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Development of a Magnetic Precision Position Sensor Based on Multipolar Magnetic Technology

G.V. Prokofiev[1,3], V.G. Stakhin[1,3], V.V. Misevich[2], B.L. Krivtz[2], M.A. Kosolapov[1,3]

[1]National Research University of Electronic Technology (MIET), Moscow,

[2]JSC «Avtoelectronica», Kaluga.

[3] IDM-Plus LLC, Moscow, Zelenograd

Abstract

The article presents the development of an absolute position sensor using a multipolar two-track magnetic system and a specialized signal processing chip. The sensor design is based on the nonius principle of obtaining the absolute position code from the magnetic sensor system on the Hall effect with tracking angle-code converters. The results of the study of the model of the developed system are presented, which confirmed its operability.

Keywords: Position sensor, Encoder, Angle to code convertor

INTRODUCTION

Designing of precision but at the same time cheap and reliable position sensors (encoders) is a very important task for many fields of industry nowadays. Designing of precision position sensors based on magnetic effect is a promising trend, because magnetic technology provides a series of advantages [1, 2]:

1) sensors based on magnetic effect have a simple design which means they are reliable and cheap for manufacturing purposes;

2) magnetic sensors are resistant to the presence of contaminating impurities such as water steam, oils, petroleum products and other optically-active impurities;

3) magnetic sensors have small dimensions.

The key component of magnetic position sensors is a dedicated microchip containing magnetosensitive sensor system with analogue processing, angle to code convertor and interface circuits.

The purpose of the present project is to develop an in-built absolute magnetic position sensor with an off-axis sensing system and a programmable conversion resolution of 18 bit. One of the main attachments is an in-built brushless DC engine of rotor position with a digital output for application in automotive electronics.

Development of the concept of convertor sensor and microchip

The designed purpose of position sensor (built-in sensor) and high requirements to resolution condition the usage of the multiband design with double magnetic scale which provides a growing phase shift within a turn (nonius scale) followed by joining of the data from both scales together which results in absolute position code with high resolution [3].

Let's consider the system consisting of 2 magnetic scales of master track and nonius track that includes 4 and 3 pole pairs respectively, Figure 1. The scales have an aligned zero point, but their numbers of pole pairs used for one period of measurement differ by 1.

Position values φm and φn of master track and nonius track respectively are determined independently of each other. Since the numbers of periods of master track and nonius track differ by 1, the difference of $\Phi m\text{-}n = \varphi m - \varphi n$ positions for the period of measurement of absolute position is a linear function. The number of the current period of nonius track N is uniquely determined by the difference of $\Phi m\text{-}n$ phases. This, in turn, allows to determine the current absolute position φA as:

$$\varphi A = \varphi m + N \cdot \varphi m\_max \qquad (1)$$

where φm_max is the maximum value of the period of master track (overall amount of step width of master track that is determined by conversion resolution of the corresponding sensing system and angle to code convertor).

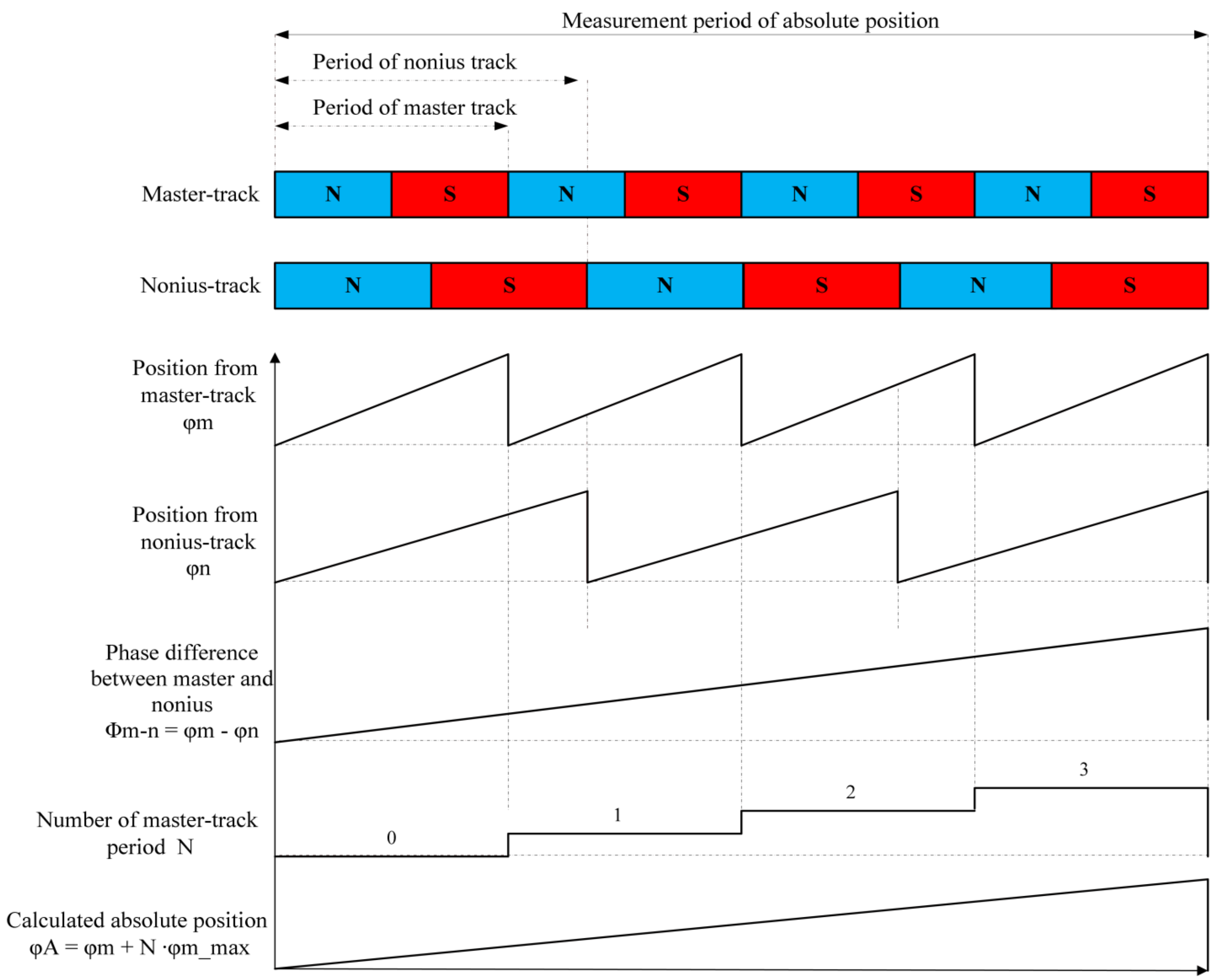

Figure 1. Explanation of the concept of the developed magnetic position sensor

If a conversion system for master track has a resolution of 4096 counts per period, then the overall conversion resolution of the system showed on Figure 1 is 4·4096 = 16384 counts which corresponds to the conversion resolution of 14 bit. So, conversion resolution of the nonius system is determined as follows:

$$N_A = m \cdot N_M \quad (2)$$

where

N_A – number of counts for the whole scale;

m – number of periods of master track;

N_M – number of counts per one period of master track.

The formula (2) concludes that the maximum possible conversion error in degrees for the proposed algorithm is:

$$ErrT = 360 / (m \cdot N_M) \quad (3)$$

The described concept allows to develop the position sensor with a high resolution that has a value primarily limited by technological factors related to the manufacture of the code magnetic disc with the required number of poles. 2 mm size of master track pole is considered basic. Maximal quantity of pole pairs on code magnetic disk (CMD) can be up to 64 which provides up to 18 bit of conversion resolution per turn (or linear period for linear motion sensor).

Figure 2 shows a functional diagram of the designed position sensor. The sensor contains a code magnetic disc with nonius scale and microchip of convertor (LSIC-MIS) that has a sensing system of master track 1, sensing system of nonius track 2, tracking angle to code convertor of master track 3, tracking angle to code convertor of nonius track 4, amplitude detectors of master and nonius tracks 5, 6, units of current control through Hall elements 7, 8, unit of joining and creation of absolute position code 9, unit of output interface of sensor 10, external microchip for storing calibration factors 11.

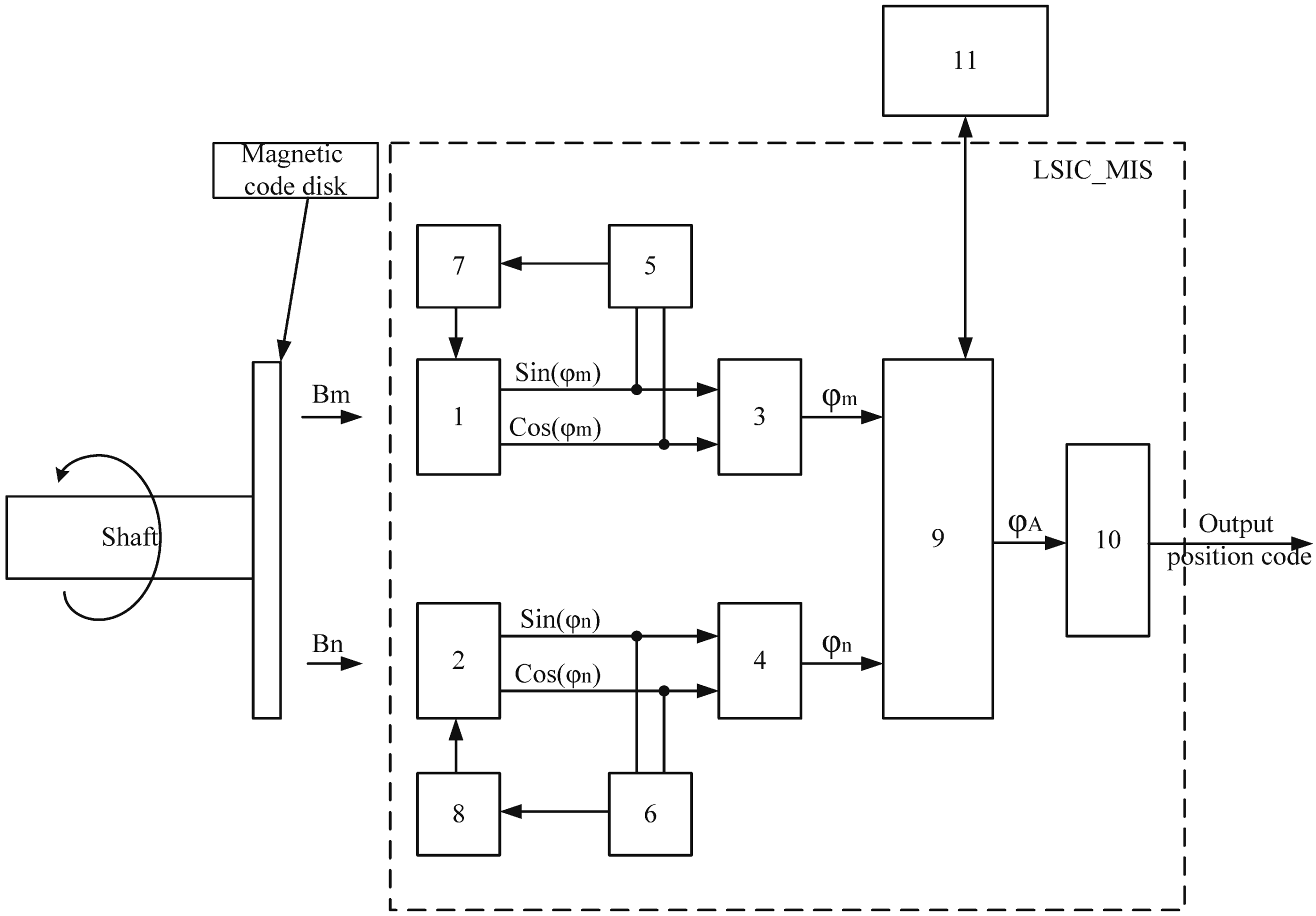

Figure 2. Functional diagram of the designed position sensor

The sensor operates as follows. Code magnetic disc is mounted on the rotor. The disc has 2 lines of magnetization that correspond to nonius algorithm. Processing microchip has 2 sensing systems 1 and 2 that transduce magnetic fields of magnetization tracks Bm and Bn into sine-cosine signals with phases that correspond to the length of pole pair of master track and nonius track. Sine-cosine signals of sensing systems are transduced into codes of phase φm and φn of master track and nonius track by means of tracking angle to code convertors 3 and 4. It is preferable to use tracking convertors due to the high speed of change of position inside each pole pair during rotation of the rotor and high requirements to the speed of analog-digital conversion with further processing.

Each channel also has an independent system of amplification adjustment that maintains amplitude of a signal at the input of angle to code convertor in a specific range independently of magnetic field induction. Such system of automatic adjustment of amplification provides stability in conversion error independently of change of distance between the code magnetic disc and the surface of a microchip, which is objectively possible in the process of operation of the sensor (effects of vibration, tolerance of mechanical assembly).

To join together the data from the tracking convertors by nonius algorithm, a digital processing unit is used. The absolute position code φA that is generated after joining the data together is converted into the required form by means of interface block 10 and then is sent to sensor output.

On the basis of the functional diagram microchip of magnetic sensor of position was designed.

The most important thing in development of magnetic field convertor is the choice of sensing elements and sensing system. Sensing system based on Hall elements was chosen. The choice was determined by the following two factors:

1) possibility of integration of Hall sensing elements into the standard roadmap of CMOS-microchips manufacturing;

2) magnetic field induction of code magnetic disc at the maximum level of 15-50 mT which is optimal for Hall elements.

Sensing system of microchip that consists of 16 Hall elements located along the edge of the crystal was designed. Microchip of convertor includes two sensing systems of such type – for master track and for nonius track, placed at the opposite sides of the crystal.

Signal from Hall elements is increased with the use of current rotation technology [4] for elimination of discharge voltage and by summarizing is converted into the sine-cosine signal with the phase proportional to the position of pole pairs in relation to the sensing system.

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After incensement and demodulation, the sine-cosine signal from Hall elements is processed by tracking angle to code convertors. There was developed an angle to code convertor that allows converting with a resolution of 12 bit for the duration of the signal and with tracking time no more than 60 ns which corresponds to the speed of pole pairs change equivalent to rotational speed of more than 240 thousand rotations per minute. This corresponds to the speed of rotor rotation for the magnetic ring with 64 pole pairs that allows the maximum resolution of 18 bit at a speed of 3800 rotations per minute.

The microchip includes a unit for joining of the data from two tracking angle to code convertors and creation of absolute position code with a resolution up to 18 bit. After joining the position code is sent to the unit of nonlinearity correction that eliminates the main trend of converting error.

The corrected position code is sent to a customer via SSI, PWM interfaces and incremental interface.

The microchip is designed with the use of serial CMOS technology with a design rule of 180 nm.

Analysis of the proposed concept of the sensor using a model

A model of position sensor was designed and manufactured to justify the suggested concept, algorithm of joining the data together and correction of code. The model included a PCB with the sizes to fit in target brushless DC engine with two sensing microchips generating sine-cosine signal and code magnetic disc with 24/23 pole pairs of master/nonius tracks, outer diameter of code disc is 40 mm, figure 3.

Figure 3. Model of the sensor, PCB is on the left, code magnetic disc is on the right, outer diameter of the disc is 40 mm

Model of the sensor was installed on a dedicated bench for analyzing position sensors with precision drive and sensors by Etalon. The distance between the surface of CMD and the microchip was approximately 1 mm. There were no special operations for precision mechanical alignment of model parts.

PCB output of the model was connected to the processing PCB, Figure 4. Conversion path that corresponds to the conversion path of LSIC-MIS microchip was used in the processing PCB based on FPLD Virtex-5. Capacity of each angle to code convertor of the model was 12 bit.

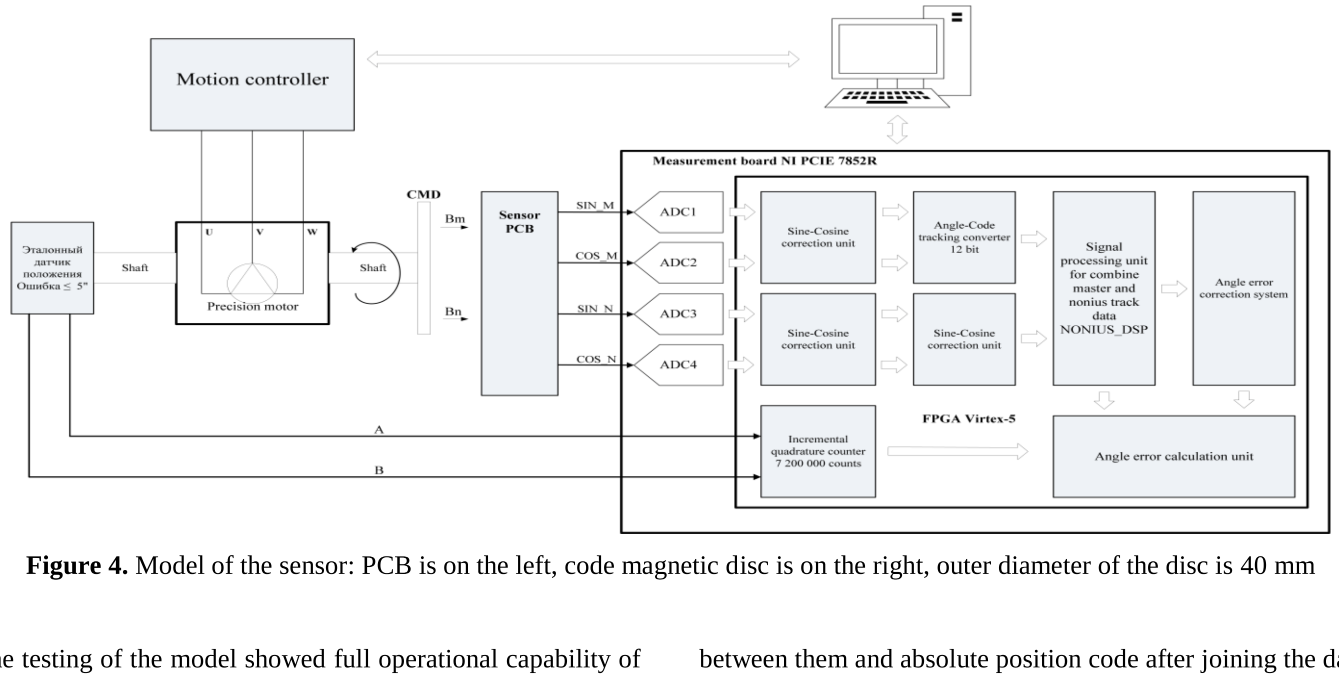

Figure 4. Model of the sensor: PCB is on the left, code magnetic disc is on the right, outer diameter of the disc is 40 mm

The testing of the model showed full operational capability of the presented magnetic position sensor concept. Figure 5 shows the results of operation of the model: outputs of master track and nonius track convertors, differences of phases between them and absolute position code after joining the data together. Output code after joining the data together has information capacity of 98304 counts, which corresponds to (2).

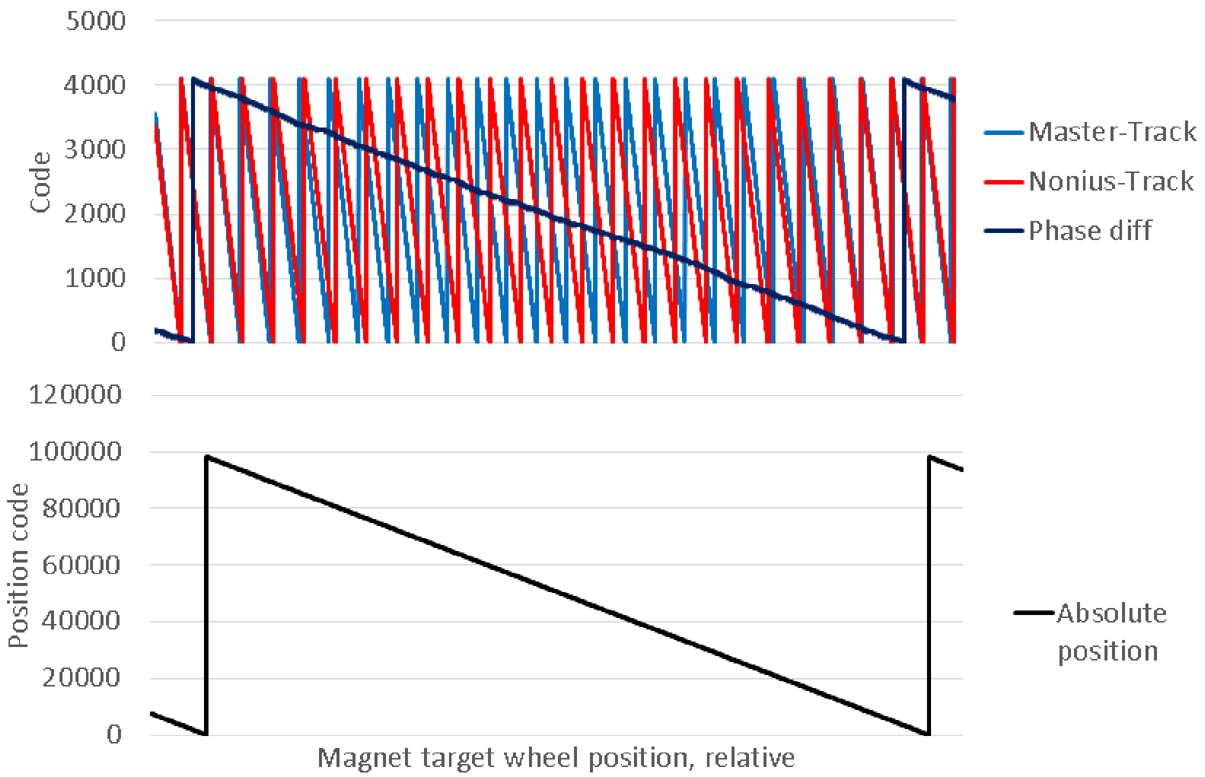

Figure 5. Diagram of operation of the model

Also operational capability of the developed algorithm for correction of conversion error was tested on the model. Figure 6 shows the diagrams of conversion error before and after correction applied to a single code magnetic disc.

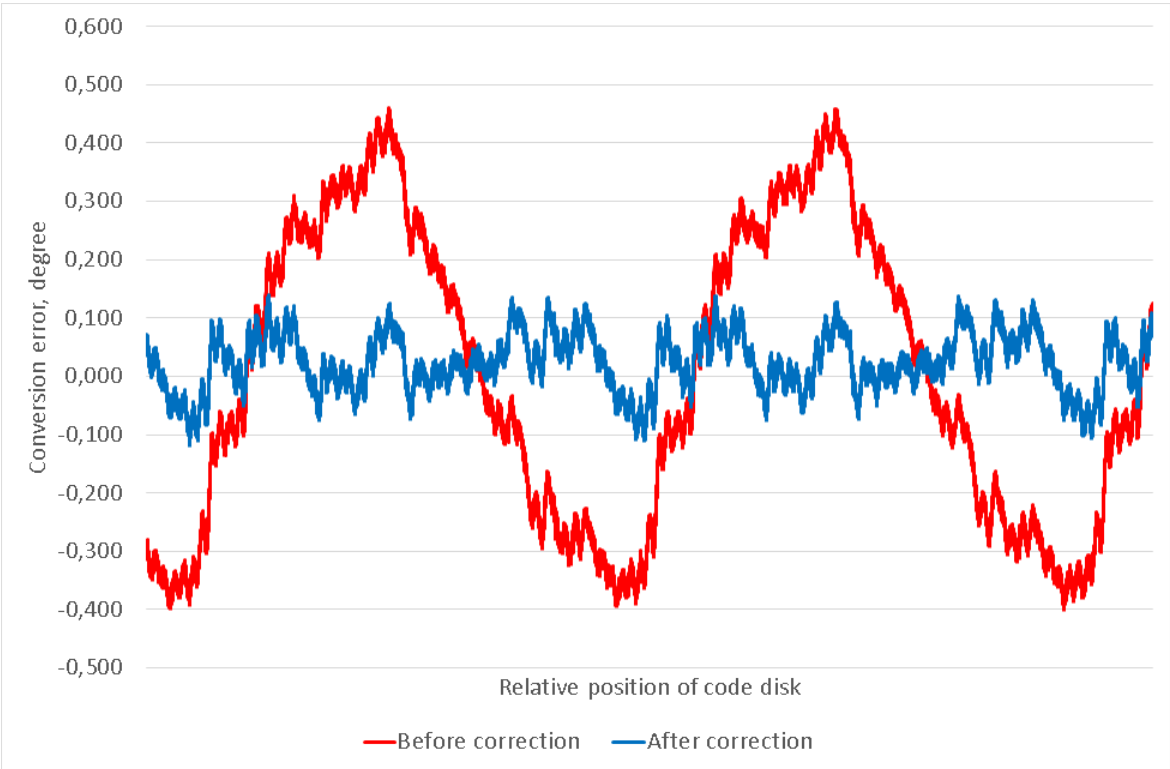

Figure 6. Conversion error of the model before and after correction

As it is shown on Figure 6, conversion error before correction is 0,86º and 0,2º after correction, which is 4 times less.

Measurements were conducted for several samples of code magnetic discs and showed same results.

The designed model was integrated into the brushless DC engine manufactured by Nidec. Analysis of the model inside the engine showed the absence of significant influence of engine rotor fields on the generated data of angular position.

TEST RESULTS

Tests of the encoder model proved operational capability of the developed design of absolute magnetic position sensor. Information capacity that corresponds to calculated capacity of 93804 counts per turn and conversion error of 0.2º without precision mechanical adjustment of the sensor was achieved with the use of code magnetic disc with 24 pole pairs of master track, linear sensing systems based on Hall effect and tracking angle to code convertors with the resolution of 12 bit. Analysis of the model of the sensor inside the running engine showed the absence of influence of rotor and windings internal fields on the values of the sensor.

CONCLUSION

Absolute magnetic position sensor with the use of multiple-band nonius magnetic system with two tracks was developed, dedicated conversion microchip that includes sensing systems based on Hall effect, angle to code convertors and digital modules of joining and correction of position code was designed. Analysis of the developed system was conducted with the use of a model. Tests operational capability of the developed design. Achieved values of resolution and accuracy are sufficient for target application, which is the in-built sensor of brushless DC engine rotor position for electric power steering.

Final value of resolution and precision will be improved after manufacturing of single-crystal microchip and code magnetic disc with large quantity of poles.

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