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Mathematical Description of the Construction Principles of Electromagnetic Mechatronic Modules of Intelligent Robots

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Abstract**: *The article is devoted to the mathematical description of the principles of construction of electromagnetic mechatronic modules for the linear motion of intelligent robots. Structural schemes and mathematical descriptions of the traction characteristics of various electromagnetic mechatronic modules of linear motion, oriented for use in the manipulation systems of intelligent robots, are considered. The features of many mechatronic modules are determined. A structural diagram of the developed single-axis electromagnetic mechatronic module, the principle of its operation and distinctive features are given.***

Keywords**: *mechatronic module, intelligent robot, electromagnet, motion module, traction characteristics, moving part.***

I. INTRODUCTION

Currently, mechatronics is an extremely dynamically developing area of modern science, engineering and technology. The main task of mechatronic modules is to create manipulative systems of intelligent robots that have qualitatively new functions and properties.

The article is devoted to the mathematical description of the construction principles of electromagnetic mechatronic motion modules of intelligent robots.

II. LITERATURE REVIEW

Electromagnetic mechatronic linear motion modules differ from other types of electromagnetic mechatronic linear motion modules in a wide variety of designs, type of traction characteristics, as well as the range of generated forces and movements. At the same time, in the literature they are classified, as a rule, only by design features: flat or cylindrical, long-running or short-running, with a retractable or external transversely moving armature, etc. With this approach, when the properties of motors as a converter are not taken into account energy, possible errors in choosing its design for a particular mechanism, and as a result, far from the optimal operating mode of the drive.

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III. RESEARCH METHODOLOGY

The traction force of a single-winding unsaturated electromagnetic mechatronic module of linear motion is described by the expression

$$F = \frac{1}{2}\frac{dL}{dx}I^2 \qquad (1)$$

If we neglect the magnetic resistance of the steel parts of the magnetic circuit and the stray gap (if any), then the inductance of the winding is determined only by the conductivity of the working gap G_δ and the number of turns ω involved in creating the flux $L = w^2 G_\delta$.

Under the working gap, we mean the gap, the geometry of which changes when moving the moving parts of the electromagnetic mechatronic linear motion module. In unsaturated engines, changes in the geometry of the working gap, as a rule, determine the change in the energy of the magnetic field, and therefore, traction and mechanical work. Considering that $G_\delta = \mu S / \delta$, where μ, S, δ – are the magnetic permeability, the area and the length of the working gap, respectively, for the inductance will take the form

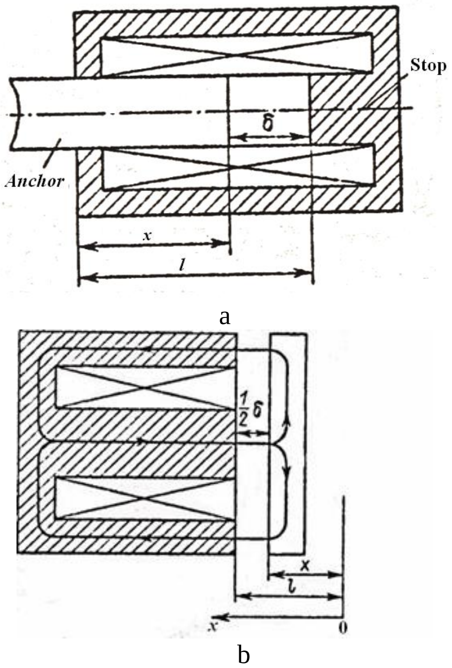
$$L = \mu S\, w^2/\delta \qquad (2)$$

IV. ANALYSIS AND RESULTS

Since the inductance according to (2) depends on four parameters, theoretical are possible 15 types of modules, corresponding to a change in one or more parameters, a change in the price determines the pulling force F; $\delta, S, w, \mu, S\delta, \delta w, \delta\mu, \delta S w, S\delta\mu, \delta w\mu, \delta S w\mu$. However, not all of them have practical implementation. Briefly consider some types of electromagnetic mechatronic modules of linear motion.

Two design options for electromagnetic mechatronic modules of linear motion of the δ-type are shown in Figure.

1.



a

b

Figure 1. Structural diagrams of δ-type modules.

For modules of this type, the inductance of the winding changes due to a change in the length of the working gap δ:

$$\frac{dL}{dx} = \mu S w^2 \frac{d(1/\delta)}{dx}, \qquad (3)$$

and therefore, the traction force F will depend on how the gap length changes with x.

For the structures shown in Fig. 1 a, the gap length δ is related to the x coordinate characterizing the position of the armature, by the relation $\delta = 1 - x$. Substituting this expression into (3), we obtain

$$\frac{dL}{dx} = \mu S w^2 \frac{1}{(l - x)^2} \qquad (4)$$

For a design having a working gap shown in Fig. 1, b. $x = l - \delta/2$, or $\delta = 2(l - x)$. In this case

$$\frac{dL}{dx} = \mu S w^2 \frac{1}{2(l - x)^2} \qquad (5)$$

It can be seen from expressions (4) and (5) that, at constant current, the force will increase with increasing x. The type of traction characteristics of the δ – type is shown in Fig. 2.

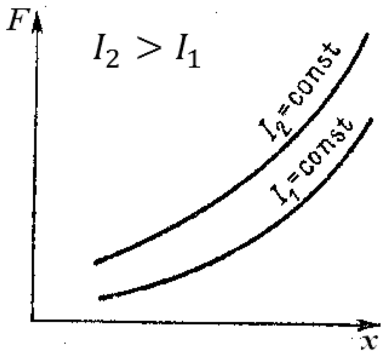


Figure 2. Traction characteristics of a δ –type module.

Examples of the design of electromagnetic mechatronic modules of linear motion of the S – type are shown in Figure 3.

The pulling force of these electromagnetic mechatronic linear motion modules depends on the nature of the change in the working gap area S when x changes:

$$\frac{dL}{dx} = \frac{\mu w^2}{\delta} \frac{dS}{dx}.$$

Area S is proportional to x, i.e. $S = kx$, where k is the coefficient of proportionality, therefore

$$\frac{dL}{dx} = \frac{\mu w^2}{\delta} k. \qquad (6)$$

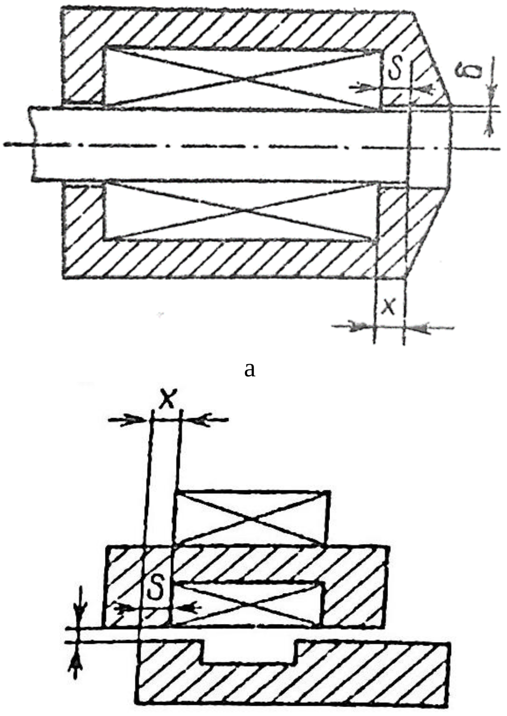


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Figure. 3. Structural diagram of an S – type module.

From (6) and (1) we find

$$F = \frac{1}{2} \frac{\mu w^2}{\delta} k I^2.$$

From the learned expression it follows that the traction characteristic of the S – electromagnetic mechatronic module of linear motion should be a horizontal line. In fact, the characteristics of the traction characteristics of electromagnetic mechatronic modules of linear motion of the S – type have a negative slope (Fig. 4).

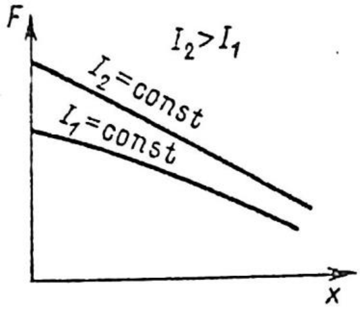


Figure 4. Traction characteristic of a δ – type module.

In electromagnetic mechatronic modules of linear motion of the $S\delta$ – type, the traction force is determined by the sum of two components:

$$\frac{dL}{dx}=\frac{\mu w^2}{\delta}\frac{dS}{dx}+\mu w^2 S\frac{\partial(1/\delta)}{dx}. \qquad (7)$$

The type of traction characteristic depends on which of the components has a greater influence: if the S – component, then the traction characteristic is closer in appearance to the characteristic of the S – type electromagnetic mechatronic module of linear motion (Fig. 5-curve 1), if the δ – component, then the traction the characteristic approaches the electromagnetic characteristic of the mechatronic module of linear motion of the δ – type (curve 2).

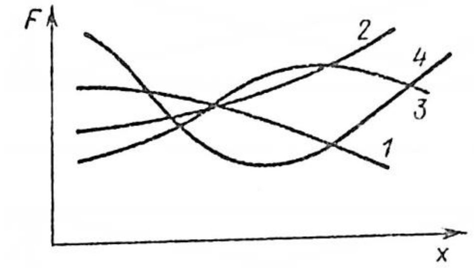
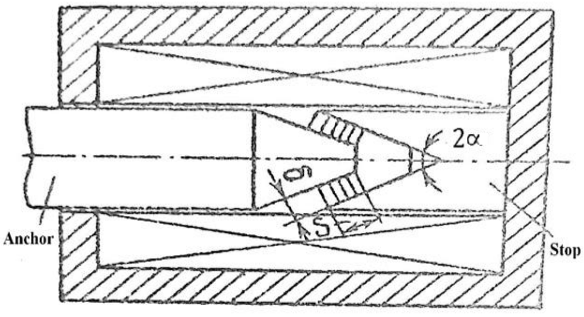


Figure. 5. Traction characteristic of S – type module.

Within the working stroke, the ratio in the traction force of the S – and δ – component can be different. So if, at small x, the δ – component has more weight in the traction force, and at large x – S –, the component, then the traction characteristic is convex (curve 3). And vice versa, if the S-component prevails at small x, and the S – component prevails at large x, then such an electromagnetic mechatronic linear motion module has a concave characteristic (curve 4).

In practice, the ratio of the S – and δ – components of the force can be changed by choosing the appropriate configuration of the elements of the magnetic system, which allows the formation of various traction characteristics. So, for example, in electromagnetic mechatronic linear motion modules shown in Fig. 6, this is achieved by changing the angle of taper α of the armature and foot.

At small angles α, the S – component will prevail in force, and as the angle α increases, the δ – component will increase and at $\alpha = 90°$ the electromagnetic mechatronic modules of linear motion of the $S\delta$ type, shown in Figure 6. a, will turn into an electromagnetic mechatronic module of linear δ – type movements.



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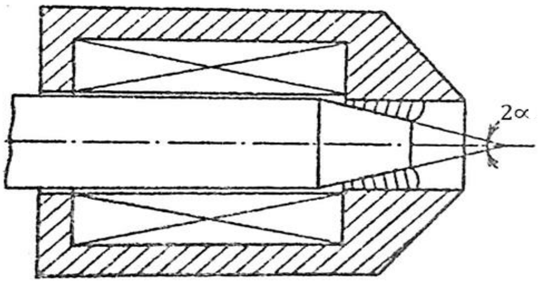

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Figure 6. Structural diagram of the module $S\delta$ – type.

In electromagnetic mechatronic modules of w – type linear motion, the number of turns of the winding is constant and does not depend on x, but when moving, the number of turns covered by the main stream changes. So, in the design shown in Figure 7, one can neglect the scattering fluxes and assume that the main flow passes through an extended section at the end of the armature. Obviously, in this case, the flux linkage and inductance will be proportional to the square of the number of turns covered by this flux. Therefore, the derivative of the displacement inductance will be determined by the expression

$$\frac{dL}{dx}=\frac{\mu S}{\delta}\frac{d(w^2)}{d\alpha}. \qquad (8)$$

With a uniform distribution of turns in the winding window, the number of turns covered by the main stream is proportional to the immersion depth of the armature: $w = c\alpha$, where $c = const$ is the proportionality coefficient, therefore

$$\frac{dL}{dx}=\frac{\mu S}{\delta}2c^2\alpha. \qquad (9)$$

From the expression (9) it follows that the traction characteristic of a w-type engine should beat close to a straight line having a positive slope Figure 8.

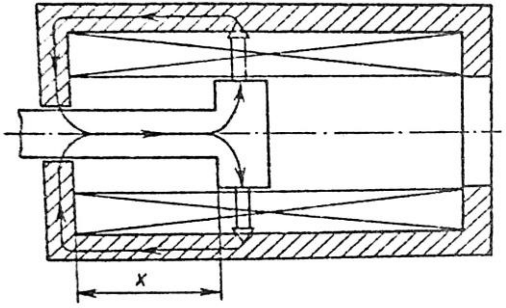


Figure 7. Design of a w – type module.

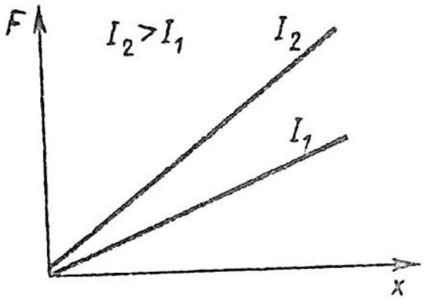


Figure 8. Traction characteristic of a w – type module.

Since in this case the traction force is created by the scattering flows between the side and end surfaces of the armature and the casing, then under the working gap should be understood all the spaces occupied by these flows. Obviously, as the armature dips, the surface of the part of the armature introduced into the winding increases (hence, the working gap area S), as well as the number of turns covered by the flow exiting the armature.

For the electromagnetic mechatronic module of linear motion of the $wS-$ type, it is true:

$$\frac{dL}{dx} = \frac{\mu w^2}{\delta}\frac{\partial S}{\partial x} + \frac{\mu S}{\delta}\frac{\partial (w^2)}{\partial x} \qquad (10)$$

Traction characteristics are shown in Figure 10.

Electromagnetic mechatronic modules of linear motion of the $\mu -$ type or piezomagnetic modules, work by changing the magnetic permeability of the magnetostrictive material. A design variant of such electromagnetic mechatronic linear motion modules is shown in Figure 11.

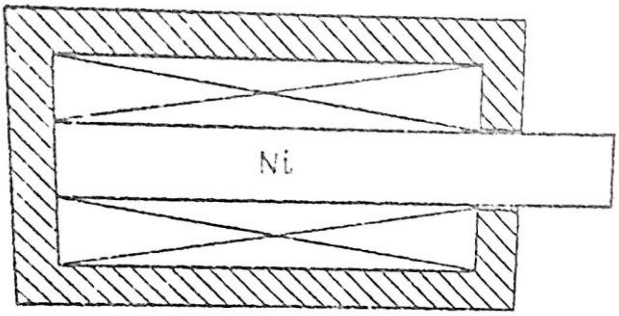


Figure 11. The design of the $\mu -$ type module.

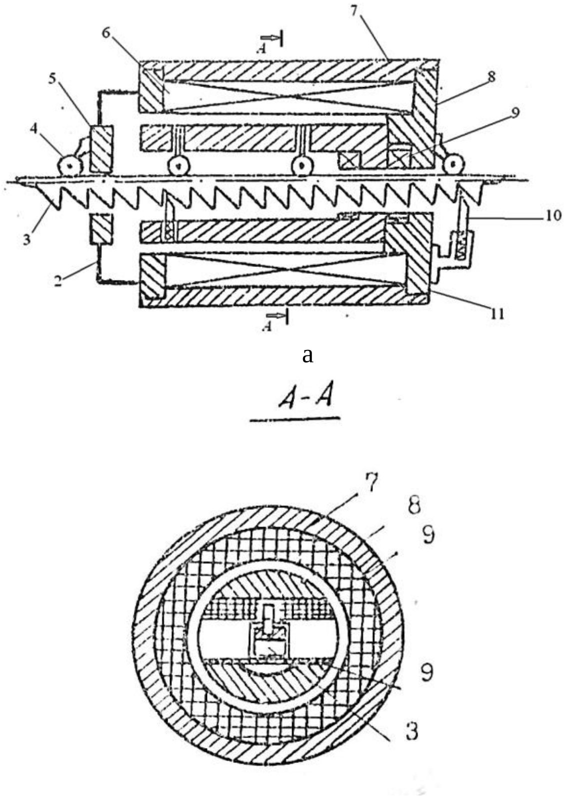
In this case, the working gap is understood as the space occupied by magnetostrictive material.

The analysis shows that electromagnetic mechatronic modules of linear motion of $\delta -$, $S -$, $S\delta -$, $wS -$ and $\mu -$ types are currently widely used.

The presented classification is convenient in that it allows for each type of electromagnetic mechatronic linear motion modules to identify the main factors that determine the magnitude and nature of the change in traction force depending on the position of the movable element. They must be taken into account when choosing the type of electromagnetic mechatronic linear motion modules for a particular intelligent robot mechanism.

The advantage of the developed electromagnetic mechatronic modules of linear motion is the absence of auxiliary elements that convert rotational motion into translational, significantly complicating the design; the possibility of obtaining a large stroke with fixed positions; high reliability, small overall dimensions and weight.

The electromagnetic mechatronic module of linear motion (Figure 12) consists of external and internal electromagnets, which are cylindrical magnetic circuits.



a

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Figure 12. Electromagnetic mechatronic module.

1-pass flange; 2-non-magnetic connector; 3 gear rack; 4-rollers; 5-internal anchor; 6.9-coils; 7.8-cylinder magnetic cores; 10-clips 11-stop flange.

The external electromagnet also includes a passage flange and a coil, and the internal one is made in the form of a glass with a vertical cut to accommodate the coil and anchor with holes in the centers. A non-magnetic connector, the magnetic circuit is rigidly connected to the passage flange. The gear rack passes through the holes in the anchor, the cylindrical magnetic circuit, the thrust flange and serves to fix the electromagnets, and also directs the movement of the electromagnets on the rollers.

When you turn on the coil of an external electromagnet (internal disconnected), the cylindrical magnetic circuits of the internal electromagnet are attracted to the stop flange. At this time, the external electromagnet is fixed motionless by means of a clamp and a gear rack. When the external electromagnet is turned off and the internal coil is turned on, the anchor is attracted to the magnetic circuit and will perform a rectilinear motion together with the external electromagnet. When alternating such cycles, the electromagnetic mechatronic modules of linear motion performs unlimited rectilinear motion with fixed positions.

V. CONCLUSION

Thus, the analysis of mathematical descriptions of the structures of electromagnetic mechatronic modules of the linear motion of the manipulation systems of intelligent robots has shown that the most promising are the modules of $\delta -, S -, S\delta -, wS -$ and $\mu -$ types.

For electromagnetic mechatronic modules of linear motion as a source of force, the main value is the armature travel and traction characteristics, since they determine the possibility of implementing the required law of motion.

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