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ABSTRACT

of the dissertation for the degree
of Doctor of Philosophy

RADIO-ELECTRONIC SYSTEM FOR MEASURING THE LOADING DEGREE OF AIRCRAFT

Specialty: 3324.04 - Operation of surface complexes, output equipments, flying machines and their systems

Field of science: Technical

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GENERAL CHARACTERISTICS OF WORK

The actuality of the topic. It is confirmed by numerous examples that the safe flight of an aircraft depends significantly on its proper loading and centralization.

The report of the Interstate Aviation Committee states that overloading of aircraft and incorrect calculation of the center of gravity causes to significant losses and fatalities. There were 50 crashes on gas turbine aircraft due to loading and centralization errors between 1958 and 2019. It should be noted that accidents occur more often in charter flights.

The following is a list of aircraft accidents that occurred due to overloading and improper centralization of the aircraft:

- On November 4, 2015, an accident occurred in Crimea due to incorrect calculation of the take off weight and center of gravity of the Cessna-336 aircraft. The flight crew and passengers were killed in the crash;
- On 05.06.2016, after aircraft landing, the wings of the aircraft BAe-125 on the flight Krasnodar-Tyumen-Neryungri were damaged due to improper centering;
-On July 10, 2017, due to the fact that the center of gravity was out of limit, the A333-type aircraft flying from Tel-Aviv Airport to Canada caused the aircraft to stop for 30 minutes on the runway.

Through the above mentioned, it is unequivocally confirmed that the problem of determining the weight and center of gravity of the aircraft is highly actual in the context of safe flight. Of course, it is desirable that the procedure for determining the weight and center of gravity of the aircraft does not interfere with the process of preparation and acceptance for flight. At the same time, it is preferable to minimize unavoidable problems. All these factors confirm the high urgency of the development of distant methods for determining the weight and center of gravity of the aircraft. In this case, the main issues that need to be addressed are the simplicity of the measurement system and the high accuracy of measurements.

Determining the dimensions of an object or any size without contact, especially at a distance, is used in the process of solving many practical problems. Various methods are used for this. One of the most common approaches is to build a spatial model of an object and then determine its geometric dimensions. Different types of distance meters, scanning laser rangefinders, various algorithms of passive and active video surveillance, etc. are used to build the spatial model of the object. The method of determining the geometric parameters of large objects based on the principle of laser triangulation is also known.

Exploration of non-contact control methods, as well as the possibility of using these distant measurement methods to determine the weight and center of gravity of the aircraft, identify and eliminate the reasons limiting their application, develop a radio-electronic system that allows non-contact and especially distant measurements are highly relevant.

The state of the problem. Currently, three main methods are used to determine the weight and center of gravity of an aircraft. These include the graphical method, the visual control method and the scales method. A brief description of these methods is as follows.

1. Graphic method. Depending on the information in the registration office, the loading schedule is completed according to the design of the aircraft, and the distribution of cargo on the aircraft and the location of the center of gravity are determined.

The main disadvantages of the method:

- requesting a new document for incorrect calculations;
- a lot of time spent on filling out documents;
- the results of the calculation depend on the level of knowledge of the employee.

2. Visual control method of loading. Unlike the first method, calculations in this method are performed by computer.

The main disadvantages of the method:

- taking into account the approximate average value for the weight of passengers in the calculations;

- the results of the calculation depend on the information received from the registration department.

3. Scales method. When measuring with the scales system, the weight (W) and center of gravity of the aircraft are determined based on the indicators (W1, W2, W3) of the scales placed under the main and nose landing gears. Despite a number of advantages, the scales method has the following disadvantages:

- high material costs for the purchase of scales;
- the need to allocate the aerodrome area required for the installation of scales on site;
- the need for additional technical means to lift the aircraft on the scales and a lot of time lost;
- practical impossibility of applying the scale method for passenger aircraft.

In the graphical method widely used in modern times to determine the weight of an aircraft, it is very difficult or impossible to accurately determine the characteristics of accidents that occur due to the complexity of providing accurate reports.

It is not advisable to use the traditional methods and tools listed above to solve the problem of non-contact distant determination of the dimensions or any size of the object. Because none of them provides high accuracy and can not be used to determine small dimensions (for example, centimeters and smaller order).

The purpose of the work. The aim of the work is to synthesize a non-contact distant control method that requires little time, small material costs to determine the weight and center of gravity of the aircraft, to create a radio-electronic system that implements this method and to study its characteristics.

The following issues have been set and resolved to reach the goal:

1. Investigation of the impact of loading rate and centralization of the aircraft on its safe flight;
2. Investigation of the characteristics and features of the methods and means used to determine the weight and centralization of the aircraft;

3. Investigation of the characteristics of the technical means suitable for non-contact distant determination of the loading and centering of the aircraft;
4. Development of methods and tools for non-contact and distant determination of the weight of the aircraft and the center of gravity;
5. Experimental study of new methods and tools for non-contact distant determination of weight and center of gravity of the aircraft.

Research methods. Deductive and inductive methods, analysis and synthesis problems, necessary sections of mathematical analysis, correlation analysis of random processes, methods of non-contact and distant determination of geometric dimensions, description-based analysis and diffraction theory were used to solve relevant problems in theoretical and experimental research sections of the dissertation. Experimental studies have been conducted to approve the results of theoretical research, and the accuracy of the results obtained has been unequivocally confirmed.

New scientific results:

1. A non-contact method for determining the loading and centering of an aircraft has been developed;
2. The distance-load dependence for the non-contact determination of the loading and centering of the aircraft has been determined and its mathematical model has been developed;
3. Technological scheme and model of radio-electronic system for non-contact and distant control of loading and centralization have been developed;
4. A coordinate grid generation algorithm with variable parameters was developed and a model for determining the displacement parameters of the aircraft was proposed on the basis of this algorithm;
5. An acousto-optic method of forming a distant marker to determine the displacement parameters of an aircraft in a stationary position and a model of a measuring device based on this method have been developed.

Basic provisions for defense:

1. Non-contact method of determining the loading and centering of the aircraft and the process of its implementation;
2. Results of theoretical studies of distance-load dependence for non-contact determination of loading and centering of the aircraft;
3. New technological scheme for loading and centralization control;
4. Model of radio-electronic system for non-contact and distant control of loading and centralization;
5. Model and algorithm for determining the displacement parameters of the aircraft on the basis of the description and the coordinate grid with variable parameters;
6. Acousto-optic method of forming a distant marker for determining of small displacements and the device that implements it;
7. Results of theoretical and experimental studies of acousto-optic marker.

The scientific and practical significance of the work is that the use and application of the proposed methods and equipment increases the efficiency, accuracy, reliability of measurement results and determination of weight and centralization of the aircraft, and thus increases flight safety. At the same time, unlike previous methods, measurements (confirmed by the results of theoretical and practical research on the example of several aircraft) can be performed without contact and also distant. The proposed acousto-optic method of forming a distant marker and the device that implements it can also be used to determine the dimensions of other objects with high accuracy.

Approbation of work. The main results of the dissertation were reported and discussed at the following national and international conferences:

1. Hasanov, A.R., Iskandarov, I.A., Agayev, E.A. The effect of errors in the weight and center of gravity of aircraft on a plane crash and methods for their determination // Materials IX Inter. STC: “AVIA-2009”, – Kiev: – septembre 21-23, – 2009, volume 2, – p. 15.29-15.32.

2. Hasanov, A.R., Iskandarov, I.A., Agayev, E.A.Determination of the weight of aircrafts with method of description // Azerbaijan Technical University. International Conference: "Perspectives of Modern Information and Communication Technologies", Baku: –september 22-24, – 2011, –p. 36-42.
3. Pashayev, A.M., Hasanov, A.R., Hasanov, R.A., Agayev, E.A. Using the features of the photoelastic effect for transmitting low-frequency information // 20th International scientific and technical conference, "Modern Television and Radioelectronics", – Moscow: – march 20-21, – 2012, – p. 71-74.
4. Pashayev, A.M., Iskandarov, I.A., Agayev, E.A. Non-contact method for determining the weight of an aircraft by the vertical movement of the fuselage // Materials XI Inter. STC: "AVIA-2013", – Kiev: – may 21-23, – 2013, volume 1, – p. 1.93-1.96.
5. Agayev, E.A. Camera Grid software for appoint weight and center of gravity of the aircraft // Proceedings of the III International Scientific and Practical Youth Conference with International Participation, – Baku: February 12-14, – 2018, – p. 102-105.
6. Agayev, E.A. System for remote control of aircraft weight // Materials of the international youth scientific conference. – Kazan: – november 6-8, – 2019, – p. 423-426.
7. Hasanov, A.R., Agayev, E.A., Huseynov, A.Q., Suleymanov, I.I., Huseyn-Zade , B.E. Computer-controlled acousto-optic delay line // Sumgayit State University Conference proceedings, Actual problems of applied physics and energetics II international scientific conference, – Sumgayit: – november 12-13, – 2020, – p. 8-15

Some results of the dissertation were used in the work "The creation of means of measuring firing density during firing trials of mortars (password: "Radio 2") " by order of the Ministry of Defense Industry of Azerbaijan (Contract No. 16 in 08.05.2014). It was used in the scientific-research works carried out according to the plan at the National Aviation Academy, the scientific results of these works were included in the annual final reports of ANAS.

One of the main results of the dissertation has been obtained patent:

Pashayev, A.M., The contactless method for determining the loading and centering of aircraft, I 2016 0003, Republic of Azerbaijan /Hasanov A.R, Isgandarov, I.A, Aghayev, E.A.: Expertise of industrial property objects Center (AzPatent) , – 2016, №5.

The dissertation was completed at the National Aviation Academy.

Personal presence of the author. The main objectives of the research and the tasks to achieve them are indicated by the author, the results were processed, systematized and discussed. The author was also directly involved in conducting experimental research.

The structure and scope of work. The dissertation consists of an introduction, four chapters, main conclusions, contains 166 pages of type written text, including 82 figures, 9 tables and a list of references of 112 titles. The work consists of 201572 characters excluding tables, figures and references.

BASIC CONTENT OF WORK

The introduction the urgency of the chosen direction of research is substantiated, the general condition of the problem is characterized, their purpose and main issues are defined, scientific innovation of the work, innovations defended and practical value of the obtained results are formed, information on approbation and dissertation structure is given.

The first chapter the center of gravity of the aircraft, the factors affecting its condition and methods of calculating tendencies were studied. It was noted that one of the main factors ensuring air safety is the correct loading and centering of the aircraft. If the requirements for these factors are not properly met and the norms for the flight characteristics of the aircraft are violated, the probability of an accident is high.

The geometric parameters of the aircraft construction and landing gears have a direct impact on the assessment of the weight and center of gravity of the aircraft. Although the geometric parameters of the landing gears (landing gears height, wheelbase, distance between the main and nose landing gears and the center of gravity) are different on each aircraft, their calculation procedure is the same. From this point of view, the study of the geometric parameters of the landing gears is one of the main issues in the process of solving this problem.

The following methods are used to determine the coordinates of the center of gravity of the aircraft:

1. Analytical (for aircraft design);
2. Experimental (for experience and operational time);
3. With the use of centralization graphs in linear and computer programs (in the process of operation);
4. Automatic (with deformation of the chassis element and the use of onboard equipment);
5. Semi-automatic (with surface measuring instruments based on data entered manually).

Experimental and centralization schedules are mainly used in widely used aircraft. A brief comparative description of the practical methods and tools used to determine the loading rate and centralization is provided in the introduction. These are the graphical method, the visual control method of loading, the scales method, and the tools associated with these methods.

The graphical method allows the calculation of the allowable load for the operation of the aircraft on the basis of the loading schedule and the centralization graphic. However, this method has the following deficiencies that directly affect the occurrence of air accidents.

- requesting a new document for incorrect calculations;
- a lot of time spent on filling out documents;
- the results of the calculation depend on the level of knowledge of the employee

Visual control method of loading. Many airlines have developed and implemented visual control systems for loading to quickly and reliably complete loading schedules and centralization graphic.

However, as noted, the method of visual control of loadings has a number of deficiencies:
- taking into account the approximate average value for the weight of passengers in the calculations;
- the results of the calculation depend on the information received from the registration department.

Scale method. When measuring with a scales system, the weight (W) and the center of gravity of the aircraft are determined based on the indicators of the scales placed under the main and nose landing gears (W1, W2, W3) (Figure 1).

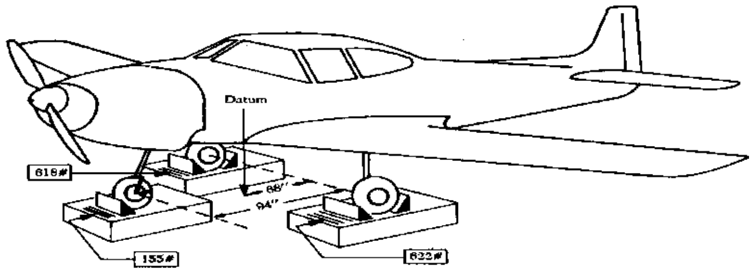


Figure 1. Appoint weight of aircraft with scale method

$$W=W_1+W_2+W_3 . \qquad (1)$$

Despite a number of advantages, the scales method has the following disadvantages:
- high financial costs for the purchase of scales;
- the need to allocate the aerodrome area required for the installation of scales on site;

- the need for an additional mechanism to lift the aircraft on the scales and a lot of time lost.
- practical impossibility of applying the scale method for passenger aircraft.

The second chapter a description of the new method developed for the distant determination of the weight and center of gravity of aircraft and the device that implements it is described.

The essence of the proposed new method for the distant determination of the weight and center of gravity of aircraft is as follows:

Loading and centering are determined by measuring the vertical displacements of the front and rear sides of the aircraft from the support points to the ground surface relative to the center of gravity of the aircraft missile stationed on the ground. To do this, the image of the aircraft is animated on a monitor through a camera. On the same monitor, the measuring grid is animated using software developed to solve the problem.

The scaling factor for the measuring grid is determined based on the known dimensions of each aircraft and the real-time values of its dimensions that remain constant during the loading process (for example, the length of the fuselage, the distance between the wing points). Then the Y1, Y2 absolute values of vertical displacements of the front and rear parts of the fuselage are calculated. The obtained results are compared with the normative values Y1n, Y2n corresponding to the empty weight of aircraft (figure 2) .

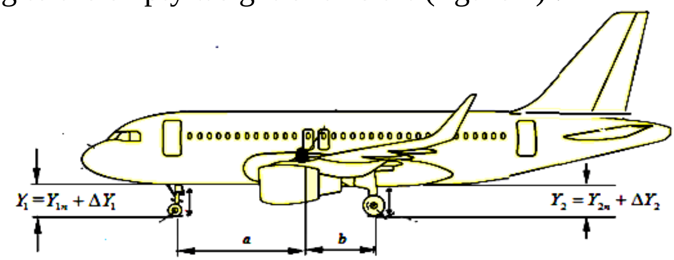


Figure 2. Vertical displacement of fuselage of the aircraft

Based on the above algorithm, the structural scheme of the method for distant determination of weight and centralization of aircraft is compiled as follows:

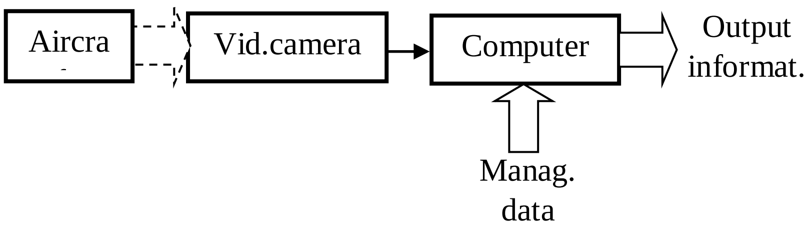


Figure 3. Distant determination of the weight and center of gravity of the aircraft

According to the structural scheme, the images of the aircraft formed by the video camera are entered into the computer. At the same time, a measuring grid is formed on the computer with the help of ‘’Camera Grid’’ software. By means of appropriate operations, the description of the aircraft is combined with the measuring grid. In this case, the image shown in figure 4 is formed on the computer.

Figure 4. Camera-Grid Application.

As can be seen from the image, it is possible to quickly determine the displacements based on the ‘’measuring grid’’ formed on the basis of the ‘’Camera Grid’’ program. Obviously, it is possible to increase the measurement accuracy to pixels. Usually such high accuracy is not required and the accuracy as parts of a millimeter is as satisfactory.

In any case, the process of distant measurements is carried out on the basis of the selected marker, and the parameters of the measuring grid are adjusted to that marker. Obviously, the accuracy of the measurement is determined by the accuracy of the selected marker. In the distance measurement process described above, one of the pre-known characteristic dimensions of the research object is used as a marker. It is clear that distant measurement is impossible if the characteristic dimensions of the research object are not known. In this case, it is necessary to have another marker. Choosing the right marker is the main difficulty of the proposed method for determining small dimensions.

From the above, it is clear that the establishment of a method of forming a high-precision marker and the device that implements this marker is highly relevant.

The marker required for distant measurements should meet the requirements of simplicity and accuracy. It should also be simple to use. It is clear that the preparation for and implementation of the measurement process should not interfere with the flight preparation process. This indicates that it is undesirable to install any marker on the frame of the aircraft. Thus, a problem of distant formation of a high-precision marker arises.

Theoretical and experimental investigation of the frequency, time and energy characteristics of the acousto-optic processor have shown that the photo-elastic effect has a high potential in the context of the formation of a distant marker.

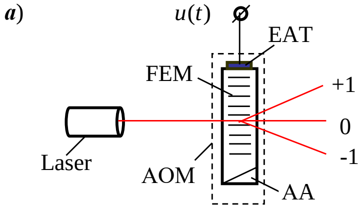
A device called an acousto-optic modulator (AOM) is used to realization the photo-elastic effect. AOM consists of a photoelastic medium FEM mounted at one end electro acoustic transducer (EAT) and at the other an acoustic absorber (AU). Glass or crystalline materials are used as FEM. The EAC converts the input signal into an elastic wave. This wave forms the running diffraction cage to side AA in the FEM. That diffraction cage reveals itself such as periodic changes in the density of the medium. Directed at a certain angle to the surface of the FEM laser beams scatter from the running diffraction cage - diffraction process takes place.

The basic quantities characterizing the photo-elastic effect are the FEM quality coefficient M, the diffraction efficiency η, and the interaction effect Q. These quantities are determined by the following formulas:

$$M=n^6p^2/(\rho\upsilon^3);\ \ \eta=(\pi^2MP_aL)/(2\lambda^2H);\ Q=K^2L/(k\cdot\cos\theta_0), \qquad (2)$$

here n is the refraction coefficient; p – photo-elastic constant; ρ - FEM density; υ - propagation speed of elastic wave in FEM; Pa - acoustic power; L - length of EAT (acoustopopic interactions); H- width of EAT; λ - wavelength of the light; θ^0 - the angle of light falling onto the surface of the FEM; K = 2π / Λ - phase coefficient of elastic wave (wavenumber); k = 2π / λ - phase coefficient of light wave (wave number); Λ is the acoustic wavelength in FEM.

The Raman-Nath and Bragg diffraction regimes can be realize in the AOM. Raman-Nath diffraction is observed when the laser beam falls perpendicular to the FEM surface (figure 5). As a result of photo-elastic interaction, symmetric diffraction orders are formed in the background focal area of the AOM. Note that figure 5 shows two different diffraction orders that are characteristic of weak photo-elastic interactions. Figure 5, a reflects schematic illustration of the Raman-Nath diffraction, and figure 5,b reflects its realistic appearance. Here are considered a weak interaction effect and therefore only represent ± 1 diffraction orders. These diffraction orders is located symmetric with respect to the light set in the non-deflected light beam and focused zero order part.



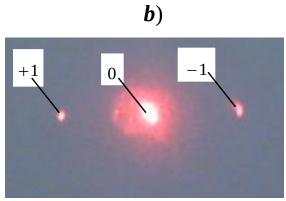


Figure 5. Raman-Nath diffraction: a) - schematic description, b) - realistic view

Processors realized based on Raman-Nath diffraction, corresponding to Q≤0.3 values of the interaction parameter, are widely used to solve various radio-technical problems up to approximately 100MHz.

In the case of Bragg diffraction, corresponding to Q≥4π values of the interaction effect parameter (figure 6), the laser beam onto the FEM surface:

$$\theta_B \approx 0,5\ \lambda/\Lambda \tag{3}$$

falls below an angle. Here θ_B - Bragg angle, λ and Λ are the optical and elastic wavelengths.

Figure 6,a reflects a schematic illustration of Bragg diffraction, and figure 6,b, reflects its realistic appearance .

For the explanation of the different diffraction modes, figure 5 and figure 6 show that the main difference in the appearance of the Bragg diffraction is that the inclining light is concentrated in a one diffraction order.

Development of the theoretical and practical basis for the use of this feature in the synthesis of high-precision measuring marker is one of the main tasks of this work.

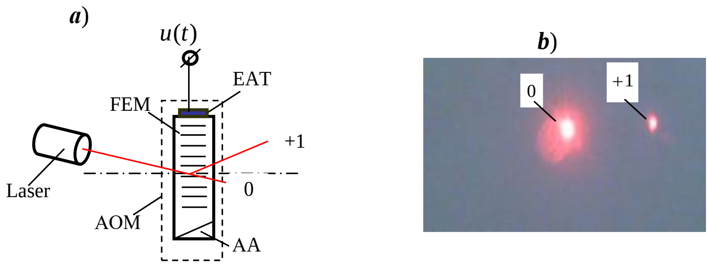


Figure 6. Bragg diffraction: a) - schematic description, b) - realistic view

Note that processors based on Bragg diffraction have been widely used, ranging from 10MHz to tens QHz.

It is more convenient to give an analytical description of the use mechanism and formation of acousto-optic marker on the basis of high-precision measuring system (figure 7). This system includes an acousto-optic processor (AOP), a video camera, collecting lens, a laser distance measurement and a monitor. AOP creates points corresponding to Bragg diffraction on the measured object. The image of the object along with those points is transmitted to the monitor by a video camera. At the same time, the monitor is synthesizing a report grid via compatible software.

The distance between points x_0 is calculated based on the distance to the object D measured via laser distance measurement. The resulting value is used to select the scaling for the report grid.

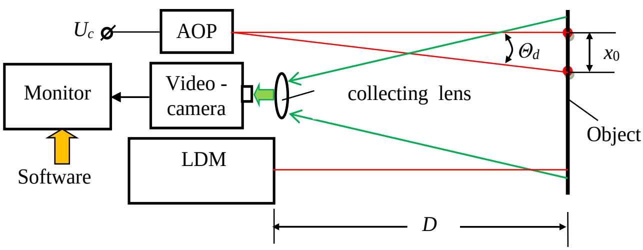


Figure 7. Distance control and measurement system based on acousto-optic marker

The third chapter are given the principle of acousto-optic marker used for accurate determination of center of gravity and weight of the aircraft is theoretically justified and its accuracy characteristics.

It is desirable to formulate the theoretical foundations of the acousto-optic marker on the basis of the schematic in figure 8. Here the controllable voltage U_c allows to choose the required frequency of the voltage generator (VG). EAT converts the radio frequency signal u (t), with a frequency ω = 2πf and a wavelength c / f, into an elastic wave with the same frequency, but with a wavelength Λ = υ / f, here c speed of electromagnetic wave in vacuum, υ is the velocity of elastic wave propagation in FEM. In this case step of running diffraction cage is defined as Λ in a photo-elastic medium.

In general, diffraction θ_d and defined by expression (3) Bragg angles θ_B are related to the following relation:

$$\sin\theta_B+\sin\theta_d= \lambda/\Lambda. \tag{4}$$

Lets study the expressions for the angles of incidence and diffraction separately for determine the nature of the dependence of the voltage that connected to nodes of the EAT of the diffraction angular. Typically, the frequency of CVG is chosen as f_0 equal to the central frequency of the AOM. In this frequency elastic wavelength is determined (step of the running diffraction cage) as $\Lambda_0=\upsilon/f_0$. Accordingly, the angle of incidence of the laser beam on the AOM surface will be determined as:

$$\theta_B=\arcsin(0{,}5\ \lambda/\Lambda_0) \tag{5}$$

In this case the diffraction angle appoint as

$$\theta_{d0} =\arcsin(0{,}5\ \lambda/\Lambda_0) \tag{6}$$

that is, the same as the angle of incidence.

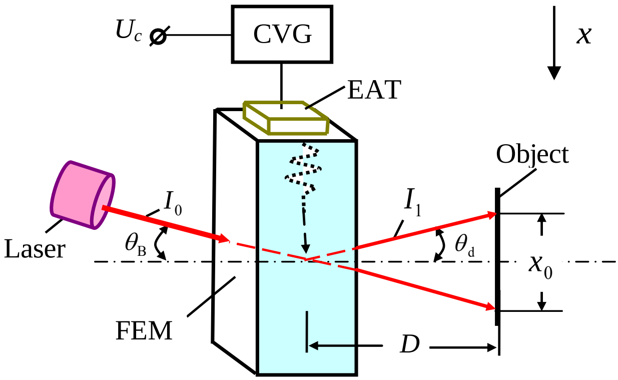


Figure 8. Schematic description of AOP used to form the distant marker

It is advisable to clarify the nature of the dependence of the angles of incidence and diffraction on the parameters of light and elastic waves using a specific example.

Numerical Analysis 1. Suppose that a semiconductor laser with a wavelength of λ = 0.64 cm is used as a coherent light source. The central frequency of the AOM realized on the FEM glass (TF-7) is 80 MHz. For used FEM is υ = 3630 m / s. Based on preliminary data and known expressions (5) and (6) for incidence and diffraction angles we find: $\theta_B=\theta_{d0}=7{,}052 \cdot 10^{-3}$.

The result of numerical analysis shows that the incidence and diffraction angles are very small, therefore, expression (6) can be written in a simpler form as follows:

$$\theta_{d0} \approx 0{,}5\ \lambda/\Lambda_0. \tag{7}$$

Using the last formula, we find the distance between the spots x_0 generated by the created by light sets on an objec in diffraction orders (see figure 7) as follows:

$$x_0 = D \cdot \sin(\theta_0) \approx 0{,}5\ D\lambda f_0 / \upsilon, \qquad (8)$$

here D- the distance from AOM to the object.

In the work process angle of incidence is constant, that is θ_B=const. Therefore, we write the expression (8) in a more general form:

$$\theta_d = 0{,}5\ \lambda / \Lambda,$$

here $\Lambda = \upsilon / f$; f – is the current frequency of CVG. So the formula for the diffraction angle is the following:

$$\theta_d = 0{,}5\ \lambda f / \upsilon. \qquad (9)$$

For selected FEM propagation velocity of elastic wave is υ=const. Therefore, according to (9), it is proved that the diffraction angle is directly proportional to the CVG frequency. This property of the Bragg diffraction is used to adjust the marker size.

The tendency of the diffraction $\Delta\theta_d$ corresponding change frequency of oscillation of the CVG up to Δf is found in the expression (9) as follows:

$$\Delta\theta_d = 0{,}5\ \lambda \Delta f / \upsilon. \qquad (10)$$

The angle position of the light band in the diffraction order only changes along the x-axis.

Thus, the change of CVG frequency up to Δf is accompanied spot of diffraction light set on the object sliding up to Δx

According to the accepted symbols and (10) formula for sliding Δx following formulas can be found:

$$\Delta x = D \cdot \sin(\Delta\theta_d) \approx 0{,}5\ D\lambda \Delta f / \upsilon. \qquad (11)$$

The above mathematical interpretation does not take into account the size of the spots generated by diffraction orders. Suppose that the wavelength λ has a circular transverse laser beam and its initial diameter is d_0. In this case, the expansion of laser radiation at an appropriate angle can be found as follows:

$$\beta=2{,}44\lambda/d_0. \qquad (12)$$

Let us take a concrete example of the effect of laser beam the process of distant measurement.

Numerical analysis 2. It is assumed that the parameters of the semiconductor laser are given: λ =0,64*mkm*; d_0=4*mm*. The diameter of the light spot created by this laser at a distance of *D*=50*m*.

According to the data based on the formula (12), the angle expansion is calculated: $\beta=3{,}904\cdot10^{-4}$.

The diameter *d* of the light spot created by the laser at a distance of D = 50m is calculated as:

$$d=d_0+D\cdot\sin(\beta)=24mm.$$

Thus, at a distance of 50 m, the diameter of the laser beam increases six times.

The results of the numerical analysis actualize the task of the placement of measuring lines. In the process of solving this problem, it is also necessary to take into account the uneven distribution of energy at the maximum level of laser beam. In the simplest case, the normal distribution (Gaussian distribution) can be taken as the basis. Suitable for the situation under discussion the following statement is compiled for Gaussian distribution:

$$f(x)=\exp\{-(x-0{,}5d)^2/[2(0{,}5d)^2]\}, \quad 0\le x\le d. \qquad (13)$$

Graphic of distribution function based on the formula (13) are given at figure 9 for d=2mm circumstance of the density of strength stream in the cross-section of the laser beam

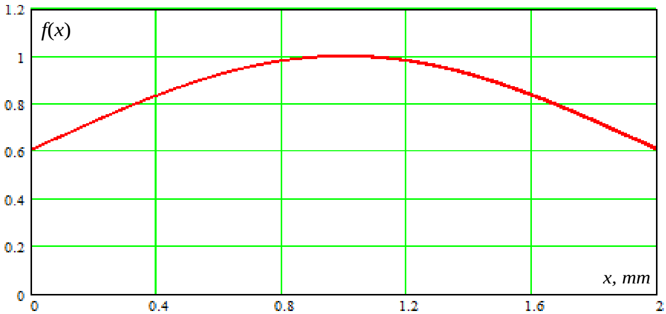


Figure 9. Graphic of distribution function for d=2mm circumstance of the density of strength stream in the cross-section of the laser beam

The graph in figure 9 shows that density of strength stream of cross-section laser beam has according to maximal mark in the center of the circular light spot.

The interaction of a circular light spot with a vertical measuring line is investigated (figure 10).

The length of the intersection of the circular light spot with the vertical measurement line is calculated with the following approximation:

$$Y(x) \approx d - 2|\Delta x|, \ \text{in that case}, \ -0{,}5d \leq \Delta x \leq 0{,}5d, \qquad (14)$$

here Δx is sliding circular light spot this or another side from center.

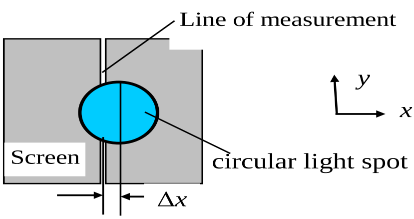


Figure 10. Interaction status light spot with measuring line

Thus, to be adapted the maximum value of a circular light spot with vertical and horizontal measuring lines during the measurement process.

The fourth chapter presents the results of experimental studies.

Experimental approbation of the idea of realization presented above of the acousto-optic marker was implemented the center frequency was performed on an AOM with f_0=80*MHz*

The experimental equipment is described in figure 11.

A brief description of the equipment and measuring equipment is given below:

1. Semiconductor laser (diameter of light bunch is 3mm);
2. High frequency signal generator – Г4-107;
3. Screw voltage generator (SVG) – laboratory variant
4. The acousto-optic modulator is based on *TФ*-7 glassware, f_0=80*MHs*;
5. Screen.

High-frequency signal generator, combined with AOM and SVG through high-frequency jacks and compatible cables. The distance from the interaction area to the screen is 9.2m. .

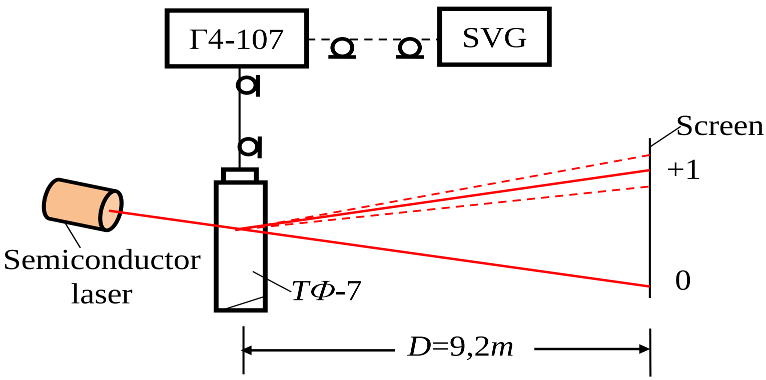


Figure 11. Schematic diagram for experimental research

As mentioned above, when studying the static adjustment characteristics of the acousto-optic marker, the high-frequency signal generator operating in carrier oscillation mode (without modulation) turning to the central frequency that is, 80MHz of the AOM. Then the frequency of the generator is changed up and down, is measured sliding of the spot of light on the screen in the first diffraction order. The results of the measurements are given in Table 1. In order to simplify the comparative analysis, this table also includes the report prices assigned according to the formulas (8) and (11).

The report and experimental graph of the marker static adjustment characteristics based on the values given in Table 1 are illustrated in figure 12. The difference between the experimental and theoretical graphs, which is quite small, is due to the rounding of the results of the experimental measurements.

Table 1. Static adjustment characteristics of the marker

S/s	frequency, MHz	Slide of spot caused by light flood, *mm*	
		Reporting result	Experimental result
1	70	55,88	56
2	72	57,48	57,5
3	74	59,08	59
4	76	60,67	61
5	78	62,27	62
6	80	63,87	64
7	82	65,46	65
8	84	67,06	67
9	86	68,66	69
10	88	70,25	70
11	90	71,85	72

Obviously, in the process of measuring by means of a measuring array formed on the monitor screen, the estimation is made with pixel accuracy and no errors are indicated.

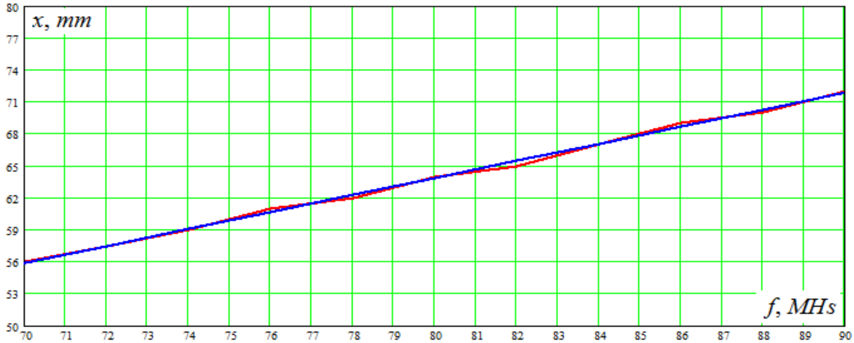


Figure 12. Report (blue) and experimental (red) graphs of the static adjustment characteristics of the marker

To observe dynamic adjustment characteristics of the acousto-optic marker, the high frequency signal generator (Г4-107) is switched to external frequency modulation mode and connects its SVG to its modulating input. Sawtooth voltage provides a change of frequency of generator between 70-90 MHz. The state of zero and one orders of light in dynamic mode is illustrated in figure 9. Apparently the state of zero order of light remains unchanged. However, state of one order of light according to the modulating process (sawtooth voltage) is scanned within a certain angle range.

The frequency scale given in figure 13 is set in the static operating mode of the acousto-optic marker.

Figure 13. Dynamic positioning of zero and one orders light on the screen

Main results

1. Contactless measurement based on the proposed radio system allows to easily determine the weight and center of gravity of the aircraft without interfering the production process;
2. The expression provides the accuracy of the contactless measurements required for practice for the dependence of the fuselage of aircraft and the vertical distance between the ground;
3. The proposed technological scheme allows optimization of the weight and center of gravity control process;
4. The software for generating variable coordinate grids provides the high accuracy of the vertical distance between fuselage of the aircraft and ground
5. The method of forming based on acousto-optic effect of the distance marker and the device realizing it provides the high accuracy of contactless measurements;
6. Theoretical and experimental researchs have confirmed the high practical value of the distance marker based on the acousto-optic effect.

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