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Inexpensive discrete PSD controller with PWM power output

***Abstract**. The most common used industrial controllers are very expensive, whereas they provide only some basic features how to affect controlling process. In some cases a settings of PWM (Pulse Wide Modulation) switching frequency is needed. Based on these reasons we decided to develop a discrete PSD controller which is a very simple, variable, and suitable to control a plenty of less complicated systems by a simple change of its characteristic parameters. By use of modern approach we create a full-featured controller including power action element on a tiny area (7cm^2).*

***Streszczenie.** Większość kontrolerów przemysłowych to urządzenia dość drogie, chociaż wykorzystuje sie w nich często tylko bazowe funkcje kontrolera. Dość często zachodzi potrzeba ustalenia sygnału PWM (Modulacja szerokości impulsu). Dlatego w pracy przedstawiono cyfrowy kontroler PSD z uproszczoną konstrukcją umożliwiający uzyskiwanie sygnału PWM. Otrzymano bardzo prosty kontroler o niewielkiej powierzchni. (**Uproszczony cyfrowy kontroler PSD z wyjściem mocy PWM**)*

Keywords: Discrete Controller; PWM; Power; PSD.
Słowa kluczowe: kontroler cyfrowy, sygnał PWM.

Introduction

PID (Proportional Integral Derivational) elements behaviour of universal controllers are well known in control systems area [1, 2]. Controllers are designed to control processes without operator's interference. Controllers automatically changes the action value $u_{(t)}$, so that a controlled value $y_{(t)}$ have a desired value $w_{(t)}$. Controller and desired controlled system forms a control loop. At controller input side a true value $y_{(t)}$ is measured (output of the regulated system). Together with demand value $w_{(t)}$ and controllers output $u_{(t)}$, it has an effect on systems input (after possible transformation).

Desired value of controlled quantity presents the point on imaginary edge, where the real value of controlled quantity should be present. Control deviation $e_{(t)}$ (error) is defined as a difference between required $w_{(t)}$ and a real value $y_{(t)}$ of a controlled quantity.

$$e(t) = w(t) - y(t) \tag{1}$$

Elements P,I and D are linked together into an outcome quantity (action interference). These elements also implicate a process of controlled system [3, 4]. Most of a controlled systems, which can be found in technical practice, has a character of dynamic system of the first or the second order, non-oscillating, with possible traffic delay. Basic system's characteristics and its behaviour are mentioned in chapter "Controllers Types". Needed basic information about discrete controllers are summarized in chapter "Discreete controllers". There are mathematical descriptions of classic continuous controllers and its derivation in discrete form followed by the description of developed control system and its basic parameters in the chapter "Experimental realization". The next chapter "Experimental identification" is focused on main system constants determination and setting up of proposed PSD controller. Conclusion deals with pros and cons of proposed solution.

The following section starts with some basic ideas concerning PID controllers for such systems.

Controllers Types

Proportional character

When a proportional behaviour is in place, the action interference is proportional to controlling deviation $e_{(t)}$ according to the following relation.

$$u(t) = Ke(t) \tag{2}$$

Using of proportional controller with systems, where controlled parameters react to action interference by constant value, results in a stabilizing at a new value [5]. This leads to creation of a permanent control deviation. When gain K is increasing, there is a way to decrease this permanent controlling deviation. But be aware to become unstable controlling system. Such state will come when controlling quantity became an oscillating or non-oscillating growing without any stint. This state can lead to damage a system or it can be the cause of unstable work of controller. To remove a permanent deviation, we are adding an integral part to the controller (if the system itself has not an integrative character).

Integration character

Integral control is used to add long-term precision to a control loop. It is almost always used in conjunction with a proportional control.

Action interference is proportional to a time on integrative behaviour. A controlling deviation is present after.

$$u(t) = u_0 + \frac{1}{T_I}\int_0^t e(t)dt \tag{2}$$

where: T_I – integrative constant, u_0 – initial condition, last state.

In controller with a connected proportional and integral parts (PI controller), the permanent controlling deviation disappear. It is eliminated by integrative behaviour of a controller, when the controller changes the action interference all the time, until it can reach the zero controlling deviation. When we increasing integral part (decreasing T_I), oscillating of controlling process has increasing tendency. This can be eliminated (partially) by adding derivative part.

Derivative character

Controller's output with derivative behaviour is proportional to speed of changes of controlling deviation $e_{(t)}$.

$$u(t) = T_D\frac{de(t)}{dt} \tag{4}$$

where: T_D – derivation channel constant, $u(t)$ – action interference of derivation channel.

A derivative behaviour can compensate (in advance) changes of controlling quantity. That is a reason why it is used to damping transients of regulation circuits. Principle is at that, that once after each change of desired or real value (implication of disturbances) of controlling quantity begins controlling parameter again gets near its (new) demand value, causes derivative part pre-emptively change in its gain "bad direction" (from off desired value). Derivative part is often used to avoidance transient development of controlling process. Derivative part shift a phase of action interference forward that is why it can stabilize control loop. Generally, when we use a derivative part, we can increase gain of integral time constant of the controller.

Discrete controllers

PSD (Proportional – Summation – Differentiation) controllers are discrete versions of regular analogue controllers [6]. In this case, it is a function of controller commit to a MICROCHIP's single chip microcontroller. It is a simple, 8-bit microcontroller unit (MCU) [7], with an analogue inputs and PWM output [8]. According to wide-spread usage of PSD in common life and also in industry, this company has many types of specialized MCUs with integrated native PSD support. But, these specialized PSD MCUs are not as simple as classic MCU for general purposes. Classic PID controller working at continuous time area is using to set-up its own parameters next well known equation.

$$u(t)=k_p e(t)+k_I\int_0^t e(t)dt+k_D\frac{de(t)}{dt} \tag{5}$$

Discrete controller has previous equation (5) a little modified.

$$u(t)=k_p e(t)+k_I T_s\sum\nolimits_{t=0}^{t} e_t+k_D\frac{y(t)-y(t-T_s)}{T_s} \tag{6}$$

where: T_S - is a sample period.

In case, the constant Ts getting near to zero, $T_S \rightarrow 0$, the equation (6) is quite similar to classic continuous controller formula (5). In a given case we using same methods of optimalization and setting up particular parameters like in classic controllers.

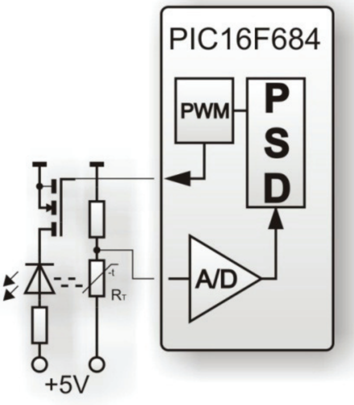

Fig. 1. Block diagram of controller and controlled system

Figure 1 presents an internal block diagram of a PSD controller. The controlled system is presenting by LED, serial resistor and power N-Channel MOSFET. Switching transistor is capable to drive high power load (e.g., 15A). Internal A/D converter takes care of the input. The thermistor RT converts LED temperature to appropriate voltage, which is converted into binary form by A/D. The result represent $y_{(t)}$, systems output. The thermistor RT is a highly non-linear component. Sufficient linearization is realized via series resistors. Software linearization is not so much complicated, but computing demands are too high for this type MCU. It means, that we knows transfer function of current thermistor, but its implementation is in assembler is very complicated, because the transfer function is commonly presented by the third order formula. In the PSD block, the action control $u_{(t)}$ is calculated. Then $u_{(t)}$ is converted into a PWM signal and directly drive connected N-channel MOSFET transistor. PWM (Pulse Width Modulation) is a way, how to very efficiently drive hi power devices. An information is coded by pulse duty cycle, while carrier frequency sustain constant.

Experimental realization

The goals of this work were to identify the controlled system, to design a discrete controller and to implement it into single chip microcontroller. The controlling system was created from power LED diode. This is a very simple system, which serves only for back verification of the controlling process. LED (Fig. 3) is warming up during its working cycle and that's why is necessary to stabilize its temperature. If we leave aside a bigger heat sink, it is possible to decrease target temperature by controlling working current. With regarding to usage of microcontroller circuits, the most appropriate controlling way seems to be driving by PWM (Pulse Width Modulation). Applied MCU has a native support of PWM with ability to drive 4 channels (to drive stepping motors). Block diagram of controller and system is displayed on (Fig. 1).

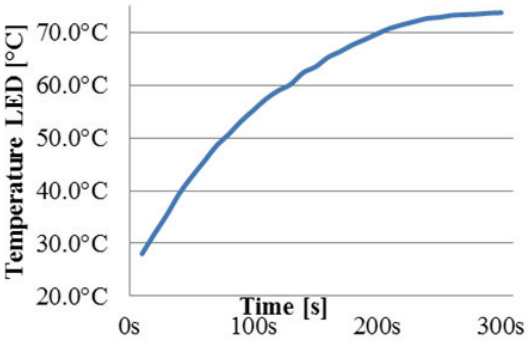

Fig. 2. Transient characteristic of LED

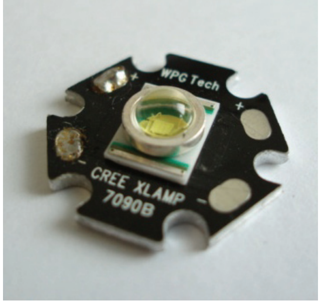

Fig. 3. Detail of power LED module

This is a first order system, eventually second order with a minor value of T_u (slope time). Its transient characteristic is displayed in Fig. 2. The system's temperature settles down to 74°C when driving with 400mA. Delivered power is about 1.4W. Maximum LED load is 4W, under the condition, that working current doesn't exceed 1A. LED die is set on small star shaped heat sink with take-out soldering areas (Fig. 3). On star shaped heat sink there is a LED chip with glass lens. Soldering pads are signed with polarity marks. Temperature progression in LED module is shown in (Fig. 4). This is a simple thermal system. Heat transmission has a linear character in bearing metal parts and strong non-linear from heat sink to outer environment.

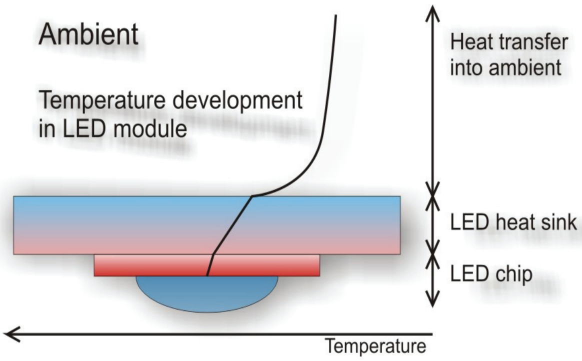
Ambient
Temperature development in LED module
Heat transfer into ambient
LED heat sink
LED chip
Temperature

Fig. 4. Temperature progression in LED module

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The Experimental identification

If the controlled system is no oscillating and proportional, then a simplest method of identification consists in determination of Tu (slope time) and Tn (rush time). On the system's input we brought a heaviside step in a form of current, which flows throw LED module. Current value was reduced to approximately 400mA, so that the safe operating condition was kept. If the working current overreached 1A, a LED module would be destroyed irreversible.

The system was powered from constant current source and we measured temperature on the bottom of the heat sink. Obtained transient characteristic is displayed on (Fig. 5) with marked steady state. Systems transient characteristic (blue) with marked steady state (green) and formula of polynomial regression curve (black). This system is relatively slow and that is why is suitable for our test.

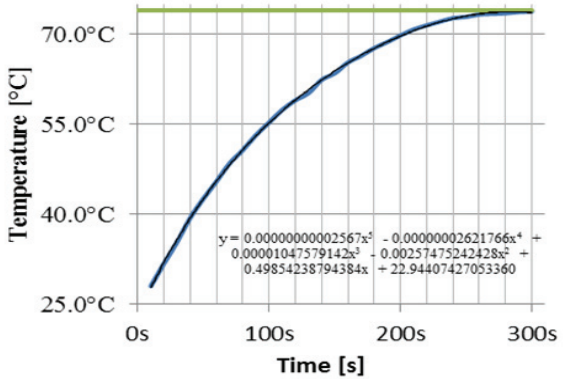

Fig. 5. Systems transient characteristic

The absence of T_u (slope time) (Fig. 5) is explained that is either insignificant, or was not present in assigned area (measuring above the flex point). In case, that we start measuring from 0°C, the S-tile shape of transient characteristics could show itself and T_u (slope time) could be measurable.

On this consideration basis, we question, 'how does the time constant vary throw the position on the transient curve?'. The beginning represents an ambient temperature in measure time. In case of measuring under the lower or higher temperatures, the beginning was not always on a same place but travel on curve up or down. That is why we created in MatLab 7.1 environment a simple function for numerical retrieval tangent line in given point. We did 9 calculations, each in time stamp +30s. The results are displayed in Fig. 6. Straight lines represent tangent lines in different working points. Numbers represent appropriate time constants of the system. It is obvious that they are not same. Theoretically, time constants of the system should stay same throughout full range, but results are very different. This is because the heat flow is significantly changing with rising temperature.

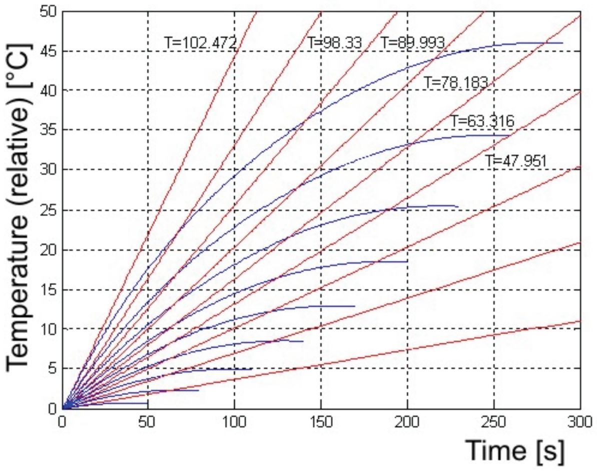

Fig. 6. Time constants of the system estimated with MatLab.

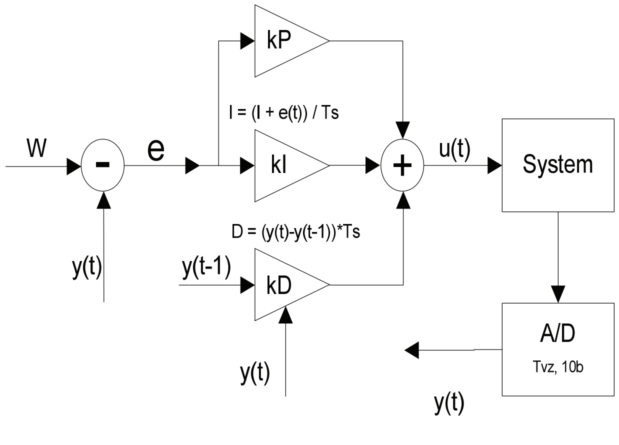

Fig. 7. Controller's block diagram.

We found out a time constant of system T_n=102s by tangent line of $h_{(t)}$ from the origin. This value represents a basic system feature and is fundamental when determining controllers' parameters.

Setting of PSD controller

Controller's block diagram is presented in (Fig. 7). With respect to the standard blocks of control loop, we can see all classic relevant components of a control loop. With regards to usage of a simple 8-bit microcontroller, we were forced to perform some simplifying steps. Absence of hardware multiplying and its high demand factor in software form resulted in an option with 1s sample rate, T_{vz} = 1s. That is why, multiplying was not required in the integral part (currently, it is multiplying by 1). Software implementation of multiplying is present on (Fig. 8). This procedure has two input variables k1 and k3 and one output k2. As we can see, this software approach is very time consuming.

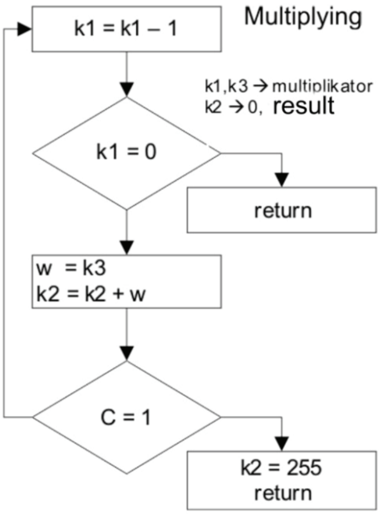

Fig. 8. Software multiplying.

The systems' output is digitized by an internal A/D converter with a 10-bit accuracy with a sampling rate T_{vz}. The acquisition time has constant value of 8μs.

Conclusion

The practical realization of this proposed solution shows the possibility of implementing discrete PSD controllers into single chip microcontrollers (MCU). With regards to low prices of these devices [7], there is a possibility to control any simple control system in a tiny area of board (7cm^2). The proposed controller has some limitations, resulting from its simplicity, such as low sampling rate, all variables are limited by 255, because of 8-bit architecture of MCU, lack of hardware multiplying and dividing or slow action control speed. These limitations can be avoided with a future development. In case of use of a powerful 16-bit MCU with hardware multiplying and dividing, it will bring more samples per second and that is why it has more ability to control quicker, more complex systems in industrial environment.

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