

МНОГОВЫХОДНЫЕ ЭЛЕКТРОПРИВОДЫ НА БАЗЕ ЭЛЕКТРОМАГНИТНЫХ УСТРОЙСТВ С ОРГАНАМИ СХВАТА

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Аннотация: В статье рассматривается новый класс электрических приводов, предназначенных для роботов и робототехнических систем, — многовыходные электрические приводы. Представлены их структурные схемы, принципы построения и функционирования, а также классификация по совокупности основных признаков. Показано, что применение многовыходных электрических приводов в конструкциях роботов позволяет существенно упростить их компоновку, а также снизить массу и габаритные размеры.

Материалы статьи могут быть полезны исследователям, аспирантам и докторантам, выполняющим научные исследования в области робототехники и электрических приводов.

Ключевые слова: многовыходной электропривод, электромагнитные устройства, органы схвата, исполнительные приводы роботов, классификационный граф, устройство управления, постоянные магниты, линейные и угловые перемещения, обратная связь

USHLASH ORGANLI ELEKTROMAGNIT QURILMALAR ASOSIDAGI KO'P CHIQUISHLI ELEKTR YURITMALAR

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Annotatsiya: Mazkur maqolada robotlar va robototexnika tizimlari uchun mo'ljallangan elektr yuritmalarining yangi sinfi — ko'p chiqishli elektr yuritmalar tahlil qilindi. Maqolada ularning struktura sxemalari, ishlash va qurilish prinsiplari, shuningdek asosiy belgilar majmuasiga ko'ra klassifikatsiyasi batafsil yoritilgan. Robotlar konstruktsiyalarida ko'p chiqishli elektr yuritmalardan foydalanish robotlarning kompozitsiyasini soddalashtirishga, shu bilan birga massa va gabarit o'lchamlarini kamaytirishga imkon beradi. Mazkur maqola materiallari robototexnika va elektr yuritmalar sohasida ilmiy tadqiqotlar olib borayotgan tadqiqotchilar, aspirantlar va doktorantlar uchun foydali bo'lishi mumkin.

Kalit so'zlar: ko'p chiqishli elektr yuritma, elektromagnit qurilmalar, ushlar organlari, robot aktuatori, klassifikatsiya grafigi, boshqaruv qurilmasi, doimiy magnitlar, chiziqli va burchakli harakat, qayta aloqa

MULTI-OUTPUT ELECTRIC DRIVES BASED ON ELECTROMAGNETIC DEVICES WITH GRIPPING ELEMENTS

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Abstract: This article presents a new class of electric drives for robots and robotic systems, namely multi-output electric drives. The study provides a detailed analysis of their structural schemes, operating principles, and classification based on multiple defining characteristics. The application of multi-output electric drives in robotic structures enables significant simplification of robot design and contributes to the reduction of mass and overall dimensions. This scientific article may be of interest and usefulness to researchers and doctoral students engaged in scientific investigations in the fields of robotics and electric drive systems.

Keywords: multi-output electric drive, electromagnetic devices, gripping elements, robot actuators, classification graph, control device, permanent magnets, linear and angular motion, feedback

INTRODUCTION

In recent years, the development of robotic and automated systems has created a growing demand for compact, efficient, and highly functional actuation solutions. Classical robot drive architectures typically rely on a set of individual actuators, each dedicated to a single joint or control element. Although this approach is widely adopted, it often results in increased mass, larger overall dimensions, more complex mechanical layouts, and higher installation and maintenance costs. These drawbacks become especially critical in multi-axis systems, where the number of actuators and transmission elements grows rapidly and limits both design flexibility and energy efficiency.

One promising direction for overcoming these limitations is the concept of **multi-output electric drives**, which are capable of generating several independent output motions from a unified electromechanical source. By producing multiple controlled displacements—linear, angular, or combined—within a single module, multi-output drives can significantly simplify robot configurations, reduce the number of separate actuators, and decrease the amount of auxiliary mechanical components such as gear trains, couplings, and mounting assemblies. As a result, robot systems can become lighter, more compact, and easier to integrate into constrained industrial environments.

Among the various multi-output actuation concepts, **electromagnetic devices equipped with gripping elements** represent a particularly effective solution. In such drives, the reciprocating motion of an electromagnet armature is converted into multiple output movements through independently controlled gripping elements and coupling mechanisms. The motion conversion is defined by the timing laws of control signals and can be implemented as continuous or stepwise displacement, which makes the approach naturally compatible with microprocessor-based control systems. Moreover, the use of electromagnetic and permanent-magnet components provides opportunities to enhance traction performance, increase specific force, and improve functional reliability in repeated short-time duty cycles typical for robotic applications.

Despite the practical advantages of this approach, the design space of multi-output electromagnetic drives is broad, and a systematic framework is required to compare variants, select rational structures, and predict performance characteristics. Therefore, this paper focuses on the principles of constructing multi-output electric drives based on electromagnetic devices with gripping elements. The study presents a generalized structural scheme of such drives, explains their operating principle, and proposes a classification method using a **classification graph** based on groups of key features. The presented framework supports the development and selection of

drive variants aimed at simplifying robotic layouts while reducing mass and overall dimensions without sacrificing functional motion capabilities and control requirements.

Recently, multi-output electric drives have been widely used as actuators in robots and robotic systems. This article presents the principles of their design, as well as a classification of multi-output electric drives according to various criteria.

MATERIALS AND METHODS

The design principle of multi-output electromagnetic drives is based on equipping the movable part (armature) of an electromagnet with several clutches, which are controlled independently by the control device, as shown in Fig. 1.

The generalized structural diagram of multi-output electromagnetic drives (MED) includes a control device (CD), a block of electromagnets and permanent magnets (EM & PM), gripping elements (GE), and mounting and coupling elements (MCE).

Electromagnets and permanent magnets serve to convert input electrical signals I_e into reciprocating mechanical displacements, while the gripping elements and coupling elements transfer the armature motion to the control elements of the automatic control system (ACS).

The number of gripping elements n corresponds to the number of control elements of the ACS. The functions converting X into X_1, X_2, \dots, X_n are determined by the temporal laws of the signals $I_e, I_1, I_2, \dots, I_n$. As a result, the reciprocating displacement X at the output of the EM & PM block is transformed into a set of linear (X_1, X_2, \dots, X_n) and angular ($\alpha_{1+1}, \alpha_{1+2}, \dots, \alpha_n$) displacements of the movable parts of the ACS control elements, which are coupled by the gripping and/or coupling elements.

In Fig. 1, thin arrows indicate signal connections coming from sensors to the CD and from the CD to the EM & PM block and GE. Thick arrows denote mechanical and energy connections.

RESULTS

Based on the generalized structural diagram, various classes of MED design variants can be developed. Possible classes of MED are represented by all possible paths on the classification graph shown in Fig. 2.

For the construction of the classification graph, the following groups of features were selected: a) features common to MED; b) features characterizing the electromagnet and gripping elements; c) features representing the mounting and coupling elements.

Some of the features used coincide with the classification features of electromagnets [1] and robot grippers [2].

Common features include: the type of output movement of the working element, the nature of change in the output value, movement speed, output force magnitude, presence of a damper, type of control, nature of control signals, presence of feedback, number of electromagnets, and presence of permanent magnets.

The output displacements of developed MED can be linear, angular, or combined linear-angular. These displacements can be continuous or discrete. An example of continuous devices is conventional DC rotary motors. In recent years, actuators with discrete motion have developed rapidly [3], which are easily integrated with microprocessor control devices. The structural diagram of such devices is open-loop. Sequences of single pulses at the input of these devices are converted into elementary movement steps.

The movement speed of MED largely depends on the actuation time of the used electromagnets.

Fast-acting electromagnets have a response time $t_{cp} \leq 50$ ms, whereas slow-acting electromagnets have a response time $t_{cp} \geq 250$ ms.

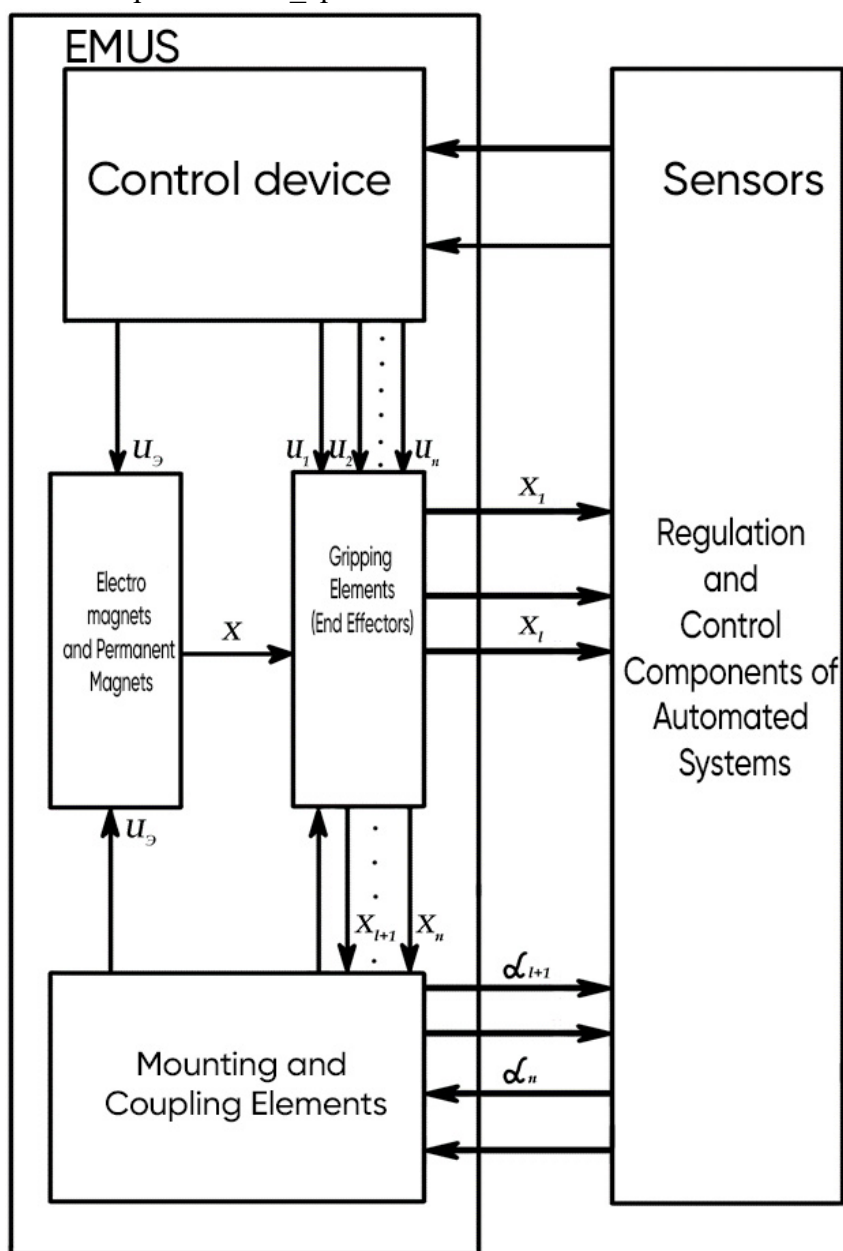


Fig. 1. General Structural Diagram of EMUS

Depending on the output force, MEDs are divided into EMUS with low, medium, and high force. The force developed by the device depends on the design of the electromagnets. Pull-type electromagnets are used for low- and medium-force EMUS, while disc-shaped and combined electromagnet designs are used to achieve high forces. In the MEDs developed by the author [4, 5, 6], electromagnets with U-shaped yokes and armatures were used, which allowed achieving high specific forces (20–40 N/kg).

The control device of MED can be either rigidly programmed or continuously externally controlled. In the first case, MED operates according to a fixed algorithm embedded in the control device. In the second case, MED operates depending on the control signals continuously received from an external control device. These control signals can be continuous, impulsive, or pulse-width-modulated. In the case of continuous control signals, MED converts them into digital form. The control device includes a pulse shaper, pulse distributor, and power amplifier.

To expand the control range, MEDs use feedback, where the output signal is compared with a set value. Optical and inductive linear displacement sensors are used as feedback sensors.

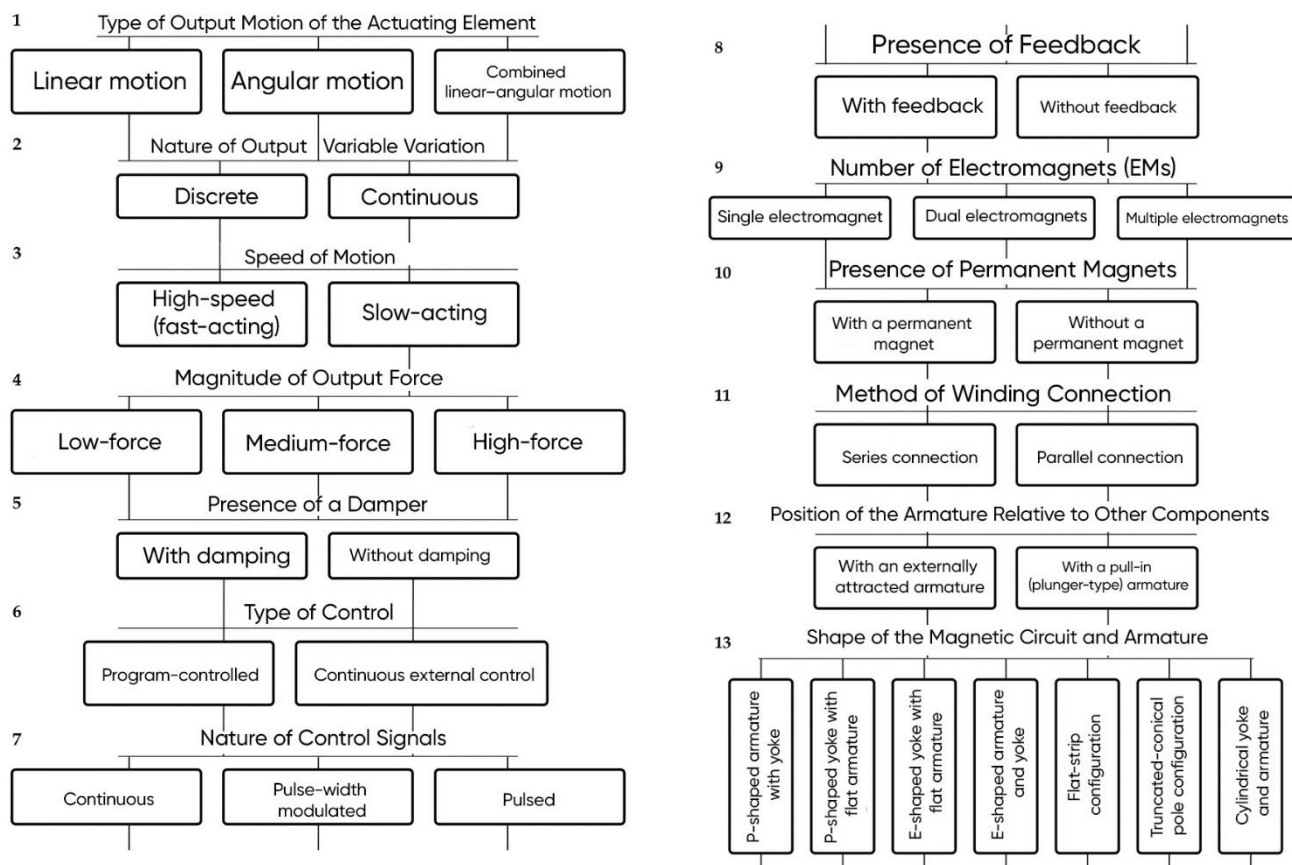
MEDs can also operate successfully in an open-loop system without feedback. In this case, each processed movement step is controlled. MED can be built with a single, two, or multiple electromagnets. The number of electromagnets determines the response speed, step size, and areas of application. Fast-acting MEDs use four or more electromagnets.

To simplify the design and increase traction force, the movable armatures in MED can be made from permanent magnets.

Classification features of MEDs that characterize the electromagnet design include the method of coil connection, the position of the armature relative to other parts, and the shapes of the magnetic circuits and armatures.

Electromagnets can have series-connected or parallel-connected coils. Depending on the position of the armature relative to other parts, electromagnets can have either an external attracting armature or a retractable armature. The magnetic circuit and armature shapes of attracting-armature electromagnets can be U-shaped (valve-type electromagnets), III-shaped, or cylindrical (disc electromagnets). Retractable-armature electromagnets can have flat poles or truncated-conical poles. In addition, there are combined electromagnets (electromagnets with shunts).

Classification features of MEDs that characterize the gripping elements include: type of gripping element, arrangement of gripping elements, method of holding the working part, type of gripper, kinematics of the connection between the gripper and the held object, and the presence of an electromagnet in the gripper assembly.



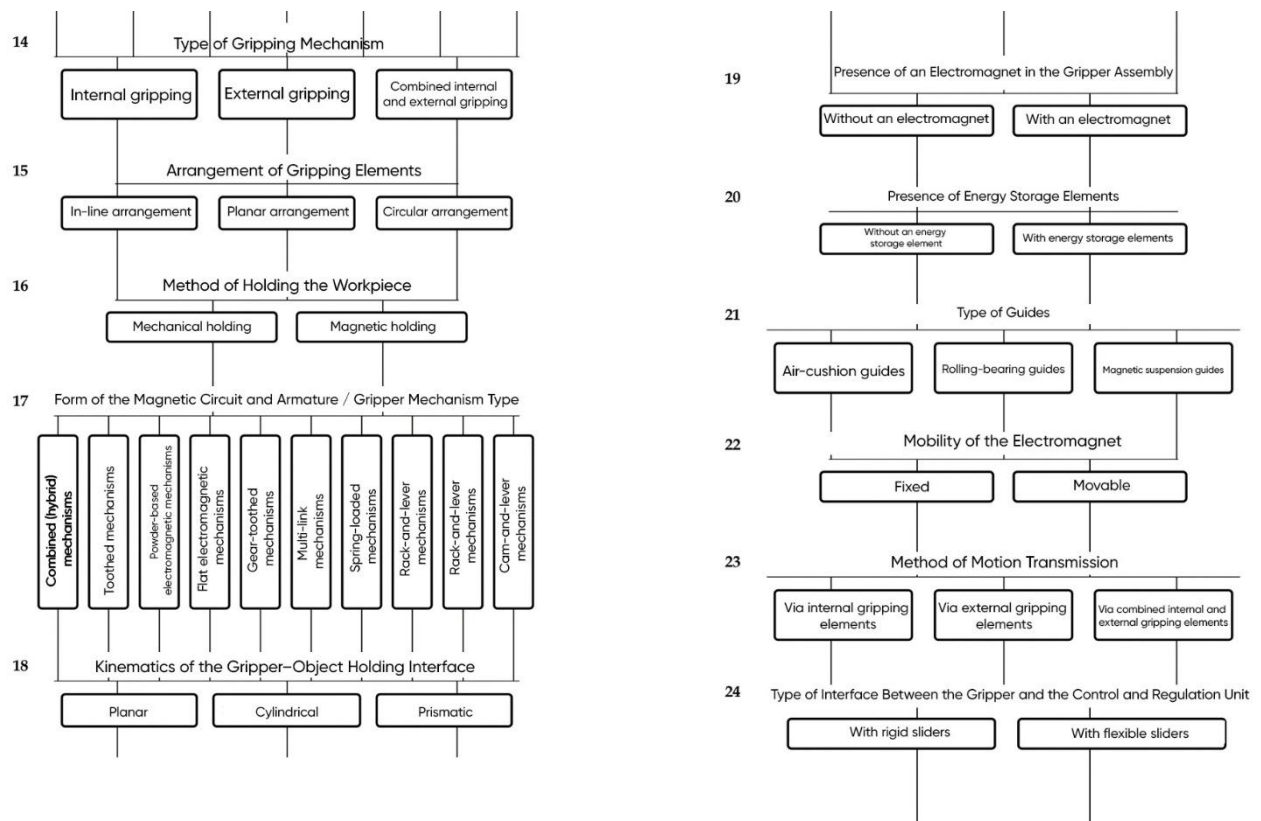


Fig. 2. Classification Graph of Multi-Output Electric Drives

DISCUSSION

When designing gripping devices, the shape and properties of the object to be grasped, the conditions of the technological process, and the features of the applied tooling are taken into account, which explains the diversity of existing gripping elements. The most important criteria when evaluating the choice of gripping elements are adaptability to the shape of the object (rod), grip accuracy, and gripping force.

Based on the type of gripping elements, MEDs can have internal grips, external grips, or both internal and external grips. External gripping elements can be arranged in a line, on a plane, or along a circumference.

Factors related to the object being grasped include the object's shape, mass, mechanical properties, dimensional ratios, and the physical and mechanical properties of its materials. The mass of the object determines the required gripping force, i.e., lifting capacity, and allows selection of the drive type and the structural base of the gripping element (GE). The surface condition of the object determines the material of the jaws used in the GE. The shape of the object and the ratio of its dimensions also influence the choice of GE design.

The characteristic “type of grip” or “structural base” refers to the classification of GEs according to their operating principle and structural implementation. The specifics of the GE operation and its interaction with the object, as well as the object properties and operational requirements, are most clearly revealed by analyzing differences in the GE design, taking into account the method of object retention.

By the method of object retention, GEs are divided into mechanical and magnetic. Mechanical GEs are further divided into lever-type, crank-lever-type, rack-lever-type, spring-type,

multi-link, and toothed. The main parameters of mechanical GEs are the force transmission coefficient K_p and efficiency. Magnetic GEs are used for grasping objects made of magnetic materials. The gripping force F_y is determined by the material properties B and the contact surface S as:

$F_y = B \cdot 10^4 \cdot 2S$ Magnetic GEs can be flat-electromagnetic, powder-electromagnetic, toothed, or combined types. A very important factor related to the process of grasping and holding an object is the kinematics of the connection between the GE and the held object. Based on this criterion, GEs can be flat, cylindrical, or prismatic. A drive with a GE can include an electromagnet or not.

To simplify the design of MED, some electromagnets are replaced with mechanical accumulators (return springs). In this case, the armatures of the electromagnets are returned to their initial positions using the return springs. For the classification of MEDs by features characterizing the properties of the mounting and coupling elements (MCE), the following features are used: type of guides, mobility of electromagnets, type of motion transmission, and type of coupling between the gripper and the control/regulation elements. The movable parts of MED can move on an air cushion, roller bearings, or magnetic suspensions. Movement of the EM & PM block is transmitted via internal or external grips. The movement of the movable parts is transferred to the rod (slider) using GEs. Sliders can be made of flexible material. The presented graph serves not only to identify the differences and similarities of various MED variants but also acts as a tool for exploring different design options of MEDs.

CONCLUSION

Multi-output electromagnetic electric drives form a compact actuation concept for robotic systems by equipping an electromagnet armature with multiple independently controlled gripping elements. The generalized structural scheme and classification graph presented in the paper support systematic selection and comparison of drive variants by common features, electromagnet/gripper characteristics, and mounting/coupling solutions. Applying these approaches can simplify robot design and reduce mass and overall dimensions while maintaining the required functional motion outputs.

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