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FUNCTIONAL TESTING OF ANGLE-DATA TRANSMITTERS OF THE LIMITED ROTATION ANGLE

Описано методику визначення нелінійності вихідної характеристики давачів обмеженого кута повороту та методику підтвердження можливості реалізації на їх базі n-розрядної кутовимірної системи. Наведено приклад цифрової обробки сигналів.

Ключові слова: індукційний давач кута, обмежений кут повороту, трансверсна магнітна система, нелінійність вихідної характеристики, тарувальна крива, похибка коду кута.

Рассмотрена методика определения нелинейности выходной характеристики датчиков ограниченного угла поворота и методика подтверждения возможности реализации на их базе n-разрядной углоизмерительной системы.

Ключевые слова: индукционный датчик угла, ограниченный угол поворота, трансверсная магнитная система, нелинейность выходной характеристики, тарировочная кривая, погрешность кода угла.

Formulation of the problem. Creating methods of functional testing for angle-data transmitters of the limited rotation angle. **The aim** is to develop the method of defining the angle-data transmitters' nonlinearity of output characteristics of the limited rotation angle, and the method of confirmation the feasibility of creating them on base of the n-bit goniometric system. **Practical value.** An example of digital signal processing is provided. **Originality.** We proposed to build a calibration curve across the even points and compare its values in the odd points of the experiment.

Keywords: inductive angle-data transmitter, limited rotation angle, transversal magnetic system, nonlinearity of the output characteristic, calibration curve, measure of code inaccuracy.

Introduction. Inductive angle-data transmitters of the limited rotation angle with the transversal magnetic system is widely used in modern electric drives of navigation and flying machines guidance.

In this regard, a need for the acceptance control testing occurred. Among other testing and inspections (checking the appearance, dimensions and joining size, winding resistance and insulation, as well as consumption power), it includes the functional tests (checking amplitude of output signals in the operating range of angles, checking the nonlinearity depending on the angle of output signals and testing the feasibility of angle-transmitter based n-bit goniometric system).

The baseline characteristic is the dependence on the rotation angle of the code that is calculated based on the amplitude of the output signal voltage windings. The formula of functional dependence of the amplitudes of the angle is depicted in the Figure 1, and, generally, it can be described with the following formula

$$E_{s1}(\alpha) = E_{av} + E(\alpha); \quad E_{s2}(\alpha) = E_{av} - E(\alpha), \qquad (1)$$

where: $E(\alpha)$ – the information component of the output signals;

E_{av} – constant component.

In the Figure 1, the following values are marked: $E_{s\max}$ and $E_{s\min}$ – the maximum and minimum values of the output amplitude in the operating range of angles $\pm\alpha_p$. Then,

$$E_{av} = 0{,}5 \cdot (E_{s\max} + E_{s\min}). \qquad (2)$$

The general requirement for the $E_{s1}(\alpha)$ and $E_{s2}(\alpha)$ is the following: they both should be line-symmetrical with respect to the vertical axis and the straight line E_{av}.

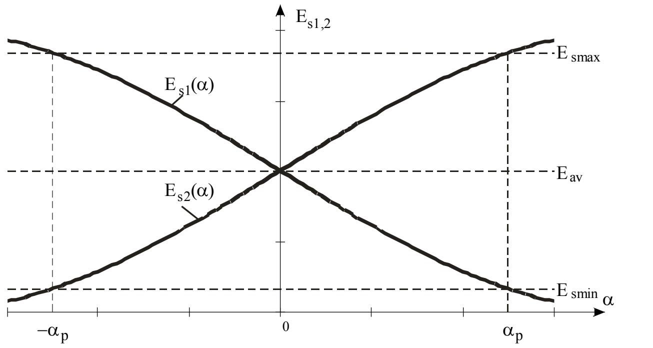

Fig. 1 – The form of functional dependencies $E_{s1}(\alpha)$ and $E_{s2}(\alpha)$

In addition, dependences of the signals' amplitude on the angle should be directly proportional. Otherwise, the value of the angle α should be determined by the function inverse to the $E(\alpha)$ function, using programmable logic integrated circuits [2, 3].

Formulation of the problem. In practice, because of the technological specifics of manufacturing angle transmitters in general and the magnetic ferrite, in particular, it is impossible to achieve the abovementioned properties of the outputs. Therefore, there is a need to assess their deviation from the ideal condition. This investigation is dedicated to creating the methods of testing the nonlinearity of the amplitude's dependence of the output signals on the angle, and checking the feasibility of implementing angle transmitter based n-bit goniometric system. Of course, when it comes to acceptance testing that each angle transmitter sample undergoes, this testing should not be too expensive. On the other hand, when producing the single sets of angle-data transmitters, it is inappropriate to create expensive testing facilities. Therefore, there is one more limitation of using analog-digital converters, of course, except for the high voltage voltmeter (type B7-28 or multimeter Protek 608).

Research objective in this article is the output characteristic of angle-data transmitters of the limited rotation angle with the transversal magnetic system.

Presenting the main material.

To carry out the necessary testing, a full-range of rotation angles $\alpha_{oper(arcmin)} = 2 \cdot \alpha_p$, expressed in arcminute, should be divided into m (recommended as odd) parts of the extreme points $i = 0 \ldots m$. When using the goniometric device, we set the appropriate angular position that corresponds with each point in the range, α_i, and determine the value of output voltage amplitude of the angle-data transmitter's signal windings $U1_i$ and $U2_i$.

After the experimental part, we should process the numerical data.

For each point in range of rotation α_i the value of numerical angle's code is defined as follows $A_i = round(\alpha_i / c)$, where $c = \alpha_{oper(arcmin)} \cdot 2^{-n}$ – *n*-bit code discrete value of the goniometric system.

The value of the digital code of angle transmitters D_i [*relat.units*] at the α_i points

$$D_i = \frac{U1_i - U2_i}{U1_i + U2_i} - \frac{U1_0 - U2_0}{U1_0 + U2_0} \quad (3).$$

The value of the digital code of the angle transmitter in discretes

$$d_i = round\left(\frac{D_i}{D_m} \cdot A_m\right) \quad (4)$$

A calibration curve Ti is obtained by assigning the real (specified) angle A_i values, to the code of the angle-data transmitter d_i in discretes for the even experiment points. The equation of a calibration curve as the dependence of actual angle on the actual code value in discretes is defined as cubic spline interpolation.

To determine the measure of inaccuracy of the code nonlinearity, a regression line as the regression curve of the first order was created

$$PR_i = round(interp(S, X, Y, X_i)), \quad (5)$$

where $X \to A_i$, $Y \to d_i$; $S = spline(Z, V)$, and $S = regress(X, Y, 1)$.

Nonlinearity error $\Delta_{нi}$ is defined as the difference between the relative magnitude of the angle-data transmitter and regressive dependence values

$$\Delta_{нi} = \frac{d_i - PR_i}{d_m} \cdot 100\%. \quad (6)$$

Goniometric system's measure of code inaccuracy in discrete system

$$\Delta_i = T_i - A_i \quad (7)$$

reaches its maximum in odd points and decreases up to zero as we approach the even ones. Obviously, to reduce the measure of code inaccuracy, for building the calibration curve as many points of the experiment as possible should be used.

Example of a use case of such method is implemented in the Mathcad package for testing the angle-data transmitter 1ДУ60 with the working angular range of 60°. It was developed at Special Design Bureau of Electromechanical Systems of the Lviv Polytechnic National University for usage in 14-bit goniometric system depicted below.

The results of experimental values are recorded in the table 1.

The value of the digital code angle A_i is defined as $A_i = round(\alpha_i / c)$,

where $c = \alpha_{oper(arcmin)} \cdot 2^{-14} = 3600 \cdot 2^{-14} = 0{,}219726562$ – the discrete value of the 14-bit code goniometric system, is expressed in arcminutes (arcmin).

The value of the angle-data transmitter's digital code D_i [arb. unit] is defined as follows (3).

The value of the digital code angle-data transmitter in discretes d_i is defined as follows

$$d_i = round\left(\frac{D_i}{D_{37}} \cdot A_{37}\right).$$

The value of a calibration curve code Ti [in discretes] is defined as $T_i = round(interp(S, X, Y, d_i))$

where $X \to A_i$, $Y \to d_i$; $S = spline(Z, V)$; and $Z_i = A_{i(even)}$, $V_i = d_{i(even)}$.

The equation of the regression straight line is defined as follows (5).

Nonlinearity error $\Delta_н$[%] is defined by (6) at the m=37.

Dependence of codes of the angle-data transmitters d_i and its regression line on the codes of the predefined corners A_i is depicted in the Figure 2. And, the non-linearity of this dependence is expressed in percentage in Figure 3.

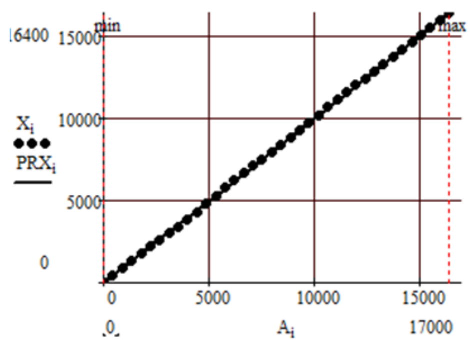

Fig. 2 – Dependence of codes' angle on the specified angle and its regression line

Table 1 – The results of experimental values

Reference number *i*	The value of the specified angles a_i *(arcmin)*	The voltage of the 1st signal winding $U1_i$ *(V)*	The voltage signal 2nd signal winding $U2_i$ *(V)*	Digital code of the specified angles A_i *(discr.)*	Digital code of the angle-data transmitter D_i *(relat.units)*	Digital code of the angle-data transmitter d_i *(discr.)*	Calculated values of the calibration curve T_i *(discr.)*	The measure of code inaccuracy Δ_i *(discr.)*
0	0	0,1371	1,4093	0	0	0	0	0
1	97,2973	0,1720	1,3756	442	0,04496	455	442	0
2	194,5946	0,2071	1,342	885	0,09007	913	885	0
3	291,8919	0,2414	1,3084	1328	0,13421	1360	1328	0
4	389,1892	0,2739	1,275	1771	0,17636	1787	1771	0
5	486,4865	0,3047	1,2421	2214	0,21666	2196	2216	2
6	583,7838	0,3343	1,2091	2656	0,25588	2594	2656	0
7	681,0811	0,3650	1,176	3099	0,29640	3004	3100	1
8	778,3784	0,3967	1,1426	3542	0,33811	3427	3542	0
9	875,6757	0,4303	1,109	3985	0,38177	3870	3989	4
10	972,973	0,4645	1,0752	4428	0,42605	4319	4428	0
11	1070,27	0,5010	1,0411	4870	0,47245	4789	4875	5
12	1167,568	0,5384	1,0067	5313	0,51960	5267	5313	0
13	1264,865	0,5785	0,9719	5756	0,56894	5767	5757	1
14	1362,162	0,6164	0,9375	6199	0,61604	6245	6199	0
…	…	…						
27	2627,027	1,0597	0,498	11955	1,18328	11996	11953	-2
28	2724,324	1,0905	0,4646	12398	1,22517	12420	12398	0
29	2821,622	1,1218	0,4312	12841	1,26737	12848	12841	0
30	2918,919	1,1534	0,3976	13284	1,30998	13280	13284	0
31	3016,216	1,1854	0,3639	13727	1,35292	13716	13727	0
32	3113,514	1,2188	0,3301	14169	1,39645	14157	14169	0
33	3210,811	1,2533	0,296	14612	1,44058	14604	14608	-4
34	3308,108	1,2912	0,2615	15055	1,48585	15063	15055	0
35	3405,405	1,3283	0,227	15498	1,53078	15519	15501	3
36	3502,703	1,3614	0,1932	15941	1,57413	15958	15941	0
37	3600	1,3899	0,1602	16383	1,61599	16383	16381	-2

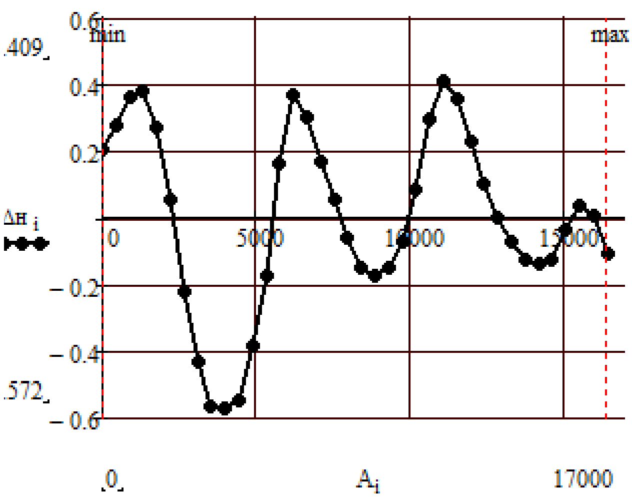

Fig. 3 – Nonlinearity of angle's code dependence on the specified angle

Dependence of the measure of code inaccuracy of the goniometric system $\Delta_i = T_i - A_i$ on the code of the specified values of the angle depicted in Figure 4.

Therefore, the nonlinearity of the source angle in the operating range of angles does not exceed 0.6%. The measure of code inaccuracy in the operating system's goniometric range of angles is less than 5 discretes that the angular dimension is equal to 1.32 *arcmin*.

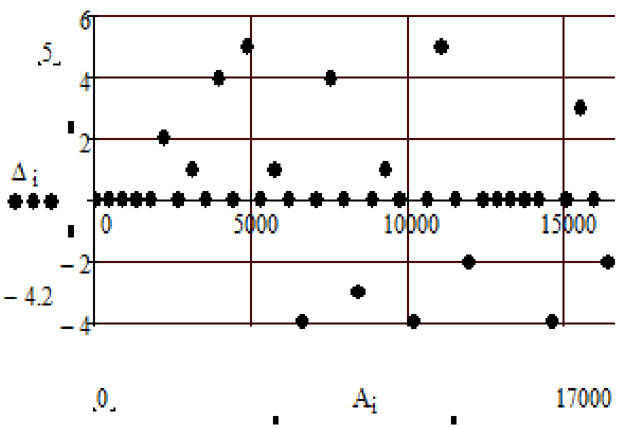

Fig. 4 – The dependence of the angle-data transmitter's code measure of inaccuracy on the code of the specified angle values

Conclusions. Therefore, the proposed method of testing does not require huge financial expenses in terms of resources and the time spent. Besides, it is sufficient for establishing the basic functional parameters of angle-data transmitters of limited rotation angle of the transversal magnetic system and can be used for developing specifications.

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