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Satbayev University

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ИЗВЕСТИЯ

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Satbayev University

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METHODS FOR IMPROVING PROCESS AUTOMATION IN THE MINING INDUSTRY

Abstract. This paper discusses topical issues of process automation in the mining industry. Depending on the type of open pit or underground mining, various automation facilities are used. In the case of open mining, in recent years, due to technological progress, photogrammetric methods using unmanned aerial vehicles (UAVs) are used for filming, the main advantage of which is the ability to perform operational control of the mining enterprise, determine the volume of warehouses and dumps by obtaining a three-dimensional digital model.

In the case of underground mining, various mechanisms are applied, including driving drums. To control the speed of the drive drum, phase shifters with electromechanical control are used. This range of phase shifters includes devices that use mechanisms controlled by an electrical signal. The principles of signal phase control themselves remain mechanical, but the possibility of electronic control allows such phase shifters to be included in automated control and measuring systems. The most important elements of an automation system are converters. The primary converter is the first in the measuring circuit and includes a primary sensitive element (probe, membrane) and other necessary elements for converting an input non-electric quantity into an output electrical quantity. The sensor may consist of one or more measuring transducers combined into a single structure. The sensor is directly affected by the measured non-electrical quantity (force, pressure, level, temperature, etc.)

The unified converter consists of a sensor and a matching circuit, the measured physical quantity is converted with an energy source into a normalized output value. The intermediate converter receives the measurement information signal from the upstream converter and, after conversion, transmits this signal to the downstream converter.

From early works on various methods for measuring mechanical quantities, it is obvious that there are many unresolved issues in this matter. Over the years, scientific publications have periodically appeared in which the authors outlined their possible methods for using phase shifters with a traveling magnetic field to measure mechanical quantities.

Also, the key point in solving this problem is certainly the technology of improving and modernizing the design of measuring phase shifters of angular displacements. In the works of some authors, it has been repeatedly suggested that it is necessary to systematize the available materials and develop a certain concept on this issue.

Key words: automation, underground mining, unmanned aerial vehicles, driving drum, transducer, sensors, probe, membrane.

Introduction. Numerous studies justify that drones can compete with traditional mapping methods in terms of accuracy, speed and economy. Land surveying is not an easy task. Traditionally, surveyors have used total stations, GPS receivers, and terrestrial laser scanners and many other tools to obtain high-resolution spatial data about the topography of the earth's surface. But due to the development of drone technology, in recent years, drones have become an outstanding tool for surveying and mapping. Drone mapping uses photogrammetry to create accurate real-life 3D models from 2D images. Photogrammetric methods combine and process several georeferenced aerial photographs, allow creating three-dimensional point clouds, raster digital elevation models and orthomosaics.

Currently, aerial photography using UAVs is used for open pit mining. Aerial photography is used to create topographic products at a scale of 1:5000 – 1:500, in connection with which a technological scheme for performing mine surveying surveys at opencast mines was developed. The technological scheme was developed based on instructions and taking into account the requirements for the accuracy of plans in scales of 1:500 – 1:5000, in which the main mine surveying schemes are drawn up.

Electromagnetic sensors of mechanical quantities firmly hold the leading position in terms of reliability in operation, simplicity in manufacturing technology and cost among a huge number of sensors. A fairly large number of scientific studies have been devoted to sensors, which are the main elements of the conversion of mechanical quantities into electrical signals [1]. This indicates that interest in such devices continues unabated.

A special place among the well-known developments in this area is occupied by measuring phase shifters with high resolution [2]. Developed on the basis of the electromagnetic system of electric micro machines, they have taken a strong position in the systems of automatic control and regulation of the most critical devices [3].

The main informative parameter of the output signal of the phase shifters is the change in the phase of the output voltage. Therefore, an important characteristic of the measuring system is the accuracy of displaying the phase and amplitude of the output voltage [4].

The basic theory of this electromagnetic system is presented by one of the authors of this article [5].

In this article, for measuring mechanical quantities, it is proposed to use phase shifters with a running magnetic field. This allows not only to simplify the design of the measuring phase shifters of angular displacements, but also to develop reliable phase shifters of linear displacements. In practice, we are talking about the unification of methods for measuring linear and angular mechanical quantities. The proposed principle of construction of sensors makes it possible to significantly reduce the overall dimensions of the information line and increase the coefficient of its use in linear displacement sensors.

Materials and methods. *The principle of operation and design features of phase sensors with a running magnetic field.* The principle of operation of phase shifters with a running magnetic field will be explained using the example of a phase linear displacement transducer, the design of which is shown in Figure 1.

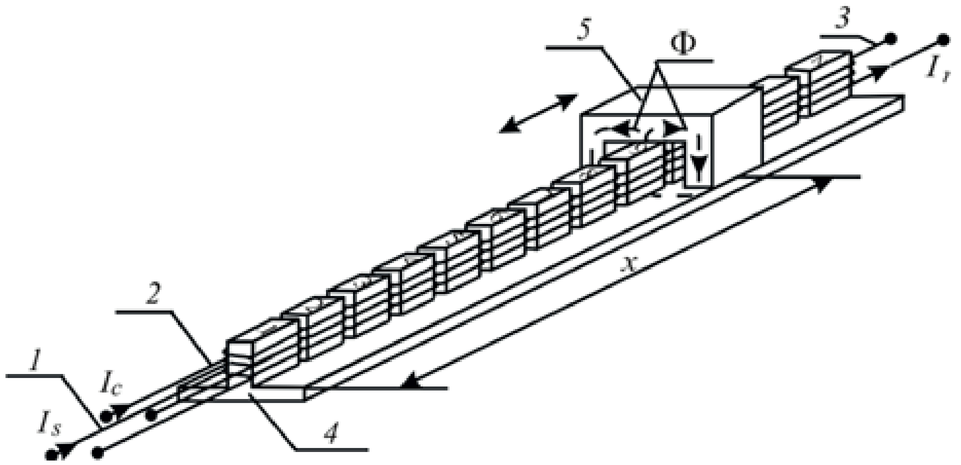

Figure 1. Phase Linear Displacement Sensor

A phase linear displacement transducer with a transverse magnetic field consists of an information line and a magnetic shunt. The information line includes: 1 - sinus winding, 2 - cosine winding, 3 - output winding, 4 - magnetic circuit of the information line, 5 - magnetic shunt.

It follows from the construction that all three sensor windings are located on a fixed part, called the information ruler. The length of magnetic circuit of *l* the information ruler has *n* teeth, on which the windings are laid. The distance between the midpoints of adjacent teeth is equal to: *a=l/n*.

The number of turns of the sinus winding of each tooth depends on its serial number and is determined by the formula 1.

$$W_{sk} = W_m \sin\left(\frac{2\pi}{n}(k - 0{,}5)\right), \quad (1)$$

where,

W_{sk} – is the number of turns of the sinus winding on the *k*-th tooth; W_m – the maximum number of turns; *n* – the number of teeth in the information line; *k* – the serial number of the tooth, varying from 1 to *n*.

The number of turns of the cosine winding changes according to the cosine law depending on the serial number of the tooth and is determined by the formula 2.

$$W_{ck} = W_m \cos\left(\frac{2\pi}{n}(k-0,5)\right), \tag{2}$$

Where, $k = 1; 2; \ldots, n$;

W_{ck} – is the number of turns of the cosine winding on the k-th tooth.

The output winding 3 has the same number of active conductors on all teeth of the magnetic circuit of the information line, equal to W_r.

The sine and cosine windings of the sensor are powered by a two-phase sinusoidal voltage source. A sinusoidal voltage is applied to the terminals of the cosine winding 2, so the winding current changes according to the following law as a function of time (formula 3):

$$i_c = I_m sin\omega t, \tag{3}$$

Where, i_c – is the instantaneous value of the current of the cosine winding; I_m – amplitude of currents; ω – is the angular frequency of the supply voltage.

Sinus winding 1 receives power from a sinusoidal voltage source, which is phase-shifted relative to the voltage of the cosine winding by a quarter of a period, so the sinus winding current will vary according to the following law as a function of time (formula 4):

$$i_s = I_m sin\left(\omega t + \frac{\pi}{4}\right), \tag{4}$$

where i_s – is the instantaneous value of the sinus winding current.

The resulting magnetizing force of the k-th tooth of the information line is determined by the sum of the magnetizing forces of the windings (formula 5):

$$F_k = I_m sin\omega t W_m cos\left(\frac{2\pi}{n}(k-0,5)\right) + I_m sin\left(\omega t + \frac{\pi}{4}\right) W_m sin\left(\frac{2\pi}{n}(k-0,5)\right). \tag{5}$$

The effective value of the resulting magnetizing force of the k-th tooth will be equal to (formula 6):

$$F_{rk} = \sqrt{I^2 W_m^2 cos^2\left(\frac{2\pi}{n}(k-0,5)\right) + I^2 W_m^2 sin^2\left(\frac{2\pi}{n}(k-0,5)\right)} = IW_m. \tag{6}$$

The initial phase of the magnetizing force of the k-th tooth is determined by the equation (formula 7):

$$\varphi_{Fk} = arctg\frac{\sin\left(\frac{2\pi}{n}(k-0,5)\right)}{\cos\left(\frac{2\pi}{n}(k-0,5)\right)}; \tag{7}$$

thus, $\varphi_{Fk} = \frac{2\pi}{n}(k-0,5)$.

In the case of equality of the magnetic resistances of the teeth, their magnetic fluxes will change according to a sinusoidal law as a function of time with equal amplitudes, but with a phase shift relative to each other by an angle $\alpha = 2\pi/n$.

The specific magnetic flux Φ_0, determined by the magnetic flux per unit length ($\Phi_0 = d\Phi/dx$), will be unchanged within the tooth. At any time t within the information line, it will be distributed according to the law of a step function. The instantaneous value of the magnetic flux at the moment of time $t = t_1$ is distributed along the axis of the information line according to a sinusoidal law, depending on the serial number of the tooth k. (formula 8):

$$\Phi_0(t_1, k) = \Phi_{0m} \sin\left(\omega t_1 + \frac{2\pi}{n}(k-0,5)\right) \tag{8}$$

Within any tooth of the information ruler with length l the specific magnetic flux as a function of time t will also change according to a sinusoidal law.

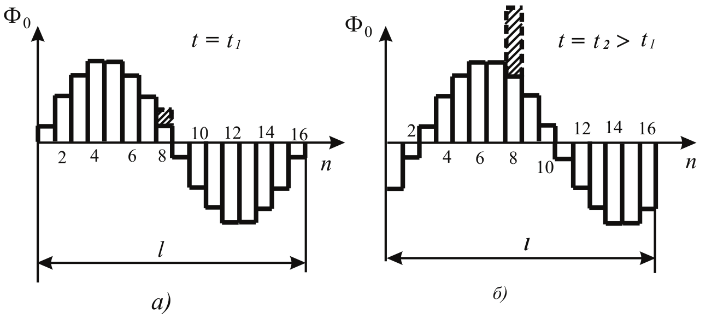

Figure 2. Distribution of specific magnetic

The main harmonic component of the stepwise distribution function of the specific magnetic flux during its expansion in the Fourier series in terms of the argument *x* in the function of time *t* and in the function *x* is described by the formula 9.

$$\Phi_0(t,k) = \Phi_{0m}\sin\left(\omega t + \frac{2\pi}{l}x\right). \tag{9}$$

Thus, the sinus and cosine windings, supplied with a two-phase voltage, create a running magnetic field, the lines of force of which are closed in the plane perpendicular to the axis of the information line.

Figure 2 shows the distribution of the specific magnetic flux along the ruler at a moment in time $t = t_1$ (Figure 2, a) and at a moment in time $t = t_2 \geq t_1$ (Figure 2, b). If the magnetic conductor of the information line is homogeneous, i.e., its specific magnetic resistance is constant along the entire length of the line, then at any moment of time the flux of the induction vector over the surface of the uniform winding will be zero [7]. In other words, the resulting magnetic flux coupled to the uniform winding will be zero and the voltage at the output of the uniform winding will also be zero. When a magnetic shunt is applied to the information line, the uniformity of the magnetic circuit along the axis x is violated. Let the magnetic shunt, the length of which along the axis x is equal to the width of the tooth $l_{ch} = l/n$, is superimposed on the 8th section of the magnetic circuit. The magnetic resistance of this section will decrease, which will lead to an increase in the magnetic flux of this section. The increase in the magnetic flux of the 8th section, caused by the change in the magnetic resistance of this section, is proportional to the shaded area in Figure *2a*.

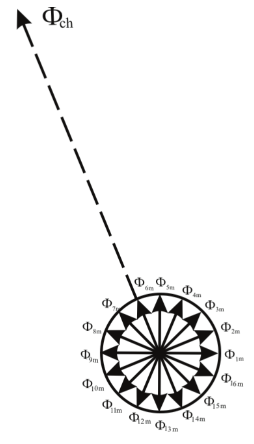

Figure 3. Vector diagram of magnetic fluxes

The resulting magnetic flux of a uniform winding in this case will not be zero and will be determined by an increase in the magnetic flux in the area of the movable magnetic shunt. The initial phase of the output voltage will be determined by the initial phase of the resulting magnetic flux, which, in turn, is determined by the initial phase of the magnetizing force of this section. The magnetic flux coupled to a uniform winding will change sinusoidal in time with an initial phase determined by the initial phase of the magnetizing force of the section. In our case, this angle will be equal to

$$\alpha = \left(\frac{2\pi}{16}(8-0{,}5)\right) = 0{,}469\pi \quad \text{radians.}$$

When moving the magnetic shunt, the initial phase of the output voltage will change in proportion to the distance from the beginning of the information line to the middle of the magnetic shunt [8].

Let us explain the operation of the sensor using a vector diagram of the magnetic flux of the teeth. Figure

3 shows a vector diagram of the magnetic fluxes of the sections in the absence of a shunt. As shown earlier, the magnetizing forces of the sections are equal in magnitude and are phase shifted by an angle α. If the magnetic resistances of the sections are equal to each other, then their magnetic fluxes will also be equal in magnitude and phase-shifted by an angle α. Since the magnetic fluxes of all 16 sections are coupled to the output winding, the total magnetic flux will be zero. The sensor output voltage will also be zero. A decrease in the magnetic resistance of the 6th section, for example, will lead to an increase in the flux of this section by an amount of Φ_{ch}. In the figure, this flow is shown with a dashed line. The resulting magnetic flux of a uniform winding will be equal to the magnetic flux Φ_{ch}. The amplitude and the initial phase of the input voltage are determined by this magnetic flux. A change in the position of the shunt relative to the information line will lead to a change in the initial phase of the resulting magnetic flux at practically unchanged amplitude.

It is necessary to clarify the method of laying the sensor windings. The active sides of the windings are the conductors located along the axis of the information line. Earlier it was indicated that the number of these conductors is determined using the formulas 10, 11, 12.

$$W_{ks} = W_m \sin\left(\frac{2\pi}{n}(k-0{,}5)\right), \tag{10}$$

$$W_{kc} = W_m \cos\left(\frac{2\pi}{n}(k-0{,}5)\right), \tag{11}$$

$$W_r = W = const, \tag{12}$$

where W_{ks} - is the number of active conductors of the sinus winding on the k - th section; W_{kc} - is the number of active conductors of the cosine winding in the k - th section; W_r - is the number of active conductors of a uniform winding, which covers all *n* the teeth of the information line; *k* - is the serial number of the tooth, varying from 1 to *n*.

The difference of the considered electromagnetic system from the existing magnetic systems of phase shifters is that the mechanical force of the interaction of the windings is directed perpendicular to the direction of movement of the magnetic field. The resulting value of this force along the direction of travel is zero, since both windings are located on the stator. The second difference is that for the normal functioning of the device, it is enough to introduce a body that violates the uniformity of the magnetic circuit of the information line. The initial phase of the output voltage will indicate the location of the discontinuity. The magnetic field of the sensor is concentrated around the active sides of the winding. The length of the magnetic field lines is much shorter than the length of the magnetic field lines of classical phase shifters. And the last but important difference is that all the windings are located on the stationary part of the device and there is no electrical connection with the moving part of the phase shifter.

It should be noted that a magnetic system with a traveling magnetic field reacts to the presence of a conductive non-magnetic medium in the magnetic field of the magnetic circuit of the information line. Despite the fact that the magnetic permeability of the conducting material of the introduced body will be practically equal to the vacuum permeability, the conducting body will have a significant effect on the magnetic field in the area of its location. This is due to the demagnetizing effect of eddy currents caused by the time-varying magnetic field of the stator. The total magnetic flux of the field in this zone will be less and the total EMF of a uniform winding will not be zero, and its phase shift relative to the reference voltage will depend on the location of the conducting body.

Results. *Phase sensor of angular displacement.*

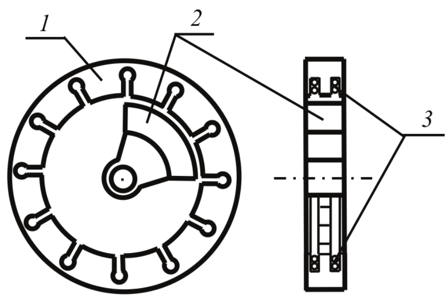

Figure 4. Sensor design

A classic electric machine phase shifter can be used as an angular displacement sensor. When the rotor turns, the EMF of the rotor windings change their initial phase. This type of sensor has a significant disadvantage in that the output winding is located on the rotor. The rotor is the moving part of the sensor. For normal operation of the sensor, it must have an electrical or magnetic connection with the stationary part, that is, with the stator. This greatly complicates the design and reliability of the sensor.

The angular displacement sensor is quite simply implemented on the basis of a magnetic system with a transverse running field. The design of the sensor is schematically shown in Figure 4. The sensor consists of stator 1, rotor 2, sensor windings 3. To obtain such a sensor, it is enough to "roll" the measuring ruler into a ring of the linear displacement sensor. In this case, the sine and cosine windings become exactly the same, shifted only in space by 90^0.

The excitation windings of the sensor fit into the grooves located on the inner surface of the stator. The number of turns of a sinus winding and a cosine winding is determined in the traditional way.

The cosine winding is similar to the sinus one, but the sections of this winding are shifted relative to the sinus sections by two teeth, that is, by 90^0 in space. Uniform winding is laid along the projections.

The construction of the phase angle encoder can be different. One of the sensor versions is a magnetic system with an internal stator. This design is quite convenient for laying the windings, as it allows the winding to be laid not only manually, but also by automatic machines.

Mechanical torque sensor: The problem of measuring torques has always been quite difficult, since the measurement conditions are not always favorable. As a rule, the issue is solved quite simply when measuring static moments, when the rotational speed of the driving and driven shafts is zero. The issue of measuring the mechanical moments of rotating shafts is being successfully solved. The most known examples of measuring the torque are changing the speed of rotation within certain limits. The main disadvantage of existing torque transducers is that, for the most part, they cannot measure the mechanical moment of both stationary and rotating shafts.

The proposed phase sensor of mechanical torques can be used with equal success to measure the torques of stationary and rotating shafts.

In addition to measuring the average value of the torque over a certain period of time, the sensor allows you to determine the instantaneous value of the torque, or to monitor the change in the mechanical torque over time with good resolution.

The sensor design is shown in Figure 5.

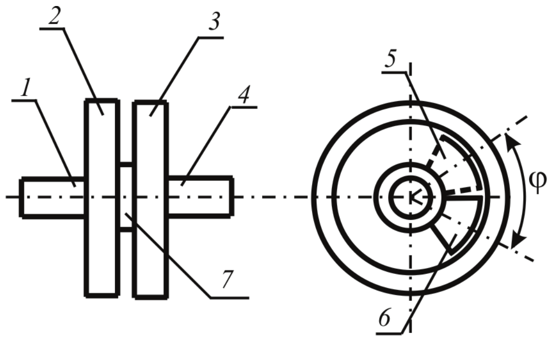

Figure 5. Cross-sectional design of the sensor

The sensor consists of two angular displacement encoders *2* and *3* located on the same axis. The shafts of the rotors *1* and *4* of the sensors are connected by an elastic element that allows the magnetic shunts *5* and *6* of the sensors to be displaced relative to each other. The axis of one sensor is rigidly connected to the driven shaft *4*, and the other sensor is connected to the drive shaft *1*. The elastic element *7* is calculated in such a way as to provide the maximum angle of twisting at the maximum measured torque.

When powering the excitation windings of the sensors with a two-phase voltage with a frequency ω, and when the axes of the sensors connected with magnetic shunts rotate at a speed Ω, the instantaneous values of the output voltages of the sensors can be described by the equations the formulas 13,14.

$$u_1 = U_{1m} \sin\left(\omega t + \Omega t + \alpha_1\right), \tag{13}$$

$$u_2 = U_{2m} \sin\left(\omega t + \Omega t + \alpha_2\right). \tag{14}$$

In the absence of a load on the shaft, the position of the rotors of the sensors relative to each other can be chosen such that $\alpha_1 = \alpha_2 = \alpha$. The same effect can be achieved using an electronic stage - a phase shifter. In the above formulas α_1 and α_2 – are the initial phases of the output voltages u_1 and u_2. When a shaft is used to transmit a mechanical torque that is not equal to zero, the elastic element will provide a certain angle of relative displacement of the shafts and magnetic shunts of the sensors. The value of the angle of displacement of the shafts will be proportional to the torque. At the angle of twist β and the angle of the initial position of the driven shaft α_1 the output voltages will change as a function of time according to the following laws (formulas 15, 16):

$$u_1 = U_{1m}\sin\left(\omega t + p(\Omega t)\right), \tag{15}$$

$$u_2 = U_{2m}\sin\left(\omega t + p(\Omega t + \beta\right). \tag{16}$$

Obviously, the phase shift between the two voltages is proportional to the torsion angle of the spring (formula 17):

$$\varphi = p\beta, \tag{17}$$

where φ – is the phase shift between voltages; p – is reduction factor, the values of which vary from 8 to 32.

"Phase lag" of voltage u_1t from voltage u(t) is provided by rotation of the drive shaft at a speed Ω. When observing voltages with the help of an oscilloscope when synchronizing with its input voltage, the output voltages u_1 and u_1 "float" relatively with u a speed that is higher, the higher the rotation frequency Ω.

A large value of the angle of twist is undesirable due to the fact that it leads to deterioration in the dynamic properties of the mechanical connection of the driving and driven shafts.

To convert mechanical torques into the angle of mutual displacement of the drive and driven shafts, an elastic element with increased rigidity should be used, which provides a small angle of relative displacement of the shafts. To measure this angle, use reduction-type phase angular displacement encoders.

Phase sensor with electromagnetic reduction. The desire to increase the sensitivity of the sensors of angular and linear displacements forces to increase the number of periods of laying windings in the sensors of angular displacements and to reduce the length of the information ruler in the sensors of linear displacements. However, there is a more convenient and more effective way to increase the sensitivity. This is the combined use of a running wave and the construction of a magnetic circuit structure according to the principle of electromagnetic reduction. Previously, a ferromagnetic shunt was considered as an element that introduces inhomogeneity into a homogeneous stator magnetic circuit (Figure 6).

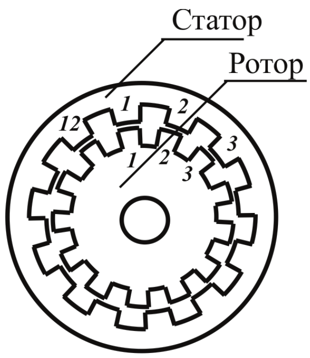

Figure 6. The design of the magnetic circuit of the reduction sensor.

In sensors with increased sensitivity, inhomogeneity is understood as not a significant change in the magnetic resistance in one place of the magnetic circuit, but a change in the specific magnetic resistance of the magnetic circuit along the information line or along the air gap of the angular displacement sensor.

Let us explain this with a specific example. In a linear encoder, the stator is a traditional ruler with a magnetic conductor made of magnetic material. The stator teeth and slots can be of the same width. This ratio was chosen only for a better understanding of the principle of operation of the sensor with electromagnetic reduction. The design of the magnetic circuit of the reduction angular displacement transducer is shown in Figure 6. The moving part of the transducer, or the so-called magnetic shunt, can be of any length. The surface of the shunt facing the stator has teeth similar to those of the stator. The number of shunt teeth is one more or one less than the number of stator teeth within the wavelength. More complex relationships between the numbers of teeth are also possible.

Discussion. In an angle encoder, linear dimensions are replaced by angular dimensions. The magnetic flux of an individual tooth will be proportional to the overlapping area of the stator tooth by the teeth of the moving part of the sensor. It is obvious that the magnetic flux is unevenly distributed in the gap. The initial phases of the fluxes of the teeth are equal to the initial phases of the magnetizing forces, and their amplitude is inversely proportional to the magnetic resistance or proportional to the degree of overlapping of the stator and rotor teeth. The vector diagram of the magnetic flux of the teeth will look as shown in Figure 7. The total flux will be large enough, and, which is very important, it will be in phase with the magnetic flux of the first tooth (Figure 7).

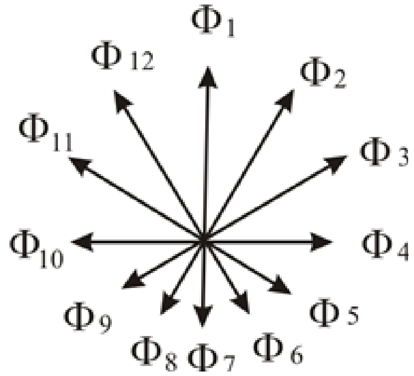

Figure 7. Vector diagram of the magnetic flux of the teeth

When the magnetic shunt is displaced by 1/12 of the tooth division, the maximum magnetic flux will take place not in the first, but in the second tooth, since the protrusion of the movable part, located opposite the first tooth, will shift to the right by a twelfth part, and the degree of overlap of the first tooth will decrease. The second stator tooth will be completely covered. If we now construct a vector diagram of magnetic fluxes and calculate the resulting vector, we can conclude that its amplitude value will remain the same, but the initial phase will change in the direction of lagging behind the previous value by $\pi/6$ rad.

When the rotor is turned 1/12 of a turn, the initial phase of the output voltage will change to 2π rad. The reduction factor in this case will be equal to 12. The sensor sensitivity will increase 12 times.

This method of increasing the sensitivity of the sensor is used both in the creation of linear displacement transducers and in the design of angular displacement transducers.

When using this method, the sensitivity in angular displacement encoders is increased when the rotor is turned by 2π rad. the initial phase φ_1 of the output voltage will change to 2π rad.

When describing the construction of the sensor, a feature of the magnetic system of the sensor with magnetic reduction has already been considered, this consists in the fact that the width of the groove is equal to the width of the tooth of the stator magnetic circuit. The rotor of such a phase shifter is generally a circle made of ferromagnetic material with a thickness equal to the stator thickness. The rotor has grooves and teeth along its entire circumference. The number of rotor teeth is one more or less than the number of stator teeth.

Above, only the distribution of the specific magnetic flux over the stator was considered for different values of the ratio of the lengths of the stator and rotor teeth *m*. To obtain the maximum output voltage, it is necessary to take into account not only the absolute value of the magnetic flux, but also the initial phase of this magnetic flux. Figure 8 shows a graph of the dependence of the amplitude of the specific magnetic flux and its initial phase on the spatial angle, where the initial phase of the maximum magnetic flux is taken to be zero.

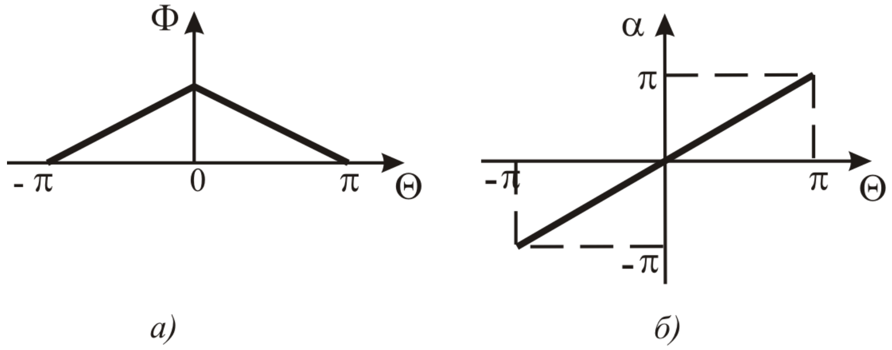

Figure 8. Graph of the dependence of the amplitude of the specific magnetic flux

The temporal angles of the phase shift are plotted vertically, and the spatial angles are plotted horizontally. The equation of the straight line located to the right of the axis of specific fluxes φ_1, will be written in the following form with *m=0,5* (formula 18):

$$\Phi_0 = \Phi_{0m}\left(1 - \frac{1}{\pi}\theta\right). \qquad (18)$$

The equation of the straight line located to the left of the axis will look like this(formula 19):

$$\Phi_0 = \Phi_{0m}\left(1 + \frac{1}{\pi}\theta\right). \qquad (19)$$

The equation of the direct dependence of the initial phases of the specific magnetic flux on the spatial angle is determined by the equation $\alpha = \theta$. Taking into account the values *m*, we obtain the equations of magnetic fluxes to the right and left of the vertical axis(formula 20):

$$\Phi_0 = \Phi_{0m}\left(1 - \frac{1}{2m\pi}\theta\right) \text{ and } \Phi_0 = \Phi_{0m}\left(1 + \frac{1}{2m\pi}\theta\right). \qquad (20)$$

Equations are valid for $\Phi_0 = 0$. For other values $\Phi_0 = 0$. The output voltage is proportional to the total magnetic flux of the output winding, which is determined by the integral of the distribution law of the specific magnetic flux over the spatial angle (formula 21):

$$\int_{-2\pi m}^{0} m\Phi_0\left(1 + \frac{2}{2\pi m}\theta\right)\cos\theta d\theta + \int_{0}^{2\pi m} m\Phi_0\left(1 - \frac{2}{2\pi m}\theta\right)\cos\theta d\theta =$$
$$m\Phi_{0m}\left[\int_{-2\pi m}^{0}\cos\theta d\theta + \int_{-2\pi m}^{0}\frac{1}{2\pi m}\theta\cos\theta d\theta - \int_{0}^{2\pi m}\frac{1}{2\pi m}\theta\cos\theta d\theta\right] = m\Phi_{0m}\left[2\sin(2\pi m) + \frac{1}{\pi m} -\right.$$
$$\left.\frac{1}{\pi m}\cos(2\pi m) - 2\sin(2\pi m)\right] = \frac{1}{\pi}\Phi_{0m}[1 - \cos(2\pi m)]. \qquad (21)$$

Thus, the total magnetic flux, providing the output voltage, changes when changing *m* according to the following law(formula 22):

$$\Phi_r = \frac{1}{\pi}\Phi_{0m}[1 - \cos(2\pi m)]. \qquad (22)$$

From the obtained equation it follows that the most effective value is $m = 0{,}5$, since $\cos\pi = -1$, in this case too(formula 23):

$$\Phi_r = \frac{2}{\pi}\Phi_{0m} \qquad (23)$$

The initial phase of the magnetic flux, which changes sinusoidal in time, is determined by the initial phase of the magnetizing force of the tooth with the maximum magnetic flux.

Conclusion. When designing measuring phase shifters with a traveling magnetic field, it should be taken into account that an important indicator of the quality of the sensor is the ratio of the voltage at the output of the sensor in the absence of a shunt U_{r0} and in the presence of a magnetic shunt U_r. The larger the ratio U_r/U_{r0}, the smaller the sensor error. To improve this ratio, it is necessary to increase U_r and decrease U_{r0}. It can be reduced U_{r0} by balancing the sine and cosine windings. An additional effect is the weakening of the magnetic coupling between the windings in the absence of a shunt.

In conclusion, it should be noted the simplicity of the construction of phase sensors with a running magnetic field on one side. On the other hand, comparing the operation of classical phase shifters with a rotating magnetic field with the phase shifters presented above, we come to the conclusion that the primary and secondary equipment ensuring their operation is absolutely identical. This gives the right to note the versatility of the presented technical solutions on the one hand. On the other hand, the scope of application of phase shifters has been expanded due to the use of phase shifters for measuring the parameters of linear displacements.

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ТАУ-КЕН ӨНЕРКӘСІБІНДЕ АВТОМАТТАНДЫРУ ЖҮЙЕЛЕРІН ЖЕТІЛДІРУ ӘДІСТЕРІ

Аннотация. Бұл мақалада тау-кен өнеркәсібіндегі процестерді автоматтандырудың өзекті мәселелері қарастырылады. Ашық әдіспен немесе жерасты дамуымен дамудың түріне байланысты әртүрлі автоматтандыру құралдары қолданылады. Ашық әзірлемелер болған жағдайда, соңғы жылдары технологиялық прогреске байланысты съемкаларды өндіру үшін ұшқышсыз ұшу аппараттарын (ҰҰА) қолдана отырып, фотограмметриялық әдістер пайдаланылады, олардың басты артықшылығы

үш өлшемді цифрлық модель алу арқылы тау-кен кәсіпорнының жұмысын жедел бақылауды орындау, қоймалар мен үйінділер көлемін айқындау мүмкіндігі болып табылады.

Жер асты жұмыстары жағдайында жетек барабандарын қамтитын әртүрлі механизмдер қолданылады. Жетек барабанының жылдамдығын бақылау үшін электромеханикалық басқарылатын фазалық ауыстырғыштар қолданылады. Фазалық түрлендіргіштердің бұл класына электр сигналымен басқарылатын механизмдер қолданылатын құрылғылар жатады. Сигнал фазасын басқару принциптері механикалық болып қалады.

Бірыңғай түрлендіргіш сенсордан және сәйкестік схемасынан тұрады, өлшенетін физикалық шама энергия көзімен нормаланған Шығыс мәніне айналады. Аралық түрлендіргіш алдыңғы түрлендіргіштен өлшеу ақпаратының сигналын алады және түрлендіруден кейін бұл сигналды кейінгі түрлендіргішке жібереді.

Механикалық шамаларды өлшеудің әртүрлі әдістері туралы алғашқы еңбектерден байқайтынымыз, бұл мәселеде бірқатар шешілмеген проблемалар бар. Ұзақ жылдар бойы ғылыми басылымдарда авторлар механикалық шамаларды өлшеу үшін жұмыс істейтін магнит өрісі бар фазалық түрлендіргіштерді қолданудың мүмкін әдістерін ұсынды.

Сондай-ақ, бұл мәселені шешудегі маңызды нәрсе, әрине, бұрыштық қозғалыстардың өлшеу фазаларының түрлендіргіштерінің дизайнын жетілдіру және жаңарту технологиясы болып табылады. Ғылыми жарияланымдар авторларының еңбектерінде қол жетімді материалдарды жүйелеу және осы проблема бойынша белгілі бір тұжырымдаманы жасау қажет екені бірнеше рет айтылған.

Түйінді сөздер: автоматтандыру, жер асты дамуы, ұшқышсыз ұшу аппараттары, барабан жетегі, түрлендіргіш, датчиктер, зонд, мембрана.

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МЕТОДЫ СОВЕРШЕНСТВОВАНИЯ СИСТЕМ АВТОМАТИЗАЦИИ В ГОРНОЙ ПРОМЫШЛЕННОСТИ

Аннотация. В данной статье рассматриваются актуальные вопросы автоматизации процессов в горной промышленности. В зависимости от вида разработок открытым способом или подземными разработками используются различные средства автоматизации. В случае открытых разработок в последние годы в связи с технологическим прогрессом для производства сьёмок используют фотограмметрические методы с применением беспилотных летательных аппаратов (БПЛА), главным преимуществом которых является возможность выполнения оперативного контроля работы горного предприятия, определения объёмов складов и отвалов посредством получения трёхмерной цифровой модели.

В случае подземных разработок используются различные механизмы, включающие приводные барабаны. Для контроля скорости приводного барабана используются фазовращатели с электромеханическим управлением. К этому классу фазовращателей относятся приборы, в которых использованы управляемые электрическим сигналом механизмы. Сами принципы управления фазой сигнала остаются механическими, но возможность электронного управления позволяет включать такие фазовращатели в автоматизированные контрольно-измерительные системы. Наиболее важными элементами системы автоматизации являются преобразователи. Первичный преобразователь является первым в измерительной цепи и включает в себя чувствительный элемент (зонд, мембрану) и другие необходимые элементы для преобразования входной неэлектрической величины в выходную электрическую величину. Датчик может состоять из одного или нескольких измерительных преобразователей, объединенных в единую конструкцию. На датчик непосредственно воздействует измеряемая неэлектрическая величина (сила, давление, уровень, температура и т.д.)

Унифицированный преобразователь состоит из датчика и схемы согласования, измеряемая физическая величина преобразуется с источником энергии в нормированную выходную величину. Промежуточный преобразователь получает сигнал измерительной информации от предшествующего преобразователя и передает после преобразования этот сигнал последующему преобразователю.

Из ранних работ по различным методам измерения механических величин очевидно, что есть ряд не решенных проблем в этом вопросе. На протяжении многих лет периодически появлялись научные публикации, в которых авторы излагали свои возможные методы использования фазовращателей с бегущим магнитным полем для измерения механических величин.

Также ключевым моментом в решении данной проблемы безусловно является технология совершенствования и модернизации конструкции измерительных фазовращателей угловых перемещений. В работах авторов научных публикаций неоднократно высказывалось предположение о том, что необходимо систематизировать имеющиеся материалы и выработать определенную концепцию по данной проблеме.

Ключевые слова: автоматизация, подземные разработки, беспилотные летающие аппараты, барабанный привод, преобразователь, датчики, зонд, мембрана.

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