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ACOUSTOELASTICITY – A NEW PERSPECTIVE METHOD FOR MEASURING OF STRESS IN ENGINEERING MATERIALS

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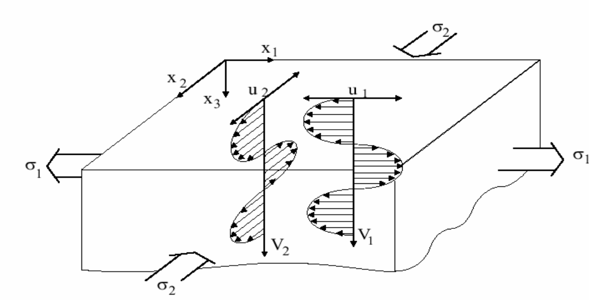
The problem of an experimental estimation of the real stressed state of machines and engineering structures is rather urgent in various industries. A wide class of constructive elements includes details with one size significantly less then the other two. In-plane stress is realized in those elements under the loading, or it is possible to consider the stressed state locally plane in the area of the nondestructive testing by ultrasonic pulse-echo method which can be used rather effectively for inspection of such details.



Combined equations (1,2) provide the evaluation of stresses in accordance with the nonlinear elastic properties of testing material and the results of precise time-of-flight measurements of shear and longitudinal ultrasonic waves:

$$\sigma_1 = K_1\Delta_1 - K_2\Delta_2 \qquad (1)$$

$$\sigma_2 = K_1\Delta_2 - K_2\Delta_1 \qquad (2)$$

where K_1, K_2 - coefficients of elastic-acoustic connection, which depend only on linear and nonlinear elastic constants of a material, have dimension of stresses and can be evaluated as a results of special testing of material's samples. The dimensionless terms

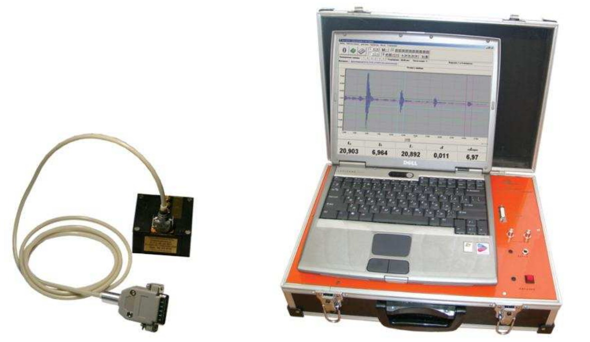
$$\Delta_1 = \left(\frac{t_3}{t_1}\frac{t_{01}}{t_{03}} - 1\right), \Delta_2 = \left(\frac{t_3}{t_2}\frac{t_{02}}{t_{03}} - 1\right)$$

do not depend on any change of an acoustical path during material's deformation and contain only relative values of acoustic parameters t_{0i}, t_i (i = 1,2,3) - time delays of pulses of elastic waves traveling along the direction 3 before and after the loading.
Index 1 corresponds to shear wave which plane of polarization is parallel to direction 1.
Index 2 corresponds to shear wave which plane of polarization is parallel to direction 2.
Index 3 corresponds to longitudinal wave which is used in addition to shear waves as a specific «thickness-meter» to provide simultaneous monitoring of the «acoustical path» for ultrasonic pulses.

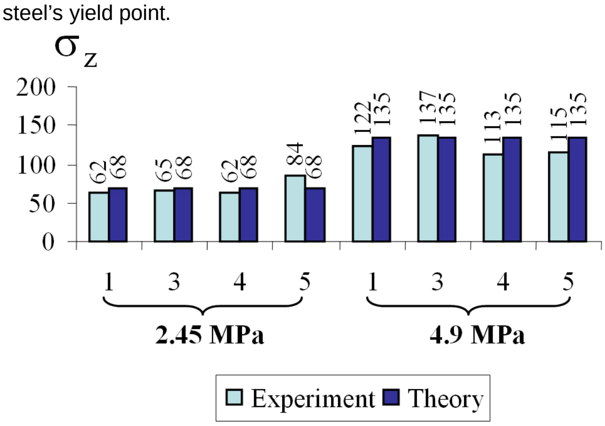
The reliability of acoustoelastic effect for biaxial stress evaluation was proved experimentally by the example of the hydrostatical loading of the closed pipe. Habriel Lame founded the analytical solution of the problem in 19th century. For a case of the thin pipe walls, the elasticity theory predicts that the «radial» stresses are essentially smaller than axial (σ_1) and circumferential (σ_2) stresses. The stressed state of a small part of a thin envelope of the pipe is performed as in-plane stress:

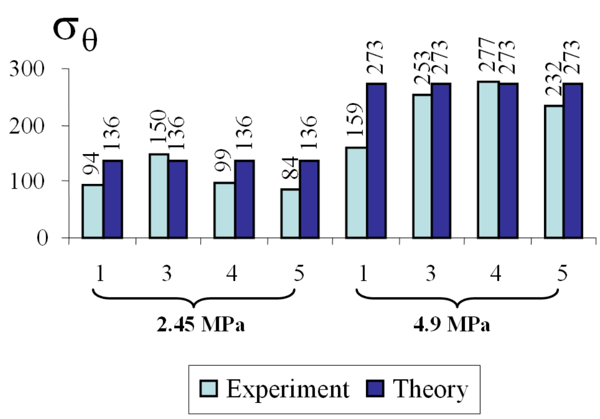
$$\sigma_1 \approx p\frac{d}{4h}, \quad \sigma_2 = p\frac{d}{2h}. \qquad (3)$$

The diameter d of steel pipes used in our experiments was 1020 mm and thickness h was varied from 9 to 14 mm. The pipes have been closed by special steel bottoms and were exposed step by step to inner pressure of water (p). The precise measurements of time-of flight of shear and longitudinal waves propagated across the plane of stress action have been made before and after the each step of loading.
Special compact device IN-5101A designed by «ENCOTES» Ltd has been used in the experiments. IN-5101A realizes the acoustoelastic effect and provides reliable measurements of uniaxial and biaxial stresses in different engineering materials under long-term load and different climate environments. Relative cheapness and safety of an ultrasonic method in comparison with x-ray, more wide opportunities at the choice of materials and practical problems in comparison with electrical tensometry or magnetic methods make the acoustoelastic effect attractive enough to achievement of these purposes.



The advanced technology for nondestructive testing of mechanical stresses in engineering materials was used in our investigations. The values of stresses acting along and across the pipe axes (axial and circumferential stresses, correspondingly) were automatically evaluated in real time by the special computational block, placed inside the experimental equipment. The results of our investigations show that the observed data are quite closed to the Lame predictions. The difference between mechanical stresses evaluated by means of nonlinear acoustics and by theoretical computations, is not exceed 5-8% of the steel's yield point.





So, the acoustoelastic method, realized with the help of the device IN-5101A, has sustained check by an arbitrary calculative method with good results. This fact allows hope for successful introduction of this rather new perspective method in practice of the nondestructive evaluation of mechanical stresses in engineering materials.

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