

The choice of the principle of functioning of the system of magnetic levitation for the device of high-performance testing of powder permanent magnets

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Abstract. The present article focuses on permanent magnets quality control problems. High-performance direct-flow type systems for the mechanical engineering production processes are considered. The main lack of the existing high-performance direct-flow type systems is a completing phase of movement of a tested product when the movement is oscillatory and abrupt braking may be harmful for high fragility samples. A special system for permanent magnets control is offered. The system realizes the magnetic levitation of a test sample. Active correction of the electric current in magnetizing coils as the basic functioning principle of this system is offered. The system provides the required parameters of the movement of the test sample by using opposite connection of magnetizing coils. This new technique provides aperiodic nature of the movement and limited acceleration with saving of high accuracy and required timeframe of the installation in the measuring position.

1. Introduction

Electric motors production is one of the most important areas of electrical engineering. DC motors have high energy efficiency and huge torque. An important element of most of electromagnetic drives is permanent magnets. Recently, permanent magnets made of ferromagnetic materials powder [1-7] have been widely used. However, their quality must be controlled. For implementation of production control of permanent magnets, direct-flow type magnetic systems are used [8]. These systems carry out high-performance movement, orientation through a magnetic texture and fixing of the test sample in the measuring position with electromagnetic field. The main lack of these systems is the completing phase of the movement of the test sample (figure 1). In the completing phase, the movement has an oscillatory nature, and braking of the test sample is rather abrupt. These factors do not allow one to use magnetic systems of direct-flow type for testing products with the increased fragility.



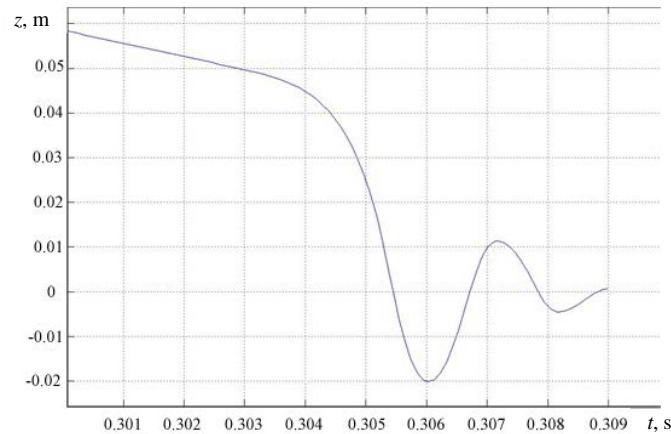


Figure 1. The trajectory of movement of the test sample in the direct-flow type magnetic system.

The objective of this research is implementation principles development of the control system based on magnetic levitation [9, 10] of the test sample by active correction of the current in magnetizing coils of the magnetic system for ensuring the set parameters of the sample movement: aperiodic nature of the movement and acceleration restriction and saving of high accuracy and timeframe of the installation in a measuring position.

2. Materials and methods

The control system of test sample magnetic levitation is offered as the solution of this task. The function chart of the control system is presented in figure 2.

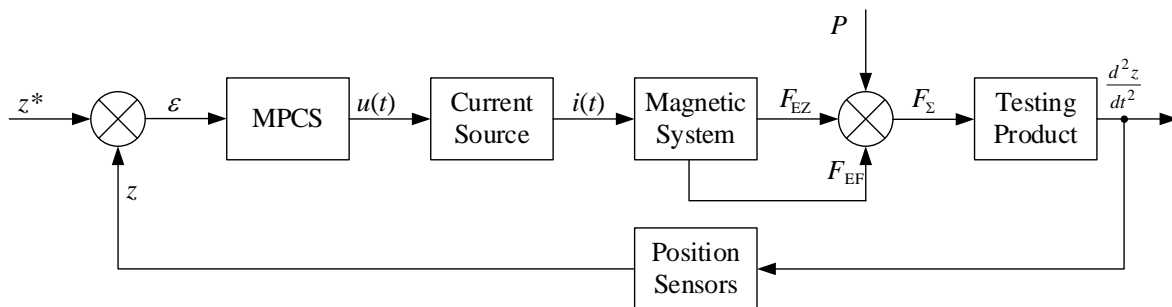


Figure 2. The block diagram of the control system of parameters of examinee levitation of the product.

Parts of the system (figure 2) are: the microprocessor control system (MPCS), the managed current source, the magnetic system, the situation sensor.

The law of the test sample movement with predetermined geometrical sizes in the direct-flow type magnetic system is described by a second order differential equation:

$$m \frac{d^2 z}{dt^2} + P + F_z(z, I) + F_x(z, I) \cdot k_F \cdot \text{sign}\left(\frac{dz}{dt}\right) = 0, \quad (1)$$

where z – the distance between centers of the test sample and the interpolar space; m , P – respectively, the weight and the gravity of the test sample; F_z , F_x – tangential and normal components of the electromagnetic force affecting the test sample, k_F – the friction coefficient of the test sample of the product against guide rails, I – the current in magnetizing coils.

3. The implementation and research of the magnetic system

Two options of current forming in magnetizing coils of the magnetic system have been considered. With the coordinated connection of magnetizing coils, the direction of vector tangential force F_z has been coordinated with gravity P . When the velocity vector of the test sample is directed to the center of the system, this force does not limit free fall acceleration, and, on the contrary, creates additional acceleration that leads to "flight" of the test sample through the installation position. Restriction on acceleration in this case is only imposed by the normal component force of F_x (1), which will be transformed to friction force F_{EF} (figure 2). There is the second shortcoming: the arisen friction force of F_{EF} results in considerable mechanical wear of guides and partial damage of the test sample.

The assumption is made that the use of opposite connection of magnetizing coils will allow one to reduce friction force and to limit acceleration of an object. To confirm that, the model of the magnetic system has been developed in the environment of *GMSH GetDP*. The model is presented in figure 3. In figure 3, the following designations are accepted: *MC* - magnetic core, *TP* - testing product, *MC* - magnetizing coils. The value of the magnetomotive force in the model was set as $Iw=20$ kA/m. The received schedules of tangential and the normal components of electromagnetic forces as dependences on the distance test sample to the center of magnetizing coils are represented in figure 4. Schedules of dependence of forces are symmetric concerning the center of the magnetic system interpolar space.

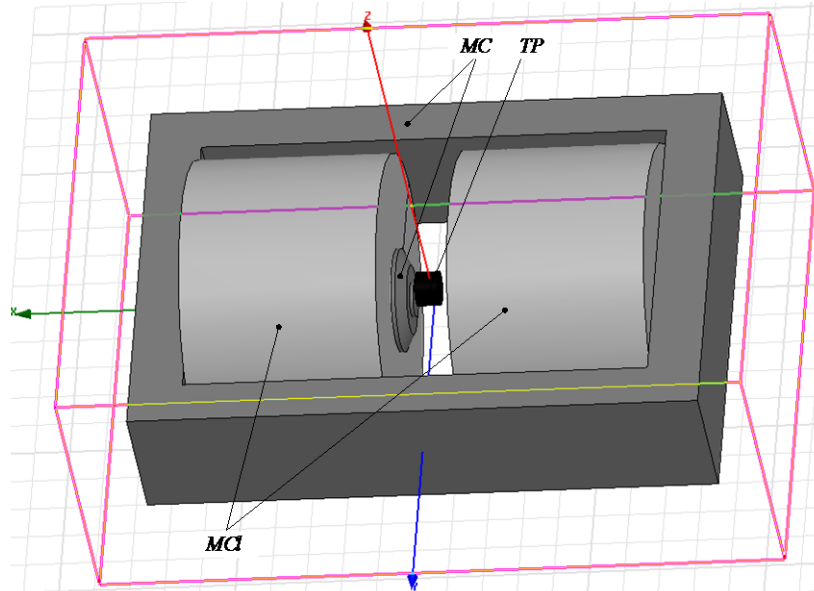


Figure 3. The model of the magnetic system in the environment of *GMSH GetDP*.

In case of oppositely connected magnetizing coils, the specified value of magnetomotive force, $Iw=20$ kA/m, owing to the centered position of the test sample in the magnetic system. The value of the normal component of electromagnetic force is $F_x=1.83$ N, and the value of the tangential force component is $F_z=0$. For retention of the test sample in the centered position, the value of the amount of operation forces has to satisfy the condition: $F_x \cdot k_F = P$ or $F_x \cdot k_F = mg$.

To solve the problem of the position control of the permanent magnet, it is necessary to develop a mathematical model of the movement process. The following prior restraints on various subjects of permanent magnets D (diameter) and h (height) were raised: $18 \leq D \leq 22$ mm; $11 \leq h \leq 14.7$ mm. To construct a mathematical model of the movement process, the apparatus of orthogonal polynomials and multi-level experiments planning is applied. The graphs in figure 4 show that in the studied area of position z , tangential $F_z(z)$ and normal $F_x(z)$ components of electromagnetic forces can not be described even by linear and quadratic functions. Similar preliminary studies indicated that

dependences $F_z(h)$, $F_z(D)$, $F_x(h)$, $F_x(D)$ can be described by a linear function.

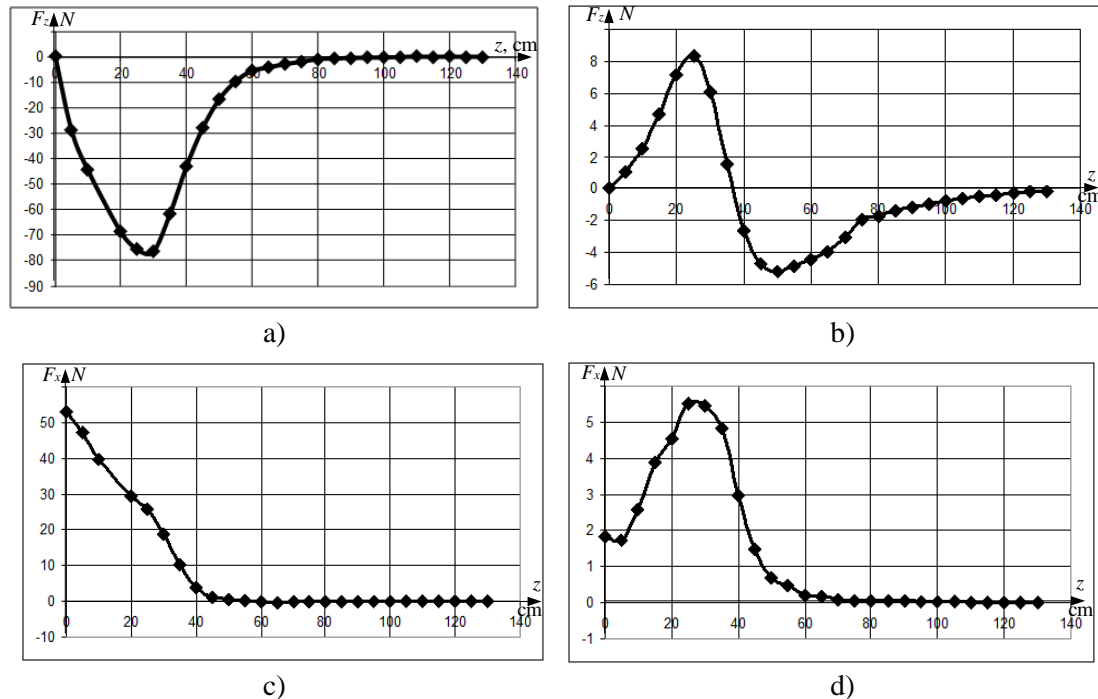


Figure 4. Schedules of the electromagnetic forces operating on the test sample depending on the distance between the center of the sample and the center of the magnetic system.

The aim of the experiment is to build the polynomial mathematical model of the movement process in the form of the regression equation. For polynomial modeling, the orthogonal polynomials are selected as a basis function. The possibility of constructing the model of a particular type depends on the number and location of the experimental points in the factor space. In this case, a complete factorial experiment was conducted. It consisted of 96 different sets of F_z and 84 different sets of F_x , which define a four-factor space, respectively, 96 and 84 experimental points. The models include orthogonal polynomials in four variables; the degree of the polynomial older for any variable is less than the number of varying levels.

In addition to single variables, the model introduced a twin, triple and quadruple product of polynomials of different variables. The complete F_z model includes: 33 pairs of works, 37 triple, 14 quadruple. The complete F_x model includes: 29 pairs of works, 32 triple, 12 quadruple. The model does not include products of polynomials of the same variable. General expression patterns are not recorded due to its bulkiness.

Experimental design for F_z includes 96 experimental points and for F_x — 84 experimental points. Since the experiment was performed with the help of a computer model, the randomization and repeated experiments were not pursued. Processing of the results consists of three operations: the calculation of a b -coefficient of the regression mathematical model, determination of their statistical significance, check of the adequacy of the model.

To find the values of the b -coefficient, it is necessary to make a structural matrix with the order of 96 for F_z and with the order of 84 for F_x . To test the adequacy of the resulting model, the predicted responses values were calculated. Then, there is the dispersion of the adequacy calculated by formula:

$$S_{ad}^2 = \sum_{u=1}^N \frac{\varepsilon_u^2}{f_{ad}},$$

where $f_{ad} = N - l$ - number of degrees of freedom; l - number of significant b-coefficients.

For the tangential component of electromagnetic force, $F_z: f_{ad,z} = N_z - l_z = 96 - 50 = 46$, and the dispersion of adequacy was $S_{ad,z}^2 = 697.2544$.

The value of the reproducibility variance was calculated when determining the significance of the coefficients: $S_{res,z}^2 = 10242$. Therefore, the calculated value of the F-criteria was $F_{calc}^z = 0.0681$.

For the normal component of electromagnetic force, $F_x: f_{ad,x} = N_x - l_x = 84 - 35 = 49$, and the dispersion of adequate was $S_{ad,x}^2 = 1210.4$.

The value of the reproducibility variance was calculated when determining the significance of the coefficients: $S_{res,x}^2 = 13285$. Therefore, the calculated value of the F-criteria was $F_{calc}^x = 0.0911$.

The tabular value F-criteria for the significance level of $\alpha = 0.05$ and the number of degrees of freedom $f_{ad} = 46$ and $f_{res} = 96$ is $F_{tb}^z = 1.00$. For $\alpha = 0.05$ and the number of degrees of freedom $f_{ad} = 49$ and $f_{res} = 84$, the tabular value F-criteria is $F_{tb}^x = 1.00$. Since $F_{calc}^{z,x} < F_{tb}^{z,x}$ in both cases, both models should recognize the adequacy of existing statistical data. The resulting adequate equation for models of F_z and F_x does not condition their complexity.

The body weight, which the magnetic system is capable to hold by means of the managed electromagnetic forces of m_{max} , makes:

$$m_{max} = \frac{F_x \cdot k_F}{g}.$$

The scheme used for determination of size k_F is presented in figure 5.

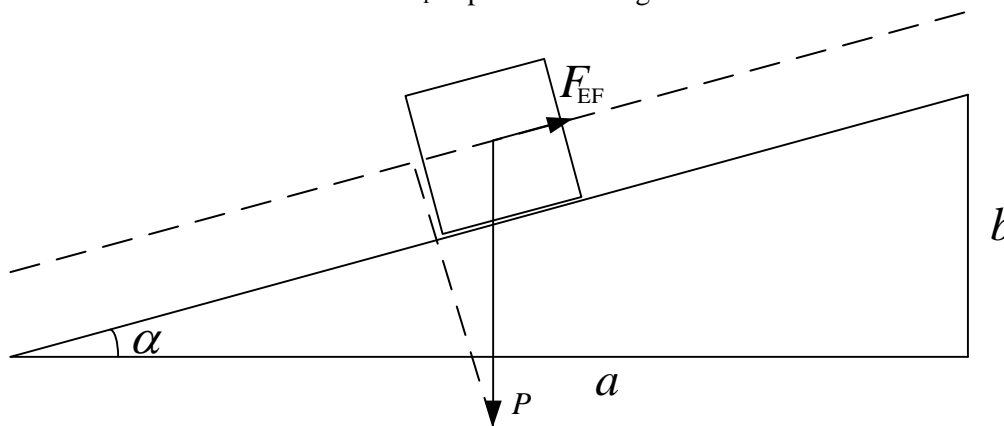


Figure 5. Scheme of k_F definition.

At some value of the slope angle of plane α on which the test product is placed, the body begins the movement. We will determine the size and the tangent of angle α by value k_F . For this purpose, we will fix values of a and b . The received friction coefficient was: $k_F = 0.25 \pm 0.02$.

Admission (± 0.02) implements a possibility of friction of the test product about the directing systems of tests by different parts. In this case, $m_{max} = 0.046$ kg.

4. Conclusion

From the analysis of charts in figure 4 that treat shortcomings of oppositely connected magnetizing coils in the magnetic system, we can conclude the following.

1. There is a need for creation of a considerably bigger value of magnetomotive force affecting the test sample.

2. The vector of the tangential component of electromagnetic force F_z is not directed opposite to the force gravity vector at all values z . When it is directed opposite to the gravity vector at $z=(37\div 120)$ mm, the test product “is involved” in the center of the magnetic system.

3. There is a significant value of normal component F_x at $z=(20\div 40)$ mm. The situation when the test sample does not reach the center of interpolar space of the magnetic system is possible.

These imperfections can be solved in the system parameters calculation phase.

The advantages of oppositely connected magnetizing coils are:

1. the direction of vectors of forces affecting the test sample at oppositely connected magnetizing coils has matched the expected. The vector of electromagnetic forces is directed conversely relatively gravity P .

2. The value of forces for oppositely connected magnetizing coils is much less than values of forces during the coordinated turning of magnetizing coils. The advantage of opposite connection, thus, is a considerable decrease in friction force of the test sample between guide rails, which leads to a considerable decrease in resources consumption of the system.

In general, it is possible to draw a conclusion that with oppositely connected magnetizing coils of the magnetic system, it is possible to create counteracting magnetic force in the required timeframe and to achieve necessary parameters of the movement of the test sample in the direct-flow type magnetic system. There is aperiodic nature of the movement and a restriction on acceleration.

The mathematical models of F_z and F_x as the basis for the construction of high-performance permanent magnet control systems used in the manufacturing process of mechanical engineering were developed.

Acknowledgments

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