

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

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Stresses arising in an engineering material under action of temperature changes, body weight; redistribution of loading leads to reduction of durability of separate elements, and, moreover, of all construction as a whole. Because of complexity of products and wide range of loading, to which their components are exposed during manufacturing and exploitation, the exact account of acting stresses not always is obviously possible. Therefore problem of an experimental estimation of the real stressed state of machines and engineering structures is rather urgent in various industries.

It is possible to solve this problem without destruction of an engineering material by the way of exiting of waves of small amplitude in comparison with stress value and evaluation with a relative error at least 0.01% changes of velocities of their propagation in comparison with the initial material.

However, directly measured ultrasonic wave parameter isn't a velocity, but (for example) a propagation time, and thickness of testing material is also varied during the variation of stresses. So, we must have three, but not two acoustoelastic equations to determine two principal stresses. One of the solutions of this problem is using of the longitudinal wave propagated in the same direction that shear waves have propagated (across the plane of a stress action). Longitudinal wave is used in addition to shear waves as a specific «thickness-meter» to provide simultaneous monitoring of the «acoustical path» for ultrasonic pulses. So, one can design and check out practically the next simple and reliable combined equations for biaxial stress evaluation on the base of precise time-of-flight measurements of shear and longitudinal ultrasonic waves [1, 2]:

$$\sigma_1 = K_1 \Delta_1 - K_2 \Delta_2, \quad \sigma_2 = K_1 \Delta_2 - K_2 \Delta_1, \quad (1)$$

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 (moduli of elasticity) and can be calculated theoretically or evaluated experimentally, as a results of acoustic-mechanical testing of material's samples. The dimensionless terms

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

contain only relative values of acoustic parameters: t_{0i}, t_i ($i = 1, 2, 3$) – time delays of pulses of elastic waves composing that unique orthogonal basis, which provides two shear (1, 2) and one longitudinal (3) waves propagation normally to a plane of stress action without the turn of a plane of polarization. The parameters Δ_1, Δ_2 do not depend on any change of an acoustical path during material's deformation.

A wide class of constructive elements includes details with one size significantly less then the other two. The ultrasonic pulse-echo method can be used rather effectively for nondestructive inspection of such a details [3, 4]. The 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 acoustical testing by ultrasonic pulse-echo method. Combined equations (1) provide the evaluation of stresses in accordance with the acoustoelastic properties of testing material and the results of precise ultrasonic measurements.

The reliability of acoustoelastic manner for biaxial stress evaluation was proved experimentally by the example of the loading of the closed pipe [5 – 7]. Habriel Lamé 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. So, the stressed state of a small part of a thin envelope of the pipe is performed as in-plane stress:

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

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, e.g. linear dependences between elastic wave velocity and mechanical stresses, 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 acoustical 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, based on the theoretical study [1, 2] and placed inside the experimental equipment. The results of our investigations show that the observed data are quite closed to the Lamé 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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