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# Three-axis control system with the direction of optical radiation

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## Abstract

***On the basis of the conducted analysis of construction principles of the known control systems, it was developed a system of three-axis control with the direction of optical radiation, which enables accurate angular stepping rotation of any of the rotors with rigidly fixed stator, and angular stepping rotation of stator around the respective axes of the rectangular coordinate system with entrenched rotors on any of the coordinate axes. With the application of the developed system, the losses for switching and inputting of radiation into the fiber optic cable constitutes 7-10 dB, which is 35-40% lower than in known devices and systems. In the proposed system, with the value of the angular rotation of the rotor steps from 4.0 mm to 0.2 mm, the accuracy of precision positioning of the rotors in stepping mode is 1.4-2.1 microns.***

**Keywords:** control system, optical radiation, piezoelectric element, optical fiber, a rotor, a stator, a radial deformation, torsional deformation, light guide

## 1. INTRODUCTION

In connection with the transition to nanotechnology, there was a need to move the micro- and nanostructures with an accuracy of a few nanometers or less. To ensure high accuracy of the performed operations in the systems of various purposes, piezoengine obtained wide application in which a mechanical displacement is achieved due to the inverse piezoelectric effect, and the material basis of such actuators is made up of piezoelectric element. Inverse piezoelectric effect is the change in linear dimensions of piezoelectric element by applying an electric field towards it. Currently, the scope of piezoengine application covers many industries, i.e. optoelectronics, telecommunications, electronics, microscopy, robotics, photographic equipment, nanometrology and others [2-6].

Development of piezoelectric equipment coincides with the beginning of the XXI century, and thus expanding the scope of piezoelectric transducers for different purposes, i.e. from the acoustic transmitters and receivers to the commutating and switching devices, positioning devices, and compensators of vibrators, micro-robots. Despite the fact that the piezoelectric effect was discovered even in the XIX century and the theory and technology of creation of piezoceramic materials started to develop from the second half of the XX century actively, it is believed that the piezoceramic - is one of the most promising materials of the XXI century. The reason for this view is the inherent properties of piezoelectric ceramics which have not been fully tapped in science, engineering and technology yet. This is due to high reliability, low weight and overall dimensions, high radiation resistance, resistance to the action of various aggressive environments, high temperature resistance, the possibility of using piezoengine directly without pre-additional kinematic relationships with the object of measurement, providing the absence of additional measurement errors and the dielectric nature of the piezoelectric elements. In addition, piezoengine are used in the development of the direction of the optical radiation control systems in telecommunications systems, ultrasound diagnostics in medicine, aviation and rail transport, energy, oil - gas complex, ultrasonic welding, cleaning of surfaces, coating, drilling, etc [4,6-12,14,15].

## 2.FORMULATION OF THE PROBLEM

The electromechanical systems have always been in a central place in the development of piezoelectric actuators for different purposes, the level of their development determined the possibility of many industries, the success of research, the fighting qualities of military equipment, etc. In connection with the development of nanotechnology, the primary task was the development and improvement of the element base of electromechanical systems. In order to solve various problems in the micrometer, and even more so in the nanometer range, it will require entirely new technologies and technical means.

Submicron range of errors of one- and multi-axis linear positioning and the second range of angular displacements is typical for modern opto-mechanical devices, baffles, optoelectronic positioning devices, optoelectronic switches and commutators, modulators with electrical and optical control, used in optical telecommunication systems, metal-working machinery, robots of micromanipulators, etc. Attempts to solve this problem through traditional electromechanical systems encounter a variety of technical difficulties. In particular, one of the main problems arising from the transfer of the output optical signals from the optical line is to study the basic laws of the input of optical radiation into the fiber optic cable, alignment of optical system with optical fiber. The problem of the optical beam energy input is also compounded by the fact that there are no coordinates of the location of receiving - transmitting devices and optical fibers, i.e., there is an angular divergence of positions between them. In the process of transmission of information of the search task, the guidance and monitoring of optical radiation requires fairly rapid changes of radiation directions on some periodic (search) or aperiodic (tracking) law [3,13,16-20]. Therefore, there is a need for classification of methods, devices, and the control parameters and three-axis control system (TCS) development with direction of optical radiation and a control circuit that provides automatic alignment of the axes of the transmitter and receiver and a fiber optic communication line with high accuracy.

## 3.CLASSIFICATION OF METHODS AND CONTROL DEVICES

It is distinguished continuous and discrete methods of control by the nature of the optical radiation motion, and the mechanical and electrical methods by the physical principles of control [2,17-20].

Mechanical methods of optical signal control are carried out by mechanical movement of the control element (mirrors, prisms, etc.). For this purpose, it is used electromagnetic, piezoelectric and magnetoelectric three-axis control system (TCS), with the direction of the optical radiation.

Electrical methods of optical signal control are realized by changing the refractive index of the medium through which the beam passes under the influence of electric or magnetic fields. Currently, it is used ultrasound (acousto-optic), electro-optical, polarization (including magneto-optical) and dispersion (injection) deflectors.

Mechanical TCS allows for large deviations of the beam (radian unit), the virtual absence of loss, low distortion, and high accuracy.

Piezoelectric TCS are related to devices with electromechanical control. To reject the light radiation, it is used small lightweight mirror, mechanically moved by reverse piezoelectric effect arising in some crystals (barium titanate, etc.) when they are exposed to an electric field control. Inverse piezoelectric effect is the compression, tension or deformation that occurs in these crystals when exposed to an electric field in a certain direction with respect to the electrical axis of the crystal.

Periodic scanning is achieved by application to the piezoelectric crystal associated with a mirror, AC voltage, which causes the bending, shear or torsional vibrations. It is distinguished plate, face, rotary, radial, torsional and shear piezoelectric optoelectronic TCS.

Relatively low controlling voltage, small size, simple structure, mechanical strength and durability allow the use of piezoelectric optoelectronic TCS in search circuits, precision pointing and tracking of optical linear paths.

## 4. TCS PARAMETERS

There is a system of characteristics and parameters to evaluate the feasibility and advisability of the use of certain types of TCS. Let us consider the most important of them [2,17-20].

The amplitude of the deflection angle $\Delta\alpha$ is the maximum angular displacement of the TCS beam, which determines the total size of the scan sector.

Resolution capacity of TCS is determined by $N$ number of different areas of the beam within $\Delta\alpha$. If $D_W$ is the width of the beam emerging from the TCS, then its angular divergence

$$\theta_{AD} \cong \xi \cdot \lambda / (n \cdot D_W), \qquad (1)$$

here $\xi = 1{,}2...1{,}3$ (for uniform intensity distribution in the beam $\xi = 1{,}22$; for a Gaussian distribution $\xi = 1{,}27$); $n$ - the coefficient of refraction of the medium.

Then the resolution of TCS is determined by the following formula:

$$N = \Delta\alpha / \theta_W. \qquad (2)$$

By substituting the value $\theta_{AD}$ in the expression (2), we obtain:

$$N = \Delta\alpha \cdot D_W \cdot n / (\xi \cdot \lambda). \qquad (3)$$

The resolution capacity of TCS is the most important parameter: in the increase (or decrease) $\Delta\alpha$ by means of TCS, the value of $N$ remains unchanged, since in this case the value of $\theta_{AD}$ will change accordingly Performance speed of TCS is determined by the transition time of the beam from one element of permission to neighboring. For continuous TCS with the direction of optical radiation:

$$t_P = 1/(\Delta f), \qquad (4)$$

here $\Delta f$ - is the transmission band of TCS and is defined as follows:

$$\Delta f = N \cdot f_s, \qquad (5)$$

here $f_s$ - is the frequency of scanning (number of scanning periods for 1 sec).
Optical TCS loss is determined as follows:

$$\tau = I_{out} / I_{inp}, \qquad (6)$$

here $I_{out}$ and $I_{inp}$ are the intensity of radiation at the output of the TCS and the input of the optical transmission medium.
TCS sensitivity deviation is defined as follows:

$$\bar{S} = \Delta\alpha / U \text{ or } \bar{S} = N / U, \qquad (7)$$

here $U$ -voltage.

## 5. DEVELOPMENT OF THREE-AXIS CONTROL SYSTEM

It is designed TCS on the basis of piezoelectric bimorph elements to improve the accuracy of positioning the direction of the optical radiation and ensure the automatic alignment of the axes of the transmitter and receiver, and a fiber-optic line. As is seen from analysis [2,3,17-21], the closest technical solution of TCS is “Piezostepping motor” [1]. It contains a rotor designed as a ball, located at an angle of 120º in a plane passing through the center of the ball, and the stator is in the form of three legs with concave spherical surfaces located in the same plane at an angle of 120º to each other, on which it is reinforced thrusters made in the form of a sphere. In this engine in the absence of the possibility of rotor moving and also with fixed rotor, the movement of the stator in the stepping mode of operation around the three axes of the rectangular coordinate system X, Y and Z limits the functionality. In addition, due to supply of AC power to the motor, the accuracy of rotor positioning decreases.
In stepping mode of rotor movement, in the second half of the voltage cycle, power is supplied to the vibrator of torsional deformation, which rotates the rotor around its axis. Thus, describing some trajectory in the space, the movement the lead moves. In the second half of the cycle after a power outage on the torsional deformation of the vibrator, it occurs braking and propulsion blackout, but due to the presence of the inertial mass of the three leads and rotor, vibrators radial deformation of the other two propellers are powered. Furthermore, there is no friction wear resistant coating in the design of the rotor of the engine and therefore, at the time of braking and after blackout of the rotor propeller, and it occurs alternating voltage attenuation for a predetermined time. It creates vibration damping of torsional deformation and two other propellers of the radial deformation vibrator receive energy and it leads to slippage of the rotor in the stepping mode of operation, which eventually contributes to an inaccurate positioning of the rotor relative to a given axis with 120º shifting.

To achieve this goal in the TCS, containing a rotor, made in the form of a ball, a stator consisting of vibrators of radial and torsional strain, it is inputted rotors made in the form of balls arranged at an angle of 90º in relation to each other in mutually perpendicular planes passing through the centers of the balls with possibility of angular rotation about the three axes X, Y, and Z of rectangular coordinate system, the vibrators are rigidly mounted to the motor stator constructed in the form of two halves of spheres, each rotor shaft, from the external side of the engine, is provided with a piezoelectric vibrator in the form of a washer radial deformation and rigidly secured to the stator and the working surface of the said balls, mechanically contacting between themselves, is provided with wear-resistant coatings.
It enhances the functionality of the proposed system to input additional rotors into the TCS, made in the form of balls at an angle of 90º with respect to each other in mutually perpendicular planes passing through the centers of the balls with the possibility of angular rotation around the three axes X, Y and Z of rectangular coordinate system. It should be noted that when the energy is supplied from the AC voltage to the electrodes of vibrators of radial (SRM) and twist (EVA) rotor deformation located on the reference axis X, through differential transmission, the circumduction of rotor is simultaneously transmitted to a rotor located on a coordinate axis Y and Z. Moreover, the same is carried out in the above sequence, so that when the voltage is supplied from the AC voltage source (Figure 2) to the electrodes and vibrators of radial and torsional deformation of the rotor located on the coordinate axis Z, rotational movement of rotor is simultaneously transmitted for due to differential transmission to the rotor, disposed on the coordinate of axes X' and a rotor disposed on a coordinate axis Y'.
The design of the proposed apparatus makes it possible to regulate the working air gap "$\delta$" (Figure 1) between the contacting wear-resistant friction coatings of working surfaces of the rotor balls, i.e., change of position of the rotor balls relative to each other by connecting the vibrators of radial deformation to the constant or alternating voltage of direct polarity to move forward and contact the other rotor, and also when braking them. In addition to the implementation of the angular rotation of any of the rotors (Figure 2, 3) with rigidly fixed stator and, if necessary, with rigidly fixed rotors on both sides of one of the coordinate axes, it allows the angular stator rotation around any of the coordinate axes of the rectangular coordinate system X, Y and Z (the direction of the trajectory of the stator angular rotations around the coordinate axes X, Y and Z are conditionally shown in Figure 3).
Availability of the piezoelectric vibrator in the form of radial deformation washer eliminates slippage of the rotor in the stepping operation, in view of the fact that when disconnecting the AC voltage from the vibrator of

torsional deformation, a constant voltage is received by the piezoelectric vibrator in the form washer of radial deformation, thus there is a clear fixation of rotor pitch, exercising its instantaneous braking, which provides increased accuracy in positioning precision of the rotor according to a predetermined angular rotation speed. Herewith, it is conducted automatic stepping mode of motor operation, leading to a significant increase in the accuracy of the positioning precision of the motor rotor, with the value of the angular rotation of the rotor steps from 4mkm to 0.2 mm, the accuracy of positioning precision of the motor rotor in the stepping mode is 14-21 microns.

Figure 1 shows the TCS with the connected deformations vibrators to a structural circuit of control, Figure 2 - rotor arrangement design in the rectangular coordinate system (X, Y and Z), Figure 3 provides a general view of a stepping motor with a rotor disposed in the stator in the form of two hemispheres in the assembly, Figure 4 shows a stepping motor design in the section of 1/4, and Figure 5 shows the shape of the pulses of alternating voltage applied to the vibrators of radial and torsional deformation of the time phase shift.

TCS (Figures 1-5) comprises a rotor 1, configured as a ball -2, -3 stator consisting of a vibrator as part of a sphere (SRM) and radial -4 (EVA) -5 torsional deformation connected to the AC source - 6 voltage.

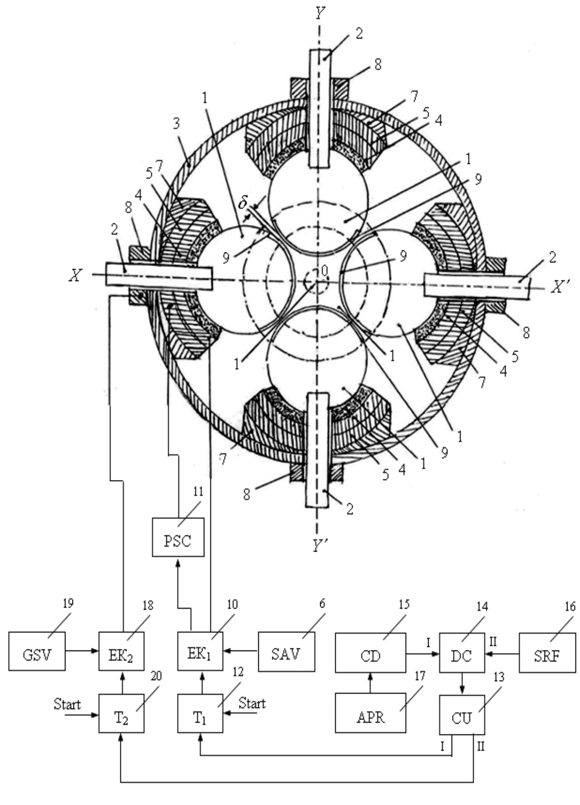


**Figure 1** TCS with deformation vibrators switched to the structural-circuit of control

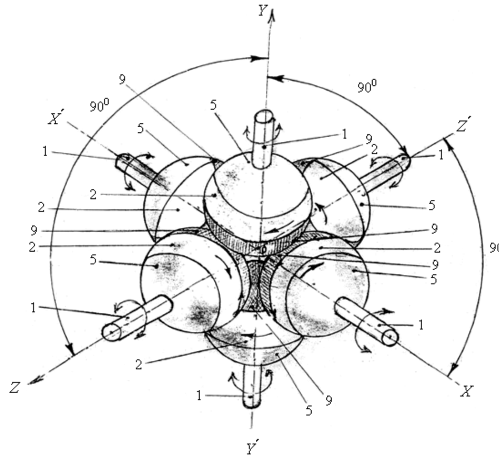

**Figure 2** Schematic location of the rotors in a rectangular system of coordinates X, Y and Z

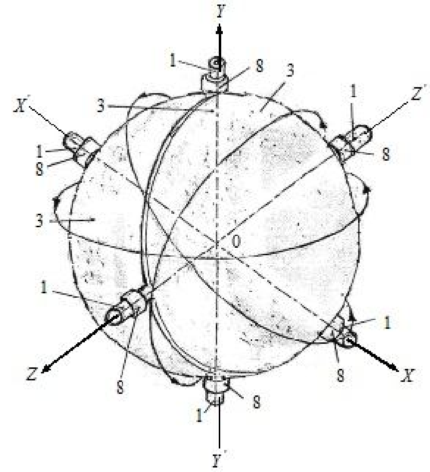

**Figure 3** General view of the stepping motor with rotors located in the stator in the form of two hemispheres assembly

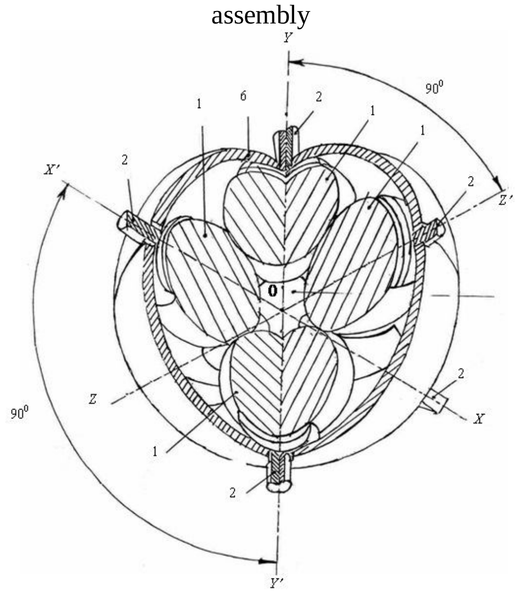

**Figure 4** Design of stepping motor in the section of ¼

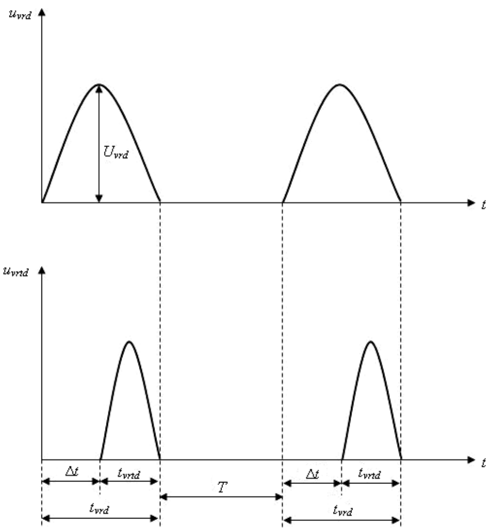


**Figure 5** The shape of the impulses of the alternating voltage, applied to the vibrators of radial and torsional deformation of time phase shift

Electronic part of the device control circuit consists of a source -6 of AC voltage, the first electronic key -10, phase-shifting circuit - 11, the first trigger -12, the control unit -13, comparator-14, counting device -15, source -16, reference frequency of set point adjuster -17 position of the rotor, the second electronic switch 18, the generator of DC -19 and the second trigger-20.

## 6.THE OPERATING PRINCIPLE OF THE SYSTEM

At the beginning of the work, before the launch the first trigger -12 (Figure 1) the required rotor position -1 is set in the set point adjuster -17. After that, at start of the first trigger -12, under the action of pulses of AC voltage source -6 (Figures 1,2,5) applied to the vibrator -4 of radial deformation of the rotor -1, located on the X coordinate axis, the latter being deformed in the radial direction presses -2 ball of the rotor -1 with working parts with friction coatings of wear-resistant material -9 of rotors -1 disposed on the coordinate axes Y and Z, supports (Figure 5), in this position (due to the phase-shifting circuit) for a time determined by the constant response time, and a pulse duration of the AC voltage source -6 ($u_{vrd}$) (Figure 5), applied to the vibrator -4 of radial deformation. The pulse of alternating voltage - $u_{vkd}$ to vibrator -5 of torsional strain is applied with some delay, after a time - $\Delta t$ needed to overcome the radial deformation of the working air gap - $\delta$ by the vibrator -4 (figure 1).

Thus, actuating the vibrator -5 of torsional deformation it rotates rotor -1 of the coordinate axis X around its axis in one step. Thus rotors -1 arranged on a coordinate axis Y and Z, are rotated by the same step size, and then the alternating voltage pulse us replaced by pause (Figure 5). After triggering of vibrators -4, 5, from the output of the set-point adjuster -17, the pulses of voltage are supplied to the input of counting device – 15 in accordance with the changing position of the rotor -1 and from its output, the voltage pulses are fed to the first input of the comparison device -14, whose second input is fed by the pulses of the reference frequency source -16 corresponding to a predetermined position of the rotor -1, coincidence of which, generates a control signal in the output of the comparison device -14, triggering the control device -13, from the first output of the latter, the voltage signals are fed to the control input of the first trigger -12, disabling and stopping the supply of alternating voltage on the vibrators 4 and 5, wherein the vibrator return back to the initial position due to own elastic force during $t_{vrd}$ and $t_{vkd}$, determined by constant response time of vibrators -4, 5 of radial and torsional deformation, simultaneously from the second output of the control device -13, the voltage pulses are received by the control input of the second trigger -20, which controls the second electronic key -18, wherein the constant voltage signal is supplied to its input from the output of generator -19, and from its signal output, DC voltage is supplied to the electrodes of piezoelectric vibrator -8 which is in the form of radial deformation washer, thus there is a clear fixation of the rotor -1 step, carrying out its instant braking.

In accordance with the above, the duty cycles in the above sequence are repeated periodically and wherein the rotor occupies a new position -1. In addition to the implementation of the angular stepping rotation by any of the rotors 1 (Figure 2, 3) with rigidly fixed stator -3, if necessary, with rigidly fixed rotors -1 on one of any coordinate axes, it allows the angular stepping rotation of the stator -3 around the respective axes of a rectangular system coordinates (direction trajectory of the angular stepping rotations around the axes of the stator is shown schematically in Figure 3).

## 7.CONCLUSION

Thus, it is developed a system of three-axis control with the direction of the optical radiation, which enables accurate angular stepping rotation of the rotors at any rigidly fixed stator and with the rotors rigidly fixed on any one of the coordinate axes - stepping angular rotation of the stator around the respective axes of the rectangular coordinate system. In applying this system, the loss of switching and input of radiation into the fiber optic cable is 7-10 dB, which is 35-40% lower than in the known devices and systems. In the developed system, at the value of the angular rotation of the rotor steps from 4.0 mm to 0.2 mm, the accuracy of precision positioning of the rotors in stepping mode constitutes 1.4-2.1 microns.

## References

[1] E.M.Yusizade, etc. Expert of the USSR No. 1021309 "Piezoelectric stepping motor" of MKP H 01L 41/08, H02N 11/00, of 07.05.81.
[2] I.I.Grodnev. Communication fiber lines. Moscow: Radio and communication, 1990. 224 p.
[3] N.A.Semenov. Losses in case of input of energy in the optical cable//Monthly scientific and technical log on a wire and radio communication, television and broadcasting "Electric communication". Moscow, 1980, No. 12. p. 24-26.
[4] O.K.Sklyarov. Fiber networks and communication systems. Sankt-Pererburg: Fallow deer, 2010. 272 p.
[5] R.R.Ubaydullayev Fiber networks. Moscow: What Trendz, 2000. 270 p.
[6] David Greenfield. Optical networks. St. Petersburg: DiaSoft, 2002. 256 p.
[7] Andrea Bianco, Davide Cuda, Paolo Giaccone, Fabio Neri, Asynchronous vs Synchronous Input-Queued Switches, IEEE GLOBECOM 2010 (Next Generation Networking Symposium), Miami, Fl, USA, December 2010.
[8] N.A.Olsson, “Lightwave systems with optical amplifiers”, J.Lightwave Technol. LT-7, 1071 (1989).
[9] D.O.Caplan, “Laser communication transmitter and receiver design”, J. Opt. Fiber Commun. Rep. 4, 225 (2007).
[10] G.P.Agrawal, Fiber-Optic Communication Systems, John Wiley & Sons, New York (2002).
[11] H.J.R.Dutton, Understanding Optical Communications, http://www.redbooks.ibm.com/pubs/pdfs/redbooks/sg245230.pdf, IBM Redbooks.
[12] Optical Networks and Technologies: IFIP TC6 / WG6.10 First Optical Networks & Technologies Conference (OpNeTec), October 18-20, 2004, Pisa, Italy.
[13] Debra Cameron, "Optical Networking", Wiley, December 2001, 288 pages.
[14] International Telecommunication Union (ITU), http://www.itu.int/home/index.html.
[15] Illustrated fiber optic glossary, http://www.fiber-optics.info/glossary-a.htm.
[16] R. Freeman. Communication fiber optical systems. The lane with English under the editorship of N. N. Slepov Moscow: Technosphere, 2004. 496 p.
[17] R.G.Dzhagupov, A.A. Erofeyev. Piesoceramic elements in instrument making and automatic equipment. Leningrad: Mechanical engineering, 1986. 256 p.
[18] G.S.Gayvoronskaya, A.V. Ryabtsov. Switches of optical signals / Scientific and technical log "Refrigerating Technique and Technology". Odessa, 2009. No. 2 (118). p. 55-59.
[19] Ya. Suematsu, Page Kataoka. Fundamentals of optoelectronics. Moscow: Patterns, 1988. 288 p.
[20] A.N. Ignatov. Light-wave devices and devices. Moscow: What Trendz, 2006. 272 p.
[21] T.M.Mansurov, G.B.Beybalayev. Optoelectronic switch of the direction of radiation. Patent for the invention No. İ 2007 0216, 27.11.2007. MKP G02V 6/00, G02V, 6/38; G02F 3/00; N03K 3/42. Official bulletin "Industrial Property". To a tank, 2007, No. 1. p. 19.
[22] T.M.Mansurov, I.A.Mamedov. Optoelectronic switch of the direction of radiation. Patent for the invention / Official bulletin "Industrial Property". To a tank, 2014, No. 4. p. 12.

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