Application of Proportional Integral Derivative [PID] Algorithms in Modern Industrial Control

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Abstract-* *A proportional-integral-derivative controller (PID controller) is a control loop feedback mechanism widely used in industrial control systems. A PID controller calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable. The PID controller algorithm involves three separate constant parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I, and D. Simply put, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. This paper evaluates the use of weighted sum of these three actions as used to adjust the process via a control element such as the position of a control valve, a damper, or the power supplied to a heating element.

I. INTRODUCTION

PID stands for Proportional-Integral-Derivative. These three controllers are combined in such a way that it produces a control signal. As a feedback controller, it delivers the control output at desired levels. Before microprocessors were invented, PID control was implemented by the analog electronic components. But today all PID controllers are processed by the microprocessors. Programmable logic controllers also have the inbuilt PID controller instructions. Due to the flexibility and reliability of the PID controllers, these are traditionally used in process control applications.

The PID control scheme is named after its three correcting terms, whose sum constitutes the manipulated variable (MV). The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. Defining (t) as the controller output, Controller manufacturers arrange the Proportional, Integral and Derivative modes into three different controller algorithms or controller structures. These are called Interactive, Non interactive, and Parallel algorithms. Some controller manufacturers allow you to choose between different controller algorithms as a configuration option in the controller software. [1]

In the absence of knowledge of the underlying process, a PID controller has historically been considered to be the most useful controller. By tuning the three parameters in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point, and the degree of system oscillation. Note that the use of the PID algorithm for control does not guarantee optimal control of the system or system stability. Some applications may require using only one or two actions to provide the appropriate system control. This is achieved by setting the other parameters to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions [2]. PI controllers are fairly common, since derivative action is sensitive to measurement noise, whereas the absence of an integral term may prevent the system from reaching its target value due to the control action.

II. PID ALGORITHMS

Controller manufacturers arrange the proportional, integral and derivatives modes into three different controller algorithms or controller structures [3]. These algorithms are called interactive, non-interactive and parallel algorithms, as shown in figures 1-3 below

$$u(t) = K_c\left[e(t) + \frac{1}{Ti}\int_0^t e(\tau)d\tau\right] \times \left[1 + T_d\frac{d}{dt}e(t)\right]$$

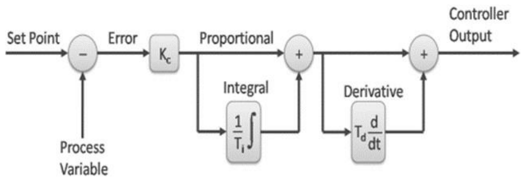

Fig 1 Interactive Algorithm

$$u(t) = K_c\left[e(t) + \frac{1}{Ti}\int_0^t e(\tau)d\tau + T_d\frac{d}{dt}e(t)\right]$$

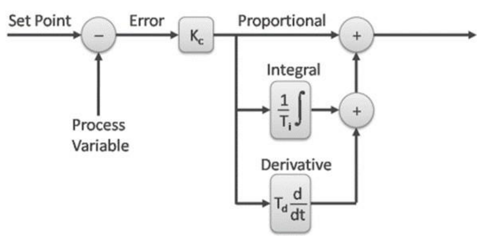

Figure 2 Non interactive algorithm

$$u(t) = K_p e(t) + K_i\int_0^t e(\tau)d\tau + K_d\frac{d}{dt}e(t)$$

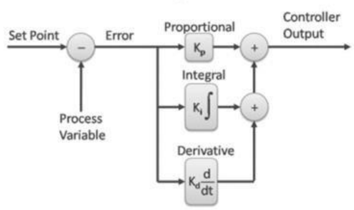

Figure 3 parallel algorithm

III. PID CONTROLLERS

PID controllers use three sub-controllers combined into one controller using a simple sum. The se controllers are:

- Proportional
  The proportional section of a PID controller is a basic intuitive approach to feedback control. A naive approach to feedback control would say, the farther away from perfect the system is, the more it should work to get perfect. In a perfect world without friction, momentum, etc., this system alone would work great! This is proportional control. However, our world is imperfect and we need to add smarter feedback compensation.

- Integral
  The integral section of a PID controller compensates environment imperfections such as friction, wind, and other such imperfections that would resist the system to reach its perfect state. An integral controller works by keeping a sum of all the error the system has seen. In calculus, this is equivalent to the area underneath the curve up to the current point. The controller increases its control signal as the summed error gets larger.

- Derivative
  The derivative section of a PID controller compensates environment imperfections such as momentum which causes the system to overshoot its perfect state. The derivative controller lessens its control signal as the speed in which it is achieving its perfect state increases. In calculus, this is the slope of the error signal.

IV. PID CONTROLLER BLOCK DIAGRAM

A closed-loop system like a PID controller includes a feedback control system. This system evaluates the feedback variable using a fixed point to generate an error signal. Based on that, it alters the system output. This procedure will continue till the error reaches Zero otherwise the value of the feedback variable becomes equivalent to a fixed point.[4]

This controller provides good results as compared with the ON/OFF type controller. In the ON/OFF type controller, simply two conditions are obtainable to manage the system. Once the process value is lower than the fixed point, then it will turn ON. Similarly, it will turn OFF once the value is higher than a fixed value. The output is not stable in this kind of controller and it will swing frequently in the region of the fixed point. However, this controller is more steady & accurate as compared to the ON/OFF type controller

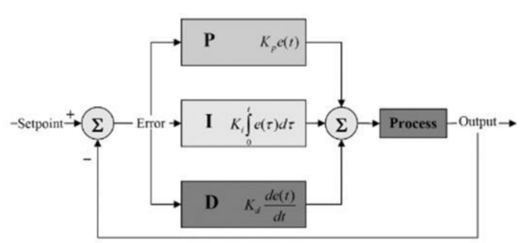

Figure 4 Block diagram of PID controller

The above figure shows the structure of the PID controller. It consists of a PID block which gives its output to the process block. Process/plant consists of final control devices like actuators, control valves, and other control devices to control various processes of industry/plant.

A feedback signal from the process plant is compared with a set point or reference signal u(t) and the corresponding error signal e(t) is fed to the PID algorithm. According to the proportional, integral, and derivative control calculations in the algorithm, the controller produces a combined response or controlled output which is applied to plant control devices.

All control applications don't need all three control elements. Combinations like PI and PD controls are very often used in practical applications.

V. TYPES OF PID CONTROLLER

PID controllers are classified into three types like ON/OFF, proportional, and standard type controllers. These controllers are used based on the control system, the user can be used the controller to regulate the method.

VI. ON/OFF CONTROL

An on-off control method is the simplest type of device used for temperature control. The device output may be ON/OFF through no center state. This controller will turn ON the output simply once the temperature crosses the fixed point. A limit controller is one particular kind of ON/OFF controller that uses a latching relay. This relay is reset manually and used to turn off a method once a certain temperature is attained.

- Proportional Control

This kind of controller is designed to remove the cycling which is connected through ON/OFF control. This PID controller will reduce the normal power which is supplied toward the heater once the temperature reaches the fixed point.

This controller has one feature to control the heater so that it will not exceed the fixed point however it will reach the fixed point to maintain a steady temperature. This proportioning act can be achieved through switching ON & OFF the output for small time periods. This time proportioning will change the ratio from ON time to OFF time for controlling the temperature.[5]

- Standard Type PID Controller

This kind of PID controller will merge proportional control through integral & derivative control to automatically assist the unit to compensate modifications within the system. These modifications, integral & derivative are expressed in time-based units.

These controllers are also referred through their reciprocals, RATE & RESET correspondingly. The terms of PID must be adjusted separately otherwise tuned to a specific system with the trial as well as error. These controllers will offer the most precise and steady control of the 3 types of controller.

- Real-Time PID Controllers

At present, there are various kinds of PID controllers are available in the market. These controllers are used for industrial control requirements like pressure, temperature, level, and flow. Once these parameters are controlled through PID, choices comprise utilize a separate PID controller or either PLC.

These separate controllers are employed wherever one otherwise two loops are required to be checked as well as controlled otherwise in the conditions wherever it is complex to the right of entry through larger systems. These control devices provide different choices for solo & twin loop control. The standalone type PID controllers provide several fixed-point configurations to produce the autonomous several alarms. These standalone controllers mainly comprise PID controllers from Honeywell, temperature controllers from Yokogawa, autotune controllers from OMEGA, Siemens, and ABB controllers.

PLCs are used like PID controllers in most of the industrial control applications The arrangement of PID blocks can be done within PACs or PLCs to give superior choices for an exact PLC control. These controllers are smarter as well as powerful as compared with separate controllers. Each PLC includes the PID block within the software programming.

VII. METHODS PID TUNING

Before the working of the PID controller takes place, it must be tuned to suit with dynamics of the process to be controlled. Designers give the default values for P, I, and D terms, and these values couldn't give the desired performance and sometimes leads to instability and slow control performances. Different types of tuning methods are developed to tune the PID controllers and require much attention from the operator to select the best values of proportional, integral, and derivative gains. Some of these aregiven below.

PID controllers are used in most industrial applications but one should know the settings of this controller to adjust it correctly to generate the preferred output. Here, tuning is nothing but the procedure of receiving an ideal reply from the controller through setting best proportional gains, integral & derivative factors[6]

The desired output of the PID controller can be obtained by tuning the controller. There are different techniques available to get the required output from the controller like trial &error, Zeigler-Nichols & process reaction curve. The most frequently used methods are trial & error, Zeigler-Nichols, etc.

- Trial and Error Method

This is a simple method of PID controller tuning. While the system or controller is working, we can tune the controller. In this method, first, we have to set Ki and Kd values to zero and increase the proportional term (Kp) until the system reaches oscillating behavior. Once it is oscillating, adjust Ki (Integral term) so that oscillations stop and finally adjust D to get a fast response.

- Process Reaction Curve Technique

This is an open-loop tuning technique. It produces a response when a step input is applied to the system. Initially, we have to apply some control output to the system manually and have to record the response curve.

After that, we need to calculate slope, dead time, the rise time of the curve, and finally substitute these values in P, I, and D equations to get the gain values of PID terms.

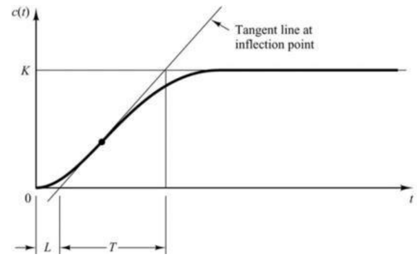

Fig 5 Process control curve

- Zeigler-Nichols method: Zeigler-Nichols proposed closed-loop methods for tuning the PID controller. Those are the continuous cycling method and damped oscillation method. Procedures for both methods are the same but oscillation behavior is different. In this, first, we have to set the p-controller constant, Kp to a particular value while Ki and Kd values are zero. Proportional gain is increased till the system oscillates at a constant amplitude.

Gain at which system produces constant oscillations is called ultimate gain (Ku) and the period of oscillations is called the ultimate period (Pc). Once it is reached, we can enter the values of P, I, and D in the PID controller by Zeigler-Nichols table depends on the controller used like P, PI or PID, as shown below.

Table 1 Zeigler-Nichols table

Controller	K_C	T_I	T_D
P	$K_u/2$		
PI	$K_u/2.2$	$P_u/1.2$	
PID	$K_u/1.7$	$P_u/2$	$P_u/8$

VIII. INDUSTRIAL APPLICATIONS OF PID CONTROLLERS

The PID controller applications include the following. The best PID controller application is temperature control where the controller uses an input of a temperature sensor & its output can be allied to a control element like a fan or heater. Generally, this controller is simply one element in a temperature control system. The entire system must be examined as well as considered while choosing the right controller.[3]

- Temperature Control of Furnace

Generally, furnaces are used to include heating as well as holds a huge amount of raw material at huge temperatures. It is usual for the material occupied to include a huge mass. Consequently, it takes a high quantity of inertia & the temperature of the material doesn't modify rapidly even when huge heat is applied. This feature results in a moderately stable PV signal & permits the Derivative period to efficiently correct for fault without extreme changes to either the FCE or the CO.

- MPPT Charge Controller

The V-I characteristic of a photovoltaic cell mainly depends on the range of temperature as well as irradiance. Based on the weather conditions, the current and operating voltage will change constantly. So, it is extremely significant to track the highest PowerPoint of an efficient photovoltaic system. PID controller is used to finding MPPT by giving fixed voltage and current points to the PID controller. Once the weather condition is changed then the tracker maintains current and voltage stable.

- The Converter of Power Electronics

We know that converter is an application of power electronics, so a PID controller is mostly used in converters. Whenever a converter is allied through a system based on the change within the load, then the converter's output will be changed. For instance, an inverter is allied with load; the huge current is supplied once loads are increased. Thus, the parameter of voltage as well as the current is not stable, but it will alter based on the requirement.

In this state, this controller will generate PWM signals to activate the IGBTs of the inverter. Based on the change within the load, the response signal is provided to the PID controller so that it will produce n error. These signals are generated based on the fault signal. In this state, we can obtain changeable input & output through a similar inverter.

- PID Controller Interfacing

The design and interfacing of the PID controller can be done using the Arduino microcontroller. In the laboratory, the Arduino based PID controller is designed using the Arduino UNO board, electronic components, thermoelectric cooler, whereas the software programming languages used in this system are C or C++. This system is used to control the temperature within the laboratory.

CONCLUSION

The parameters of PID for a specific controller are found physically. The function of various PID parameters can be implemented through the subsequent contrast between different forms of controllers.

This interfacing system can efficiently calculate the temperature through an error of ± 0.6℃ whereas a constant temperature regulates through simply a small difference from the preferred value is attained. The concepts used in this system will provide inexpensive as well as exact techniques to manage physical parameters in a preferred range within the laboratory.

REFERNCES

[1] Bennett S (1993) Development of the PID controller. IEEE Control Syst Mag 13(6):58–62

[2] Khodadadi H, Ghadiri H (2018) Self-tuning PID controller design using fuzzy logic for half car active suspension system. Int J Dyn Control 6(1):224–232

[3] Porter B, Jones AH (1992) Genetic tuning of digital PID controllers. Electr Lett 28(9):843–844

[4] Zhenbin W, Zhenlei W, Guangyi C, Xinjian Z (2005) Digital implementation of fractional order PID controller and its application. J Syst Eng Electr 16(1):116–122

[5] Díaz-Rodríguez Iván D, Sangjin H, Bhattacharyya Shankar P (2019) Analytical design of PID controllers. Springer, Berlin. ISBN 978–3–030–18227–4

[6] Ziegler John G, Nichols Nancy B (1942) Optimum settings for automatic controllers. J Dyn Syst Meas Control Trans ASME 115:220–222

[7] Borase, R.P., Maghade, D.K., Sondkar, S.Y. et al. A review of PID control, tuning methods and applications. Int. J. Dynam. Control 9, 818–827 (2021). https://doi.org/10.1007/s40435-020-00665-4