Determination of fatigue resistance characteristics of helicopter rotor blade

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Abstract. This paper presents an investigation of the fatigue resistance testing of structural elements of the helicopter by the example of testing of helicopter rotor blades samples. Endurance tests of components and structural elements of aviation equipment are the laboratory reproduction of external influences corresponding to the typical operating conditions, cyclic loading and functioning. However, these tests do not include research related to the gradual accumulation of damage leading to the emergence and propagation of cracks and construction failure. In this regard, a special interest is learning the process of cracks growth during the specimens’ full-scale tests. A brief description of the blades endurance tests process with simultaneous video shooting has been given. Stretching static load is applied to the samples, after those samples are additionally loaded by alternating bending moment. Videos of the cracks growth are processed and the data about the time of subcritical crack growth are obtained. This information is displayed as a graph. The control and measurement system is considered which is used in the process of testing for recording of values of stress occurring in tested specimens because of alternating bending load applied to them. The characteristics of fatigue strength are determined, fatigue graph is plotted, durability arithmetic mean and standard deviation are determined, assemblage of durability distribution curves, assemblage of fatigue curves and endurance distribution curve are plotted, endurance limit arithmetic mean and standard deviation are determined. The achieved results have importance for the prediction of the safe operation term of the helicopter rotor blades.

1. Introduction

Creation of a test complex for carrying out resource tests of products and elements of aircraft structures that includes automation and optimization of production processes, a special quality control system for these tests, is an urgent task.

Resource testing of products and structural elements of aviation equipment is the reproduction in the laboratory of external influences corresponding to the conditions of typical operation, cyclic loading and functioning [1, 2]. Each serial product of aviation equipment is tested on stands with the help of which the quality of manufacturing and debugging of aggregates and systems is checked. Solving this problem requires predicting the occurrence of crack-like defects and their further development. To speed up the detection of defects, long-term tests can be carried out with a significant
excess of loading parameters. After the completion of the tests, the product is completely disassembled, flushed, inspected. The general requirement for the state of the parts after the test is the absence of defects of emergency nature. The positive results of periodic tests confirm the conditionality of the entire batch of units, assemblies and parts produced by the plant. If large cracks are found during testing or disassembly, the tests are considered to have failed. After clarifying the reasons, duplicate tests may be allowed. After finding out the reasons for the defect, the customer may be allowed to retest. Tests are qualified as successful if they were not destroyed by the tested products and assemblies, as well as failures that, during operation, could lead to dangerous failures.

The determination of the resource of the product is carried out in accordance with the normative documents. However, these tests do not include studies related to the gradual accumulation of damage leading to the formation and development of cracks, structural failure. In other words, the permissible operational fatigue damages of the structure are not included in the service life of the product, provided that the crack grows slowly. In this connection, particular interest is the study of growth of cracks in the conduct of full-scale testing of samples [3, 4].

2. Stands for fatigue strength tests

The resource tests of helicopter blades were in the laboratory “Reliability, Strength of Products and Structures”, established at the East Siberian State University of Technology and Management and LLC “Small Innovative Enterprise “Baikal Scientific Strength Center”. To carry out the tests, drawings have been developed, according to which test benches have been made (Figure 1).

Samples are attached to the stands using wedge-shaped fittings.

During the tests, loads that correspond to real operating conditions are reproduced, and indications (loads, deformations) are taken, on the basis of which the conclusion is made about the degree of conformity of the object to the established technical standards.

During the tests, the growth of cracks in the test specimens is recorded using a specially designed imaging apparatus. Figure 2 shows photos of the specially apparatus and fatigue failure of the blade after testing.
Figure 2. a – camera set for carrying out experimental works: 1 – tripod DEXP WT-3770, 2 – helicopter rotor blade, 3 – fixing bands, 4 – GoPro HERO4 Silver video camera; b – fatigue failure of the blade.

3. Complete probability diagram of fatigue
Since the limit of endurance in a symmetrical cycle and the number of cycles before failure are random variables, the fatigue fracture process is therefore of statistical nature, and building a fatigue line from the test results of several samples can cause errors. In this connection, in order to obtain more accurate results, it is reasonable to construct complete probability diagrams of fatigue from the results of testing a large number of samples.

Tests are carried out at several levels of alternating loading before failure (in our case, the tests were carried out under four loading regimes – the maximum amplitude of the alternating voltages was 100 MPa, 85 MPa, 75 MPa and 55 MPa, respectively). Then, based on the results of testing a series of \( n = 28 \) samples at a constant loading level, a variation series is created in which the results are arranged in order of increasing durability (i.e., the number of cycles that the sample survived to failure):

\[ N_1 < N_2 < \ldots < N_n. \]

The arithmetic mean of the logarithm of longevity is determined by the formula:

\[ \bar{N} = \frac{\sum_{i=1}^{n} N_i}{n} = 5.023 \cdot 10^3. \]

Scattering of values \( N \) about the mean value is determined by the root-mean-square deviation, calculated by the formula:

\[ S_n = \sqrt{\frac{1}{n-1} \left( \sum_{i=1}^{n} N_i^2 - \frac{1}{n} \left( \sum_{i=1}^{n} N_i \right)^2 \right)} = 1.007. \]

In order to construct a complete probability diagram of fatigue, in addition to the durability values \( N \), it is necessary to know the so-called fracture probability estimates (cumulative frequencies) calculated by the formula:

\[ Q_i = \frac{i - 0.5}{n} \cdot 100\% , \]

where \( i \) – sample number in the variational series, \( n \) – number of samples tested at a given loading level (\( n = 28 \)).

A complete probability diagram of fatigue can be represented as a family of longevity distribution curves or as a family of fatigue curves corresponding to different values of estimates \( Q \). The diagram in the form of a family of curves for the distribution of longevity in the coordinates “the decimal logarithm of the number of cycles of loading to failure (logarithm of longevity) – the accumulated frequency” for four loading regimes is shown in Figure 3.
Figure 3. Complete probability diagram of fatigue in the form of a family of distribution curves of longevity: 1 – $\sigma_a = 100$ MPa, 2 – $\sigma_a = 85$ MPa, 3 – $\sigma_a = 75$ MPa, 4 – $\sigma_a = 55$ MPa.

The fatigue curves corresponding to different values of the fracture probability estimates $Q$ (the second case) can be obtained as follows. The resulting curves are dissected by horizontal lines corresponding to different values $Q$, and on the basis of the values at the intersection points the fatigue curves in the coordinates “the maximum amplitude of the variable stresses $\sigma_a$ – the logarithm of durability $\lg N$” are constructed for different values of the fracture probability estimates $Q$. Most often in practice, the following values of probability estimates are chosen: 1%, 10%, 30%, 50%, 70%, 90% and 99%. The resulting family of fatigue curves is shown in Figure 4.

Figure 4. Complete probability diagram of fatigue in the form of a family of fatigue curves: 1 – $Q = 1\%$, 2 – $Q = 10\%$, 3 – $Q = 30\%$, 4 – $Q = 50\%$, 5 – $Q = 70\%$, 6 – $Q = 90\%$, 7 – $Q = 99\%$.

Using the fatigue diagram, we construct the distribution curve of the endurance limit (Figure 5).

Figure 5. Endurance limit distribution curve.
4. Experiment video recording

Based on the results of video recording processing, information on the dynamics of the change in the dimensions of the crack can be obtained. This information is displayed in the form of a graph - the dependence of the rate of crack growth on the time of its growth (Figure 6).

![Dynamic of the crack length and Dynamic of the crack width](image)

**Figure 6.** Graphs of increase in the dimensions of the crack.

In the beginning the crack is born and gradually grows up [5, 6]. The process of rapid growth of cracks takes only 5-10% of the total growth time of the crack before the final destruction. All the rest of the time we have to start and gradually grow up the cracks. Development only gets those cracks that have a sufficiently long length and sharp top. One of them leads to the final destruction of the part.

5. Conclusion

Based on the results of the tests, a fatigue graph was constructed, the arithmetic mean and the standard deviation of the logarithm of longevity were determined, a family of longevity distribution curves, a family of fatigue curves, the endurance distribution curve, and the mean and the standard deviation of the endurance limit were determined. Based on the processing of videotapes, it is established that 90-95% of the time of its growth the crack grows slowly and does not affect the strength of the structure as a whole. The obtained results make it possible to predict the life (term of safe operation) of the helicopter blades, which prevents the emergence during the flights of emergency situations that threaten the death of the crew and passengers [7–10]. The test results data will be used for further improvement of the helicopter blades production technology at JSC “Ulan-Ude blade factory”.

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