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FRACTIONAL WAVELET ANALYSIS OF MECHANICAL STRESSES IN COMPOSITE PLATES

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Damage assessment in polymer and composite structures can be carried out using a wide range of structural diagnostics methods, which include thermography, ultrasound and radiographic methods, etc. One of the most promising methods is the vibration method, which meets the basic requirements for testing procedures, namely, it must be non-destructive and, if possible, non-invasive [1]. Methods of this type should ensure the detection, localization and identification of various types of damage at the earliest possible stage.

In general, algorithms for identifying mechanical damage and stress can be improved using wavelet transforms [2]. In particular, a computationally efficient crack detection technique based on the stationary wavelet transform is widely used. Numerous numerical experiments were based on both continuous and discrete transforms, as well as a combination of these methods. It should be noted that the use of *B*-spline wavelets in discrete transforms provides high sensitivity in detecting mechanical stress in the volume of composite structures and shows greater accuracy in localizing damage [3].

The computational approach presented in this paper is based on the application of various heuristic optimization methods to find the best values of the parameters of two-dimensional fractional B-spline wavelets used to identify damage in composite plates. Two-dimensional fractional B-spline wavelets were used in the computational model. In addition, optimization algorithms were applied to select the values of the optimal fractional order and the wavelet shift parameter and the scaling function used in the procedure for identifying mechanical stresses and shifts in the volume of the computational specimen.

The calculation algorithm is based on the discrete wavelet transform, which uses multiresolution analysis. The scaling functions of the *B*-spline $\beta(x)$ constitute the space of square-integrable subspaces L^2 (*R*) and form a sequence of functional spaces W_i in the following form:

$$\{\kappa(0)\} \subset W_{-2} \subset W_{-1} \subset W_0 \subset W_1 \subset W_2 \subset L^2(R). \qquad (1)$$

The general form of the scaling function of a fractional order α, τ-*B*-spline β_τ can be expressed as

$$\beta_\tau(x) = \sum_{k=0}^{\infty} |\alpha + 1, k - \tau| \rho_\tau(x-k), \qquad (2)$$

where:
$\alpha \in R$ is an order of the scaling function;
$\tau \in R$ is a shift parameter;
$\rho\tau$ is the function in the composite form.

B-spline wavelets of fractional order $\psi_\tau(x)$ can be written using the two-scale relation

$$\psi_\tau(x/2) = \sum_{k \subset Z} h_\tau(k) \beta_\tau(x-k), \qquad (3)$$

where: $h_\tau(k)R$ is a refinement filter.

The fractional discrete wavelet transform algorithm uses the Fourier series. In this case, it is necessary to use the method of complexification of *B*-spline wavelets of fractional order generated using pairs of Hilbert transforms. Such a transformation makes it possible to obtain directionally oriented complex wavelets. Complexification is based on a combination of wavelets with the same order but different shift values, in particular

$$\psi_\tau(x) = \psi_{\tau-1/2}(x) + j\psi_{\tau+1/2}(x). \qquad (4)$$

Mechanical damage and displacements were modeled by excluding elements in individual areas. Three damage cases were considered: a through crack of an elongated shape; a square exclusion on the top of the plate and a case with multiple damages. The results of optimization of wavelet parameters show that the applied optimization algorithms give optimal and sufficiently quickly converging solutions. The wavelet order in most cases tended to the upper boundary of the considered restrictions, and the shift parameter always reached almost integer values. It is found that when the value of α reaches values from 0 to 1, the filtering procedure is insufficient, i.e. the values of the detail coefficients are shifted by the analyzed signal. But for higher values of α, the wavelet energy is distributed along its support, and the damage positions are blurred in the resulting wavelet set, which negatively affects the damage localization procedure. The shift parameter τ does not reach values close to the cases of causal *B*-splines, which proves that the use of fractional *B*-spline wavelets with unlimited τ can slightly improve the damage detectability.

Summary and conclusions. The presented study modifies the method of damage identification in composite plates based on modal shape displacements and its processing using fractional wavelet transform. The results of numerical experiments allow us to conclude that the use of spatial fractional B-spline wavelets improves the sensitivity of the method, taking into account the possibility of continuous change in the parameters of the applied wavelet, especially in the case when the wavelet parameters are optimized.

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