Reducing Energy Consumption in the Control System of Mechanism for Mixing Viscous Composition Through Fuzzy Rules

Alexey Sinyukov
Department of electric drive
Lipetsk State Technical University
Lipetsk, Russian Federation
zeitsn@yandex.ru

Tatyana Sinyukova
Department of electric drive
Lipetsk State Technical University
Lipetsk, Russian Federation
stw0411@mail.ru

Elena Gracheva
Department of Power Supply of Industrial Enterprises
Kazan State Power Engineering University
Kazan, Russian Federation
grachieva.i@bk.ru

Jose Goncalves
Department of Electrical Engineering
FET, University of Namibe
Namibe, Angola
j.goncalves@unibe.ao

Rosario Miceli
Department of Engineering
University of Palermo
Palermo, Italy
rosario.miceli@unipa.it

Stanimir Valtchev
NOVA School of Science and Technology
UNINOVA – CTS and LASI
NOVA University Lisbon
2829-516 Caparica, Portugal
ssv@fct.unl.pt

***Abstract*—The article discusses a device designed for mixing substances of different viscosities. Typically, devices of this kind have a control system that allows the object to function with the same time parameters, both when mixing ingredients and when stopping the mechanism. The consequences of this operating cycle are often thermal overheating of the engine and increased electricity consumption. In this regard, there is a need to study the existing control system with a view to further improving it, which will avoid the listed phenomena. As an option for solving existing problems at the facility, it is proposed to introduce a frequency converter into the control system, which is controlled by a fuzzy controller. The developed fuzzy controller is a fundamentally new block, the structure and operation of which is not based on controllers already available in the standard Matlab library. The use of the proposed regulator in the control system of the mechanism for mixing a viscous composition will reduce electrical energy consumption by 15.3 percent compared to the electrical energy consumption in the original control system.**

Keywords— fuzzy controller, simulation modeling, electric drive, energy saving, control system

I. Introduction

Devices whose function is to mix viscous substances, such as glue, to a homogeneous consistency are used in various types of enterprises. Equipment of this type is characterized by the specific nature of the load. A characteristic feature of control systems for mechanisms for mixing glue is the inability to receive a speed feedback signal. The mechanism used for mixing the glue includes an electric motor, on the shaft of which elements used for mixing the glue are installed through a coupling. Mechanisms for mixing glue operate in intermittent mode, accompanied by frequent starts and braking.

An analysis of the proposed methods for modernizing electric drive control systems for mixing viscous substances shows that research is being conducted in this direction.

In [1], a device was proposed to regulate the mixing process, which makes it possible to increase the homogeneity of the mixture. The developed device makes it possible to achieve an energy saving effect, this occurs due to the creation of inertial forces in the stirred liquid. The proposed solution provides only a fixed task for the depth of the funnel in the mixing apparatus, which is not always feasible. Also, the system does not provide for increasing the starting torque of the electric drive.

A control system using an adjustable electric drive is considered in [2]. To obtain homogeneity of the mixed composition, the loading sequence, rotor speed, current position of the plunger are monitored, temperature readings are constantly taken at the mixing stage, and labor costs are monitored. In devices of this kind, a current direction in modernizing such systems is the regulation of mixing processes in order to improve the quality indicators and homogeneity of the product. In this case, the modernization process is aimed at incorporating speed control functions into the control system. A positive component of this method is the reduction of peak energy costs.

In work [3], a vector, frequency-current control system for an electric drive is considered. This control system makes it possible to provide torque up to 1.5 pu. at rest, which allows to mix the composition with increased viscosity. Systems containing units operating on the basis of artificial intelligence have proven themselves well.

In [4], it was proposed to introduce a coefficient for changing the error rate into the traditional PID controller to form a new fuzzy PID control structure.

In article [5] it is proposed to supplement the traditional PID controller with fuzzy control. This device will achieve an energy-saving effect.

Analysis of the works shows the advantage of using controllers with fuzzy control laws. When forming multifunctional control actions, the following feature arises: their connection is not determined analytically or the deflecting effect on the automatic control system is not constant in level and dynamism [6, 7].

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II. OUTLINE OF THE PAPER

The work is described in the next chapter in several main stages that follow the next outline:

- Analysis of the standard control system.
- Analysis of the existing problems of the real object.
- Improvement of the control system.
- Modelling of the proposed system.
- Analysis of the obtained results.
- Practical implementation of the proposed solution.

III. GENERAL DESCRIPTION

The block diagram of the glue mixing mechanism, shown in Fig. 1, includes an electric motor M, which receives power from an alternating current source through a contactor, the activation of which is regulated by a clock pulse generator. The motor shaft is connected to the mixing element. The mixing device is located in a tank into which the adhesive composition is supplied. The control system has a calculation unit, which, based on data on the instantaneous phase values of currents I_{abc} and voltages U_{abc} and the time of mixing the composition and waiting, calculates the maximum values of current and energy consumed during the period of bringing the adhesive composition to the desired consistency; the obtained data allows one to analyze the nature of the process from the energy side component.

The parameters of mixing time and waiting time vary depending on the adhesive composition, its components and volume, while the mixing speed has a fixed value, its change directly depends on the value of the mechanical load on the shaft.

The waiting time (to) is accompanied by braking of the electric drive, at which time an increase in the dynamic viscosity of the adhesive composition is observed. The mixing period (tp) is characterized by a decrease in viscosity. All viscosity indicators and the rate of crystallization of the adhesive composition are usually determined depending on the composition of the adhesive. Accordingly, the use of the same time parameters when mixing the composition and during the period when the mechanism is stopped is not relevant, as it leads to overheating of the engine and increased energy consumption, therefore the standard scheme (Figure 1) needs to be modernized.

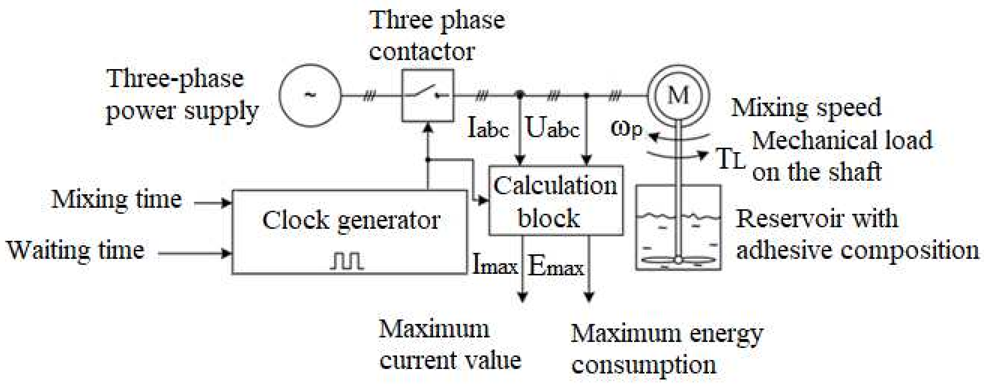

Fig. 1. Glue mixing mechanism control system.

In the work, in order to eliminate the above problems, it is proposed to introduce into the control system, instead of a three-phase contactor, a frequency converter (FC), which is controlled by a fuzzy controller (FR) (Fig. 2). In the proposed version of the control system, the speed of mixing the adhesive composition is controlled by a frequency converter.

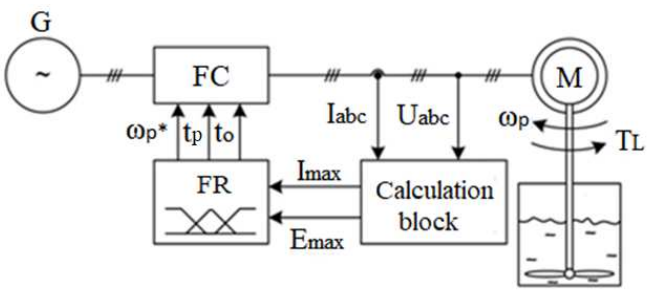

Fig. 2. Upgraded control system for the glue mixing mechanism.

At the output of the fuzzy controller, signals of waiting periods and mixing time, mixing speed are generated - task signals supplied to the frequency converter. The input signals of the fuzzy controller are the maximum values of current and consumed energy.

The inverter of the converter is assembled using a three-phase bridge single-level circuit from IGBT with freewheeling diodes [8, 9]. The inverter is actually powered by a three-phase bridge diode rectifier. The Simulink computer model uses a galvanic cell as a DC voltage source to speed up the simulation process. This approach seems acceptable since modern frequency converters provide voltage stability in the DC link at the level of a galvanic source of infinite power [10]. Power losses on the rectifier can be considered separately, as a result of which there is no need to model these losses. The voltage in the DC link is fixed. The electrical power consumed by the inverter is calculated in the model using DC and voltage signals. The power part of the modernized electric drive model is presented in Figure 3. The motor and load parameters, as well as the signal measurement system in the model remain unchanged. The "p" signal is used as the inverter input signal - an array of 6 pulse-width modulation signals for switching the IGBT of the inverter.

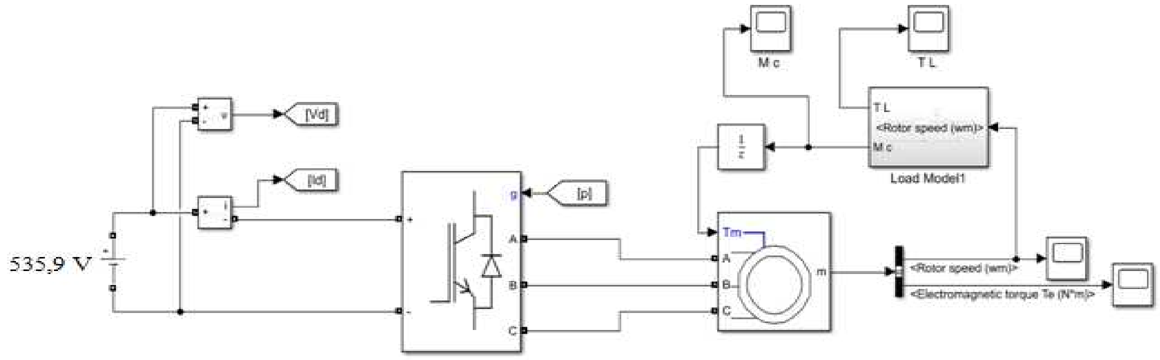

Fig. 3. Power part of the modernized electric drive model

The implementation of the fuzzy controller is proposed based on the Mamdani algorithm. The novelty of the proposed solution lies in the creation of a fuzzy controller not borrowed from the MATLAB Simulink library. A positive component of the proposed solution is the acceleration of the modeling process and the reduction of the required computing resource.

At the fuzzification stage, the following linguistic terms are accepted: M – small; C – average; B – big.

The initial rule base has the following logical representation:

1. If current M & consumed energy M, then set speed C & mixing time C & stopping time B;

2. If current M & consumed energy C, then set speed M & stirring time M & stopping time C;

3. If current M & consumed energy B, then set speed M & mixing time M & stopping time M;

4. If current C & energy consumption M, then set speed C & mixing time B & stopping time C;

5. If current is C & energy consumed is C, then set speed is C & stirring time is C & stopping time is C;

6. If current C & energy consumption B, then set speed C & mixing time M & stopping time M;

7. If current B & energy consumption M, then set speed B & mixing time B & stopping time C;

8. If current B & energy consumption C, then set speed B & mixing time B & stopping time M;

9. If current B & energy consumption B, then set speed C & mixing time C & stopping time M.

At the aggregation stage, degrees of truth for linguistic terms were found (Fig. 4).

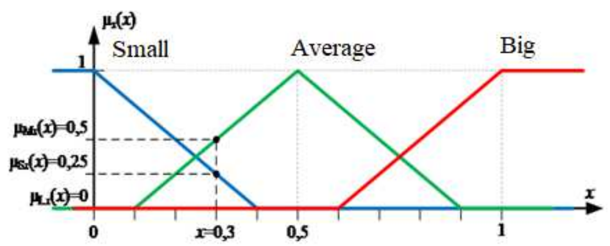

Fig. 4. Visual display of functions.

When activated, weighting coefficients were found for all sub conclusions. It is based on the Mamdani algorithm; when activated, the minimum function is applied (Fig. 5).

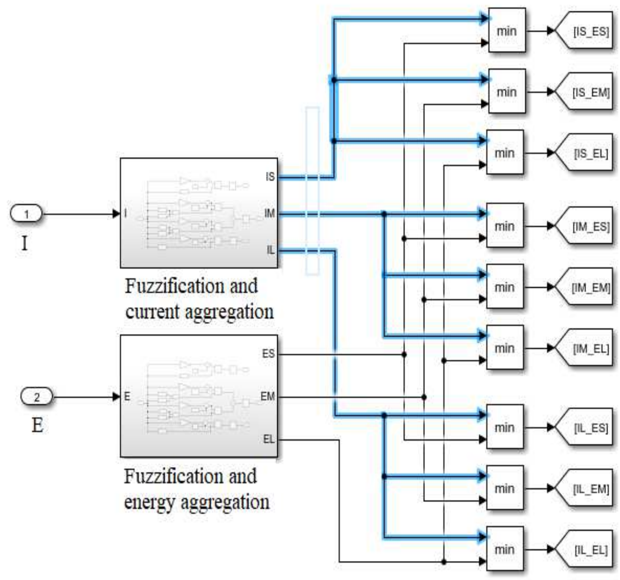

Fig. 5. Structures of the "aggregation" and "activation" blocks.

Next, at the accumulation stage, the above rules of fuzzy inference are used.

The last stage is defuzzification, in which clear values of the membership function are found by transforming fuzzy terms into clear data (Fig. 6).

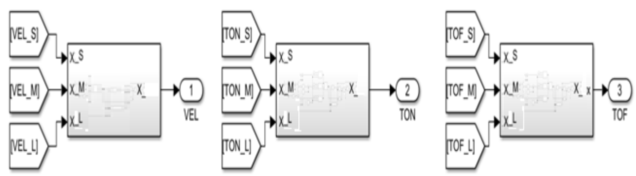

Fig. 6. Defuzzification system model.

When developing a fuzzy controller, the input signals of the fuzzy controller are scaled to conventional units, and the output signals are scaled to maximum values.

IV. Simulation Results

Simulation of a control system with the proposed fuzzy controller was carried out in the Matlab Simulink environment, the results obtained were compared with the original circuit. Fig. 7 shows velocity generation graphs. When using a fuzzy controller in a control system, 17 periods of speed control are formed within 30 seconds of operation. It is noticeable that the process is accompanied by speed control and consists of periods of mixing and waiting. Speed regulation occurs in the range of 80 – 140 rad/s, which corresponds to the terms "Medium" and "Large" of the regulator. The mixing time is adjusted in the period from 1 to 1.75 s, which also corresponds to the "Medium" and "Large" terms of the regulator. The waiting time regulation process is observed in the range from 0.2 to 0.6 s, which corresponds to the "Small" and "Medium" terms of the regulator.

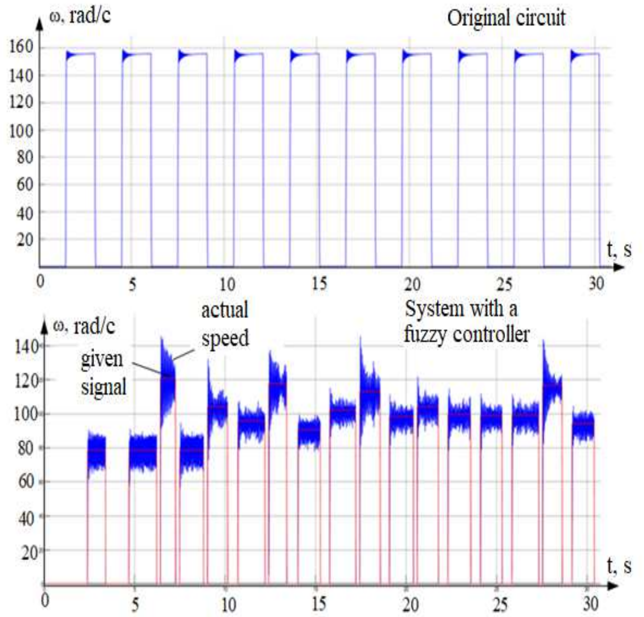

Fig. 7. Speed characteristics.

When using the original control system, the change in the load torque during mixing is proportional to the viscosity of the adhesive composition (Fig. 8), according to the technological process.

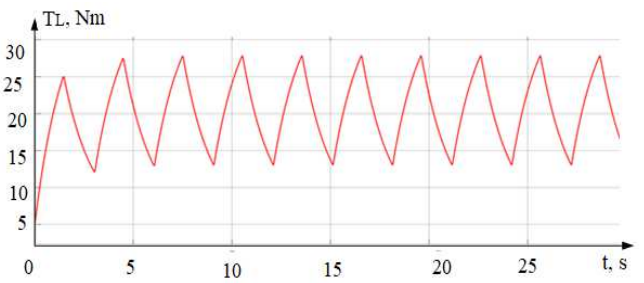

Fig. 8. Characteristics of the load moment in the original system.

When using a fuzzy controller in a control system, the regulation process is carried out by controlling the value of the starting current, and the load value is limited to 27 N·m. Load fluctuation when using a fuzzy controller is observed in the range of 16 - 25 N·m, whereas in the original system, load regulation occurs in the range from 13 to 27 N·m, these indicators are explained by the increased frequency of engine switching. The average shaft load for both control systems has almost the same value of about 20.25 N·m. An increase in engine rotation speed is accompanied by a rapid decrease in load, which is due to the nature of the load (Fig. 9).

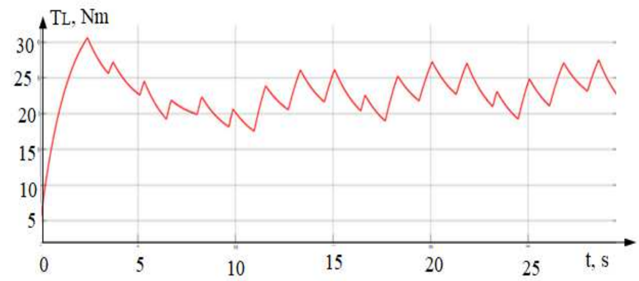

Fig. 9. Characteristics of load torque in a system with a fuzzy controller.

The formation of the energy consumption process when using the original control system is shown in Fig. 10. Horizontal sections of a fixed type correspond to the waiting period of the electric drive, at this stage the viscosity of the adhesive composition increases. The energy consumed by the electric drive during the mixing period is recorded by the integrator. At the initial stage of mixing, the energy accumulated by the integrator is reset, and then it increases abruptly, almost linearly, as the engine starts. A linear growth pattern in electricity consumption is observed throughout the entire period of mixing the adhesive composition.

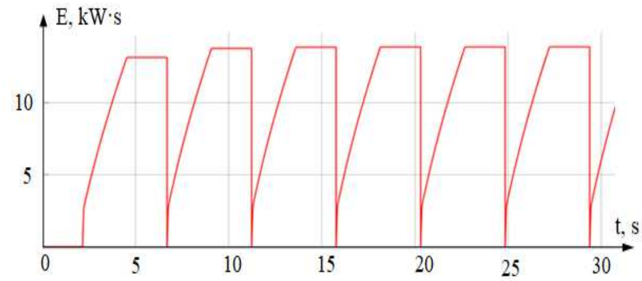

Fig. 10. Nature of energy consumption in the original system.

The use of a fuzzy controller in the electric motor control system leads to a reduction in electrical energy consumption during the mixing period (Fig. 11). In this case, the energy consumed by the electric drive is in the range from 5.2 to 7 kW·s, in contrast to the original control system, in which the value of the consumed electricity reaches 9.48 kW·s. Analysis of the graph shows that energy consumption during the mixing period decreases from 45.15 to 26.16 %.

After 30 seconds, in a system with a fuzzy controller, an energy consumption of 104.6 kW·s is observed, while in the original control system, which has fixed values of on-time periods and speed, the electricity consumption is 123.5 kW·s. Consequently, the use of a control system with a developed fuzzy controller leads to a reduction in electrical energy consumption by up to 15.3 percent.

Despite the fact that some indicators have been achieved to reduce energy consumption and reduce the starting current, there is an increase in the operating time of the electric drive with this type of control from 61% to 88%, while the standard control provides an on-time duration equal to 52.38%. Therefore, there is a need for additional analysis of the engine thermal balance.

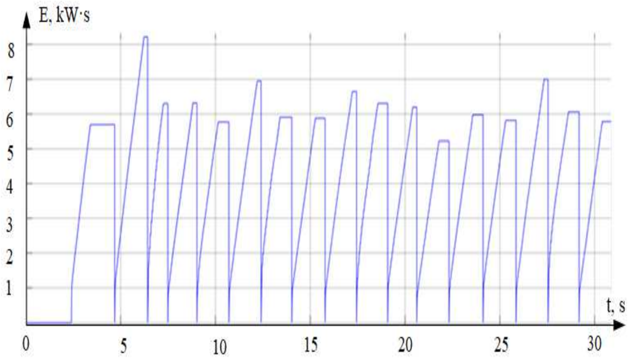

Fig. 11. The nature of energy consumption in a system with a fuzzy controller.

The use of a fuzzy controller leads to a decrease in electrical energy consumption over a period of 5.2 to 7 kW·s, while with standard control, electricity consumption was at the level of 9.48 kW·s. Therefore, the use of a fuzzy controller led to a reduction in electricity by 26.16 - 45.15%.

Following the presented outline in the list Chapter II, the practical implementation is done on the real object, shown in Fig.12.

A series of experiments was conducted during the implementation of the proposed control system, that included a fuzzy controller of the real object, shown in Fig.12.

This implementation in the practical mixing equipment permitted a strict control on the consumed energy, without being necessary to modernize the mechanical system of the equipment, nor to install sensors for velocity and position. The control was based exclusively on the data obtained from the current sensors, already available inside the frequency converter.

The obtained experimental data from the real modernized equipment coincided practically with the data obtained at modelling and simulation of the same object. The error was less than 1%.

Fig. 12. Real object implementation.

CONCLUSIONS

Based on the results obtained during the study, the following conclusions can be drawn:

- the proposed model of a system containing a fuzzy controller in its structure requires less computing power;

- the proposed system allows you to automatically calculate the mixing and waiting time using the regulator;

- due to the presence of a fuzzy controller in the system, the system automatically reacts to changes in load parameters and adjusts the adjustable parameters depending on the indicators of disturbing influences;

- the use of the developed regulator in the control system leads to a reduction in energy consumption.

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