Application of laser ultrasound method for control of residual stresses in special materials

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## Analogs

<table>
<thead>
<tr>
<th>Name of a method</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray method</td>
<td>Accuracy of measurements is 20 MPAs (~ 5%), high spatial resolution</td>
<td>Small depths (standard depth of penetration of x-ray radiation in steel makes ~ 10 microns) are controlled. Labor-consuming procedure of electrolytic preparation of a surface. Control of remote sites of designs is limited to the device sizes.</td>
<td>Radiation danger</td>
</tr>
<tr>
<td>Method of measurement of noise of Barkgauzen</td>
<td>High sensitivity of a method; locality of carrying out measurements; limited, but controlled thickness of an informative layer; simplicity of realization of a method; portability of the equipment; variety of sensors</td>
<td>Large number of influencing factors: distinction of microstructures, sizes of residual plastic deformation, condition of a surface, etc.</td>
<td>Only ferromagnetics</td>
</tr>
<tr>
<td>Method of measurement of coercive forces</td>
<td>Efficiency and simplicity of procedures of measurements, rather low requirements to preparation of a surface of area of control</td>
<td>Demands the development in reduction of tension of factors stirring to measurement, first of all variations of a chemical composition and metal structure</td>
<td></td>
</tr>
<tr>
<td>Method of magnetic memory of metal</td>
<td>Simplicity of realization of measurements, portability of measuring equipment, universality of approach for all materials</td>
<td>Low sensitivity at measurements on materials with a high hardness, strong nonlinearity of the characteristic at compression deformations, a considerable error at low levels of tension</td>
<td></td>
</tr>
<tr>
<td>Acoustic methods</td>
<td>Simplicity of realization of measurements, portability of measuring equipment, universality of approach for all materials</td>
<td>High precision of measurement of speed of distribution of ultrasonic waves which needs to be measured rather locally is required</td>
<td>Demands high-precision measuring equipment</td>
</tr>
</tbody>
</table>
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Tools of laser ultrasound method for control of residual stresses in products made of special materials

Method advantages:

• The sizes of the opto-acoustic converter with equipment allow to control residual stresses in remote sites of the products.
• Possibility of control of residual stresses in any planes of large sized products.
• Simple preparation of a surface for the control of residual stresses.
• Insignificant mass-dimensional characteristics of the equipment allow to control residual stresses in conditions of production.
• Lack of radiation hazard excludes need of registration of the sanitary and epidemiologic conclusion.
• High sensitivity and universality of approach for all materials.
Laser ultrasound method

\[ c_l = \frac{L}{\Delta t - \Delta t_0} \]

\( L = 30,813 \text{ mm} \) – base of measurements;
\( \Delta t \) – time of arrival of an acoustic impulse to the receiver;
\( \Delta t_0 \) - signal delay in a radiating path.
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Excitement and opto-acoustic transformation of a laser impulse

The scheme of the phenomenon accompanying impact of a laser impulse on the absorbing environment

Profiles of optoacoustic signals at various acoustic impedances of N: 1 – 0; 2 – 0,4; 3 – 1; 4 – 2,5; 5 – ∞
The values obtained without the application of external load

$$\sigma = 0 \text{ MPa}, \ t = 10.103 \text{ microsec}$$

The values obtained under the influence of the stretching force

$$\sigma = 220 \text{ MPa}, \ t = 10.117 \text{ microsec} \rightarrow \Delta t = 14 \text{ nanosecond, } \Delta v = 15 \text{ m/s.}$$
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**Results of ratio studies of ultrasonic waves speed to tension in special steel**

![Graphs showing the relationship between tension and ultrasonic wave speed](image)

*Results of ratio studies of ultrasonic waves speed to tension in special steel samples 5 mm thick (a) and 20 mm thick (b): ♦ – experimental points; — – regression lines

$$\sigma = k_V \frac{V - V_0}{V_0}$$

- $V$ - speed of a head ultrasonic wave in the presence of residual stresses;
- $V_0$ - speed of a head ultrasonic wave in the absence of residual stresses;
- $k_V$ - the experimental coefficient describing elastic properties of a material of samples.

$$k_V = -88117.75\,\text{MPa} \quad \text{(steel No1)} \quad k_V = -80110.00\,\text{MPa} \quad \text{(steel No2)}$$
Results of ratio studies of ultrasonic waves speed to temperature in special steel samples 5 mm thick (a) and 20 mm thick (b):

♦ – experimental points; — – regression lines

\[ \Delta V = k_t \Delta t \]

\[ \Delta V = V(t_i) - V(t_j) ; \]

\[ V(t_i) \] - speed of a head ultrasonic wave in sample at its temperature \( t_i \); 

\[ V(t_j) \] - speed of a head ultrasonic wave in sample at its temperature \( t_j \); 

\[ k_t \] - the experimental coefficient describing temperature properties of a material of samples.

\[ k_t = -3.07 \frac{m}{s \cdot ^\circ C} \] (steel №1)  \[ k_i = -2.56 \frac{m}{s \cdot ^\circ C} \] (steel №2)
Results of ratio studies of ultrasonic waves speed to tension and temperature in steel samples

Experimental dependence for determination of residual stresses in products:

\[ \sigma = k_V \frac{(V + k_t (t - t_0)) - V_0}{V_0} \]

- \( V \) - speed of a head ultrasonic wave in a tested product;
- \( V_0 \) - speed of a head ultrasonic wave in a control sample from the same material, as tested product, but not having the residual and enclosed tension;
- \( t \) - temperature of tested product;
- \( t_0 \) - temperature of control sample;
- \( k_V \) - the experimental coefficient describing elastic properties of a material of samples;
- \( k_t \) - the experimental coefficient describing temperature properties of a material of samples.

Steel №1:

\[ k_V = -88117,75 \text{ MPa}; \quad k_t = -3,07 \text{ m} \quad s \cdot ^\circ C \]

Steel №2:

\[ k_V = -80110,00 \text{ MPa}; \quad k_t = -2,56 \text{ m} \quad s \cdot ^\circ C \]
### Technical characteristics of the model test car OSM-200-10

<table>
<thead>
<tr>
<th>Parameter</th>
<th>value</th>
</tr>
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<tbody>
<tr>
<td><strong>Model part</strong></td>
<td></td>
</tr>
<tr>
<td>Limits of reproduction of force steps on 10000 N, kN</td>
<td>10-2000</td>
</tr>
<tr>
<td>Error of reproduction of force, %</td>
<td>±0.02</td>
</tr>
<tr>
<td>Length of the course of the lower clip, mm</td>
<td>0-700</td>
</tr>
<tr>
<td><strong>Reference part</strong></td>
<td></td>
</tr>
<tr>
<td>Limits of reproduction of force steps on 500 N, kN</td>
<td>2-100</td>
</tr>
<tr>
<td>The standard provides unit reproduction with a relative mean square deviation of result of measurements $S$</td>
<td>not exceeding $5 \times 10^{-6}$ at 15 independent measurements</td>
</tr>
<tr>
<td>The relative not excluded systematic error $\Theta$</td>
<td>not exceeding $1 \times 10^{-4}$</td>
</tr>
<tr>
<td>The relative standard uncertainty estimated on type A, $W_A$</td>
<td>not exceeding $5 \times 10^{-4}$ at 15 independent measurements</td>
</tr>
<tr>
<td>The relative uncertainty estimated on type B, $W_B$</td>
<td>not exceeding $6 \times 10^{-6}$ H</td>
</tr>
<tr>
<td>Overall dimensions, mm (length x width x height)</td>
<td>6290 x 2150 x 7150</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>37000</td>
</tr>
</tbody>
</table>

### Appearance of the model test car OSM-200-10
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Sample for the calibration of the laser and ultrasonic defectoscope UDL-2M with the PLU-6N-02 sensor

Sketch of the sample for calibration, the sample is made of steel 20

Distribution of mechanical tension in the sample for calibration, the sample is made of steel 20
Results of calibration of the laser and ultrasonic defectoscope UDL-2M with the PLU-6N-02 sensor