UDC 531.7:62-2:629.7 (043.3)

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The development of a differential-digital method for precision measurements of the geometric parameters of aviation details

In this article we propose a new method of measuring complex three dimensional surfaces of aircraft parts in static and dynamic modes. The method allows to conduct measurements in closed conditions and at the site of the aircraft disposition. The method consists in the continuous determination of the coordinates of the points of the surface of the detail and their representation in a three-dimensional graphic depiction.

The rapid development of the aviation industry in modern times is accompanied by a significant increase in the requirements for the reliability of the mechanisms functioning and observance of high accuracy and speed during measuring them. Inaccurate parts manufacturing significantly affects the performance of aircrafts, such as durability, reliability and, to a large extent, depend on the correctness of the choice of shape tolerances and location of the surface.

This, in turn, requires the aviation enterprises to improve the accuracy of the measuring operations, the optimal choice of geometric parameters measuring instruments of the parts and units, the development of new and improved existing methods of measuring the linear-angular dimensions of the parts that would be acceptable in combination with modern computer trichrometers modulation programs and resistant to production conditions.

To solve the problem a method of measuring the complex spatial surfaces of aircraft parts in static and dynamic modes was crafted. The method allows to conduct measurements in closed conditions and at the site of the aircraft disposition. The method consists in the continuous determination of the points coordinates of surface detail and their computer processing and three-dimensional representation of a result.

We recommend usage of such sensors as: optical, optical fiber and video. By scanning the surface of the detail, these sensors allow the determination of coordinates with high accuracy and speed (more than 10^5 measurement points per 1 second).

It is also possible to carry out automatic corrections of temperature and vibration errors, which allows using these sensors in the workshop.

A cluster to determine the deviation of the shape and location of the surfaces was entered, which corresponds to the tolerance field according to the spectrum of the color image.

Differential-digital method is implemented in the following sequence:

1. Installing the detail and based on regular reference points, which are specified in the design documentation.

2. Carry out technical measurements of a limited number of points, which allow the simultaneous combination of a mathematical model (reference model) with a crafted detail.

3. Preliminary calculation of spatial alignment or transfer parameters.

4. Measurement in the automatic mode of optical sensors scanning with not less than 150 - 1100 points on the surface of the detail, depending on the size and field of admission on its geometric parameters (Fig. 1).

5. Estimation of the accuracy of the base of the detail.

6. Conduct of control measurements at separate points where there is an abnormal deviation.

7. The color image is converted to numeric data and the distribution of color information is handled.

8. A graphic image is created on clusters and maps are obtained to identify the trend of the surface of the entire detail and for each sector.

The value of the color of the discrete points of the digital image forms the area represented in the form of isolines. As a result, a color image area is formed which corresponds to a deviation from the shape and location of the surfaces and differs from each other in color.

Specialized software includes digital model of the reference aircraft detail in form of geometric parameters. The software is based on the mathematical model of the aircraft component.

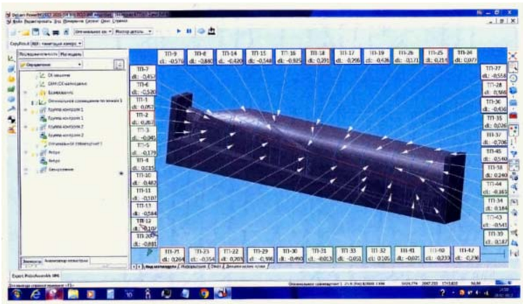

Figure 1. Results of the measurement of the surface of the aircraft component with the determination of the error and deviation of the form

In addition to measuring flat details, the big task is to determine the curvature of the surface and the angle of rotation of the plane of the detail.

This dependence is in the form of a three-dimensional array, in which one column occupies the angle of inclination of the plane, the second - the curvature of the detail the third - the coordinate. When scanning on the surface of a detail, a function is used which is based on the mathematical model of the detail process.

To scan the surface of the detail, used a function which is based on the mathematical model of the detail process.

The definition of geometric parameters in the Power Inspect program is similar to the geometric deviations from the shape and location of surfaces, as well as more complex second-order surfaces that include a large number of parameters.

The obtained values of the angle of inclination of the plane and the curvature, as well as the value of the coordinates, are compared with the field of admission to this detail and with the spectrum that is represented in the Fig. 2.

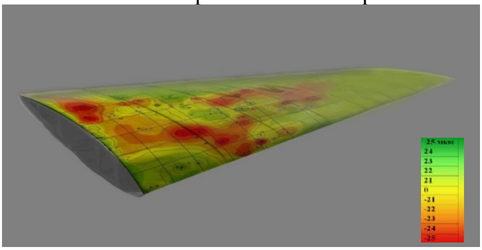

Figure 2. Color map of geometric parameters of deviation from the shape and location of the surface

Differential-digital method makes it possible to study the errors, determine the geometric parameters of the detail and obtain the cross sections with the help of advanced methods of algorithmic errors corrections, which provides a zero displacement for working conditions of measurement after the training procedure with the obtaining of the statistical result. In the result of research systematic error of coordinate points of the surface details reduced by 0.3 mm.

The development of a differential-digital method involves the use of an additional information parameter in a mathematical model, which includes in the conditions of the task of measuring the geometric parameters of aircraft parts of a complex curved form of additional (a priori) information, which leads to the problem of correcting in accordance with the method of regularization for a functional.

$$\Omega(x,\lambda) = |Ax - b|^2 + \lambda|x - x_0|, \tag{1}$$

where $\lambda \to \infty$, x_0 – a priori vector of the solution, which coincides with the regularization coefficient.

We use this approach to solve the problem of determining the geometric parameters of aircraft parts of a complex curved form using the triangulation of Delone and using the operation of minimizing the sum of squares of the deviation, we obtain the following expression:

$$\Phi(\alpha) = \sum_{i=1}^{n} \delta_i^2 + \mathrm{reg}\,(a, w), \tag{2}$$

where $\sum_{i=1}^{n} \delta_i^2$ – the sum of the squares of deviation n measured points, then from the constructed surface; $a = a_0, a_1, \dots, a_i, \dots, a_k$ – desired geometric parameters of the measured aircraft part; $\mathrm{reg}(a, w)$ – regulatory member, which includes information on the nominal value of the geometric parameter and the regularization factor w

$$\mathrm{reg}(a, w) = w \sum_{i=1}^{k} \left(a_i - a_{i_{yjv}}\right)^2, \tag{3}$$

Thus, we obtain the task of a regularizing link, which characterizes the deviation of the geometric parameters of the aviation component from their nominal values. You can get a clear minima in the minimization function. The obtained results were stable and met the size of the field of tolerance of the measuring part.

Mathematical expectation of the number of deviations from the geometric form at carrying out of n_i technological operations d_i^* can be represented by the expression

$$d_i^* = k_{n,i} n_i p_{0,i}, \tag{4}$$

where $k_{n,i}$ – the average value of the coefficient of influence of external destabilizing factors on the reduction of the accuracy of the measurement of the geometric parameters of the details.

It is known that at each measurement and at each level of control of the aircraft component there is a certain probability of detecting certain deviations from the given geometrical parameters d_i made in n_i technological operations

$$d_i = k_{n,i} n_i p_{0,i} \prod_{z=0}^{m_i} (1 - p_{k,z}), \tag{5}$$

where $p_{k,z}$ – the probability of detecting deviations from the given form and plane during the measurement (at $z = 0$, $p_{k,0} = 0$); m_i – total number of measuring operations.

The complexity of geometrical parameters details can be represented by the expression

$$K_c = K_{\text{т}} K_z K_n K_{\text{т.о}}, \tag{6}$$

where K_c, $K_{\text{т}}$, K_z – factors of complexity, accuracy and roughness details; K_n – number of operations and conversions; $K_{\text{т.о}}$ – coefficient characterizing the complexity of the measurement.

If the geometric parameters of the aircraft part are within the tolerances, then at the initial moment of time the probability of finding the initial parameter p_0 in the permissible limits is equal to unity

$$p_0 = \int_{-\Delta_H}^{\Delta_B} \varphi[a(t_0)] da = 1, \tag{7}$$

where $\varphi[a(t_0)]$ – density of distribution of probabilities of the original geometric parameter a at the initial moment of time.

Since the designed designer circuit usually uses not the entire range of possible values of output parameters, the probability of introducing a geometric parameter deviation can be expressed as

$$q_{\text{с−к}} = 1 - p_0 p(\Delta), \tag{8}$$

where $p(\Delta)$ – the probability of using the entire range of values of the original geometric parameter of a particular aircraft component.

Given that in the process of work the initial geometric parameters of a particular aircraft component are changed, the number of deviations made from the given form and plane $Д_{\text{с−к}}$ is equal to

$$Д_{\text{с−к}} = \sum_{i=1}^{k} d_i \left\{ 1 - p_0(\Delta) \int_{-\Delta_{\text{н}_i}}^{\Delta_{\text{в}_i}} \varphi[a(t)]\, dt \right\}, \tag{9}$$

where d_i– the number of repeated measurements of the *i*-th geometric parameter of the detail.

It is proved that deviations from the form and plane $Д_{с-к}$ are practically not detected in measurements carried out under normal conditions. Only the defects of the first group are detected.

The resulting describes the total number of deviations that may occur in the aircraft component. However, they all actually have a different nature of origin. The greater the loading of airborne parts due to the deviation from the geometric shape or plane, the greater the probability of manifestation of these defects. Depending on the load, the manifestation of deviations can be described by a n-dimensional normal distribution

$$f_n(R) = \frac{1}{\sigma_1 \dots \sigma_n \sqrt{(2n)^n D}} exp\left\{-\frac{1}{2D}\sum_{i}^{n}\sum_{k}^{n} D_{ik}\frac{R_i - a_i}{\sigma_i}\frac{R_n - a_k}{\sigma_k}\right\},$$

where D_{ik} – algebraic complement of the element ik to determinant D;

$$D = \begin{vmatrix} 1 & r_{12} \dots r_{1n} \\ r_{2n} & 1 \dots r_{2n} \\ & \dots \\ & r_{n1} \dots 1 \end{vmatrix}. \quad (10)$$

The presented model of the estimation of the number of deviations from the geometric form and the plane allows us to use computer programming to predict the possible appearance of defects in the form under exploitation conditions. The study and analysis of the intensity of detection of deviations shows that in the initial period, the intensity is of great importance, and then gradually decreases.

Conclusions

Differential-digital method makes possible to study the errors, determine the geometric parameters of the aircraft parts and obtain the cross sections with the help of advanced methods of algorithmic errors correction, which provides a zero displacement for working conditions of measurement after the training procedure with the obtaining of the statistical result.

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Thus, we obtain the task of a regularizing link, which characterizes the deviation of the geometric parameters of the aircraft parts from their nominal values. You can get a clear minima in the minimization function. The obtained results were stable and satisfy the size of the field of tolerance of the measuring part.

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