Rayleigh surface waves in assessing the state of metal structures

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Abstract. The work is devoted to the search of a method of ultrasonic sounding for identification of the material state, permitting to refer the diagnosed structure to the class of structures, whose state is connected with the appearance of plastic deformations. The study has shown the application of surface Rayleigh waves allows to estimate the stress-strain state of metal structures in the field of both elastic and plastic deformation.

1. Introduction

Buildings and structures of increased responsibility must undergo a periodic examination, the results of which make conclusions about the current state of load-bearing structures.

According to the results of inspection there can be next conclusions:
1. A building is in the active work state;
2. A building is in the emergency condition, reconstruction and strengthening of load-bearing elements is required without evacuation of people and stopping the workflow;
3. A building is in the emergency condition, there can be reconstruction and strengthening of load-bearing elements only with compulsory evacuation of people;
4. A building is in the emergency condition and is subject to demolition.

Diagnostics and monitoring of stress-strain state of carrying structures on time allow to avoid point number 3, 4, therefore to avoid huge expense. Besides one of the important parts is improving experimental methods of nondestructive check and its mathematic bases.

One of the perspective directions in solving the problem of operational control and diagnostics of stress-strain state of steel structures is an acoustic method based on phenomenon of acoustical anisotropy of medium with acting stresses [1]. In case of resiliencies the difference in speed of elastic waves, value of anisotropy is proportional to principal stress difference [2–11]. Besides in this formula of potential energy of deformation the nonlinear elastic Murnaghan’s model is used in mind with the member of the third order by the deformations components [2].

According to the active normative document inelastic deformations must not appear in building constructions. Nevertheless, during the exploitation inelastic deformations may appear for a number of reasons: design mistakes; occurrence of unaccounted extreme loads (storms, seismic effects, abnormal high snow load); wrong exploitation (for ex. changing the purpose of premises, there is an archival
depository despite the cabinet and etc.), in the results of which design loads are risen sharply [12, 13]. The identification of emerging plastic deformations is very important and urgent task. In the field of inelastic deformations, the dependence of the value of acoustic anisotropy on the degree of plastic deformation becomes nonlinear, which makes it difficult to decipher the results of monitoring the stress-strain state during diagnostics by the method of measuring the speed [10,14–18].

However, in practice, when studying a real structure, it is a priori unknown at what stage of deformation, which can be elastic or elastoplastic, the diagnosed structure is located. The need to monitor the situation and determine the moment when the metal of the structure enters to the region of inelastic deformations determines the relevance of the work.

The work is devoted to the search for a method of ultrasonic sensing to identify the state of the material, which allows attributing the diagnosed structure to the class of structures whose state is associated with the appearance of plastic deformations.

2. Methods
As an object of study, it was chosen hot-rolled steel grade S275, designed for operation at variable loads in the temperature range from -40 to + 425 degrees.

The uniaxial stress-strain state of the material was created by tensile testing of twelve flat proportional samples according, 8 mm thick with a working part width of 20 mm and non-standard samples in the form of a strip 200 mm wide with a working part length of 400 mm. The tensile test was carried out on a universal testing machine manufactured by Tinius OIlsen Ltd, model H100KU, and a machine TsDMU-30 with a maximum load of 30 tons. The influence of the stress-strain state on the parameters of the elastic sounding wave was studied using Rayleigh surface waves. The choice of such waves was due to the universality of their application for ultrasonic testing of parts and blanks of any shape [19].

The surface wave was created by piezoelectric transducers (PET) at oscillation frequencies of 2; 5 and 10 MHz. The radiating and receiving piezoelectric transducers were installed in one block at a distance of 50 mm fixed from each other. The emitting PET was excited using the A1214 flaw detector. The probe pulse was recorded using a Tektronix TDS2022 oscilloscope with a maximum time resolution of 2 ns. As a numerical indicator of the elastic wave velocity change as a result of deformation, the delay of the received signal relative to the informative point (the transition of the pulse through a zero value) is selected. An increase in the delay value compared to the initial position indicates a decrease in the speed of the probe pulse and vice versa at a constant distance between the emitting and receiving transducers.

3. Results and Discussion
Figure 1 shows the dependence on the delay stress (propagation velocity of the probing Rayleigh wave) of a 2 MHz pulse in a tensile test of a strip 200 mm wide. The direction of wave propagation was oriented both parallel and perpendicular to the acting stress.
Figure 1. Dependence of the delay on the magnitude of the effective stress during parallel and perpendicular propagation of the probe pulse

With increasing tension in the elastic region ($\sigma < 300$ MPa), the delay in the case of parallel propagation of the probe pulse to the current stress decreases (the speed of the probe pulse increases), in the case of a perpendicular propagation of the probe pulse, the delay increases (the speed of the probe pulse decreases). An increase in velocity in the case of an increase in stress during the parallel propagation of the probe pulse occurs asymmetrically in comparison with its decrease during perpendicular propagation. At stresses in the region of plastic deformations ($\sigma_{0.2} < \sigma < \sigma_B$), the speed of the probe pulse decreases (the delay increases) with increasing stress, both for parallel and perpendicular propagation of the probe pulse to the acting stress. It is not difficult to notice that in the case of purely elastic deformations ($\sigma < \sigma_{0.2}$), the difference in delays (velocities) of waves propagating in parallel and perpendicular to the direction of action of the stress in the material under load is proportional to the acting stress. In the case of plastic deformation ($\sigma > \sigma_{0.2}$), the dependence of acoustic anisotropy (delay difference) on the applied stress is nonlinear and decreases with increasing stress. This makes the solution to the problem of assessing the magnitude of plastic deformation by measuring acoustic anisotropy without obtaining additional diagnostic signs problematic.

Figure 2 shows the dependence of the stress and the delay (velocity) of the elastic Rayleigh wave on the strain during tensile testing of proportional samples. The propagation direction of the Rayleigh wave is oriented parallel to the applied stress.

From Figure 2 it can be seen, that in the region of elastic deformation under tension with increasing strain, the delay decreases linearly (the speed of the elastic wave increases). In the region of plastic deformation, the dependence of the elastic Rayleigh wave velocity has a complex nonlinear character and decreases with increasing strain. The change in the delay in the elastic region does not depend on the frequency of the probe pulse. In the field of plastic deformation, a significant dependence of the velocity on frequency is traced. It should be noted that since the penetration of the Rayleigh wave in depth is of the order of the wavelength, these dependences and velocity differences relate to different thicknesses of the probed material. The last one indicates an uneven distribution over the thickness of the structure transformation during plastic deformation [20, 21] in the absence of a dispersion of the phase velocity of the Rayleigh wave (classical theory) [19].
4. Conclusions
The study showed that the use of Rayleigh surface waves makes it possible to evaluate the stress-strain state of metal structures in both elastic and plastic deformations. The results obtained suggest the dependence on the frequency of the surface velocity of Rayleigh waves as a diagnostic feature of a material subject to elastoplastic deformation. This indicator can be the basis of the decision-making method that allows attributing the diagnosed object to the class of metal structures, the state of which is associated with the appearance of plastic deformations.

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Figure 2. Deformation dependence of the stress and delay for probing pulses with a frequency of 2; 5 and 10 MHz.
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