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CLIMATIC RECONSTRUCTION OF ELASTIC CHARACTERISTICS OF A HELICOPTER HINGELESS COMPOSITE ROTOR

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ABSTRACT

The procedure of ANSYS software application for solving the inverse strength problem for composite elastic element of helicopter main rotor is presented. The simplex method is used for selection of parameters by means of minimization of the objective residual functional. Two variants of the search are considered: one-dimensional and three-dimensional. The dependences of elasticity characteristics of torsion material on the temperature changes, obtained as a result of identification, are presented.

Key words: fiber glass plastic, rubber, temperature, elasticity characteristics, torsion beam, simplex method, main rotor hub, ANSYS.

INTRODUCTION

For innovation development of modern helicopter technics it is necessary to solve the problem of creating units with combinations of properties which not available only metals and traditional manufacture methods. Modern constructions of helicopter units are designed, as a rule, from composite materials on the polymeric basis. Thanks to the use of composite materials it has become possible on-condition operation of many critical helicopter units. The fundamentally new constructions of units functionally corresponding to metallic ones have been developed. But the high potential of composite materials is not always implemented in constructions with the expected effect when originally designed. There are several reasons: the imperfections of the existing methods of construction calculation, design and manufacturing technology; insufficient attention to composite materials behavior, both when manufacturing, and under service conditions.

The subject of the study is the torsion of helicopter main rotor – elastic element, which connects blade to the shaft. It is the functional analog of the most complicated and critical unit of main rotor – the metallic hub with the horizontal (flapping), vertical (lag) and horizontal (feathering) hinges. Torsion carries out the functions of flapping, lag and feathering hinges, but does not contain bearings and rubbing parts. It is the composite sandwich construction, which is composed of the alternating layers of epoxy glass-fiber-reinforced plastic and rubber.

Fig. 1. Elastic hub of “Ansat” helicopter

Torsion consists of three main parts (Fig. 1): root, working and tip parts. The root part, designed to transmit forces and bending moments to the shaft of the main gearbox, has a central hole for attachment to the hub body and the hole for a spherical jacket support. The working part is elastically deformable and consists of the glueing of PCM and rubber layers. It is divided by longitudinal splits into the torsion beams to reduce the torsion stiffness. The bending of this torsion part in two planes provides blade flapping motion and blade swing motion (the motion about the lag hinge) and the twisting of this torsion part provides the change of blade pitch angle. The tip part of torsion is intended to connect it to blade adapter. Root and tip parts of torsion are massive composite structures. Operational life of working part defines the operational life of torsion.

Multilayer elastic element has a number of operational advantages: it does not have bearings, therefore it does not require greasing; it possesses high strength-weight properties; it has good value of structural damping, which if necessary can be controlled [1]. But during its operation it should be taken into account that the strength properties of composite materials and especially rubber depend on the temperature. As an example, Figure 2 gives the values of modulus of elasticity of aluminum-borosilicate fiberglass E grade (1), resin 5-211B grade (2) and rubber (3) plotted versus the temperature. These dependences are particularly noticeable in the range of helicopter operational temperatures ($\pm 50^\circ C$), where the most essential change in mechanical properties is observed for rubber (200 – 300%) and binder (about 20%) and concerns changes of modulus of elasticity. Fiber glass loses its properties only at very high temperatures ($400 \div 500^\circ C$).

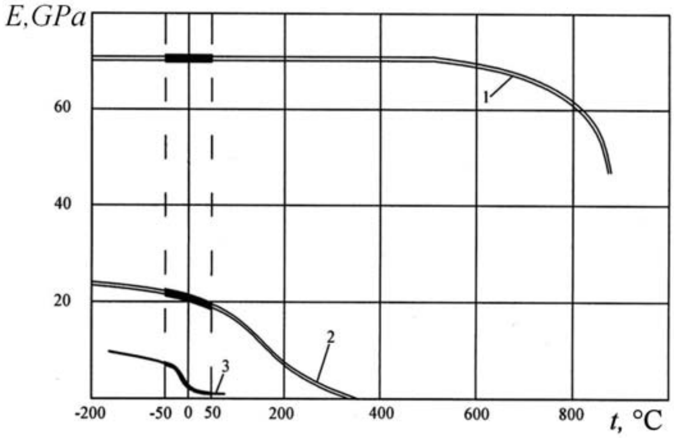

Fig. 2. The experimental values of modulus of elasticity of aluminum-borosilicate fiberglass E grade (1), resin 5-211B grade (2) and rubber (3)

EXPERIMENTS

Experimental strength tests of composite material T-25 were carried out in the laboratory "Strength and reliability of aircraft structures" of KSTU. During the tension of the fiberglass test pieces having the angle of reinforcement of 0° the temperature change influenced the value of the modulus of elasticity as follows: $E_{(t=-50^\circ)} = 53\text{GPa}$, $E_{(t=23^\circ)} = 52\text{GPa}$, $E_{(t=50^\circ)} = 45\text{GPa}$ [2].

Full-scale bending tests in the planes of thrust and rotation as well as twisting tests of one of four torsion beams of the “Ansat” helicopter were conducted in the climate-controlled chamber. The torsion beam consists of 12 packages having 10 layers of fiber glass with reinforcing direction of 0° and 11 layers of rubber in its working part. At the torsion beam ends rubber is replaced with layers of fiber glass reinforced at the angle of $45^\circ C$, the thickness of rubber layer several times exceeds the thickness of fiber glass layer.

In the process of testing the shearing forces in two planes (thrust and rotation) and the torque implemented in the form of the force pair were applied by turns to the end of the torsion beam, fixed as a cantilever. Experiment was conducted at different temperatures of torsion from $-50^\circ C$ to $+50^\circ C$. At that there were measured the displacements of control points in bending in horizontal and vertical planes (L_1, L_2) and in twisting (L_3). Displacements of the control points are shown in Fig. 3 by symbols .○.

METHOD

Earlier the characteristics of rubber were selected by identification of the results of the torsion beam full-scale bending tests in the plane of thrust by means of simulation in NASTRAN software. But elasticity characteristics of torsion beam gained as a result didn’t allow us to simulate the experimental results of torsion beam twisting [3].

Recalculations carried out in the ANSYS software environment using the detailed model of torsion beam also did not give the desired results (Fig. 3). The experimental results disagreed not only with the results of twisting calculation but also with the results of bending calculation in vertical plane – up to 33% (Fig.3a), in horizontal plane – up to 30% (Fig.3б) (the dashed line). With the increase of the fiber glass modulus of elasticity up to 64.2 GPa the difference between theory and experiment in torsion bending in two planes reduces to a minimum (Fig. 3a, Fig. 3б), but it leads to significant discrepancy between calculation and experimental results in torsion bend twisting (Fig. 3в).

In the process of performing calculations the authors came to the conclusion that it is not possible to solve the task by the method of visual sorting, since the high problem sensitivity to the values of elasticity modulus and the need to analyze a large amount of results do not make it possible to attain the acceptable accuracy of parameters selection. So, to automate the search process and considerably reduce the amount of the visually analyzed information the application of one of the optimization methods is desirable.

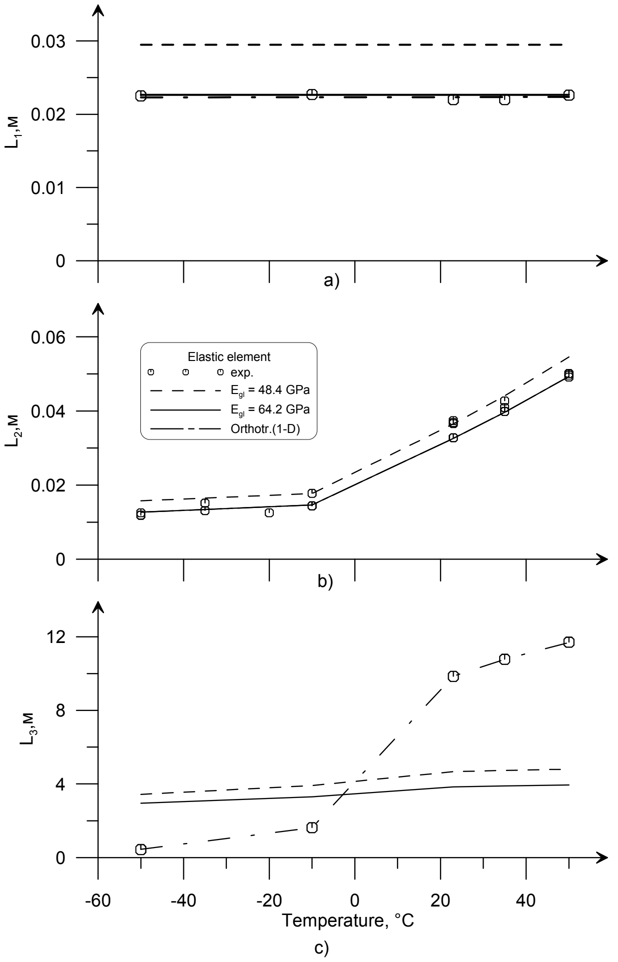

Fig. 3. Comparison of experimental and calculated results

The solving of the reverse strength problem by the sequential solving of number of direct problems in order to make the identification of various elasticity characteristics of materials is very complex and expensive process in the context of computational resources [4]. What is more, using poor experimental data (there are known only displacements, the rotation and twist angles of the torsion tip depending on the temperature) it is necessary to restore the influence of the temperature change on the elasticity characteristics of rubber and fiber glass, from which the torsion beam is made.

According to the expert estimations the Nelder-Mead universal simplex method is selected as a method of optimization [5], implemented in a programming language APDL for application in the ANSYS software.

Let us present fiber-glass plastic reinforced with the angle of 0° along the axis of the torsion beam, of which the construction of torsion consists mainly, as orthotropic material. The Ox axis is put in the plane of rotation opposite to the rotor rotation, the Oz axis – in the plane of thrust in the rotor thrust direction and the Oz axis – along torsion beam in the direction of centrifugal force. Then we will have different elasticity characteristics of fiber glass along the different axes of the torsion beam. It is necessary to have 9 values that characterize elastic properties of fiber glass along orthotropy axes (E_x, E_y, E_z, G_{xy}, G_{xz}, G_{yz}, $\mu_{xy}, \mu_{xz}, \mu_{yz}$). The rubber will be modeled as an isotropic material (E_{rub}, μ_{rub}). In general, all these values to different extent depend on the temperature of material, and not all elasticity parameters identically affect the results of loading.

OPTIMIZATION RESULTS

In order to save computational resources, let us consider the two most common variants of identification. In the first version we choose G_{xz} of fiber glass as unknown and the values of the other characteristics are fixed (1-D one dimensional optimization). In the second version we choose three elastic characteristics of fiber glass and rubber as the unknowns (3-D three-dimensional optimization) (E_{rub}– for rubber, E_z, G_{xz} – for fiberglass). The values of the other characteristics of elasticity are fixed.

The optimization search produced the following result: both optimization variants (1-D and 3-D) give satisfactory results for displacement and twist angle of torsion beam – the difference between displacement and twist angle of torsion, obtained by experiment and calculation is minimal (Fig. 4). But during the one-dimensional optimization the target value G_{xz} of fiber glass at a temperature $-50°C$ reaches rather large physically unreal value (Fig. 5, the dashed line). During three-dimensional optimization the change in value E_z is unessential, and the values E_{rub} of rubber as well as G_{xz} of fiber glass remain within the reference data given in the Fig. 2.

Identification results gives that in the temperature range from $-50°C$ to $+50°C$ the elastic characteristics of the material of the torsion beam can be approximately simulated by the following characteristics: $E = (0.184 \div 1550) \cdot 10^7$ Pa – for rubber; $E_z = (6.7 \div 6.57) \cdot 10^{10}$ Pa, $G_{xz} = (4.06 \div 20.7) \cdot 10^9$ Pa – for fiber glass.

The analysis of the convergence of the search process gives the results which show that at high temperatures ($t \approx 50°C$), when the elasticity characteristics of the torsion depend mainly on three elasticity characteristics examined above, it is possible to reach the rather good accuracy of identification (dispersion of the results of calculation relative to experimental data $D_x < 10^{-11}$, Fig. 5). The search process becomes more complicated at low temperatures ($t \approx -50°C$) at which it is impossible to attain the good accuracy of results ($D_x \approx 10^{-7}$).

Further increase of the required accuracy leads to the fact that the process of search leaves the region of the physically realizable values (Fig. 5). At small temperatures the influence of the elastic characteristics, which were assumed to be constants, begins to affect the process; therefore the selected number of parameters must be more than three.

For the detailed identification of elastic characteristics, especially this concerns minus temperatures $t < -10°C$, it is desirable to have results of the more informative specially planned experiment. The temperature range from $-5°C$ to $+20°C$, in which an abrupt change in the strength characteristics of materials occurs may be a particular case.

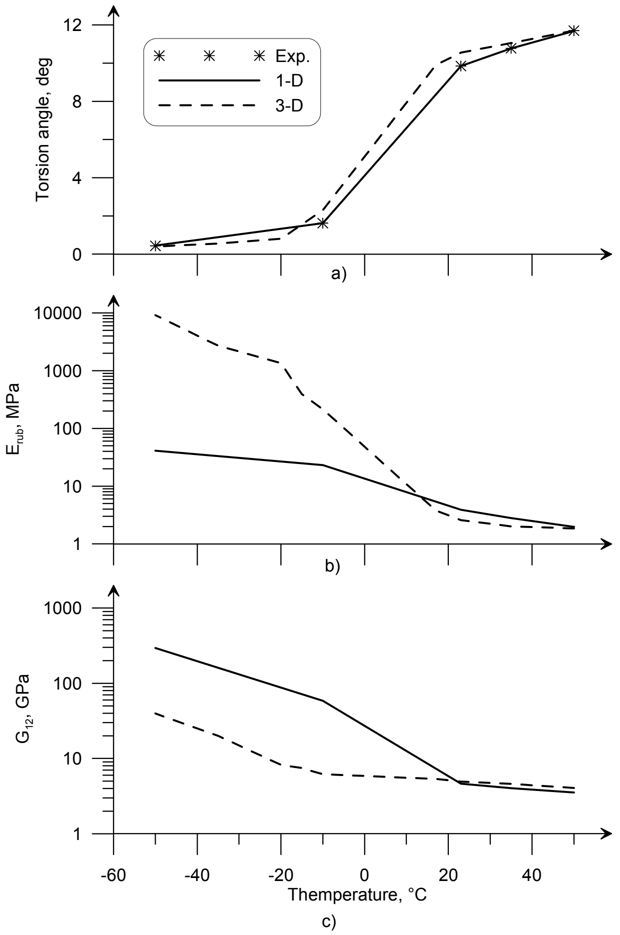

Fig. 4. The results of 1-D and 3-D optimization

Application of the Nelder-Mead simplex method for the identification of elasticity characteristics of torsion material allows to select the necessary elasticity characteristics of torsion depending on the temperature in the process of the computer-aided search with the accuracy acceptable for practical purposes. Characteristics of materials obtained by the identification can be used to simulate the boundary conditions in calculating the vibrational and aeroelastic characteristics of blades and rotor shaft. But to calculate the stress-strain state of the torsion bar it is necessary to use more complicated optimization models with many parameters using data of specially performed experiment.

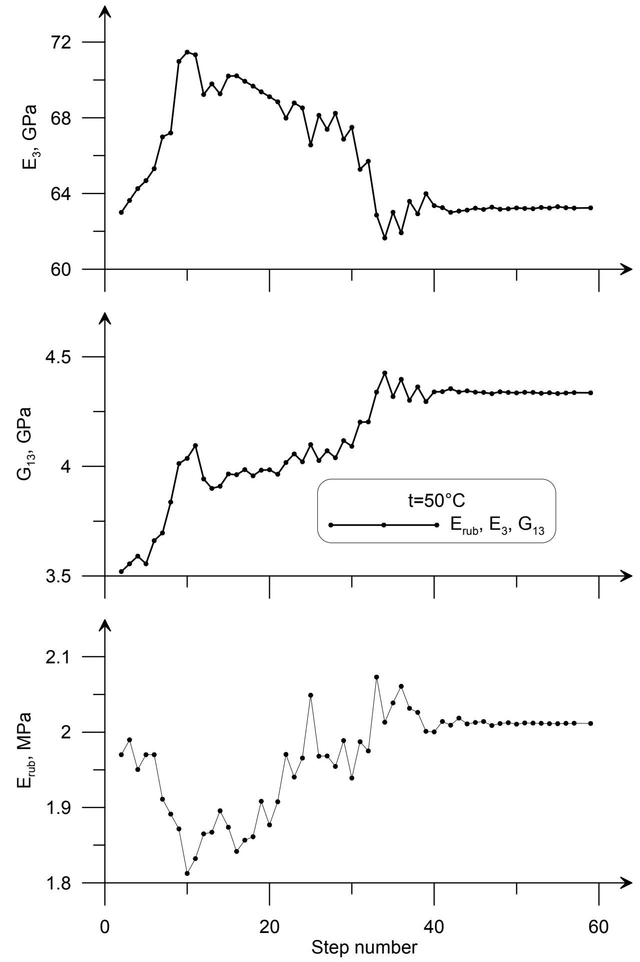

Fig. 5

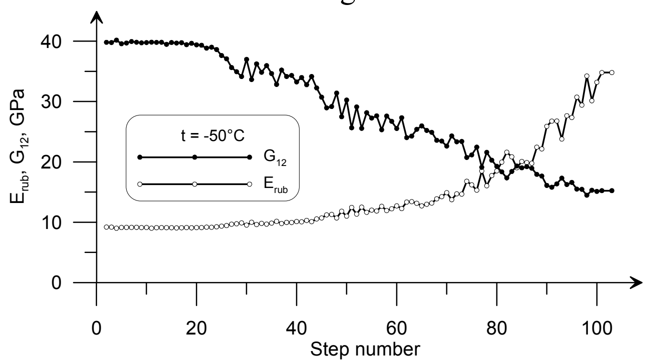

Fig. 5. The analysis of the convergence of the search process

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