Methodology to Provide Strength and Service Life of Composite Hingeless Rotor Elastic Elements

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Abstract: The abstract shall not exceed 250 words. It summarises the paper in such a way that the reader does not need to refer to the full paper in order to understand it.

INTRODUCTION

The hingeless main and tail rotors are widely used as standards in the present-day helicopter design. Although the production costs somewhat rise, such structures are justified at the expense of lower operation costs (change to operation by condition) and simpler maintenance procedures. High qualities of such structures are provided by the application of current composite materials, by a high level of design and improved analytical and experimental methods; these methods can be used for solving problems of structure parameter optimization and realization of specified characteristics of static strength and service life with respect to fatigue strength.

In accordance with the standard documentation existing in Russia for helicopter certification (FAR-29, FAR-27), not only helicopter flight performance, but also composite materials produced by the developer must meet the certification requirements.

In addition to the certification requirements for environmental conditions of helicopter operation in Russia, specifications to a helicopter under development involve its flight within a range of ambient temperature variation (±50°C), at high humidity and impact of hostile media.

Since 1993 Kazan Helicopters has been developing a family of light single-rotor helicopters. The certification tests of the Ansat helicopter with takeoff weight to 3.3 ton are scheduled to terminate in 2003, and we hope to obtain a type certificate in accordance with the certification requirements of FAR-29.

1. SPECIAL FEATURES OF THE ANSAT HELICOPTER HUB

The Ansat helicopter is equipped with a hingeless main rotor and composite blades of main and tail rotors. These structures of different design versions are today subjected to numerous kinds of tests to ensure basic strength and service life parameters.

In selecting an optimal solution for the main rotor (MR) hub structure, the most important criteria among many variants were the structure mass, operational manufacturability (and hence – cost), reliability and failure safety.

The main rotor hub is designed as a hingeless one with an elastic torsion that performs the functions of flapping, lag and feathering hinges (Fig. 1).

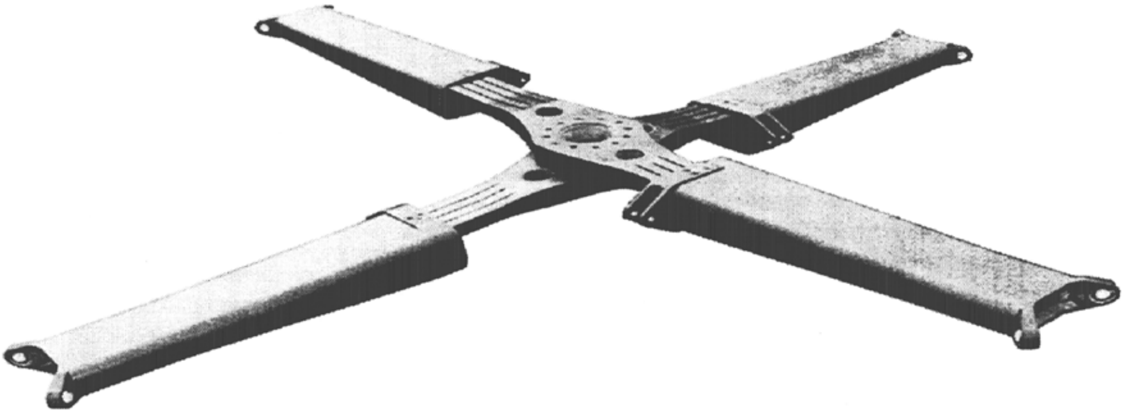


Figure 1. General view of MR hub

The main rotor hub torsion is designed as a composite beam. An elastic deformable section is made as a rectangular beam and consists of compacted packets and interlayers; packets of high-modular fiber-glass plastic and interlayers of low0modular viscoelastic and plastic material alternate in height. To reduce torsional rigidity, the beam has longitudinal slots; therefore, this torsion section can be used as a feathering hinge of the main rotor hub.

The rigidity and geometrical parameters of the torsion packets on the elastic deformable section are so selected that they provide the necessary frequency characteristics for the system "MR hub–blade" in the flapping and rotation planes, as well as strength and required service life. Unlike other elastic elements of the beam type, the low modular plastic materials with visco-elastic properties used in the torsion afford certain damping of blade vibrations in two planes.

The low-modular viscoelastic material interlayers between the high modular fibre-glass plastic packets allow these packets to operate under a variable load in the flapping plane with "tensile–compressive" strains and a small bending. This is due to the shear strains in the interlayers resulting in higher parameters of the torsion service life.

The torsion axis displacement from the shaft axis in the rotation plane Δ provides for bending moments relief of the torsion root in the rotation plane M_{rot} (Fig. 2). A cone angle provided by the torsion reduces its bending loads in the flapping plane.

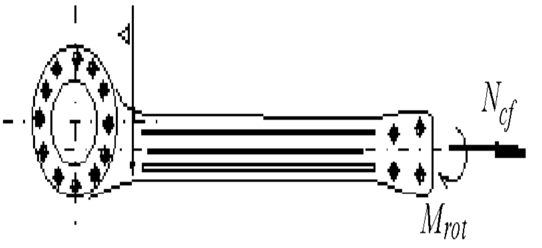


Figure 2. Rotation plane

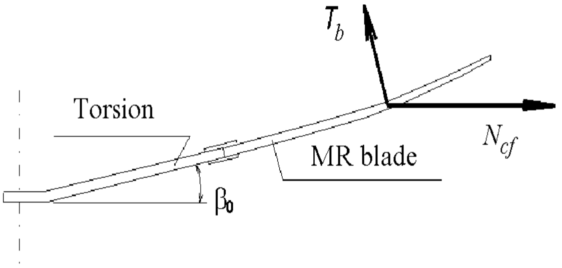
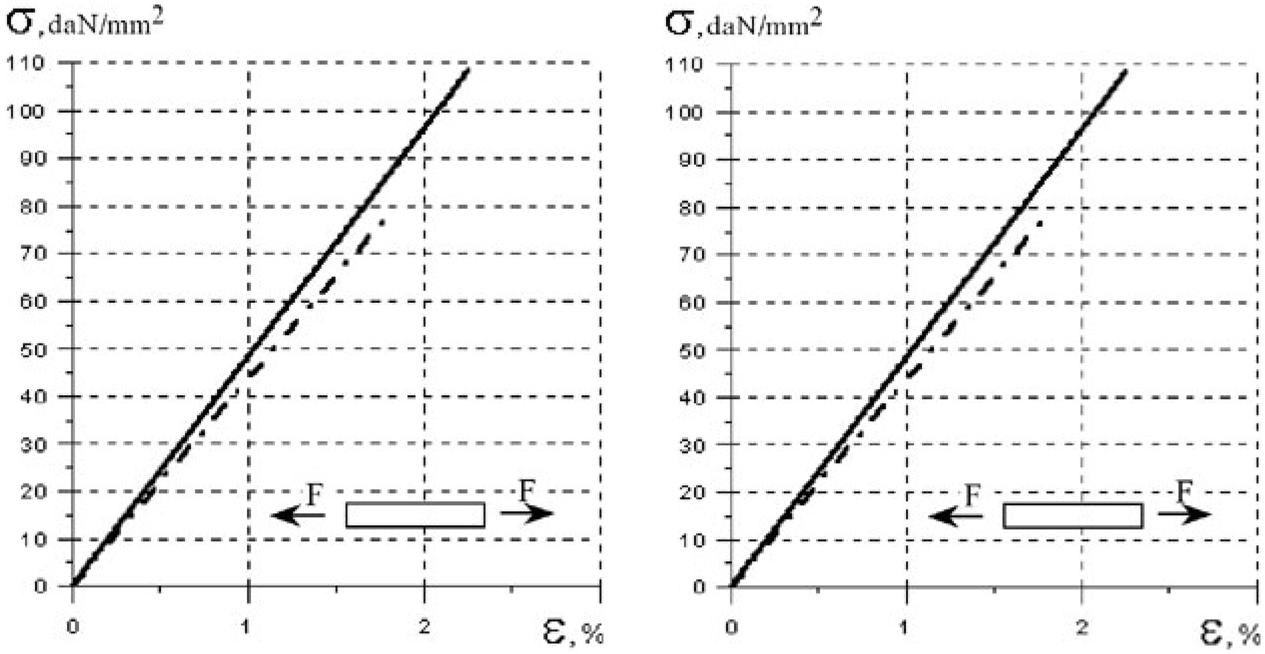


Figure 3. Bending plane

A special feature of the hub structure is the fact that the torsion housing which transfers a torque and controlling actions from the blade to the wobble plate bears no tensile and bending loads owing to the kinematic scheme of torsion attachment.

2. DETERMINATION OF MECHANICAL CHARACTERISTICS OF MATERIALS USED FOR TORSION MANUFACTURE

To create a data bank on the physical and mechanical properties of composite materials used in manufacture of an elastic element, tensile (rupture) and bending (fracture) tests were conducted in accordance with the certification requirements.



a) tension *b) bending*

Figure 4. comparison of the $\sigma - \varepsilon$ relations for the specimens exposed and not exposed to a radiation action

Standard specimens were used for the tests. The experimental $\sigma - \varepsilon$ diagrams for the variants of tensile and bending tests are shown in Fig. 4., a gives comparison of the $\sigma - \varepsilon$ relations for the specimens exposed and not exposed to a radiation action. As is seen from the diagrams presented the relation $\sigma - \varepsilon$ retains its linear character to the point of failure. To meet the specification requirements the physical and mechanical properties of composite materials were in addition tested at increased (to +80°C) and decreased (to –50°C) temperatures. Not only standard specimens but also fragments of the elastic element structure were subjected to environmental tests.

3. DETERMINATION OF HELICOPTER LOADS

3.1 Analytical and Experimental Determination of Helicopter Main Rotor Loads

Since the Ansat helicopter being developed is a totally new helicopter of this class in rotorcraft production of Russia, prediction of loads on its lifting system was a rather labor-intensive problem. The reliable flight data on loads were first obtained only in 2000, but the bench tests of elasticelement specimens have been conducted since 1997.

In this situation a demand arose for design methods to predict loads, and for their creation we had to solve a number of problems associated with the operation characteristics of the hingeless main rotor [1 – 3]:

1. Development of a model of helicopter spatial aeroelastic trimming using a geometrically nonlinear model of blade deformation;
2. Development of a simplified model of torsion deformation on the basis of a beam multilayer composite structure. A design model of this type is intended to create a torsion compliance matrix in the zone of blade articulation. The model takes into account a blade root space position under load in the problems of aeroelastic calculation.

3.2 Analytical and Experimental Evaluation of General Static and Local Strength under the Action of Equivalent Design Loads

A torsion is a beam of a complex shape with the complex rectangular cross-section; it has openings and three longitudinal slots dividing the working section into four “grooves” (Fig. 6). The beam model makes it impossible to determine the torsion stress-strain state with a required accuracy; therefore, the design scheme was based on the finite-element method in the three-dimensional statement.

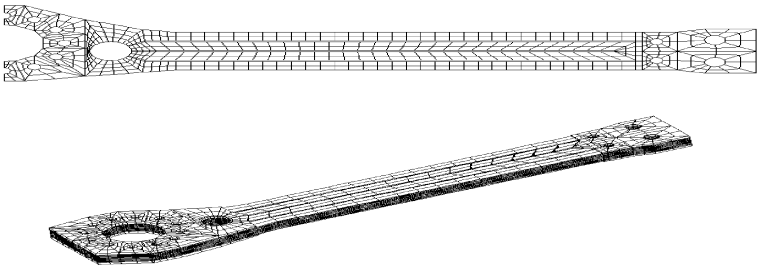


Figure 5. Torsion

A grid of finite elements was used which makes it possible to adequately represent all geometric features (cutouts, adapters, fillets, and others).

A a three-dimensional model with a set of finite elements across the thickness is used in the calculation; the number of finite elements is equal to the number of layers of significantly different materials. Since the number of layers is great, but each layer is small in thickness, the use of linear approximation in the transverse direction is quite justified. For the exact representation of the geometry features and displacements, quadratic approximation was used in the plane of layer placement (in the direction of two other coordinates). As a result of mathematical modeling, an algebraic problem with 145296 unknowns was obtained. Its solution was based on the finite-element technique with the use of the grid described in plan and according to the placement pattern (each layer is a finite element). The mathematical model is described in detail in [2]. The calculation results for basic loadings (bending, tension, torsion) well agree with the experimental data.

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