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Experimental tests of fuzzy logical temperature controller of an electric resistance chamber furnace

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Abstract— **The paper presents an innovated hardware and software platform for the implementation of the fuzzy controller for temperature and temperature slope change in an electric resistance chamber furnace. The point of this paper is to present the modern hardware and software tools that we used to lift up the base for continuation of the research done in the laboratory for electrical heating of Faculty of electrical engineering, University of Belgrade, more than 15 years ago. In that period, also the robustness of control in respect to the amount of load in the furnace was investigated. This paper focuses to the further investigation of the robustness. More precisely, experiments were performed to study if the controller can be applied as "plug and play controller", i.e. if the controller can be applied without additional tuning on another furnace with the similar construction in respect to the one where the fuzzy controller is tuned. The tests on two electric chamber furnaces with different rated power and volumes confirm the "plug and play controller" principal is realistic.**

Keywords-temperature control; fuzzy controller; chamber furnace; microcontroller

I. INTRODUCTION

The controlled system is electric resistance chamber furnace for a temperature of up to 1500 °C. As presented in [1], the furnace has nonlinear characteristic, i.e. the temperature resistance depends on heating power. The temperature resistance represents transfer function of the controlled system and it is calculated as the ratio of temperature rise and heating power. At different power steps, the temperature resistances are also different. Another important issue is that the transfer function of controlled system is not known, i.e. it can vary depending on the amount and type of load inside the furnace; the changes of the material in the furnace (furnace load) cause the change of temperature capacitance and consequently change of the transfer function of the controlled system. Those are the reasons why the PID controller isn’t easily applicable neither from theoretical nor from practical point of view. Realization of different types of controllers (hysteresis and adaptive PID) and results of their usage are also presented in [1]. Basically, for the determination of parameters of PID controller Dahlin algorithm [2] was applied, where the parameters of the controller are calculated starting from the transfer function of the furnace containing dead time and the sum of two exponential functions as a response to step excitation. As stated above, the parameters of the transfer function differ for different step excitations (constant heating powers). It has been confirmed from performed set of heating experiments with step shape for the heating power, starting from the cold furnace state. In the application of Dahlin algorithm described in [1] the parameters of PID controller were changed at each of sample points (sample period 15 s). The PID parameters were calculated using the parameters of the transfer function corresponding to the instantaneous value of the heating power obtained at the controller output in previous sample point.

Many research showed that fuzzy controllers have a good behavior in nonlinear systems, for example for control of shunt active power filter [3], the electric arc furnaces [4-6] and generally for temperature control in different type of furnaces [7-9]. A lot of comparisons between fuzzy and traditional PID control of heating processes in furnaces have been done and the main conclusions are that fuzzy control is not perfect; it can give slower response and cause steady state error, but it is mostly better solution than traditional PID control, because it can make heating process more energy efficient [10], cause smaller overshoots and less oscillations [11], and give smooth response [12].

In [13], good performance of fuzzy controller has been presented; it has been shown that using of this controller leads to good dynamic response of the controlled system for desired referent temperature and also for desired referent temperature slope. It is also shown that the fuzzy controller is robust in respect to presence of the load in the furnace chamber. One of the practical concerns is whether the fuzzy controller can be used as “plug and play” controller on the chamber furnace

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differing from the furnace on which the fuzzy controller is adjusted. Testing the behavior of controller in this regard was the motivation to re-launch the research. Bearing in mind a long pause (more than 15 years) from the end of the previous research and development working phase, which was concluded with the publication of the paper 13], natural first step was to innovate the hardware and software platform.

II. CONTROL HARDWARE AND SOFTWARE

The chamber of the furnace of the 5 kW rated power is shown on Fig. 1 (a) loaded furnace in cold state, b) heated furnace without load. As it can be seen on Fig. 1 there is a thermocouple placed inside the chamber of the furnace. Fig. 2 shows the measuring, control and actuator components of the controller hardware.

Thermocouple is type K (NiCr-Ni) and it is slipped into the chamber from the back side of the furnace so that thermocouple measuring (hot) junction is placed in the middle of the furnace chamber. The measurable range of this type of thermocouple is from -270 °C to 1372 °C, whereby the range of thermoelectric voltage that is generated at cold ends of the thermocouple is between -6.458 mV and 54.819 mV, at a referent temperature of cold ends of 0 °C.

a) Inside of unheated furnace chamber with load

b) Inside of heated furnace chamber without load

Figure 1. Furnace chamber

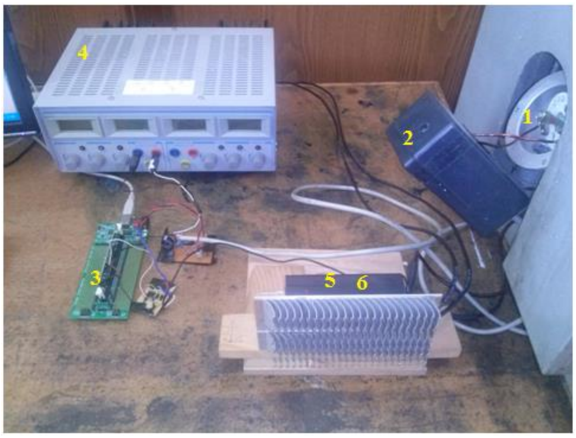

Figure 2. Measuring, control and actuator part of the controller

1) Thermocouple type K (NiCr-Ni), 2) Monolithic thermocouple amplifier (AD595), 3) Microcontroller (Texas Instruments Delfino TMS320F28335), 4) Stabilized DC source (+12V), 5) Zero voltage crossing optically isolated triac driver MOC 3040, 6) Triac BTA 40/600

For adjustment of the voltage signal from the cold ends of thermocouple to the operating voltage range of the A/D converter of the microcontroller, analogue integrated circuit AD595 is used. In addition to the linear differential amplification, this circuit also has abilities of cold junction compensation and signalizing the interruption of the thermocouple. AD595 is placed directly at cold ends of the thermocouple, and it gives at the output a voltage signal in the range of 0 to 10 V, which is linearly dependent on the temperature of the thermocouple.

The input voltage range of the A/D converter is 0 to 3.3 V. Adjustment to this range is done by a resistive voltage divider. Additionally, the low pass RC filter for frequencies up to 1 kHz is applied for conditioning the signal for A/D converter.

Temperature measurement is performed at every 10 ms. The value of the temperature which is taken as the input in the fuzzy controller is the mean value of consecutively measured 1500 samples over a 15 s period.

The 32-bit microcontroller Texas Instruments TMS320F28335 is applied. One A/D converter peripheral (input) and two digital output peripherals were used.

The actuator is BTA 40/600 triac, which can be used for a current up to 40 A and a voltage up to 600 V. The triac is controlled via MOC 3040 optocoupler circuit based on the state of the digital output GPIO4 of the microcontroller.

The MOC 3040 is an optically coupled isolator that isolates power stage from the microcontroller using infrared light emitting diodes and infrared sensitive transistors. The monolithic silicon detector provides the zero crossing network voltage detection and triggers the tirac at that moment. In this way sudden load current jumps are avoided. By turning on and off of the triac, the heating power is controlled, where the minimum period of switching is 10 ms.

Having in mind previous information about MOC 3040 circuit, the frequency of possible change of the state of the digital output is set to 100 Hz (period T = 10 ms). The period of calculation of the heating power is 15 s. Thus, to obtain the heating power *P* determined by fuzzy controller the number of

10 ms periods in which the digital output state is equal to the Boolean one (triac is ON) is equal to

$$n = \left(\frac{15\,s}{0.01\,s}\right)\left(\frac{P}{5000\,W}\right), \qquad (1)$$

where P is the output controller power in [W] and 5000 W is the rated furnace heating power. Thus, the value of *n* changes in the range from 0 (triac is OFF; heating power is zero) up to 1500 (triac is ON during whole 15 s period; the heating power is equal to the rated power of 5 kW).

A second digital output (GPIO34) is connected to the microcontroller light emitting diode (LED). The state of this digital output is programmed to be equal to the state of the pulse generator block (block in the Simulink model) that works with a frequency of 1 kHz and which turns on and off the LED every half second. The purpose is to control the execution of the program, i.e. the indication of the controller normal operation.

The power supply source for electronics is a stabilized DC source of +12 V.

The algorithm of control is implemented in Matlab using the Simulink and Target Support Package libraries. Then, function Build translates the Simulink model in C code, which is dropped into the RAM memory of the microcontroller using Code Composer Studio (CCS) 3.3. CCS 3.3 also enables tracking of the variables and setting parameters during program execution [14-16].

Fig. 3 shows Matlab Simulink model of the controller in discreet domain. Set of blocks 1 loads the analogue signal from microcontroller input pin into the Simulink control program and converts the value to the temperature in °C averaged in 15 s. The set of blocks 2 represent fuzzy controller with its two parts, one for temperature and one for slope control. Block Log enables data logging on the PC. Set of blocks 3 shows scaling and connecting of Simulink model with the microcontroller digital output, i.e. transferring of controlling signal to the external hardware components (optocoupler and triac). This part of the model via parameter P_choice does switching between constant output signal (P_wanted) to the value which is obtained from the fuzzy controller (Power). Via parameter Choice in this part of the model the heater can be completely turned off. The other two small group of blocks (set of blocks 4 and set of blocks 5) are time counter – time is needed for controlling the process of logging data (set of blocks 4) and the second digital output which is connected to the LED of microcontroller (set of blocks 5).

III. Construction of the Furnace

Both electro-resistant chamber furnaces on which tests were carried out are of similar structure – furnace chamber presented in Fig. 1. Around the parallelepiped chamber for storage of the load there are resistant heaters in gutters made of electro-insulation material – electro-chamotte. This layer is characterized by high thermal capacity and good heat conductivity. The next layers closer to the exterior of the furnace are thermal insulation in the form of a foamy chamotte, which has a low thermal capacity and low heat conductivity, and a steel sheet that shapes the furnace. The resistant heater is connected to phase voltage (rated value 231 V).

Table I presents the dimensions of both furnaces. The number of heaters (more specifically, the number of gutters with spiral elements) on each side of the chamber for both furnaces is given in Table II. Heaters do not exist on the back wall and on the door of the chamber.

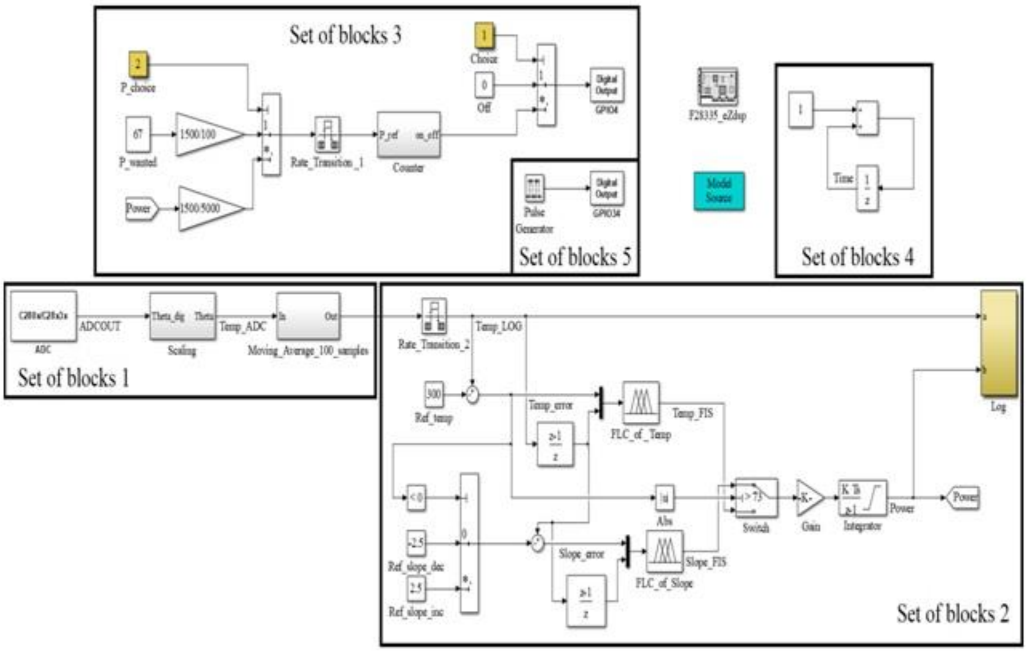

Figure 3. Matlab Simulink model

TABLE I. DIMENSIONS OF THE TESTED FURNACES

	Furnace of 5 kW		Furnace of 5.5 kW	
	Outside	*Inside*	*Outside*	*Inside*
Width (mm)	500	192	650	200
Height (mm)	433	124	693	160
Length (mm)	700	490	770	547
Volume (m^3)	0.1515	0.01167	0.2401	0.0260

TABLE II. NUMBER AND LENGTH OF THE HEATERS IN THE TESTED FURNACES

	Furnace of 5 kW	Furnace of 5.5 kW
Side walls	4	5
Ceiling	6	0
Floor	6	4
Length of heaters (mm)	350	320

IV. FUZZY CONTROLLER

The task of the fuzzy controller is to keep the temperature slope at referent value in the zone in which the temperature is far from the set temperature. The control switches from slope to temperature control when the temperature approaches to the referent temperature. Setting fuzzy controller in the zone of temperature control is being done in purpose of reaching the reference temperature without overshoot. In elementary conventional digital control, the controller is designed to achieve a change of controlled temperature as exponential time function with a single time constant of specified value. The concept of the fuzzy controller we proposed is different: the slope is kept (as it is the case on the initial linear part of the exponential function) up to the zone near referent temperature. It should be noted that nonlinear pre-filters, including slope-limiters, are routinely used with conventional digital controllers, enabling tracking the same reference pattern as we set for fuzzy controller.

The concept to separate the zone in which the control of the temperature slope is applied from the zone where the control of temperature is applied makes practical implementation of the fuzzy controller much easier. The complexity and the setting of two different controllers is much easier than the one controller with more inputs and more rules. Following the concept to separate fuzzy controllers, two Fuzzy Inference System (FIS), one for temperature control, one for slope control, both having two inputs and one output, are formed in Matlab. Additional advantage of this concept is that a single FIS with four inputs would take bigger memory resources of a microcontroller.

The design of the fuzzy controller was done using the Fuzzy Logic Toolbox within the Matlab program package. Fuzzy controller based on the Sugeno type FIS, where the output can be a constant or a linear function is applied.

Inputs to the FIS are described via Membership Functions (MF). For temperature control the inputs are temperature error (measured minus reference value of the temperature (MF-A, Fig. 4)) and the temperature change slope (MF-B, Fig. 5). Inputs to the FIS for temperature slope control are slope error (current temperature slope minus referent value of slope (MF-C, Fig. 5)) and a change in the temperature slope (MF-D, Fig. 6). Exit from both structures is the increment of power (positive or negative) in percent of the rated power (Table III).

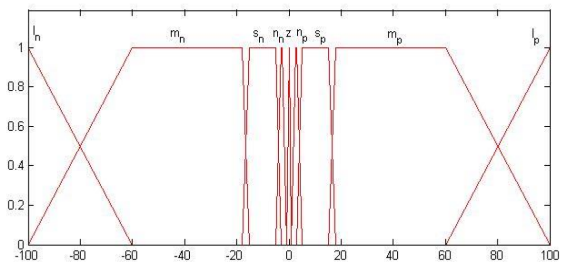

Figure 4. MF-A for temperature error in °C

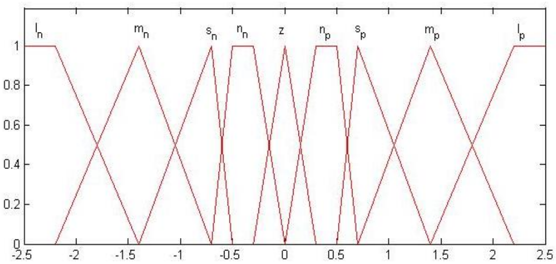

Figure 5. MF-B, i.e. MF-C for temperature change slope in °C/ 15 s

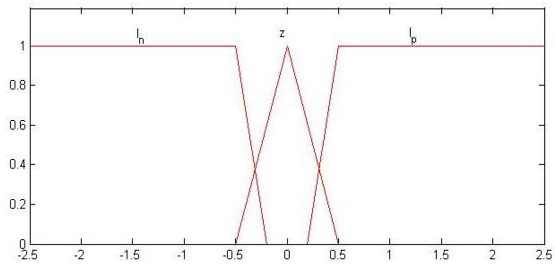

Figure 6. MF-D for change of slope in °C/ 15 s

TABLE III. MEMBERSHIP FUNCTIONS OF THE OUTPUT VARIABLE – INCREMENT OF HEATING POWER IN %

	l_n	m_n	s_n	n_n	al_n	a_n	z	a_p	al_p	n_p	s_p	m_p	l_p
P_i	-100	-60	-15.6	-9.3	-6.3	-2.3	0	2.3	6.3	9.3	15.6	34.4	100

Meaning of labels on Fig. 4, 5, 6 and Table III:

- l_n / l_p – large negative / positive,
- m_n / m_p – medium negative / positive
- s_n / s_p –small negative / positive,
- n_n / n_p – near zero,
- a_n / a_p – around zero,
- al_n / al_p – almost zero,
- z - zero.

The membership functions of the temperature error are set for the range from -100 °C to 100 °C, while the membership range for the slope control is from -2.5 °C/ 15 s to 2.5 °C/ 15 s. Output from the controller for the value of temperature / temperature slope below the lower (negative) limit is zero, and for the value of temperature / temperature slope above the upper (positive) limit is 100 %. At the exit of the controller, a percentage increment of power is obtained in the range of minus 100 % to 100 %, which affects the change in the power of the furnace with a 3.33 W step.

The initial definition of all elements of the temperature controller and the temperature slope controller are presented in [13], and it relates to: a) Membership Functions (MF) of input variables of triangular and trapezoidal shape (Fig. 4, 5, 6), b) Membership Functions of the output variables that are constants (Table III) c) the fuzzy rules for the temperature controller, with the inputs MF-A and MF-B (Table IV), d) the fuzzy rules for the temperature slope controller, with the inputs MF-C and MF-D (Table V), e) the value of temperature on which, after approaching the reference temperature, control switches from the temperature slope control to the control of temperature (67 °C). The correction of the controller, which was initially set up and tested on simulations, was, as in [13], performed based on an experiment on a real controlled object (furnace). Details can be found in [17]. In the upgraded version of the hardware and software developed after publication [13], the microcontroller code (TI TMS320F28335) is generated directly from Matlab. Also, during the development and testing of the controller, a rule viewer was used, in which the active MF functions and execution logic of the fuzzy rules can be monitored during the simulation, based on the values of the input variables.

TABLE IV. BASE OF RULES FOR TEMPERATURE CONTROLLER

		MF-A								
		l_n	**m_n**	**s_n**	**n_n**	**z**	**n_p**	**s_p**	**m_p**	**l_p**
MF-B	l_n	l_p	l_p	l_p	m_p	m_p	l_p	l_p	l_p	l_n
	m_n	l_p	l_p	m_p	s_p	s_p	m_p	l_p	s_p	l_n
	s_n	l_p	l_p	s_p	n_p	n_p	s_p	m_p	s_p	l_n
	n_n	l_p	l_p	s_p	n_p	n_p	n_p	s_p	n_p	l_n
	z	l_p	m_p	n_p	a_p	z	a_n	n_n	m_n	l_n
	n_p	l_p	a_n	n_n	n_n	n_n	n_n	s_n	l_n	l_n
	s_p	l_p	al_n	s_n	l_n	s_n	n_n	s_n	l_n	l_n
	m_p	l_p	n_n	m_n	l_n	m_n	s_n	m_n	l_n	l_n
	l_p	l_p	m_n	l_n	l_n	l_n	m_n	l_n	l_n	l_n
Rule		1	2-10	11-19	20-28	29-37	38-46	47-55	56-64	65

TABLE V. BASE OF RULES FOR SLOP CONTROLLER

		MF-C								
		l_n	**m_n**	**s_n**	**n_n**	**z**	**n_p**	**s_p**	**m_p**	**l_p**
MF-D	l_n	m_p	s_p	s_p	s_p	n_p	n_n	m_n	l_n	l_n
	z	m_p	s_p	s_p	s_p	z	n_n	m_n	l_n	l_n
	l_p	m_p	s_p	s_p	s_p	n_n	n_n	m_n	l_n	l_n
Rule		1	2	6	7	4,3,5	8	9	10	11

V. EXPERIMENTAL RESULTS ON THE SMALLER FURNACE

After adjusting the controller, four experiments were performed (one for empty furnace with lower rated power (5 kW), one for the same furnace with lower power but with the load (a parallelepiped piece of iron weighing 16 kg), one for empty furnace of higher rated power (5.5 kW) and one for the same furnace of higher power with the parallelepiped piece of iron weighing 16 kg).

For each of the experiments, a computer simulation was performed and their results are shown on the figures along with the results of the measurements. In simulations performed in Simulink, the electric resistance chamber furnace is represented by a transfer function whose parameters are determined from the measured response of the system to the step function of heating power (the temperature is measured in the empty furnace). Responses (increase of the temperature inside the furnace) which are measured for different power values, smaller or equal to the rated, are shown in [1]. Then, the parameters of the transfer functions in the time domain are estimated, and based on them, the parameters of the transfer function of the controlled object in complex (s) and discrete (z) domains were determined. A typical form of transfer function which describes the dynamics of the furnace in the complex domain is:

$$G(s) = \frac{1-e^{-T\,s}}{s} \frac{K}{(T_1\,s+1)(T_2\,s+1)} e^{-N\,T\,s} \qquad (2)$$

(K is static gain, $\tau = NT$ is the time delay (the whole number of sample periods), T is the sample period, T_1 is the time constant introduced by the actuator, T_2 is the time constant introduced by the controlled process, with $(1 - e^{-T\,s})/_{s}$ is modeled A/D converter). The corresponding function in a discrete domain is [2]:

$$G(z) = \frac{g\,(z-z_z)}{(z-z_{p1})(z-z_{p2})} \qquad (3)$$

Below are the results of testing the final version of the controller for empty and loaded furnace of 5 kW rated power. The simulations did not take into account the change in the parameters of the furnace with the power of heating, instead the constant transfer function of the furnace was taken, which is determined according to the response recorded for 45 % of the rated power.

The values of the parameters of the transfer function in the discrete domain recorded for the step function of 45 % of the rated power of 5 kW are:

$g = 8.94 \cdot 10^{-4}$, $z_z = 0.997$, $z_{p1} = 0.9926$, $z_{p2} = 0.9992$, $N = 8$.

Applying such constant transfer function for the furnace in the simulation is the main reason for the deviation of the simulated result from the results obtained by measurements on the furnace, especially in the case of a loaded furnace, where the increase in the thermal capacity and the time constant of the control object is not taken into account. Note that the agreement of the results of simulation and measurement in this case is not of prime importance. Namely, it turned out that the adjustment of the controller, that is, the change of the membership functions and the fuzzy rules, can be done quite simply based on the values registered during the tests on the real furnace, with the fuzzy controller being initially tuned using a computer simulation (in Simulink). It is not realistic to expect that only on the basis of the results of the simulation a controller can ideally be set up and be applied directly (without additional fine tuning) on a real furnace. In that sense, although it reduces the degree of intervention in the final fine tuning based on the results of the measurements on the real furnace, the practical aspect of accurate modeling of the thermal behavior of the furnace is not so important, since it cannot be expected that it is possible to completely eliminate the additional fine tuning of the fuzzy controller based on the measurement results on the real furnace.

Fig. 7 shows a temperature increase for an empty electrical resistance chamber furnace obtained by measurement and simulation (using Simulink). Corresponding temperature errors are presented in Fig. 8. The given referent temperatures are 400 °C, 600 °C and 800 °C, respectively, and the set slope of the temperature change is 1.3 °C/ 15 s. Parts of the experiment for each of the reference temperatures lasted about 2.5 hours. Fig. 9 shows the values of the temperature change of the loaded furnace obtained by measurement and simulation. Corresponding temperature errors are presented in Fig. 10. The referent temperature values are 400 °C, 600 °C and 700 °C, respectively, while the reference slope is 1.5 °C/ 15 s.

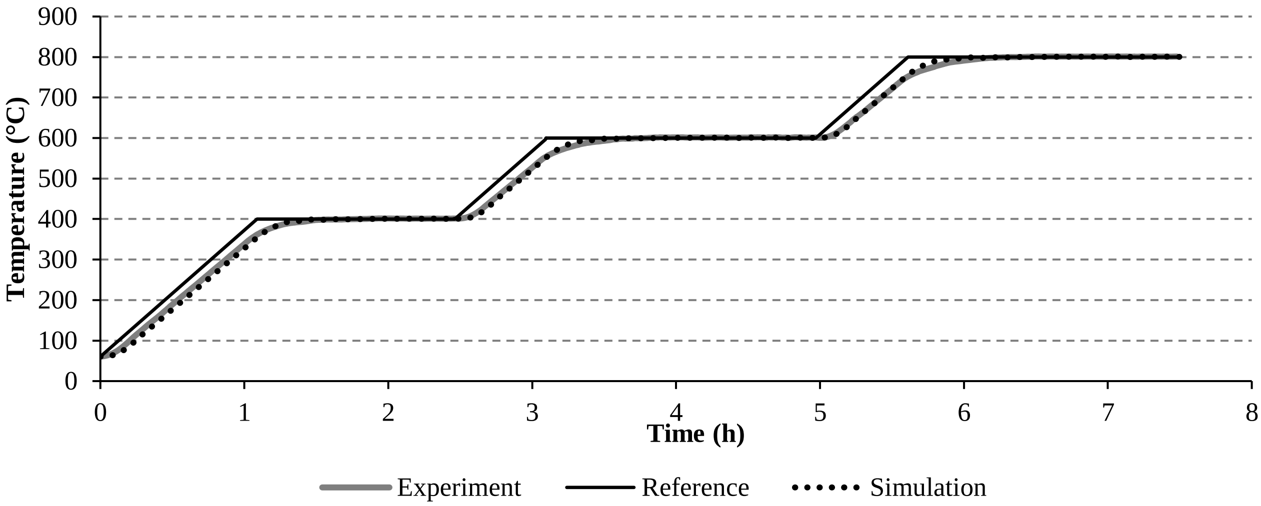

Figure 7. Temperature change during the experiment on the empty furnace of 5 kW

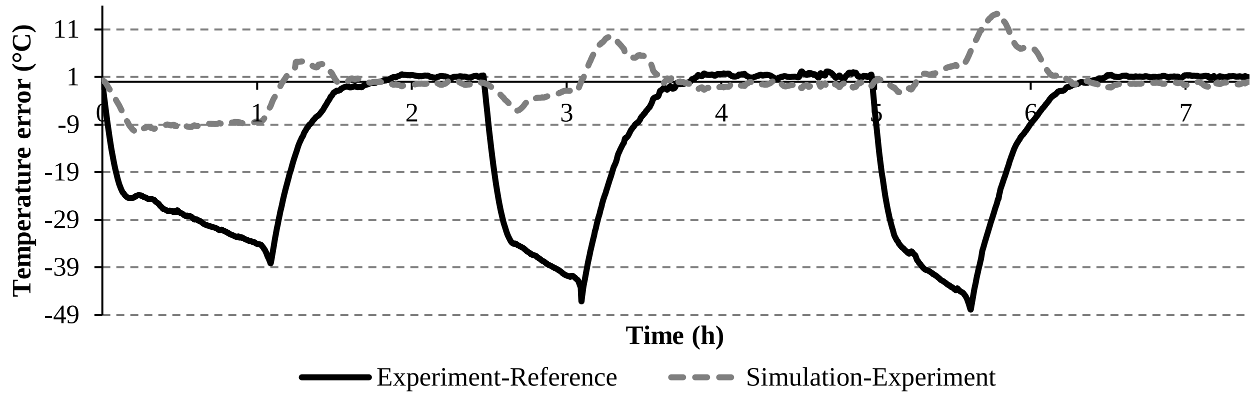

Figure 8. Temperature error during the experiment on the empty furnace of 5 kW

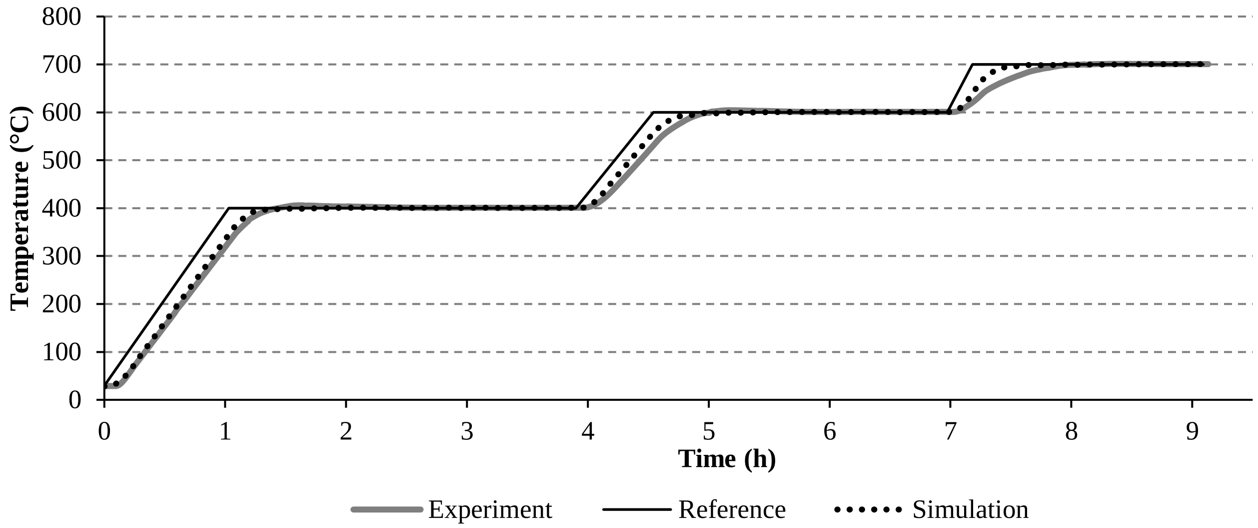

Figure 9. Temperature change during the experiment on the loaded furnace of 5 kW

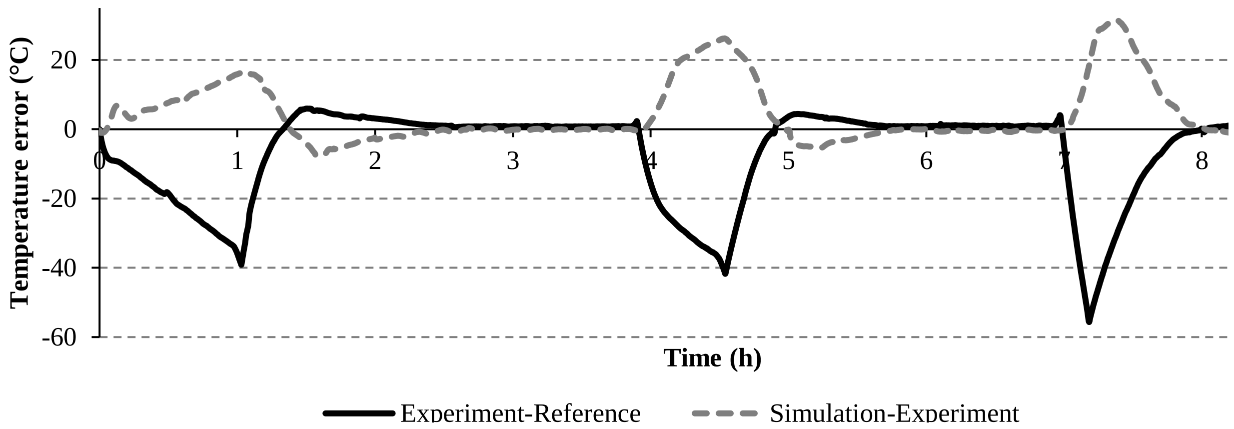

Figure 10. Temperature error during the experiment on the loaded furnace of 5 kW

VI. EXPERIMENTAL RESULTS ON THE BIGGER FURNACE

Fig. 11 shows a temperature increase for an empty electric resistance chamber furnace obtained by measurement and simulation (using Simulink). Corresponding temperature errors are presented in Fig. 12.

Fig. 13 shows the values of the temperature change of the loaded furnace obtained by measurement and simulation. Corresponding temperature errors are presented in Fig. 14. The set temperatures and slope of the temperature change for both cases were identical to those that were set for an empty smaller furnace.

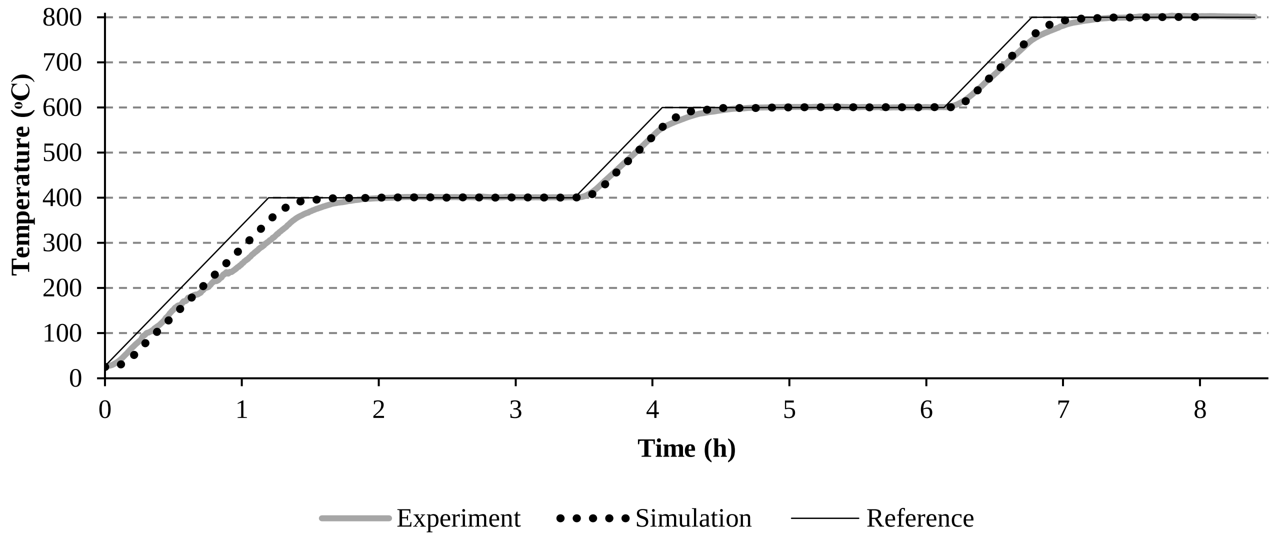

Figure 11. Temperature change during the experiment on the empty furnace of 5.5 kW

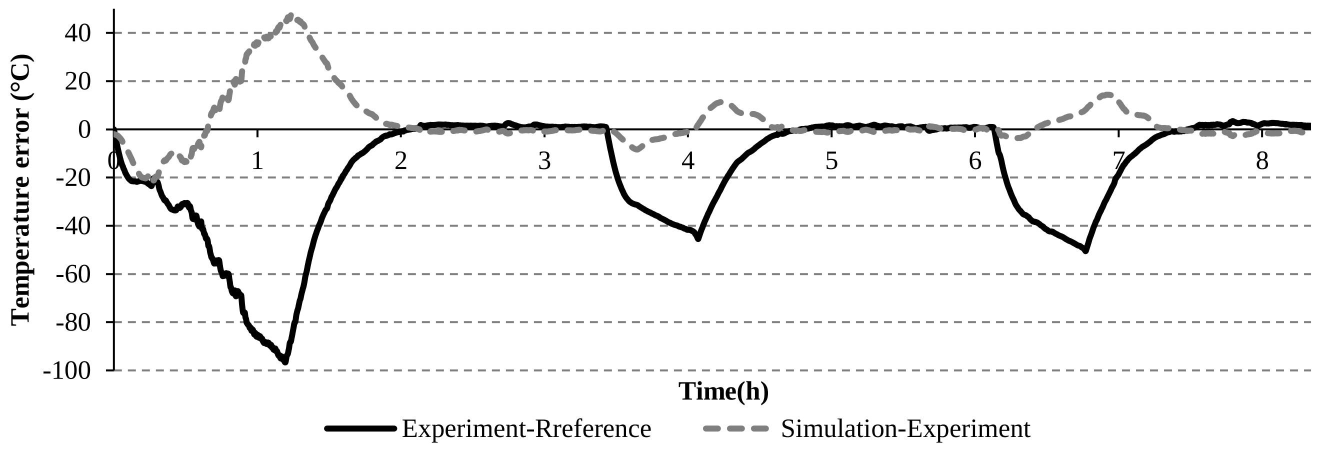

Figure 12. Temperature error during the experiment on the empty furnace of 5.5 kW

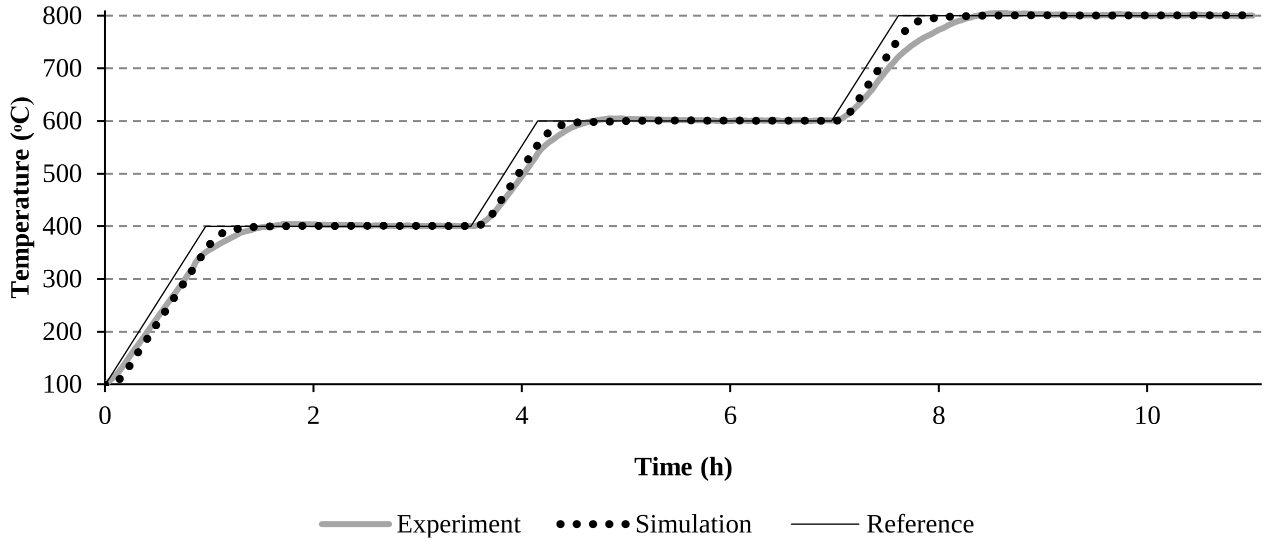

Figure 13. Temperature change during the experiment on the loaded furnace of 5.5 kW

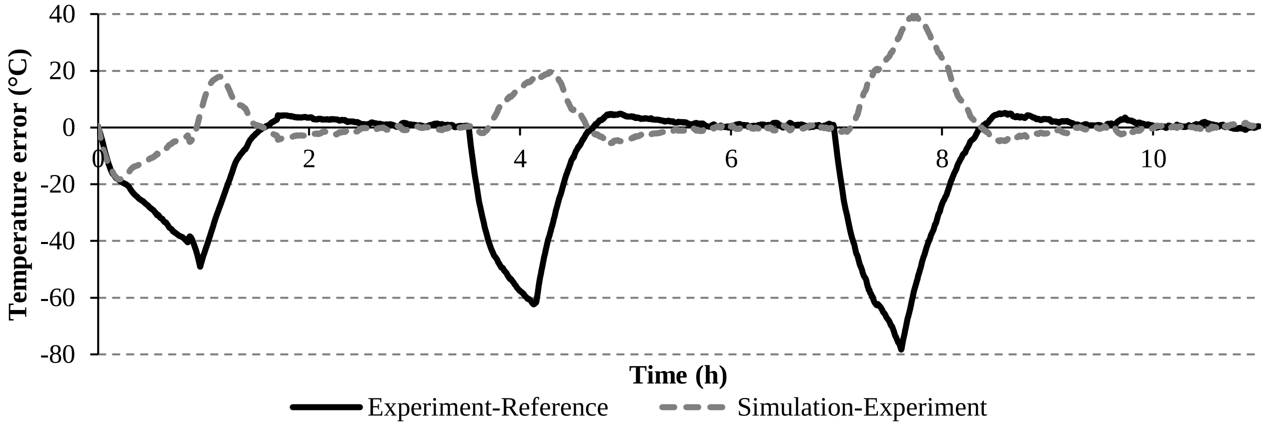

Figure 14. Temperature error during the experiment on the loaded furnace of 5.5 kW

VII. COMPARISON OF THE EXPERIMENTAL RESULTS FOR TWO DIFFERENT FURNACES

The values of the maximum temperature overshoot above the reference and the mean square errors (MSE) from the reference values of the temperature and the slope of its change are shown in Table VI, for empty furnaces and in Table VII for loaded furnaces; The values are given for each of the temperature and slope references from experiments and in tables are described like parts of experiment I (for temperature reference of 400 °C), II (600 °C) and III (700 °C or 800 °C) (see Fig. 7, 9 and 11).

MSE is calculated according to next formula:

$$MSE = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \tag{4}$$

TABLE VI. WHERE N REPRESENTS NUMBER OF MEASURED VALUES AND $\bar{x}$ IS THE REFERENCED VALUE.MAXIMUM TEMPERATURE OVERSHOOT AND MSE IN RESPECT TO THE REFERENCE VALUES OF THE TEMPERATURE AND THE SLOPE OF ITS CHANGE FOR EMPTY FURNACES

	Max overshoot (°C)		MSE of slope (°C/s)		MSE of temp (°C)	
P_{rated}	***5 kW***	***5.5 kW***	***5 kW***	***5.5 kW***	***5 kW***	***5.5 kW***
I	1.57	2.60	0.7238	0.8312	1.0889	1.4135
II	2.18	1.89	0.8351	0.8273	1.3665	1.0373
III	1.44	3.43	0.8530	0.8188	1.0674	2.0746

TABLE VII. MAXIMUM TEMPERATURE OVERSHOOT AND MSE IN RESPECT TO THE REFERENCE VALUES OF THE TEMPERATURE AND THE SLOPE OF ITS CHANGE FOR LOADED FURNACES

	Max overshoot (°C)		MSE of slope (°C/s)		MSE of temp (°C)	
P_{rated}	***5 kW***	***5.5 kW***	***5 kW***	***5.5 kW***	***5 kW***	***5.5 kW***
I	5.97	4.32	0.4360	0.6223	2.4565	2.2026
II	4.42	4.86	0.6452	0.7119	2.0234	2.1204
III	1.32	5.12	1.6596	0.7807	0.8667	2.1354

Graphical presentation of the periods used to determine MSE are presented on Fig. 15. This illustration is based on the data from the experiment presented on Fig. 13.

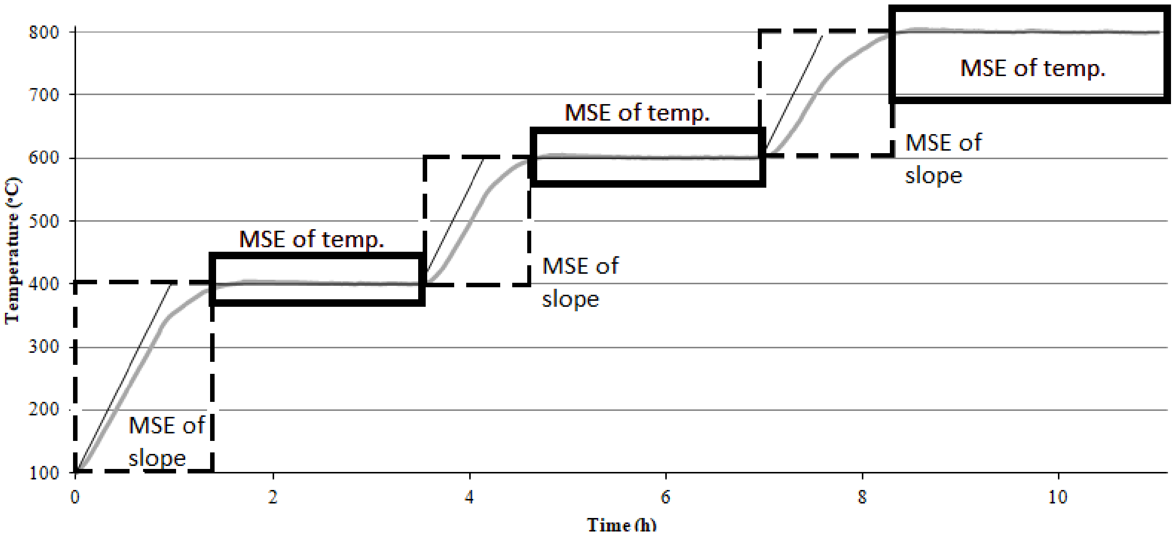

Figure 15. Periods used for the determination of MSE

The values of MSE of temperature are given for the periods from the moment when the temperature in the furnace for the first time exceeds the reference of the temperature until the moment of changing (increasing) reference temperature or the end of the measurements (the case of referent temperature of 800 °C).

MSE of slope is observed from the moment of setting new reference of the temperature to the moment when the measured temperature for the first time exceeds the reference.

As the final indication of the robustness of the fuzzy controller that is set on a smaller furnace (5 kW) and then applied to another furnace of rated power of 5.5 kW, the MSE for the tests on the loaded furnace are observed. Values of MSE for the parts of experiments are given in Table VI and VII, and MSE for whole experiments are calculated on the same way like it is explained above and their values differ on the third decimal point: for a 5 kW peak, it is 1.7587, while for a furnace of 5.5 kW it is 1.7504. These values for whole experiment are obtained from the unique sum of the squares of the errors of temperatures and the squares of the errors for slope. In other words, these values are obtained by merging the values for which MSE of temperature and MSE of slope, described in previous two paragraphs, are obtained.

VIII. CONCLUSION

The presented paper represents the stage of return / continuation of the research about temperature control in electric chamber furnace after more than 15 years of achieving promising results of the application of the fuzzy control to such technical problem. It is obvious that the tools for the development and the testing of the fuzzy controller increased a lot. Using existing Toolbox in Matlab it is possible to easily implement the fuzzy controller, adjust it on the simulations, and then generate the code for the microcontroller. Code Composer Studio allows code testing and makes it comfortable to perform fine tuning of the controller by changing it in Matlab.

The paper presents realization of the microprocessor fuzzy temperature and temperature slope controller. The results of tests on two different furnaces show that the implementation of the plug and play principle is not unrealistic. However, in order to make a more general conclusion, additional tests should be carried out on several furnaces. As a next step, tests are planned using simulations on furnaces of different design characteristics, whereby the simulation model of the furnace will be based on the physical model of heat transfer (not based on the transfer function of the furnace as a control object, as done in this paper).

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