Processing of videos of the fatigue cracks propagation in the rotor blades of the helicopter

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Abstract. The article describes the processing of videos of growing fatigue cracks in the main rotor blades of a helicopter, which are formed during their fatigue tests on the stand. A specially created computer program allows to determine the geometrical parameters of a crack based on video recording (length, width, extreme points, center of gravity). Each frame of the video is binarized, after which a binary matrix is created on its basis, which is subject to element-by-element processing. The obtained data are presented in the form of a graph showing the dependence of the crack growth rate on the time of its growth. The graph is traced in the Mathcad program, as a result, two data vectors are created — the time and crack growth rate, which undergo an interpolation procedure with the construction of a third-degree polynomial. According to the results of the integration of the polynomial, the critical length of the crack is determined, after reaching which its rapid growth begins.

1. Introduction

During the fatigue tests of the main rotor blades of a helicopter, video footage of the growth of fatigue cracks arising in these blades is made [1]. An example of a sequence of frames from such a video is shown in figure 1, where the crack position is indicated by an arrow. The final frame corresponds to the moment of destruction of the sample - dividing it into two parts.

![Figure 1. Images from crack growth video.](image-url)
The aim of the study is to determine the growth rate of fatigue cracks, their critical length and time of subcritical propagation on the basis of available video.

To achieve this aim it is necessary to solve the following tasks: the creation of a method for processing video recordings; determination of the geometric parameters of the crack on each frame of the video based on the results of processing this frame; tracing and interpolation of the obtained data in order to determine the crack growth rate, time of its growth and critical length.

2. Research methodology

In order to determine the growth rate of cracks, a computer program was developed for video processing, in which each found crack has a separate entry in the internal database of the program. After the file was loaded into the program, the recording was divided into separate frames. Each frame was binarized (converted from color to black and white) [2]. The binarization threshold is selected so that the crack area on the frame remains black and all other pixels become white. An example of the image obtained as a result of binarization is shown in figure 2.

![Binarized frame and an example of a matrix corresponding to such a frame.](image)

For each binarized frame, a matrix $F$ was created consisting of zeros and ones (figure 2), where the white pixels of the background correspond to the zeros and the black pixels of the crack correspond to the ones [3]. This matrix was subjected to elementwise processing.

After processing the entire matrix, the database contains information about all the cracks found on the frame. These records were processed, the results of which identified the main parameters of the cracks - length, width, extreme points, center of gravity (figure 3).

Thus, following the results of processing the entire video, information was obtained on the dynamics of crack growth. These data are presented in the form of a graph (figure 4), where the abscissa axis is the time of crack growth in hours, and the ordinate axis is the rate of its growth in millimeters per hour [4]. It is seen that in the process of testing the crack growth rate gradually increases until a sharp jump occurs, ending with the destruction of the sample.

Small jumps of graphs up and down are due to the fact that the tip of the crack is poorly visible on some frames, so the rate of its growth is determined with some error - on some frames the crack looks longer, on others it is shorter.

The resulting graphs are traced in the Mathcad package (figure 5). As a result of this operation, two data vectors were created - the crack growth time in hours and the crack growth rate in millimeters per hour [5].
The data obtained were subjected to an interpolation procedure with the construction of the interpolation cubic polynomial. The interpolation cubic polynomial representing the dependence of the crack growth rate (mm h\(^{-1}\)) on the time of its growth (h) is described by equation (1):

\[
v_{\text{length}} = 8.386 \cdot 10^{-7} t^3 - 1.364 \cdot 10^{-4} t^2 + 5.722 \cdot 10^{-3} t + 0.255.
\]  

**Figure 3.** Determination of geometric parameters of cracks.  
**Figure 4.** Kinetic graphs of crack propagation (horizontal axis – crack growth time (h); vertical axis – crack growth rate (mm h\(^{-1}\))).  
**Figure 5.** Tracing the graph in the Mathcad package.
3. Results
Substituting different values of crack growth time into formula (1), we obtain the values of crack growth rate. These data are presented in the table 1.

| Crack growth time (h) | Crack growth rate (mm h⁻¹) |
|------------------------|-----------------------------|
| 1                      | 0.26                        |
| 10                     | 0.3                         |
| 50                     | 0.31                        |
| 100                    | 0.35                        |
| 120                    | 0.43                        |
| 140                    | 0.431                       |
| 150                    | 0.73                        |
| 160                    | 1.11                        |
| 170                    | 1.41                        |
| 180                    | 1.76                        |
| 190                    | 2.17                        |
| 195                    | 2.4                         |
| 200                    | 2.6                         |

The data in the table is displayed as a graph (figure 6). As can be seen from the graph, the rapid growth of the crack begins after 140 hours of its propagation.

Figure 6. Graph of crack growth rate in blade samples depending on the time of its growth.

To determine the value of the critical crack length, we integrate equation (1) over time with an upper limit of 140 hours, corresponding to the beginning of the rapid crack growth:
\[ \int_{0}^{140} 8.386 \cdot 10^{-7} t^3 - 1.364 \cdot 10^{-4} t^2 + 5.722 \cdot 10^{-3} t + 0.255 \, dt = 47.544 \text{ mm.} \]

The obtained value is consistent with the experimental data - during the tests it was noted that rapid unstable crack growth begins when it reaches a length of 45-50 mm.

4. Conclusions
The period of subcritical crack propagation can be included in the assigned blade resource, since in this period, averaging the first 140 hours of crack propagation, the blade destruction does not occur. In a specified time, the crack grows to a length of 45-50 mm, after which its rapid unstable propagation begins, then the operation of the blade becomes dangerous.

The developed program allows to determine the growth rate and critical length of the crack with a sufficient degree of accuracy, which is confirmed by the good convergence of the results of the program with the experimental data. The developed software can be used to assess the growth rate and time of fatigue cracks in various engineering objects.

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