Development Model of the Micro-Actuator Based on a Coreless Motor for Electronic Medical Pipette

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***Abstract*— Medical pipette with electronic control is an important and indispensable modern device. The paper analyzes the importance of the use of regulated electronic medical pipettes in medical and related fields. Modern approaches to the development of their micro-electromechanical actuator are outlined. To improve the design and control system of the electronic medical pipette, it is necessary to develop an appropriate mathematical model, which requires the parameters of the micromotor, most of which are missing from the manufacturer's descriptions. At the first stage, a model for a 610 series coreless motor (6 mm - diameter, 10 mm - length) for supply voltage (3.0 - 3.7V) was developed and researched using a specialized package for designing and simulating electromechanical systems JMAG Designer. With the help of the model in JMAG Designer, some of the necessary parameters of the coreless motor are determined. At the second stage, an algorithm was developed and a series of experimental studies of the 610 series coreless motor was practically carried out in order to obtain all the necessary parameters for the further development of a high-precision model. Based on the experimental results, the transfer function was obtained, a high-precision model of the coreless motor was developed in MATLAB, and the corresponding current and speed transition processes were obtained, which confirmed the accuracy of the obtained model. The transition process of the current on the model in case supplied with a voltage of 3.7V coincided at the operating point with an error of 8.1%, the speed of rotation of the motor coincided with an error of 5.7%. A model of an electric microdrive based on a coreless motor for an regulated electronic medical pipette was developed and its operation was investigated.**

Keywords— medical pipette, coreless motor, identification, dosage, mathematical model

I. Introduction

The modern development of microelectromechanical systems (MEMS) in the context of improvement and development of the element base, executive mechanisms, means of their design and research, significantly expands the fields of science and technology of their application. One of the topical and promising fields of MEMS application is medicine and related fields: molecular biology, analytical chemistry, as well as in many medical tests and laboratory research. An important component of the medical field is the realization of laboratory research, registration and analysis of fluid manipulation data [1]. Dosing of liquids should be accurate, precise, high-speed, efficient, and convenient. To perform such tasks, medical electronic pipettes are used [2].

A pipette [2] is a laboratory instrument used to accurately measure and transfer small volumes of liquid. In general, pipettes can be classified into two main types according to the operation mechanism: manual and electronic pipettes. Manual pipettes are controlled by the mechanical force of the user's thumb. Electronic pipettes [3-5] (Fig. 1) contain a micro electric motor powered autonomously from a battery. This micro motor drives the dosing mechanism instead of hand power. Electronic pipettes are equipped with electronic control panels that allow the user to set the desired volume of liquid. When the user presses the operating button, the electric motor drives the piston in a controlled manner to precisely dispense the liquid. Electronic pipettes [3] have a number of advantages over manual ones. They provide better ergonomics, reduce the strain on the user's hand, making them suitable for long dosing tasks. Electronic pipettes provide better dosing accuracy and precision due to electronic motorized control. The electronic mechanism ensures consistent and controlled dosing, reducing possible errors caused by manual force variations. They also often have additional functions and modes and digital displays for measuring volume. However, electronic pipettes tend to be more expensive than manual pipettes because of their additional technology and features.

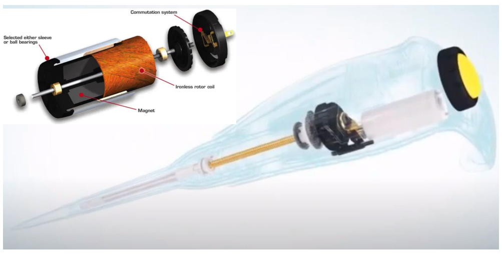

Fig. 1. Coreless micromotor and electronic micropipette

Various micro-electric motors are used for the construction of MEMS electric drives of electronic medical pipettes (EMP): stepper, direct current brushless or coreless [6, 7]. Coreless DC motors are best suited to meet the requirements for EMP operation, with a thin-walled armature design that does not contain iron in the magnetic core. Coreless motors can be used for various medical devices such as pumps, ventilators, surgical tools, scanners and prosthetics. They can offer high reliability, low noise, and precise control for these critical applications. A coreless DC brushed motor (Fig 1.) has high efficiency, no cogging torque, smooth position and speed control, high efficiency, low noise, high torque, low weight, very low rotor inertia, dynamic start-stop operation. Unlike iron-core motors, the rotor consists only of a light, thin-walled material with copper coils wound around it and a shaft. This construction is designed for rapid acceleration.

An electronic pipette with a MEMS actuator is a complex design with a high cost. For the study, improvement and development of new EMP devices, realization field experiments is not an optimal process. This is due to the complex and specific conditions of real experiments in the biochemical and medical fields. Therefore, it is necessary to develop a mathematical model of MEMS based on the coreless DC motor and make its computer simulation. For this purpose, MATLAB Simulink [8] interactive software is used – a tool for simulation and analysis of dynamic systems. It is a block diagram modeling program for designing and modeling based on an analytical mathematical model of the device. In MATLAB Simulink for successful MEMS based on the coreless DC motor simulation, a mathematical model of the coreless DC motor with corresponding parameters is necessary.

Coreless DC motor is a specific type of DC motor [7]. Manufacturers of series coreless DC motors provide only the values of rated voltage, armature resistance, and rated angular speed of the rotor. These data are obviously not enough for the mathematical description and computer modeling of the motor and the construction of the MEMS electric drive of the EMP. Therefore, there is a need to determine the parameters of the coreless DC motor using special software and experimentally. In this work, the JMAG software [9] was used with the purpose to PMSM motor project design calculation. JMAG is a software for modeling, developing and designing electrical devices, for designing such devices as motors, actuators, circuit components and antennas. JMAG uses simulation technology to accurately analyze a wide range of physical phenomena that include complex geometries, various material properties, and heat and structure at the center of electromagnetic fields. In this work, JMAG was used to model the structure, the topology of the stator turns, the properties of the magnet material, and obtain a 3D model of motor. To obtain a complete set of coreless DC motor parameters, experimental studies must be carried out. Therefore, there is a need to model the MEMS electric drive of the EMP. For this, it is necessary to apply a complex approach, which consists in making full-scale experiments of the coreless motor prototype, CAD design in JMAG software, and the actual development of the analytical model of the MEMS electric drive of the EMP in MATLAB and its computer research.

II. Literature review

The development and implementation of MEMS based on the coreless DC motor of the electronic pipet is a complex and specific process due to the field of application of the device. Medical manufacturing companies keep their own developments secret, providing only superficial information.

Application of Coreless motor in MEMS of the EMP is a promising modern solution. For example, in [7] it is shown that the motor without a core has no iron losses and achieves greater efficiency and acceleration. Since electronic pipettes are powered by batteries, the increased efficiency of such a motor allows you to use them on a single charge for longer. For pipetting, a brushed DC motor requires additional components such as gears and encoders to convert rotary motion into linear motion and control the motion of the motor. In [10], the expediency of using a coreless DC motor in low-power equipment, in particular medical and industrial high-precision instruments, is substantiated. The optimization technique "gray wolf optimizer" is applied. This confirms the expediency of determining the reference parameters of the coreless DC motor in MEMS of the EMP and developing a mathematical model of the actuator for the EMP. In [11], the design features of an electronic pipette with a micro electric motor of low power, with multi-purpose capabilities, portable, reliable and easy to operate are presented. This work presents the results of software development based on the MSP430 MCU IAR Embedded Workbench platform. As well as the design of low-power circuit solutions. It is advisable to develop a mathematical model of such a system based on MEMS based on the coreless DC motor for testing and debugging circuit and algorithmic solutions. In [12], the process of integrating electronic pipettes into a general robotic bioscreening system in the field of analytical research was developed. In such specific processes, it is advisable to use electronic pipettes for high-precision work with liquids with different volume ranges (5-200 μl and 50-1000 μl). The main focus [12] is on the hardware and software implementation of connecting electronic pipettes to the control system of high-level technological biochemical processes. A software and hardware implementation approach using a wired connection has been implemented. Structural modifications of automation devices, pipette holders and cable guides were also made. The obtained automation results were compared with the system with manual pipettes. The results obtained by the authors [12] are based on field tests and research. This approach has disadvantages in terms of complexity, high cost, and possibly potential biological hazards. In order to eliminate these shortcomings, it is necessary to develop mathematical and computer models of both the electronic pipette and the executive elements.

In [13], a mathematical model of an electric motor with elements and the actual power supply circuit was developed. To obtain the necessary parameters, appropriate design and engineering calculations were made based on analytical formulas. A computer simulation of the mathematical model was made for comparison with the results of experimental studies. The obtained results show the expediency of creating mathematical and computer models for the study of actuators of different power based on electric motors. After an analytical and calculation approach to solving the problem of determining the necessary parameters of the motor under study, a computer model was developed in [14] and a study of a single-phase collector motor powered by an AC voltage regulator was conducted, based on the design and technical calculation. Computer simulations were performed in MATLAB Simulink with various parameters and settings of the power AC Voltage Controller.

In [15] also presents the results of the design and construction calculation of a small washing machine motor and the determination of the main parameters of an