UNIVERSITATEA Petru Maior TÂRGU-MUREŞ

Scientific Bulletin of the „Petru Maior” University of Târgu Mureş
Vol. 8 (XXV) no. 1, 2011, ISSN 1841-9267

# PID DAYLIGHT CONTROL SYSTEM

**Horatiu Stefan Grif**
”Petru Maior”University of Târgu Mureş, Romania
hgrif@engineering.upm.ro

## ABSTRACT

*The paper describes the implementation and the tuning of a digital PID controller used in a daylight control application. Due to the fact that the process is unknown, an experimental method, Ziegler-Nichols, for the tuning of the PID controller was used. The obtained PID parameters do not offer a good behavior of the ALCS. To improve the performances of the ALCS, supplementary tuning of the PID parameters, via step response analysis, was made. The step response acquiring and analysis may have an expensive time cost. To avoid the time cost the present paper offers an algorithm which guide the designer to chose, in a slight manner, not only a set but a set family of the PID parameters for which the ALCS has a good behavior. Also, the algorithm presents the way how the ALCS user can set his desired ALCS speed reaction to the daylight variations.*

**Keywords**: daylight, PID controller, automatic lighting control system, experimental tuning, step response

### 1. Introduction

The proportional-integral-derivative (PID) algorithms was imposed in different industrial fields due to their robustness and simplicity and also, due to the experience acquired by the designers according the implementation and the tuning of the PID controllers using classical methods.[1] Due to these two qualities (robustness and simplicity) the PID controllers become an “industrial standard”, even, in time, was proposed different other process control methods.[2]

### 2. Automatic lighting control system: the block diagram and the experimental stand

In Fig. 1 is presented the block diagram of the automatic lighting control system (ALCS), where are denoted: $E_{desired}$ – the desired illuminance on the working plane; $E_{measured}$ – the measured illuminance on working plane; $E_{real}$ – the illuminance on the working plane; $E_{daylight}$ – the daylight illuminance on working plane; $E_{electric}$ – the illuminance on working plane due to electric light; **ε** - control error; **u** – control action.

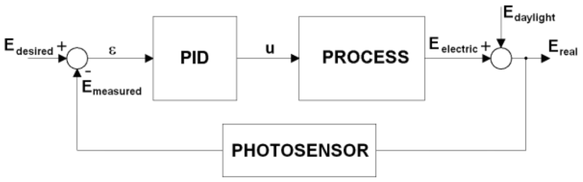

***Fig. 1.*** *Block diagram of the control system*

Unlike simple control algorithms, the PID controller is capable of manipulating the process inputs based on the history and the rate of change of the signal. This gives a more accurate and stable control method.[2] The controller “reads” the illuminance on working plane by the photosensor. Then it subtracts the measured illuminance from the desired illuminance to generate the error value. The error will be manipulated in three ways [2]: to handle the present, through the proportional term, recover from the past using the integral term and to anticipate the future, through the derivative term.

***Fig. 2.*** *The experimental stand [4]*

The experimental stand is presented in Fig. 2. which is composed by: 1 - calculation equipment (IBM compatible, PIII, 433MHz, 64Mb RAM computer), 2 - execution element (accomplished with two modules produced by Tridonic company: DSI-A/D converter, digital ballast PCA 2/36 EXCEL ) introduced in the lighting body, 3 - the technological installation based on two 36W fluorescent lamps, 4 - light sensor (multifunctional LRI 8133/10 sensor produced by Phillips), 5 - data acquisition board with two 8-byte conversion channels (an A/D channel, a D/A channel), 6 – working plane (the surface plane of the desk).[3]

## 3. The PID controller

### 3.1 The PID structure

The PID structure is presented in Fig. 3 where $T_i$, and $T_d$ denote the time constants of the integral and derivative terms, $K_p$ denote the proportional gain, **u** denote the control action and **ε** denote the control error.

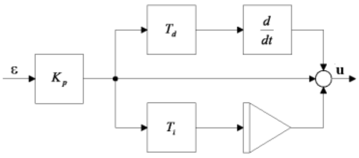

***Fig. 3.*** *The PID structure* [2],[4]

The corresponding mathematical model in time domain for the structure from Fig.3 is given by [1],[2]:

$$u(t) = K_p \cdot \left( \varepsilon(t) + \frac{1}{T_i} \int_0^t \varepsilon(\tau) d\tau + T_d \cdot \frac{d\varepsilon(t)}{dt} \right) \qquad (1)$$

In the present paper the PID controller is implemented in digital fashion which uses the discrete form of the (1) given by [2]:

$$u(k) = K_p \cdot \varepsilon(k) + K_i \cdot h \cdot \sum_{j=0}^{k} \varepsilon(j) + \frac{K_d}{h} \cdot (\varepsilon(k) - \varepsilon(k-1)) \qquad (2)$$

where

$K_i = K_p / T_i$, (3)

$K_d = K_p \cdot T_d$ (4)

are the integral and derivative gains. The sampling time is denoted by *h*.

### 3.2 The tuning parameters of the PID controller

Because the mathematical model of the process is unknown to find the parameters of the PID controller was performed an experimental tuning of the PID controller parameters.

During the years was developed a series of experimental tuning method some of them like Ziegler-Nichols, Offereins, Oppelt, Kopelovici can be consulted in [5]. For the present paper was chosen Ziegler-Nichols tuning method. This method require, for tuning the controller parameters, the valuation of the output signal oscillations amplitude and frequency of the control system when this is at the stability limit. [6] The method has good results in automatics [4] but is recommended to use in case of the close loop control system which support the stability limit oscillations [7].

The first step in this method is setting the integral and derivative gains to zero, increasing the proportional gain until a sustained and stable oscillation (as close as possible) is obtained on the output. Then the critical gain $K_c$ and the oscillation period $P_c$ are recorded and the $K_p$, $T_i$, and $T_d$ values are adjusted accordingly [2]:

$K_p = 0.65K_c$, (5)

$T_i = 0.5P_c$, (6)

$T_d = 0.12P_c$. (7)

## 4. Experimental results

The structure presented in section 3.1 was implemented as a program write in C language. The program was compiled and executed on the calculation equipment denoted by 1 in Fig. 2. The sampling time was set to 0.055 seconds. The desired illuminance on working plane is set to 100 [$lx_{d8bv}$]. The meaning of abbreviation *d8bv*, used in this section, is “digital 8 bits value”. The value 100 $lx_{d8bv}$ represents the equivalent value obtained by conversion with 8 bits A/D converter of the 500 lx, which represents the illuminance on working plane measured by an analog luxmeter. The value 127 $V_{d8bv}$ represents, by conversion with 8 bits D/A converter, the equivalent for a d.c. voltage with value $5V_{dc}$. [3], [4]

The tuning of the PID controller parameters was performed using Ziegler-Nichols presented in section 3.2. The first sustained and stable oscillation occurs when the critical gain reach the value $K_c$=2.73 (Fig.4). The oscillation period is $P_c$= 0.975990566 seconds.

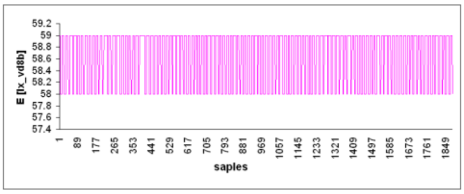

***Fig. 4.*** *The first sustained and stable oscillation [4]*

Using equations (3)÷(7) the values of the PID controller parameters are: $K_p$=1.7745, $K_i$=3.63630564, $K_d$=0.207827431. For these values the step response of the ALCS has a big overshoot (Fig. 5).

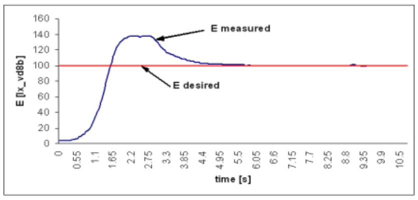

***Fig. 5.*** *Step response of the ALCS, PID parameters obtained by Zyegler-Nichols method ($K_p$=1.7745, $K_i$=3.63630564, $K_d$=0.207827431) [4]*

Analyzing Fig. 5, supplementary tuning of the parameters is necessary to optimize the performance of the PID controller. To perform that, the author was passed the next three steps:

**Step 1.** Keeping constant the values of $K_i$=3.63630564 and $K_d$=0.207827431 was acquired the step response family of ALCS for different values of the $K_p$ (Fig. 6).

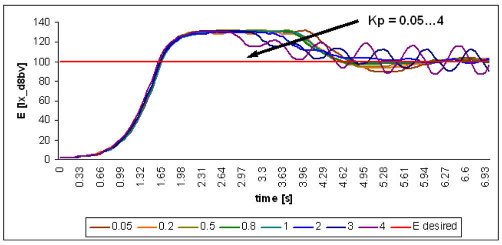

***Fig. 6.*** *Step response family of the ALCS ($K_p$=variable, $K_i$=3.63630564, $K_d$=0.207827431)*

The increases of the $K_p$ will produce a decreasing of the transient response duration but increase the risk of a sustained oscillatory behavior.

Analyzing the step response family from Fig. 6 the author was chosen for the proportional gain the value $K_p$=0.8.

**Step 2.** Keeping constant the values of $K_p$=0.8 and $K_d$=0.207827431 was acquired the step response family of ALCS for different values of the $K_i$ (Fig. 7).

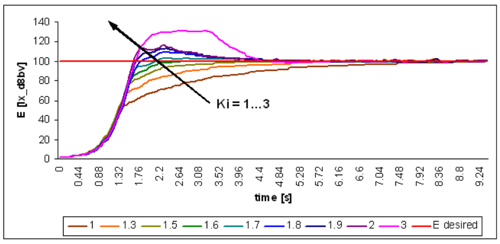

***Fig. 7.*** *Step response family of the ALCS ($K_p$=0.8, $K_i$=variable, $K_d$=0.207827431)*

The increasing of the $K_i$ will produce a decreasing of the transient response duration but will produce increasing of the overshoot. Analyzing the step response family from Fig. 7 the author was chosen for the integral gain the value $K_i$=1.6.

**Step 3.** Keeping constant the values of $K_p$=0.8 and $K_i$=1.6 was acquired the step response family of ALCS for different values of the $K_d$ (Fig. 8).

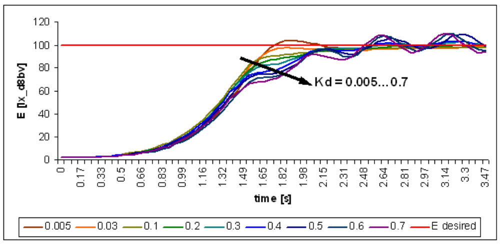

***Fig. 8.*** *Step response family of the ALCS ($K_p$=0.8, $K_i$=1.6, $K_d$=variable)*

The increasing of the $K_d$ will produce a decreasing of the overshoot, an increasing of the transient response duration but also will produce the increasing of the risk of a sustained oscillatory behavior of the automatic lighting control system.

Analyzing the step response family from Fig. 8 the author was chosen for the derivative gain the value $K_d$=0.2.

The step response of the ALCS, with the parameters ($K_p$=0.8, $K_i$=1.6, $K_d$=0.2) chosen after the three steps described above, is presented in Fig. 9. The ALCS has a good behavior: it has no overshoot, the steady-state error is zero, transient response duration is acceptable (the ALCS take around 2.5 seconds to achieve on working plane 100 $lx_{d8bv}$ illuminance level, starting from $3lx_{d8bv}$.)

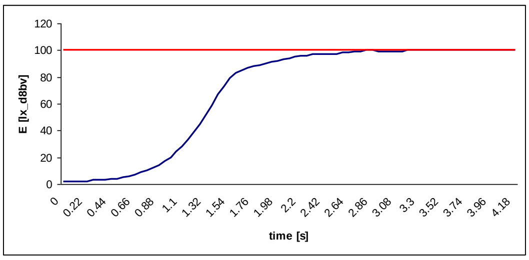

***Fig. 9.*** *Step response of the ALCS ($K_p$=0.8, $K_i$=1.6, $K_d$=0.2)*

After the tuning process the ALCS stability was tested by disturbing the illuminance on working plane using two ways: one way by modifying the daylight contribution (denoted by “daylight disturbance”), and the other, by turn on/off the electric light (denoted by “electric light disturbance”) of the room, where is placed the experimental stand. The daylight disturbance was performed as follow: cover a part of the window of the room; turn on the ALCS and wait to achieve the desired illuminance on working plane; uncover fast the window and wait the ALCS to achieve the desired illuminance on working plane; cover back fast the window and wait the ALCS to achieve the desired illuminance on working plane. The presence of the daylight disturbances are indicated in Fig. 10 by the small picks. The presence of the electric light disturbances are indicated in Fig. 10 by the big picks. As it can seen in Fig. 10 the ALCS is stable.

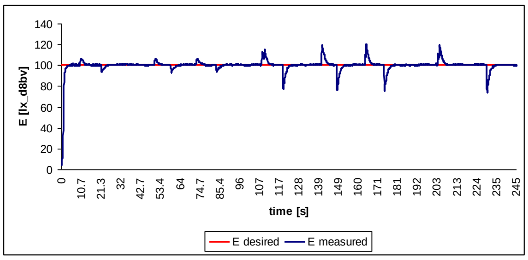

***Fig. 10.*** *The ALCS behavior during the presence of the disturbances – the measured illuminance trajectory*

Taking the gains $K_p=0.8$, $K_i=1.6$, $K_d=0.2$ a couple of proportions between them can be calculated:

$$(K_i/K_p \, , K_d/K_p) = (2, 0.25) \tag{8}$$

Keeping constant the proportions (8) and modifying the proportional gain $K_p$ a step response family of the ALCS was acquired (Fig. 11).

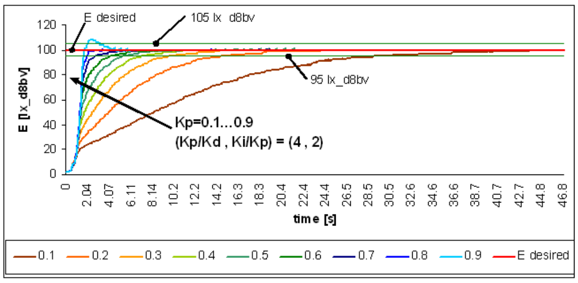

***Fig. 11.*** *Step response family of the ALCS* $((K_p,K_i,K_d)=(0.1,0.2,0.025)\ldots(0.9,1.8,0.225))$

Analyzing the step response family from Fig. 11 the overshot will be smaller or equal to 5%$E_{desired}$ if $K_p<0.9$, $K_i=2\cdot K_p$ and $K_d=0.25\cdot K_p$. The increase of scaling gains will reduce the transient response period. For $K_p=0.9$ ($K_i=1.8$, $K_d=0.225$) the overshoot is 8%$E_{desired}$. But, from the human eye perception this value of the overshoot may not be perceived by the user.

## 5. Algorithm for the experimental tuning of the PID parameters

Considering the work from previous section the author is proposing the following algorithm for the experimental tuning of the PID parameters.

**Step 0:** Using one of the classical experimental tuning method, find values for the three gains ($K_p$, $K_i$, $K_d$) of the PID controller (i.e. Ziegler-Nichols). Will denote the found values of the three gains with $K_{p0}$, $K_{i0}$, $K_{d0}$. If the PID controller will not work very well with these values of the gains go to the Step 1;

**Step 1:** Keeping constant the values of $K_i=K_{i0}$ and $K_d=K_{d0}$ acquire the step response family of automatic control system (ACS) for different values of the $K_p$ around the value $K_{p0}$. Analyze the step response family of the ACS and chose a value of $K_p$, denote by $K_{p1}$, for which the ACS satisfy all desired performances or a part of them.

**Step 2:** Keeping constant the values of $K_p=K_{p1}$ and $K_d=K_{d0}$ acquire the step response family of ACS for different values of the $K_i$ around the value $K_{i0}$. Analyze the step response family of the ACS and chose a value of $K_i$, denote by $K_{i1}$, for which the ACS satisfy all desired performances or a part of them.

**Step 3:** Keeping constant the values of $K_p=K_{p1}$ and $K_i=K_{i1}$ acquire the step response family of ACS for different values of the $K_d$ around the value $K_{d0}$. Analyze the step response family of the ACS an chose a value of $K_d$, denote by $K_{d1}$, for which the ACS satisfy all desired performances or a main part of them.

**Step 4:** Compute the proportions between the gains

$$p_1= K_{i1}/K_{p1} \tag{9}$$

$$p_2= K_{d1}/K_{p1}. \tag{10}$$

Acquire the step response family of the ACS for different values of $K_p$ around the value $K_{p1}$ ($K_i=p_1\cdot K_p$, $K_d=p_2\cdot K_p$). Analyze the acquired step response family and chose a range for $K_p$ for which the ACS satisfy the performances. Thus, the ACS human user can chose and set one of the multiple possible behaviors of ACS, modifying just one parameter, the $K_p$ gain. The other two gains will be set automatically by multiplying $K_p$ with the corresponding proportion, $p_1$ or $p_2$ ($K_i=p_1\cdot K_p$, $K_d=p_2\cdot K_p$).

## 6. Conclusions

Easy design, easy implementation and a stable automatic control system represent enough reasons to recommend such system to be implemented on chip controllers and use in daylight control applications.

Using an algorithm like the one presented in the present paper the PID parameters tuning via step response analysis become a comfortable tune tools in case of the control systems where the process has an unknown mathematical model.

Keeping constant the proper proportions between the PID gains and modifying the proportional gain ("rotate just one potentiometer") it can modify the reaction speed of the ALCS. This feature offers the human user the possibility to set the ALCS to act as the user want. Also, technical speaking, this type of ALCS can be used in two different applications: the first type are those applications where from the human eye perception point of view the illuminance must be constant (for example design laboratory); and the second type are the applications where the users need to feel the changes in the light environment due to the natural variations of daylight (for example office and home applications).

## References

**[1]. Horațiu Zărnescu** - *Ingineria reglării automate*, Ed. Univ. "Petru Maior", Tg. Mureş, 1998;

**[2]. ***** - *AVR221: Discrete PID controller*, Atmel Corporation, 2006;

**[3]. H.S. Grif, A. Gligor, C. Dumitru** - *Neural Daylight Control System with On-Line Inverse Process Modeling*, International Conference Interdisciplinarity in Engineering INTER-ENG 2009, Tg. Mureş, pp. 177-181;

**[4]. H.S. Grif** - *Contribuții privind tehnici de inteligență artificială în conducerea sistemelor de iluminat interior. PhD. Thesis*, Technical University Cluj Napoca, Romania, 2006;

**[5]. I., Dumitrache** - *Tehnica reglării automate*, Ed. Didactică şi Pedagogică, Bucureşti, 1980;

**[6]. G.F. Franklin, J.D. Powel, E.N. Abbas** - *Feedback Control of Dynamic Systems*, Prentice Hall, 2001;

**[7]. M. Vînătoru** - *Conducerea automată a proceselor industriale*, Vol. 1, Ed. Universitaria, Craiova, 2001.