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FUZZY PROCESS CONTROL OF SUPPLY AND DISTRIBUTION OF ASPHALT MIX WITH THE PAVER

АСФАЛЬТБЕТОН ҚОСПАСЫН АСФАЛЬТ ТӨСЕУІШПЕН БЕРУ ЖӘНЕ ТАРАТУ ПРОЦЕСІН АНЫҚ ЕМЕС БАСҚАРУ

НЕЧЕТКОЕ УПРАВЛЕНИЕ ПРОЦЕССОМ ПОДАЧИ И РАСПРЕДЕЛЕНИЯ АСФАЛЬТОБЕТОННОЙ СМЕСИ С ПОМОЩЬЮ АСФАЛЬТОУКЛАДЧИКА

Аңдатпа. *Анық емес басқару жүйесінің құрылымы асфальтбетон қоспасын асфальт төсегішпен тасымалдау және таратудың ішкі жүйесі мысалында зерттеледі. Анық емес PID реттегіші жасалды. Басқару объектісінің имитациялық моделі және MATLAB & Simulink бағдарламалық ортасындағы анық емес кері байланысты басқару жүйесінің моделі әзірленді. Анық емес және цифрлық PID реттегіші бар басқару жүйесінің жұмысын модельдеу және салыстырмалы талдау. Қоспаны беру мен таратуды басқару жүйесінің анық емес контроллері MATLAB & Simulink-те, контроллер үшін логикалық ережелерді әзірлеу арқылы жүзеге асырылады.*

Түйін сөздер: *интеллектуалды басқару, анық емес контроллер, анық емес контроллер синтезі, PID контроллері, симуляциялық модель, фидер жылдамдығы, шнек, қырғышты фидерлер, асфальт төсеуіш.*

Аннотация. *Структура нечеткой системы управления изучается на примере подсистемы транспортировки и распределения асфальтобетонной смеси асфальтоукладчиком. Разработан нечеткий PID-регулятор. Разработана имитационная модель объекта управления и модель системы управления нечеткой обратной связью в программной среде MATLAB & Simulink. Моделирование и сравнительный анализ работы системы управления с нечетким и цифровым PID-регулятором. Нечеткий контроллер системы управления передачей и распределением смеси осуществляется в MATLAB & Simulink, путем разработки логических правил для контроллера.*

Ключевые слова: *интеллектуальное управление, нечеткий контроллер, нечеткий синтез контроллера, PID контроллер, симуляционная модель, скорость фидера, шнек, скребковые фидеры, асфальтоукладчик.*

Abstract. *The structure of a fuzzy control system is studied by the example of a subsystem for the transportation and distribution of asphalt concrete mix by an asphalt paver. A fuzzy PID controller was developed. A simulation model of the control object and a model of the fuzzy feedback control system in the MATLAB & Simulink software environment have been developed. Modeling and comparative analysis of the operation of a control system with a blurred and digital PID controller. The fuzzy controller of the mixture* *transmission and distribution control system is implemented in MATLAB & Simulink by developing logical rules for the controller.*

Keywords: *intelligent control, fuzzy controller, fuzzy controller synthesis, PID controller, simulation model, feeder speed, auger, scraper feeders, paver.*

Introduction. The road industry in Kazakhstan is characterized by reform processes. It is necessary to improve the organization of road construction, improve the quality of materials and increase the efficiency of the technology of road pavement construction.

Improving the quality of asphalt concrete road surfaces depends on many factors. It is known from scientific works that up to 50% of road surface defects can be eliminated by providing a greater degree of compaction. Asphalt concrete pavement compaction is provided successively by an asphalt paver, asphalt road rollers: light; medium; heavy. The world's leading states: USA; Japan; Germany, etc.

An asphalt paver is a linear road construction machine designed for receiving the mixture into a hopper, transporting and distributing the mixture along the width of the pavement, profiling and compacting the road surface. Considering the stacker as a control object, it can be characterized as a complex technical system consisting of several branches of automatic control systems.

The advertising materials of companies producing asphalt pavers inform about the offers of automated, intelligent machines. At the same time, modern asphalt pavers are equipped with automatic control systems (ACS) leveling working equipment to obtain the necessary profile of the roadway and the evenness of the coating. The remaining functions in the stackers have a hydraulic drive with electric slide control.

The relevance of the topic of the work is due to the need to develop an effective automatic control system for the process of uniformity of the supply and distribution of the mixture flow by the paver.

The theoretical basis for creating an automated stacker is TAU and mathematical modeling methods. Modern ACS are equipped with programmable logic controllers. Also, for control objects with processes with increased complexity, it is recommended to use artificial intelligence technologies for description. Studies on models of fuzzy regulators of speed control systems for road rollers are known from foreign publications.

For the control object under consideration – an asphalt paver, it is possible to suggest using a fuzzy controller for the control system of the subsystem of transportation and distribution of the mixture along the width of the pavement.

The transportation of the mixture is carried out by a scraper feeder, and the distribution over the width of the coating is carried out by a screw distributor.

The properties of fuzzy logic to process incomplete information, simulate human knowledge and provide informed solutions suggest its intensive use for real-time monitoring of technological processes, as well as solving problems related to the practical implementation of process control systems. The use of fuzzy logic in control systems makes it possible to reduce operator interference in the control process and, therefore, allows the development of new control methods more adapted to the industrial environment.

Regulators built on the basis of fuzzy logic, in some cases, are able to provide higher quality indicators of transients compared to classical regulators. In addition, using methods of synthesis of fuzzy control algorithms, it is possible to optimize complex control circuits without conducting comprehensive mathematical research.

Literature Review

In a system that is unclear to researchers, the ways of controlling the operational structure of an asphalt paver through various paths are considered. Based on this, N.N. Zuikova (2016) developed a web speed control system with a fuzzy controller in research works [1], however, the system is not suitable for a density system only because it regulates the speed of the web, and proposed the efficiency of using a fuzzy controller when controlling the speed of the web [3]. Simulation of a digital control system for the laying speed [4]. Amadore A., Bosurgi G. and Pellegrino O. In the work (2018) [2], data on the compaction of asphalt concrete from a hot mixture using fuzzy clustering methods were analyzed. The method helps to improve the quality of asphalt. In the study of Moazami D., Behbahani H. and Muniandi R. (2011) [5] proposed a system for restoring the road surface and prioritizing road maintenance using fuzzy logic. This system is effective for urban roads, not for large highways. Suman, S. K. and Sinha, S. (2017) [6] developed a road surface maintenance regime using a fuzzy logical inference system. The mode in a fuzzy logic system is suitable for road maintenance in warm regions of Kazakhstan.

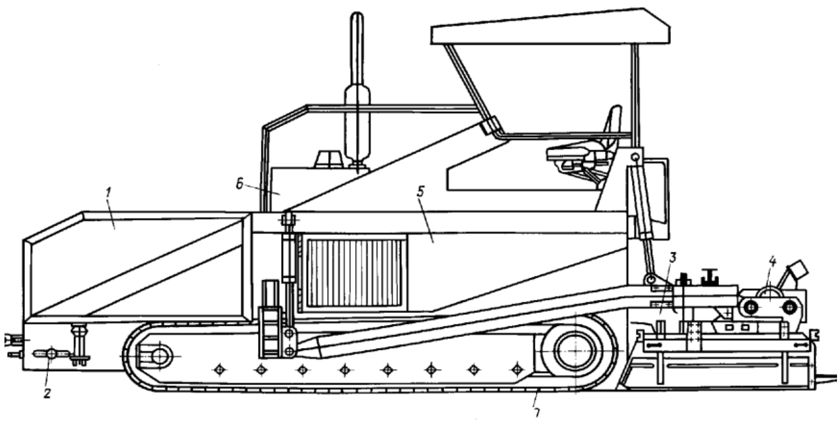
Materials and methods of research.

The principle of operation of the paver is shown in Figure 1.

The crawler paver consists of a receiving hopper 1, feeders 2, distributing augers 3, a sealing working body 4 mounted on a self-propelled crawler chassis 5 with an engine 6, pumps for the drive of feeders and distributing augers 3, a drive mechanism for hydraulic propellers 7.

The following process occurs[1]:

Asphalt concrete mixture is fed into a special receiving hopper 1 of the paver. The feed is carried out from the dump truck body, which is moved during unloading by the pushing force of the stacker rollers. From the receiving hopper, the mixture is constantly fed through an adjustable discharge opening by scraper feeders 2 into the screw chamber, from where, using augers 3, it is evenly distributed over the surface of the pavement and over the entire width of the laying. The amount of mixture coming from the hopper is regulated by the position of the damper, installed at different heights by adjusting screws. With the help of a block of working bodies, which includes a ramming beam and a smoothing plate, profiling, pre-sealing of the layer to be laid and finishing of its surface are provided. To obtain a given transverse profile (flat horizontal, single–pitched or double-pitched), the smoothing plate is divided into two parts along the length, connected at the bottom by a hinge, and at the top by a screw screed [2].



Picture 1 . Technological scheme of the asphalt paver

This article is a continuation of the source [3], where the functions and properties of an asphalt paver, which is a self-propelled machine on a rammed or asphalt road, were investigated as an object of control (OU). The asphalt paver includes a hopper for the supplied mixture, screw feeders, front and rear frames, a cab, a digital surface treatment mechanism for regulating laying. The working body (executive body) of the paver is a ramming bar with a built-in vibration exciter [4]. Here the authors of the article consider the results of research on the properties of the developed simulation scheme for controlling the speed of the paver.

The first condition is to describe the operating conditions of the developed model of its hydraulic transmission [5]. The development of the transmission simulation model was carried out in the MATLAB environment with the integration of two other libraries: SimMechanics and SimHydraulics. The Fuzzy Logic Toolbox library was used to develop a fuzzy controller of a closed system. The main blocks used for modeling are shown in Figures 2-5.

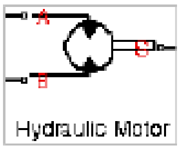


Figure 2. Hydraulic motor simulation unit

Figure 3. Block, simulation of a hydraulic pump

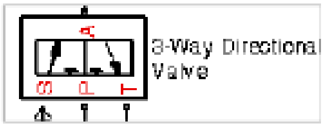


Figure 4. Block, simulation of a three-position hydraulic distributor

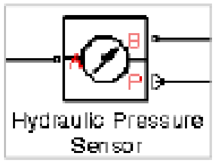


Figure 5. Pressure sensor simulation unit

The block diagram of the nonlinear control system is shown in Figure 6.

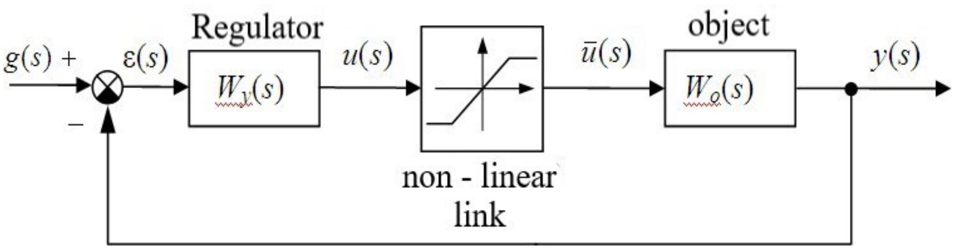


Figure 6. Block diagram of a nonlinear control system

The block diagram of the digital controller is shown in Figure 7.

The ADC is an analog-to-digital converter, and the DAC is a digital–to-analog converter [6].

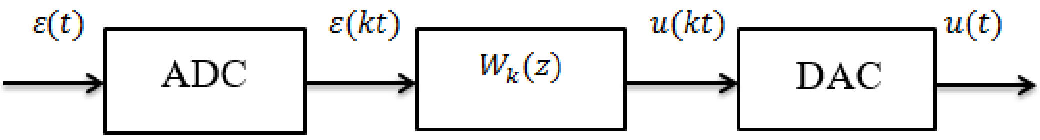


Figure 7. Block diagram of a digital PID controller

The model of the digital PID controller in MATLAB&Simulink will look like this:

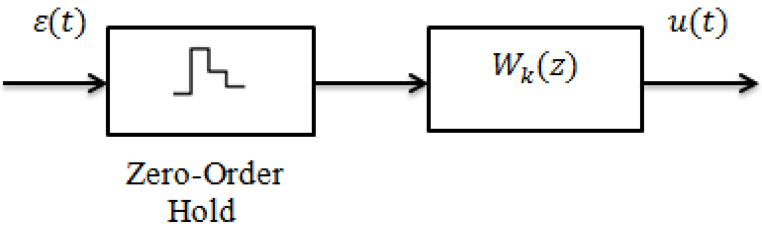


Figure 8. Digital controller diagram

The system of automatic supply and distribution of asphalt concrete mixture includes [7]:

– hydraulic distributor of the feeder drive;
– screw drive hydraulic distributor;
– hydraulic motor of the feeder drive;
– hydraulic motor of the screw drive;
– hydraulic pump of the feeder and auger drive;
– feeder speed sensor;
– screw rotation speed sensor;
– volume sensor;
– control unit (feeder);
– control unit (auger);

In the process of feeding and distributing asphalt concrete mix, it is necessary to control the equipment by the speed of movement of feeders and by the speed of rotation of augers.

The main requirements for the system include:

• ensuring the supply of the required volume of asphalt concrete mixture (speed control of feeders);

• ensuring the required speed of asphalt concrete mix distribution (control of screw rotation speed);

• easy to set up when working with the system[8].

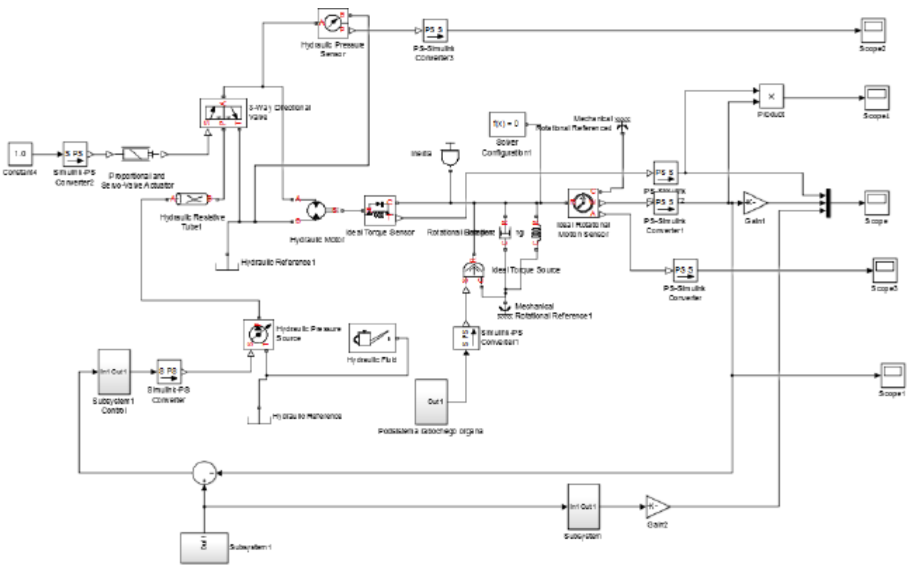


Figure 9. Simulation diagram of an asphalt paver

Two types of controller are used in the simulation model: digital and fuzzy PID controller. The digital controller operates on the basis of calculated coefficients. A control error is received at the input of the digital controller. The fuzzy controller works on the basis of a compiled knowledge base and the transfer function of the control object.

The regulators are combined into subsystems Subsystem Control (digital controller) and Subsystem (fuzzy controller). The readings are taken from the Scope oscilloscope[9]. The model of the analog PID controller is shown in Figure 9.

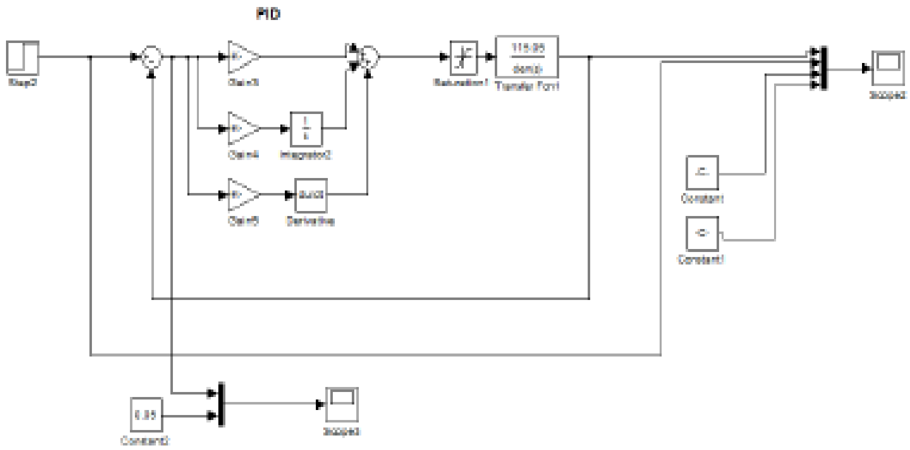


Figure 10. Simulation model of an analog PID controller

Results and discussion.

The purpose of this study is the fuzzy control of the process of feeding and distributing asphalt concrete mix of the asphalt laying machine by a PID controller built on the basis of Matlab&Simulink with logical rules written in the Fuzzy Logic environment. Then it is selected based on expert responses, such as sealing, overlap, redevelopment, etc. In the elements of the asphalt concrete mixture.A linear membership function is widely used is triangular membership function and the corresponding fuzzy numbers are called Fuzzy Numbers.

From expert opinions taken from Table 1, values of each kind of membership function are compared, and assisted by maintenance standards to get the final value for building up the model. The type of membership function is Triangular, the analyzed value is the boundary value, and the mean is the central value, marking the shape and interval of each membership function in the Fuzzy Logic Model.

Table 1. Rule Base of Fuzzy logic Inference System

Parameter	MF	Attribute	Function value			Universe of discourse
			Left	central	Right	
Pothole	Triangular	None	0	0	0	0-30 cm
		Low	0	10	20	
		High	20	30	30	
Crack	Triangular	Good	0	0	5	0-20 %
		Fair	5	7.5	10	

		Poor	10	15	20	
		Very poor	20	40	40	
Parameter	MF	Attribute	Function value			Universe of discourse
			Left	central	Right	
Roughness	Triangular	Very good	0	0	2	0-6 m/km
		Good	2	2.5	3	
		Fair	3	3.5	4	
		Poor	4	5	6	
Rutting	Triangular	Very good	0	0	5	0-100 mm
		Good	5	7.5	10	
		Fair	10	17.5	25	
		Poor	25	37.5	50	
		Very poor	50	100	100	
Quality	Triangular	Very good	100	100	90	0-100 %
		Good	90	85	80	
		Fair	80	70	60	
		Poor	60	50	40	
		Very poor	40	40	0	

The fuzzy logic inference engine consists of a rule base and a database Table 2. The data base defines the membership function of the fuzzy sets used as values for each system variable and the rule base maps fuzzy values of the input to fuzzy values of the output. These rules are expressed in an If-Then format.

Table 2. Rule Base of Fuzzy logic Inference System

If Pothole	And Crack	And Rutting	And Roughness	Then Quality
None	Good	RUT≤5	≤2	Very Good
Low	Good	RUT≤5	≤2	Fair
High	Good	RUT≤5	≤2	Poor
None	Poor	5< RUT≤10	2<IRI≤3	Poor
Low	Poor	5< RUT≤10	2<IRI≤3	Poor
High	Poor	5< RUT≤10	2<IRI≤3	Very Poor
None	Fair	5< RUT≤10	3<IRI≤4	Fair
Low	Fair	5< RUT≤10	3<IRI≤4	Fair
High	Fair	5< RUT≤10	3<IRI≤4	Poor
None	Poor	10<RUT≤25	3<IRI≤4	Poor
Low	Poor	10<RUT≤25	3<IRI≤4	Poor
High	Poor	10<RUT≤25	3<IRI≤4	Poor
None	Fair	25<RUT≤50	4<IRI≤6	Poor
Low	Fair	25<RUT≤50	4<IRI≤6	Poor
High	Fair	25<RUT≤50	4<IRI≤6	Poor

However, to be simpler, the model uses only the AND operation among input parameters, And methodisM in, Implementation method is Min, Aggregation method is Max and in Defuzzification operator is recommended by ways: Center of Gravity (COG) Defuzzification (Centroid). Analysis of adopted parameters was carried out on MATLAB software.

Parameters of the PID controller: $K_p = 1.756, K_I = 0.723, K_D = 0.41$ The graph of the transition process of the PID controller is shown in Figure 11. The time to enter the 5% zone of the set value of the output signal of the regulator is about 0.8 s and there is no overshoot [10]. The simulation model of the digital PID controller is shown in Figure 12.

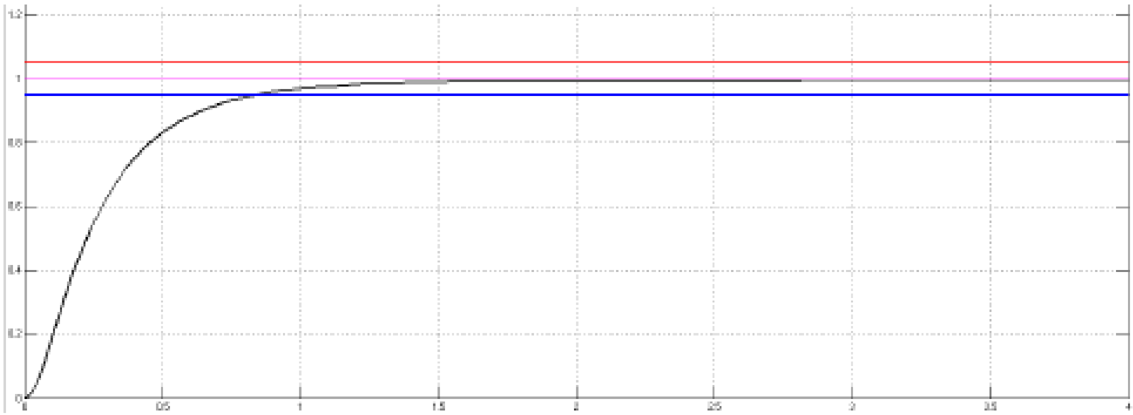


Figure 11. Graph of the transition process of the analog PID controller

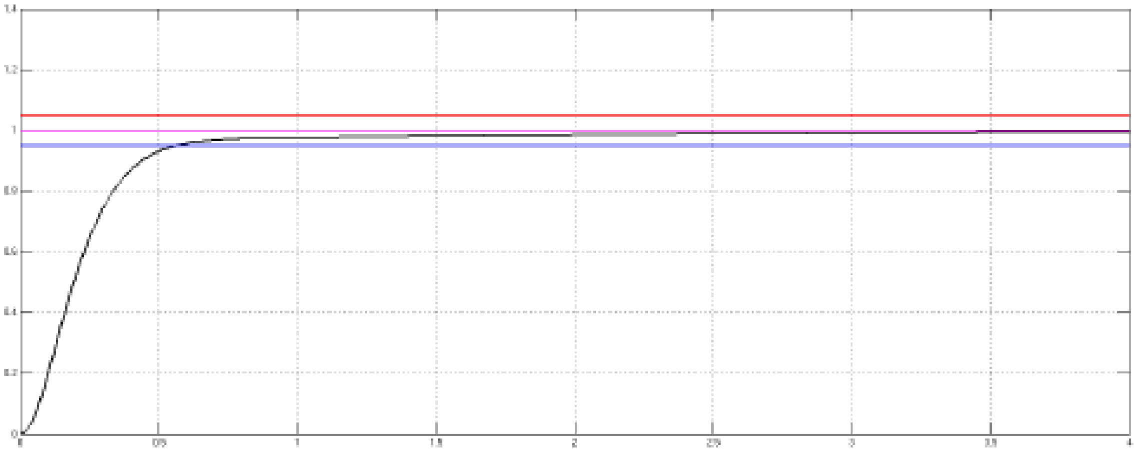


Figure 12. Diagram of the transition process of the digital PID controller

The synthesis of the parameters of the digital controller determined their following values: $T = 0.005s,\ K_p = 125.641, K_I = 248.634,\ K_D = 123$ the time to enter the 5 % zone was 0.6 s. There is also no overshoot [11].

The simulation model of the fuzzy controller of the object [5] is shown in Figure 10. To maintain a constant simulation step and eliminate overshoot, a Transfer Fcn block has been added at the input. The fuzzy controller is modeled by the Subsystem block.

This model is constructed by adding an analog controller to the model (Figure 8) a fuzzy logic block (Figure 12). The Fuzzy Logic Controller block simulates the operation of the fuzzy logic block . The block parameters specify the name of the file in which the fuzzy rules are set [12] (Figure 13).

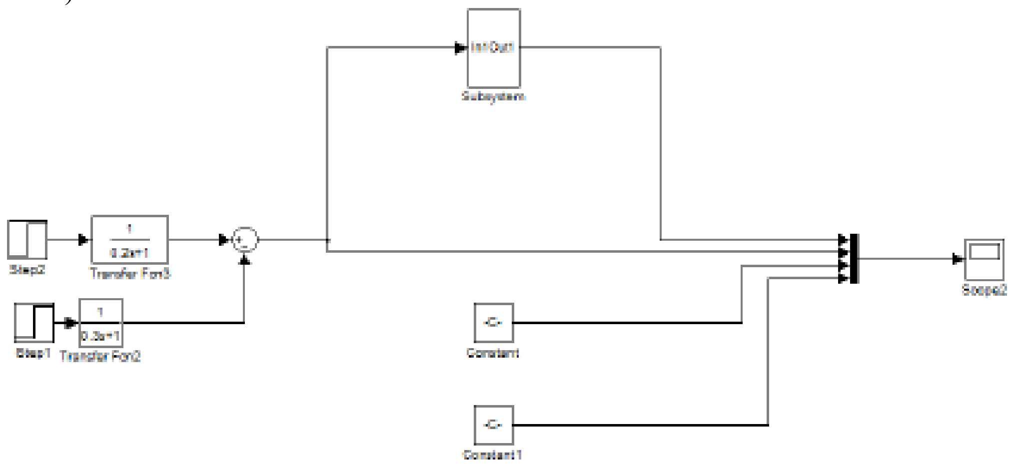


Figure 13. Simulation model of a fuzzy controller

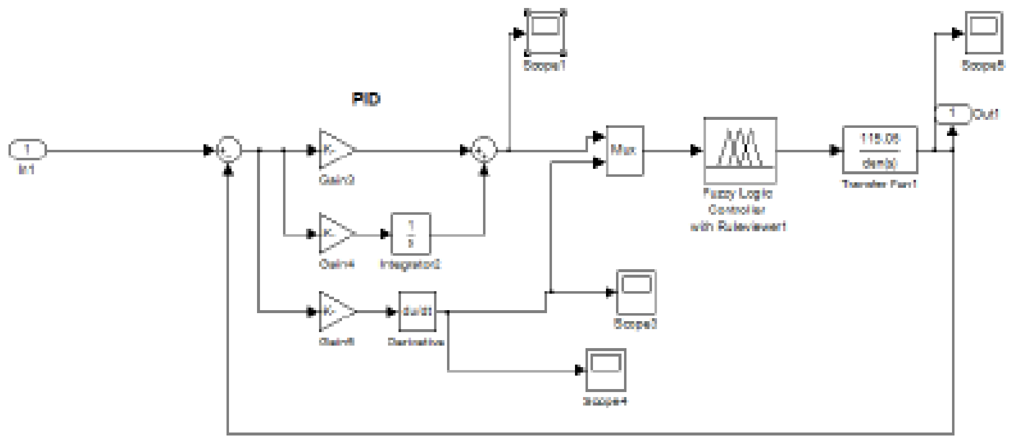


Figure 14. «Subsystem» with Fuzzy Controller

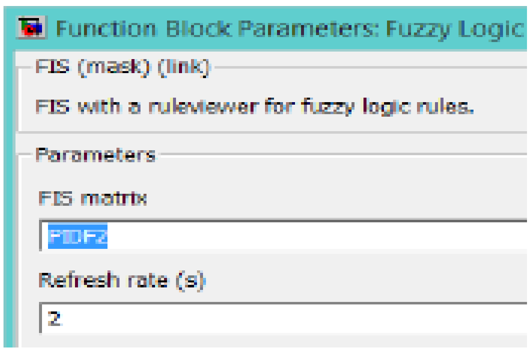


Figure 15. Fuzzy Controller Block Properties

Before the simulation is carried out, Rules are added to the workspace of the MATLAB environment. To do this, open the Rules editor window via the File → Export → menu To Workspace.

Next, the name of the exported file is specified and the export is confirmed. A file with the specified name [13] will appear in the workspace. The graph of the transition process of the fuzzy controller is shown in Figure 14.

It can be seen that there is an overshoot on the graph calculated by the expression:

$$.y = \frac{y_{max} - y_{ins}}{y_{ins}} * 100\% = \frac{12{,}5 - 12}{12} * 100\% = 4{,}2\% \quad (1)$$

Over-regulation does not exceed the permissible norm of 5%. The developed models of digital and fuzzy PID controller allow modeling the process of regulating the speed of the paver [14].

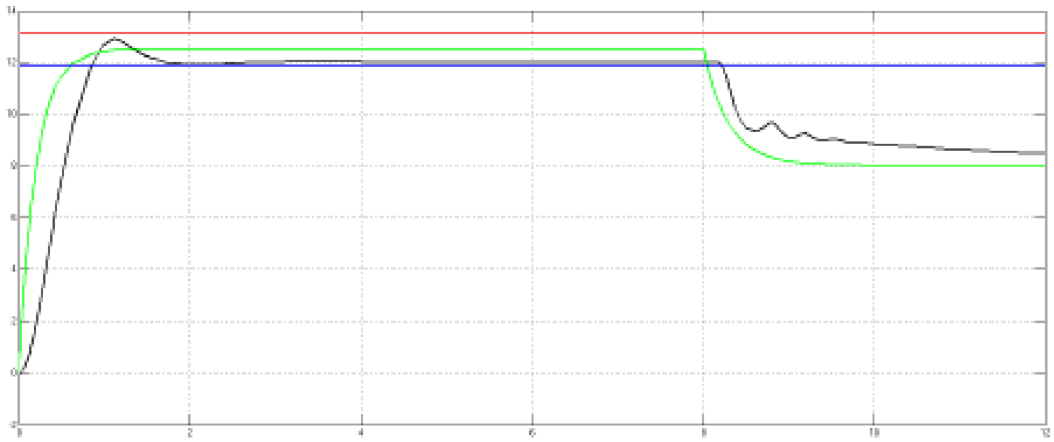


Figure 16. Graph of the transition process of a fuzzy PID controller

For such a process, two types of Rules are compiled with different values of the membership function (OP) of the output variable. The structures of the knowledge base of the output variable are shown in Figures 17-19. Graphs of changes in the speed of the paver are shown in Figures 18-20 [15].

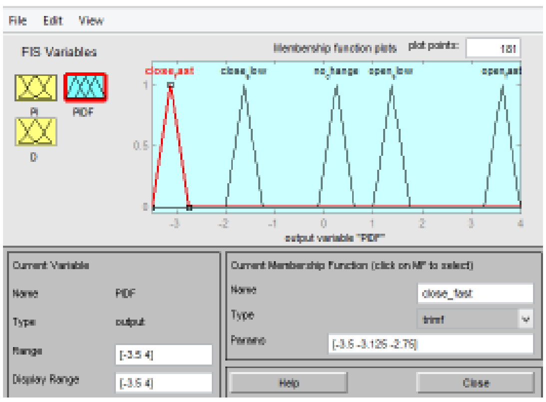


Figure 17. The structure of the knowledge base with disjoint terms of the output variable FIS 2

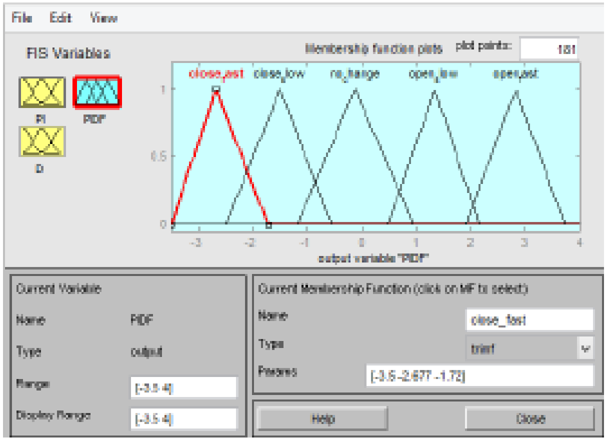


Figure 18. The structure of the knowledge base with overlapping topics of the output variable FIS 21

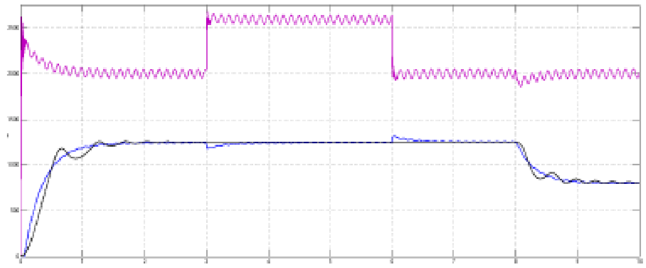


Figure 19. Speed change graph with FIS 2 rules

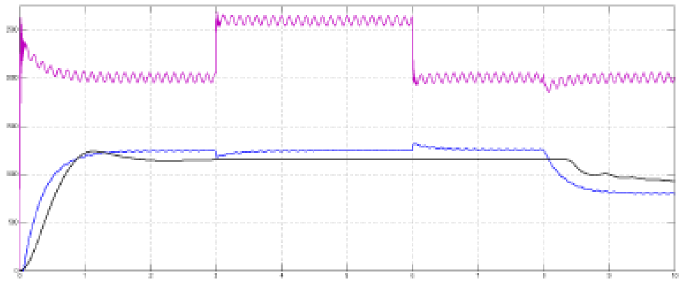


Figure 20. Speed change graph with FIS 21 rules

The purple color (Figure 17) shows the change in the moment of inertia of the system. The graph of the speed change relative to the moment change with an analog PID controller is shown on the graph with a blue line, the black line shows the working out of the speed according to the compiled Rules. The graphs show that with an increase in the range of variation of the output function, the graph of the change in the speed of the paver changes. At the same time, overshoot is reduced, even the practical elimination of velocity pulsation is noticeable (Figure 19). The performance of a system with a fuzzy controller is much better than the performance of a system with a digital PID controller[16].

Thus, as a result of the research conducted by the authors of the mode of operation of the paver, the dynamics of the asphalt concrete pavement construction process was analyzed. The positive results obtained are formulated by the following conclusion:

1. Rules have been developed in accordance with the established norms in the Fuzzy Logic Toolbox function in the Matlab&Simulink environment
2. According to the rules in Fuzzy Logic Toolbox, the structure of distribution and regulation of the asphalt paving machine mixture using a PID controller has been developed
3. The resulting model and his work made it possible to develop a system for controlling the speed of the paver, namely, obtaining a mathematical model of the OP in terms of the space of state variables.
4. The parameters of the transfer function of the OP are determined when controlling the speed of the paver and evaluating its dynamic characteristics.
5. The parameters of a fuzzy PID controller are synthesized and a simulation scheme of an object with a fuzzy controller is compiled.
6. A new task of the resulting control system is formulated so that the maximum value of the speed of the paver in relation to the steady-state value in transient modes does not exceed 8% in the entire control range.
7. In the controlled system of the speed of movement of the op-amp, the transition time when working out the task at a speed of 1 rad/ s did not exceed 1 s.
8. The models obtained in the MATLAB environment are adequate, since the parameters according to the simulation results practically correspond to their real values.
9. Also, the compiled simulation models of the process of controlling the speed of an asphalto-stacker with digital and fuzzy PID controllers using Simulink and SimScape & Fuzzy Logic Toolbox packages were investigated.
10. The OU controller does not distort the control processes and provides astatic regulation of the speed of the paver in a given range.
11. The practical independence of the change in the speed of the paver from the main disturbing influences is revealed.

Conclusions.

In conclusion, the structure of the technical system on the example of transportation subsystems and the distribution of asphalt concrete mix with asphalt concrete cover. Theoretical bases of application of non-linear logic in control systems are considered. Developed functional and structural schemes of systems of management of processes of transportation and distribution of mixtures. There is a design of a non-precision regulator for the system under consideration. An imitation model of an automatic (intelligent) automatic control system with feedback was obtained in the MATLAB & Simulink environment. Computer simulation of control systems with PID-regulator and non-regulator as an object of control in the studied range of variation. Conducted a comparative analysis of the results of modeling the work of control systems with the considered regulators. Implementation of a non-linear regulator model in the language of a programmable logic regulator based on the schemes and principles of operation of a non-linear system obtained using MATLAB & Simulink.

The result of this study is a fuzzy control of the process of feeding and distributing asphalt concrete mixture using a PID controller developed on the basis of Matlab & Simulink with logical rules written in the Fuzzy Logic Toolbox environment. The rules were developed according to the rules set in the Fuzzy Logic Toolbox functions based on Matlab&Simulink. According to the rules of Fuzzy Logic Toolbox, the structure of distribution and regulation of asphalt concrete mixture control using a PID controller has been developed.It is then selected based on expert responses, such as conveyor rotation speed, sealing, overlay, reconstruction, etc.in elements of asphalt concrete mix.

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