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ФОРМИРОВАНИЕ ОПТИМАЛЬНЫХ УРОВНЕЙ КВАНТОВАНИЯ УПРАВЛЯЮЩИХ ТОКОВ ДЛЯ ЛИНЕЙНОГО ШАГОВОГО ПРИВОДА ПРЕЦИЗИОННЫХ СИСТЕМ ПЕРЕМЕЩЕНИЙ

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GENERATING OF OPTIMAL QUANTIZATION LEVELS OF CONTROL CURRENTS FOR LINEAR STEPPING DRIVES OF PRECISION MOTION SYSTEMS

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Предложена методика учета накопленной и температурной погрешностей при формировании координатной сетки дискретности линейного шагового привода. Разработан алгоритм определения оптимальных уровней квантования управляющих токов фаз привода, минимизирующих погрешность позиционирования, в результате которого формируются файлы коррекции для использования в программном обеспечении системы управления. С помощью станции контроля точностных параметров ЛШП были проведены исследования стабильности координат узлов сетки дискретности, которые подтвердили эффективность предложенного алгоритма и методики формирования координатной сетки дискретности.

Ключевые слова: квантование управляющих токов, линейный шаговый привод.

Ил. 2. Библиогр.: 4 назв.

The paper proposes a method of taking into account accumulated and temperature errors while forming coordinate discrete grid of a linear stepping drive. An algorithm for determination of optimal quantization levels of control currents of drive's phases has been developed in the paper; it minimizes an error of positioning that forms correction files for application of a control system in the software. Investigations on stability of discrete grid nodes coordinates have been carried our with the help of a monitoring station for accurate parameters of linear stepping drive. The investigations have proved an efficiency of the proposed algorithm and methodology for forming coordinate discrete grid.

Keywords: quantization of control currents, linear stepping drive.

Fig. 2. Ref.: 4 titles.

Introduction. Modern manufacturing technologies of the product of precision mechanics and microelectronics are producing greater requirements to the technological equipment by accuracy of positioning and trajectory motions, coordinate resolution and operating speed. The achieving of high characteristics of automated equipment on the base of linear stepping drive can be accomplished either by calibrating of motion system, for example, using high resolution discrete grid, or by using an additional coordinate measuring system, which is built on feedback sensors of position or velocity, as the component of control system with subsequent processing of information in control system with adaptive regulation.

Our analysis [1] showed that characteristics of accuracy and coordinate resolution in between 2–5 micrometers can be satisfied without the realizing of feedbacks and increasing cost of linear stepping drive engineering package by changing the control system software using the files of correction of quantization levels of control currents. In this regard, the subject of this article is algorithms and software for the forming of quantization levels of control currents of linear stepping drive phases from the condition of optimal positioning accuracy of precision motion system.

Algorithm of the taking into account the errors which are arisen when forming of coordinate discrete grid. In the work [2] the authors proposed the mathematical model and the method of the forming a high resolution coordinate discrete grid for the entire workspace on the condition of sinusoidal distribution of forces generated by the poles of electro phase modules. But in practice the distribution of electromagnetic forces in the gap is not sinusoidal due to the manufacturing inaccuracy of toothing structures, the inhomogeneity of the magnetic resistance and hysteresis of inductor poles and magnetized area of stator, the thermal alteration of dimensions of poles of phase modules, tangage and yaw of the inductor when it is moving on the stator, and due to some other factors. As a result, the division of the motion period will be irregular. The experimental investigations of the division of the motion period showed that it is irregular within one period of toothing structure and the character of division is not equal on different periods; it depends on the accumulated positioning error and the temperature factor which leads to temperature drift of stator's coordinate grid.

Let's consider our proposed algorithm for the taking into account the accumulated and temperature errors of positioning when the discrete grid is formed. This algorithm is based on the using of reference grid and coordinate system with the origin in the point which is the beginning of toothing structure period of linear stepping motor's stator. The initial step size of reference coordinate system is constant and equal to

$$\Delta = \frac{\tau}{2Uf},$$

where τ – period of the tooth surface; U – number of quantization levels of phase currents; f – number of motor phases.

The calculation and correction of accumulated error and error, which occurs due to thermal expansion of the stator of a drive, are carried out by a formula

$$X' = X + P_N + P_T,$$

where X – reference coordinate; P_N – correction due to error accumulation period of motion; P_T – correction due to temperature drift of the coordinate system.

The correction for the accumulated error P_N is calculated by the following formula

$$P_N = -(X_{Si} - X_i),$$

where X_{Si} – the measured coordinate on period i; X_i – reference coordinate on period i; i – number of motion period, it is defined as an integer part of fraction X_i/τ.

The correction of thermal expansion of the stator P_T is calculated by the following formula [3]

$$P_T = \frac{[(D_{j+1} - E_{j+1})(T - D_T j) - (D_j - E_j)\times}{D_T(P_D - P_E)} \to$$

$$\to \frac{\times(T - D_T(j+1))]P_D}{D_T(P_D - P_E)} -$$

$$-\frac{[(D_{j+1} - E_{j+1})(T - D_T j) - (D_j - E_j)\times}{D_T(P_D - P_E)} \to$$

$$\to \frac{\times(T - D_T(j+1))](X + P_N)}{D_T(P_D - P_E)} -$$

$$-\frac{D_{j+1}(T - D_T j) - D_j(T - D_T(j+1))}{D_T},$$

where T – absolute time, it is measured from the beginning of the work of drive or from the moment of the end of technological run; D_T – interval for retrieving data on the temperature drift of the size of displacement field in reference points; P_D – coordinate of the first reference point (at the beginning of workspace movements); P_E – coordinate of the second reference point (at the end of workspace movements); D_j – magnitude of the temperature drift of the coordinate of the first reference point at moment jD_T; E_j – magnitude of the temperature drift of the coordinate of the second reference point at moment jD_T; j – index number of current temperature correction value in arrays D and E, it is defined as an integer part of fraction T/D_T.

Before the calculation of correction P_T it is necessary to perform an hours-long technological run of linear stepping drive when the inductor is cyclically moving within whole workspace of coordinate system. After each time interval D_T the values D_j and E_j are stored in array D for the first reference point P_D and in array E for the second reference point P_E. When arrays D and E have been formed the correction P_T is calculated for the correcting of temperature drift of the workspace sizes for any functioning interval of linear stepping drive.

Optimization of quantization levels of control currents. The algorithm of determining the optimal quantization levels of control currents is based on the method presented above and consists of 5 stages: 1) technological run; 2) base correction of discrete grid of motion period; 3) correction of coordinate accumulated error in the beginning of motion period; 4) the minimizing of error of node coordinates of discrete grid within motion period; 5) calculation of temperature drift of dimensions of coordinate system components.

The technological run is performed for bringing the parameters of components of coordinate system to the operating values. Base correction of discrete grid of motion period is carried out on a randomly selected motion period within workspace of a coordinate system. Then the correction files are formed in accordance with the method presented, and these files are used for choosing the quantization levels of control phase currents which correspond to the coordinates of a positioning point.

To realize the optimal correction of the irregularity of discrete grid step the procedure has been proposed; it includes: 1) calculation of nominal coordinates C_k of discrete grid step nodes within a motion period; 2) calculation of nominal values of quantization level codes A_k, B_k of control phase currents; 3) measurement of the actual coordinates M_k of discrete grid nodes within a motion period; 4) definition for each discrete grid node the codes of optimal quantization levels of control currents which correspond to the minimal error of coordinate.

The calculation of nominal values of quantization level codes of control phase currents is carried out by a formuls [3]:

$$A_k = INT\left[\frac{U}{2} - \left(\frac{U}{2} - 1\right)\sin\left(\frac{2\pi C_k}{\tau}\right)\right];$$

$$B_k = INT\left[\frac{U}{2} - \left(\frac{U}{2} - 1\right)\cos\left(\frac{2\pi C_k}{\tau}\right)\right],$$

where INT – operation of the finding of an integer part of number; C_k – nominal coordinate of discrete grid node k.

Then the measurement cycle of actual coordinates M_k, which are the positioning points of inductor of linear stepping drive when the codes A_k, B_k of quantization levels of phase control currents are used, is carried out; the measurement is made by means of automated station of the testing of precision parameters of coordinate systems, the station is described in the next section of the article.

At last stage the codes of quantization levels of control currents which minimize the error ε_k of positioning to the node k of discrete grid are determined, and codes A_l, B_l of quantization levels of control currents for position l are assigned to codes A_k, B_k of quantization levels of phase control currents for position k from the following condition:

$$\varepsilon_k = \min\left|C_k - M_l\right|,$$

where ε_k – positioning error in discrete grid node k; M_l – actual coordinate of discrete grid node l.

Automated station for the forming of discrete grid. The developed algorithm of the forming of set of optimal quantization levels of control phase currents of linear stepping drive has been implemented in the software of automated station of the testing of precision parameters which has been created in PLANAR Corporation (Minsk, Belarus) for the forming of high resolution discrete grid. Functional structure of automated station is shown in Fig. 1.

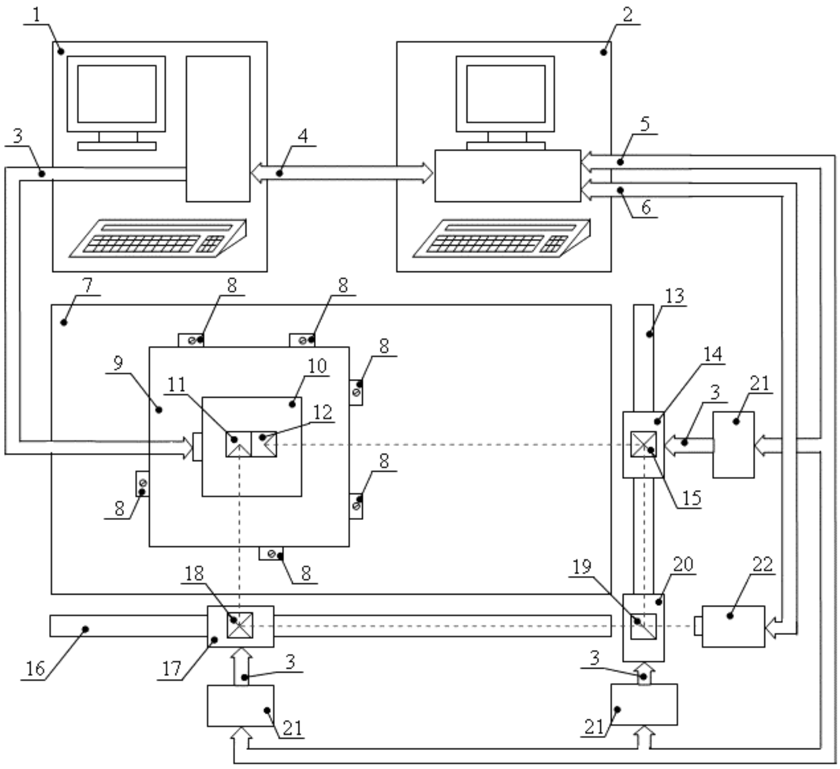

Fig. 1. Functional structure of automated station of the testing of precision parameters of linear stepping drive

It consists of control system 1 of investigated stepping drive, coordinate measuring system 2, interface 3 of phases of investigated drive, carriages 14 and 17 of interferometers for measuring axes *X* and *Y* (they are marked in Fig. 1 as 16 and 13 respectively), interface 4 of synchronization of drive control system with coordinate measuring system, interface 5 of control of carriages 14 and 17 and carriage 20 of rotary mirror, interface 6 for reading data of photodetector. Control of measuring carriages 14, 17 and 20 is carried out by the carriage controller 21. Stator 9 of investigated linear stepping drive with movable inductor 10 and reflectors 11 and 12 of measuring axes *Y* and *X* respectively are rigid arranged on massive base 7 using the fixing element 8.

Thereby, functionally the station of the testing of precision parameters contains the following systems:

- control system of linear stepping motor on the base of industrial single-board computer PCA-6753-F-G0A2 Advantech and generators of phase currents, each of which provides the control of two motor phases by pulsing currents;
- coordinate measuring system, which is built on the base of precision laser coordinate measurer Dynamic Calibrator HP 5529A (Hewlett-Packard Company) and allows the measuring of coordinate with discreteness of 0.0001 micrometers [4];
- positioning system of optical elements on the base of linear stepping motor.

The developed software of coordinate measuring system contains the measuring procedures for motion step accumulated error of linear stepping drive’s inductor, for division irregularity of full step of motion, for irregularity of discrete grid step, for checking of repeatability of positioning coordinate, for testing of hysteresis.

Using the automated station of the testing of precision parameters of linear stepping drive the investigations of stability of coordinates of discrete grid nodes were carried out. They were fulfilled within one motion period with step 0.001 mm for two-coordinate linear stepping motor with toothing structure period τ of stator and inductor poles of electro phase modules which was equal to 1 mm (τ = 1 mm). During the investigation two series of experiments were performed with an interval of 13 days, using three experiments for each series with interval of one day. The results shown in Fig. 2 confirmed that the changing of coordinate deviations of coordinate system discrete grid nodes is stable over time.

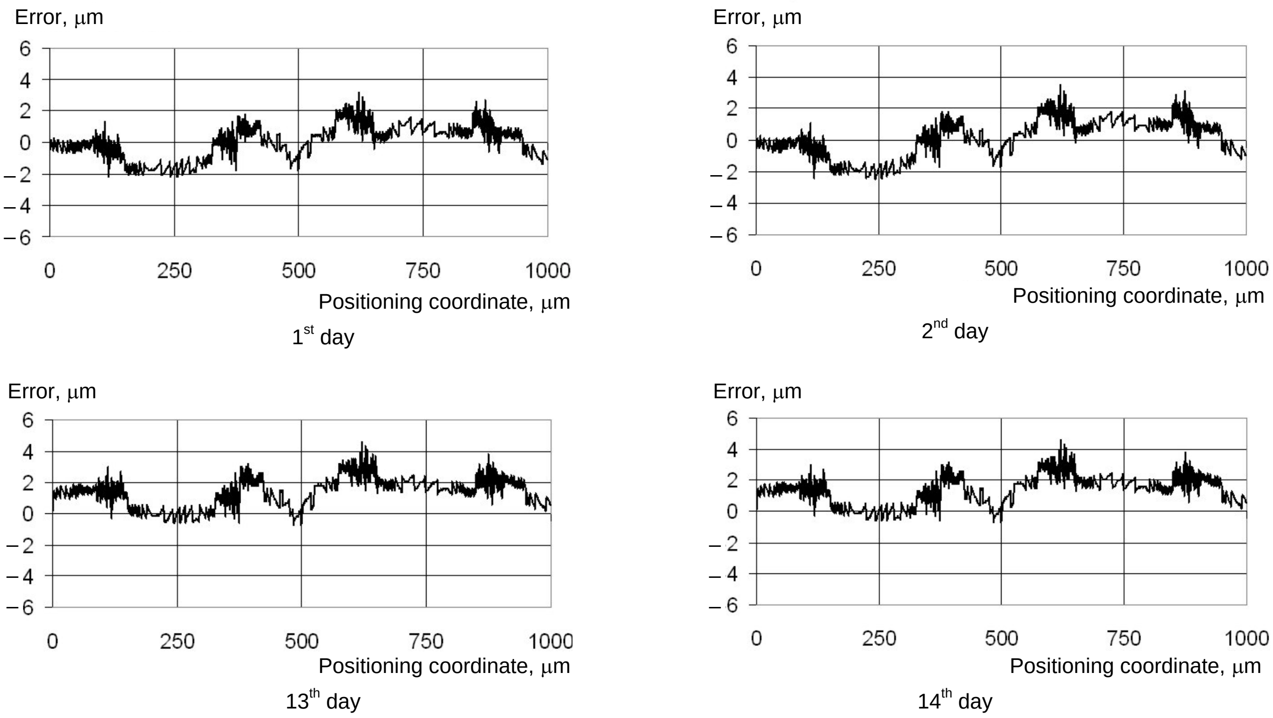

Fig. 2. Graphs of displacement of discrete grid nodes from nominal coordinates

In spite of some differences in the nature of the error changes presented by graphs in Fig. 2, it is evidently that the deviation values are within the band of 5.0 micrometers, and the deviation from mean value is not greater than 2.5 micrometers. All it confirms that the discrete grid is stable and the algorithm and method of forming the grid proposed are effective.

CONCLUSION

The algorithm and software for determining of optimal quantization levels of control currents of linear stepping motor phases have been developed.

Usage of the files of optimal position correction of discrete grid nodes in the control system allows the increasing of positioning accuracy of linear stepping drive of precision motion systems to 2–5 micrometers without physical feedbacks.

An optimal correction of position of discrete grid nodes could be implemented in the software of control system of linear stepping drive using automated station of the testing of precision parameters.

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ЭНЕРГОСБЕРЕЖЕНИЕ И ИНФОРМАЦИОННЫЕ ТЕХНОЛОГИИ

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ENERGY SAVING AND INFORMATION TECHNOLOGIES

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Рассмотрен подход к разработке методологии комплексной модернизации системы управления энергоресурсами предприятий строительной отрасли на основе использования современных информационных ресурсов и технологий. Предложена укрупненная концептуальная схема системы управления энергоресурсами. Изложены принципы информатизации системы управления, на основе которых разработана архитектура корпоративной информационно-аналитической системы как инструментально-технологического комплекса, предназначенного для модернизации системы управления энергоресурсами предприятия.

Ключевые слова: энергосбережение, система управления энергоресурсами, информатизация, информационно-аналитические системы.

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