ISSN 2278-3091

International Journal of Advanced Trends in Computer Science and Engineering, Vol.2 , No.2, Pages : 159-163 (2013)
Special Issue of NCRTECE 2013 - Held during 8-9 February, 2013 in SMK Fomra Institute of Technology, OMR, Thaiyur, Kelambakkam, Chennai

Realization and Real Time Implementation of PF-PID Control Algorithm using PLC on a Pneumatic Process

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***Abstract* - PLC plays a vital role in the control and automation of various process industries. The robustness of PLC can be increased by using sophisticated control algorithms. Many research papers have been published incorporating complex control algorithms in PLC. This work analyses the programming, implementation and performance analysis of position form proportional-integral-derivative control algorithm (PF-PID) using a PLC to control a pneumatic process. The ladder functions in GE Fanuc Versamax PLC are used to develop the control algorithm. The performance of the complete PF-PID algorithm using PLC on the pneumatic system is validated using the various time-integral performance criteria in order to select the optimum PID parameters the experimental results are compared with the response of the same system with the position-form algorithm and the in-built PID function block in the PLC. It is observed that the proposed position-form control algorithm is able to track the parameter variation quickly and perform better in load disturbances. The algorithm is successfully tested and the desired performance of pneumatic process is achieved within a short time**.

***Keywords* - Position-form Algorithm, Pneumatic system, In-built PID, PLC, Ladder functions.**

I. INTRODUCTION

This paper elucidates the design and implementation of position form PID control algorithm using the PLC ladder functions on a pneumatic process. Microcontrollers and in-built PID algorithm using PLC can also be used for this purpose. But they are having some flaws. In built PID algorithm acquires more number of registers. But the proposed algorithm utilizes fewer numbers of registers. And also in the inbuilt algorithm only the sampling time values and gain values can be changed. Only the final values can be viewed clearly not the mediate values. But the algorithm explained in this paper can be useful to view the intermediate values. This can help to overcome some errors and helps in continuous monitoring. John “Zeke” Ziegler and Nathaniel Nichols may not have invented the proportional-integral-derivative (PID) controller, but their famous loop tuning techniques helped make the PID algorithm the most popular of all feedback control strategies used in industrial applications. The Ziegler-Nichols tuning techniques, first published in 1942, are still widely used today. Then, as now, the point of “tuning” a PID loop is to adjust how aggressively the controller reacts to errors between the measured process variable and desired set point. If the controlled process happens to be relatively sluggish, the PID algorithm can be configured to take immediate and dramatic actions whenever a random disturbance changes the process variable or an operator changes the set point. The position form PID algorithm used in this paper is implemented with the help of PLC. [4]

II. SELECTION OF PLC FOR AUTOMATION

The most important advantage of PLC is that the PLC algorithm can be used to control multiple processes effectively and simultaneously. The expandability of the process inputs provokes on the need for advanced microcontrollers. Hardware enhancements include larger memory capacity, larger number of inputs/outputs handling, analog input/output and high-speed data communications between programmable controllers. Also if a programming error has to be corrected in a PLC control ladder diagram, a change can be typed in quickly. Suppose that a panel wired relay has four contacts and all are in use when a design change requires three more contacts, time has to be taken to procure and install a new relay or relay contact block. Using a PLC, however, only three more contacts would be typed in. PLC offers pilot running thus saving valuable factory time.

PLC is a solid-state device and therefore it is more reliable than mechanical systems. Some of the other advantages of

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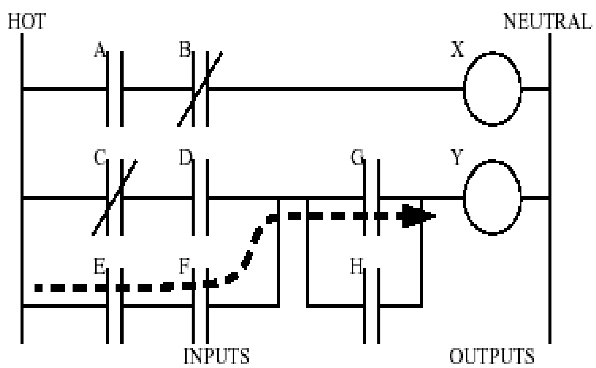
using PLC are flexibility, lower cost, documentation and security. In Foster farms dairy in Modesto, California, one large, powerful PLC system, with 222 I/O terminals, practically runs the whole operation [6]. Because of such advantages PLC is incorporated for the control purpose.

III. PLC AND PROGRAMMING

Fixed memory contains the program set by the manufacturer into the special IC chips called ROM. The fixed memory in ROM cannot be altered or erased during the CPU's operation. The alterable memory is stored on IC chips called RAM that can be programmed, altered and erased by the programmer / user. The input module terminals receive signals from wires connected to switches, indicators and other input



information devices. The output terminals provide o/p voltages to energize motor and valves, operate indicating devices and so on.

Fig. 1. A Simple Ladder Logic Diagram

The first PLCs were programmed with a technique that was based on relay logic wiring schematics. This eliminated the need to teach the electricians, technicians and engineers how to program a computer - but, this method has stuck and it is the most common technique for programming PLCs today. An example of ladder logic can be seen in fig.(1). An input may come from a sensor, switch, or any other type of sensor. An output will be some device outside the PLC that is switched on or off, such as lights or motors. In the top rung the contacts are normally open and normally closed, which means that if input *A* is on and input *B* is off, then the power will flow through the output and activate it. Any other combination of input values will result in these outputs *X* being off.

IV. DESIGN OF CONTINUOUS PID

A. Process Identification

The process reaction curve (PRC) method is used to find the process parameters such as process gain (K_p), process lag (t_d) and time constant (τ) by letting the pneumatic process in manual mode. The PRC response is shown below in fig (2).

Manual controller output in % is given to the final control element, control valve, and the response of the process is observed. From the obtained open loop response of the process, at some given condition, the delay time, slope value and time constant were found out from the curve. Thus the transfer function, G(S), can be modeled as

$$G(s) = \frac{K_p e^{-t_d s}}{\tau S + 1} \qquad (1)$$

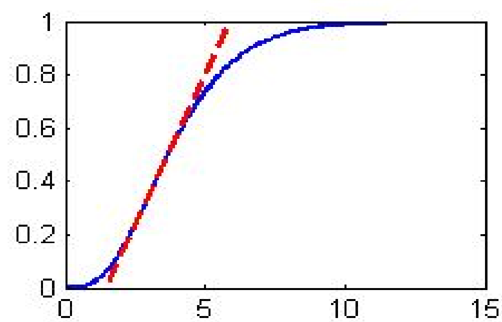


Fig .2 Process Reaction Curve

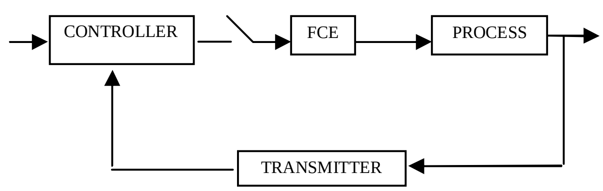


Fig .3 Block diagram for closed loop response

B. Controller Tuning

Tuning is nothing but the individual adjustment of the proportional, integral and derivative terms. Controller parameters are tuned so that the closed loop system meets the following five objectives: stability and stability robustness, usually measured in the frequency domain, transient response, including rise time, overshoot, and settling time, steady-state accuracy, disturbance attenuation and robustness against environmental uncertainty and robustness against plant modeling uncertainty, usually measured in the frequency domain. There are several methods for tuning a PID loop. The choice of the method will depend largely on whether or not the loop can be taken offline for tuning, and the response speed of the system. If the system can be taken offline, the best tuning method often involves subjecting the system to a step change in input, measuring the output as a function of time, and using this response to determine the control parameters. The Cohen-coon tuning method is adopted in this paper and the formulas used for the continuous PID controller are,

$$K_p = 1/K\ (\tau/td)\ [(4/3) + (td/4\tau)] \qquad (2)$$

$$Ti = td\ [(32 + 6(td/\tau)) / (13+8\ (td/\tau))] \qquad (3)$$

$$Td = td\ [4/(11 + 2(td/\tau)] \qquad (4)$$

where τ denotes the Time Constant. The equations (2) to (4) has to be implemented in the continuous PID controller expression,

$$\mathrm{Output(t)} = K_p \left(e(t) + K_{ip} \int_0^t e(\tau)\, d\tau + K_{dp} \frac{de}{dt} \right) \qquad (5)$$

$$K_i = 1/Ti \qquad (6)$$

$$K_d = Td \qquad (7)$$

V. Experimental Setup

Pressure process tank is mounted on base plate. The process tank is a cylindrical structure of length 15'' and diameter 5.5''. The tank has three tapping for air inlet, relief valve or muffler and dial type pressure gauge. Air inlet of 20 Psi is supplied through the opening and is regulated with the air filter, also called as pressure regulator. The inlet pressure supply is measured with the pressure gauge. This inlet air pressure is given to the process tanks via pneumatic control valve. The pressure inside the process tanks are displayed through the pressure gauge indicated as PI in the fig. 5.

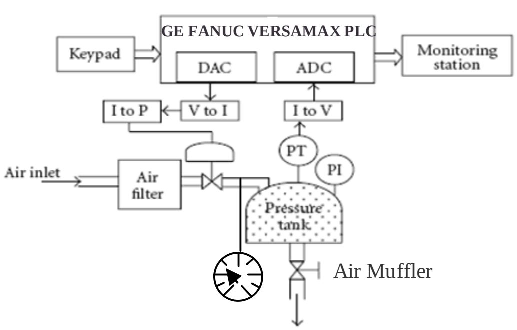


Fig 4 Experimental Setup

Air muffler acts as a load disturbance for the process. The pressure transmitter is used to sense the pressure signal in the range 0 to 100 Psi and provides an electrical output in the range of 4-20mA. This 4-20 mA signal from the transmitter mounted on the process tank is given to analog input module of the PLC system. The 4-20mA current signal is converted into 0-5V signal by the current to voltage (I/V) converter present inside the analog input module. The A/D Converter converts the analog voltage into digital bits and the processor represents signals in the range of 32767 to 32767. Then the 0-5V signal output of the D/A Converter present on the output side is converted into 4-20mA by the V/I converter. This current signal from the analog output module of the PLC is converted into 3-15 Psi by the current to pressure converter (I/P) present in the process setup. This conversion is essential as the final control element is a pneumatic control valve.

VI. Digital PF-PID Controller

In practice there are two PID control algorithms available. They are velocity form PID(VF-PID) and position form PID(PF-PID) control algorithms. In this paper position form PID control algorithm is used since the pneumatic process is a faster process and hence the PF-PID algorithm itself provides desirable response.

A. Approximation of Digital PF-PID Controller

The first term $K_p[e(t)]$ of continuous PID Eqn (5)which is responsible for the proportional action is replaced with the term $K_p(E_n)$ in Eqn.(10) where as in the second term, the integral of the error is replaced with the summation of errors as in Eqn. (8)

$$\int e(t)dt = \Sigma\ e_n \qquad (8)$$

and the derivative action performed by the third term (de/dt) in Eqn.(5) is replaced with the difference term as in Eqn (9)

$$de/dt = (E_n - E_{n-1}) \qquad (9)$$

Thus equation which is to be realized is modified for the discrete shown below,

$$m_n = K_p(E_n) + K_pK_I\, T\, \Sigma E_n + K_pK_d / T\, (E_n - E_{n-1}) + U_S \qquad (10)$$

The PLC algorithm uses the position form equations for calculating the controller output with the help of all gain values K_p, K_i and K_d.

B. Digital PF-PID Controller Realization

The flow chart in fig.5 explains the sequential steps involved in the PF-PID logic implementation. The process variable and set point are stored in specific registers and the difference, the error, is stored in another register. The PF-PID expression as in Eqn. 10 is realized through the simple arithmetic ladder logic functions. The error E_n and E_{n-1}, calculated and stored in a register for each sampling instant, is then passed on to the PF-PID expression. These steps are repeated for each sampling instant.

VII. Experimental Results

A. Process Modeling

The process modeling can be done by setting the process in manual mode at certain given conditions. The process parameters obtained for the process are,

$K_p = 2.37$, $t_d = 3.2$, Time constant (τ) = 20.75

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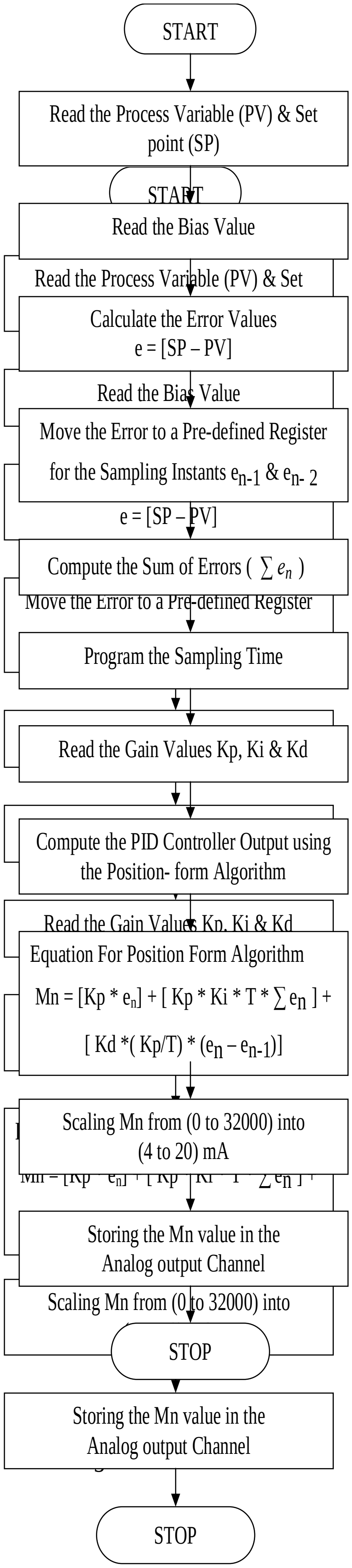

Hence the transfer function obtained for the process is shown here as

$$T.F = 2.37 / (20.75S + 1) \tag{11}$$

B. Controller Parameters

Since there are some approximations in Ziegler-Nichols tuning method, Cohen-coon method is implemented in this paper. By substituting the process parameter values in Eqn (2)-(4), the controller gain parameters are obtained and the values are shown below,

$$K_P = 3.24\ ,\ \ K_i = 0.08,\ \ K_d = 1.75$$

C. Closed Loop Response

By using the controller parameters the closed loop response can be obtained by using the PLC position form logic .The closed loop response for the In-built PID algorithm using PLC logic is shown in fig.(6),

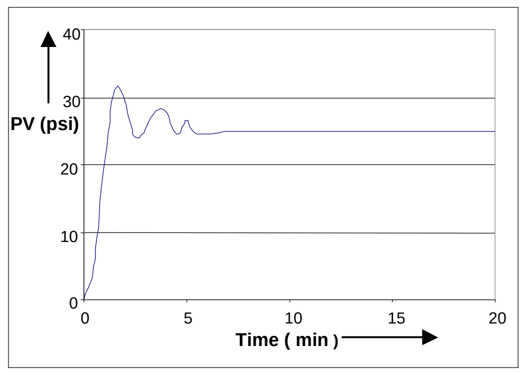

Fig .6 In- built PID response

In this response the process settled at 7 minutes with a peak overshoot of 7 psi,and second overshoot at 3 psi.

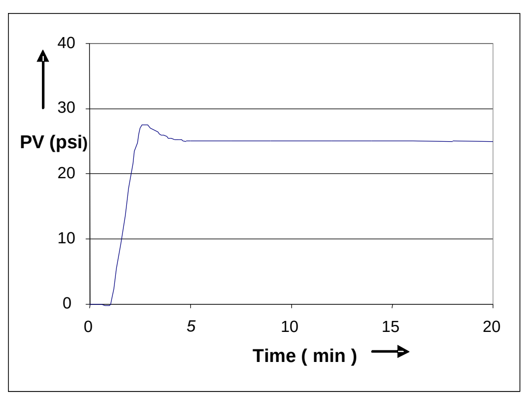

Fig 7 Response obtained using position form Algorithm

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Similarly the response obtained using the developed position form logic of PLC is shown in fig.(7). In this response the process settled at 5 minutes with an overshoot of 3 psi which is negotiable.

VIII. DISCUSSION

Using PLC the design of PF-PID control algorithm was carried out and implemented to control a pneumatic process in a closed-loop system. PLC is much efficient in testing application programs than conventional controllers. It is obvious from the response shown in fig.(7) that the In-built PID controller produces a slower response with more oscillations.

But the PF-PID algorithm developed in this paper gives faster response with less settling time and minimum oscillations as seen in the fig.(8). The position form algorithm has distinct property that it maintains its own reference in U_s. However it has drawbacks namely Lack of bumpless transfer from manual to auto switching, Reset Windup due to integral controller in test mode. The PLC recalculates the full value of the valve setting at each sampling interval. These drawbacks can be eliminated by using more robust control algorithms which opens further scope in the research area.

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