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Simulation of A Fuzzy Controller for Controlling A Two-Mass Electromechanical System

Abstract: **-** This study presents a model with a fuzzy logic controller (FLC) for controlling a two-mass electric drive operating with a dynamic load. In the Simulink environment of the MatLab software package, a model of the mechanical part of the electric drive system with a proportional integral differential (PID) controller was built, which was tested for two different characteristics created by the technological mechanism. The low performance of a system with a PID regulator has been proven, especially in electric drive systems operating with a shock load. The expediency of using Fuzzy logic regulators for electric drive systems operating under uncertain conditions is substantiated. To ensure the required efficiency of the electric drive system, a FLC model has been developed in the Fuzzy Logic Toolbox environment of the MatLab software package. To control the mechanical part of the electric drive system 16 laws have been formulated. Tests of the electric drive control system model with a FLC confirm its high efficiency when changing the load torque according to various laws. A hybrid model was synthesized with the help of the ANFIS editor. It has been confirmed that the hybrid network provides satisfactory identification quality.

Keywords: Fuzzy Logic, A Neural Network, A Two-Mass System, Control, An Electric Drive.

I. INTRODUCTION

The efficiency of modern industries, transport and life support is determined by the quality of management of the electric drive system used in them [1-3]. The main function of the electric drive is to set in motion the working mechanisms in accordance with the requirements of the technological regime. This movement is performed by the mechanical part of the electric drive, which includes the rotor of the electric motor, a transfer device and a working mechanism [4, 5]. Standard controllers are often used in complex process control systems. Currently, proportional-integral-derivative (PID) controllers continue to be used in the electric drive control systems because of their versatility, simplicity and reliability [6, 7]. A large number of works are known in which the use of a PID controller has made it possible to provide the expected indicators [8-12]. These controllers are especially successfully used in the electric vehicle control systems [10, 11, 12], ensuring their smooth operation. The results show that with the help of a PID controller, it is possible to quickly and accurately ensure the required speed of an electric vehicle [11,12].

To improve the performance of control systems for the technological processes, it becomes necessary to use a PID controller in combination with Model Predictive Control (MPC) [13]. This approach is applicable to the electric drive systems operating in a predictable mode. In practice, it is difficult to simulate the exact characteristics of dynamic phenomena occurring in various modes of operation of the electric drive systems of a number of technological mechanisms. In some modes, the characteristics of the motor can have a significant effect on the fluctuations in the elasticity of the mechanical part of the electric drive system. These fluctuations, in turn, affect the performance characteristics of the power part of the drive system, contribute to the deformation of elastic links and the occurrence of other emergency situations. The use of traditional methods of controlling the electric drive system is especially ineffective in the case of technological mechanisms operating with a randomly varying load [14, 15]. To solve this problem, the idea of replacing linear regulators with nonlinear ones is used, which is implemented using a neurocontroller.

A number of works are known in which controllers of artificial neural networks are used in control systems of the electric drives [16-19].

Due to the constant training of the neural network, the neuroregulator allows you to adapt to changing conditions, predict and anticipate changes in the system and work ahead of the curve, reducing the inertia and delay of the system [16].

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Despite the fact that neurocontrollers provide high speed and high control efficiency, among their disadvantages it is still possible to highlight the fact that neurocontrollers are mainly designed and adapted for a specific object of regulation. In addition, it is difficult from an implementation point of view.

A serious alternative to digital control is the use of fuzzy logic capabilities [20,21], which allows to reduce the complexity of control algorithms, reduce the time of design and implementation into production. In control systems of complex technological processes, controllers based on fuzzy logic are especially effective [21].

The qualitative indicators and accuracy of the automated control system (ACS) are determined, after the disappearance of the external influence and the completion of transient processes, by the ability of the system to return to a steady state.

The analysis shows that, although the results obtained in the field of the electric drive control are of great practical importance, they are still focused on individual special cases of the electric drive system control. They lack the ability to eliminate external influences and return the system to a steady state with high performance and accuracy after the completion of the transient process.

Taking into account the applied features of controlling the mechanical part of the electric drive control system, it can be established that the synthesis of the regulator, taking into account their fuzzy characteristics, is of actual scientific and technical interest.

The aim of the study is to simulate a fuzzy controller for controlling the mechanical part of the two-mass electric drive system, which increases control efficiency due to processing speed and high accuracy.

II. MATERIALS AND METODS

In this work, the mechanical part of the electric drive system with a random load change is used as a controlled object, the block diagram of which is shown in Fig. 1.

The first mass (moment of inertia J_1) is represented by an electric motor. The second mass (moment of inertia J_2) is represented by a technological mechanism. The motor and mechanism are connected by an elastic structure with a stiffness coefficient of ***c.***

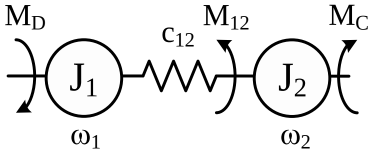


Fig.1. Diagram of the mechanical part of the electric drive

The mathematical model of a two-mass mechanical model looks like this:

$$\begin{cases} M_D - M_{12} = J_1 \dfrac{d\omega_1}{dt} \\ M_{12} - M_c = J_2 \dfrac{d\omega_2}{dt} \\ \dfrac{dM_{12}}{dt} = c(\omega_1 - \omega_2) \end{cases}$$

where M_D is the torque of the electric motor, M_c is the torque of resistance of the technological mechanism on the motor shaft, M_{12} is the stretching moment; c is the stiffness of the connection between the electric motor and the technological mechanism, ω_1, ω_2 are the rotational speeds of the motor and the mechanism, respectively.

In this case, studies were conducted on the electric drive system of the grinding process, which is widely used in mineral processing and the production of building materials. This process is difficult to control due to the fact that inside the crushed load regularly undergoes qualitative and quantitative changes, which are of an uncertain nature [22]. The results were considered for 2 cases of changes in the torque of resistance, which are more common in the grinding process:

- the torque of resistance created by the mechanism changes according to the $m_o + m_1\omega_2 + m_2(\omega_2)^2 + m_3(\omega_2)^3$ law (Fig. 2),
- the torque of resistance created by the mechanism has a stepped shape (Fig. 3).

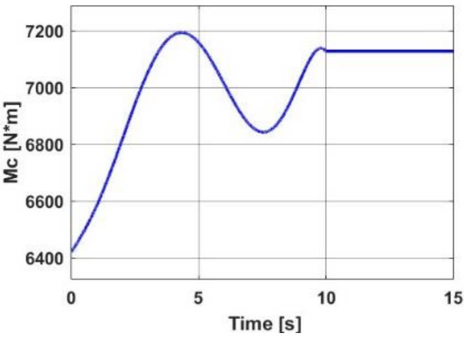


Fig. 2. The torque of the resistance of the technological mechanism varies according to the $m_o + m_1\omega_2 + m_2(\omega_2)^2 + m_3(\omega_2)^3$ law.

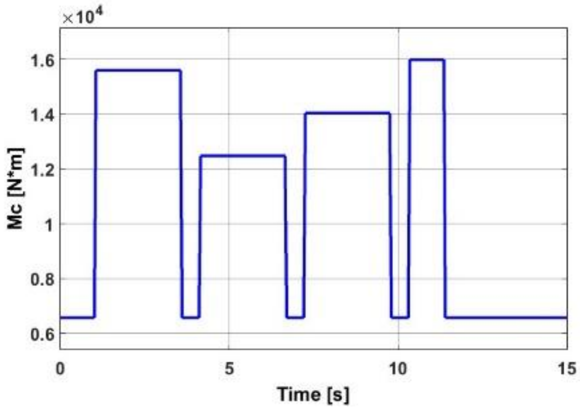


Fig. 3. The torque of the resistance of the technological mechanism varies according to a stepwise dependence

In the Simulink environment of the MatLab software package, a model with a PID controller of the mechanical part of the electric drive system was built (Fig. 4). Observations were made for 2 different cases of load changes mentioned above.

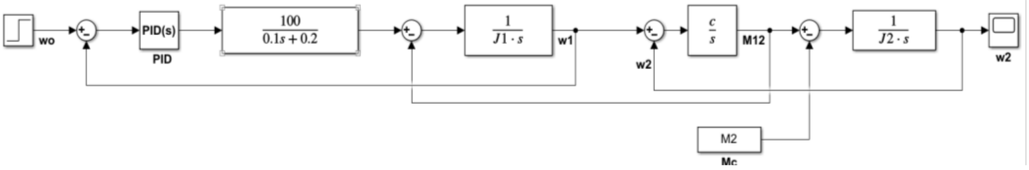
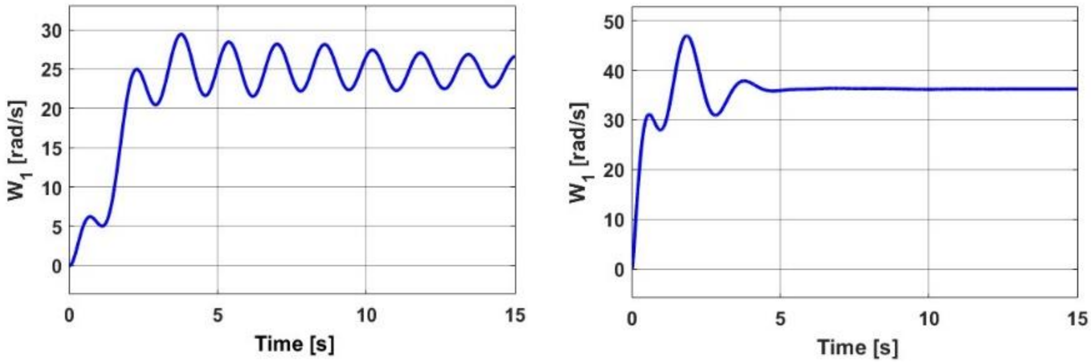
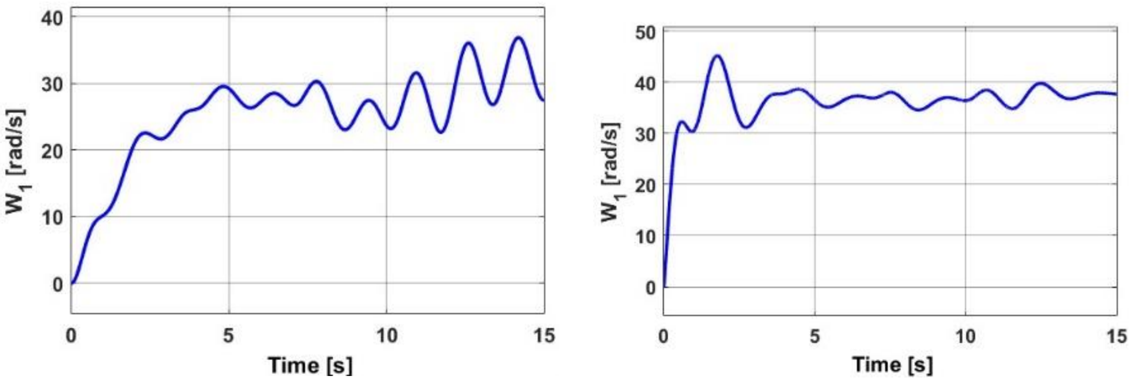


Fig. 4. Model with PID controller of the mechanical part of the electric drive system.



a) b)

Fig. 5. In case of a change in the load torque shown in Fig. 2: a) the motor rotation speed before the PID controller, b) after regulation.



a) b)

Fig. 6. In case of a change in the load torque shown in Fig. 3; a) the speed of rotation of the motor before the PID controller, b) after regulation.

It follows from Fig. 5 and 6 that with a dynamic change in the torque of load resistance, the PID controller does not provide the desired regulation. In one case, the angular velocity of the motor is regulated with a significant delay (Fig. 5), and in the other case, the change in the speed of rotation of the electric motor is partially regulated (Fig. 6), which cannot be considered a satisfactory result.

Taking into account the results obtained, the possibility of using a controller with fuzzy logic was considered. The fuzzy logic controller is successfully used in control systems due to the following features:

- has a nonlinear structure and can be successfully used both in systems with nonlinearities in their structure and in systems with nonlinear external influences.
- It can have many input and output variables that are related to each other by certain rules. The rules work in parallel, even if a conflict of rules is allowed by a specialist, then other rules can resolve the conflict that has arisen.
- Modeling of a fuzzy controller is simplified by applying the "if"- "then" rules.

The core of the Fuzzy logic controller is a block with fuzzy logic [20] (Fig. 7).

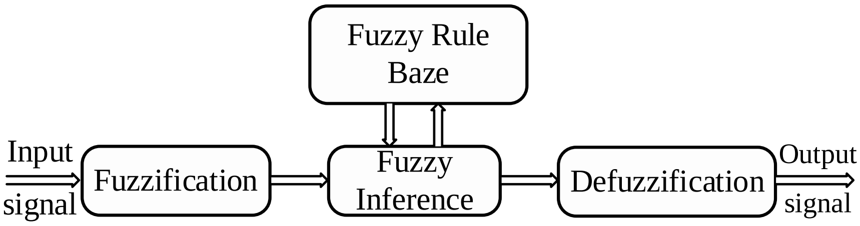


Fig. 7. The structure of the basic block of fuzzy logic.

The structure of the basic block of fuzzy logic includes three main blocks [20]. The fuzzification block, the logical solution formation block and the defuzzification block. In the block of the logic solution shaper, fuzzy sets are processed, the output signal of the block is determined by the methods of specifying the fuzzy implication and composition.

The transition from the space of physical variables to fuzzy ones is carried out using the fuzzification operation (fuzz) and is determined by the type of specification of fuzzy membership functions (in the form of a Gaussian function). The return to physical variables is performed by a defuzzification operation (dfz) and is performed by center of gravity (cog) methods.

III. RESULTS

In order to increase the efficiency of the mechanical part of the electric drive system, a model of a fuzzy controller was developed. Details of the results obtained are given below.

To build a control system with a fuzzy controller, sets of input signals have been generated. For this purpose, we used data obtained for its rotation speed as a result of observations of the operation of the electric motor (Fig. 8).

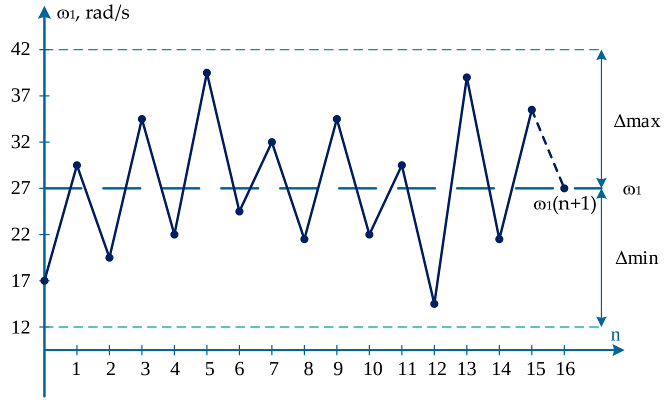


Fig. 8. The speed of rotation of the motor during long-term operation of the motor.

Using the Fuzzy Logic Toolbox environment of the MatLab software package, a Sugeno–type fuzzy output system was created (Fig. 9) with four inputs (wo(k), Wo(k–1), W1(k-1), W1(k–2)) and one output (w1(k)).

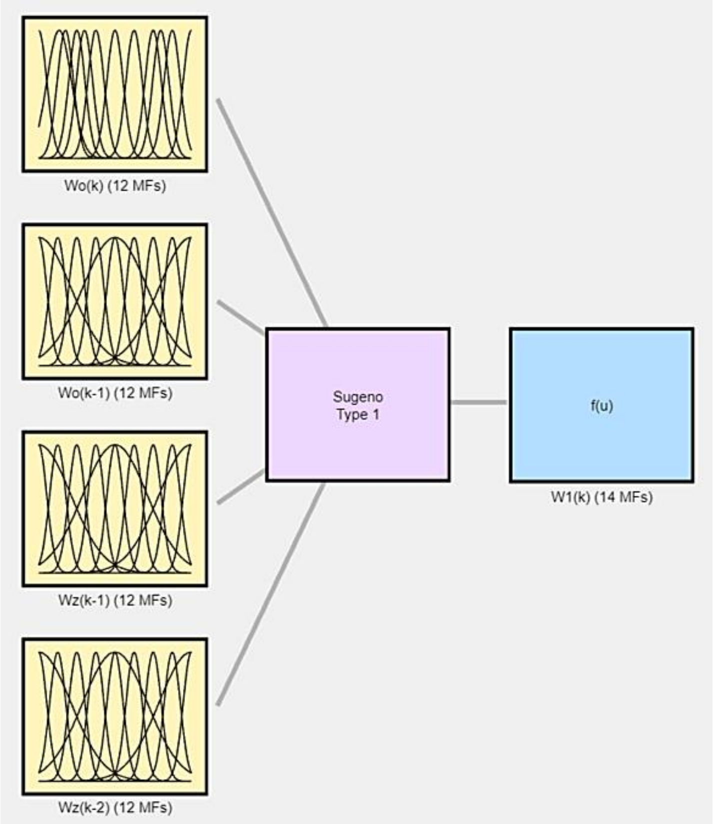
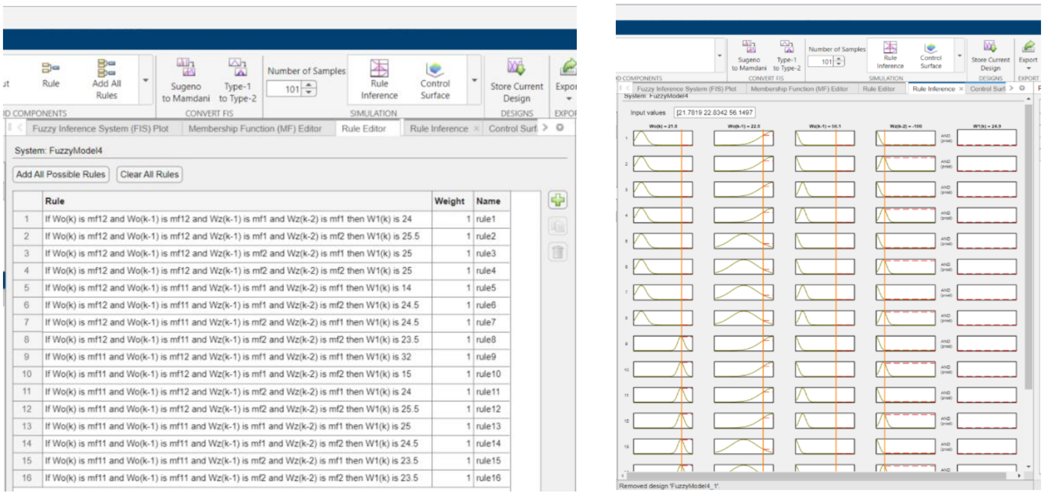


Fig. 9. Generation of a Sugeno type fuzzy output system with 4 inputs and one output.

A Gaussian membership function was chosen for the input variables. Their number is set according to the number of points in the sequence of the input signal. For the mechanical part of the considered electric drive system, their number is set to 12.

A database of rules has been formed. Each rule establishes the correspondence of the membership functions of the incoming variables to the numerical value of the output variable.

16 Rules have been formulated for controlling the mechanical part of the electric drive system (Fig. 10).



System: FuzzyModel4

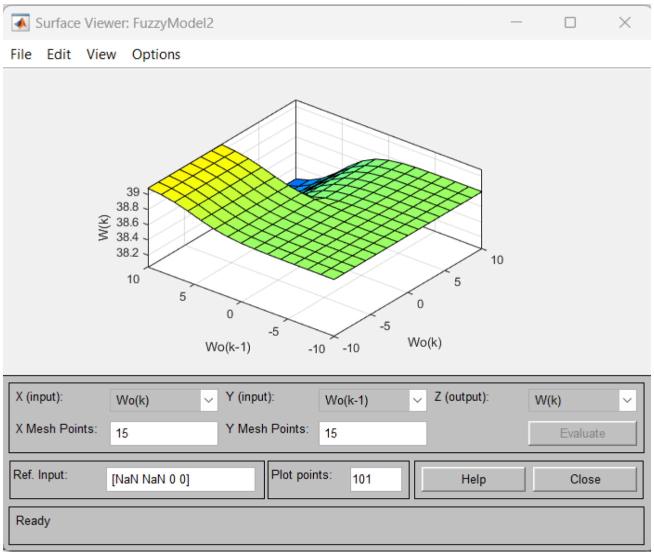
	Rule	Weight	Name
1	If Wo(k) is mf12 and Wo(k-1) is mf12 and Wz(k-1) is mf1 and Wz(k-2) is mf1 then W1(k) is 24	1	rule1
2	If Wo(k) is mf12 and Wo(k-1) is mf12 and Wz(k-1) is mf1 and Wz(k-2) is mf2 then W1(k) is 25.5	1	rule2
3	If Wo(k) is mf12 and Wo(k-1) is mf12 and Wz(k-1) is mf2 and Wz(k-2) is mf1 then W1(k) is 25	1	rule3
4	If Wo(k) is mf12 and Wo(k-1) is mf12 and Wz(k-1) is mf2 and Wz(k-2) is mf2 then W1(k) is 25	1	rule4
5	If Wo(k) is mf12 and Wo(k-1) is mf11 and Wz(k-1) is mf1 and Wz(k-2) is mf1 then W1(k) is 14	1	rule5
6	If Wo(k) is mf12 and Wo(k-1) is mf11 and Wz(k-1) is mf1 and Wz(k-2) is mf2 then W1(k) is 24.5	1	rule6
7	If Wo(k) is mf12 and Wo(k-1) is mf11 and Wz(k-1) is mf2 and Wz(k-2) is mf1 then W1(k) is 24.5	1	rule7
8	If Wo(k) is mf12 and Wo(k-1) is mf11 and Wz(k-1) is mf2 and Wz(k-2) is mf2 then W1(k) is 23.5	1	rule8
9	If Wo(k) is mf11 and Wo(k-1) is mf12 and Wz(k-1) is mf1 and Wz(k-2) is mf1 then W1(k) is 32	1	rule9
10	If Wo(k) is mf11 and Wo(k-1) is mf12 and Wz(k-1) is mf1 and Wz(k-2) is mf2 then W1(k) is 15	1	rule10
11	If Wo(k) is mf11 and Wo(k-1) is mf12 and Wz(k-1) is mf2 and Wz(k-2) is mf1 then W1(k) is 24	1	rule11
12	If Wo(k) is mf11 and Wo(k-1) is mf12 and Wz(k-1) is mf2 and Wz(k-2) is mf2 then W1(k) is 25.5	1	rule12
13	If Wo(k) is mf11 and Wo(k-1) is mf11 and Wz(k-1) is mf1 and Wz(k-2) is mf1 then W1(k) is 25	1	rule13
14	If Wo(k) is mf11 and Wo(k-1) is mf11 and Wz(k-1) is mf1 and Wz(k-2) is mf2 then W1(k) is 24.5	1	rule14
15	If Wo(k) is mf11 and Wo(k-1) is mf11 and Wz(k-1) is mf2 and Wz(k-2) is mf1 then W1(k) is 23.5	1	rule15
16	If Wo(k) is mf11 and Wo(k-1) is mf11 and Wz(k-1) is mf2 and Wz(k-2) is mf2 then W1(k) is 23.5	1	rule16

Input values [21.7819 22.8342 56.1497]

a) b)

Fig.10. a) the base of rules; b) the process of processing the input signals of the fuzzy controller of the mechanical part of the electric drive system.

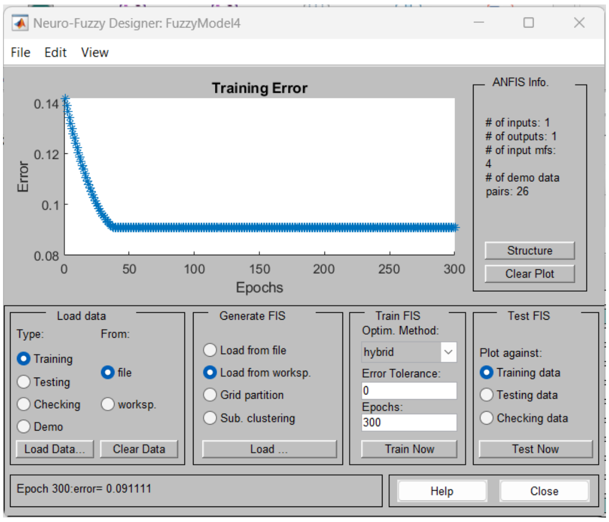
The surface of a simulated fuzzy controller for controlling the two-mass electromechanical system is presented. Fig. 11 shows a surface view of the relationship between the inputs Wo(k), Wo(k-1) and the output W1(k).



X (input): Wo(k)
Y (input): Wo(k-1)
Z (output): W(k)
X Mesh Points: 15
Y Mesh Points: 15
Ref. Input: [NaN NaN 0 0]
Plot points: 101
Ready

Fig. 11. Dimensional input–output surface plots.

Using the Neuro - Fuzzy Designer interface, the system has been trained, tested and checked. About 2000 data were collected at the input and output of the system. The collected data was divided into three separate datasets, of which 50% were used for network training, 25% for testing, and 25% for re-checking. The training error was 0.0911 (Fig. 12). In Fig. 13, the training data are marked with blue dots, and the corresponding to them output values of fuzzy logic are marked with red asterisks.



# of inputs: 1
# of outputs: 1
# of input mfs:
4
# of demo data
pairs: 26

Type: ● Training ○ Testing ○ Checking ○ Demo
From: ● file ○ worksp.

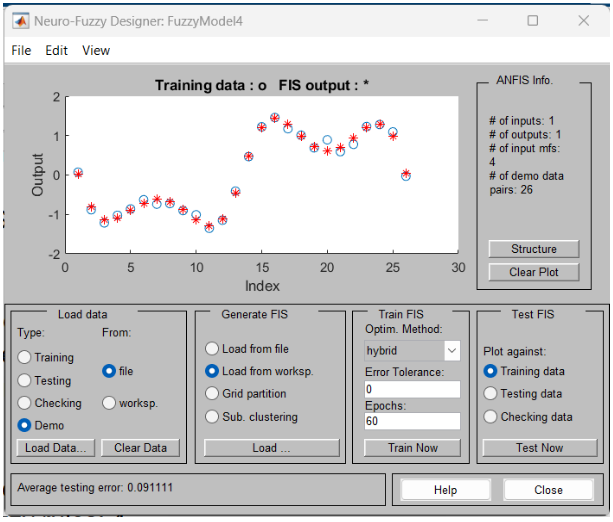
○ Load from file
● Load from worksp.
○ Grid partition
○ Sub. clustering

Optim. Method: hybrid
Error Tolerance: 0
Epochs: 300

Plot against: ● Training data ○ Testing data ○ Checking data

Epoch 300:error= 0.091111

Fig 12. Training error.



# of inputs: 1
# of outputs: 1
# of input mfs:
4
# of demo data
pairs: 26

Type: ○ Training ○ Testing ○ Checking ● Demo
From: ● file ○ worksp.

○ Load from file
● Load from worksp.
○ Grid partition
○ Sub. clustering

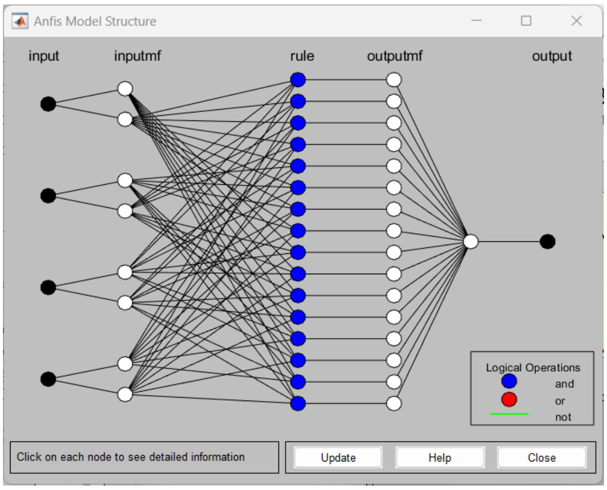
Optim. Method: hybrid
Error Tolerance: 0
Epochs: 60

Plot against: ● Training data ○ Testing data ○ Checking data

Average testing error: 0.091111

Fig. 13. Training data.

After training, you can visually evaluate the structure of the constructed fuzzy hybrid neural network ANFIS (Fig.14)



Click on each node to see detailed information

Fig. 14. Structure of the created hybrid network.

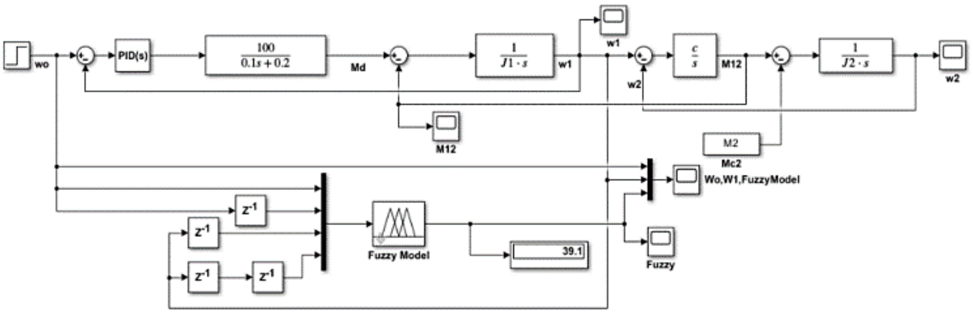


Fig. 15. Fuzzy control model of the mechanical part of the electric drive

Layer 1: Input is the input layer of a hybrid neural network for phasing.

Layer 2: The Inputmf are the outputs of the neurons in this layer represent the values of the membership functions at specific input values.

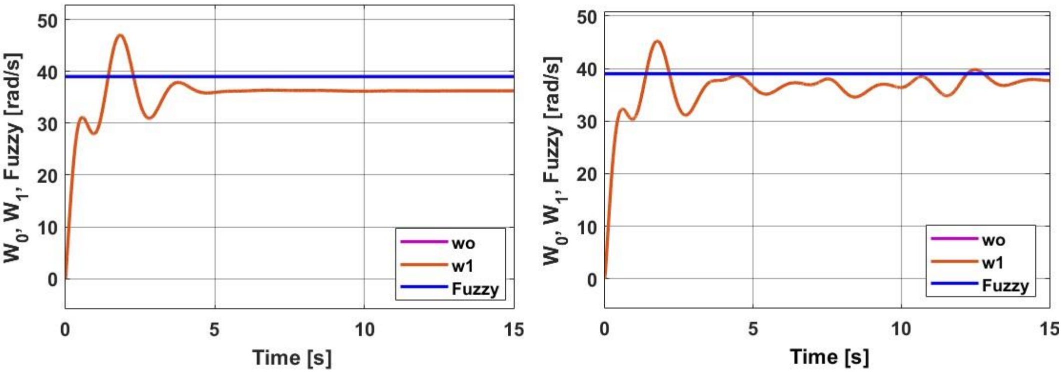
Layer 3: Rule outputs: The neurons of this layer are the degrees of truth of the prerequisites of each rule of the system's value base.

Layer 4: Outputmf: The neurons of this layer calculate and form the values of the outputs of variables.

Layer 5: Output: The neurons of this layer perform a defuzzification operation.

To confirm the reliability of the efficiency of controlling the mechanical part of the electric drive system using a fuzzy controller, it was modeled in the Simulink environment (Fig. 15).

The model tests shown in Fig. 15 confirm the high efficiency of the control system with a fuzzy logic controller when changing the load torques according to various laws (Fig. 16).



a) b)

Fig. 16. Control of the rotation speed of the electric motor using a PID controller and a fuzzy logic controller: a) the load torque varies according to the law shown in Fig.2; b) the load torque varies according to the law shown in Fig.3.

IV. CONCLUSIONS

The electric drive systems of various mechanisms used in technological processes are exposed to randomly changing factors during operation, which can make the elastic vibrations of the mechanical part of these systems the most intense. In order to avoid accidents caused by elastic vibrations occurring in the mechanical part, the possibilities of using traditional regulation were considered. For cases of changes in the load torque created by the technological mechanism, according to two different laws, graphs of changes in the rotation speed of the electric motor before and after PID regulation were considered. It was found that the use of a traditional control system with a PID controller does not provide satisfactory required results.

During operation, the elastic links of the mechanical part can deform and wear out, causing uncontrolled changes in the stiffness of the joint and the stretching moment. It turns out that the complexity of controlling the system under consideration is due to both a random change in the torque of resistance created by the mechanism and unknown changes in the parameters of the mechanical part during operation. They served as the basis for modeling new intelligent approaches to controlling the mechanical part of an electric drive system.

To control the mechanical part of the electric drive system, a model with a Fuzzy logic controller was proposed. The model with four inputs and one output was created in the Fuzzy Logic Toolbox environment of the MatLab software package. To ensure the operation of the system, a set of input signals was formed, which made it possible to formulate 16 rules for controlling the mechanical part of the system.

The performance of the proposed model was evaluated in the Simulink environment. A comparative analysis of the control capabilities of systems with PID controllers and fuzzy logic controllers has shown that, regardless of the nature of the change in the torque of resistance, the fuzzy logic controller provides high control efficiency. In particular, at the time of suspension of the learning process, the error was 0.0911.

The identification error of the hybrid network synthesized based on the training results did not exceed 9 %, which is a satisfactory result for the electric drive system under consideration.

The results obtained suggest that the use of a fuzzy logic algorithm to control the mechanical part of an electric drive system makes it possible to ensure high quality indicators for systems with previously unknown or highly variable parameters, which makes their use in drive mechanisms of technological units very promising.

Acknowledgments:

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REFERENCES

[1] A. P. Korneev, Y. Niu, M. S. G. Mansoor, Z. S. Jabbar, J. F. Tawfeq, A. D. Radhi, “Design and Implementation of a Distributed Parameter Electromechanical System Control System for Automation and Optimization,” Journal Pengabdian dan Pemberdayaan Masyarakat Indonesia, vol. 3, no. 1, pp. 28-34, 2023.

[2] M. K. Baghdasaryan, “Methods for Investigating the Operation Modes of the Electrical Drive Motor used in the Mineral Raw Material Grinding Process,” in Methods of Research and Optimization of the Mineral Raw Material Grinding Process, New York, USA, NOVA science publishers, pp. 165-179, 2019.

[3] M.Yu. Shabalov, Yu.L. Zhukovskiy, A.D. Buldysko, B. Gil, V.V. Starshaia, “The influence of technological changes in energy efficiency on the infrastructure deterioration in the energy sector,” Energy Reports, vol. 7, pp 2664-2680, November 2021.

[4] A. Veltman, D.W.J. Pulle, R. W. Doncker, **“**Fundamentals of Electrical Drives,**”** Springer International Publishing Switzerland**,** 2016, 341p.

[5] R. W. Doncker, D.W.J. Pulle, A. Veltman, Advanced Electrical Drives. Analysis, Modeling, Control. Springer Nature Switzerland AG 2020, 419 p.

[6] R. Damayanti, B. Syawaludin, H. Arif Gunawan, “Design of PI and PID Control System for Induction Motor Control on Gamma Irradiator Characterization Prototype Using a Modified Ziegler-Nichols Method,” Journal of Electrical Technology UMY (JET-UMY), vol. 6, no.2, pp. 94-102, December 2022.

[7] S. Bucz, A. Kozákova PID Control for Industrial Processes. 2018. 218 p.

[8] S.M. Alghamdi, M.N. Ajour, N.H. Abu-Hamdeh, A. Karimipour, “Introducing a new PID controller to control the addition of PCM to the building with ventilation heat recovery installation to reduce the energy demand of the cooling system,” Journal of Building Engineering, vol. 56(2), 15 September 2022.

[9] K. H. Ang, G. Chong, “PID Control System Analysis, Design, and Technology,” IEEE transactions on control systems technology, vol. 13, no. 4, pp.559-576, 2005.

[10] A.D.O.S. Dantas, A.F.O.A. Dantas, J.T.L.S. Campos, D.L.A. Neto, and C.E.T. Dórea. PID Control for Electric Vehicles Subject to Control and Speed Signal Constraints. Journal of Control Science and Engineering vol. 2018, Article ID 6259049.

[11] G. Huang, X. Yuan, K. Shi, X. Wu, **“**A BP-PID controller–based multi-model control system for lateral stability of distributed drive electric vehicle,**”** Journal of the Franklin Institute, vol 356, no 13, pp. 7290-7311, September 2019.

[12] A. A. Jassim, E. H. Karam, M. E. Ali, “Design of Optimal PID Controller for Electric Vehicle Based on Particle Swarm and Multi-Verse Optimization algorithms,” Engineering and Technology Journal, vol.41, pp. 446- 455, 2023.

[13] A. Aboelhassan, M. Abdelgeliel, E. E. Zakzouk, M. Galea, “Design and Implementation of Model Predictive Control Based PID Controller for Industrial Applications,” Energies, 13, 6594, 2020.

[14] M. K. Baghdasaryan. A. T. Ulikyan, “Study of the operating state of a synchronous motor electric drive by means of changes estimation of the stator current behavior,” International Review of Electrical Engineering (IREE), vol. 17, no 2, pp. 177-184, 2022.

[15] M. Baghdasaryan, A. Avetisyan, “Study of Stability Conditions of the “Electric Drive Motor - Technological Mechanism” System,” International Review of Electrical Engineering (IREE), vol.18, no 2, pp.111-118, 2023.

[16] S. Amine, O. Mokhiamar. A study of stability and power consumption of electric vehicles using different modern control strategies. ”Alexandria Engineering Journal,” vol 58, pp.1281–1290. 2019.

[17] D. V. Chernyshev, “Neural Network Control of an Electromechanical System,” Results of the 2020 International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon), Vladivostok, Russia, 8 December 2020.

[18] M. Kaminski, T. Tarczewski, “Neural Network Applications in Electrical Drives – Trends in Control, Estimation, Diagnostics, and Construction,” Energies 16, 4441. 2023.

[19] M. P. Belov, I. S. Nosirov, A. M. Belov, “Synthesis neural network controller for two-mass electromechanical system of lathe machine’s feed drive,” Izvestia St. Petersburg Electrotechnical University, vol 8, pp.70-76, 2018.

[20] W. Santos. Fuzzy Control Systems: Design, Analysis and Performance Evaluation. New York, USA, NOVA science publishers, 2017, 252 p.

[21] M. V. Faleev, T. K. Xuccein, "Intelligent control of electric drives with digital synchronization," Vestnik Ivanovo State Energy University, vol. 3, pp. 1-3, 2009.

[22] M. K. Baghdasaryan, D.V. Davtyan, "Energy Saving in the Ore Beneficiation Technological Process by the Optimization of Reactive Power Produced by the Synchronous Motors," International Review of Electrical Engineering (IREE), vol. 16 no. 4, pp. 377-384, 2021.