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INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

DESIGN AND MODELING OF PASSIVE COMPONENTS OF LINEAR PATH OF OPTICAL COMMUNICATION

T.M.Mansurov, Ch.P.Aliev, S.A.Dzhebrailova
Department of Radio Engineering and Telecommunication
Azerbaijan Technical University, Baku, Azerbaijan

DOI: 10.5281/zenodo.165009

ABSTRACT

It was conducted the analysis of structural construction of the organization schemes of the optical communication with passive components, i.e, optoelectronic switch and the device of precision positioning of the radiation direction. Based on the analysis it was concluded that the existing components did not provide high accuracy of switching and positioning the direction of the optical radiation, which leads to loss of energy when entering the optical radiation into the optical fiber at the points of mechanical connection. For this purpose, it was developed the organization scheme of the optical communication with passive components, design scheme, the control scheme and mathematical model of functioning of the optoelectronic switch and the device of precision positioning of the direction of optical radiation. It was shown that the developed optoelectronic switch and the devices of precision positioning of the direction of radiation could reduce the time and improve the accuracy of the switching and positioning of the optical radiation direction, to compensate the loss at the mechanical connection places and commissioning of the radiation into the fiber optic cable within 3...5 dB, which is 50...55 % less than in the known devices. These devices offer significant advantages over the electro and magneto-electric deflection systems, which include low power consumption, high accuracy, reliability and manufacturability. This suggests that the proposed construction can find its use in modern optical communication systems.

KEYWORDS: precision positioning, remote optoelectronic switch, the direction of emission, fiber waveguide, piezoelement, optical fiber.

INTRODUCTION

Improving the quality and efficiency of transmission of various types of information and the expansion of telecommunications services to telecommunication networks is conditioned with the introduction of optical transmission systems. The introduction of such systems determines the development not only in the telecommunications industry, but also electronics, nuclear energy, space exploration, engineering, shipbuilding, and so on. Organization of optical communication is related to the construction of a linear path with passive components that make certain losses at the places of mechanical connections, when switching and positioning the direction of radiation in the optical fiber (OF). Along with the improvement of parameters and improvement of optical cable constructions of various purposes, there is no less urgent issue of creating a reliable, structurally simple and advanced functionality of the passive components, i.e., optoelectronic switches, positioning devices and other switching devices, without which it is impossible to build a linear path of the branched optical networks. The efficiency of the optical signal transmission process is provided with the matching devices, for which it is used the optoelectronic switches and the device of positioning the direction of radiation. These devices can reduce the power loss as compared with the losses in the physical connection of the radiation source RS with OF [1-11].

FORMULATION OF THE PROBLEM

The time and accuracy of switching OF and efficient positioning of the radiation-direction depends on the complexity of the construction and manufacturing of optoelectronic devices technology OD. In this regard, there is a problem of development and simulation of passive components of the linear path of the optical communication, i.e., development of the optoelectronic switch, positioning devices of simplified design and the schemes to control them which allow to increase the accuracy of switching and positioning the direction of OR, to reduce the losses associated with the radial displacement and angular misalignment of the radiation source RS and OF, as well as extend the functionality of these devices.

SELECTION CRITERIA FOR DEVELOPMENT

The transmission efficiency of OR is determined by many factors, which includes improving the efficiency of existing linear structures, reducing the dispersion distortion, increase of regenerator section length, reducing the number of intermediate non-performing regeneration points, study of the basic laws of the agreed inclusion of RS with OF, switching and positioning the radiation direction when entering from OR into OF.
Improving the efficiency of the transfer of OR consists of the solution of two main tasks, ie finding the objective function and the determination of the values of indicators that would allow the device to work at extreme values of the objective function. Guided by the above principles, the objective function can be determined as follows:

$$E_{eff} = \{\max[\eta_{eu}, K_{inp}, L_{rs}], \min[t_{sw}, n_{URP}]\}, \quad (1)$$

here η_{eu} − the coefficient of effective use of a linear structure; K_{inp} − input ratio of OR into OF; L_{rs} − the length of the regeneration site; t_{sw} − switching time of OF; n_{URP} − the number of non-performing intermediate regeneration points.
To ensure the effectiveness of the transfer of OR, a research is carried out in this work on the development of tools that provide the required values of switching time and input factor indicating the degree of matching of the output of transmission system with the input of line.

DEVELOPMENT OF SCHEMES OF THE OPTICAL COMMUNICATION ORGANIZATION

The organization scheme of the linear path of the optical communication with an optoelectronic switch and the device of precision positioning of the OF optical cable shown in figure 1.

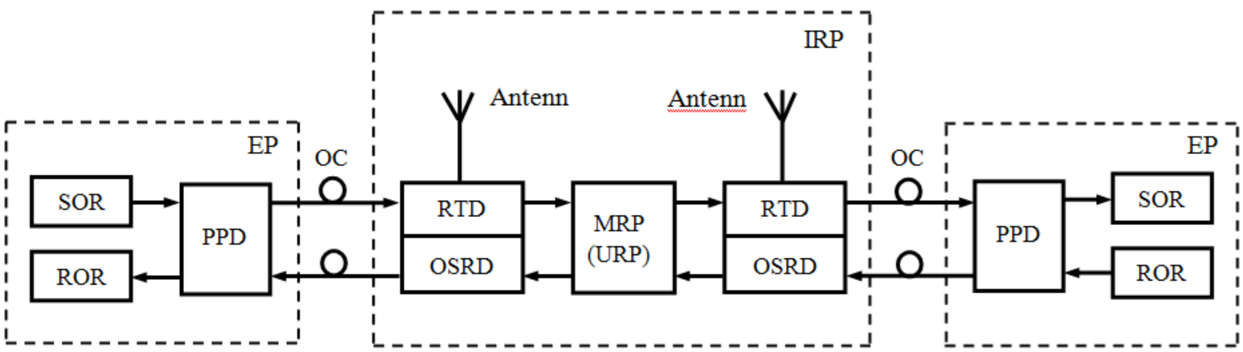

Figure 1. The organization scheme of the optical communication

The scheme of organizing the optical communication consists of endpoints EP, an intermediate regeneration point IRP and the transmission medium of optical cable OC. In its turn, each of EP consists of a source of OR , SOR receiver of OR, ROR and precision positioning device PPD, and IRP consists of receiving - transmitting device RTD with an antenna, optoelectronic switch of the radiation direction OSRD and maintained MRP and/or unattended regeneration points URP and OC as a guide medium.
Now, let us separately consider the task of developing the passive components of the linear path of the optical communication.

THE DEVELOPMENT OF OPTOELECTRONIC RADIATION DIRECTION SWITCH

In [12-16] it was solved the tasks of developing OSRD of the mathematical model of functioning and scheme of the experimental installation for testing to remove the dependence of voltage from the shaft braking times for different values of torque on the shaft of piezoelectric motor. This device enables remote switching of OF, it allows remotely change the direction of OR smoothly in the range of 0^0 to 360^0, to reduce the area of interaction of the radiating surface of OR with OF and switching time compared to the duration of the transmitted bits. On the practical side, it allows to solve the organization task of the hot backup method for transport networks of high levels (STM-64, STM-256 and above), the pulse duration with less than 100 ps.

DEVELOPMENT OF PRECISION POSITIONING DEVICES

As is known from [17], the direction positioning devices include a relatively large number of mechanical components and assemblies with complex geometrical shape and configuration, complicating their construction, as well as reducing the accuracy of the positioning process. In addition, after stopping the mechanical unit of advancement, the accuracy of scanned radiation positioning decreases which leads to a partial loss of the radiation energy of the transmitted signal. Therefore, the operational reliability of this design is low because OF of fibers, serving as communications channel are in a mobile state. As shown in analysis, the existing devices have certain losses in the places of mechanical connection, a complicated design and limited functionality. Therefore, in order to reduce the losses in the mechanical connection places, improve positioning accuracy of the radiation directions ensuring the alignment of axes of transceiver and OF, the precision positioning device is designed with high accuracy.

As is known [12-17], the existing optoelectronic switch contains mirror reflector, focusing lens, optical fibers, stepper motor, an operational amplifier, a counting device, comparing circuit, the sampling unit, the logical key, alternator current generator, electronic switch, trigger, LED and photodiode.

To solve this problem in the known optoelectronic switch, further it is additionally included with piezoceramic braking element -16, the first phase-shifting circuit -17, second flip-flop -18, second electronic switch -19, the first DC generator -20, the electrodes of the piezoceramic breaking element -21, wear-resistant tip of the piezoceramic brake element -26, the source of optical beam -28, the second phase-shifting circuit -29, generator of output pulses -30, comparison unit -31, the unit of the reference voltage -32, the third trigger-33, the automatic tuning unit -34, the second generator DC -35, the third electronic switch -36, piezoceramic bimorph element-37, the electrodes -38 of bimorph piezoceramic element. Optical fiber -23 of the optic cable -22 is placed in the housing unit of -24 in sections -25. The transfer of the optical signal carried out by fiber optic OC -27 and the optical beam from the source -28 is directed to the reflector. For receiving the optical beam photodiodes -13 are mounted on the device sections. Mechanical contact of the bimorph piezoceramic element with a cylindrical shaft is made with tip -39 piezoelectric element. The new elements and design, introduced in the proposed device are marked by the dashed line and conventionally indicated with position -40. The device starts to work with the help of key -41.

The overall design and electronic control units ECU is shown in figure 2 [17].

From the source of optical radiation -28, the beam is directed to the reflector -12, reflecting (in figure 2, the optical beam path is shown by the dotted line) and passing through the focusing lens -13, falls on the desired photodiode -10 and the signal from its output is transmitted to the operational amplifier -2, after amplification, from its output - to the counting device -3 and the comparison circuit -4. When there is a coincidence of the input signal of the comparison circuit - 4 and the output signal of sample block -5, in the output of comparator -4, a signal appears and is transmitted to the control block of the logic key input -6. From the first of its output, signal's getting into the second input of the first trigger -9, it turns it to its original state and as a result of this, the electronic key -8 disconnects the alternator -7 from the electrodes -15 of the piezoceramic element of the device. Simultaneously from the second output of logical key -6, the signal being delayed by phase-shifting circuit -17, then it is fed to the control input of the second trigger -18 and switches the second trigger from one stable state to another one. Similarly, the signal is supplied to the control-input of the second electronic switch -19, and the constant voltage of the first generator of constant current -20 from the second electronic switch -19 is fed to electrodes -21 of the piezoceramic braking element -16 and due to its mechanical deformation along the length of the tip -26 of the piezoceramic braking element -16, it instantly stops the cylindrical shaft -11.

At the same time the signals from the photodiodes -10 supplied onto the inputs of the operational amplifier -2 through its second output sit are supplied to the control input of the second phase-shifting circuit -29. With its output through the sample block -5, through one of the channels with a certain delay the signal is fed to a pulse shaper -30. The signal corresponding to a specific channel -23, placed in the sections -25 and in the sample block -5, depending on the relative signal from the output of the optical beam source -28, the voltage signal from the photodiode -10 is compared with voltage of the reference voltage unit. At equal levels of the compared signals, the signal is analogically supplied from the first output of the comparison block -31 to the control input of the third trigger -33, from its output to the control input of the third electronic key -36, and to its another input from the second generator of constant current -35. From the signal output of the third electronic switch -36 the voltage is fed to the electrodes of piezoceramic element -37.

ISSN: 2277-9655
Impact Factor: 4.116

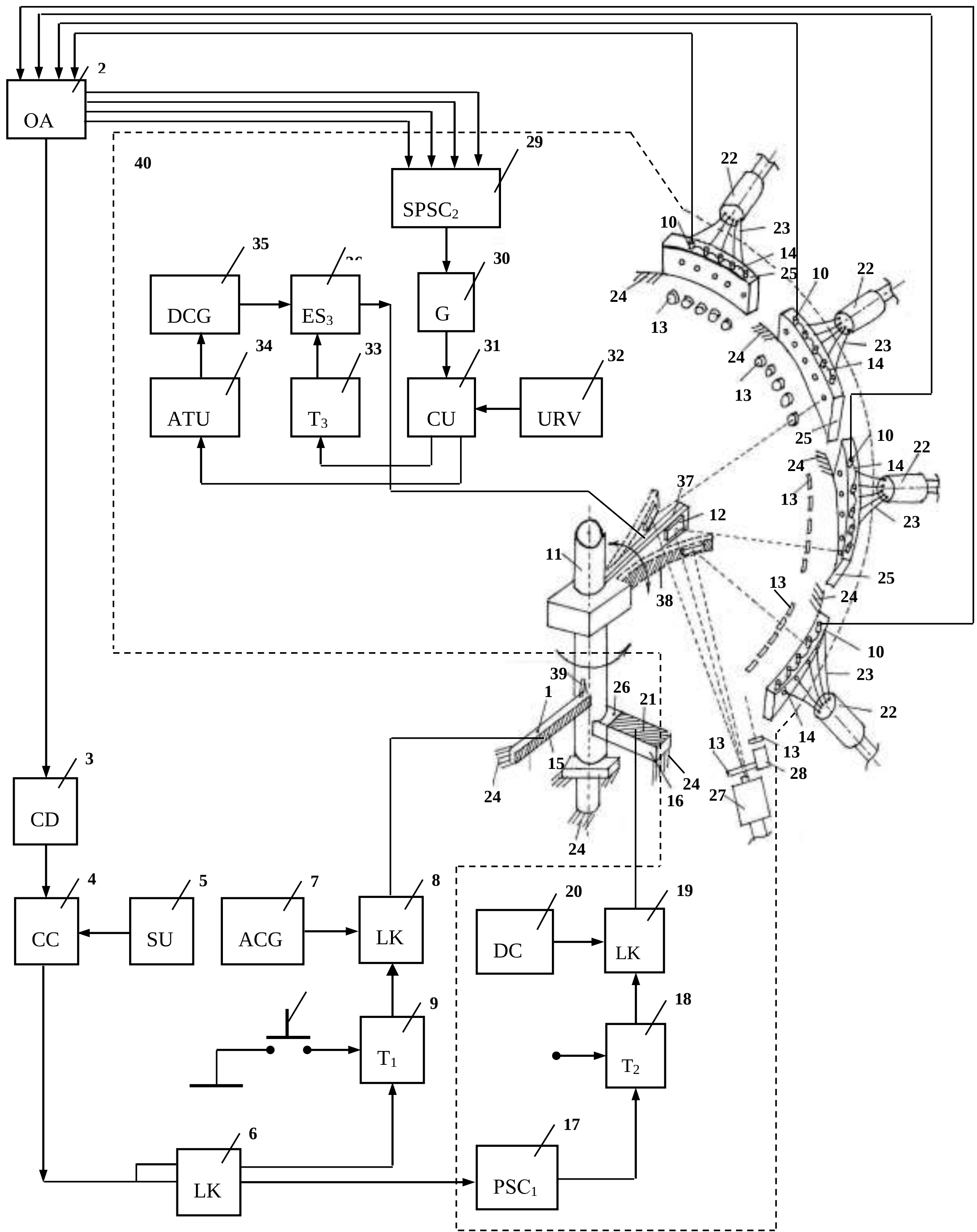

Figure 2. Block-diagram of its ECU with electronic circuitry and its control

In the inequality of the voltages of the comparison block -31 and the voltage of the block of the reference voltage unit -32, the control voltage is supplied to the control input of the automatic adjustment unit with feedback -34 and automatically transferred to the piezoceramic element -37 and due to its mechanical bent deformation, the optimum position of OR is ensured, directed to the reflector -12, with respect to the optical channel -23, the loss of OR is reduced and thereby the positioning accuracy increases.

MATHEMATICAL MODELS OF THE FUNCTIONING OF ECU

Despite the fact that the technologies and equipment, established for optical transport networks are designed and improved with high rates, however, the evidence-based and conventional simulation techniques of the operation process of such devices do not exist. Therefore, the greatest interest is the task of developing a mathematical model of the functioning of ECU with directions of OR.

In the devices [17], of the piezoelectric element of rectangular cross section, receiving power from an external source, it is subjected to longitudinal tensile strain, determined in accordance with:

$$\Delta_{\text{пр}} = \frac{2T_{mt} \cdot l_1}{\pi E_{\text{Y}}} = \frac{2 \cdot 19{,}6 \cdot 10^6 \cdot 5 \cdot 10^{-2}}{3{,}14 \cdot 7 \cdot 10^{11}} = 6 \cdot 10^{-6} = 6\,mkm, \quad (2)$$

here T_{mt} – is the mechanical tension in the center of the plate and equals to $19{,}6 \cdot 10^6\,(N/m^2)$, l_1 – length of piezo and equals to $5 \cdot 10^{-2}$ (m), modulus of elasticity (Young's modulus) and for piezoceramics of brand STBS-3 an equals to $0{,}8 \cdot 10^{11}\,(N/m^2)$.

At the same time, as a result of longitudinal deformation of the piezoelement, its bending takes place, which is defined by the formula:

$$\Delta_{ld} = \frac{F_{\text{м}} \cdot l_1^2}{3E_{\text{Y}} \cdot J}, \quad (3)$$

here $F_{\text{м}}$ – is the maximum force that acts on the part of piezoelement (*N*), J – the moment of inertia for a rod with a rectangular cross-section (m^4).

In the described vibrational mode, deflection "Δ" is a function of not only the coordinates "*x*", but also the time that is:

$$\Delta = f(x,t). \quad (4)$$

Studies show that the quality of performance of the displacement mechanism such as uniformity of step and movement force, of the working body in the first case and of the rotor rotational shaft in the second case, is largely dependent on the dynamic stability of the piezoelement during the operation in the oscillatory mode. The experimental researches of the performance, conducted by using the sensors, that measure the dynamic effects, show that in the mentioned operating mode, the piezoelement is exposed to the force of the working body or in the second case, of the engine rotor shaft directed at its bend along the tangent to the elastic line (figure 3).

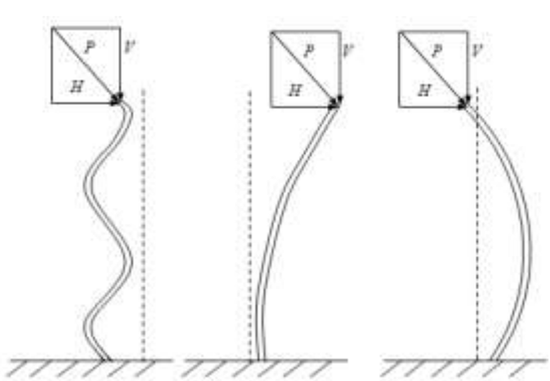

Figure 3. Vibration forms of the piezoelement under the action of the follower force

Laying out the force P into two components (figure 3) into vertical $-V$ and horizontal deflections $-H$, for small deflections, at the order of $1 \cdot 10^{-5}$ mm, the tangential force can be considered constant. The force H, is also specific, its value is essentially dependent on the deflection of the end sections, and the force is equal to the multiplication of the stiffness of piezoelement K_{sp} in the form of a rectangular bar on the deflection increment Δ, i.e,

$$F = K_{sp}\Delta. \quad (5)$$

The differential equation of the bent axis is as follows:

$$E_Y J \frac{d^4\Delta}{dx^4} + P\frac{d^2\Delta}{dx^2} = q, \quad (6)$$

here $q-$is the intensity of the lateral load, $J-$is the moment of inertia for a rod with a rectangular cross-section:

$$J = \frac{l_2 \cdot l_3^3}{12}. \quad (7)$$

When $P \neq 0$, the elastic line of piezoelement combines the first and the second own forms for the left side of the loop. For the equiation $K = F(f)$, the prevailing is the first form of vibrations, and for the right – is the second (figure 4).

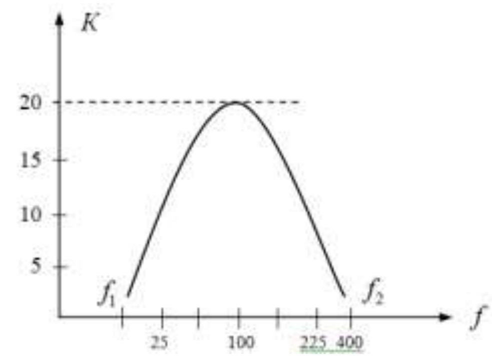

Figure 4. Loop of vibration frequency of the pezoelement at different compressive forces

Fig. 5 shows the dependence of the linear speed of movement of the working body $-V_{wb}$ on the magnitude of the pressing force $-F_{pf}$ of the pezoelement to the working body for different values of the frequency of the supply voltage.

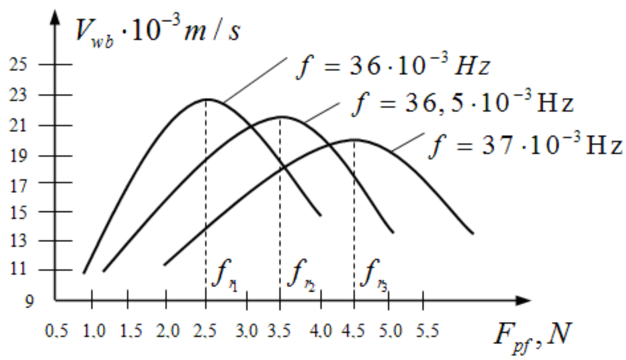

Figure 5. The dependence of the linear speed of movement of the working body of the magnitude of the pressing force to the working body of piezoelement

From these dependences it is seen that the curves are almost of the same shape of curve, as shown in Fig. 5. At the limit point of the loop, the frequencies are merged and this point corresponds to the value of the compressive force $K \approx 20.$ When $K > 20$ the vibration system will be unstable and it will be swing providing with additional energy through the work of non-conservative force component $P.$

It should be noted that the change in the direction of the force $P,$ resulting from the conditions of the problem must take place due to some external voltage of the energy source for the system. If we seek additional roots of the equation, then we get new loops connecting the third and fourth own frequency, fifth and sixth, etc. However, it should be noted that the limit point of the first loop turns lowest, and it determines the critical load, which is approximately equal to:

$$P_{kl} \approx \frac{2\pi^2 E_Y J}{l_1^2}, \quad J = \frac{l_2 \cdot l_3^3}{12}. \tag{8}$$

For the piezoelement in the form of a rectangular ceramic rod TSTBS -3:

$$P_{kl} \approx \frac{2 \cdot 3{,}14 \cdot 0{,}8 \cdot 10^{11} \cdot 136 \cdot 10^{-14}}{(5 \cdot 10^{-2})^2} = 267{,}6\,kg. \tag{9}$$

Given the geometric dimensions of the piezoelement, tensile strength at longitudinal deformation [3]:

$$\sigma_{ld} = P_{kl} / l_2 \cdot l_3. \tag{10}$$

Breaking load P can be measured if the section of the piezoelement is used as a sensor, and the value calculated by the formula with given electrical parameters:

$$\sigma_d = E_{\sim} d_{31} \cdot E_Y \cdot Q_M, \tag{11}$$

here $E_{\sim} -$ is the electric field intensity at specimen failure (V/m), $d_{31} -$ is the longitudinal deformation piezomodulus (m/V), $E_Y -$ Young's modulus (N/m^2), $Q_M -$ mechanical quality factor.

CONCLUSION

Thus, this developed remote optoelectronic switch of the direction of radiation and precision positioning device can reduce time, improve the accuracy of the switching and positioning of the direction of the optical radiation, ensure the loss of local mechanical connection and commissioning of the radiation into the fiber optic cable within 3...5 dB, which is less by 50...55% than in known devices. These devices offer significant advantages over the electro and magneto-electric deflection systems, which includes low power consumption, high accuracy, reliability and manufacturability.

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