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MOBILE LIDARS. INFLUENCE OF EXTERNAL MECHANICAL ACTIONS ON ACCURACY OF LIDAR AIMING

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The questions of designing mechanical system load-bearing elements «lidar radiator-lidar basis-automobile» in order to reduce external mechanical effects on lidar aiming accuracy have been considered.

In Russia (USSR) first experiments on atmosphere laser sounding started in 1965. Remotability of laser measurements, the possibility to determine air characteristics, obtain information about atmosphere properties at different altitudes, good space-time resolution connected with short pulse duration and high frequency of laser pulses iteration make laser sounding method irreplaceable.

The work on defining the influence of external mechanical actions on mechanical system «Lidar radiator-lidar basis-automobile» determining lidar aiming accuracy carried out by the Institute of atmosphere optics of RAS SD together with the department of precise instrument engineering of TPU is presented in the article.

Lidars are applied both in stationary and mobile variants, Fig. 1.

Fig. 1. *Mobile lidar on the basis of automobile PAS*

Mechanical system «Lidar radiator-lidar basis-automobile» in operating condition is influenced by a free-running automobile motor with vibration mechanical effect. This motor serves as electric supply generator of systems (navigation, television, gas analysis, meteorological system, information) connected with the lidar. Vibrations appearing both in separate links and in whole in the construction of lidar basis load-bearing elements are transferred to the radiator and at considerable distance to the probing zone the vibration amplitude forming fractions of mm at radiator turn into tens of m on the object (Fig. 2).

Vibrations and oscillations of the vehicle body result in changing the position of construction elements [1–3] that, in its turn, causes the changing light spot position of laser emission on probed object both due to optical circuit misalignment and due to vibrations of guidance system glasses placed on the roof of the car.

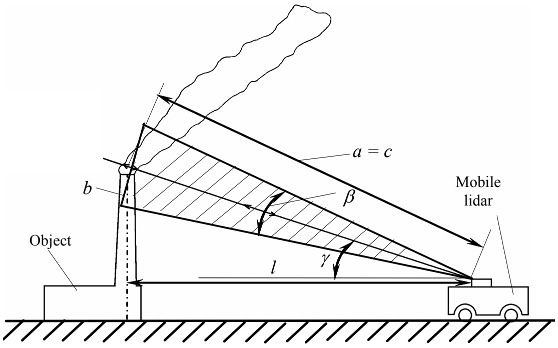

Fig. 2. *Scattering region of aiming lines (of a beam) at mechanical effects: β is the angle of error zone; γ is the slope angle; a, b, c are the sides of triangle*

Creation of optimal basis construction (selection of kinematic circuit, choice of sections of load-bearing element of the construction, application of vibration dampers) allows avoiding negative influence of external effects.

To make design solutions when developing mechanical system «Lidar radiator-lidar basis-automobile» it is necessary to know frequency and amplitude of vibration on different parts of car body at vehicle motor running as well as vibration amplitude of the body at puffs.

For estimating possible vibration values in the Institute of atmosphere optics of RAS SD the preliminary researches of oscillations and vibration frequency of lidar using production bus PAS-3205 chosen as the vehicle were carried out.

Vibrations were measured in different points of saloon and roof of stationary bus (hard soil) at motor running at different revolutions with shocks load (bus dead weight) and at partially loaded springs (bus frame was set on wooden posts imitating jack). Sensors placement is shown in Fig. 3.

The results of bus body vibration measurements in mm are presented in the Table. The results of measuring vibration in horizontal plane are set off in boldface font.

The dynamic of mechanical system «Lidar radiator-lidar basis-automobile» is described by differential equation

$$A\ddot{q} + m_K a_K + B\dot{q} + Cq = Q_F. \qquad (1)$$

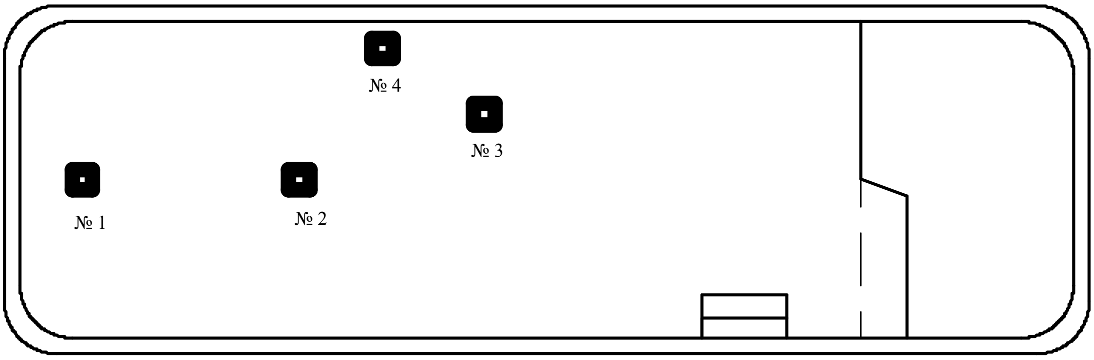

Fig. 3. *Placement of vibration sensors in car saloon*

Table. *Vibration of the bus PAS-3205 in checkpoints*

№ of a sensor	Vibration source									
	Motor operation, revolutions						External effect			
	Low, up to 150 rev/min		Medium, 400...600 rev/min		High, 600...800 rev/min		Walking in the saloon		Saloon swaying	
	Springs	Columns	Springs	Columns	Springs	Columns	Springs	Columns	Springs	Columns
1	0,142	0,520	0,139	0,129	0,104	0,094	1,332	1,369	4,388	0,628
2	0,135	0,724	0,144	0,134	0,144	0,157	0,929	2,950	1,154	2,745
3	**0,085**	**0,277**	**0,090**	**0,069**	**0,089**	**0,073**	**0,399**	**0,733**	**0,627**	**1,083**
4	0,104	0.565	0,087	0,085	0,076	0,066	0,448	0,447	0,577	1,408

Taking into account the fact that wheels linear motion, considering infinitesimality moving of their centre of mass, may be neglected let us reduce (1) to the classical form of second-order differential equations for vibration systems:

$$\ddot{q} + 2n\dot{q} + k^2 q = \frac{1}{A} Q_F, \qquad (2)$$

where $2n = \frac{B}{A}$; $k^2 = \frac{C}{A}$; $A = J_L + J_C + J_W$, where J_L, J_C, J_W are the inertia moments of lidar, chassis and wheels correspondingly; m_W are the mass of wheels; B is the damping coefficient; C is the stiffness coefficient.

Equation (2) is the general differential equation of forced vibrations in mechanical system with one freedom. The parameters of oscillating process (amplitude, frequency, damping coefficient) depend on coefficient values at derivatives that is on technical parameters of mechanical system.

First of all, lidar vibration amplitude is of interest as it properly determines the accuracy of its aiming.

General solution for equation (2) is well known and determined by the expression

$$q = q_0 e^{-nt}(\cos k^* t + \frac{n}{k^*} \sin k^* t) + \frac{q_0}{k^*} e^{-nt} \sin k^* t, \qquad (3)$$

where $k^* = \sqrt{k^2 - n^2}$ is the frequency of damped vibration, t is the time.

The first term of expression (3) describes the vibrations of mechanical system occurring as a result of its initial deviation from equilibrium position q_0 and the second one describes the vibrations occurring as a result of initial velocity $\dot{q}_0$ imposing to this system.

If the system under consideration is influenced both by restoring and resisting forces and from a certain point of time t_1 by disturbing force $Q_F(t_1)$ then it causes additional increment of generalized velocity $d\dot{q}_{дon}$ for the time interval Δt_1. Then taking into consideration this fact the infinitesimal increment of generalized coordinate dq is determined by the expression

$$dq = d\{q_0 e^{-nt}(\cos k^* t + \frac{n}{k^*} \sin k^* t) + \frac{\dot{q}_0}{k^*} e^{-nt} \sin k^* t\} + \\ + \frac{d\dot{q}}{k^*} e^{-n(t-t_1)} \sin k^*(t - t_1). \qquad (4)$$

The second term of the right part (4) represents additional increment of coordinate q of integrated disturbing force applied to the system.

Integrating in the range from $t_1=0$ to $t_1=t$ at low resistance ($n<k$) we obtain:

$$q = q_0 e^{-nt}(\cos k^* t + \frac{n}{k^*} \sin k^* t) + \frac{\dot{q}_0}{k^*} e^{-nt} \sin k^* t + \\ + \frac{1}{ak^*} \int_0^t Q_F(t_1) e^{-n(t-t_1)} \sin k^*(t - t_1) dt_1. \qquad (5)$$

The expression (5) is a general solution of differential equation (2) in case of low resistance ($n<k$, absence of shock absorber).

At $n>k$ (the case of high resistance, presence of shock absorbers) the system moves aperiodically.

In this case general solution of the equation (2) has the form

$$q = Ae^{-nt} \operatorname{sh}(\sqrt{n^2 - k^2} t + \beta),$$

where $A = \sqrt{q_0^2 + \frac{(q_0 + nq_0)^2}{k^2 - n^2}}$, $\operatorname{ctg} \beta = \frac{q_0 + nq_0}{q_0 \sqrt{k^2 + n^2}}$ are determined by the initial conditions.

In the given case the freedom of movement may be considered relative to longitudinal and lateral axes that is convenient for analytical movement analysis. In practice to determine the error zone these movements should be interconnected geometrically by the coordinates that supports defining error values of lidar aiming line.

The swing of aiming line in operating mode in angular values (neglecting optical system error) is determined by the expression:

$$\arccos\beta = \frac{a^2+c^2-b^2}{2ac} = \frac{2(\frac{l}{\cos\gamma})^2 \pm q^2}{2(\frac{l}{\cos\gamma})^2}\cos\gamma. \quad (6)$$

Denominations accepted in the expression (6) are given in Fig. 2.

It follows from the expression (6) that vibrations of lidar aiming line depend on technical characteristics of the basis where it is set.

Removal (reduction) of the above mentioned vibrations is firstly possible setting lidar on the basis which is not connected with car saloon and secondly additionally setting lidar on shock absorbers possessing the ability of dissipation of external action energy.

Increasing stability in the area of lidar aiming line is possible due to its setting on the frame. The frame has the possibility of small angular errors as it is set on viscoelastic supports situated all around the body. Besides, the required pendulosity is constructively supported in the frame for increasing antihunting efficiency.

Such engineering solution allows firstly automatically supporting frame direction in place vertical and secondly, in lidar operating mode excluding mechanical actions from running car motor to lidar optical system due to energy dissipation in viscoelastic supports.

Functional kinematic diagram of lidar fixing on the frame set on the above mentioned supports and possessing pendulosity is presented in Fig. 4.

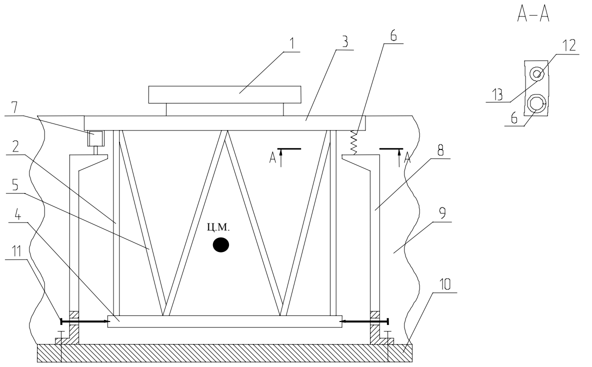

Fig. 4. *Kinematic diagram of lidar fixing on the frame*

Lidar – 1 consists of 2 telescopes: radiator and detector. Optical elements of telescopes are set on the common body – 2 representing framed structure. The body – 2 consists of (upper – 3 and lower – 4) rings related by cantilevers – 5.

Lidar – 1 is set on the upper ring – 3 of the body – 2 through the springs – 6 fixed in pairs and dampers – 7 on the arms – 8 fixed on the floor – 10 of car saloon – 9. Minimal quantity of viscoelastic elements fixed in pairs is four.

There are constructive elements of resilient member set – 6 and damper – 7 on the upper ring – 3. Resilient member – 6 represents cylindrical helical compression spring.

Resilient member – 6 is fixed to the arm – 8 with the other end.

Damper – 7 represents typical construction of linear type damping device and consists of the body – 13 of cylinder form fixed on the upper ring – 3, piston – 12 fixed on the arm – 8. Piston – 12 can traverse linearly in the body – 13 of the damper in this case the piston – 12 is connected with the arm – 8 through the uncoupler allowing the piston – 12 having little angular deflections in the body – 13 of the damper. The inner cavity of damper body is filled up with viscous (for example polysiloxane) liquid.

Thus, lidar – 1 is set up through the viscouelastic shock absorbers (spring – 6, damper – 7) on the arms – 8 which are fixed, in their turn, to the car – 9. Pendular mobile system has a mass centre (M.C. or Ц.М., Fig. 4) lower than the plane of positioning viscoelastic shock absorbers. These complex technologies allow achieving removal task of external vibration mechanical action influence on the position of lidar aiming line at object probing. It is nessesary remember that in such mechanical system in lidar operating mode there is a case of small vibrations when pendulum eigenfrequency does not depend on vibration amplitude of the latter that additionally increases the efficiency of suggested passive stabilizing system.

The dynamic of frame motion in orthogonal directions in lidar operating mode is described by free differential equations. In the case of small vibrations

$$\begin{cases} J_\alpha\ddot{\alpha} + \mu_\alpha\dot{\alpha} + c_\alpha\alpha + Pl\alpha = Q\sin(pt+\delta) \\ J_\beta\ddot{\beta} + \mu_\beta\dot{\beta} + c_\beta\beta + Pl\beta = Q\sin(pt+\delta) \end{cases}, \quad (7)$$

where J_α, J_β are the frame inertia moments relative to suspension axis in orthogonal directions; α_α, α_β are the damping coefficients; c_α, c_β are the stiffness coefficients of resilient element; P is the weight of the construction; p is the frequency of external actions; l is the distance from the axis to the mass centre of mobile part; Q is the amplitude of external periodical effect.

In the given device $J_X=J_Y$, $\ddot{\alpha}=\ddot{\beta}$, $\dot{\alpha}=\dot{\beta}$, $\alpha=\beta$, $\alpha_\alpha=\alpha_\beta$, $c_\alpha=c_\beta$ occur.

As the frame motion in orthogonal directions are not connected then the dynamic of frame moving relative to each axis may be considered independently.

Let us divide both parts of the first equation in the system (7) on the frame inertia moment and introduce the notations $\frac{c+Pl}{J_X}=k^2$; $\frac{\mu}{J_X}=2n_1$; $\frac{Q}{J_X}=h$.

The first differential equation in the system (7) has the form:

$$\ddot{\alpha} + 2n_1\dot{\alpha} + k^2\alpha = h\sin(pt+\delta). \quad (8)$$

In the given case high resistance to external disturbance from damper occurs i. e. $n>k$.

In amplitude form the particular solution of the equation (8) defining forced vibrations has the form

$$X = B\sin(pt+\delta-\varepsilon). \quad (9)$$

Carrying out mathematical operations with the equation (9) we obtain the solution in the form

$$X = \frac{h}{\sqrt{(k^2-p^2)-4n_1^2p^2}}\sin(pt+\delta-\varepsilon).$$

Maximal amplitude of the frame at external action Q is determined by the expression

$$B = \frac{h}{\sqrt{(k^2 - p^2) - 4n_1^{\,2} p^2}}, \tag{10}$$

where k is the natural frequency of the frame, p is the frequency of external action.

It follows from the expression (10) that the larger the amplitude of the external mechanical action (h in numerator) the larger frame vibration amplitude with lidar but the larger damping coefficient of viscoelastic support n in denominator the less frame amplitude at external vibration action.

Selecting the corresponding constructive values k, p, n, l, J, c, P (expressions 7, 10) the frame vibration amplitude in the range of idle revolutions of car motor is possible to reduce practically to zero.

Conclusion

The technology of lidar vibrostabilization problem is analytically justified that allows minimizing the vibration amplitude of its aiming line in operating mode. It is achieved both by setting up viscoelastic shock absorbers and varying the parameters of mechanical system «Lidar radiator-lidar basis-automobile»: inertia moment, differences of natural and forced vibrations, damping coefficients, construction stiffness, pendulosity value.

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LARGE-FORMAT LASER RANGE

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New principle of large format scanning laser range construction for mobile object navigation realized on the basis of piezoelectric drive of laser beam inclination control has been suggested. Optimal drive parameters and laws of controlling range laser beam scanning were determined. Limiting angular format by azimuth coordinate (the most important one for navigation of water and ground mobile objects) up to hemisphere size is 180°. The proposed principle is approved in adaptive television automatic system, means of control and diagnostics of laser beam state at stochastic influence.

In many tasks solved in measurement technology, radiolocation, astronomy, optical communications, location, orientation, navigation and many other one of the problems is a support of high resolution and accuracy of defining mobile object coordinates in wide field of view of devices and systems [1–4]. The possibilities of applying in laser systems the adaptive optics elements for precision control of radiation characteristics carrying information about spatial field and objects in it are attractive. Piezoelectric converters «electric signal – force action» are used as executive actuators of microcontrol for adapting systems and controlling wave front of laser beams. The experience shows that piezoelectric actuators are rather effective in the adaptive optical engineering. Their advantages are fully determined by the degree of complexity of control and STC algorithms accepted in the devices that allows decreasing field structure deformations caused by the factors of random and active disturbance reaction on the final result of system operation [1–9].

Piezoelectric actuators having rapid response and small dimensions are applied for picture stabilization in scanning microscopes and microtome vibroknives besides laser, thermal imaging, location, navigation and adaptive engineering [1–9]. Their further development as the efficient elements of radiation control is restrained by narrow scanning range. In spite of variety [3, 4] of actuator constructions the problem of developing the optimal structure of laser beam control actuator could be hardly considered a solved one or close to completion. Scanning actuator of laser cross section beam as the element of control system of ship navigation [2, 7] has individual peculiarities due to the necessity of high accuracy at coordinate determining for controlling mobile object in real time in wide azimuth region of its place for navigation of media on curved paths.

The original scanning actuator of laser cross section beam [5] as the element of navigation system of mobile object in wide angular range of coverage with laser beam close in dimension to hemisphere in azimuth region is described in the given paper. The variants are analyzed and laser cross section actuator is optimized for improving its technical characteristics, the results of studying the application of one of its modifications in model turbulent medium are given.