DETERMINATION OF PID CONTROL PARAMETERS OF PLASMATRON PLASMA REACTOR

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Abstract

The paper presents determination of PID controller parameters for application of plasmatron powered plasma reactor designed and build in Industrial Research Institute for Automation and Measurements. Plasma reactor is the key element of the test setup, designed to research, processing and recovery of metals from waste of electric and electronic equipment, focusing on electronic printed circuit boards. Experiment was carried out with power of 36 kW. In experiment two temperatures were measured in two points of the reactor chamber, allowing verification of thermal response. Basing on identification of thermal parameters of the plasma reactor carried out in previous paper [7], the PID controller was chosen, as suitable to control second order inertia object. Parameters of used PID controlled were determined using MATLAB-Simulink toolbox. Calculated PID model was utilized for plasma reactor parameters control, allowing examination of energy saving by reducing of plasmatrons power, and stabilization of process parameters.

Key words: PID, recycling, electronic waste utilization, plasma technology

1 Introduction

Increasing digitalization of appliances, and machines equip them with electronic circuit boards. Those electronic circuit boards after end of life of appliance, becomes hazardous waste, that needs to be treated property. Mass production of electric and electronic equipment, requires huge amounts of nonrenewable resources, like metals including precious, and rare earth. It is important to develop new effective ways of treating waste of electronic printed circuit boards (PCB), because they are also new „renewable” resource that can supply recycled metals for new production. By processing the waste of electronic circuit boards, it is possible to recover metals, energy, and decrease its hazardous effect on environment.

Waste of electrical and electronic equipment (WEEE) is a global concern. In the 27 EU countries it is estimated that the weight of produced waste WEEE in 2005 was 8.3 - 9.1 million Mg (tones), 25% of which is collected and processed, while remaining 75% is not registered and does not occur in collection points [1,2]. Such state of waste management system can be caused by lack of processing capacities and suitable technologies which can utilize WEEE effectively. The amount of WEEE rises continuously [3,4] in 2008 Sweden collects 16.7 kg/capita of WEEE, Britain 8.2 kg/capita, Austria 6,5 kg/capita [5]. Moreover European Commission proposes rising collection targets from 4 kg/capita to 65% of average mass of electrical and electronic equipment placed on market (WEEE directive 2002/96/EC) [6]. WEEE has to be utilized, but it also can become a source of valuable resources. Need for technology allowing recovery and neutralization of this waste is strong in Poland, due to huge technological and organizational gap between Poland and west European countries..

Traditional simple WEEE processing technologies i.e. manual dismantling, milling, allow recovery of most of the waste mass. Also new robotic technologies offers new approach to WEEE dismantling decreasing human labor and energy consumption [7]. However every waste processing technology also generate waste, and does not allow full neutralization and recovery. One of such fraction that require specialist processes is the waste of printed circuit boards, and the second one is the “under sieve” fraction from milling of WEEE waste. Currently in Europe only few plants process electronic printed circuit boards, and they use pyrometalurgical processes. There is no such installations in Poland. Important is also that the waste of electronic printed circuit boards, is only a part of the total input in those technologies. Moreover there is no complete processes for neutralization of waste of printed circuit boards and recovery of metals form them. That is why research project was undertaken, financed by Polish National Centre for Research and Development, to investigate and design plasma process allowing processing of waste of printed circuit boards and recovery of metals they contain.

In Industrial Research Institute for Automation and Measurements the test setup was designed and constructed to investigate plasma processing of waste of electronic and electric equipment for recovering of metals and its neutralization. The stand is presented on Figure 1. The key component of the test setup is the plasma reactor, equipped with three plasmatrons - plasma sources, each located 120^{o} around the reactor chamber. The test position is equipped with peripheral systems, measurement and control apparatus for data acquisition and control of the process, during research.

Figure 1. Overview of laboratory setup: 1) Plasma reactor, 2) Plasmatron, 3) Molten product collection, 4) Fumes Exhaust – chimney, 5) Waste package transporter, 6) Plasmatron power supply, 7) PLC – automation and data collection apparatus cabinet, 8) Automatic waste package feeder

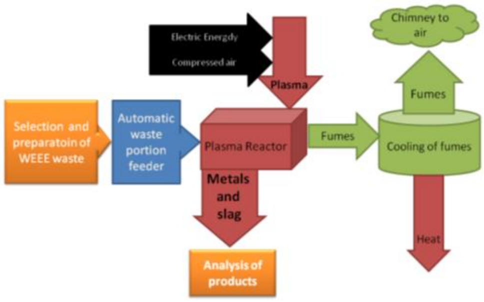

Figure 2. Block diagram of the designed process for research over high temperature plasma technology for metals recovery and electronic waste utilization

The high temperature plasmatron plasma reactor is the key component of laboratory setup for research over high temperature utilization of waste of printed circuit boards, for metals recovery. Block diagram of laboratory setup is presented on Figure 2. Designed test setup allows wide range of possible experiments and data acquisition during research over waste processing and metals recovery. Designed plasma process is being carried out by the fallowing steps presented on Figure 2. Prepared waste portion is transported through automatic feeder to the plasma reactor chamber. In the reactor chamber waste is being incinerated and molten by three plasma streams, next the incineration fumes are being transported to the scrubber where they are neutralized, cooled and then released to the atmosphere. As to the metals and slag, in molten form metals and slag flows out form the reactor and sets in casts, from which it can be recovered and recycled. Figure 3 presents cross section of the reactor, arrows marks the waste and metals route (orange arrow), plasma stream (black arrow), and the fumes exhaust direction (red arrow).

2 Reactor chamber construction

Reactor chamber construction consist three layers: first from inside is fire proof concrete, next is the thermal insulation, and last is the external metal construction shell. Reactor chamber is hexagonal and its construction is presented on the figures 3 and 4. Such construction allows containing in its volume temperatures ranging for 1500 up to 1650 ^{o}C. However, in the area where the plasma streams has direct effect on waste, the temperatures exceeds the temperature measured above, however due to difficulties of measurement of temperatures above 2000 ^{o}C, this temperature currently is not measured.

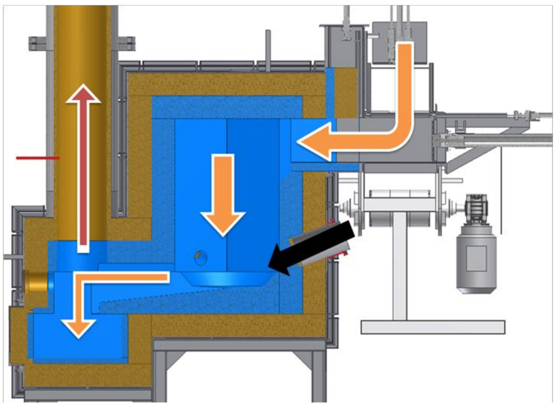

Figure 3. Cross section through plasma reactor with presented material flow. Waste, and molten product – orange arrows, plasma stream – black arrow, fumes – red arrow

The plasmatron plasma reactor have three sources of heat, which are 20 kW arc plasmatrons. Plasmatrons efficiency reaches 80% of energy to plasma heat efficiency. However calculating the plasmatron efficiency including efficiency of the power source, overall efficiency decreases to 70%.

Each plasmatron generates stream of plasma, that flows out at the bottom of the reactor chamber. Plasma is produced from compressed air, that is used as plasmatron working gas. Three plasmatrons consume 11 Nm^3/h of air during normal operation.

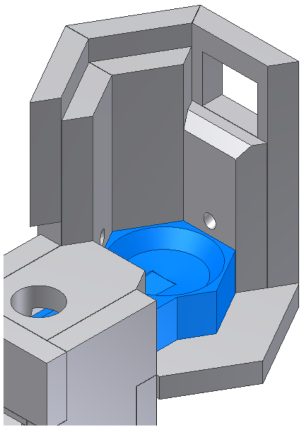

Figure 4. Internal construction of plasma reactor – CAM model

3 Measurement of tempearture in the reactor

Temperature inside the reactor chamber is measured in two points located 30 mm away from reactor wall, and placed in theirs centre. Temperature probe A is located 350 mm above reactors surface, and probe B is located 30 mm above reactor surface. Both sensors are thermocouples type B in ceramic cover. Sensors placement is shown on Figure 5.

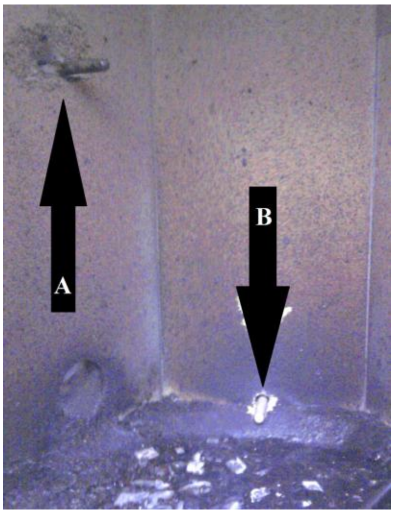

Figure 5. Placement of the temperature measurement probes: A – 350 mm above reactor surface, B – 30 mm above reactor surface

4 Determination of of control alghoritm and its parameters

For determination of control method, mathematical, linear model of the developed reactor has to be determined. We consider, that input variable is power *P* (kW) provided to the plasma reactor and output variable *T* (^{o}C) is temperature in the reactor.

Analyse of the physical background of the changes of temperature in the reactor shows, that the time constant of heating up of the reactor chamber, is about 3 minutes, whereas the time constant of heating of the concrete walls of the reactor is to over 22 hours. For this reason transfer function *G(s)* of the plasma reactor was determined as inertial second order given by equation (1).

$$G(s) = \frac{K_p}{(1+T_{p1}\,s)(1+T_{p2}\,s)}, \qquad (1)$$

where K_p is gain of the object, T_{p1} and T_{p2} are time constants of inertial elements.

Identification was based on step response of the reactor, with given step input power of the plasmatrons [7]. Results of identification of parameters of transfer function G(s) are presented in the table 1. Identification was carried out for two points of plasma reactor

Table 1. Results of identification of parameters of transfer function *G(s)* [7]

Step response for power P=36 kW	
Measurement point A	Measurement point B
$K_p = 94{,}8 \pm 0{,}7$	$K_p = 47{,}45 \pm 0{,}09$
$T_{p1} = 84235 \pm 934$	$T_{p1} = 21455 \pm 105{,}14$
$T_{p2} = 201{,}8 \pm 1{,}6$	$T_{p2} = 224{,}55 \pm 5{,}13$

Basing on identification of thermal parameters of the plasma reactor, the PID controller was chosen, as suitable to control second order inertia object. This controller was operating in control loop using temperature signal from point A.

Point A was chosen for control loop due to the fact, that temperature in this point is higher, that temperature in point B [7]. As a result, using temperature in point B as an input parameter for control, may lead to malfunction of plasma reactor, due to exceeding its maximal temperature. Maximal temperature of reactor operation was estimated as $1900^{o}C$. It is determined by temperature durability of elements of plasma reactor.

Schematic diagram of control system is presented in figure 6. Control loop is oriented on temperature in point A, whereas temperature in point B is only observed.

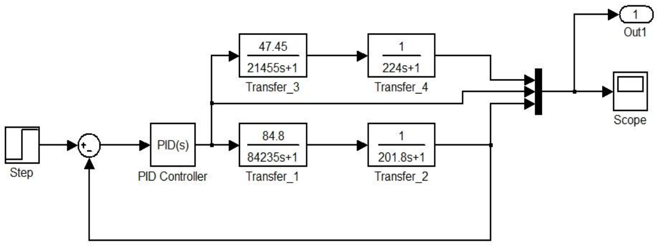

Figure 6. Mathematical model of plasmotron reactor system

Parameters of used PID controlled were determined using MATLAB-Simulink toolbox. There were applied following criteria for PID controller:

- stability of the system,
- minimal time of temperature stabilization,
- output power limited to 40 kW for full range of operation of controller.

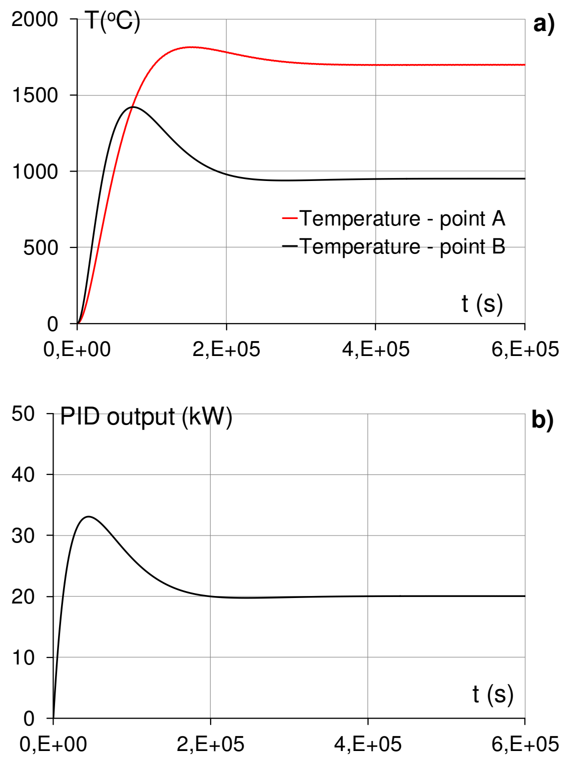

Figure 6. Time plots of: a) temperature T in points A and B in controlled system, b) PID controller effort

As a results of tuning parameters of PID controller, it was determined, that:

- linear element gain should be: $1.413e^{-2}$,
- integrating element gain should be: $3.092e^{-7}$,
- derivative element gain should be: $-1.934e^{2}$.

Time plots for temperature in points A and B, using control system presented in figure 6, for T=1700 ^{o}C in point A are presented in figure 7a. Controller effort is presented in Figure 6b. Limited controller effort should be indicated.

5 Summary

Basing on carried out identification of thermal parameters of the plasma reactor and identified transmittance, presented in previous paper [7], the PID parameters tuning for control of temperature was carried out.

Such automatic control is very important in undergoing research, allowing examination of energy saving by reducing of plasmatrons power, and stabilization of process parameters. Presented identification will be also used in mathematical modeling of plasmatron plasma reactor equipped with three plasma sources.

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