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Electromechanics

Theoretical Principles of Electromagnetic Oscillation Motor with Asymmetrical Stator

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This paper describes theoretical principles and operating regimes of an elaborated at the Agricultural University of Georgia electromagnetic oscillation motor with angular vibrations of armature. The motor comprises a symmetrical four-pole armature with a DC winding and asymmetrical four-pole stator with an AC winding with two parallel paths. The biggest amplitude of the linear oscillations of the armature is adjusted depending on how the work member is fixed on the arm; the amplitude of the angular oscillation is up to 14 deg. It is not necessary to maintain an accurate air gap between the stator and the armature. This motor is designed for the use in agriculture and industry as a drive for feeders, transporters, sorters and for a number of other purposes where a vibratory drive with directional oscillations is needed. More than 20 patents from 12 countries protect the novelty of the designs. *© 2023 Bull. Georg. Natl. Acad. Sci.*

oscillation, electrical motor, synchronous, energy efficiency

Vibration is widely used in various fields of modern technology [1, 2]. Although the most common are the vibratory electric drives with *rotary* machines, promising are electromagnetic vibratory drives, the main advantages of which are much lower power consumption when operating in a resonant or near-resonant mode, the ability create vibration with a frequency of more than 100 Hz, the ability to control the vibration amplitude regardless of frequency. The effectiveness of the electromagnetic oscillation motors essentially depends on the choice of design parameters and relationship of the magnetic system. Therefore, it is an urgent task to create procedures for rational choice of parameters in the design of electromagnetic oscillation motors that ensure their reliability and high efficiency.

Electromagnetic vibrators are becoming more and more popular, and there is a variety of implementations available today [3 - 5]. However, motors of this type are still limited in their applications due to a number of drawbacks: insufficient oscillation amplitude, complex design and metal consumption, heavy weight and dimensions of the motor, they have very high noise level and are short-lived due to the collisions of the armature and stator, they consume too much energy. These issues were the subject of numerous theoretical investigations, experiments and inventions.

Materials and Methods

The primary purpose of our work was to reduce the amount of metal required for manufacture of electromagnetic vibrators and increase the reliability and step up the amplitude of an electromagnetic vibrator. The other purpose of the work was to create an electromagnetic oscillation motor wherein the structural design of the stator and the arrangement of the winding coils should enhance the efficiency factor and the power factor, as well as provide the ability to control the amplitude of oscillations of the armature by varying the biasing current. These objectives are achieved in constructions of electromagnetic oscillation motors elaborated at the Agricultural University of Georgia.

Patents of USA, UK, Germany, India, Australia, Brazil, Canada, Georgia and other countries [6, 7], protect intellectual property for inventions. On the international level they are designed for the use in agriculture and industry as a drive for feeders, transporters, sorters and for a number of other purposes where a vibration drive with directed vibrations is needed. The developed oscillation motors are simple in design and makes it possible to save 400 kg of metal per unit in a 4 kW modification, which provides significant production costs reduction. The greatest amplitude of oscillations of the vibrator is adjusted depending on how the work member is fixed; the vibration amplitude is up to 14 degrees. There is no need in keeping an accurate air gap between the stator and the rotor.

By its action, the considered electromagnetic motor with angular oscillations [2] is similar to synchronous motors. The biasing winding of the motor is connected to a DC source and creates constant magnetic field. Thus, the rotor of the motor is a permanent electromagnet located in the magnetic field of the stator. In this case, the pole of the stator magnetic field attracts the opposite pole of the rotor, trying to match their magnetic axes. The stator magnetic field drags the rotor with its magnetic field, and the rotor oscillates with the frequency of the magnetic field - the rotor and the stator magnetic field oscillate synchronously. As a result, the motor, consuming electrical energy from a single-phase source, causes oscillations of the working mechanism, transferring mechanical energy to it. The oscillation frequency of the motor rotor is determined by the frequency of the stator magnetic field and does not depend on the load moment on the shaft.

Laboratory studies of the aforementioned oscillation motors revealed positive energy indicators (performance, $\cos\varphi$) but also significant disadvantages: the presence of magnetic leakage fluxes in the non-working part of the stator magnetic circuit and parasitic one-sided radial attractions that bend the armature shaft, cause accelerated wear of the bearings and the motor as a whole, and reduce its efficiency. The first drawback was largely eliminated by creating non-magnetic gaps in the stator yoke [8], and the second by motor version with eight (instead of four) poles on stator and on rotor and two axes of symmetry of the armature passing in the middle of gaps filled with non-magnetic material in the stator yoke [9].

Below an electromagnetic vibrator that combines positive qualities of the above four designs and at the same time permits to control the amplitude of the vibrations is considered. The electromagnetic oscillation motor is schematically illustrated in Fig. 1; it comprises a symmetrical four-pole armature with a DC winding and an asymmetrical four-pole stator with an AC winding, made up of two parallel-connected paths, each of said path includes two series-connected coils (12, 13 and 14, 15), characterized in that the adjacent stator poles (3, 4) forming one pair are offset in opposite directions, while the adjacent poles (5, 6) forming another pair are offset toward each other with respect to the symmetry axes of respective poles (8, 9 and 10, 11) of the armature by a distance, equal to one half of the width b of stator poles, and each path of the alternating current winding being received on the respective pair of adjacent stator poles (3, 4 and 4, 6), and, the coils (18, 19 and 20, 21) of the DC winding are connected in pairs in a matched-series fashion and received on the adjacent poles (9, 10 and 8, 10) of the armature, the pairs of coils (18, 19 and 20, 21) being connected in opposition. To reduce leakage fluxes and increase the efficiency of the motor, the yoke of the stator magnet is made with two nonmagnetic gaps 25 [8].

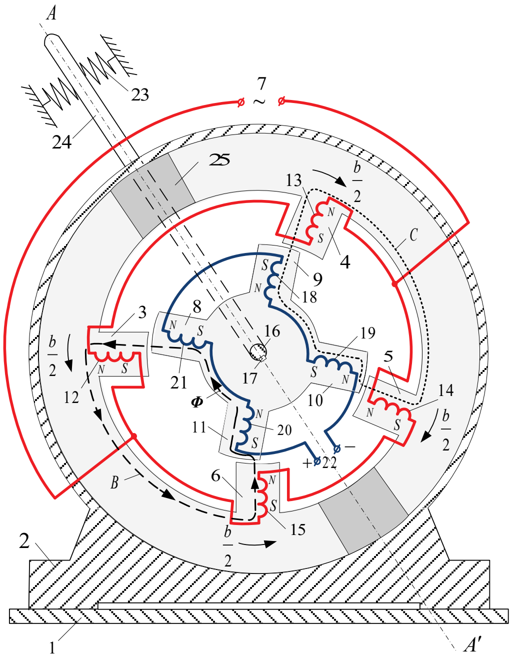

Fig. 1. Schematic drawing of the electromagnetic oscillation motor. The following symbols are used: the total magnetic flux linkage Φ in the paths *B* and *C* of the magnetic circuit; *N* and *S* are the respective polarities of the poles 3, 4, 5, 6 of the stator and poles 8, 9, 10, 11 of the armature.

The oscillation motor has a base plate 1 (Fig. 1) supporting on feet 2 a salient-pole stator, which is asymmetrical circularly, and mirror-symmetrical with respect to the symmetry axis $A - A'$, the stator having poles 3, 4, 5 and 6 supporting thereon DC winding connected to AC power supply source 7. The adjacent poles 3 and 4 of the stator, forming one pair, are offset in opposite directions from one another with respect to the axes of symmetry of the respective poles 8 and 9 of the armature of the motor through a distance $b/2$ equally to half the angular width b of the stator poles 3 and 4. The adjacent poles 5 and 6 of the stator, forming the other pair, are offset toward each other relative to the axes of symmetry of the armature poles 10 and 11 corresponding to them by similar distance $b/2$.

The AC winding includes two paths connected in parallel. One path is a series connection of two coils 12 and 13 received on the poles 3 and 4 which are spaced in excess of the mean interpolar spacing π, equal to $2\pi R/4$, where R is the stator bore radius, *m*. The other path is a series connection of two coils 14 and 15 received on the stator poles 5 and 6, which are spaced, as already explained, by a distance short of the mean average interpolar spacing π.

Inside the stator on a revolving armature shaft 16 with the aid of a key 17 is mounted a symmetrical four-pole armature with its DC winding. The coils 18 and 19, 20 and 21 of the DC winding are connected in pairs in a matched series and spooled, respectively, on the adjacent poles 9, 10 and 8, 11 and the pairs are interconnected opposite each other. The stator and armature are mechanically interconnected with the aid of bearings (not shown in the drawing), and through springy elements 23 connected with a lever arm

24, mounted rigid on the shaft 16. Depending on the required amplitude of oscillations, the work member can be fixed either on the shaft 16 of the motor or on the arm 24.

Fig. 2. a and 2b illustrate the time curves of variation of the magnetic flux linkages Φ, $\Phi_{\sim}$ and Φ_{-} crossing the annular air gap of the oscillation motor, where $\Phi_{\sim}$ is the magnetic flux linkage developed of the stator winding, Φ_{-} is the magnetic flux linkage developed by the armature winding, Φ is the total magnetic flux linkage, t is time, and ω is the conditional rotation speed of the magnetic flux linkage.

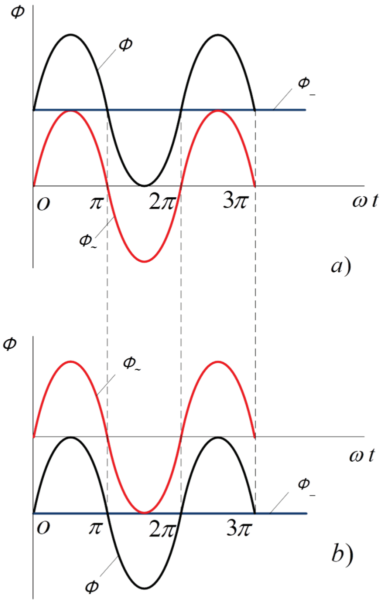

Fig. 2. Variation in time of magnetic flux linkages.

The electromagnetic oscillation motor disclosed here operates as follows. In the situation shown in Fig. 2a, during the half-cycle from 0 to π of the AC, flowing through the stator winding, the alternating magnetic flux linkage $\Phi_{\sim}$ in the path B of the magnetic circuit is added to the permanent magnetic flux linkage Φ_{-} developed by the DC winding of the armature, the resultant magnetic flux linkage Φ being conditionally positive. With the total magnetic flux linkage Φ in the path B of the magnetic circuit being at its maximum, the flux linkage Φ (Fig. 2b) in the path C (Fig. 1) practically equals zero. During the successive half-cycle from π to 2π of the AC flowing through the stator winding the process is reversed: the total flux linkage Φ (Fig. 2b) in the path C is at the maximum, whereas the flux linkage in the path B equals zero. Consequently, there is created a sign-variable driving torque causing angular oscillations of the armature according to the harmonic law, one of the preconditions of the development of this driving effort in the operation of the oscillation motor being the asymmetrical arrangement of the poles 8, 9, 10 and 11 of the stator relative to the symmetry axes of the corresponding poles 8, 9, 10 and 11 of the armature, with an angular shift through one half ($b/2$) of the angular width b of the pole 3, 4, 5 or 6.

The electromagnetic oscillation motor offers an enhanced efficiency factor, owing to the stator winding being directly connected to the AC source 7, and also due to the fact that all stator poles 3, 4, 5, 6 and all poles 8, 9, 10 and 11 of the armature take part all the time in the development of the electromagnetic effort. The incorporation of the DC winding for biasing the armature compensates the reactive power and thus steps up the power factor ($\cos\varphi$).

By controlling the biasing current of the armature, it is possible to vary the amplitude of the angular oscillations. With the coils 18 and 19, 20 and 21 of the armature winding being connected in pairs, counting from the power source 22, in a matched-series fashion, and with the pairs being interconnected in opposition, the electromotive force (EMF) developed at the terminals of the armature winding equals zero. In the absence of semiconductor rectifiers are included in its structure, the manufacturing cost of the herein disclosed oscillation motor is much lower, whereas its reliability characteristics are much higher.

The oscillating electrical motors, considered as drivers, differ from other electrical machines by temporal properties of mechanical movement. In these motors the torque periodically changes in direction and magnitude.

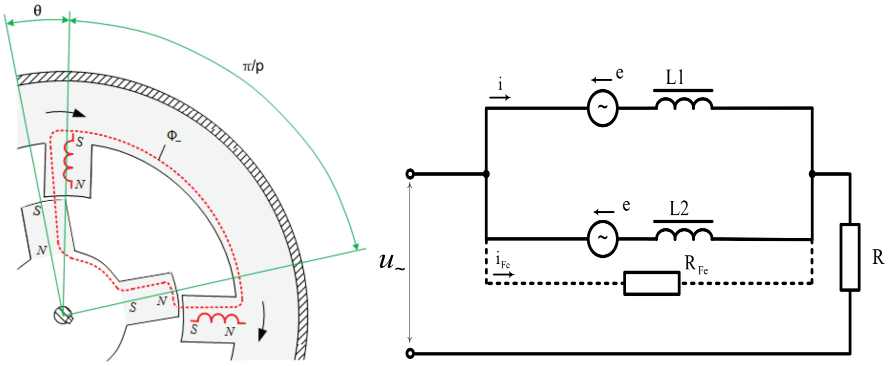

Fig. 3. Electrical substitution circuit of the electromagnetic oscillation motor.

Fig. 3 shows an electrical substitution circuit of the electromagnetic oscillation motor consisting of two identical parallel shafts. Equation for the voltage on the AC winding

$$U = iR + e\,,\ V, \tag{1}$$

where $e = e' + e''$ and $e' = \frac{d\psi}{dt}$ – transformation EMF, and $e'' = \frac{d\psi}{dS}$ is the feedback EMF; Ψ – magnetic linkage, *Wb*; S – working area of the air gap, m^2; the active resistances of the parallel branches R, *Ohm*, are equal to each other.

Magnetic flux linkage of the exciting coil [10]

$$\Phi = iL(\Theta) + \sum\nolimits_{\mu=1}^{n} i_\mu M_\mu + \psi\cos p\Theta\,,\ Wb \tag{2}$$

where i is the current of the parallel path of the motor winding, *A*; M_μ is the mutual inductance, *H*; Θ - the angle of the torsion from the initial state, *Rad*. Considering that a magnetic circuit is saturated with magnetization when a current passes through one parallel path and the other path is no saturated, it is fair to assume that these magnetic systems will have no magnetic interconnection, and the mutual inductance M_μ will be equal to zero.

The equation for torque can be derived from the winding power balance expression

$$ui = Ri^2 + \frac{dW}{dt} + m\frac{d\Theta}{dt}\,,\ W\,, \tag{3}$$

where ui is the consumed energy, Ri^2 is the *electric power loss*, *W*, dW/dt is the change in magnetic field energy over time, and $md\Theta/dt$ is the mechanical energy, *N*. Because the energy of the magnetic field

$$W = \frac{Li^2}{2}\,,\ J, \tag{4}$$

then if we put equation (4) in the expression (1) for the supply voltage *u*, we get:

$$i\frac{d\Phi}{dt} = \frac{dW}{dt} + \frac{md\Theta}{dt}\,, \tag{5}$$

from which we receive for the torque

$$m = i\frac{d\Phi}{d\Theta} - \frac{dW}{d\Theta}\ , Nm, \tag{6}$$

but if we put expression (2) in the equation (6) for the magnetic flux linkage and the expression (4) for magnetic energy, we get:

$$m = i\frac{d\left(iL\right)}{d\Theta} + i\Phi\frac{d\cos\Theta}{d\Theta} - \frac{d\left(i^2L\right)}{2d\Theta} = i^2\frac{dL}{d\Theta} - pi\Phi\sin p\Theta - \frac{i^2dL}{2d\Theta} + iL\frac{di}{d\Theta}. \tag{7}$$

We can neglect the second and fourth terms of the right side hand in equation (7), and then we get:

$$m = \frac{1}{2}i^2\frac{dL}{d\Theta} - pi\Phi\sin p\Theta\,, \tag{8}$$

and given equation (3)

$$m = \frac{1}{2}i^2L\cos\Theta \text{ - } pi\Phi\sin p\Theta. \tag{9}$$

The torque of the electromagnetic oscillation motor is included in the well-known equation of motion:

$$m = J\frac{d^2\Theta}{dt^2} + M_r\left(\frac{d^2\Theta}{dt^2}, \frac{d\Theta}{dt}, \Theta, t\right) + D\frac{d\Theta}{dt}\ , \tag{10}$$

where J is the modified to motor shaft moment of inertia, kgm^2, and the damping factor D is determined by mechanical (springs) and electrical (eddy currents) damping. The moment of resistance M_r consists of the load moment M_l and frictional moment M_0 inside and outside the motor. The instantaneous angular velocity of rotation of the groove must be taken into account here ω .

Conclusions

The research presented in this paper showed, that there are various drives of periodical movement used in modern transport devices and agricultural machines and can be considered as the advanced and well promising field of application of the oscillating motors.

The analysis of specific features of the proposed oscillating electromagnetic oscillating motor, consisting of two moving parts (stator and armature), interconnected centrically, enables to draw the following conclusions:

An electromagnetic motor with angular armature oscillations has been created, while the design of the stator and the location of the coils increase the efficiency and power factor, and provide the ability to control armature oscillations.

The properties of an oscillation motor consisting of stator and armature as well as the operating modes of such motor can be quantitative evaluated by the power factor and by the mechanical resistance of load.

It should be noted that the presented principle of structure of the oscillating rotary electromagnetic oscillation motor can be used in various devices.

ელექტრომექანიკა

ასიმეტრიულსტატორიანი ელექტრომაგნიტური კუთხით რხევადი ძრავის თეორიული პრინციპები

ა. დიდებულიძე* და გ. ჯავახიშვილი**

**აკადემიის წევრი, საქართველოს აგრარული უნივერსიტეტი, აგრარული და საბუნებისმეტყველო მეცნიერებების სკოლა, თბილისი, საქართველო*
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ნაშრომში აღწერილია საქართველოს აგრარულ უნივერსიტეტში დამუშავებული ელექტრომაგნიტური კუთხით რხევადი ძრავის მუშაობის რეჟიმები. ძრავა მოიცავს სიმეტრიულ ოთხპოლუსიან როტორს მუდმივი დენის გრაგნილით და არასიმეტრიულ, ასევე ოთხპოლუსიან სტატორს ცვლადი დენის გრაგნილით. ძრავის რხევების მაქსიმალური ამპლიტუდა რეგულირდება იმისდა მიხედვით, თუ ცენტრიდან რა მანძილზე ფიქსირდება მუშა ორგანო, ხოლო კუთხური ამპლიტუდა შემოიფარგლება 14 გრადუსით. ამ კონსტრუქციაში არაა საჭირო სტატორსა და როტორს შორის ზუსტი საჰაერო ღრეჩოს შენარჩუნება. ძრავა განკუთვნილია სოფლის მეურნეობასა და მრეწველობაში მკვებავების, ტრანსპორტირების, დამხარისხებლების ამძრავად გამოყენებისთვის და აგრეთვე სხვა მიზნებისთვის. კონსტრუქციის სიახლე დაცულია საბჭოთა კავშირის საავტორო მოწმობით, აშშ-ს, კანადის, ინდოეთის, დიდი ბრიტანეთის, გერმანიის, საფრანგეთის, ჩეხეთის, ბულგარეთის, ავსტრალიის, ბრაზილიისა და ფინეთის პატენტებით, საცდელი ნიმუშები დამზადდა ცხინვალის ქარხანა „ელექტროვიბრომანქანა“-ში და ექსპონირებული იყო მოსკოვის, ლაიპციგის, ბუდაპეშტისა და ბუქარესტის გამოფენებზე.

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