

Development and program implementation of elements for identification of the electromagnet condition for movable element position control

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Abstract. Developing the experimental design of new electromagnetic constructions types in engineering industry enterprises requires solutions of two major problems: regulator's parameters setup and comprehensive testing of electromagnets. A weber-ampere characteristic as a data source for electromagnet condition identification was selected. Present article focuses on development and implementation of the software for electromagnetic drive control system based on the weber-ampere characteristic measuring. The software for weber-ampere characteristic data processing based on artificial neural network is developed. Results of the design have been integrated into the program code in LabVIEW environment. The license package of LabVIEW graphic programming was used. The hardware is chosen and possibility of its use for control system implementation was proved. The trained artificial neural network defines electromagnetic drive effector position with minimal error. Developed system allows to control the electromagnetic drive powered by the voltage source, the current source and hybrid sources.

1. Introduction

Electromagnets, along with transformers, are the most common representatives of electromagnetic designs. Proportional electromagnets are the most complex system [1, 2]. This type of electromagnetic drives requires systems that can control parameters of electromagnets elements movement. In experimental development of new products, it is important to setup parameters of regulators and make complex testing of electromagnets. Also, high reliability requirements are denoted for this class of devices when it's used as a part of increased responsibility systems. Complexity and continuous improvement of the magnetic systems now demand a new high-precision approaches to control of the movable elements position. Automated systems controlling production of the intelligent electric drives are required for implementation of an effective approach. One of the basic elements of production systems is the stand for diagnostics and regulator parameters setup. When developing an experimental production of new proportional electromagnets of direct current, the specified stand can be presented in the form of the automated system for researches and complex tests. These operations are intended to improve productivity of optimization processes of electromagnets designs, including the use of new materials or known materials in limit operating modes.

From the consumer's point of view, electromagnet main characteristics are mass-dimensional indicators and energy parameters. However, using electromagnets must also be considered in



determining their particular performance. The performance of the electromagnet in creating a traction force value estimated by the time constant of a current rise in the winding. Usually, dynamic properties of the electromagnet are characterized by time constant τ_M , which is calculated by the formula:

$$\tau_M = \frac{L}{R},$$

where L – inductance of the winding, R – resistance of the solenoid coil.

2. Materials and Methods

To improve the performance, the force of an electromagnet with a negative feedback current in the electromagnet winding is used. In this case, the source of the power control system is converted to the type ‘voltage source’, referring to the ‘current source’ or ‘hybrid source’ that requires further analysis and consideration in the design.

When boosting the electromagnet coil connected to power supply voltage U and current I , it appears that the current-loop can reach steady state value I_S , which is defined as

$$I_S = \frac{U}{R}.$$

Current feedback limits the amount of current I at the level of the nominal value of I_N , corresponding to a given input value.

The main characteristics of the power supply of the electromagnets control systems include: maximum voltage U_M , maximum current I_M and maximum power P_A , which is calculated according to the formula:

$$P_A = U_M I_M.$$

If I_S is estimated at a fraction of I_M by using coefficient $k_A < 1$, then we have:

$$I_S = k_A I_M.$$

In this case, the following conclusion can be done: for the case when the current source or a hybrid power source was used, the time constant is defined by the expression:

$$T_M = \frac{\tau_M I_N}{I_S},$$

and it also can be expressed by the formula:

$$T_M = L \frac{I_N}{U_M}.$$

Consequently, we will have:

$$T_M = \frac{L I_N^2}{k_A U_M I_M} = \frac{2 F_N \delta}{k_A P_A},$$

where δ – the air gap between the armature and the yoke of the electromagnet; F_N - traction, determined by the formula:

$$F_N = \frac{B_N^2 S_M}{\mu_0} = \frac{L I_N^2}{2 \delta},$$

where S_M – the square of the armature, $\mu_0 = 4\pi 10^{-7}$ – the magnetic constant, B_N – induction in the gap defined by the formula:

$$B_N = \mu_0 I_N \frac{w}{2 \delta},$$

where w – the number of turns in the electromagnet winding.

The expression for the T_M time constant corresponding to the current source indicates that with chosen values of k_A and δ , electromagnet performance depends on the ratio of F_N and P_A . Therefore, for different basic designs of electromagnets, the problem of speed increasing can be solved by

varying the power supply.

With high complexity of the control object (for example, a current source having a power limit or configuration of the magnetic system of the electromagnet has a high geometrical complexity) or in the absence of complete a priori information about the object it becomes necessary to apply intellectual technologies of control [3-6]. Now, a very large number of publications are devoted to intellectual technologies that confirms relevance and popularity of these control systems.

The proposed approach is based on the following assumptions. The position of the electromagnet movable element x defines a degree of magnetic circuit closure d . The degree of of magnetic circuit closure d determines the level of magnetic flux F at a preset value of magnetopropellent Iw . The level of a magnetic flux has direct interrelation with the flux linkage of the winding of magnetic conductor ψ . Thus, there is physical interrelation between the weber-ampere characteristic of electromagnet $\psi(Iw)$ and the position of its movable element, $x: x \rightarrow d \rightarrow F(Iw) \rightarrow \psi(Iw)$. Based on this assumptions, the automatic control system for rather high complexity of the controlled object in the absence of rather complete information can be developed (figure 1).

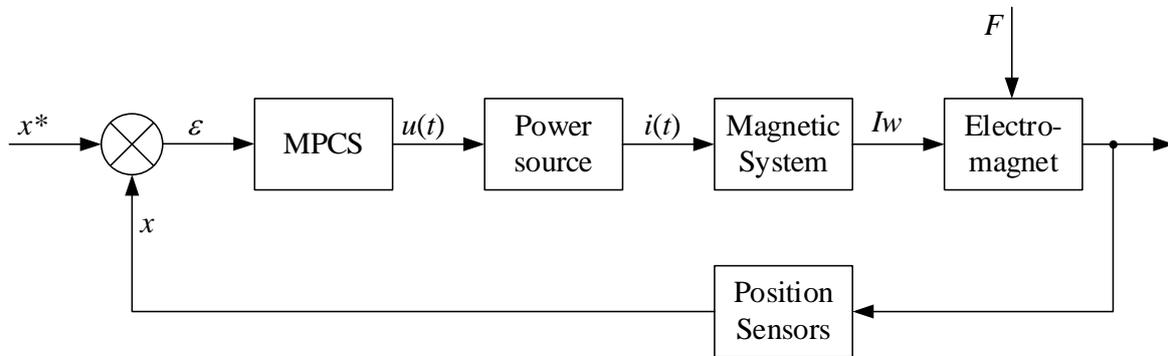


Figure 1. The block diagram of the automatic control system of the electromagnet.

Parts of the system (figure 1) are: the microprocessor control system (MPCS), the managed power source, the magnetic system, the position sensor, the electromagnet.

The purpose of the work is to develop software for identification of the electromagnet condition (Position Sensor) and implement it to system of movable element position control. Herein the weber-ampere characteristic has to be used as information source [7]. Researches were conducted with the use of elements of the theory of magnetic field, the theory of automatic control, mathematical modeling with the use of the licensed package of the programs ‘*Matlab, LabVIEW*’.

3. Results and Discussion

Automatic control system represent as the hardware-software complex providing continuous and effective control of complex technical systems or the proceeding processes in real time.

Generally, for creation of the automatic system for electromagnetic drive control, the aim to provide high-speed performance, a movable part of the drive definition accuracy with no need of large-size sensors using is pursued.

In present work, software for the control system of the electromagnetic drive movable element is developed in the environment of graphic programming of *LabVIEW* [8]. The software includes the artificial neural network developed in *MathScript* component of *LabVIEW*. *MathScript* uses the *MATLAB* library for implementation and training of the artificial neural network. The Weber-ampere characteristic is input data for the artificial neural network (figure 2a). The first entrance is values of current (i), the second entrance is a values of flux linkage (ψ). Positions of the electromagnetic drive movable element (figure 2b) received by laser sensor were used as the training data.

The trained artificial neural network [9] defines position (x) of the movable element by the weber-

ampere characteristic processing. It gives the opportunity to exclude the position sensor from the automatic control system that influences its dimensions, weight and cost. The artificial neural network after training needs to be integrated into the control system hardware. The hardware component with its own software and a possibility of integration of applied programs for autonomous system is necessary. The possibility of connection analog input and output signals, digital outputs for current source effective control is also necessary [10]. Availability of constant memory or connection of peripheral equipment as information storage with possibility of data accumulation for artificial neural network training is necessary.

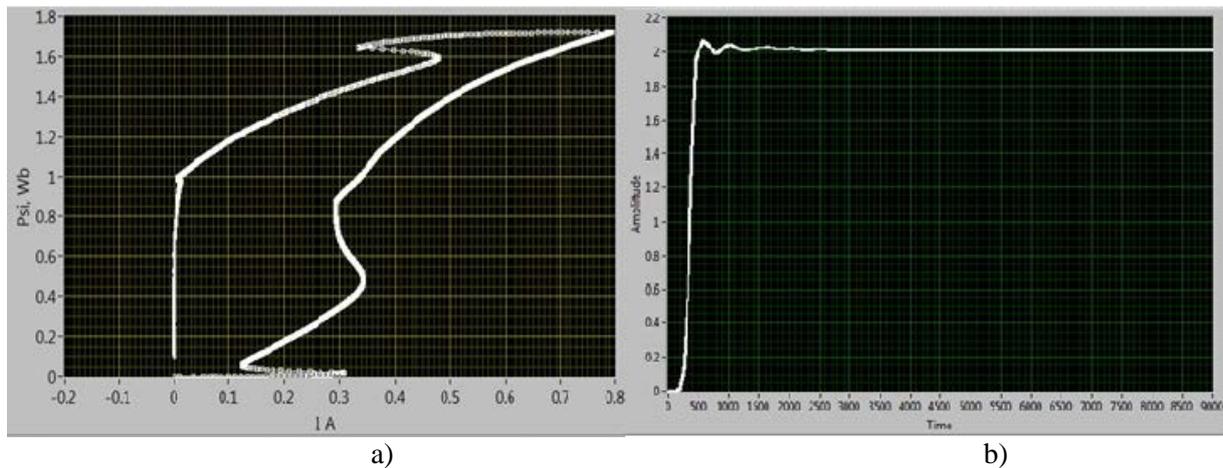


Figure 2. The weber-ampere characteristic (a) and the schedule of position of the movable element (b) of the operating cycle of the electromagnetic drive.

The industrial controller ‘National Instruments SBRIO-9636’ meets all necessary requirements. The chosen controller has its own software RAM size of 512 MB, USB storage devices connection possibility, 16 analog single inputs or 8 differential, 4 analog outputs. ‘National Instruments SBRIO-9636’ has small dimensions in comparison with analogs that allows one to get a compact size of the control system.

As an object of control the direct current electromagnetic drive was used. The dynamic weber-ampere characteristic was measured, and also position (x) of the movable part by means of the laser sensor in the course of operation was defined.

As a basis of the control system, the three-layered artificial neural network with the return distribution of the mistake has been chosen. For its training data on the position of the movable part of the electromagnetic drive were used. The result of this artificial neural network depends on the number of the data which are used for training. For minimal error achievement, a training network with 1000 epochs was used. Epoch is one of all examples of the training data with simultaneous correction of network weights (for specific examples, depending on network solving correctness). When an artificial network was trained, a little number (hundreds, or even tens) of epochs can be demanded. During the epoch, network scales can be corrected not on every training example. If the artificial network was already trained to solve correctly this specific example, it is possible to cease to demand continuous "improvements" of quality of the solution of this example (as these improvements will already be insignificant) and to allow artificial network to direct its attention to other examples which for the present are solved with insufficient accuracy. The result of training of artificial neural network is shown in figure 3.

Regarding the implementation of control system for electromagnetic drive it should be noted that in it the PID-law of control on current (I) is implemented. Into analog channel AI0 of the SbRIO-9636 controller the value of current is transmitted and into the channel AI1 the value of the electromagnetic drive windings voltage is transmitted. The output signal from the industrial controller SbRIO-9636 is

depending on the calculated value of electromagnet movable element position. This output is the control signal for the current source.

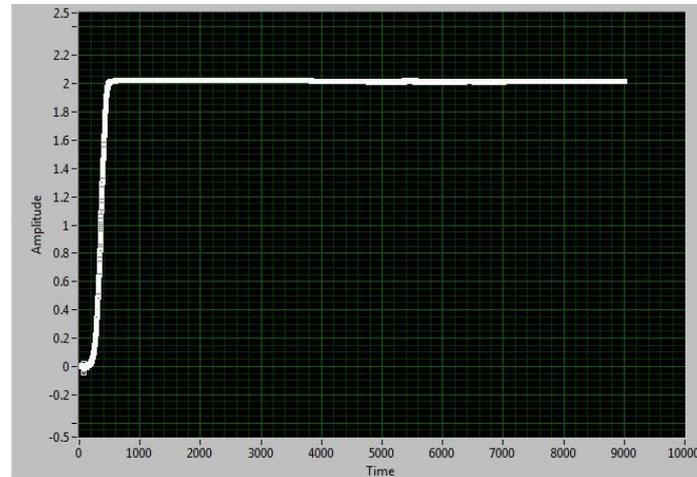


Figure 3. Result of work of artificial neural network.

4. Conclusion

After training, artificial neural network defines the position of electromagnetic drive movable element by its weber-ampere characteristic data. But thus for each separate electromagnetic drive, it is necessary to train new neural network for its functioning without increase in error. Position that received by using the trained artificial neural network and real positions differ less than for 5 %. It confirms that developing control system based on artificial neural network is perspective task as the accuracy of movable element positioning aims at 95 % with no need to use the special position sensor.

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