A three-axis optical radiation positioning device

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A B S T R A C T

On the basis of the conducted analysis, an optical radiation positioning device is developed, the working body of which is a 3-axis differential stepper motor that allows increasing the accuracy of positioning the direction of optical radiation propagation and expanding its functionality by introducing additional rotors designed in the form of spheres placed at an angle of 90º relative to each other in mutually perpendicular planes, passing through the centers of the spheres with a possibility of angular rotation around the three axes of the rectangular coordinate system. This device is a component of optical telecommunication networks and fiber-optic communication lines and can be used as a three-axis optical radiation positioning device. In the proposed device at the value of angular rotation steps of the rotors ranging from 4.0µm to 0.2mm the accuracy of rotor positioning in a step mode of operation is 1.4÷2.1µm.

1. Introduction

On the basis of the conducted analysis it was concluded that among the known devices there is a similar device in terms of technical idea, which contains a rotor designed in the form of a sphere, equipped with three drivers placed at an angle of 120º in the plane passing through the center of the sphere, and the stator is designed in the form of three supports with concave spherical surfaces located in the same plane at an angle of 120º to each other, on which the thrusters designed in the form of part of a sphere are mounted [1]. In this device, the rotor is designed in the form of a sphere and has three drivers placed at an angle of 120º in the plane passing through the center of the sphere, and the stator is designed in the form of three supports with concave spherical surfaces, which limits its functionality. This is due to the fact that in the device, there is no possibility of rotor motion, and no possibility of the stator motion around the three axes of the rectangular coordinate system X, Y and Z in a step mode of operation when the rotor is fixed. The accuracy of positioning of the rotor of the motor is relatively low, because according to the description, the motor is powered by an alternating voltage. In the step motion mode of the rotor in the second half of the cycle, the voltage is fed to the torsional strain vibrator, which rotates the rotor around its axis. At the same time, the drives move tracing out a certain trajectory of motion in space. Due to the inertial mass of the three drivers and the inertial mass of the rotor in the form of a sphere, in the second half of the cycle, after the power supply to the torsional strain vibrator is stopped, the radial strain vibrators of the other two thrusters receive power at the moment of braking, de-energizing the thruster. However, due to the absence of

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wear-resistant friction coatings in the sphere-shaped rotor of the known motor, as well as at the moment of braking of the rotor after de-energizing of the thruster, the sinusoidal supply voltage damping occurs for some time, through the damped torsional strain vibrators, even after de-energizing of the torsional strain vibrators and the radial strain vibrators of two other thrusters receiving supply voltage, resulting in the rotor slipping in the step mode of operation, which ultimately leads to inaccurate positioning of the rotor relative to the specified axis with a 120º displacement.

The object of this study is a three-axis device optical radiation positioning device, and the aim is to expand the functionality and improve the accuracy of optical radiation positioning.

2. Development of a three-axis device optical radiation positioning device

To achieve this aim, the three-axis differential stepper motor containing a rotor in the form of a sphere, a stator consisting of vibrators in the form of radial and torsional strain in the form of parts of a sphere, connected to alternating voltage source, is supplemented with rotors in the form of spheres placed at 90º angle relative to each other in mutually perpendicular planes, passing through centers of the spheres with possibility of angular rotation around three axes X, Y, Z of the rectangular coordinate system. The vibrators are rigidly mounted in the stator of the motor designed in the form of two halves of a sphere, each rotor shaft from the outer side of the motor is equipped with a piezoelectric vibrator in the form of a radial strain washer rigidly mounted on the stator, and the mechanically contacting working surfaces of said spheres have a wear-resistant friction coating. The signal input and the first signal output of the first electronic switch are connected, respectively, to the AC voltage source and to the electrodes of the radial strain vibrator; the second output of the first electronic switch through the phase-shifting circuit is connected to the torsional strain vibrator electrodes. The control input of the first electronic switch is connected to the output of the first trigger, the control input of which is connected to the first output of the control device, the control input of which is connected to the comparison device, the first control input of which is connected to the output of the counting device, and the reference frequency source is connected to the second control input. The counting device input is connected to the output of the rotor position setter, the signal input and the signal output of the second electronic switch are connected to the DC generator output and the electrodes of the piezoelectric vibrator in the form of a radial strain washer, respectively; the control input of the second electronic switch is connected to the output of the second trigger, the control input of which is connected to the second output of the control device [2].

The distinctive essential feature concerning the addition to the motor of extra rotors in the form of spheres placed at an angle of 90º relative to each other in mutually perpendicular planes, passing through the centers of the spheres with the possibility of angular rotation around the three axes X, Y, Z of the rectangular coordinate system, contributes to expanding the functionality of the proposed motor.

It should be noted that when feeding voltage from AC voltage source to the electrodes of radial (rsv) and torsional (tsv) vibrators of the rotor – 1 located on the X-0 coordinate axis, the rotational motion of the rotor is simultaneously transferred by differential gear, to the rotor – 1 located on the Y-0 coordinate axis and to the rotor – 1 located on the Z-0 coordinate axis (Fig. 2).

And the same is done in the above sequence, so that when feeding voltage from AC voltage source to the electrodes of radial and torsional strain vibrators to the rotor located on the Z-0 coordinate axis, the rotational motion of the rotor is simultaneously transferred by the differential gear to the rotor located on the X'-0 coordinate axis and the rotor located on the Y'-0 coordinate axis (Fig. 2).

The design of the proposed device allows to regulate the running clearance "δ", between the contacting wear-resistant friction coatings of the work surfaces of the rotor spheres, i.e., to change the position of the rotor balls relative to each other by connecting the radial strain vibrators to a direct polarity DC or AC voltage source for forward movement and contacting with another rotor, and also during their braking (Fig. 1).

Besides angular rotation of any of rotors, with rigidly fixed stator, and if necessary with rigidly mounted rotors on both sides on one of coordinate axes, allows angular rotation of the stator around any of coordinate axes of the X, Y, Z rectangular coordinate system (the trajectories of direction of the stator's angular rotation around the X, Y, Z coordinate axes are conventionally shown on Fig. 3).

Distinctive essential features concerning the connection of the signal input and the first signal output of the first electronic switch, respectively, to the AC voltage source and to the electrodes of the radial strain vibrator, the second output of the first electronic switch through the phase-shifting circuit connected to the electrodes of the torsional strain vibrator, the regulation of the phase shift of AC voltage supply, the response time first of the radial strain vibrator, then with a lag in the response time of the torsional strain vibrator ensuring the cyclicity of the rotor's angular rotation in a step mode of operation is achieved. This also improves the positioning accuracy of rotos of the stepper motor. The distinctive essential feature concerning the connection of the control input of the first trigger to the first output of the control device, the control input of which is connected to the comparison device, the first control input of which is connected to the output of the counting device, and the second control input is connected to the reference frequency source, the input of the counting device is connected to the output of the rotor position setter, the signal input and the signal output of the second electronic switch are connected respectively to the output of the DC generator and to the electrodes of the piezoelectric vibrator in the form of the radian strain washer, the control input of the second electronic switch is connected to the output of the second trigger, the control input of which is connected to the second output of the control device.

The presence of the piezoelectric vibrator in the form of a radial strain washer excludes the rotor slippage in the step mode of operation, due to the fact that when the AC supply voltage from the torsional strain vibrator is switched off, the piezoelectric vibrator in the form of a radial strain washer receives DC supply voltage, while there is a clear fixation of the rotor step, implementing its instant braking, which improves the rotor positioning accuracy in accordance with the specified number of angular rotations. The connection of the signal input and the signal output of the second electronic switch, connected respectively to the output of the DC generator and the electrodes of the piezoelectric vibrator in the form of a radial strain washer, the control input of the second electronic switch is connected to the output of the second trigger, the control input of which is connected to the second output of the control device carries out the automatic step of the motor, leading to a significant improvement in the accuracy of precision positioning of the motor's rotor, at the value of the rotor's angular rotation step rotors ranging from 4.0μm to 0.2mm the accuracy of rotor positioning in a step mode of operation is 1.4÷2.1μm. As can be seen, all above-mentioned features of the developed device are essential, and the presence of each, when checked for novelty and key differences in design, functionality and technical result, have been established to make a direct impact on technical result "expansion of functionality and increase of the accuracy of precision positioning of rotors of a three-axis differential stepper motor", i.e., all these features are in cause-effect relation with the specified technical result [2-6].

Fig. 1 shows an optical radiation positioning device in the form of a stepper motor in section with strain vibrators connected to the control circuit, Fig. 2 shows the rotor layout design in a rectangular coordinate system (X, Y, Z), Fig. 3 gives a general view of a stepper motor with the rotors placed in the stator in the form of two hemispheres in the assembly, Fig. 4 shows a sectional view of the stepper motor, and Fig. 5 shows the waveform of the AC supply voltage pulses applied to the radial and torsional strain vibrators with a temporal phase shift.

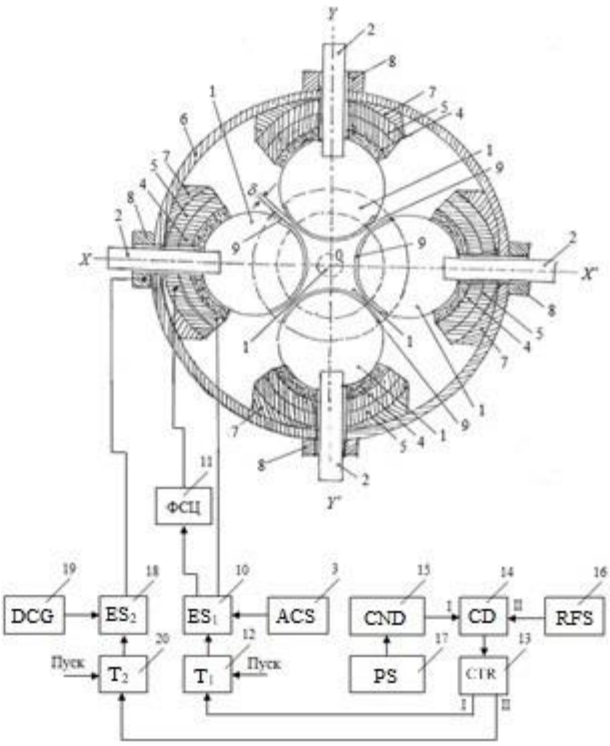

Fig. 1. Sectional view of a stepper motor with strain vibrators connected to the control circuit diagram

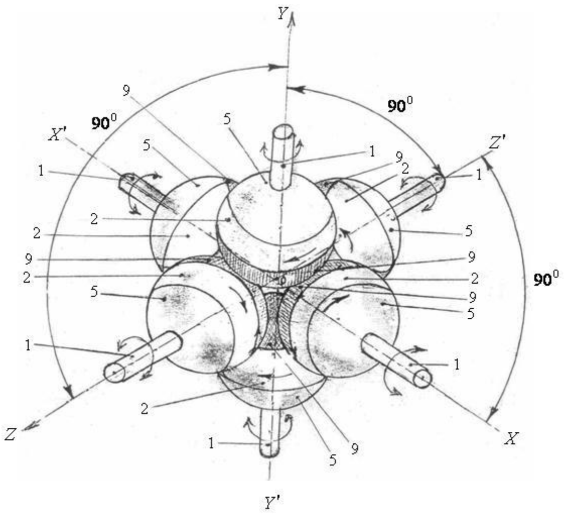

Fig. 2. Rotor layout design in a rectangular coordinate system

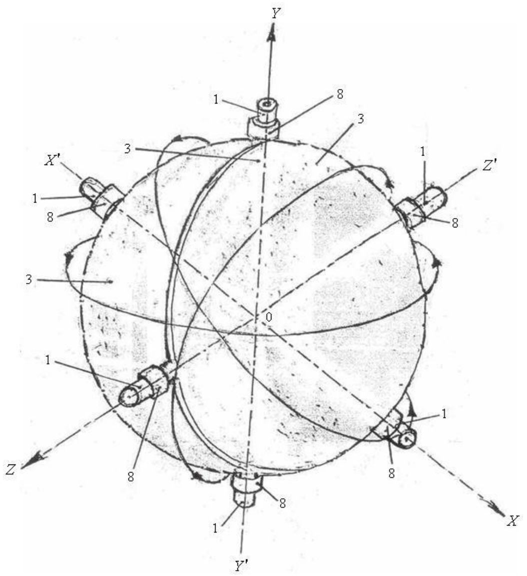

Fig. 3. General view of a stepper motor with the rotors placed in the stator in the form of two hemispheres in assembly

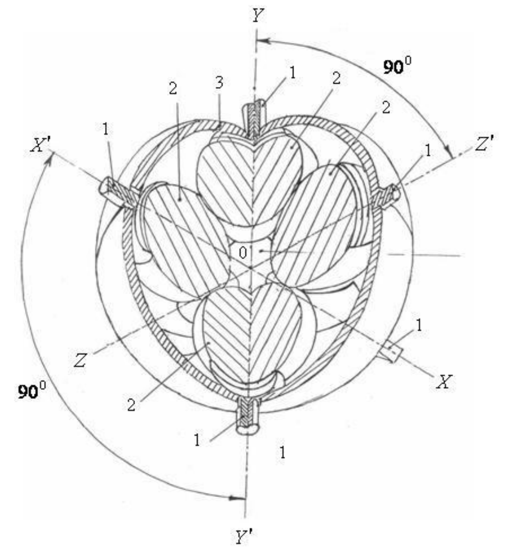

Fig. 4. Sectional view of a stepper motor with the rotors placed in the stator in the form of two hemispheres in assembly

The three-axis differential stepper motor shown in Figs. 1-5 contains a rotor – 1 in the form of a sphere – 2, a stator – 3 consisting of vibrators in the form of part of a sphere of radial (rsv) – 4 and torsional (tsv) – 5 strain vibrators connected to an AC voltage source – 6. This device was supplemented with rotors, designed, respectively, in the form of spheres located at an angle of 90º relative to each other in mutually perpendicular planes passing through the centers of these spheres (Fig. 1-4).

Radial (rsv) and torsional (tsv) strain vibrators are rigidly mounted – 7 in the motor's stator, designed in the form of two hemispheres (Fig. 3), each rotor shaft from the outer side of the motor is provided with piezoelectric vibrator in the form of a radial strain washer – 8. The working surfaces of the spheres in mechanical contact with each other are provided with wear-resistant friction coatings – 9 (Fig. 1).

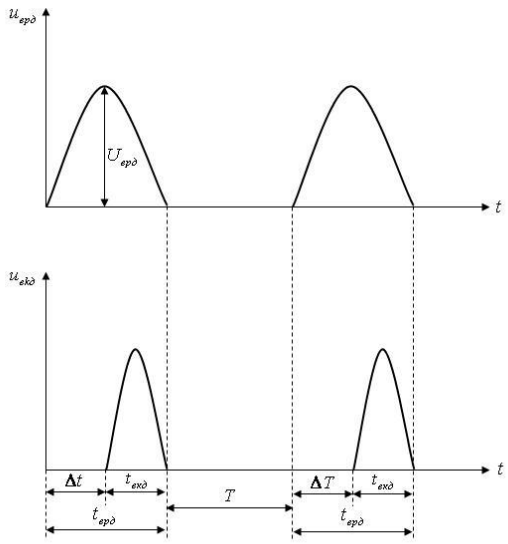

Fig. 5. The waveform of the AC supply voltage pulses applied to the radial and torsional strain vibrators with a temporal phase shift

The control circuit of a three-axis differential stepper motor consists of AC voltage source (ACS) – 3, first electronic switch (ES_1) – 10, phase-shifting circuit (PSC) – 11, first trigger (T_1) – 12, control device (CTR) – 13, comparison device (CD) – 14, counting device (CND) – 15, reference frequency source (RFS) – 16, rotor position setter (PS) – 17, second electronic switch (ES_2) – 18, DC generator (DCG) – 19 and second trigger (T_2) – 20.

3. Operating principle of the three-axis optical radiation positioning device

At the beginning of operation, before starting the first trigger (T_1) – 12, in the rotor position setter (PS) – 17 the required value of the position of the rotor – 1 is set. Then when starting the first trigger (T_1) – 12, under the influence of AC voltage pulses – 6 U(rsv) (Fig. 1, 2, 5), applied to the radial strain vibrator – 4 of the rotor – 1 located on the X0 coordinate axis, the latter, deforming in the radial direction presses the ball – 2 of the rotor – 1, with the working parts with friction coatings – 9 made of wear-resistant material of rotors – 1, located on the U0, Z0 coordinate axes, supports (Fig. (Fig. 5) in this position (by means of the phase-shifting circuit) over a certain time determined by the response time constant and the duration of the AC supply voltage pulse U (rsv) applied to the radial strain vibrator – 4 (Fig. 5). To the torsional strain vibrator – 5 with some delay the AC voltage pulse U(tsv) is applied and after a time interval Δt, which is necessary for the radial strain vibrator – 4 to overcome the running air clearance – "δ" (Fig. 1). Thus, the torsional strain vibrator – 5 is activated and rotates the rotor – 1 of the X0 coordinate axis around its axis by one step. The rotors located on the Y0 and Z0 coordinate axes are rotated by the same amount of step, then the AC voltage pulse is replaced by a pause (Fig. 5). After the activation of the radial and torsional strain – 4, 5 from the output of the rotor position setter – 17 voltage pulses corresponding to a change in the position of the rotor – 1, go to the input of the counting device – 15, from whose output voltage pulses are sent to the first input of the comparison device – 14, the second input of which receives pulses of the reference frequency voltage – 16 corresponding to the specified position of the rotor – 1. Their coincidence at the output of the comparison device – 14 generates the control signal that starts the control device – 13, from the first output of which voltage pulses come to the control input of the first trigger – 12, turning off and stopping the AC voltage to the radial and torsional strain vibrators – 4, 5. The radial and torsional strain vibrators – 4, 5 due to their inherent elastic forces return to the original position during the time t_{rsv} and t_{tsv}, determined by constant response time of the radial and torsional strain vibrators – 4, 5, at the same time from the second output of the control device – 13 voltage pulses come to the control input of the second trigger – 20, which controls the second electronic switch – 18, and to its signal input DC voltage is supplied from the generator output – 19, and from its signal output DC voltage is supplied to the electrodes of the piezoelectric vibrator – 8, designed as a radial strain washer. At that, a precise fixation of the step of the rotor – 1 takes place, implementing its instantaneous braking.

Working cycles are periodically repeated in the above sequence, with the rotor – 1 taking a new position. Besides implementation of angular stepping rotation of any of the rotors – 1 (Fig. 2, 3) with rigidly mounted stator – 3, if necessary also with rigidly mounted rotors X0, X0 from both sides, along one of any coordinate axes it allows implementing angular stepping rotation of the stator – 3 around the respective axes of rectangular coordinate system (the trajectories of direction of angular stepping rotation of the stator around the coordinate axes are conventionally shown on Fig. 3).

4. Conclusion

Thus, the developed device belongs to the class of components of optical telecommunication networks and fiber-optic communication lines and can be used as a three-axis optical radiation positioning device, which uses a stepper motor with multi-axis rotating rotors as the operating element. In the proposed device at the value of angular rotation steps of the rotors ranging from 4.0μm to 0.2mm, the accuracy of rotor positioning in a step mode of operation is 1.4÷2.1μm.

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