RESIDUAL STRESSES DETECTION IN ROLLING STOCK WHEEL SETS BY MEANS OF ELECTROMAGNETIC ACOUSTIC METHOD

Graviy BUDENKOV, Vitaly MURAVIEV, Victor STRIZHAK,
Andrey PRYAHIN, Evgeny BALOBANOV
Izhevsk State Technical University (IzhGTU), Izhevsk, Russia

## Introduction

Internal residual stresses in the rim of railway carriage wheel are formed because of technological stresses caused by physical and physicochemical processes at production (at rolling and subsequent thermal treatment), and operational stresses caused by dynamic, cyclical and static loads.

Insignificant compressive stresses or very weak tensile stresses evenly distributed along height of the rim are observed usually at production. Transition of rolling stock on using of high-strength solid wheels with heightened content of carbon has considerably changed distribution of residual stresses in the wheel rim. It is obtained that level of compressive stresses in solid wheels is lowered gradually passing to tensile stresses during operation. Abnormal increase of stresses gradient occurs in the some wheels. Facing of the wheel profile normal solidity implemented at repair brings to some expansion of level compressive stresses. For wheels with heightened solidity such effect is revealed in appreciably less degree.

Extraordinarily high stresses are realized in the operation process at cyclical loads in area of interaction wheels and rails that can bring to wears, breakaways of wheels tread area, occurrence and fast growth of fatigue cracks at large internal residual stresses and especially large thermal loads from intensive inhibition, even in the absence of metallurgical defects. Wears and other defects of wheel sets cause to increase of dynamic forces influencing both railway carriage and railway track and threatening safety to train motion.

It is found from research of destroyed wheels, that the isolated cases of wheel fractures because of occurrence fatigue cracks near with rim of solid- rolled wheel can arise in case overload of railway carriage, unfavorable combination of the rim minimal thickness and presence defects on wheel tread surface (chips, burns) exceeding normalized value and leading to shock type of applying vertical loads especially in winter time. Magnitude of technological residual stresses in solid-rolled wheels has considerable influence on their cyclical strength, propagation velocity of cracks and reliability wheels at operation.

In this connection, Russian Railway Standard STO 1.11.002-2008 and Directive Document 32-144-2000, European Standard EN 13262-2004 provides instrumental testing of residual stresses in the rims of solid-rolled wheels at their production and operation.

## Method of research

Acoustic method practically has not alternative for testing of internal residual stresses in material of railway wheels. Method is based on registration of change propagation velocity elastic waves under the influence of stresses. The relative velocity change $\Delta C/C$ from stresses $\sigma$ in a generalized form can be represented as [2]:

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

where, $\beta$ - acoustic-elastic coefficient depending on type of ultrasonic waves and direction their propagation with relation to the vector of the deforming force, $\beta_1(\lambda,\mu)$ - acoustic-elastic coefficient being determined by Lame's constants of second order $\lambda, \mu$ and caused by geometric nonlinearity; $\beta_2(\lambda,\mu,l,m,n)$ - acoustic-elastic coefficient depending on Lame's constants and

Murnagan's elastic constant of the third order *l, m, n* and in generally caused by physical nonlinearity.

The testing of residual mechanical stresses in rims of the solid-rolled wheels must be performed by means of ultrasonic testing in according with Russian Railway Standard 1.11.002-2008 and Directive Document 32-144-2000. The hoop component of stresses is detected, while the radial component remains almost constant. According to those documents, the maximal value of residual stresses near with taping line should be negative (compressive) and shall not exceed of 190 MPa in the hoop direction. The difference of values measured at different point on the height of the rim must not exceed the value determined in the technological documentation on testing. The depth of layer under rim surface where stresses reach zero (become tensile) must be at least 40 mm.

Ultrasonic testing of residual mechanical stresses in the rims of the solid-rolled wheels is performed by method which consists in axial sounding of rim by transverse waves plane-polarized in the radial and hoop direction. Acoustic measurements are performed with the inner lateral surface of the rim in the side of comb for new wheels at least in five points along the height of the rim at a depth of 10 mm or more from the wheel tread.

Ultrasonic polarization-time method has been used. The method is based on measuring elastic anisotropy of material by means accurate detecting of the difference on propagation time along rim width of the two cross-polarized shear waves with planes of polarization coinciding with main stresses in anisotropic material.

Values of time delays of shear waves $t_1$ and $t_2$ are used to calculate hoop stress $\sigma$ by the formula [3]:

$$\sigma = D\left(\frac{t_1}{t_2}\frac{t_{01}}{t_{02}} - 1\right), \quad (2)$$

where $D$ – elastic-acoustic connection coefficient for researching material, $t_{01}$ and $t_{02}$ - time delays of shear waves in the absence of load (they show anisotropy of the material). As initial values of time delays $t_{01}$ and $t_{02}$ can be accepted values measured at point of the rim closest to the centre of the wheel where compressive stresses must be minimal.

Elastic-acoustic connection coefficient $D$ can be determined by the formula [3]:

$$D = \frac{8\mu^2}{4\mu + n}, \quad (3)$$

where $\mu$ - Lame constant, $n$ – Murnagan constant of third – order. Knowing elastic-acoustic connection coefficient $D$ the difference between radial and axial stresses can be calculated.

The measuring accuracy depends on texture of the material. About texture degree can be judged by amplitude of echo-signal in depending on turn of the polarization plane. In textured material the amplitude of echo-signal varies strongly.

## The experimental plant for research

The experimental plant has been developed for research of processes of propagation of transversal waves in the rim and estimation of their nonlinearity depending on an intense condition, the functional scheme and photo are represented in figure 3. The generator of electric pulses *3* of flaw detector DUC-66 forms the powerful probing electric pulse (amplitude about 300 B), submitted on non-contact electromagnetic - acoustic transducer (EMAT) *2* established on a lateral surface of wheel rim *1*. In the rim with help of EMA transmitter *2*, short acoustic pulses of transversal waves with the basic frequency in a spectrum of ~2,5 MHz which after distribution on thickness of the rim and reflections from an opposite surface are registered same non-contact EMAT *2*, with transformed acoustic oscillations in electric pulses. The acoustic oscillations transformed into an electric signal through the amplifier *4* of flaw detector DUC-66 move on the digital oscillograph *5 (*Instek GDS-8405) on which screen it is possible to observe probing signal and series of echo signals. The generator of electric pulses and display of the oscillograph are synchronized. Magnitude of time delays of share waves $t_1$ and $t_2$ are measured at two positions EMAT with polarization in radial and hoop directions. Measurement accuracy of velocity of the waves directly defines accuracy of an estimation of stresses.

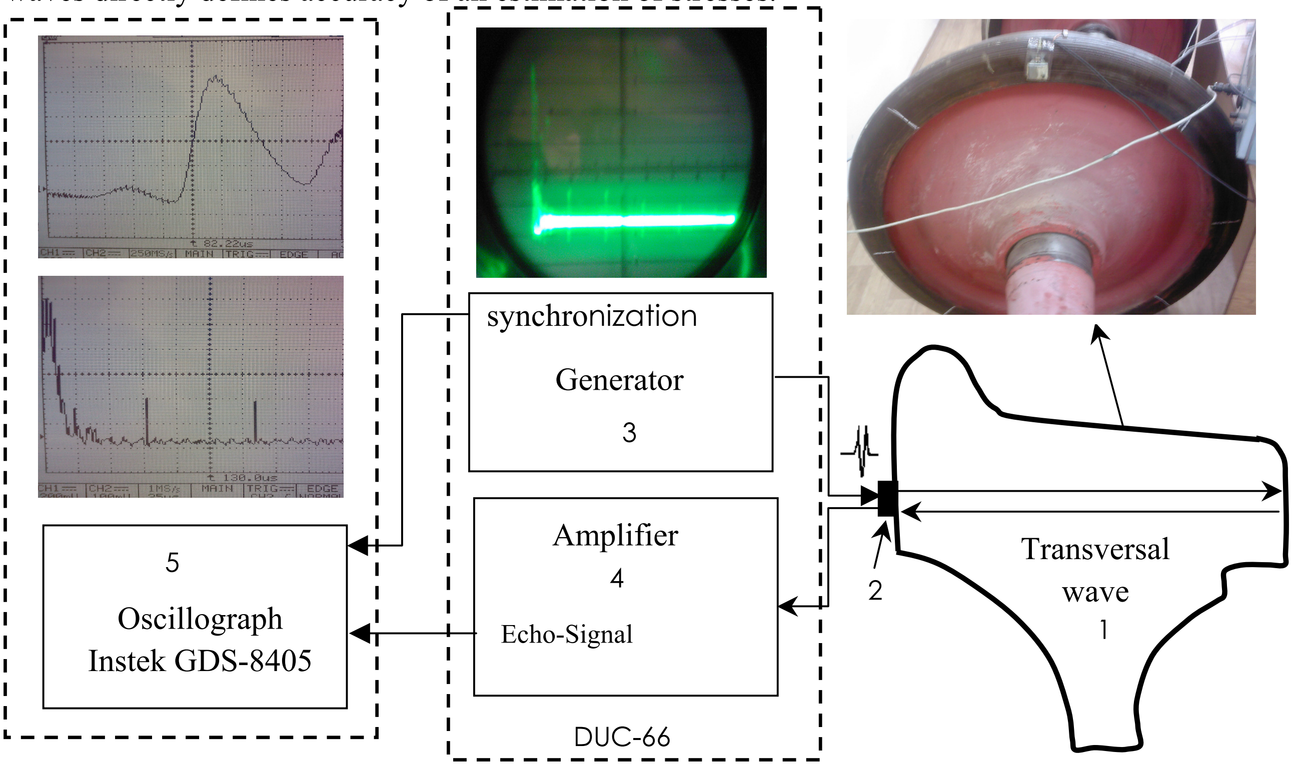


Fig. 1 The functional scheme of plant

Application of the digital oscillograph as registrar with digitization frequency $f_\partial$ = 1 GHz (the period of digitization $T_\partial = 10^{-9}$sec) in experimental plant has ensured the instrumental error of wave propagation velocity measurement on the basis of 260 mm:

$$\frac{\Delta C}{C_0} = \frac{T_\partial}{t_0 + T_\partial} \approx 0.01\% . \quad (4)$$

On condition that minimal delay time of registration will be exceed $T_\partial$ in 5 times (in view of methodical errors), the error of determination of stress can be provided no more than 10 MPa.

At accuracy and reproducibility of the method acoustic tensometry essential influence renders quality of acoustic contact between the acoustic transducer and testing object. The non-contact way of excitation and reception of transversal waves with the help of the developed EMAT allows to get high enough efficiency of radiation and reception of transversal waves and allows to exclude influence of quality of acoustic contact.

## The results of experimental research. Discussion of the results

Measurements of stresses were done in rims of four solid-rolled wheels (in the article only two wheels are discussed) with diameter 957 mm in six cross-sections along the diameter and in three points along the height of the rim for each cross-section (fig.2). The wheels are produced of steel according to GOST 10791-2004 and TU 0943-157-01124328-2003. Propagation time of shear waves, having normal polarization with the tread surface of wheel and with parallel to it, was measured sequentially at each point. Calculation of the stresses for relevant field was done in according to formulas 2-3.

Distribution diagrams of calculated hoop mechanical stresses for two wheels are shown on the fig. 3. From presented diagrams it follows that distribution of stresses is extremely not evenly along rim tread for the wheel with number 95-206033-18-327-09. So the maximal calculated stress for extreme points (20 mm from wheel tread) of the rim not exceed 190 MPa, but ratio between maximal and minimal values $\sigma_{max}/\sigma_{min}$ (irregularity of stresses) is ~ 2 times. The distribution of stresses for middle points (40 mm from wheel-tread) not repeats a distribution shape for extreme points, that says of stresses irregularity both in case hoop direction and radial direction of the rim.

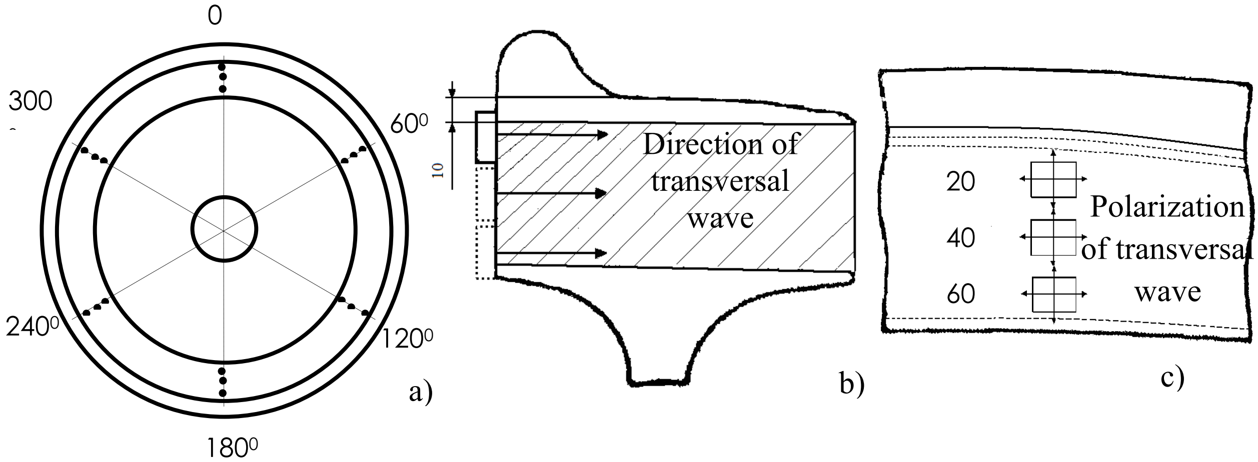


Fig.2 The method of sounding of the solid-rolled wheel rim: installation location of the transducer along circumference of wheel (a), along width of the wheel rim (b), (c).

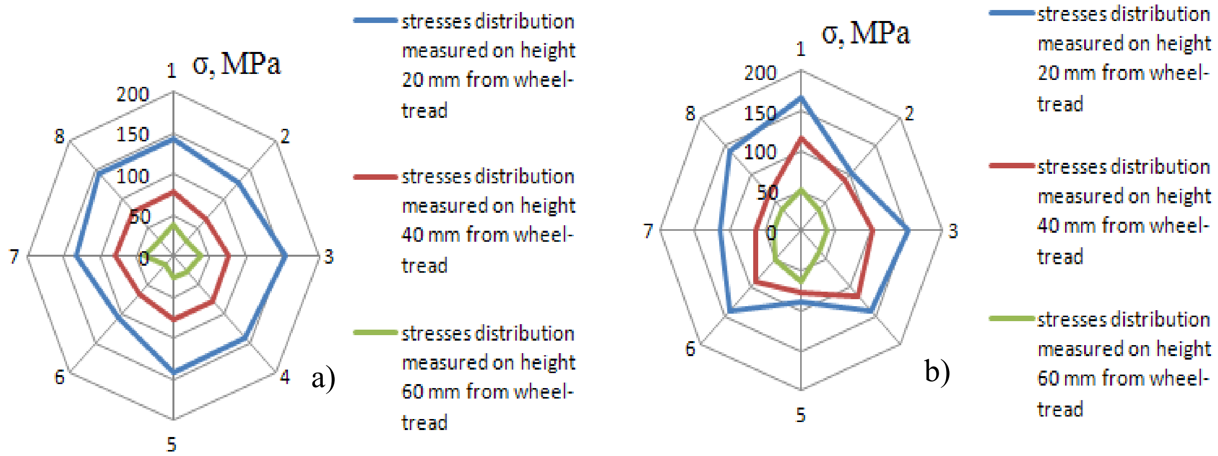


Fig. 3 Distribution diagrams of calculated mechanical stresses in the solid-rolled wheels rims: №95 206035 18 329 05 (a); №95 206033 18 327 09 (b)

Such irregularity can cause deformation state of wheel rim and fast growth of transversal cracks in during operation process. In case of wheel with number 95-206035- 18-329-05 the stresses distribution is more evenly without evident maximal values, although the difference of absolute magnitudes of stresses between extreme points for lines 6-2 and 7-3 is about 25 MPa . Magnitudes of stresses not exceed 190 MPa.

## Conclusions

Developed to researching stress-strain state of the rims of solid-rolled wheels carriages experimental plant allows to realize echo-pulse polarization-time method, which is consisted in measurement of propagation velocity of the two shear waves with cross-polarization and provides measurement error not exceeded of 0.01%. Application of non-contact electromagnetic acoustic transducer in the plant allows to exclude influence of acoustic contact quality, determining reliability and reproducibility of measurements results.

Research of stress-strain state rims of two solid-rolled wheels demonstrated that in one of them the stresses distribution is extremely not evenly and ratio between maximal and minimal values is ~ 2 times. Demonstrated stress-strain state of wheel can cause different defects of wheel tread, emergence and fast evolution of fatigue cracks in operation process.

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