Smart angular displacement sensor for agricultural field robot manipulators

Rustam Baratov[1], *Almardon* Mustafoqulov[1*]

[1]"Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University, 39 Str.K.Niyazov, 100000 Tashkent, Uzbekistan

Abstract. This study presents the electromagnetic angular displacement sensor and its technical characteristics. The existing electromagnetic angular displacement sensors have been thoroughly analyzed and compared with other types of sensors. The reason for the low sensitivity of the electromagnetic angular displacement sensor has been investigated and some technical modification to the existing sensor has been made. The magnetic circuits of the electromagnetic sensors have been analyzed. A method is proposed for expanding the range of angular measurements up to 180 degrees and increasing the sensitivity of the electromagnetic sensor without compromising the measurement accuracy. This, in turn, allows high-precision control and measurement of rotating mechanisms of all types of mechatronic systems and agricultural robots.

1 Introduction

Today, the smart control and measurement of angular displacement in all rotational mechanisms of agriculture, water management, railways, transport, textile industry, and construction are urgent issues. Recently modern robotic manipulators are applied in agricultural food production, fruit harvesting, processing, and packaging that have rotational mechanisms where is required precise control and measurement of angular displacement. The role of mechatronic systems (robots) with artificial intelligence in the quality and safe harvesting of agricultural products is also growing. When controlling the rotational parts of such devices small deviations of the angles can damage or energy loss of mechanisms on a big scale. Hence, precise angular displacement sensors development for smart systems of agricultural field robots is one of the technical issues which is required immediate solutions. [1,2,3,4,5,6,7,8,9,10].

In order to overcome these shortcomings, below we have analyzed the angular displacement sensors working in different operating conditions.

It can also be seen from Table 1 that time and energy savings can be achieved by controlling the rotating mechanisms of the existing machinery in the quality and efficient harvesting of agricultural products. To avoid these problems, it is necessary to analyze different angular displacement sensors.

---

* Corresponding author: mustafoali777@gmail.com

The two-coordinate ferromagnetic angle displacement sensor consists of the permanent magnetic field, which consists of two mutually perpendicular intersecting circular discs with windings distributed across opposite sections through the diameter of the rotating part, and a winding of the driving part. The disadvantages of the two-coordinate angle displacement sensor are the complexity of the design and the low reliability, which is due to the presence of a ferromagnetic fluid located inside the spherical surface. The operation of the device with a magnetic fluid results in a highly dense state of the spherical surface. In addition, the magnetic fluid is an expensive thing. We also have investigated optical sensors designed to measure angular displacement. Optical angular displacement sensors (encoders) in which the each position of the shaft corresponds to a digital output code. Therefore, the rotating mechanism starts working as soon as it starts. The disadvantages of this type of angular displacement sensor are that it can miss angular pulses for any reason. This leads to errors in determining the angle of rotation until the zero mark returns to its original position (Figure 1.) [15,16,17].
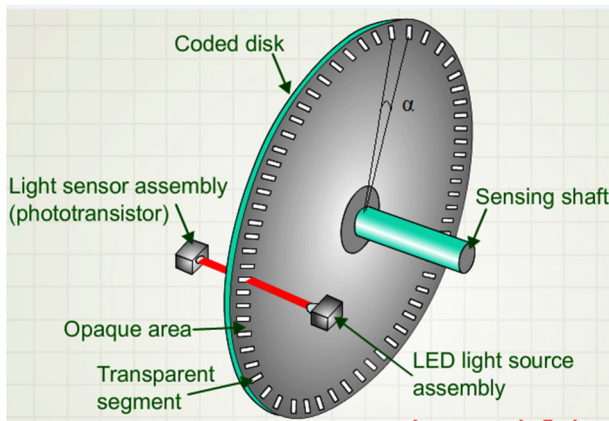

Fig. 1. Optical angular displacement measuring sensor.

As can be seen from Figure 1, there is a certain distance between the notches (holes), which means that it does not measure the angle α at this exact location.

Usually electromagnet transformer type of angular displacement sensor has high reliability in extreme conditions. So in this study we have reviewed different type of angular displacement sensors.

However, the analysis performed showed that the sensitivity of the electromagnetic sensor was significantly low than others. This is because only part of the magnetic flux generated by the magnetic motive force crosses the diameter of the ring because the sensitivity of the sensor is directly related to its output signal.
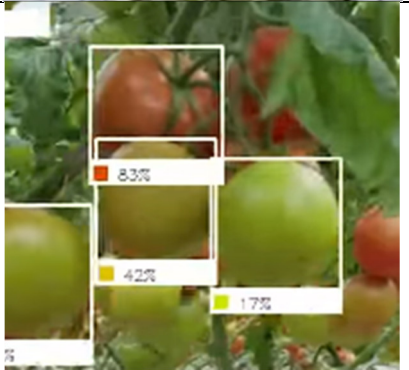
The importance of continuous automated robotics in the implementation of routine tasks is increasing. It is important to control the rotating parts of such robotics and measure the angular displacement of robotic manipulators designed for harvesting. By controlling the rotating mechanisms of robot-manipulators used in agriculture, it is possible to save time as well as save electricity.

The income of a modern farm is directly related to the number of workers. Harvesting the ripe crops will also require a large number of employees, but the use of robot manipulators instead of people will be useful in carrying out routine work. The U.S. agricultural workforce has decreased by 2% because of agricultural field robot manipulators. Josh Lessing has been working on overcoming this problem since he founded the Root AI project on agricultural robotics in 2018. The company has now developed a robot called Robot AI Virgo, which is used to determine whether a tomato is ripe or not,

and is designed to selectively pick ripe tomatoes One of the disadvantages of this robot is that the hand that collects the same product (tomatoes) turns to the same 90^0 angle (Table 1). [11]. As above mentioned there is a major problem is precise control of the angular displacement of rotating mechanisms of agricultural field robot manipulators. Because the study is devoted to developing an electromagnetic angular displacement sensor which have more reliable than others. By controlling the rotation mechanisms of robotic manipulators used in agriculture, it is possible to save electricity and time.

As we know, agricultural products (like tomatoes) do not ripen at the same time.

Table 1. The process of determining the state of the tomato product by the robot "Robot AI Virgo".

T/p	Tomato readiness (%)	Sensor deflection position (Degree ^{0})	Pictures
1	95-100	90	
2	80-95	90	
3	60-80	90	

It is noteworthy that the robot turns to the same angle to collect all the products. This, in turn, leads to an increase in energy consumption. In addition, the amount of time spent is the same [12,13,14].

This defect is found in all robotic manipulators. As in all robotics, there are big problems in controlling the angular displacement of the rotating mechanisms of agricultural robotic manipulators.

Taking into account the above existing problems, the main goal of this article is to increase the reliability of the angular displacement sensor measuring the rotating mechanisms of agricultural robotic manipulators and to expand the measurement limit.

2 Materials and methods

Below we review the technical parameters of the currently available and recommended ferromagnetic angular displacement sensor. Initially, the technical parameters of the angular displacement sensor obtained as the prototype have been calculated. The prototype belongs to the field of control and measurement technology and is designed to measure angular displacement in aviation technology, including various control circuits of electrical and electromechanical devices [18,19].

Structure and technical parameters of the existing sensor. The first we have considered the magnetic circuits of the transformer type of angular displacement sensor, which is taken as a prototype. Figure 2 shows the magnetic circuits of the angular displacement sensor and as is known the total value of the magnetic resistance between points A and B is determined as follows:
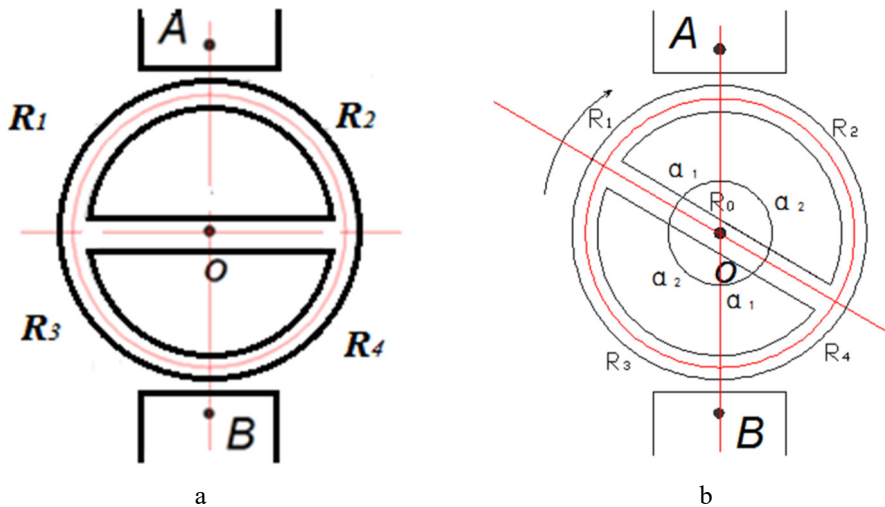

a   b

Fig. 2. Magnetic circuit of the angular displacement sensor (a- initial position of the rotating ferromagnetic disk, b-position of the rotating ferromagnetic disk at the beginning of the movement)

As can be seen from the Figure.2 after the movement of the rotating ferromagnetic disk begins, the magnetic resistances on the arms of the moving disk change depending on the movement (R_1, R_2, R_3, R_4). But the magnetic resistances on the opposite arms are equal to each other ($R_1 = R_4$, $R_2 = R_3$). Here only the magnetic resistance of the diameter of the rotating ferromagnetic disk does not change i.e. it does not depend on motion ($R_0 = $ const.).

$$R_1 = R_4 = \frac{l_1}{\mu\mu_0 S} \tag{1}$$

$$l_1 = \alpha_1 \cdot \frac{\pi}{180} r \text{ and } l_2 = \alpha_2 \cdot \frac{\pi}{180} r \tag{2}$$

D   diameter of the magnetic field path on the rotating ferromagnetic disk;
S_0 cross- section area of the diameter of the rotating ferromagnetic disk;
S   cross-section area of an arm of the rotating ferromagnetic disk;
μ_0 absolute permeability;
μ permeability of the material;
l1 and l2 - the length of the magnetic field path on a rotating ferromagnetic disk.

As can be seen from the Figure.2 after the movement of the rotating ferromagnetic disk begins, the magnetic resistances on the arms of the moving disk change depending on the angle. Depending on the state of change of the rotating disk, the dependence of the total magnetic resistance between points A and B on the angular displacement is as follows.
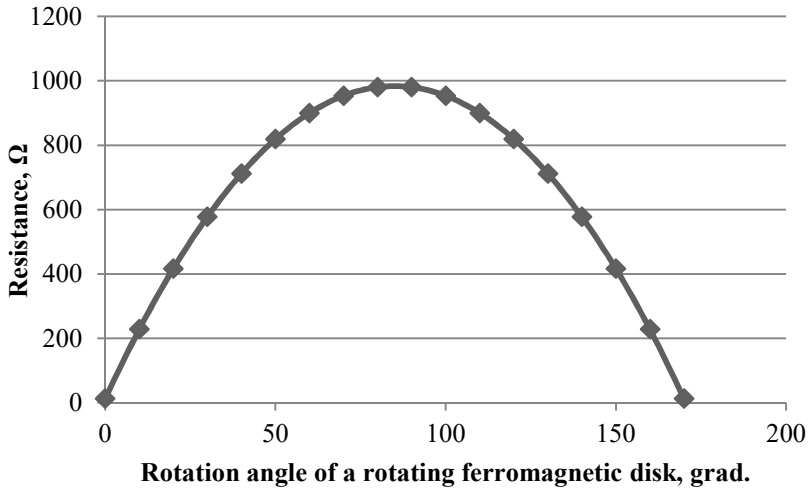
$$\Sigma R = f(\alpha) \tag{3}$$

Fig. 3. Diagram of the total magnetic resistance depending on the angle of rotation.

It is known from the diagram that the rotating ferromagnetic disk of the sensor measuring the angular displacement of the transformer converter returns to its original position again at 90 degrees. According to Figure 5, we determine the reading of the voltmeter in the measuring vessel depending on the state of change of the rotating ferromagnetic disk. When a constant current (I) is applied to the ferromagnetic core (housing), the magnetic flux generated in it is as follows (Figure 5) [20,21,22].

$$\Phi = \frac{\omega I}{\Sigma R_\mu} \tag{4}$$

ω the number of turns of the reel.

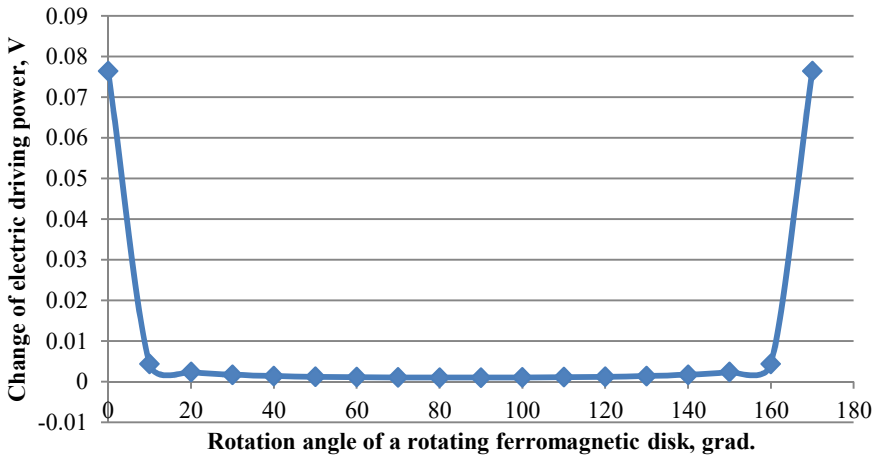$$e = -\omega \frac{\Delta\Phi}{\Delta t}; \tag{5}$$

Fig. 4. Diagram of voltage dependence of angular displacement.

As can be seen from this Figure, it is difficult to accurately measure the angular displacement from 50 degrees to 130 degrees using an existing angle displacement sensor. The sensitivity of the sensor that measures the angular displacement of a transformer converter increases when measuring the range of this angle ($50^0 < \alpha < 130^0$). This, in turn, represents a shortcoming of the Transformer converter angle displacement sensor.

Calculation of the magnetic parameters of the sensor that measures the proposed angular displacement. We will now consider the magnetic parameters of the sensor that measures the recommended angular displacement. The shape of the rotating ferromagnetic disk is different, as is the principle of operation of the sensor that measures the angular displacement of a transformer converter (Figure 6.a).
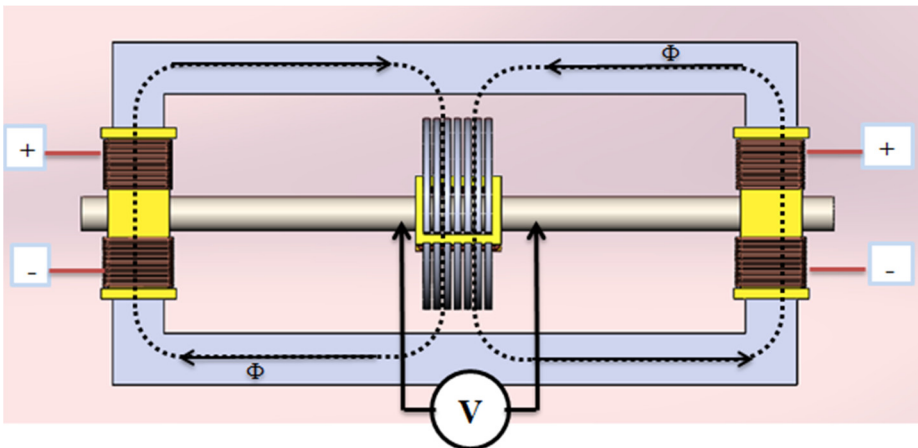

Fig. 5. 3D view of the proposed angular displacement sensor.

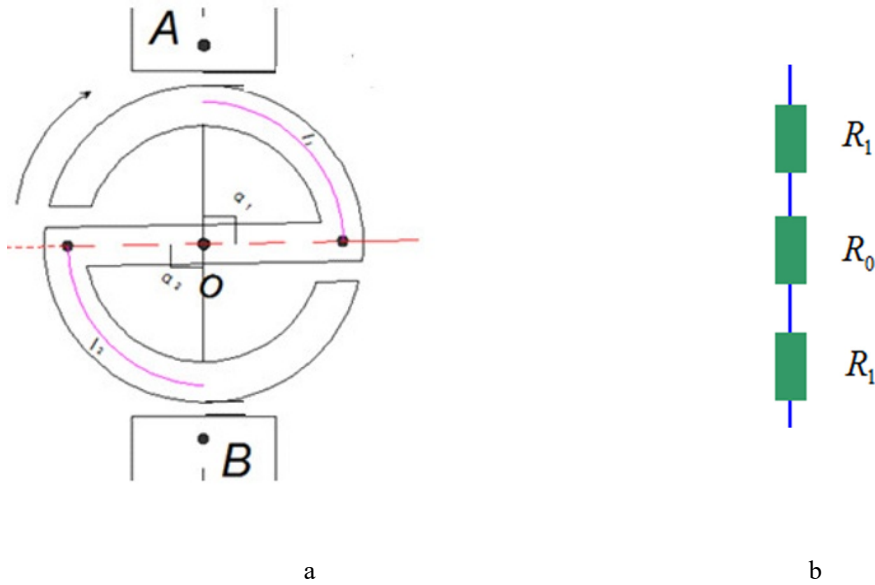<div align="center">a</div> <div align="center">b</div>

Fig. 6. a is the stationary state of the rotating ferromagnetic disk, b is the circuit for switching the magnetic chains to the electrical circuit.

$$R_1 = \frac{l_1}{\mu \mu_0 S_1};$$ (6)

$$R_0 = \frac{D}{\mu \mu_0 S_3};$$ (7)

$$\Sigma R = 2R_1 + R_0$$ (8)

3 Results and discussion

In the above sections, various angular displacement sensors have been analyzed and their advantages and disadvantages have been presented. The conducted theoretical analyzes show that sensors measuring the angular displacement of rotating mechanisms need to have a high accuracy and a large range.

Below are the theoretical analysis results of a sensor with high reliability and a wide measurement range (0-180 0) for measuring the angular displacement of the rotating mechanisms of agricultural robot-manipulators.

The result of the calculation of the recommended angular displacement sensor. Consider the voltage change depending on the clockwise position of the rotating ferromagnetic disk of the sensor that measures the recommended angular displacement according to Figure 5[20]. When the ferromagnetic material (housing) is connected to a fixed source, the direct current (F) is calculated as follows:

$$\Phi = \frac{\omega I}{\Sigma R_\mu};$$ (9)

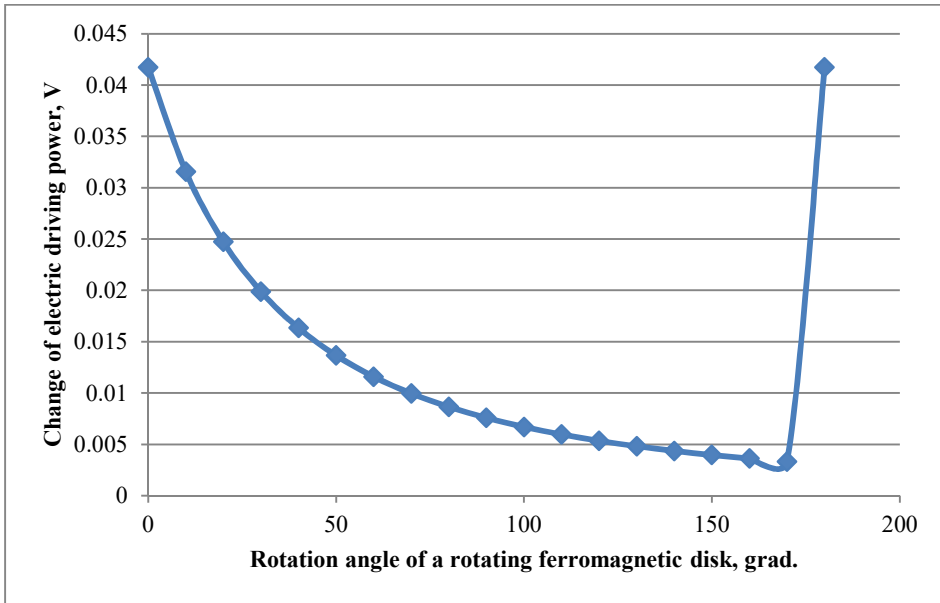$$e = -\omega \frac{\Delta \Phi}{\Delta t};$$ (10)

Fig. 7. Voltage-dependent diagram of the angle of rotation of the proposed angle shear sensor

As can be seen from this Figure, the sensitivity of the proposed angular displacement sensor allows accurate measurement of angular variation up to 180^0, uniform at each point of the rotating ferromagnetic disk (Figure 7). The main difference from the current sensor is that, as a result of the design change, its measurement range can be accurately measured in the range from 50^0 to 130^0.

4 Conclusions

The existing problems in the field of quality harvesting of agricultural products through the use of robots can provide continuous information about its location and accurate analysis of many aspects of the farm. The lack of precise control of the bursa movement of the rotating mechanisms of existing robots leads to a decrease in the speed of product assembly. In order to solve the existing problem, a sensor to control the rotating mechanisms of robotic manipulators was developed. The reliability of a sensor that measures the recommended angle displacement is higher than the reliability of an existing sensor. It is also capable of measuring angular displacement up to 180 degrees at exact values. This project is planned to apply the proposed angular displacement sensor to the rotation mechanisms of agricultural robotic manipulators and provide prototype views during the pilot process and in our further research.

References

1. Y. Oktarina, T. Dewi, P. Risma, M. Nawawi, *Tomato Harvesting Arm Robot Manipulator; A Pilot Project* J Phys. Conf. Ser., **1500** (1) (2020)
2. S. Fountas, N. Mylonas, I. Malounas, E. Rodias, C. H. Santos, E. Pekkeriet, *Agricultural Robotics for Field Operations,* J. Sensors (Basel)*,* **20** (9) (2020)
3. A. Taofik, N. Ismail, Y. A. Gerhana, K. Komarujaman, M. A. Ramdhani, *Design of Smart System to Detect Ripeness of Tomato and Chili with New Approach in Data Acquisition,* IOP Conf Ser Mater Sci Eng, **288 (**1), 0–6 (2018)

4. C. Hu, X. Liu, Z. Pan, P. Li, *Automatic detection of single ripe tomato on plant combining faster R-CNN and intuitionistic fuzzy set*, J. IEEE Access, **7,** 154683-154696 (2019)
5. S. Popowski, W. Dabrowski, *Measurement and estimation of the angle of attack and the angle of sideslip*, J. Aviation, **19 (1),** 19-24 (2015)
6. R. Baratov, N. Pirmatov, A. Panoev, Y. Chulliyev, S. Ruziyev, A. Mustafoqulov *Achievement of electric energy savings through controlling frequency convertor in the operation process of asynchronous motors in textile enterprises,* IOP Conf Ser Mater Sci Eng, **1030**, (2021)
7. H. Zangl, L. M. Faller, W. Granig, *Optimal design of angular position sensors*, COMPEL - Int J Comput Math Electr Electron Eng, **36** (5), 1372-1385 (2017)
8. S. S. Mehta, T. F. Burks, *Vision-based control of robotic manipulator for citrus harvesting*, J. Comput Electron Agric, **102,** 146-158 (2014)
9. A. Denmukhammadiev, A. Mustafoqulov, H. Valikhonova, E. Sobirov, T. Raimov, *Electricity metering and backup power supply for multi-storey buildings*, J. E3S Web Conf., **264**, 05051 (2021)
10. R. Baratov, N. Pirmatov, *Low - speed generator with permanent magnets and additional windings in the rotor for small power wind plants and micro hydro power plants*, J. IOP Conf Ser Mater Sci Eng, **883** (1), 012183 (2020)
11. *Root AI raises seed funding for Virgo robot to harvest multiple crops* https://www.therobotreport.com/root-ai-raises-seed-funding-for-virgo-robot-designed-to-harvest-multiple-crops/ (accessed May 02, 2022)
12. *Root AI - Join the future of farming* https://root-ai.com/#tech (accessed Oct. 06, 2022)
13. *Root AI unveils its tomato-picking robot Virgo* https://www.cnbc.com/2019/05/11/root-ai-unveils-its-tomato-picking-robot-virgo.html (accessed Oct. 06, 2022)
14. *Root AI - Introducing Virgo- YouTube* https://www.youtube.com/watch?v=XlXSGqvP-A8&t=84s (accessed Oct. 06, 2022).
15. *Rotary angle sensor - Wikipedia* https://ru.wikipedia.org/wiki/ Rotary angle sensor (accessed May 02, 2022).
16. I. K. Patentu, C1, **30** (19), 1-9 (2006)
17. A. Safarov, K. Sattarov, M. Bazarov, A. Mustafoqulov, *Issues of the electromagnetic current transformers searching projecting*, J. E3S Web Conf, **264,** 05038 (2021)
18. *Transformer inverter angular movements* https://russianpatents.com/patent/216/2161774.html (accessed May 02, 2022).
19. I. K. Patentu, C2, **19**, 1-7 (2006)
20. R. J. Baratov, A. U. Djalilov, C*ODEN(USA): JSERBR An Improving Method of Linearity of Magnetic Flux Distributionin Air Gap with Long Iron Cores,* J. Sci Eng Res, **5** (11), 158-164 (2018)
21. *An Improved Magnetic Equivalent Circuit Model for Iron-Core Linear Permanent-Magnet Synchronous Motors* | Request PDF https://www.researchgate.net/publication/224587224_An_Improved_Magnetic_Equivalent_Circuit_Model_for_Iron-Core_Linear_Permanent-Magnet_Synchronous_Motors (accessed May 10, 2022).
22. B. Sheikh-Ghalavand, S. Vaez-Zadeh, A. Hassanpour Isfahani, *An improved magnetic equivalent circuit model for iron-core linear permanent-magnet synchronous motors*, J. IEEE Trans. Magn, **46** (1), 112-120, (2010)
23. H. Zhao, H. Feng, *A novel angular acceleration sensor based on the electromagnetic induction principle and investigation of its calibration tests*, J. Sensors (Switzerland), **13** (8), 10370-10385 (2013)