Scientific quarterly journal ISNN 1429-7264

Agricultural Engineering

2014: 4(152):241-251

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2014.152.099

# THE USE OF THE SCILAB SOFTWARE WITH A RTAI EXTENSION FOR PROTOTYPING A TEMPERATURE CONTROLLER OF THE THERMAL BIOMASS PROCESSING INSTALLATION

Dariusz Wiśniewski, Joanna Hałacz*, Michał Wójcik

Department of Electrical Engineering, Power Industry, Electronics and Automatics
University of Warmia and Mazury in Olsztyn
*Contact details: ul. Oczapowskiego 11,10-719 Olsztyn, e-mail: jhalacz@uwm.edu.pl

ARTICLE INFO

*Article history:*
Received: April 2014
Received in the revised form: September 2014
Accepted: October 2014

*Keywords:*
*reactor*
*thermal processing*
*identification*
*temperature control*
*PID*
*robust controller*
*SCILAB*

ABSTRACT

The objective of the paper was to design and test various variants of the thermal biomass processing controllers. The process took place in a batch reactor consisting of a metal chamber into which thermal energy was supplied through a diaphgram with the use of a 2 kW power ceramic band heater. The chamber of the reactor along with the heater was thermally insulated. A classic solution of a PID controller and its variety - a robust PID controller, resistant to the object parameters fluctuations was selected for tests. The Linux Debian system and the SciCosLab environment, consisting of graphic SciCos environment were used for the operation of the stand. The system kernel was modified for operation in real time through a RTAI module (Real Time Application Interface). Analysis of the results shows that, a robust controller ensures better quality, which besides a shorter time of response, behaves better in case of the object parameters fluctuations.

## Introduction

Research on prototyping a controller for temperature control of the thermal biomass processing resulted from the necessity to develop an effective system of maintaining stable temperature in the batch reactor, which is the control object. The control object was designed for research on the thermal biomass processing. A reactor is a complex thermodynamic system, in which phase changes and heat exchange phenomena take place. Due to the process complexity and many unknown physical coefficients, creating a mathematical model of the thermal biomass processing in a batch reactor is very difficult based on the physics law. In order to determine the process model, which is indispensable for setting a controller, identification tests were carried out by a "black box" method. The black box method consists in the input and output signals analyses and the obtained parameters are physically senseless. In the research on modelling the process, parametric identification was applied and the model structure was accepted as an inertial object with a transport delay. Then, parameters of the accepted model structure were determined from the object step response. The presented method of obtaining the process model is an efficient method for inertial objects with a transport delay and enables fast prototyping of controllers.

## The objective and scope of the paper

The objective of the paper was to select a temperature controller in the thermal biomass processing reactor, which would ensure resistance to the object parameterschanges, which mainly result from an endothermic reaction inside it. For this purpose, a classic PID controller and a robust PID controller were designed and tested and then a comparative analysis of the obtained controllers concerning heating and maintaining temperature in the reactor was carried out. An industrial computer with x 86 platform operating under the Linus Debian control, whose kernel was modified to work inreal time through the RTAI module (Real Time Application Interface) was used for the research. The SCILAB environment with a graphic extension SciCosLab for simulation, measurement and testing inreal time was installed.

The control object consists of a metal chamber and a ceramic heater which encircles the reactor chamber, the power of which is 2 kW. The reactor chamber along with the heater was thermally insulated by aluminosilicate insulation. Identification research and tests of the selected controllers were carried out on the presented reactor. A classic solution was selected, namely a PID controller and a robust PID controller. A very popular binary controller was not used in the tests on account of great thermal volume of the metal casing, which would have resulted with considerable readjustments in comparison to the set value.

Programming environment, as well as an operational system, used in the construction process of the stand, was selected due to the open source. The Linux Debian and SciCosLab environment, which includes the graphic environment SciCos, was applied. The system kernel was modified for operation in real time through the RTAI module (Real Time Application Interface). The COMEDI controllers, which combine a programmer layer with expansion cards connected to the ISA or PCI buses, are significant factors.

Implementation of temperature controllers of the pyrolysis reactor in Linux x86 system with the installed RTAI module.

Figure 1 presents a schematic representation of the control system used for controlling the process temperature in the reactor. It is an example of the control system in the closed system, which performs the task of stabilization of the controlled size in the HIL technology (English: Hardware In The Loop) – the HIL simulation technology which consists in connecting a part of a real object to the feedback loop.

Thermal biomass processing temperature control takes place through a computer equipped with the Linux-RTAI system. Suitable controllers implemented on the above mentioned platform are the process controllers.

Model identification, construction and tests of controllers, as well as their later research took place in the open source software available in Linux-SciCosLab. A description of the programming foundations and particular blocks is included in the available literature (Campbell et al., 2006; Bucher et al., 2008; 2010).

Based on Brzózka's publication (2002) it was determined that the sampling period for temperature control systems should be within 10 to 20 s. Controllers should be prepared for the sampling time of 10 s. Unfortunately, restrictions of the SciCosLab software and the

RTAI-Lab software caused the need to set the controllers for a shorter sampling time of 1 s, which resulted only in the necessity to increase the calculation power of the computer.

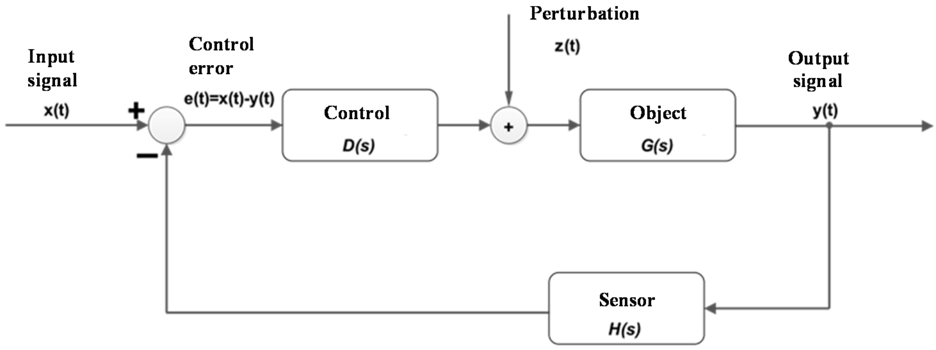


*Figure 1. A schematic representation of the stand for control of the pyrolysis process temperature*

### Model identification

Each dynamic linear model is characterized with transmittance expressed with a general formula:

$$G(s) = \frac{L(s)}{M(s)} \tag{1}$$

in the case of the first degree inertial delay model:

$$G(s) = \frac{k}{sT+1} e^{-sT_0} \tag{2}$$

where:
$G(s)$ – operator transmittance,
$k$ – reinforcement,
$T$ – time constant,
$T_0$ – transport delay time

The object of the paper was to construct a temperature controller of biomass thermal processing. Thus, a parametric identification method was selected. It assumes linearity of the control object in the entire scope of the control signal. This assumption is correct in the case when the heated reactor is not filled with batch material. Such object defines then a multi-inertial structure, which the most frequently, is modelled as a first-degree inertia with a transport delay. A parametric method of identification consists in determination of the object parameters, the structure of which is known based on the analysis of the step response course for a step or impulse function (Łysakowska and Mzyk, 2005; Ogata, 2002).

The first step in the step response analysis of the system was to find a point of inflection of the step response (fig. 2). The point of inflection is in the place, where the first derivative reaches the maximum and the other derivative equals zero (Bronsztejn et al., 2009;

Orzydłowski and Łobodziński, 2001). Figure 2 presents three plots: the upper plot presents the course of the step response of the system, the central – the course of the first derivative value, and the lower one presents the course of the second derivative value. Common point of all plots, which determines the point of inflection has been marked with a black line.

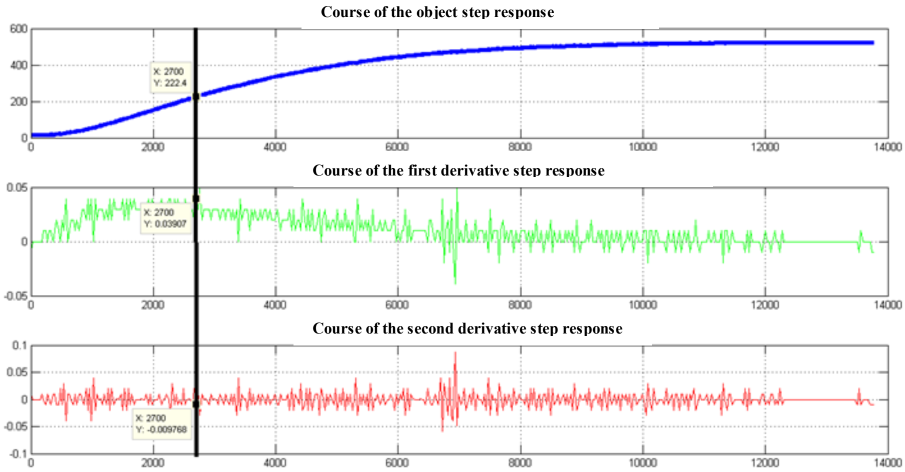


*Figure 2. Determined point of inflection*

In the point of inflection, a tangent to the course of step response was determined. The object reinforcement was determined as a relation of the temperature increase to the increase of the control signal value at the analogue output of the card. For the considered object this are respectively: 505°C and 3.4V.

The approximate model data were read out from the plot (fig. 3):
reinforcement – k=148,5294, time constant – T = 4250s. delay – $T_o$ = 890.

In order to increase the preciseness of determination of the model parameters, optimization methods for searching for such parameters, which ensure the highest compliance with the real data, were applied. For this purpose, optimization of the function with the derivative- free optimization DFO was applied (Palczewski, 2014). This method consists in searching for the minimum of functions in the set range. The algorithm assumes a division of the segment into smaller parts and searching for the minimum in the vicinity of the centre of the selected segment.

As a result of optimization, new model values were obtained:
reinforcement – k=150,5294, time constant – T = 2670 s. delay – $T_o$ = 1294.

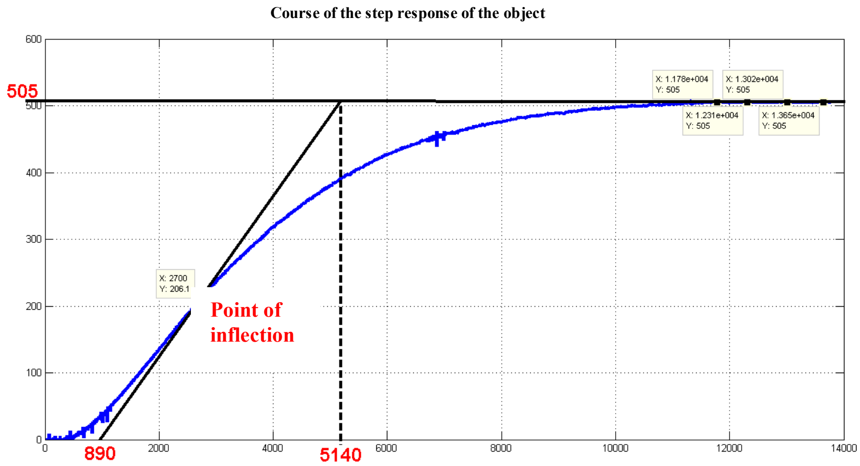


*Figure 3. Step response of the object with marked parameters: time constant, delay, reinforcement*

The obtained model served for setting controllers and their simulation tests. Transmittance of the constant model according to the above values and pattern (2) is:

$$G(s) = \frac{150.5294}{2670s+1} e^{-1294s} \tag{3}$$

**Construction and implementation of the PID controller**

Tunings of the PID controller (Brzózka, 2006) were presented in a discreet variant and calculated from Ziegler-Nichols formulas (Brzózka, 2006) in the following manner:

– proportional term:
$$K = \frac{1}{k}\left(\frac{1{,}2T}{T_0+\frac{T_S}{2}} - \frac{0{,}3TT_S}{\left(T_0+\frac{T_S}{2}\right)^2}\right) = 0.016439, \tag{4}$$

– integrator:
$$\frac{T_S}{T_i} = \frac{0{,}6TT_S}{K\left(T_0+\frac{T_S}{2}\right)^2 k} = 0.0003863, \tag{5}$$

– derivative term:
$$\frac{T_d}{T_S} = \frac{0{,}5T}{KT_Sk} = 539.4792, \tag{6}$$

where:

$k$ – reinforcement is: 150.5294,
$T_0$ – delay is: 1294 s,
$T$ – time constant is: 2670 s,
$T_s$ – sampling time is: 1 s.

The determined controller tunings controlled the temperature quite well. The only drawback of these tunings is a very long time of control which is approximately $7 \cdot 10^4$ s. The principles of the tunings selection with Ziegler – Nichols method provide only approximate, pictorial values of particular terms, at the same time they are the starting point for finding such tunings at which regulation takes place in a satisfactory manner (Ogata, 2002). Thus, it was decided to select manual tunings which ensure a more precise regulation. The tunings were selected with a trial and error method and the values of particular terms present as follows:

– proportional term: old value: 0.016439, new value: 8.0639,
– integrator: old value: 0.0003863, new value: 0.002563,
– derivative term: old value 539.5, new value 539.5

After the parameters are adjusted, the value is regulated with a greater precision and is obtained in a shorter time of $1.4 \cdot 10^4$-$1.5 \cdot 10^4$ s, which was presented in figure 4.

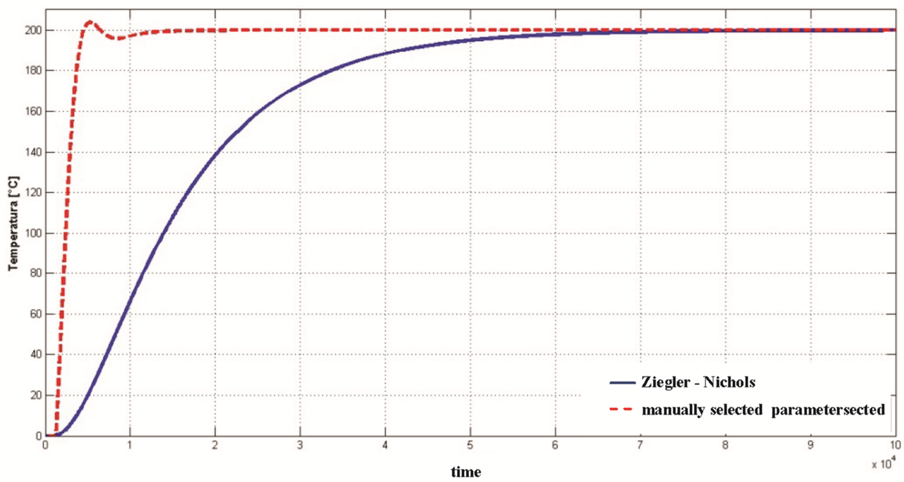


*Figure 4. The course of the value regulated by the discreet PID controller with the calculated values of tunings and manually selected parameters*

The Saturation block is a significant part of the PID controller. It limits values within 0 to 10, provided for the object. It prevents the effect of the controller tuning.

The PID controller design with the object model must have included input/output of the measurement card. Figure 5 presents the design appearance of the PID controller with a feedback loop in the HIL technology.

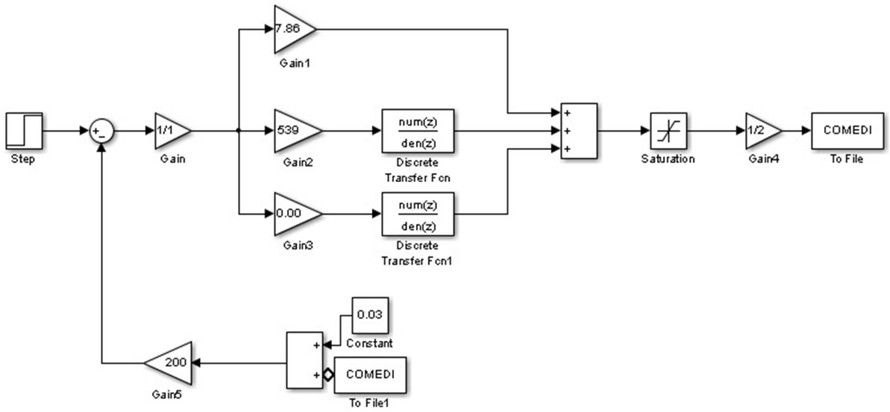


*Figure 5. Appearance of the PID controller with a feedback loop in the HIL technology made in SciCos programme with operation of the input/output cards with COMEDI controllers*

**Design and implementation of the robust PID controller**

A robust controller is such a discrete control system, which is not sensible to perturbations of the object parameters (Brzózka, 2002). Two connected controllers are used for its construction. One of them is responsible for regulation of the value set according to the introduced mathematical model parameters, whereas the other is responsible for regulation of the set value based on the real object. Such combination causes that the unit becomes insensible to big deviations of the object parameters.

The first PID loop assumes model values pursuant to the ones obtained during the identification process, whereas values of the PID controller correspond to the values described above. The second loop is related to the real object, the parameters of which may change during the process. In the designed model, perturbations in the form of changing model values (insulation is burnt, inaccuracy of reflecting the model parameters towards the real object, etc.) were included: time constant from the valueof 2670 s to the value of 2550 s, reinforcement changes from 150.5294 to 155, delay changes from 1294s to 1400 s.

Figure 6 presents the course of control of the value controlled by the described controller. This value was set with the PID controller response to the same signal. The robust controller showed greater readjustment which is related to the introduced perturbations in the form of model parameters changes. However, despite high parameters deviations, the controller in the time of approximately $1 \cdot 10^4$ s worked out the set point.

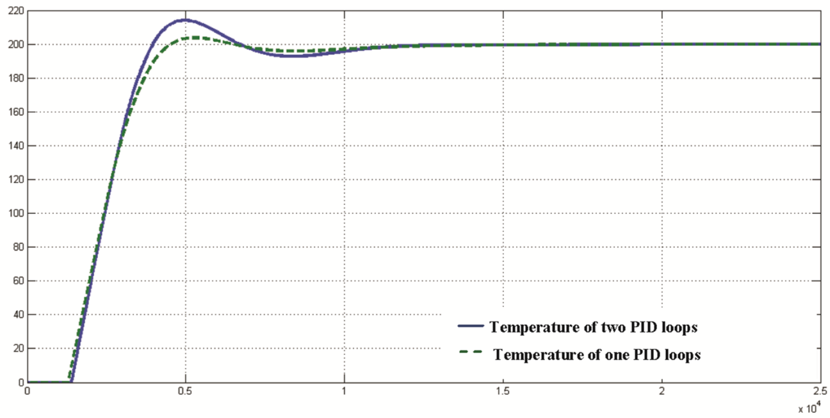


*Figure 6. The course of the value regulated by the discrete robust controller PID*

Like, in the case of the PID controller, it was necessary to adjust the PID robust controller to the operation with the COMEDI controllers. A schematic representation of such a controller is presented in figure 7.

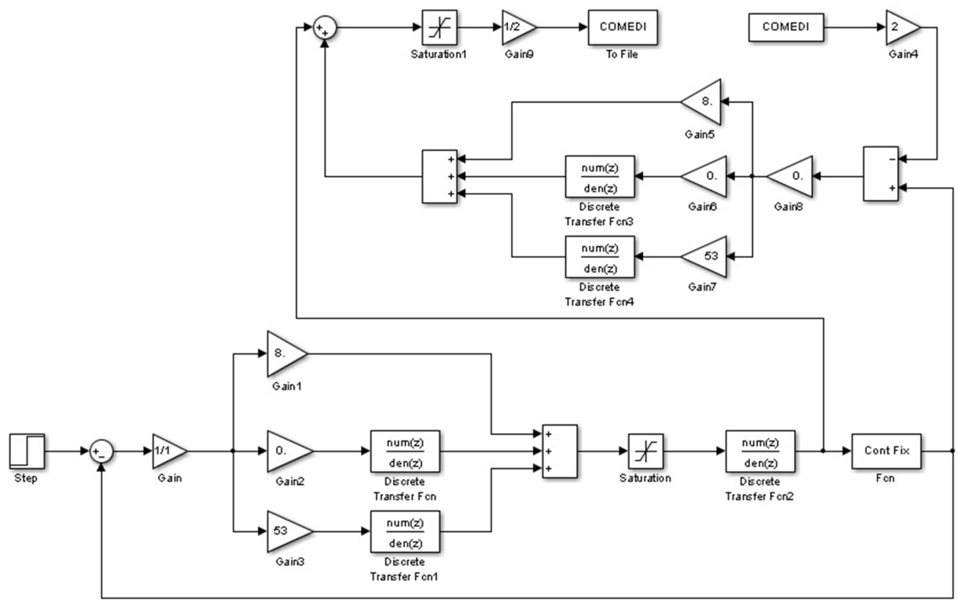


*Figure 7. Appearance of the PID controller with a feedback loop in the HIL technology made in the SciCos programme with operation of input/output cards with COMEDI controllers*

## Research results

Tests of the designed control system on the real object consisted in determination of dynamic properties of controllers with regard to the step function of the set point. The objective of the designed controllers was to achieve the set point in possibly the shortest time and with the possibly the smallest control error. In tests of both controllers, the set point was changing in a step manner from zero to the temperature of 200°C. The designed PID controller reflected very well the set temperature without readjusting in time, which was 7000s (less than 2 hours). Then, the value was within the limits198.3°C-200.2°C, which is in a possible control error and the readout error of thermocouple and conversion of its signal into a standardized signal within the tension standard 0-10V. Then, the second of the tested controllers, the robust PID controller was implemented. Temperature stabilization took place after 5700 seconds (approx. 1.5 h). The signal was within 198 -201°C which is within an admissible measurement error. Figure 8 presents the course of the controlled value (temperature) when using controllers on the real object- thermal biomass processing installation.

According to the comparison, the robust PID controller (green colour) worked out a signal in approx. 5700 s, whereas the PID controller (blue colour) worked out the same signal value in 6800 seconds. This difference is approx. 110 s, that is, almost 20 minutes. It should be emphasised that the robust controller started control from the temperature lower by approx. 7°C, which in the beginning of control may be crucial. Temperature courses in the reactor obtained from measurements characterize with small (at the level of the measurement error) deviations from the set point.

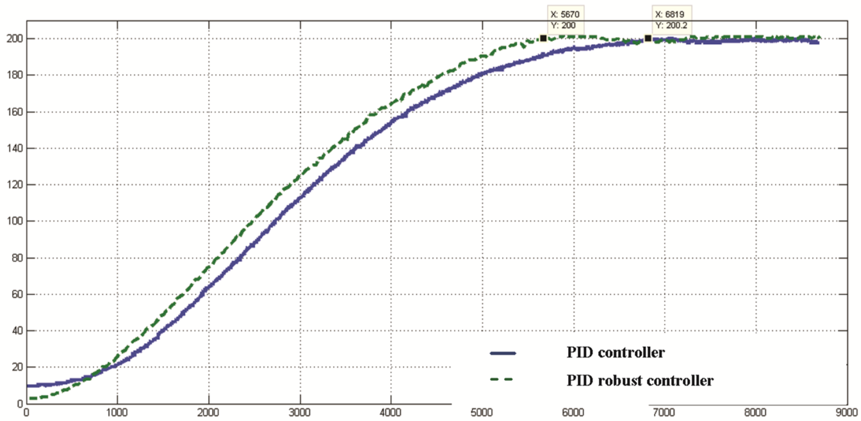


*Figure 8. Comparison of temperature control courses by: the PID controller and the robust PID controller*

## Conclusion

Temperature control in thermal biomass processing is a significant issue particularly in batch reactors, whose operation characteristics is not determined. Such situation causes high variability of the controlled object mainly due to endothermic reactions, which take place with various intensities and in various process stages. The tests, which were carried out on the real object allowed verification of practical realizations of controllers and their usefulness in temperature control in batch processes. The tests covered the PID classic controller tuned on the model obtained as a result of parametric identification of the non-batch object and the robust PID controller. Better parameters of operation were obtained for the robost controller especially with regard to the control time. Besides, it better reacted in the case of parameters changes caused by reactions in the reactor. However, advantages of the PID controller, on the basis of which the robust controller has been constructed, should be emphasised. It has a simpler structure than the robust controller and simultaneously a simpler implementation because it does not require implementation of the discrete process model, which translates into lower demand of machines for computing power and the reduction of implementation costs.

## References

Bronsztejn, I.N.; Siemiendiajew K.A.; Musiol, G.; Muhlig, H. (2009). *Nowoczesne kompendium matematyki*. Warszawa, PWN, ISBN 83-01-14148-4.

Brzózka, J. (2002). *Regulatory cyfrowe w automatyce*. Warszawa, MIKOM, ISBN 83-7279-238-0.

Brzózka, J. (2006). *Regulatory i układy automatyki*. Warszawa, MIKOM, ISBN 83-7279-380-8.

Bucher, R.; Mannori, S.; Netter, T. (2008). *RTAI-Lab tutorial: Scilab, Comedi, and Real-time control*, Pozyskano z: https://www.rtai.org/RTAILAB/RTAI-Lab-tutorial.pdf.

Bucher, R.; Mannori, S.; Netter, T. (2010). *RTAI-Lab tutorial: Scicoslab, Comedi, and Real-time control*, Obtained from: http://robertobucher.dti.supsi.ch/bucherdl/RTAI-Lab-tutorial.pdf.

Campbell, S.L.; Chancelier J.P.; Nikoukhah R. (2006). *Modeling and Simulation in Scilab/Scicos*. New York, Springer, ISBN: 978-0-387-27802-5.

Łysakowska, B.; Mzyk, G. (2005). Komputerowa symulacja układów automatycznej regulacji w środowisku MATLAB/Simulink, Wrocław, OWPW, ISBN 83-7085-854-6.

Ogata, K., (2002). *Modern control engineering*. New Jersey, Pearson Education International, ISBN 0-13-043245-8.

Orzydłowski, M.; Łobodziński, W. (2001). Identyfikacja obiektów cieplnych metodami czasowymi i częstotliwościowymi dla celów regulacji. *Pomiary Automatyka Kontrola*, 3, 12-14.

Palczewski, J.. *Matematyka stosowana. Optymalizacja II*. Warszawa, Uniwersytet Warszawski, 2014. Obtained from: http://mst.mimuw.edu.pl/wyklady/op2/wyklad.pdf.

# WYKORZYSTANIE OPROGRAMOWANIA SCILAB Z NAKŁADKĄ CZASU RZECZYWISTEGO RTAI DO PROTOTYPOWANIA REGULATORA TEMPERATURY INSTALACJI DO TERMICZNEGO PRZETWARZANIA BIOMASY

**Streszczenie.** Celem pracy było zaprojektowanie i przetestowanie różnych wariantów sterowników procesu termicznego przetwarzania biomasy. Proces odbywał się w reaktorze wsadowym składającym się z metalowej komory do której poprzez przeponę dostarczana była energia cieplna za pomocą grzałki ceramicznej opaskowej o mocy 2kW. Komora reaktora wraz z opasującą ją grzałką była zaizolowana termicznie. Do testów wybrano klasyczne rozwiązanie regulatora PID oraz jego uodpornioną na zmiany parametrów obiektu odmianę – regulator odporny PID. Do obsługi stanowiska, wykorzystano system Linux Debian oraz środowisko SciCosLab, w którego skład wchodzi środowisko graficzne SciCos. Jądro systemu zostało zmodyfikowane do pracy w czasie rzeczywistym poprzez moduł RTAI (Real Time Application Interface). Analiza wyników wskazuje, iż lepszą jakość regulacji zapewnia regulator odporny, który poza szybszym czasem odpowiedzi, lepiej się zachowuje w przypadku zmian parametrów obiektu.

**Słowa kluczowe:** reaktor, termiczne przetwarzanie, identyfikacja, regulacja temperatury, PID, regulator odporny, SCILAB