinal ultrasonic wave propagating with the velocity c_{X1} in the direction of X_1 the eigenvalue of Christoffel generalized equation is obtained from the expression:

$$\rho c_{X_1}^2 = (\lambda + 2\mu) + A\sigma_{11} + B(\sigma_{22} + \sigma_{33}) . \qquad (10)$$

The stress component σ_{11}, σ_{22}, σ_{33} determine the value of the stress vectors acting in X_1, X_2, X_3 directions respectively. In the expression (10) coefficients λ and μ are constants of Lame coefficient, A and B coefficients are non-linear elastic modules of the third order [11], [13]. Lame constants define the velocity of the longitudinal acoustic wave in the stress-free material – Christoffel equation eigenvalue in the absence of the initial static stresses:

$$\rho c_o^2 = (\lambda + 2\mu) . \quad (11)$$

The relative velocity variation of the acoustic waves, caused by the presence of static stress in the material, is very little. Therefore

$$\frac{c_{X1}^2 - c_o^2}{c_o^2} = \frac{(c_{X_1} - c_o)(c_{X_1} + c_o)}{c_o^2} \approx \frac{2\,(c_{X_1} - c_o)}{c_o} . \qquad (12)$$

Thus, from the expression (10) to (12) it follows that if there is only unaxial stress of stretching or compression in the material ($\sigma_{11} \neq 0$, $\sigma_{22}=\sigma_{33}=0$) between the value $\sigma_{11}$and the change in velocity of longitudinal ultrasonic wave relative to its values there is a linear relationship for the material in the stress-free state:

$$\sigma_{11} = A_1 \frac{c_{X_1} - c_o}{c_o} , \qquad (13)$$

where the factor of proportionality $A_1 = 2(\lambda + 2\mu)/A$ is defined as a linear and non-linear modules of elasticity of the material. From the expression (13) that, for determining the uniaxial stress it is necessary to measure the change in velocity of longitudinal ultrasonic wave relative to its value in the stress-free material. Exactly this linear relationship will be used in the development of methods of measuring temperature of tensile and compressive stresses in the rails.

ii. Requirements necessary for the implementation of the methodology

It should be noted that to get the absolute value of the stress $\sigma_{11}$the calibration of the method is required. Calibration is the measurement of the relative change in velocity of longitudinal ultrasonic wave in samples with a known load values (see, for example, [6], which allows determining the proportionality constant A_1 in the expression (13).

To ensure high accuracy of ultrasonic wave velocity during the diagnosis of non-uniform distribution of unaxial stress in rails it has been suggested to use the laser thermo-optical excitation ultrasound of so-called pulsed optico-acoustic effect [14].
Schematically, the principle of the laser excitation of ultrasonic pulses is depicted in Figure 1. The laser light with a characteristic pulse width τ_L and r_o radius of the beam falls from a transparent medium along normal to the surface of the absorbing medium. The optical absorption constant in this medium is equal to α, time dependence of the intensity of the absorbed laser pulse is described by $I_o f(t)$ function. Absorbing medium may be the researched object, and specially selected strongly absorbing medium with known optical and thermophysical characteristics of laser source of ultrasound or optical-acoustic source. If a strong absorption of light, i.e. when performing a ratio of $\alpha r_o >> 1$ the one-dimensional geometry of excitement of an impulse of longitudinal ultrasonic waves takes place.
In Figure 1 axis Z is directed towards the absorbing medium, the plane z = 0 corresponds to the boundary of absorbing and transparent medium, $\tau = t - z/c_a$ and $\tau_{tr} = t + z/c_{tr}$ are time traveling at velocity of corresponding waves, and coordinate systems, c_a and c_{tr} are velocity of longitudinal acoustic waves in absorbing and transparent medium, respectively.

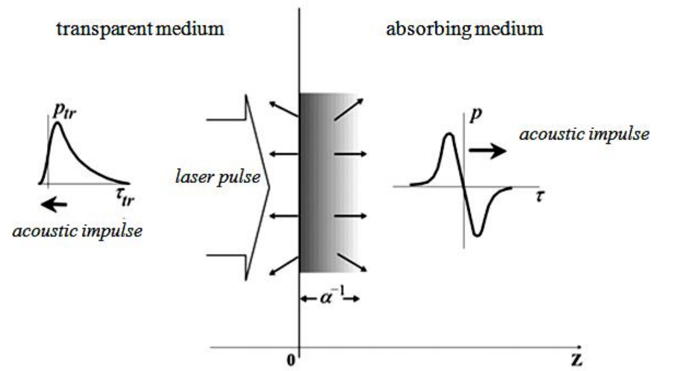


Fig. 1. Principle of the laser thermo-optical excitation of the ultrasound

The arrows conditionally show direction of displacement of particles of the absorbing medium when there is thermal expansion. The shaded area is the area of elevated temperature By absorbing of the laser pulse there occurs inhomogeneous non-stationary heating of the near-surface layer of the medium, the thickness of this layer is about α^{-1} . If the duration of the laser pulse the length heat of diffusion in the medium $\sqrt{\chi \tau_L}$ (χ is temperature conductivity of the medium) does not exceed the depth of penetration of light in the medium: $\alpha^2 \chi \tau_L \leq 1$ (that obviously is performed when τ_L in tens of nanoseconds and of the absorbing medium –

dielectric with α> 1 cm[-1]), tthen the diffusion of heat does not affect the distribution of temperature in the medium and by the termination time of the laser pulse the heat absorption area is [14]:

$$T' = \left(\alpha E_0 / \rho_0 C_p\right) \exp(-\alpha z), \qquad (14)$$

where $E_0 = I_0 \tau_L$ is the surface density of absorbed energy of the laser pulse, C_p is specific heat of the medium, ρ_0 is the density of the absorbing medium in non-perturbed state. Temperature field (14) causes the mechanical stresses in the near-surface layer of the medium, the absolute value of which is described by the expression

$$\sigma = c_a^2 \rho' + c_a^2 \rho_0 \beta^* T', \qquad (15)$$

where ρ' is the density increment, $\beta^* = \beta(1 - 4c_s^2/c_a^2)$ is density, effective thermal expansion coefficient of the absorbing medium, β is volumetric thermal expansion coefficient, c_s is shear velocity of the acoustic waves in the medium. If the duration of the laser pulse is small enough, then the heat can be considered as almost instantaneous. This means that the stress does not have time to relax over the duration of the laser pulse, i.e. transit time of the ultrasonic waves on the heat is $t_a = (\alpha c_a)^{-1} >> \tau_L$ or

$$\alpha c_a \tau_L << 1. \qquad (16)$$

In this case, by the termination time of the laser pulse action the medium density will not change ($\rho' = 0$) and the mechanical stresses will repeat the temperature distribution:

$$\sigma = \frac{c_a^2 \beta^*}{C_p} \alpha E_0 \exp(-\alpha z), \; z > 0. \qquad (17)$$

These mechanical stresses are shared equally between the pressure wave traveling deep into the absorbing medium and the wave, propagating to the boundary. As a result, longitudinal ultrasonic wave pulses $p_{tr}(\tau_{tr})$ and $p(\tau)$ accordingly (Figure 1) start to propagate both into the transparent and absorbing medium. If the receiver of the ultrasonic signals is located by on the part of the absorbing medium, such a registration scheme is called a direct one. If it is recorded an ultrasonic pulse propagating into a transparent medium, such a registration scheme is called an indirect one. Profiles of the ultrasonic signals, detectable with indirect and direct registration, are expressed respectively [15]:

$$p_{tr}(\tau_{tr}) = T \frac{c_a^2 \beta^*}{2C_p} \alpha E_0 \exp(-\alpha c_a \tau_{tr}) \, \theta(\tau_{tr}), \qquad (18)$$

$$p(\tau) = \frac{c_a^2 \beta^*}{2C_p} \alpha E_0 \left[\exp(\alpha c_a \tau)\theta(-\tau) + R \exp(-\alpha c_a \tau)\theta(\tau)\right], \qquad (19)$$

where $\theta(\tau)$ is Heaviside step function. The coefficients of reflection R and passage T of the ultrasonic waves across the boundary of the absorbing and transparent medium are determined by the ratio of $N = Z_a / Z_{tr}$ acoustic impedances of these medium:

$$R = \frac{Z_{tr} - Z_a}{Z_{tr} + Z_a} = \frac{1 - N}{1 + N}, \qquad (20)$$

$$T = \frac{2 Z_{tr}}{Z_{tr} + Z_a} = \frac{2}{1 + N}, \qquad (21)$$

where $Z_a = \rho_o c_a$, $Z_{tr} = \rho_{otr} c_{tr}$, ρ_{0tr} are density of the unperturbed transparent medium. Expressions for temporary profiles of the ultrasound signals (18) and (19) are obtained for the dependence of the envelope of the intensity of the laser pulse, taken in the form of $I_o f(t) = I_o \tau_L \, \delta(t) = E_o \delta(t)$, where δ (t) is the Dirac Delta function, because the heat of the absorbing medium was considered to be almost instantaneous.

Findings

i. Results of mathematical calculations.

The calculated profile of ultrasonic impulse of longitudinal acoustic waves – the optico-acoustic (OA) signal excited at the absorption of very short laser impulse in dielectric ($\alpha c_a \tau_L << 1$) is shown in Figure 2. It consists of sections of the exponent, which is determined by the optical absorption constant.α OA signal propagating in the transparent medium has only the compression phase ($T > 0$), OA signal propagating in the absorbing medium consists of compression phase and the next phase of compression (if N < 1, R > 0) or depression (if N is 1, R < > 0).

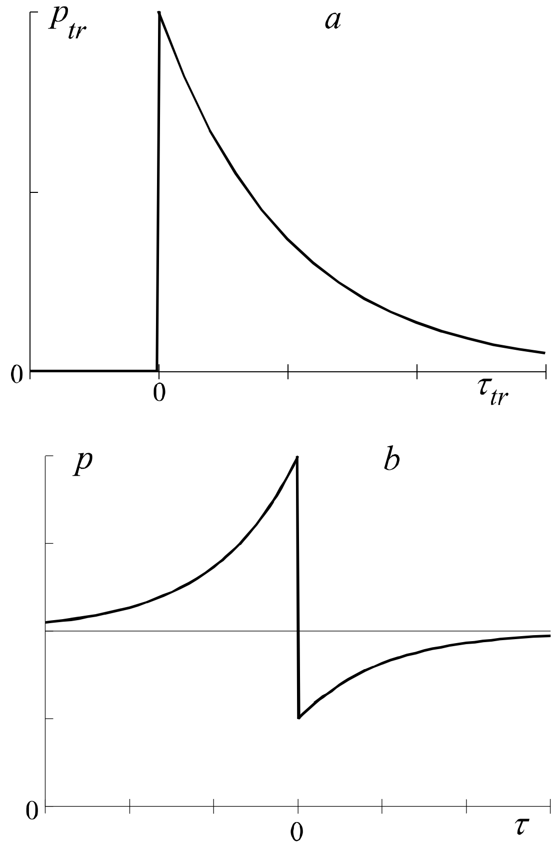
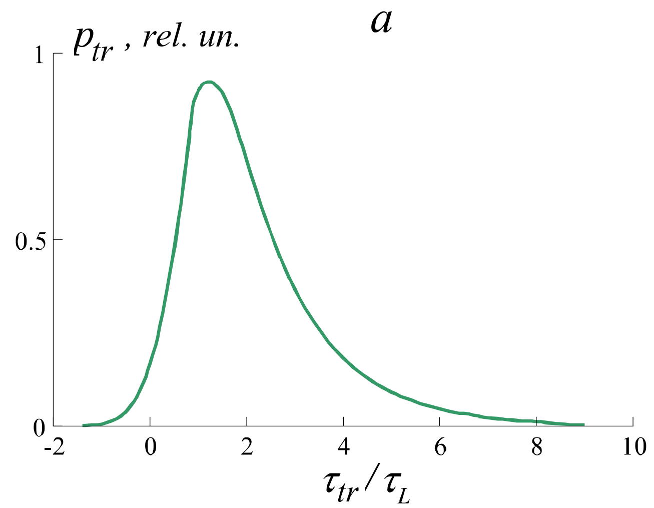


Fig. 2. Theoretically calculated temporary profiles of the optical and acoustic signals originating at instant laser pulse heating: (a) indirect signal registration, (b) direct signal registration at N > 1

When small, but finite values $\alpha c_a \tau_L$ (really is $\alpha c_a \tau_L \le 0.3$), finality of the laser pulse width causes that the front of OA signal at the indirect registration is defined by the integral from the front of the laser pulse. Figure 3A shows the theoretically calculated of the temporal profile of OA for temporal shape of Gaussian of the laser pulse intensity $f(t) = \exp\left[-(t/\tau_L)^2\right]$ in case of the indirect registration. In the case of the direct registration with a sound-hard boundary of the absorbing medium ($Z_a << Z_{tr}$, $N \approx 0$) the finality of the laser pulse width is evident in the smooth of the top of OA signal (Figure 3B, curve 1), with an acoustically free border ($Z_a >> Z_{tr}$, $N >> 1$) the duration of the transition between the stages of compression and depression has order of τ_L (Figure 3b, curve 2).



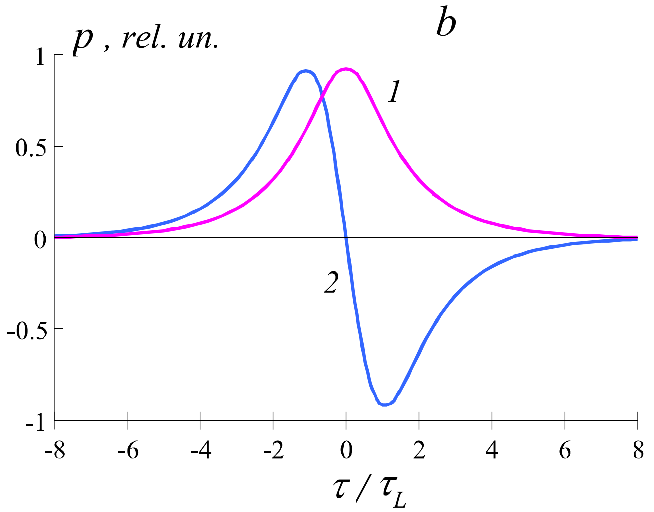


Fig. 3. Profiles of the optico-acoustic signals excited by a Gaussian laser impulse with the characteristic duration of τ_L: (a) indirect signal registration, (b) direct signal registration (1 – sound-hard boundary, 2 – acoustically free boundary of the absorbing medium)

Thus, optimum selection of parameters of pulse laser radiation and properties of the absorbing medium for receiving OA of signals with the set of amplitude and spectral characteristics is possible in each specific objective of nondestructive ultrasonic diagnostics. As can be seen, pulsed optico-acoustic effect allows obtaining powerful short ultrasonic signals, the application of which is to improve the accuracy of time-of-flight measurement in ultrasonic diagnosis systems of the stressed state of materials seems very promising.

ii. The results of the laboratory and experimental research.

A device model was manufactured for preliminary experiments on studying of features of distribution of impulses of head ultrasonic waves under a rail head surface in the directions up and down of a rail.

The laser and ultrasonic converter was used In the device model for diagnostics of a tension of rail bars similar to the one described in work [16]. Principle of operation of this converter is schematically represented in Figure 4.

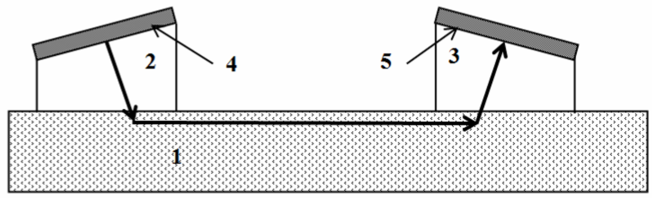


Fig. 4. The principle of operation of the laser-ultrasonic transducer

To conduct time-of-flight measurements of the velocity of the head acoustic waves propagating along the rail, the inverter is located on the smooth surface of the rail head 1. The laser source of ultrasonic probing pulses 2 and broadband piezoelectric receiver 3 structurally are combined in a single converter body. The laser impulse is absorbed in the plate from special plastic 4 which is in rigid acoustic contact with the prism and acoustic line of the ultrasonic source. To register this pulse is used a piezoelectric receiver through the piezo polymer film 5 attached to the prism and acoustic line of the receiver, also made of plexiglas.

The velocity of the head ultrasonic wave, which is also applicable under the head surface rail, is calculated by the formula:

$$T = \frac{2Z_{tr}}{Z_{tr}+Z_a} = \frac{2}{1+N}, \quad (22)$$

where τ_1 is the time interval between the moment of registration the pulse of the head waves of piezo-receiver and the moment of the radiation of the laser pulse, τ_2 and τ_3 is the pulse ultrasonic flight times in the prisms-acoustic lines of the laser receiver and piezoelectric receiver respectively, L is gauge length, i.e. the distance between the point of entrance into the rail and exit point of the rail of the pulse of the head waves. Thus, the only measured size at diagnostics of the rails by means of the offered laser and ultrasonic converter is the time interval of τ_1 (see expression (22)). Accordingly, only the error in determining the value will affect the accuracy of the determination of the velocity of ultrasound in the rail. Estimates show that in order to ensure the resolution of laser-ultrasonic stress measurement method in rails at the level of 7-8 MPa the accuracy measurement τ_1 based on the interval of 30 mm should be at the level of 1-2 ns.

Choice as a sounding of ultrasonic waves due to the fact that, as stated in the works [17], [18], this type of waves are most sensitive to temperature stresses in the rails. In addition, the head waves are practically not sensitive to roughness and curvature of the surface of the object under control. When distributing the head waves along the rail it will be provided the maximum sensitivity of the system to the presence of stress-type stretching or compression, since the effect of these stresses and the direction of sounding waves will be the same. Experiments carried out in the work [16], have shown that indeed the head waves are quite sensitive to the presence of a unaxial stresses in the rails.

Researches in this work were conducted with use of the model of the device on specially made rail samples. For measuring speed in two mutually perpendicular directions are one and the same converter was consistently in the appropriate directions on the running surface of the rail.

As the filter frequency used for mathematical processing of the signals super Gaussian filter of the following form was selected:

$$S(f) = \exp\left[-(f/f_{\max})^4\right]\cdot\left\{1-\exp\left[-(f/f_{\min})^4\right]\right\}. \qquad (23)$$

The parameter $f_{\max}$ specifies the upper edge of the filter pass band (on level 1/e) and the parameter $f_{\min}$ – lower edge of the filter pass band. In the conducted research, the values of these parameters were $f_{\max}$ = 9 MHz, $f_{\min}$ = 0.2 MHz, corresponding to a frequency filter shown in Figure 5.

Super Gaussian frequency filter was chosen for the following reasons – sharp fall-off the "wings" of the filter and no amount of frequency dispersion (dependence of the phase of the signals upon frequency). Because of the latter fact, the position of the acoustic pulses on the time scale do not in general and their maximums in particular does not change during the filtration.

Figure 6a shows the temporal profiles of the pulses of the ultrasound waves that are registered during the propagating in the rail head toward the up and down the rail, after the frequency filtering in Figure 6b it separately shown the maxima of those impulses on a larger scale. The position of the maxima of the signals τ_1 is determined with accuracy not worse than ± 2 ns, the sum of the times $\tau_2+\tau_3$ =5.058 µs and base length dimension L = 29.797 mm are calibrated values used for laser-ultrasonic converter (see expression (22)). At distribution of an impulse along a rail the value τ_1 makes (10.130±0.002) µs, at distribution across a rail – $\tau_{1_{along}}$ = (10.202±0.002) µs. According to (22), velocity of the head ultrasonic waves at distribution along a rail is equal to $c_{h_{along}}$ = 5875±2 of m/s, at distribution across a rail $c_{h_{across}}$ = 5793±2 of m/s.

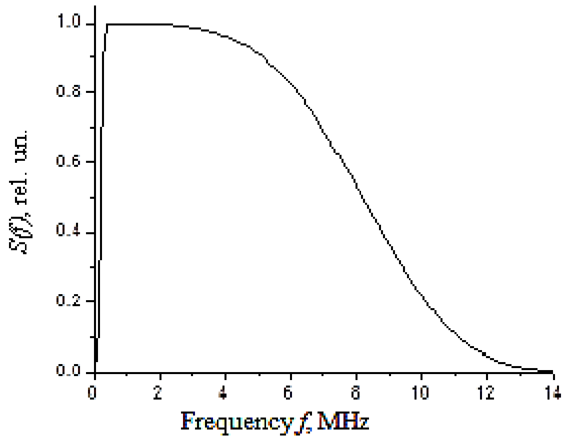


Fig. 5. Frequency filter for mathematical processing of the ultrasonic signals

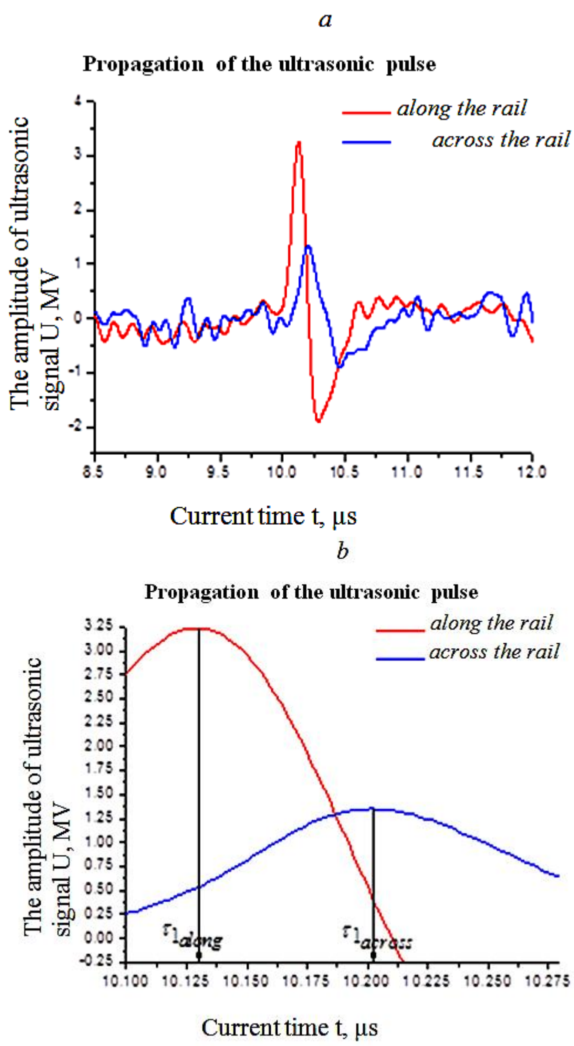


Fig.6. Pulses of the head ultrasound waves that are registered in the propagate in the rail head toward the up and down of the rail (a); the maxima of those impulses on a larger scale(b)

The error of determination of the value (± 2 ns) leads to an error of the calculated ultrasound velocity at the level ± 2 m/s that meets requirements to technical characteristics of the offered device model for diagnostics of railbars.

Discussion

The difference in the velocity of the ultrasonic waves propagating in the rail head in the direction of up and down the rail $\Delta c = c_{along} - c_{across}$ = 82 m/s, due to the influence of the velocity of ultrasound textures created after rolling. Also the texture influences attenuation of ultrasonic waves – at distribution across a rail the increase in attenuation of ultrasound that leads to reduction of amplitude and increase in duration of the registered impulse in comparison with a case of distribution of an impulse along a rail is observed (see figure 6a). Provided there are uniaxial stresses in a rail the value $c_{h_{along}}$ will change in comparison with its value in not intense metal, and $c_{h_{across}}$ will remain invariable and equal to its value in not intense metal. Thus, the presence of stress type tension-compression in the rail will be judged by the change in the value Δc. To use this technique in operation it is necessary to conduct measurements of values $c_{h_{along}}$ and $c_{h_{across}}$ by scanning all new railbars either before putting it in the interval nor directly after putting it. Then there must be an e-passport of the railbar – a database based on the values of ultrasonic wave velocities $c_{h_{along}}$ and $c_{h_{across}}$ in each plot of the measurements along on railbar.

A sample from the new rail type P65 length of 40 cm was used. To conduct experiments to study the dependence of the rate of head ultrasonic waves propagation in the rail head in the direction along the rail, with the applied uniaxial compressive stress. The ambient temperature was changed within 26.1-26.3°C. Since the temperature coefficient of longitudinal ultrasonic wave velocity changes in steel is-$0.67 \cdot 10^{-4}$ 1/°C [19], the influence of environment temperature on the ultrasonic velocity change will be significantly less than the measurement error, so it is possible to assume that the measurements were carried out at a constant temperature. Figure 7 presents the dependence of the value $c_{h_{along}}$ on the compressive load (N), applied to the head rail. It is seen that this dependence can be approximated by some linear function. Factor A_1, similar to that used in the expression (13) and describing the dependence of the velocity of ultrasonic waves from the applied compressive load, for this sample of the rail was equal to $A_1 = 3.62 \cdot 10^4$ t. To improve the accuracy of measurement of velocity of ultrasonic waves it is necessary to increase the number of samples of the registered signal.

Measuring the velocity of head ultrasonic waves propagating across the rail head, could not be implemented because of the strong influence of the curvature of the head in the transverse direction to the clamp level of the converter to the surface of the rail.

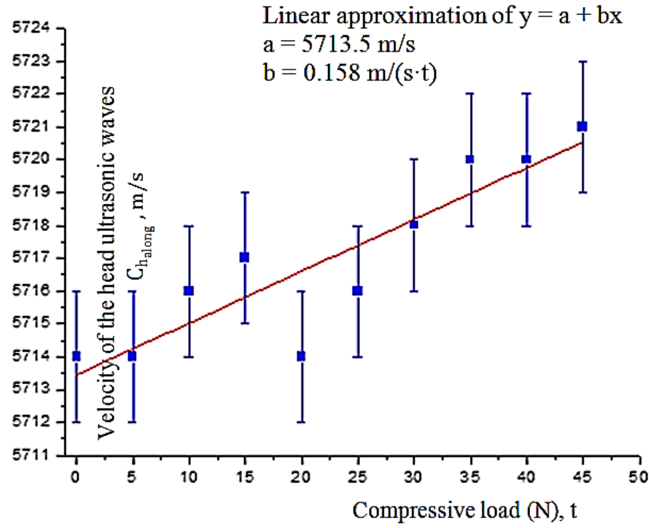


Fig. 7. Dependence of the velocity of the head ultrasonic waves propagating along the rail head, from the compressive load

Conclusion

1. The carried-out theoretical analysis has shown the possibility of creation of the model of the device for diagnostics of a tension of railbars of continuous welded rails on the basis of laser excitement of short nanosecond impulses of head acoustic waves with the use of broadband piezoelectric registration of these impulses. The proposed approach allows solving the problem of high accuracy of the ultrasonic wave velocity at low base measurements for the diagnosis of non-uniform stress distribution along the length of the railbar.
2. The device model for laser and ultrasonic nondestructive control of tension in rails is created.
3. Experiments were conducted to study the characteristics of pulse propagation of ultrasonic waves beneath the surface of the rail head in directions up and down the rail.
4. Experiments were conducted to study the effect of compressive load on the velocity of propagation of the ultrasonic waves in the head rail in the direction of along the rail. The obtained dependence characterizes the linear increase in velocity of the ultrasonic waves with increasing of the applied load, based on this dependence the acoustoelasticity connection factor was calculated for the sample rail type P65.
5. Further research is needed for choosing the type of the ultrasound waves which are not affected by a mean of stresses in the rails, and the geometry of their radiation and propagation in the head rail.

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