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Influence of Control Algorithms Parameters on an Electromechanical Converter with a Secondary Discrete Part

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Abstract: An alternative configuration of a device with a secondary discrete part using a magnetic system of a similar multi-phase inductor machine and concentrated windings without an internal rotor is proposed. An algorithm of sensorless control of a motion process of a secondary discrete part is proposed. The analysis of the distribution nature of the magnetic field for various switching algorithms is carried out to reduce negative influence of the “dead” zones of the first and second order. The features of the movement process of the secondary discrete part in the working chamber of the device are considered. The results of in the electromagnetic force change affecting a ferromagnetic working element are presented, and recommendations for the application of switching algorithms are given.

Keywords: Electromechanical converter, Secondary discrete part, Sensorless control, Mathematical modeling, Switching algorithm.

1 Introduction

Electromechanical devices with a secondary discrete part are unique and universal in their application and can be used in various industries: technological processes for handling oil and petroleum products [1, 2] cleaning biological waste, mixing liquid materials [3] and creating colloidal solutions [4]. A wide range of applications led to the appearance of a significant number of design models. The investigated apparatus with a secondary discrete part has different terminology in different literature sources, including the vortex layer activator [4], the electromechanical activator [5], the vortex layer apparatus [6, 7], the traveling field grinder or the reactor with a vortex layer of ferromagnetic particles [8]. However, based on the features of the operation principle, all known devices are suitable for the above description, all of them should be defined as electromechanical converters with a secondary discrete part.

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At the same time, despite the intensity and variety of research, in most cases, the designs of devices with a secondary discrete part have not undergone significant changes, retaining the tradition of applying a rotating magnetic field. The device is shown in Fig. 1 consists of a cylindrical inductor 1 with a distributed electric winding 2, a non-magnetic material pipeline is located in the rotor place, which is a working chamber 3 and ferromagnetic elements 4 arranged in it, a large set of which is a working member.

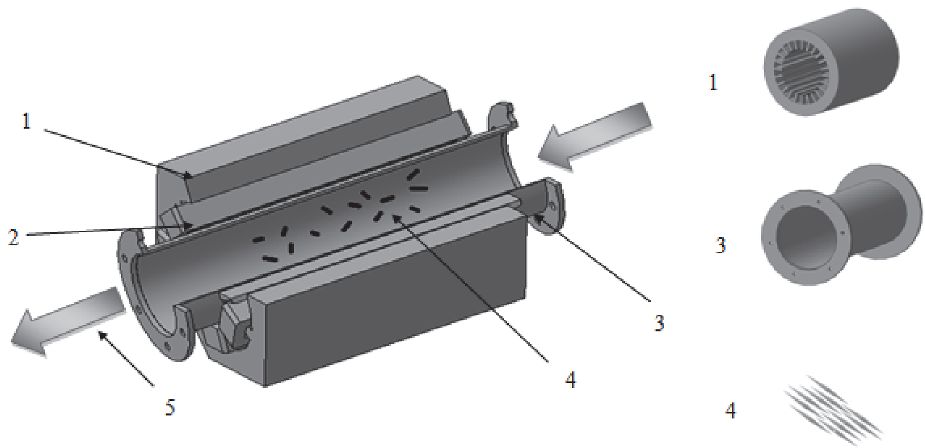


Fig. 1 – *Construction of the device with a secondary discrete part: 1 - the case of the device; 2 - winding; 3 - pipe made of non-magnetic material; 4 - ferromagnetic elements; 5 - the flow of processed raw materials.*

It is necessary to note that significant shortcomings opposed to the popular opinion about the effectiveness of the rotating magnetic field in electromechanical converters with a secondary discrete part, all the previously developed designs deal with the problem of existence of “dead” zones [4] inside the inductor boring. The “dead” zones are the areas of the working chamber, in without fast motion of the ferromagnetic elements. There are two such zones: in the center of the working chamber and the angular regions of the inductor teeth. In general, the presence of “dead” zones is due to uneven distribution of magnetic induction in the volume of the working chamber. The presence of a “dead” zone in the angular regions of the inductor teeth is explained by the high values of the magnetic induction, which is 3–4 times greater than the induction value located near the center of the inductor. The primary cause of the “dead” zone in the center of the inductor is the low value of the magnetic induction due to the large non-magnetic gap. The motion of working elements under the influence of an external rotating magnetic field is accompanied by the presence of a whole complex of forces, of which, in this case, it is the centrifugal force that ejects the working ferromagnetic elements from the central region of the working chamber. As a result, the generated unidirectional rotating magnetic field leads to the inevitable presence of a "dead" zone in the center of the inductor boring. In this connection, when solving the problem of the presence of "dead" zones, an attempt was made to change the character and trajectory of the elements motion of the secondary discrete part by means of refusing to use a rotating magnetic field. For the basis a new magnetic system of the electromechanical converter with a secondary discrete part is used, as the authors of the article [9, 10] adopted a multiphase magnetic system of an inductor machine without a rotor. A distinctive feature of the projected device is the discrete movement of the magnetic field, regulated by the appropriate switching of power switches of each phase. Each ferromagnetic working element, taken separately, makes a motion, orienting itself along the lines of the magnetic field force, making a translational motion and moving to a region with a large value of magnetic induction. As a result, the array of ferromagnetic elements, for the most part, it repeats the motion of an individual ferromagnetic element, moving successively from one active phase of the inductor to another.

Thus, in the framework of this research work, the authors faced the task of solving two main tasks:

1. Search of an effective basic phase switching algorithm to ensure the main movement of ferromagnetic elements in the working chamber during operation;
2. Investigation of possible combinations of phase switching creating conditions for the movement of ferromagnetic elements through the center of the working chamber.

2 Influence Studying

To effectively use the capabilities of the electromechanical converter with a secondary discrete part the current of phase excitation must be controlled by the position of a large population ferromagnetic elements. Induction machines with the internal rotor, served as the basis for creating a new configuration of electromechanical converter, use physical sensors of the rotor position, fastened to the shaft of the machine. For an electromechanical converter with a secondary discrete part, due to the absence of a shaft there is a large non-magnetic gap and complex stochastic motion of discrete medium, the use of the position sensor is impossible.

Meanwhile, the movement of a secondary discrete medium can be controlled indirectly, using the results of modeling the process of motion of a discrete part. It leads to the necessity of studying the influence of the dynamic elements motion of the secondary discrete part on the period of recurrence. This period is the time interval between two adjacent power key switches.

The purpose of this article is an evaluation of the influence of the control algorithm on the electromechanical properties and characteristics of an electromechanical converter with a secondary discrete part. Studies were carried out for a single ferromagnetic element using the FEMM 4.2 software package [11].

Continuing to draw an analogy with inductor machines, we can assume that an electromechanical converter with a secondary discrete part can have three main types [12] of phase control algorithms: two basic single, pair symmetrical and one special unbalanced algorithm, involving the combination of several different phases, to create the conditions of displacement of ferromagnetic elements through the center of the working chamber.

In accordance with the nature of the created magnetic field, the motion of the ferromagnetic element is divided into equal angular zones (Fig. 2a). The number of angular zones is determined by dividing 3600 by the number of phases of the inductor. To evaluate the character of the process of motion of a single ferromagnetic element a single angular zone corresponding to the region of the movement of a single ferromagnetic element between the poles of the active phases of the switched commutation algorithm was chosen.

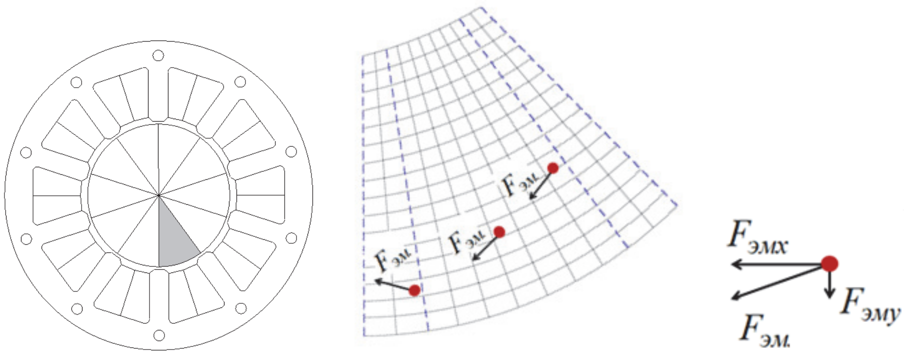
Under the conditions of the investigated configuration of the magnetic system, when the magnetic field, moves discretely through the working chamber in accordance with the switching algorithm, , the results of the study of one particular area would be valid for the remaining 10 regions, therefore, within the framework of this work, studies would be conducted for a single selected area.

Figs. 2a and 2b show a fragment of the investigated region of the working chamber, corresponding to the zone of the ferromagnetic elements motion of one switching cycle. Let us list the main tasks are to be addressed when investigating phase-switching algorithms:

– providing the maximum force from the magnetic field;

– elimination of the “dead” zone of the first order.

To eliminate the “dead” zone of the first order and ensure smooth movement of the element along the working chamber, in this particular region it is necessary to provide a maximum of the electromagnetic force $F_{ЭМХ}$ (Fig. 2c) along the projection of the OX axis when the ferromagnetic element moves more horizontally. Otherwise, if the electromagnetic force is significantly exceeded along the OY axis over an analogous index along the OX axis, the ferromagnetic element will “stick” in the interdental zone, without going through the path to the next-pole pole (the dashed line in Fig. 2b). Thus, to reduce the negative effect of the “dead” zone of the 1st order, one of the first tasks is to search for a phase-switching algorithm in which the value of the electromagnetic force along the OX axis assumes the maximum value. An additional criterion of the efficiency of the switching algorithm will be the investigation of the character of the electromagnetic force in the diametrical direction and the search for an effective switching algorithm when the values of the electromagnetic force in the center of the inductor and on the surface of the bore were as close to each other as possible.



(a) (b) (c)

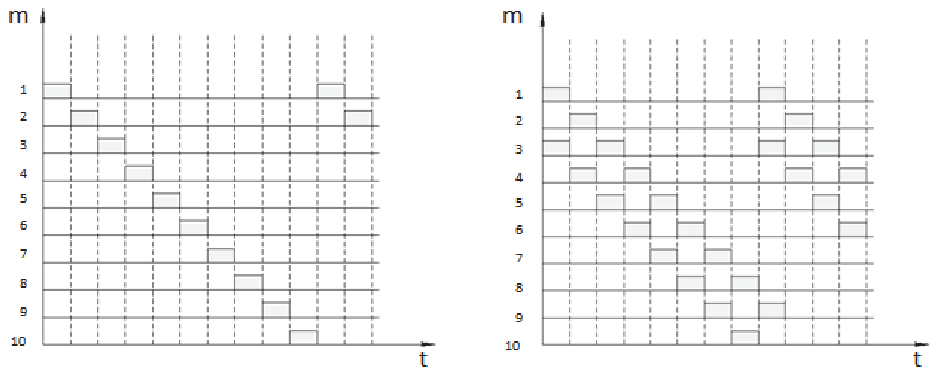
Fig. 2 – *The space of the investigated angular zone of the working chamber.*

To determine the electromagnetic force the function of the FEMM 4.2 software complex was used, to find the force acting on the ferromagnetic element through the weighted stress tensor. The automatic calculation of the weighted tensor of tension is based on the volumetric integral of the Maxwell tension tensor along the contour enclosing the ferromagnetic element [11]. The force acting on the moving element is determined by this method as:

$$F_{м} = -\int_{S} \sigma_{EM} \nabla \gamma \, \mathrm{d} S \,, \qquad (1)$$

where γ is a function taking the value 1 inside the contour S and 0 outside the contour.

Investigation of the nature of the change in the electromagnetic force for various switching algorithms was carried out in two directions: a study was made of the character modification of the electromagnetic force acting on the ferromagnetic element in the diametrical direction of the removal of a ferromagnetic element with a step of 2 mm from the active pole; a study of the nature of changing electromagnetic force acting on the ferromagnetic element in the chord direction of removal of the ferromagnetic element with a step of 2 mm from the active pole.



(a) (b)

Fig. 3 – *The switching algorithm: a) single symmetric; b) symmetric pair*.

Based on the analysis of possible commutation algorithms, the maximum values of the electromagnetic force acting on the ferromagnetic element were obtained for the paired phase-switching algorithm. The results of modeling the magnetic field in an electromechanical converter with a secondary discrete part are shown in Figs. 4 and 5. The presented dependences of the electromagnetic force can be seen when moving away from the active pole, in the diametric and chorda directions, the maximum value of the electromagnetic force acting on a single ferromagnetic element is obtained for the pair phase-shift algorithm. As a result, a given configuration of the magnetic system is supposed to be, a large set of ferromagnetic elements, repeating the motion of a single ferromagnetic element, it can be assumed using the paired switching algorithm, the probability of “sticking” in the interdental zone is significantly less, due to a larger free path, traversed by the element before attraction moment to the active pole.

Special attention is required the most complicated algorithm for switching power keys as special implementation, to create conditions for the secondary discrete part moving through the center of the working chamber.

To eliminate the “dead” zone of the 2nd order and create the conditions for moving the element through the center of the working chamber, it is necessary to provide the maximum value of $F_{ЭМY}$ along the projection of the OY axis when the ferromagnetic element moves more in the vertical direction, moving to the center of the working chamber. Otherwise, the ferromagnetic element will be attracted to the nearest active pole along the working chamber.

On the basis of numerous studies of various phase switching combinations, the only correct solution was the application of the switching algorithm shown in Fig. 6.

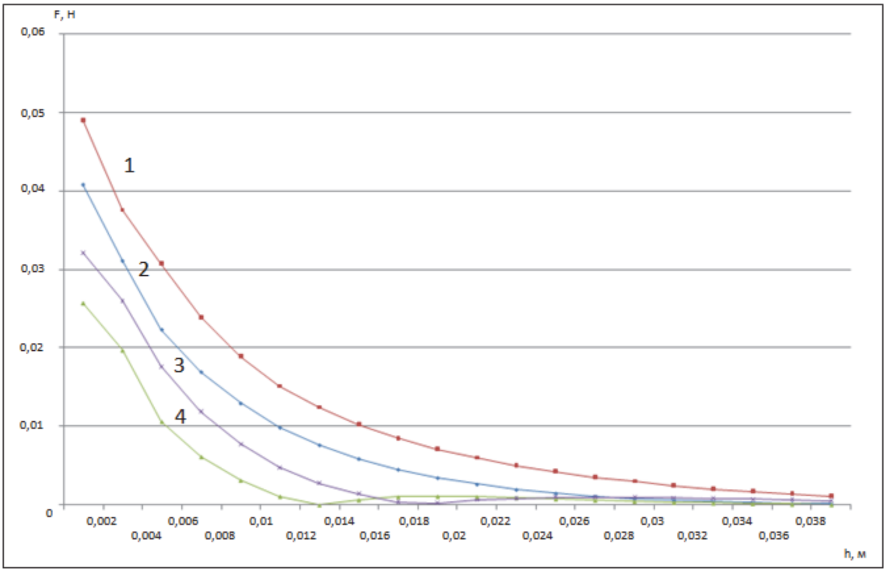


Fig. 4 – *The distribution of the electromagnetic force in the diametrical direction from the active pole to the center. Electromagnetic force: 1 - for a pairing algorithm, 2 - for a single algorithm. Electromagnetic force along the OX axis: 3 - with a pairing algorithm; 4 - with a single.*

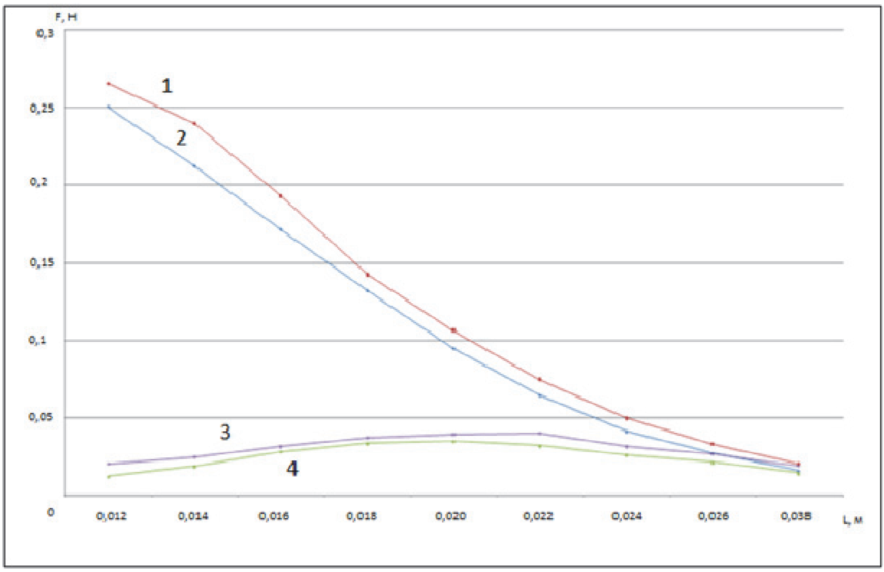


Fig. 5 – *Distribution of the electromagnetic force in the chord section from the active pole. Electromagnetic force: 1 - for a pairing algorithm, 2 - for a single algorithm. Electromagnetic force along the OX axis: 3 - with a pairing algorithm; 4 - with a single.*

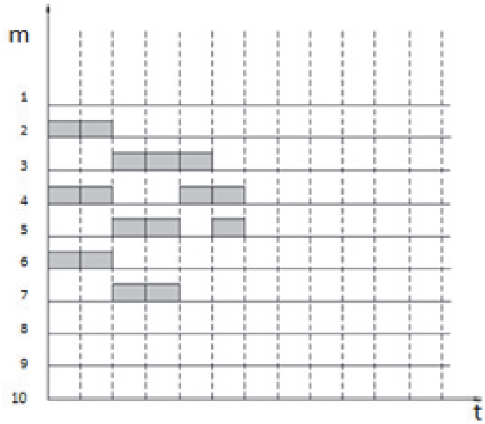


Fig. 6 – *Special phase switching algorithm.*

3 Conclusion

1. A new configuration of the magnetic system is presented and analyzed, having the main difference in the method of exciting the motion of ferromagnetic elements in the working chamber.
2. Analysis of the processes occurring in the working chamber for a given configuration of the magnetic system made it possible to infer the inefficiency of the current widely used method of estimating the efficiency of the secondary medium motion in the form of searching for the optimal distribution of magnetic induction equal to the range of values 0.1–0.2 T by volume of the working chamber. It is possible even if full implementation of these criteria in the design process does not ensure the elimination of the "dead" zones of the 1st and 2nd order. The study of the nature of the electromagnetic force action is the most effective. For this configuration of the magnetic system, the electromagnetic force was investigated for various switching algorithms.
3. Couple switching makes it possible to obtain the maximum value of the electromagnetic force acting on the ferromagnetic element, including for the projection of the force along the axis corresponding to the direction of effective motion, thereby increasing the mean free path of the element. The investigated special phase switching algorithm creates necessary conditions for moving the ferromagnetic working elements through the center of the working chamber, significantly reducing the cross-section of the "dead" zone of the second order.

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