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LABORATORY BENCH TO ANALYZE OF AUTOMATIC CONTROL SYSTEM WITH A FUZZY CONTROLLER

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Abstract

The paper represents laboratory bench to analyse a system of automated control with a fuzzy controller. The laboratory bench consists of a thermal object, and software and hardware complex involving logic controller VIPA System 200 V as well as HMI / SCADA system Zenon Supervisor 7.0. The thermal object is described with the help of the second-order differential equation using “current value within the power converter of electric heater-air temperature inside a thermal object” control channel. Coefficients of the differential equation depend upon location of a dampener and upon rotation frequency of a centrifugal fan.

Control error (ie deviation between the specified temperature value within the thermal object and its current value), and derivative of the error, represented in the form of linguistic variables involving five triangular terms and two trapezoidal (extreme) ones have been used as the input values of the fuzzy controller. Output value of the fuzzy controller is the electric power supplied to the electric heater and assuming seven specified values. Selection of the specific value of electric power depends upon knowledge base being a finite set of rules of fuzzy sets falling into line with the applied linguistic variables.

To implement such a system of automated control with a fuzzy controller, original software has been developed making it possible to analyze a process of thermal object heating with the use of human-computer interface. Interaction algorithm of certain program elements has been described. Experimental results, concerning the thermal object transfer from different initial conditions to terminal ones, have been demonstrated. A dependence of mean-square error of the controlled value upon the control period has been demonstrated.

Keywords: laboratory bench, thermal object, hardware-software complex, programmable logical controller, dynamic model.

1. RELEVANCE

Currently, there are a large number of automation objects in industry, the management of which by traditional methods is impossible due to insufficient information in terms of their properties, useful signals and noise acting on them. The presence of uncertain or fuzzy information leads to the fact that traditional quantitative methods used in the theory of automatic control are not effective enough [1]. As a result, difficulties arise in the identification of the automation object and the formation of control algorithms for them. One of the ways to overcome these difficulties is to use fuzzy concepts and knowledge, conduct operations using fuzzy logical rules and obtain fuzzy conclusions based on them that allow to generate sequences of actions on a managed object [2-4].

In the scientific literature, much attention is paid to the mathematical and physical modelling of control systems with a fuzzy controller or control algorithm. In [5–7] were studied fuzzy control structures for nonlinear objects of various physical nature in the SIMULINK MATLAB environment. As a result of computational experiments was shown a control efficiency. However, there is no information on the relationship between the values that determine the effectiveness of control, and the values that characterize the features of the control actions. This complicates the choice of technical means for the implementation of control systems, as well as the organization of interaction of control tasks with other tasks that can be solved using the selected computing system.

In [8, 9] were performed a physical modelling of control systems with a fuzzy controller. However, the lack of a human-machine interface with the possibility of operational influence on the conditions of the experiment and visualization of changes in input and output values in a convenient form for the researcher in the on-line mode complicates the conduct of wider and deeper studies. In addition, these physical models cannot be used as laboratory stands for the training of qualified personnel who possess modern knowledge and practical skills in the synthesis and analysis of automatic control systems (ACS) for various purposes, including the management of automation objects.

Nowadays, the laboratory base of scientific and educational institutions is being updated with the use of technical products of world famous companies such as: Siemens, ABB, Moeller, Shneiderelectric [10]. The use of modern devices allows you to create effective laboratory and diagnostic stands for solving the problems of preparing future competitive engineers in the field of automation and for solving the problems of testing of modern technological process control systems [11, 12]. However, laboratories created in this way have disadvantages - low adaptation to the research and lack of methodological support.

2. FORMATION OF OBJECTIVES

It is required to improve the efficiency of laboratory facilities use for learning at the expense of their adaptation to solving problems of synthesis and analysis of ACS with fuzzy controller. Objective is to develop ACS by means of a thermal object with fuzzy controller to solve training problems.

The Department of Automation and Instrumentation of the Dnipro University of Technology has implemented a laboratory bench (Fig. 1) being hardware-and-software complex, and involving thermal controlled object; and hardware, and software for the automated control system [13-16] which makes it possible to study and analyse the automatic systems implementing different control strategies.

The laboratory stand consists of three main zones: - the chamber in which the process of heating is carried out; - control, adjustment and display panel; - the panel of the controller, power supply units and actuators.

The chamber (Fig.2) consists of flow-though rectangular prism shaped container, centrifugal blower, suction flue, electric heater, screen and thermal converter. Centrifugal blower and suction flue are located on the opposite sides of the container. Electric heater, screen and resistance temperature device are located between them.

Centrifugal blower provides continuous cold air supply from environment inside thermal unit. Depending upon screen position, suction blower engine rotation frequency and electric capacity applied to heating element, air warms up to a certain temperature [17-19]. Air temperature variation is controlled with resistance temperature device.

Fig. 1. Appearance of the laboratory bench

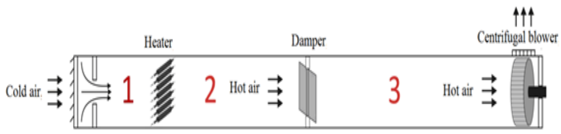

Fig. 2. Schematic representation of the working areas of the chamber

Hardware component of automatic control system has been developed on the basis of VIPA System 200 V programmable logic controller (PLC) The structure of hardware component is shown on Fig. 3. PLC in automatic control system serves as remote analogue input / output module [20-21].

The Vipa System 200V programmable logic controller is one of the most advanced VIPA controller family. They are used in industrial automation systems with increased requirements for equipment reliability and for the time parameters of control loops. The CPUs are compatible by a set of instructions with the popular SIMATIC S7-300 controllers and can be programmed using WinPLC7 software (VIPA) or STEP 7 (Siemens).

The System 200V series is built on a modular basis, which allows you to optimally select the configuration for a specific task and easily modify the system when it is expanded or changing its requirements.

All I / O modules and interface modules are universal, which allows you to combine them with any CPU in this series. At the same time, it is possible to choose a processor module with optimal performance for solving the control problem.

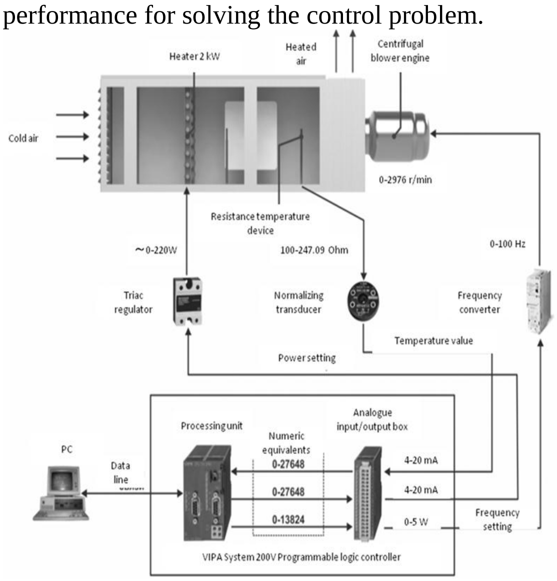

Fig. 3. Structure of automatic control system

The VIPA System 200V Series controllers have good response times and are suitable for controlling batch, continuous and batch production.

Table I shows the automation equipment of a laboratory bench.

Table I. Automation Tools

Measuring devices and converters	**Actuators**	**Display units**
Thermal converter TSP U Open / Close Sensor Pulse Sensor BUP-50S PKP11 damper position control device Frequency converter Lenze 8200 Vector	SD-54 motor reducer MS7134 Induction Motor	Heater display unit and m4v Autonics thermal converter display unit

The software component of ACS includes software of programmable logic controller designated for arrangement of calculation processes and software of personal computer on the basis of HMI / SCADA of Zenon Supervisor 7.0 system for the purposes of human-machine interface and various types of regulators implementation.

Zenon is a software and hardware package for creating automation systems produced by the world leader in HMI / SCADA solutions, COPA-DATA. This software and hardware complex is focused on solving the problems of process visualization, machine operations and production management. It offers simple object-oriented design, full compatibility and integration into a single automation system of various devices, from individual terminals to dispatch control points with redundancy. Zenon's openness allows you to quickly implement a reliable connection with any hardware or software, works perfectly on industrial PCs and devices with Windows CE.

This bench provides settlement of a wide range of tasks related to study of technical automation systems facilities, research of identification methods and principles of technological objects control, acquiring of practical skills of automatic system programming in real-time scale [22-24]. However, basic hardware and software facilities of laboratory bench do not provide fuzzy ACS research what limits its application for educational purposes.

Fig. 4 demonstrates thermal object as a control object.

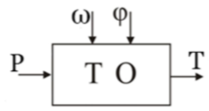

Fig. 4. Structure of the thermal object

In this context: T is temperature inside the object (ie controlled value); P is power supplied to the electric heater (ie controlling value); ω is rotation velocity of asynchronous motor (i.e. exciting value); and φ is location of a dampener (i.e. exciting value).

The separation of input values into controlling values and exciting ones is not terminal since they may change over depending upon the research objective.

Dynamic model of the thermal object along "current value within power converter of electric heater-air temperature inside a thermal object" control channel (rotation frequency of a centrifugal fan is 50 Hz; the dampener is in a fully open position) is the second- order aperiodic link [13].

Fuzzy controller is represented in the form of the three units: fuzzifier, area of fuzzy logics, and defuzzifier (Fig.5) [25-27].

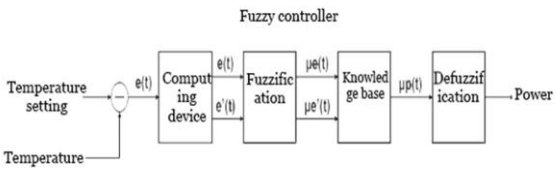

Fig. 5. Structure of the thermal object

Controlling error $e(t)$, calculated as a difference between the specified temperature value and actual temperature within the thermal object, and velocity $e^{'}(t)$ of the error variation, calculated as difference between the current errors and during previous period respectively are the input values of the fuzzy controller.

The values are developed within the computing device getting then to the fuzzification unit terminal where they obtain specific values of membership functions $\mu e(t)$ and $\mu' e(t)$ of corresponding linguistic terms. At the stage, fuzzy controller operates with linguistic variables. According to the obtained terms, knowledge base formulates fuzzy logical conclusion transmitted to a defuzzification unit in the form of linguistic variable Power and degree of its membership $\mu p(t)$. Defuzzification translates the fuzzy value into the absolute power value supplied to an executive unit (ie electric heater).

The fuzzification stage determines correlations between numerical values of input variables of controlling error, its variation velocity, and values of membership values of terms of linguistic variables corresponding to them.

Each linguistic variable is represented with the help of seven terms - five triangular terms, and two trapezoidal ones. Table II explains variation ranges of the input values.

Table II. Variation ranges of the input values

Input value	TEXT_MINIMUM_VALUE	TEXT_MAXIMUM_VALUE
Error	-10 about WITH	10 about WITH
Velocity	-6 about WITH	6 about WITH

Figures 6 and 7 demonstrate membership functions of certain terms of linguistic variables Error and Velocity. The terms are specified respectively: LN - *large negative* ; AN - *average negative* ; SN - *small negative* ; N - *normal* ; SP - *small positive* ; AP - *average positive* ; and LP - *large positive* .

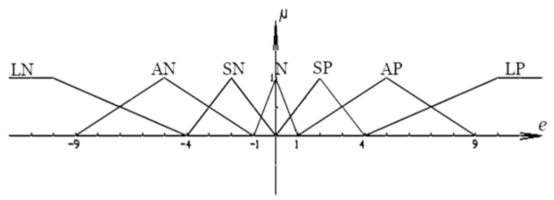

Fig. 6. Terms of set of linguistic variable *Error*

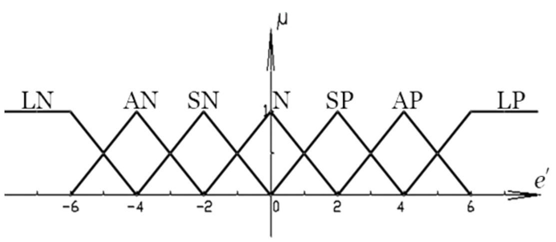

Fig. 7. Terms of set of linguistic variable Velocity

The knowledge base has been formed using rule set of fuzzy products of $A \Rightarrow B$ type where A is a condition of core of fuzzy products, B is termination of a core of fuzzy products; and "⇒" is index of a logical consequence.

Table III represents the fuzzy production rules derived as a result of processing of expert knowledge, concerning the controllable object, accumulated by the Department academics and students.

Table III. knowledge base

e / e'	**LN**	**AN**	**SN**	**No**	**SP**	**AP**	**SP**
LN	LN	LN	LN	LN	LN	LN	LN
AN	LN	LN	LN	LN	CO	SN	SN
SN	LN	LN	AN	MO	No	No	SP
No	LN	AN	SP	SP	AP	LP	LP
SP	SN	SP	AP	LP	LP	LP	LP
AP	AP	AP	LP	LP	LP	LP	LP
SP	LP	LP	LP	LP	LP	LP	LP

In the context of the Table III, values of linguistic variables *Error* and *Velocity* are conditions of cores (labels of rows and columns respectively). Core termination is at the intersection of the rows and columns corresponding to the linguistic variable *Power* . Physical value of *Power* varies within 0% -100% range.

In terms of one controlling variable, transformation of its linguistic value into a physical value (i.e. defuzzification process) is not complicated. Table IV represents the transformation results.

Table IV. Correspondence between linguistic values of Power variable, and its physical values

Terms of linguistic variable *Power*	LN	AN	SN	No	SP	AP	LP
Values of quantity of *Power* value	0	16.65	33.35	50	66.65	83.35	100

Implementation of ACS with fuzzy controller involved the development of original software operating within WinPLC7 environment, and making it possible to analyse a process of thermal object control in terms of different values of specifying data as well as exciting data with the use of human-computer interface . The software actualizes sequence of operations in accordance with the algorithm shown in Figures 8. and 9 explains the human-computer interface with 10 s controlling procedure.

Figures 10 and 11 represent the results of the experiments in terms of the heat object control for control periods of 10 s and 70 s respectively.

Table V demonstrates dependence of the mean square deviation of control error δ_ε on control period T_{con} calculated according to the experimental data obtained during the experiments in terms of a heat object. Experimental data were registered in each 0.1 s. Mean square deviations of the control error are determined according to [28]:

$$\delta_\varepsilon = \sqrt{\frac{\sum_1^n (T_i - T_z)^2}{n-1}}, \quad (1)$$

where n is the sample volume; and T_i and T_z - are temperature value and the specified temperature value respectively.

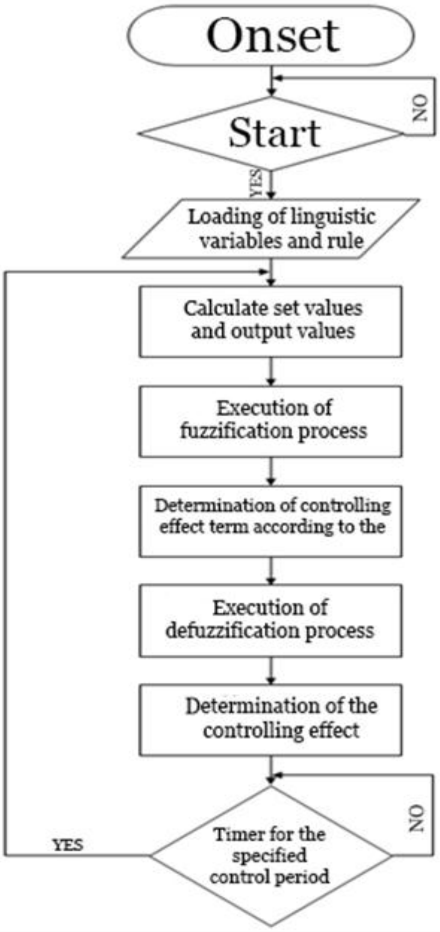

Fig. 8. control algorithm

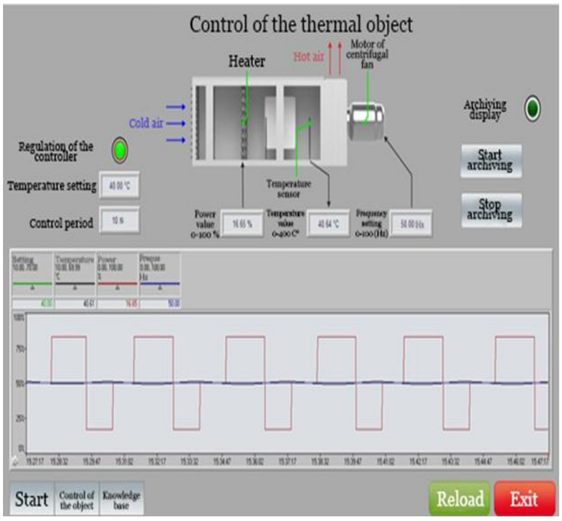

Fig. 9. Human-computer interface

According to the data given in Table V, the normalized correlation coefficient $r_{\delta_\varepsilon,T_{con}}$ was calculated to reveal the linear relationship between the T_{con} values by the method given in [28]. The result of the calculations are given in Table VI.

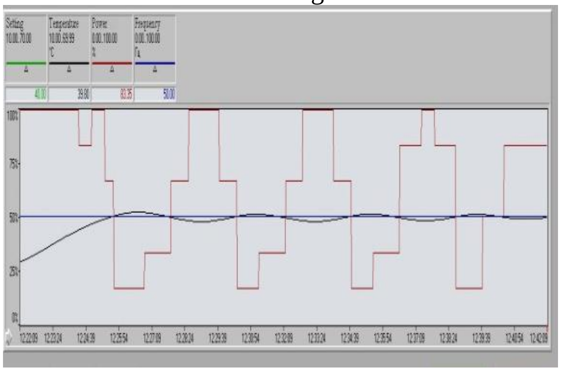

Fig. 10. The result of the experiment for T $_{con}$ = 10 s

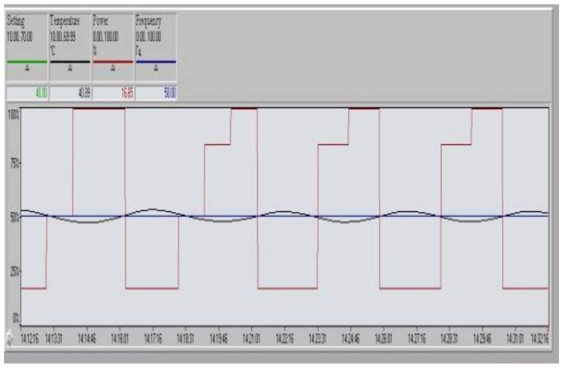

Fig. 11. The result of the experiment for T_{con} = 70 s

Table V. Dependence of a mean-square error upon the control period

T_{con}, s	10	20	30	40	50	60	70	80	90	100
δ_ε	0.41	0.55	0.73	0.96	1.09	1.15	1.33	1.46	1.99	2.08

Table VI. The Results of the Calculation of the Normalized Correlation Coefficient

	Average $\bar{\delta}_\varepsilon, \bar{T}_{con}$	Root mean square deviation $\delta_{\delta_\varepsilon}, \delta_{T_{con}}$	Cor-relation coeffi-cient $R_{\delta_\varepsilon,T_{con}}$	Norm-lized correlation coefficient $r_{\delta_\varepsilon,T_{con}}$
δ_ε	1.18	0.56	16.63	0.98
T_{con}, s	55	30.28		

Here: $\bar{\delta}_\varepsilon$ and $\bar{T}_{con}$, are average values of mean square deviation of the control error and control period respectively; $\delta_{\delta_\varepsilon}$ and $\delta_{T_{con}}$ are the standard deviations of δ_ε and T_{con}, respectively; D_{δ_ε} and $D_{T_{con}}$ are the standard deviations of δ_ε and T_{con}, respectively; $R_{\delta_\varepsilon,T_{con}}$ and $r_{\delta_\varepsilon,T_{con}}$ are the correlation coefficient and the normalized correlation coefficient. The normalized correlation coefficient $r_{\delta_\varepsilon, T_{con}}$ is close to unity, which corresponds to the presence of a liner relationship between the quantities δ_ε and T_{con} .

The linear dependence $T_{con} = f(\delta_\varepsilon)$ is determined from the following expression [19]:

$$T_{con} - \overline{T}_{con} = r_{\delta_\varepsilon, T_{con}} \frac{\delta_{T_{con}}}{\delta_{\delta_\varepsilon}} (\delta_\varepsilon - \overline{\delta}_\varepsilon). \qquad (2)$$

After substitution in (2) of the parameter values from Table VI we get:

$$T_{con} - 55 = 0.98 \frac{30.28}{0.56} (\delta_\varepsilon - 1.18). \qquad (3)$$

As a result of identical transformations, we finally have:

$$T_{con} = 52.99\delta_\varepsilon - 7.53. \qquad (4)$$

Figure 12 shows graphs of the experimental (red colour) and analytical (blue colour) dependencies $T_{con} = f(\delta_\varepsilon)$, respectively, according to the data in Table V and expression (4).

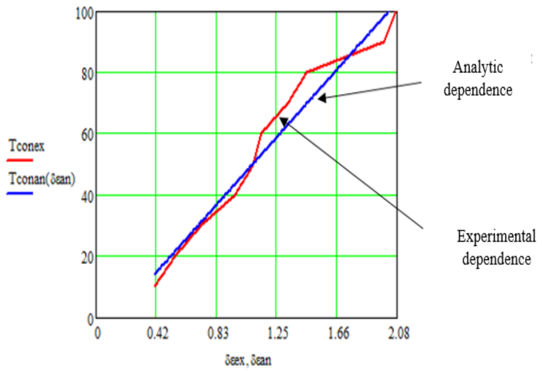

Fig. 12. Graphs of experimental and analytical dependencies $T_{con} = f(\delta_\varepsilon)$.

3. CONCLUSIONS

The paper describes synthesis of ACS with fuzzy controller in the process of thermal object control for the specific rotation frequency of centrifugal fan, and location of a damper. If variation of the parameters takes place then results of the synthesis will be distinct. Namely ACS development for different conditions and its efficiency evaluation is the small research task during experiments carried out with the help of the laboratory bench in the context of “Theory of the automated control” subject.

ACS with a fuzzy regulator may be implemented on the basis of the software and hardware which include programmable logical controller VIPA System 200 V and HMI / SCADA system Zenon Supervisor 7.0. The fuzzy control algorithm and human machine interface have been developed to change the conditions of functioning for a control system during the experiment.

Analytical dependence of the control period upon the control accuracy has been obtained. The dependence may be applied to substantiate the selection of control parameters while distributing computational resources of the software and hardware.

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