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EXPERIMENTS ON TEMPERATURE CONTROL USING ON-OFF ALGORITHM COMBINED WITH PID ALGORITHM

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Abstract

The paper presents an automated system for the temperature control using a PIC microcontroller, a digital temperature sensor with I2C and a MOSFET as actuator. The control strategy is a proportional-integrative one, preceded by an on-off algorithm. The most important data is presented on a graphical interface. In order to send the parameters of the process and the command states to the computer, the serial communication is used.

Keywords: temperature control; PIC microcontroller, PID controllers, adaptive control

1. Introduction

In the industrial applications, the precise control of the processes' parameters implies the necessity of adequate strategies for monitoring.

In this paper, the authors propose a strategy of monitoring and control of the temperature, using a PIC16F826 microcontroller and the discrete controller implemented on the PC. This study refers to the design, implementation and testing of the control schematic. With adequate modifications, the schematic can be extended for the control of other parameters, such as flow, level, pressure etc.

This field's literature presents the microcontrollers' using problem for the industrial applications and highlights similar studies and experiments.

So, the fundamentals of the PIC microcontrollers, with hardware and software details, are very well presented in [1]. The elements of designing and implementation with microcontrollers and microprocessors, the set of instructions, the organizing and addressing of the memory, the interruption system etc. are developed in [2,3]. The PID and the On-Off classical control algorithms with the tuning criteria are presented in [5]. The study from [4] presents an automated system used for the temperature control of the fluid. The control algorithm is an on-off type with hysteresis one and it is implemented with a PIC microcontroller and a relay as its actuator. Experiments of PID auto-tuning controllers, implemented on microcontrollers and used for the temperature control are developed in [6]. A set of techniques which provide a systematic approach for automatic adjustment of controllers in real time, when the parameters of the plant dynamic model are unknown and/or change in time are developed in [7]. The architecture of the temperature control system using the PIC18F4620 microcontroller, the programming software and the PID control are presented in [8]. The paper [9] describes the functionality of a temperature controlling system using PIC18F45K22 microcontroller.

An example of embedded system design for the temperature control, which uses the PIC16F876A, with different block diagrams and conditioning, are presented in [10]. In the paper [11] the microcontroller based water level sensing is investigated in order to manage the power consumption and the water overflow. The paper [12] relate the appliance of adaptive model predictive controller that is designed to handle temperature control of continuous stirred tank reactor.

In [13], an adaptive PID control algorithm is used in order to track the process temperature. The control algorithm employs Lyapunov function based artificial neural networks for online tuning of PID actions.

The paper [14] deals with a PIC microcontroller to monitor and record the value of temperature, humidity, soil moisture and sunlight of the natural environment. In order to solve the problem of high overshoot and slow calculation speed in the design of temperature control system, the paper [15] propose an adaptive control algorithm based on characteristic model. Also, for the design and implementation of the temperature control schematic presented in the paper, the recommendations from the [16, ..., 18] data sheets were considered.

In this section of the paper a short review of studies on the temperature control, from the literature is presented. In Section 2 the block diagram and the electronic schematic for the temperature control are presented. In Section 3 the control algorithm with implemented subroutines and the graphical interface are detailed. Experiments of PI controlled systems, tuned by the Ziegler – Nichols criteria, preceded by on-off control and the final conclusions are provided in the final section.

2. The schematic control

The block diagram designed for the temperature acquisition and the command of the heating elements (electric resistance) consist of (Fig. 1):

- acquisition and signal processing block;
- computing, recording and display block.

The acquisition block is an interface between the PC and the process (furnace) and ensure:

- the processing of the signal receiving from the temperature sensor and sending to the PC;
- the modulation of the voltage for the heating element.

This block consists of (Fig. 2):

- MCP9803, digital temperature sensor with I2C interface [17];

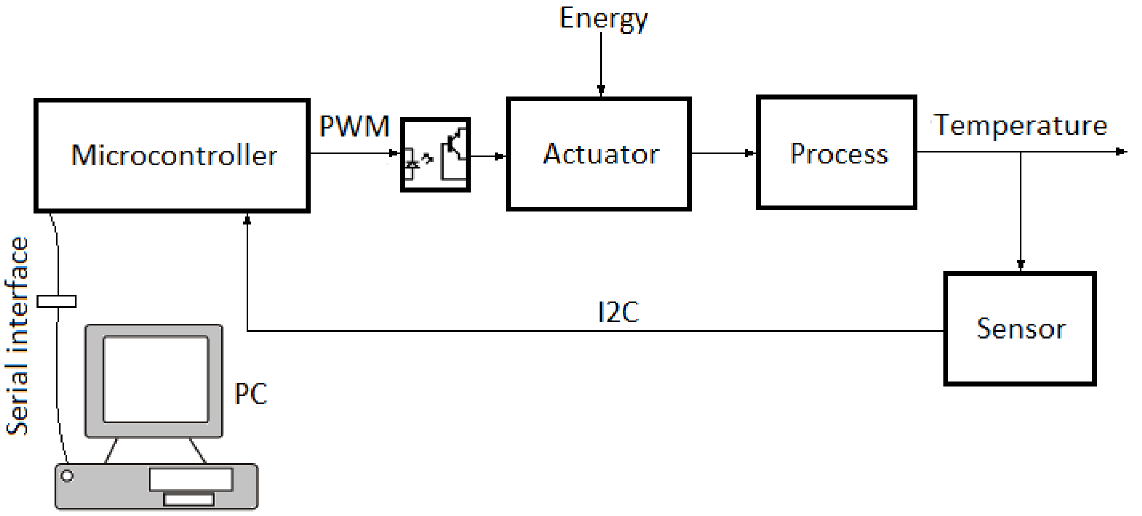

Fig. 1: The block diagram of the temperature control

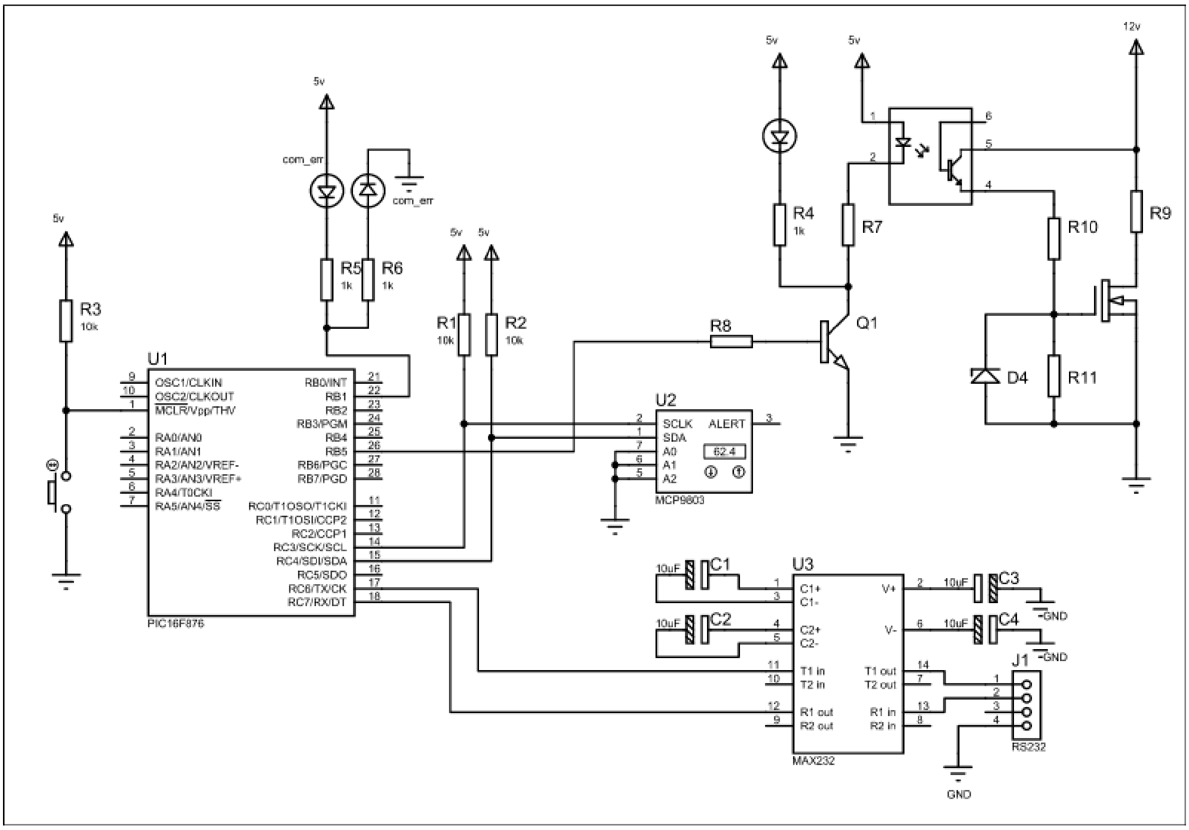

Fig. 2: The electronic schematic

- PIC16F876, 8 bits microcontroller [16];
- MAX232 driver driver/receiver for RS232 serial interface [18];
- MOSFET transistor as actuator for high power and low voltage;
- Optocoupler that provide electrical isolation between the supply voltage and the lower voltage;
- Quartz oscillator, signaling LEDs, connectors.

The microcontroller communicates with the temperature sensor through I2C bus and receives 12 bit, binary data (temperature), then waits data from RS232.

This data is sent to the PC. If there are no data, after a specified time, the supply voltage of the heating element is stopped, and the receiving subroutine is reactivated.

After the data receiving, a test decides if data are in the (0 - 100)% admissible domain, which is exactly the amount of power to be supplied to the heating element (expressed as a percentage). The control of the power is based on the Pulse Width Modulation (PWM), with a rectangular fixed-frequency signal and a variable duty cycle.

3. The software application

The dependence of the average power by the on-time PWM is presented in Fig. 3, with the time (T) of the command signal, generated by the microcontroller, of 10 seconds.

So, for a 1% power, a pulse of 0.1 sec./T is generated, this value being the on-time resolution of the PWM. The power can be percentage controlled in the (0 - 100)% range.

The program in the PIC16F876 microcontroller is structured in subroutines, for (Fig. 4):

- USART setting (Universal Synchronus Asynchronus Receiver Transmiter) for serial transmission, with 9600 baud, with one stop bit and no parity bit;
- setting of the temperature sensor: 12 bits, meaning 0.0625 ^oC resolution;
- data reception/transmission from/to PC, without locking, with 5 seconds time out;
- I2C/SMbus type communication;
- MSSP setting (Master Synchronus Serial Port), for SMbus, with 100 kHz communication;
- pulse width modulation by software;
- sensor (temperature) reading, two bytes: MSB for the integer and LSB for the fractional value.

The program for the digital controller is written based on LabWindows/CVI and has the following facilities:

- manual control of the heating element;
- using of the P, PI and PI with anti-windup controllers;
- using of the adaptive controller;
- save – load and display of the measured data.

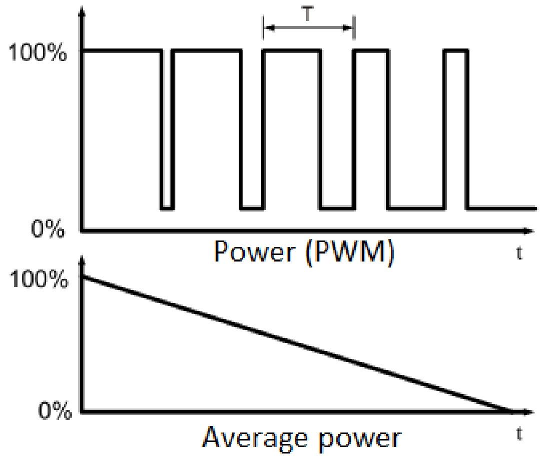

Fig. 3: The dependence of the average power by the PWM

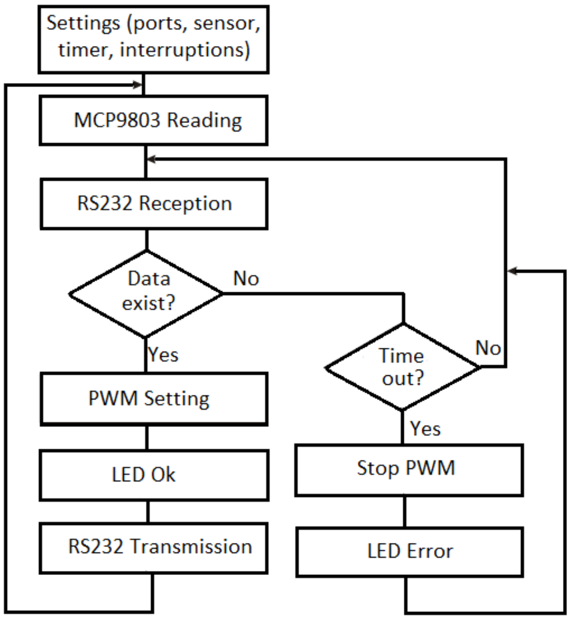

Fig. 4: Flow chart

The graphical interface highlights (Fig. 5): buttons (1,2,16) for start/stop and program exit; serial port selection (3); data load/save (4,5); data save mode (6); index display (7); setting of the output power (8); selection of the controller type (9); tuning parameters (10,11); display of the instant/average output power (12,13); temperature display (14); temperature set point (15); sizing of *Oy* and *Ox* axis (17,18,19,20); reset (21); errors messages (22); display of the *Oy* and *Ox* axis (23,24); temperature (25).

4. The experimental results and conclusions

During the process identification there may be significant temperature increases, that could damage the process components (sensors, physical structures etc.), so beforehand an on-off control is made at a temperature value of 90% out of the set point value.

During this on – off control procedure, the average power is calculated by averaging of the command pulses in time.

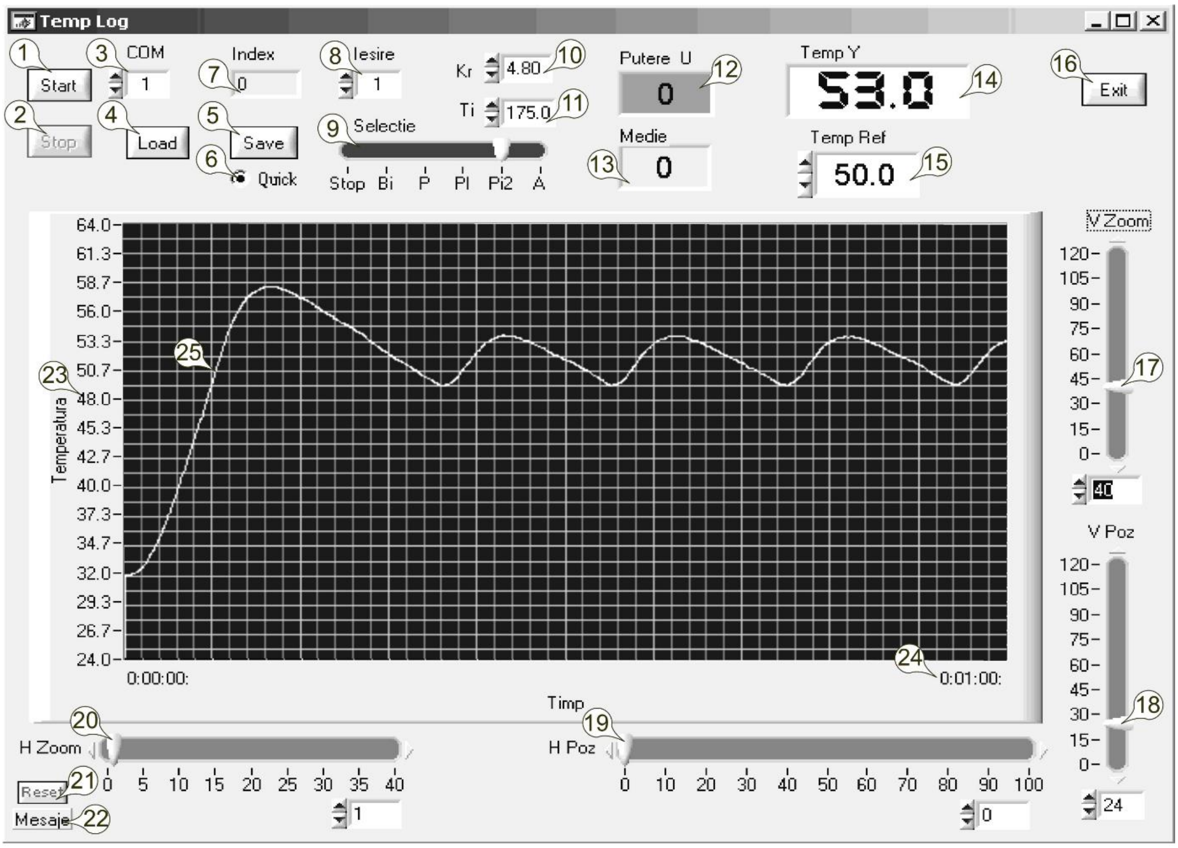

Fig. 5: The graphical interface

If the average power variation does not exceed 2% in the last 2 times (T), the on-off control stops and the control system switches to a PI control and a constant output power, which is equal with the calculated average power.

E.g., for the set point of 50°C, the control starts with a set point value of 45°C and an on-off algorithm, then switches to a PI algorithm, followed by the increase of the set point temperature value with 10%, meaning 50°C (Fig. 6, Fig. 7).

Similarly, Fig. 8 presents the PI control with the set point value of 55°C.

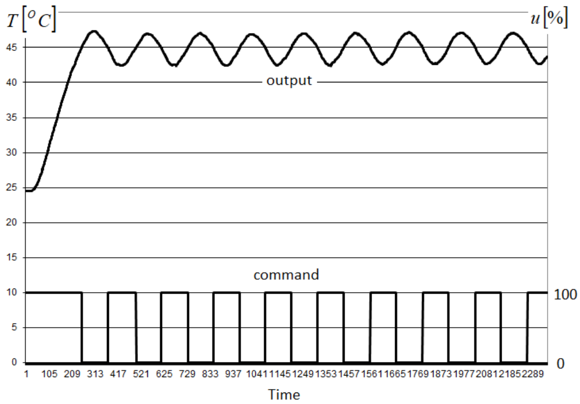

Fig. 6: On-off control with set point of 45°C

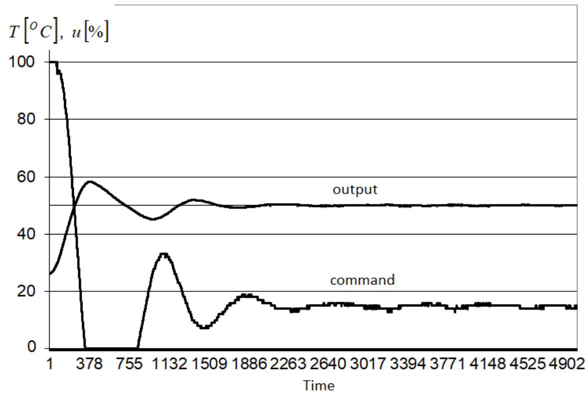

Fig. 7: Proportional-Integrative (PI) control with set point of 50°C

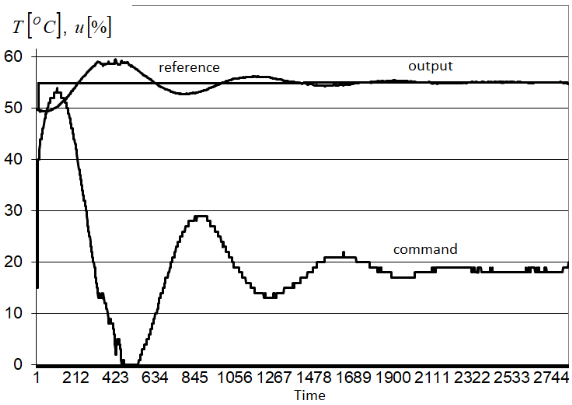

Fig. 8: PI control with set point of 55°C

The tuning of the controllers is the most important task that needs to be solved in order to achieve the set-up performances imposed in the closed-loop system.

The tuning parameters of the PI controller are calculated using the Ziegler-Nichols criteria, available for the slow processes with one time constant and delay time [4]. In turn, these parameters are obtained by offline identification, using the Cohen-Coon graphical method [4].

Starting with an on-off controller and a reduced set point value (90%) the output temperature has a hysteresis of about 2ºC, but the process components are protected. By switching to the PI algorithm and to the "total" set point (100%), the steady state error is zero.

From practical point of view, using a serial bus reduces the cabling costs and prototyping time, making it the ideal solution based on microcontrollers.

The major disadvantage is given by the significant reduction of the communication speed, between the components of the system. This disadvantage is diminished in the case of the microcontrollers where the most of the components are integrated in the same circuit. The PWM has a major advantage, because the actuator loses less power, compared to the analog system.

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