EXPERIMENTAL METHOD OF INVESTIGATING THE EFFECT OF LOW-VELOCITY IMPACT ON DAMPING CAPACITY OF MULTILAYER WOVEN CFRP

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The method of experimental study of the effect of local damage from a low-energy impact on the non-ideally elastic resistance of woven carbon fiber composites of a multilayer structure is considered. The amplitude-dependent logarithmic decrement of vibrations is taken as a characteristic of the non-ideal elasticity of the material. The presented experimental technique makes it possible to obtain experimental data on the dissipative properties of intact and damaged samples of materials under the conditions of their pure bending.

Keywords: vibrodiagnostic, vibration damping, damage, carbon fiber reinforced plastic, composite material

Introduction. Designs of modern aviation equipment are characterized by an increasing use of polymer composite materials reinforced with carbon fibers. The high specific strength and stiffness of composite materials allow for improved technical and economic performance of such systems and enhanced reliability. However, structural imperfections may arise during the manufacturing and operation of multilayer composite elements, significantly impacting their ability to withstand static and dynamic loads. Detecting such damages at their early stages is crucial for ensuring the safety and reliability of equipment objects. Consequently, developing scientifically based methods for diagnosing damage to composite structures during operation is essential. One such method is the analysis of changes in the natural frequency of vibrations [1] of damaged structures resulting from stiffness degradation. However, this method is less effective for small relative volumes of damage. Hence, there is a need to explore new, more effective vibration indicators of damage presence. Several studies, including [2–4], suggest that characteristics of energy dissipation in the material can serve as such indicators.

The purpose of this research is to develop experimental methods for investigating the impact of local damage to multilayer woven carbon fiber reinforced plastics (CFRP) caused by low-energy impacts, and to determine its effect on the nature of the amplitude dependence of the level of dissipated energy in CFRP.

The method of experimental study. The experimental method for studying the effect of local damage on the dissipation of vibration energy in the material is based on the concept of amplitude-dependent logarithmic decrement of vibrations [5–6]. The study of dissipative properties of materials was conducted on prismatic samples of 220×20×4 mm size under pure bending conditions, ensuring a uniform stress state along the undamaged sample's working part. For this purpose, the sample of the researched material *1* (Fig. 1) was rigidly fixed in inertial masses *2* and suspended on thin long strings. Vibrations were excited using electromagnets *3* and metal discs *4*.

To simulate the impact of small stones and foreign objects, a copper device was developed (Fig. 1). The localized damage of the working part of material samples through low-energy impacts occurred directly in the oscillating system. The working part of the sample was positioned at the center of the matrix *5* with a round hole of 18 mm diameter. The impact energy was determined by the height *h* to which the load mass *6* rises. The movement and setting of the load in motion were facilitated using the string *7* and the trigger *8*, along the guide pipe *9* with an internal diameter of 65 mm.

The study of multilayer CFRP sample impact damage was carried out using four types of impactors (I–IV). Removable impactors *10* made of hardened steel had two parallel edge cutouts forming platforms for strain gauges. Two strain gauges, connected in series to eliminate bending strain, constituted the active part (a quarter) of Wheatstone bridge circuit. Contact force $F_c(t)$ during impact damage with an energy of 10 J of the multilayer samples made of woven CFRP T300 by four types of impactors (I–IV) is shown in Fig. 2. The impact energy $E_a(t)$ absorbed by the material was calculated from the contact force diagram (Fig. 2) using formulas [7]:

$$E_a(t) = \frac{m}{2}\left(v_i^2 - v(t)^2\right) + mgu(t),$$

$$u(t) = v_i + \frac{1}{2}gt^2 - \frac{1}{m}\int_0^t\int_0^t F_c(t)\,dtdt,$$

$$v(t) = v_i + gt - \frac{1}{m}\int_0^t F_c(t)\,dt,$$

where $v(t)$ and $u(t)$ represent velocity and displacement, g is the gravity acceleration, m is the impactor mass (4.5 kg), and v_i is the impactor velocity just before its impact on the specimen.

After local damage of the sample, as shown in Fig. 3, the oscillating system (see Fig. 1) was suspended on long metal strings for further studies of the damping capacity, following the methodology presented in [5–6].

Results and conclusions. According to the results of the conducted research, effect of impact energy's impact on the level of dissiaption of vibration energy in material samples and its dependence on amplitudes of relative cyclic deformation in the range of 10^{-4}...10^{-3} were established. It is shown that for

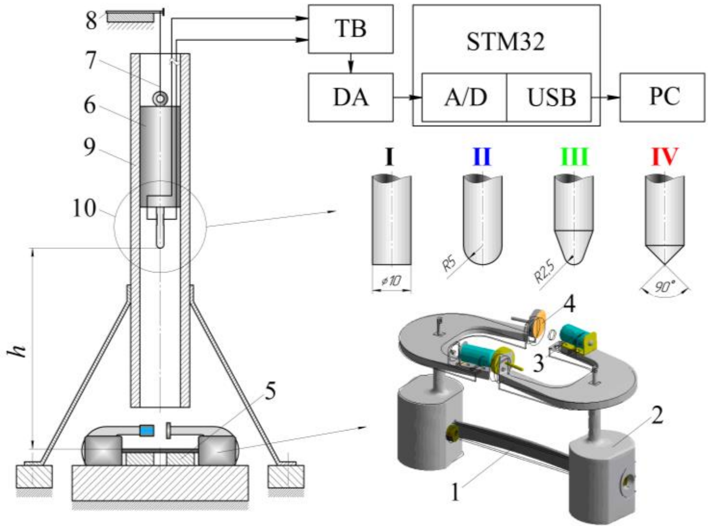

Fig. 1. Scheme of the experimental setup for low-energy impact damage of woven CFRP samples.

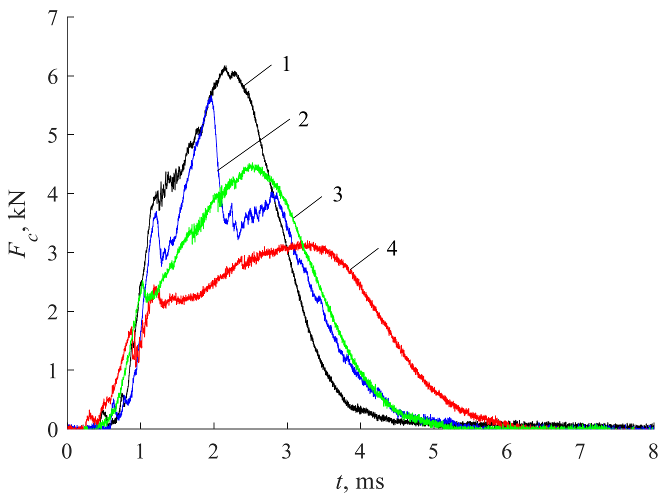

Fig. 2. Time dependence of the contact force during impact load with an energy of 10 J for different types of impactors: 1 – type I; 2 – II; 3 – III; 4 – IV.

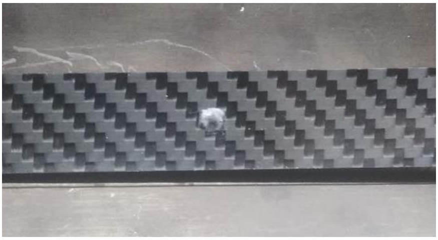

Fig. 3. A working part of a multi-layer woven T300 CFRP twill type sample damaged by a type IV impactor with an energy of 10 J.

damaged samples, the dependence of the logarithmic decrement of vibrations on the amplitude of cyclic deformation has a local maximum at small values. However, a relatively large increase in the level of energy dissipation and the specified nature of its dependence on the amplitude are observed for damaged samples with a critical value of the impact energy.

The developed experimental methods can be valuable for diagnosing damage in composite structures and ensuring their safety and reliability during operation. Further studies will be aimed at advancements in vibration-based damage detection techniques using the amplitude-dependent energy dissipation.

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