

A NEW SOFTWARE TO SHOW THE BEHAVIOUR OF THE PID CONTROLLER

Part II. Influence of the setting parameters of DSCs

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Abstract

Some DSC calorimeters, such as the model DSC 111, built by the society Setaram, allow the user to set the temperature programming parameters. Usually default values furnished by the constructor are often used, but it is very interesting to study the thermal behaviour of the regulation of the calorimeter under different conditions and with different kinds of set point temperatures.

For this research, we have developed in C language a set of software in order to demonstrate the behaviour of the (proportional integral derivative) PID controller of the DSC. It can help the user to choose correct values for P, I and D parameters according to the kind of experiment conducted. The software allows studies of extra parameters, such as the sampling rate of the computerized PID controller or the determination of filtering of the correction.

Keywords: DSC, PID controllers, tuning PID parameters

Introduction

In Part I [1] of this work, we presented the notions used for the development of the software. We first gave some principles concerning the regulations, control loops, and PID controllers [2–5]. These principles permitted a description of the three command laws used in the PID controllers. We then gave the method used for the digitization of an analog PID controller in order to computerize it [6, 7]. This method uses an algorithm able to avoid the well-known overloading problem in controllers which use an integral command law.

Finally, we presented the development of the software named PIDX and written in C language. We provided the user with the ability to change the most important parameters of the calculations at any time. The output of the software is fully graphic. The performance of the PID parameters chosen by the user can be applied to various signals: sine, rectangular, triangular and logarithmic. In Part II, we present the experiments conducted with this software.

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Experimental

The experiments consisted in setting the parameters of the PID controller for a given signal and measuring the performance obtained. To quantify this performance, we defined a global error index, GEI :

$$GEI = \sum_i^{i_{\max}} |t_c(\text{idelay}) - t_m(\text{idelay})|$$

GEI is calculated for each entire display screen. For a better representation of the performances of the algorithms, we use an average GEI defined for one calculation:

$$GEI_m = \frac{i}{i_{\max}} GEI \quad (1)$$

Study of step function for the set point signal

For our experiments, we set the processing parameters (lowpass filter, sampling rate and time delay) to standard values: $N=10$, $h=0.8$ and $delay=13$. The ARW algorithm chosen is the standard one. The default values for the PID parameters at the start of the software are: $P=2$, $I=2$, and $D=1$. For these conditions, $GEI_m=0.06280763$. Then by modifying the PID parameters, it is possible to visualize their influence on the behaviour of the controller (Fig. 1).

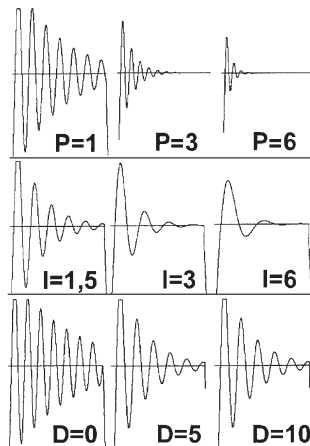


Fig. 1 Influence of the parameters on the behaviour of the controller

By exploring different values for these parameters, it is possible to obtain very efficient behaviour of the controller, such as, for example, in Fig. 2.

Similar studies can be conducted with the other kinds of signals: sine, logarithmic, triangular and the signal issuing from the experimental form, as we will show below.

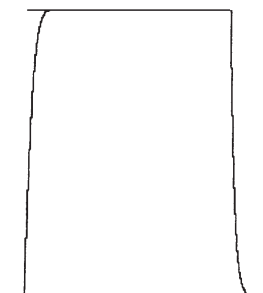


Fig. 2 Efficient behaviour of the controller

Automatic setting of the PID parameters for the controller

For the analog PID controllers, there exist a number of methods for tuning of the parameters. One of the best known is the Ziegler-Nichols method, which we will not describe here [8]. For our software, we included automatic procedures in order to evaluate the best parameters for a given environment. For the moment, these procedures are systematic and included in distinct software called OPTDX. They consist in three iterations on the three PID parameters with correct intervals. For the present preliminary studies, we have used the following conditions:

Table 1 Experimental conditions for iteration on the PID parameters

Parameters	Initial value	Final value	Step
Proportional	0	4.8	0.2
Integral	0	6	0.1
Derivative	0	1	0.5

For each calculation, the error calculated and the corresponding parameters are saved in a file. We used these values on the above families of signals and the obtained results are presented in Table 2.

Table 2 PID parameters obtained with iterative procedure

Signal	P	I	D	GEI_m
Rectangular	4.8	4	0	0.01701144
Sine	4.8	3.6	0	0.01352016
Logarithmic	4.8	3.2	0	0.00962487
Triangular	4.8	6	1	0.00631863
File	4.8	6	0.5	0.0140561

We note that for the parameter P we have the same value, 4.8. The derivative value is often equal to 0, and for the integral we obtain intermediate values. To interpret these results, for the rectangular signal we plotted the evolution of the different

calculations in order to establish the influence of each parameter on the final error. Figure 3 shows the evolution of GEI_m according to the calculations on the parameters. The x -axis represents the number of calculations.

We observe an oscillating decreasing curve. By examining the values of the parameters, we see that the global decreasing shape of the curve is caused by the proportional term P ; this is normal behaviour because the power of the correction is proportional to this parameter. It is possible to see the influence of the parameters I and D with enlarged views from Fig. 3. Figure 4 shows an enlarged view of the selected rectangular area from Fig. 3 for a constant value $P=1.2$.

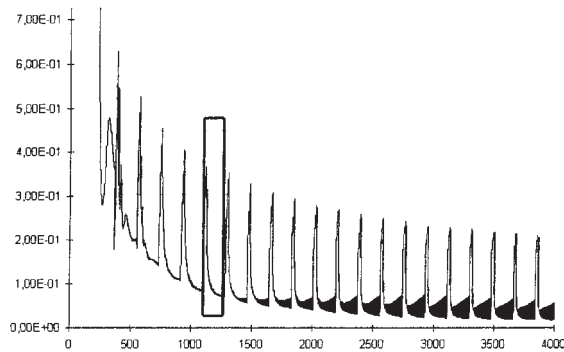


Fig. 3 Evolution of GEI_m value for a rectangular signal

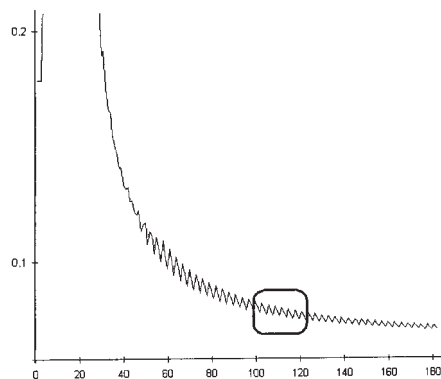


Fig. 4 Enlarged view of the selected area from Fig. 3. This shows the influence of the parameter I

This part of the curve is also globally decreasing. We can see that the smaller values of GEI_m correspond to larger values of the parameter I . This is because the integral term I can be considered an accelerator for the correction. In Fig. 4, we can observe small oscillations given by the derivative parameter D , so in Fig. 5 we show an enlarged view of the rectangular selected area from Fig. 4. For this extracted part, the parameter P is equal to 1.2 and the parameter I goes from 3.3 up to 3.9.

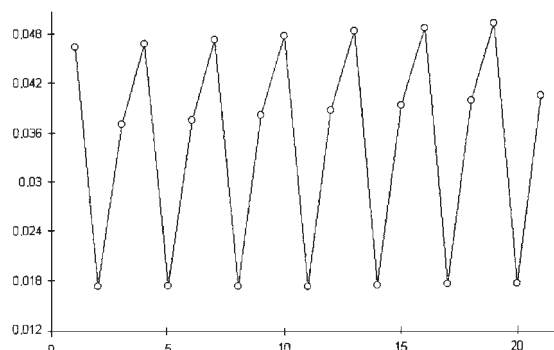


Fig. 5 Influence of the parameter D on the evolution of GEI_m

For our iterative calculations, the derivative term D is set with the three values 0, 0.5 and 1. For this part of the curve, the smallest values for GEI_m are achieved for $D=0$, and the largest ones for $D=1$.

From the view of Fig. 3 we decide to enlarge the values of the parameters. Table 3 shows these new experimental conditions, applied for the first calculations, which allow a rough framing of the values.

Table 3 New experimental conditions for iterations on the PID parameters

Parameter	Initial value	Final value	Step
Proportional	0	20	1
Integral	0	20	1
Derivative	0	0.5	0.5

From the above calculations, we have determined that the smallest value for GEI_m was given for the following parameters: $P=14$, $I=2$ and $D=0$. Accordingly, we refined the experimental conditions, as shown in Table 4.

With these new values, we obtained the refined parameters: $P=14.9$, $I=1.8$ and $D=0$. If we put these values in the PIDX software, we obtain the display shown in Fig. 6.

Table 4 Refined experimental conditions for calculations on a rectangular signal

Parameter	Initial value	Final value	Step
Proportional	13	15	0.1
Integral	0	10	0.1
Derivative	0	0.5	0.5

By using the two-step method described above, we see immediately that the deviation between the desired and measured signal is very small. The time of calculations used for optimization of the parameters with a wide range of values, as in Ta-

ble 3, is about 11 min on a Pentium 133 MHz computer with graphic display output, and about 2.5 min without graphic display.

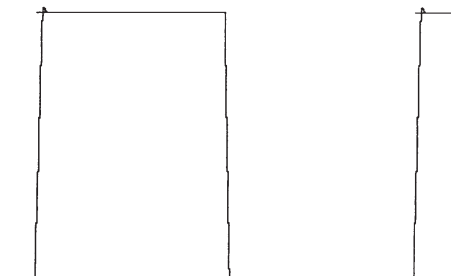


Fig. 6 Display of the performance obtained with optimized parameters for a rectangular signal

With this two-step determination, we conducted experiments with two other kinds of signals. For the triangular signal (which is the kind of temperature profile most often used in calorimetry), we had the same rough experimental conditions as in Table 3. The parameters obtained: $P=9$, $I=20$ and $D=0.5$. For the refined calculations, the conditions are given in Table 5.

Table 5 Refined experimental conditions for a triangular signal

Parameter	Initial value	Final value	Step
Proportional	9	10	0.1
Integral	0	20	0.1
Derivative	0	0.5	0.5

The final parameters obtained are $P=9.6$, $I=19.2$ and $D=0$. To check their degree of fit, we put them in the PIDX software and obtained the display shown in Fig. 7.

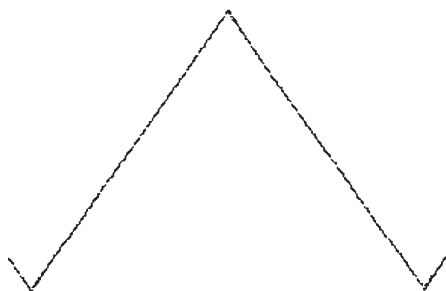


Fig. 7 Display of the performance obtained for a triangular signal

In Fig. 7, it is impossible to distinguish the desired and measured signal. Thus, the experimental conditions chosen allow the PID software to follow the desired temperature profile exactly.

Finally, we used our numeric PID simulator on an experimental profile from a DSC 111 curve. Such a curve does not represent a profile of temperature, but a profile of thermal heat flow, due to the temperature. We shall consider the shape of this profile only in order to assess the behaviour of our PID software and to evaluate its ability to follow this signal.

We first applied the rough conditions from Table 5. We obtained the following parameters: $P=8$, $I=20$ and $D=0$. The refined conditions are given in Table 6.

Table 6 Refined experimental conditions for the DSC profile

Parameter	Initial value	Final value	Step
Proportional	8	9	0.1
Integral	0	20	0.1
Derivative	0	0.5	0.5

The final parameters calculated are $P=8.1$, $I=19.9$ and $D=0$. We performed calculations in the PID software with these parameters and obtained the graphic display shown in Fig. 8.

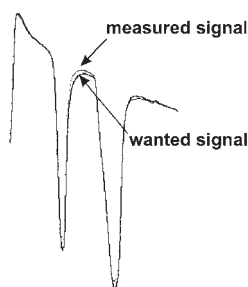


Fig. 8 Display of the performance obtained for a DSC signal

We see that there are two areas where the curves are slightly different. For a PID controller, it is normal to have minor difficulties with such signal shapes because peaks are great variations that can be regarded as pulses. Moreover, these negative peaks are under a highly decreasing baseline. However, this experiment revealed the strength of this kind of controller.

Determination of PID parameters with the DSC 111 tuning abilities

The experiments described above were conducted by using the full capabilities of our software in the selection of the iteration conditions for the 3 parameters P , I and D . For curiosity, we simulated the behaviour of the real PID controller included in the DSC 111 calorimeter; we must adapt its setting to the software. The real setting capabilities of the DSC 111 are presented in Table 7.

Table 7 Real possible settings for the DSC 111 calorimeter

Parameter	Initial value	Final value	Step
Proportional	0	10	0.01
Integral	0	3	1
Derivative	0	3	1

These values are normal for an analog device and come from the fully analog electronic construction of the controller. As stated above, from a strictly electronic point of view, the PID controllers are built with operational amplifiers (OPs). Usually, we have an OP for the *I* and *D* stages, and a potentiometer which will represent the parameter *P* and explains the continuous feature of its tuning. Finally, according to the structure of the controller, we will have 1 or 2 OPs which will sum up the former actions.

We can then easily reproduce these features in our software by tuning the iterative determination of the three PID parameters with the values from Table 7. In order to evaluate this new behaviour, we tested the software with the same kinds of signals as presented above. For a rectangular signal, the parameters found in the DSC 111 conditions are $P=7.74$, $I=3$ and $D=0$. We then plotted the output of our software with these parameters and compared it with that obtained in Fig. 6. We have assembled part of these two displays in Fig. 9.

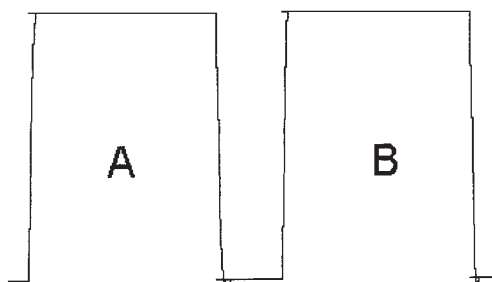


Fig. 9 Comparison of correction for two different sets of PID parameters: A – parameters calculated for the capabilities of the DSC 111 calorimeter; B – parameters calculated with our two-step method shown above

We clearly see that the two responses are very similar. If we consider the error GEI_m , we have for A $GEI_m(A)=0.01425623$ and for B $GEI_m(B)=0.01296703$; so hence, between these approaches we have a relative error Er :

$$Er=100 \frac{|GEI_m(A)-GEI_m(B)|}{GEI_m(B)}=9.94\% \quad (2)$$

We conducted such comparisons on the other signals: triangular, logarithmic and the experimental profile shown in Fig. 8. In Table 8, we list the corresponding GEI_m and error Er calculated with relation (2).

Table 8 Comparison of error with DSC 111 capabilities and the two-step method

Signal	$GEI_m(A)$ (DSC 111 capabilities)	$GEI_m(B)$ (two-step method)	$Er/\%$
Rectangular	0.01425623	0.01296703	9.94
Triangular	0.00627160	0.00505473	24.07
Sine	0.01005700	0.00922749	8.99
Logarithmic	0.00838759	0.00766146	9.47
Experimental	0.00907951	0.00665276	36.48

The smallest relative errors are obtained for the sine, rectangular and logarithmic signals. This is normal, in consequence of the shapes of these signals, which possess long level sections (rectangular profile) or very slow curved variations (logarithmic and sine profiles). In these cases, the capabilities of the DSC 111 are sufficient to allow a good fit between the desired and measured signals. The larger relative errors involve signals with great variations (triangular profile) or irregular shape (experimental curve) and pose some difficulties when we use the DSC 111 tuning.

If we consider only the values of GEI_m , we note that the best performances are obtained for the triangular shape. This is normal because after each change of the slope of the signal the correction calculated by the controller goes in the same direction as the new slope, so the following errors are very small. In the best cases, it is impossible to distinguish the desired from the measured signal.

The worst GEI_m values are obtained for rectangular and experimental signals because a rectangular profile possesses important breaks between constant levels, and there is no slope which could help the controller to calculate its corrections by going in the same direction. This feature is independent of the capabilities of the calculations, such as, for example, the value of the steps for the rectangular signal is small (9.94%), but the GEI_m are large (0.01425623 and 0.01296703).

From these results, we see that it is possible to use the tuning features of the DSC 111 capabilities to determine the best PID parameters which can be used for a given experiment. In fact, for the most classical use of DSC 111 calorimeters, we can say that it is less important to have a very accurate choice of the parameters than to have a homogeneous approach. To illustrate this, we performed two different experiments on our DSC 111 with the following settings: $P=5$, $I=2$ and $D=0$, and $P=5$, $I=2$ and $D=5$. For the experiment, we simply chose the insertion of an empty capsule in the sample cell of the calorimeter; this is assumed to simulate a sudden change in the thermal behaviour in the calorimetric block. Figure 10 shows the DSC curves obtained.

We clearly see the great difference in the signal for exactly the same experiments. Hence, we must keep in mind that a bad setting of the parameter D can give false results, such as, for example, the enthalpy of a phenomenon. The parameters P and I also influence the signal, but to a lesser extent. However, smaller differences can alter the results of accurate calculations, as in the determination of kinetic parameters from DSC curves, for example. Thus, if very accurate results must be compared

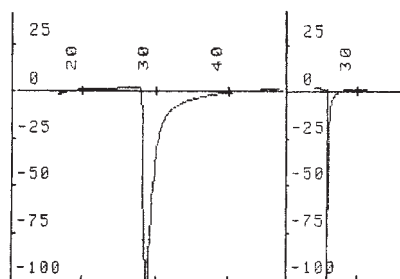


Fig. 10 DSC experiments with 2 different settings of parameter D

with others obtained from a different calorimeter, the setting of the PID regulation must be the same. Then, from these experiments and considerations, for our real experiments on the DSC 111, we chose the following set of parameters: $P=8.5$, $I=3$ and $D=0$, which represents a good compromise. We applied our software with these values with the above kinds of signals, and included the GEI_m obtained in Table 9.

Table 9 Performances obtained with $P=8.5$, $I=3$ and $D=0$

Signal	GEI_m (DSC 111 capabilities)
Rectangular	0.01412109
Triangular	0.00619808
Sine	0.01005700
Logarithmic	0.00863518
Experimental	0.00955196

These values are very good and show the same tendencies as those in Table 8. The fitting performances are also very satisfactory.

Conclusions

In this work, we have developed a set of software able to simulate the behaviour of a thermal PID controller. It is possible to test in real time the influence of the 3 parameters according to given desired input signals (rectangular, triangular, sine, etc.).

With an iterative approach, the software can adjust the 3 parameters in order to minimize the error between the desired and a simulated measured temperature. The parameters obtained can then be used to display graphically the behaviour of the numeric PID according to the time for the input desired signal. This set of software can be used in order to visualize the evolution of this behaviour according to the setting of the parameters P , I and D .

As this work is a good example of the optimization of parameters, we think it will be very interesting to replace the current iterative process of determination of the parameters by a new one using genetic algorithms. The time taken in the calculations will certainly be shorter, as already seen in a previous work [9].

Finally, as our numeric PID controller is very easy to use and interface, we intend to conduct tests in order to connect our software to the power stage of the analog regulation of our DSC 111. These tests will allow evaluation of the capability of our numeric PID controller to control a real thermal system.

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