IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
Volume 2, Issue 4, June 2020
Impact Factor: 4.819

Hybrid Power Supply System of Rotor-Type Electromagnetic Separator Windings with Incomplete Determination of Parameters Load

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Abstract: *Consideration is given to the control characteristics of rotating magnetic separators with a high gradient. There are provided structural schematics of control systems employing fuzzy logic controllers for high-gradient electromagnetic separation. A new structural diagram of the hybrid control system of the rotor-type electromagnetic separator, which combines conventional and intelligent control approaches, is proposed. Based on a rotary electromagnetic separator, it is demonstrated that the employment of hybrid control methods makes it possible to boost energy efficiency significantly in electrical technologies employing current sources in power circuits where system characteristics are uncertain.*

Keywords: Hybrid Automatic Control System, Fuzzy Logic Controller, High-Gradient Electromagnetic Separator Of The Rotor Type.

I. INTRODUCTION

In the current conditions of Ukraine's integration into world markets, there is a need to increase the energy efficiency of domestic industrial equipment, namely, to reduce energy consumption per unit of production and increase technological efficiency, that is, to significantly increase the quality of output products and the productivity of equipment, economic efficiency, as a result of those above, which means a reduction in the cost of production. All this is possible thanks to the intellectualisation of the management of electrical engineering complexes, which are the basis of any technological process.

Technological processes in which energy efficiency improvement gives the most meaningful results are electrical technologies with current sources in power circuits and electrical engineering complexes using frequency-regulated electric drives of various modifications. Preliminary estimates make it possible to claim that the intellectualisation of the control of technological processes will reduce energy consumption by up to 5% and increase the productivity of equipment by up to 10–15% ((Hartani et al., 2022); (Petrosov et al., 2022); (Atasoy et al., 2022); (Wang et al., 2023); (Meng et al., 2021); (Mishra et al., 2022)). Electrotechnical complexes that utilise current sources in power circuits occupy a significant role in the global industry, particularly in India, even though such technologies appear obsolete. They were designed and manufactured in the second half of the 20th century but are still in successful use today.

The most common and characteristic electro technological complexes with current sources in power circuits use stabilisation and regulation of the primary electrical technological variable - operating current. Such complexes include, first of all, complexes with high-gradient electromagnetic separators of the rotor type, in which the primary technical variable is the current in the magnetisation windings, as well as complexes that use stabilisation and regulation of the operating current in the primary or secondary windings of special transformers with a load that does not change linearly or has an undefined character in some areas of the dynamic operating characteristic. Such complexes include installations for the production of basalt staple superfine fibres, installations for electro slag remelting, installations for coating polymer films, installations for growing silicon single crystals, high-temperature resistance furnaces (vacuum furnaces), galvanic installations, electrolysis installations in non-ferrous metallurgy for the production of aluminium, magnesium, zinc, copper, nickel, electrolysis plants in the chemical industry for the production of chlorine, hydrogen, sodium, and nitrogenous substances.

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1.1 The Purpose

Work is a substantiation of the feasibility of using hybrid control methods in electrical technologies with current sources in power circuits using the example of an electromagnetic separator of the rotor type.

Today, high-gradient magnetic separation is the most promising technology for the beneficiation of weakly magnetic ores and placers, as well as deep cleaning of quartz and other sands at mining and beneficiation enterprises. Significant results were achieved by the scientific and technical centre of magnetic separation "MAGNIS" under the direction of R.S. Ulubabov (Luan et al., 2023), which, in collaboration with several domestic institutes and enterprises, in particular the Institute of Electrodynamics of the National Academy of Sciences of Ukraine, developed high-performance rotary separators for the enrichment of weakly magnetic ores (Liu et al., 2021). Figure 1 shows a simplified structural diagram of the technological separation process with a rotary separator.

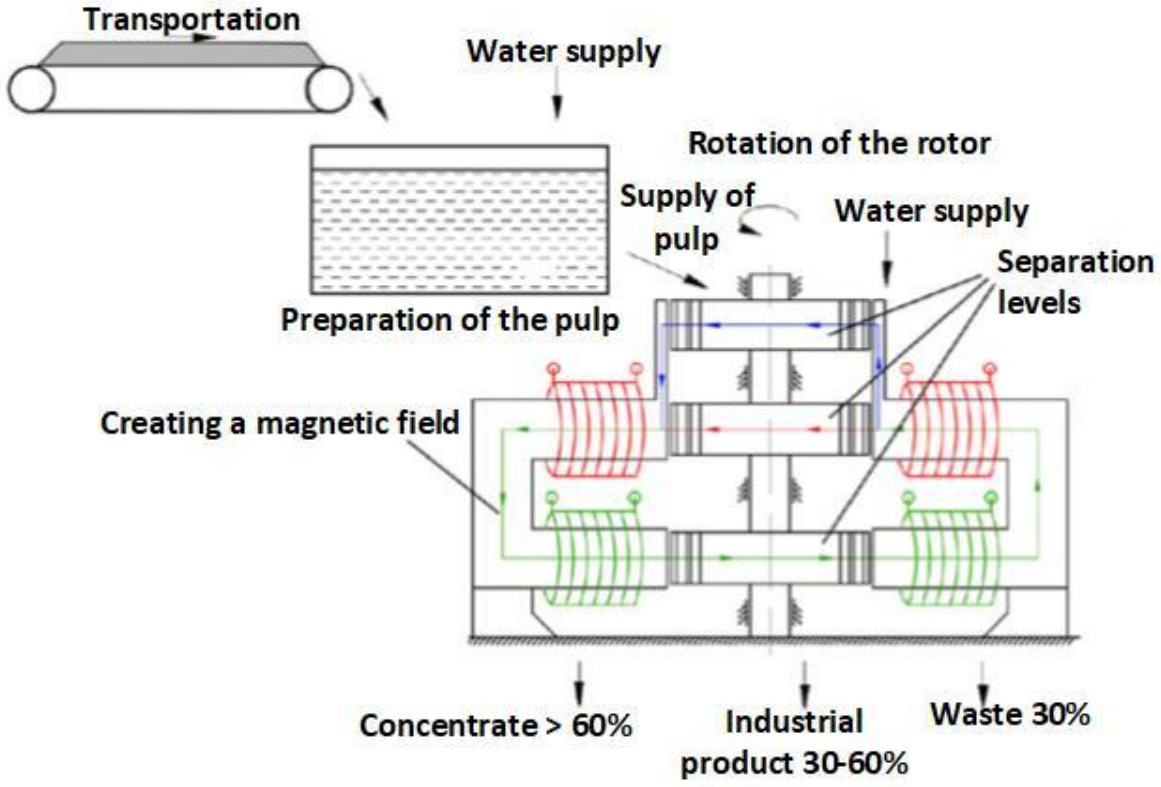

Figure **1**

In (Liu et al., 2021), a study of the influence of the technological parameters of separation, magnetic induction in the working zones B and the performance of the separator Q on the amount of co-rich ore in the initial magnetic product β was carried out. In addition to the dependence of the influence of the productivity value on the used power for various degrees of magnetic induction in the separator's working zones.

Given the complex interrelationship of ore enrichment indicators and their energy characteristics with the technological parameters of the separator, the non-linear nature of the dependence of the magnetic induction in the working zone of the separator on the value of the magnetising current of its windings and the unpredictable behaviour of the value of the magnetic permeability of the ore in conditions of uncertainty and complexity accurate mathematical description of the state of the object, the external environment and other factors, optimal control of the technological process based on classical optimal control systems with deterministic feedback does not seem possible.

The use of precise classic methods of regulating magnetic induction in the working zones of separators is hampered primarily by the low reliability of the description of the technological process, as it appears quite challenging to precisely describe all its details relating to the loading of materials with different properties that vary by hundreds of times. In addition, it is required to consider numerous disturbance elements, such as a change in the voltage of the power supply network, the ageing of the magnetisation windings, and temperature fluctuations, among others.

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Implementing optimal control algorithms for the nonlinear transmission characteristics of the separator by using regulators with linear continuous proportional-integral laws in the absence of complete and reliable information about the object of regulation leads to the complication of the regulator's structure, its adjustment and operation. The use of linear regulators in the electromagnetic separation system with non-stationary operating modes leads to a non-linear change of the control parameters. There is a need to solve the tasks of determining and repeatedly adjusting the control coefficients. Therefore, the solution to this task requires creating such a regulation system that would make it possible to get rid of multiple adjustments of coefficients and ensure the quality of the technological process regardless of the nonlinearity of the regulation parameters and fluctuations of external factors.

Therefore, a rotary separator control system based on fuzzy logic was developed, which consists of a concentrate quality controller (Zec et al., 2021) and a proportional-integral current controller in the windings (Ko & Youn, 1998). In fig. 2 and fig. 3 shows the corresponding functional diagrams. The fuzzy controller of the concentrate quality provides the specified value of the content of the valuable ore component in the total mass β at maximum productivity (Qmax), minimum energy consumption (Pmin) and minimum impact on the power supply network (THDmin) depending on the specified operating mode. At the controller's output, we have the performance task signals Qz, the currents of the upper and lower currents of the separator tiers. Thus, by controlling the quantity of productivity Q (rate of ore supply to the separation system) and the values of the magnetic induction of the upper Bvn and the lower Bvn of the tiers, we achieve control of the quality of the initial concentrate.

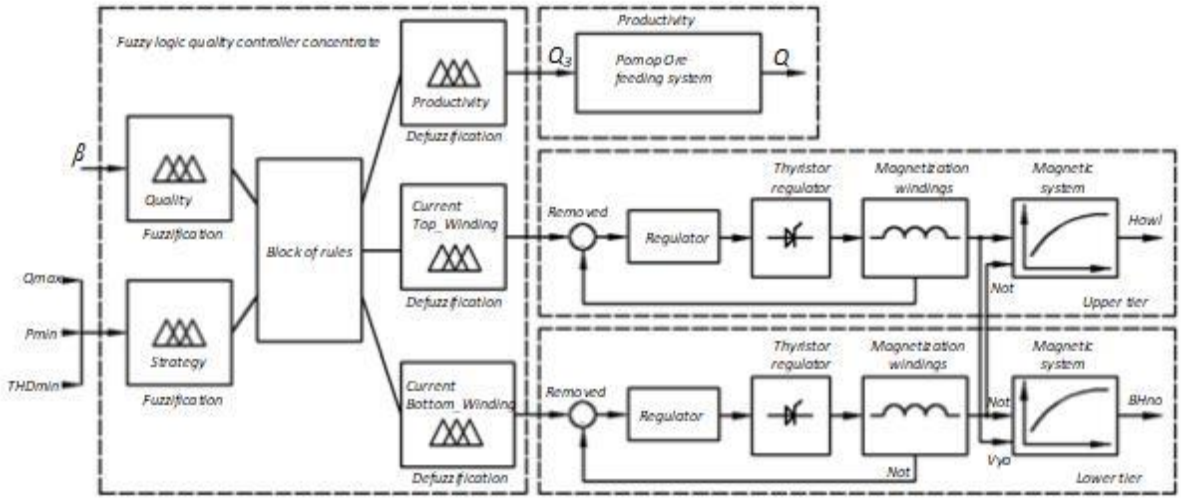

Figure **2**

The fuzzy proportional-integral current controller in the magnetisation windings of the electromagnetic separator because, in addition to the primary deviation control circuit, added current control circuits and their rate of change is introduced, ensures the desired quality of transient processes, the specified accuracy in steady-state modes, and the speed of the system response in emergency modes.

DC regulators with a fuzzy logic-based control system developed at the Institute of Electrodynamics of the National Academy of Sciences of Ukraine and manufactured at the enterprise "Scientific and Technical Firm "TEMS" were implemented by the scientific and technical centre of magnetic separation "MAGNIS" as part of electromagnetic separators of the rotary type "MAGNIS ERM" on several mining and beneficiation plants and mines in Ukraine, Kazakhstan, and other countries. Regulators with hybrid control have proven their effectiveness. Thus, in the energy-saving mode of use, the developed method makes it possible to ensure the quality of the initial concentrate at the level of β=52% while reducing energy consumption by 2.7 times, and, for example, in the emergency mode, the duration of the system shutdown is significantly reduced compared to the traditional way. Thus, the time of the voltage transient is reduced by fifteen times and the current – by 7.5 times.

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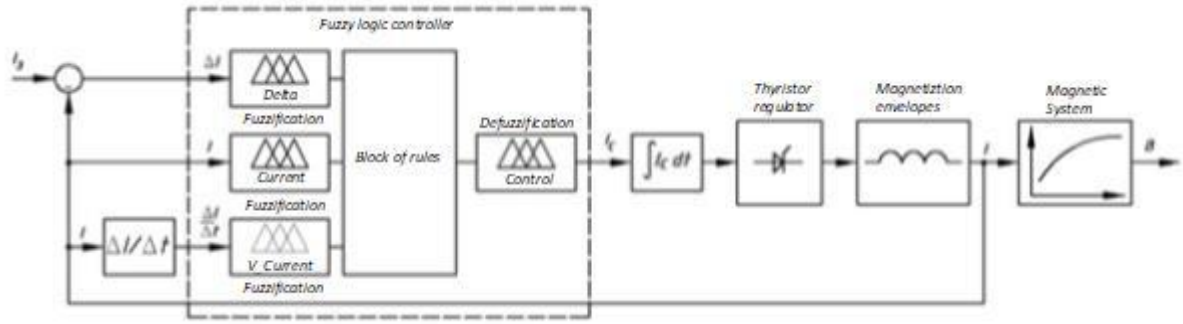

Figure **3**

As we can see, the most important task during the development of modern technical means of automatic control of technological processes is to increase the efficiency of managing technological objects. At the same time, two main factors hinder the improvement of control efficiency and the quality of regulation: the instability of the parameters of the control object during operation and the requirements for the quality of law, which are constantly changing. To solve such control tasks, it is possible to apply intelligent hybrid systems, which can simultaneously use the advantages of traditional control tools and artificial intelligence methods. The intellectualised hybrid control system examined in this study is governed by the law of transformation, according to which a new knowledge structure of the system is derived from the previous one.

Thus, the hybrid system must be considered a system of data processing and interaction consisting of two levels. The intellectualised hybrid control system examined in this study is governed by the law of transformation, according to which a new knowledge structure of the system is derived from the previous one. Two-level positioning makes it possible to consider the general design of the data processing system from different points of view; at the same time, the interaction of the elements (components) of the structure is not only mechanical or electrical in nature but also informational, which is an essential attribute of modern organisational and technical systems. The analysis of the development of hybrid control systems makes it possible to conclude that the models used within hybrid systems are implemented separately depending on the set goal. In particular, the hybrid system based on the everyday use of classical and fuzzy controllers is depicted as a block diagram in Fig. 4.

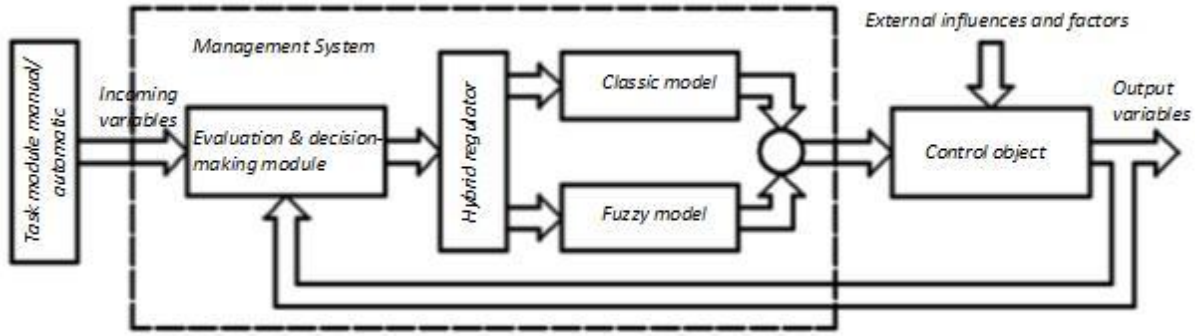

Figure **4**

The proposed intellectualisation of the management of technological processes helps increase domestic industrial equipment's energy and technical efficiency. In the technological process of high-gradient magnetic separation, only analogy or digital proportional-integral-differential regulators were previously used, configured for optimal control of the object under specific conditions that do not change. Using such regulators with incomplete certainty of the technical parameters of working environments must meet modern requirements. To accurately carry out the control process, there is a need for operational changes in the tuning coefficients of the proportional-integral-differential regulator, which are associated with changes in the parameters of the technological load, with changes in the composition and quality of raw materials in the technical process, with ageing and wear and tear of equipment, with changes environmental parameters. In addition, the absence of overregulation is essential, which indirectly leads to energy savings.

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Given this, the main requirements for regulators are self-determination of the type of object, automatic selection and correction of regulation parameters during operation, and minimum reaction time to changes in operating modes. Thus, the issue of applying effective regulation methods based on a deterministic description of the state of regulation objects and applying the principles of adaptive control (which ensures optimal regulation in the case of an unknown and unpredictably changing mathematical model of the thing) becomes relevant.

Any technological process can be divided into two parts (stages) - the development of a mathematical model and the synthesis of a control system. For a portion of the technological process in which large time constants characterise the control operations of the electrotechnical complex, it is recommended to create a classical model of the control object and a continuous control system. For the other part of the technological process, in which the control operations of the electrotechnical complex are characterised by small time constants or the uncertain nature of parameter changes, it is recommended to create a fuzzy model of the control object and an adaptive (innovative) control system. The magnetisation winding control subsystem and the higher-level electro technical complex control system can be clearly distinguished in the considered electro-technological process of high-gradient magnetic separation. Thus, the hybrid intelligent control system of the complete technological process contains classic and fuzzy models of the control object.

The creation of a system of intelligent control of electrotechnical complexes includes the development of mathematical models, strategies, methods, synthesis and production of control systems and means, which requires unique and general knowledge that takes into account the existing interrelationships between electric, magnetic, technological parameters (variables) and forms knowledge bases about these relationships based on experimental and computational studies with incomplete certainty of technical characteristics.

II. CONCLUSION

Using the technological process of high-gradient electromagnetic separation, as an illustration, it is proved that the use of hybrid control methods makes it possible to significantly increase energy efficiency in electrical technologies with current sources in power circuits that have uncertain system parameter knowledge. Thus, the introduction of regulators with hybrid control in installations with electromagnetic rotary separators makes it possible to maintain the quality of the initial concentrate at a level of =52 per cent while reducing energy consumption by 2.7 times. In the emergency mode, the duration of the system shutdown is reduced by fifteen times compared to the traditional method and the current - by 7.5 times. The use of a new structural diagram of the hybrid control system of electrotechnical complexes with current sources in power circuits and with frequency-regulated electric drives in future developments makes it possible to combine the advantages of classical and intelligent methods.

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