International Conference
1ST International Conference on Innovations, Recent Trends and Challenges in Mechatronics, Mechanical Engineering and New High-Tech Products Development
MECAHITECH'09

Bucharest, 8-9 October 2009

Intelligent Mechatronic Device Presenting PID for Setpoint Control Replacement

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ABSTRACT

This mechatronic system for regulating the working parameters pressure – flow for hydraulic equipment, was developed in the INOVARE program, based on a pneumatic valve with electrohydraulic command, whose constructive and functional solution is a novelty (patent application No. A/00098/2006). For their control many algorithms are developed. This paper gives a control algorithm based upon digital PWM controller.

INTRODUCTION

General aspects of feedback loop systems

The general scheme of a mechatronic system with feedback is given in Figure 1 and relieves some interesting general features. If H is the transfer function of the closed-loop system and the transfer function of the open loop system then can write:

$$e = i - x \quad (1)$$

$$x = F \cdot o = f \cdot a \cdot e \quad (2)$$

$$H = \frac{o}{i} = \frac{h \cdot e}{e + h \cdot F \cdot e} = \frac{h}{1 + F \cdot h} \quad (3)$$

$$dH = d\left(\frac{h}{1+af}\right) = \frac{1}{(1+af)^2} dh \quad (4)$$

$$\Rightarrow \frac{\Delta H}{H} = \frac{\Delta h}{(1+hF)^2} \cdot \frac{(1+hF)}{h} = \frac{\Delta h}{h} \cdot \frac{1}{1+hF} \prec\prec \frac{\Delta h}{h} \quad (5)$$

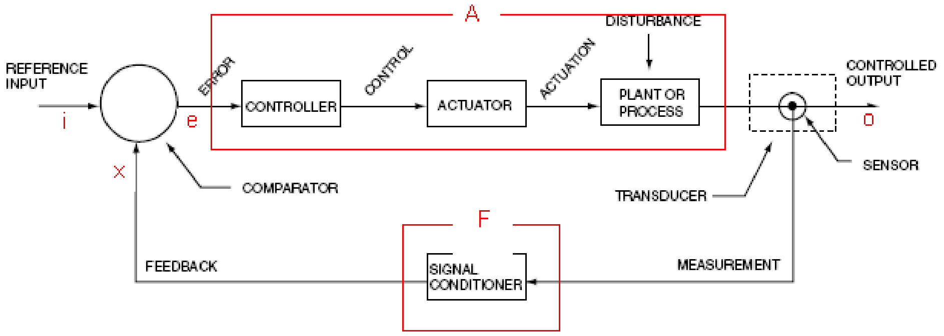

Figure 1: General closed loop with feedback diagram

Formula 3 shows an important property of a feedback system to **stabilize the transfer function** in the sense of desensitization compared to block action parameters. The closed-loop transfer function depends only from the global transfer function of measuring block that needs to be much less sensitive to harmful influences.

Another major advantage of using closed loop is the **linearization of transfer function.** As seen in the Formula 5, a transfer function linearity deviation for the open-loop accounts for a much smaller variation of the closed-loop transfer function.

The pneumatic valve with electrohydraulic command, despite of having a high degree of nonlinearity in their operation, are very often used as commanding devices in the hydraulic systems. The control of these and many other processes implies numerous obstacles even though it is possible to reduce the degree of the pneumatic valve model to the third order model without losing nonlinearity. A frequent method for using linear controllers is linearization of the system around a given working point. The proportional-integral-derivative (PID) algorithm is the most common control algorithm used in industry. With PID, you specify a process variable and a set point. The process variable is the system parameter you want to control, such as pressure or flow rate, and the set point is the desired value for the parameter you are controlling corresponding in input range of 4 to 20 mA.

The proportional gain determines the ratio of output response to the error. The error is the difference between the set point and the process variable. In general, increasing the proportional gain will increase the speed of the control system response. However, if the proportional gain is too large, the process variable will begin to oscillate.

The integral component sums the error term over time. The integral response will continually increase over time unless the error is zero, so the effect is to drive the steady state error to zero.

The derivative component causes the output to decrease if the process variable is increasing rapidly. The derivative response is proportional to the rate of change of the process variable. Most practical control systems use very small derivative time, because the derivative response is highly sensitive to noise in the process variable signal. The criteria for the choice of the microcontroller PIC from Microchip was the possibility's of incorporate a lot of peripherals (like ADC's, DAC's), communications peripherals (like UART, SPI, I2C, etc) and DSP functionalities. The necessity to test the practical implementation of the circuit and observe its performance implied the connection of this one to some well known processes. One limitation appears in the third order process systems, which is in phase of study and implementation. The applications are the most diverse in the industry, due to its simplicity, use of usual electrical measures and fast start up application and use.

The mechatronic system for pneumatic valve, adjusting and PID control.

Figure 2 presents the experimental model of the mechatronic system for pneumatic valve controlling, and adjusting. It consists of: electromagnetic pneumatic valve, electronic control block and a pressure sensor electrically connected to electronic command unit. The pressure transducer is connected to the exit hole of the valve through a hose.

FEATURES:

- *nominal diameter: DN6*
- *maximum pressure: 6 bar*
- *regulated pressure: 0…5,8 bar*

- *pressure sensor: 0-10bar*
- *voltage supply: 220V*

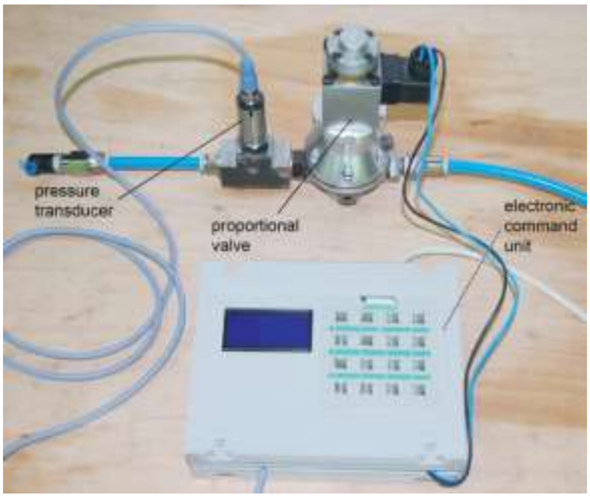

Figure 2: Experimental model of the mechatronic system

Discrete effective microcontroller PID implementation

Converting over to a digital system, Y(t) is measured by an A/D converter. In order to implement the PID controller, the PICmicro® microcontroller will have to do some approximations of integral and derivative terms. Starting with the derivative term, we can use the following finite difference equations for our approximation.

$$Y = K_1 X + K_2 \int X dt + K_3 \frac{dX}{dt} \tag{6}$$

If derivative operator is applied it will result:

$$\frac{dY}{dt} = K_1 \frac{dX}{dt} + K_2 X + K_3 \frac{d^2 X}{dt^2} \tag{7}$$

Going to finite differences it will result:

$$\frac{Y_n - Y_{n-1}}{T} = K_1 \frac{X_n - X_{n-1}}{T} + K_2 X_n + K_3 \frac{(X_n - X_{n-1}) - (X_{n-1} - X_{n-2})}{T^2} \tag{8}$$

$$Y_n = Y_{n-1} + P(X_n - X_{n-1}) + IX_n + D(X_n - 2X_{n-1} + X_{n-2}) \tag{9}$$

Where $P = K_1 \qquad I = K_2 T \qquad D = \frac{K_3}{T}$ (10)

Practically we implemented relation (9) in the program (see Figure 3), where X is calculated as the difference between the signal from the transducer (after it was numerical converted by 10bits A/D, embedded in microcontroller) and the desired reference.

In this paper we use some terms which we explain bellow:

• **Plant** – The physical output parts of the system.
• **Sensors** – The devices that measure the variables within the Plant.
• **Setpoint** – This is a value which is converted to a voltage that the process drives towards.
• **Error Signal** – This is the difference between the response of the Plant and the desired response (Setpoint).

The frequency of the PID control loop is also going to be selected to simplify the math routines. The Integral term, in Equation (8), shows that each error term needs to be multiplied by the sampling period (which is the same as dividing by the sampling frequency). By choosing a sampling frequency in powers of 2's, a very fast divide routine can be done by using the right shift command, where each right shift is a divide by 2. It is very similar for the Derivative term, except the left shift would be used for a multiply by 2. Knowing this, choose 256Hz as the sampling frequency. This is sufficient for a wide range of applications.

After a while, the integral term will also begin to contribute to the controller's output as the error accumulates over time. In fact, the integral term will eventually come to dominate the output signal because the error decreases so slowly in a sluggish process. Even after the error has been eliminated, the controller will continue to generate an output based on the history of errors that have been accumulating in the controller's integrator. The process variable may then "overshoot" the setpoint, causing an error in the opposite direction. If the integral tuning constant is not too large, this subsequent error will be smaller than the original, and the integral term will begin to diminish as negative errors are added to the history of positive ones. This whole operation may then repeat several times until both the error and the accumulated error are eliminated. Meanwhile, the derivative term will continue to add its share to 2 of 5.

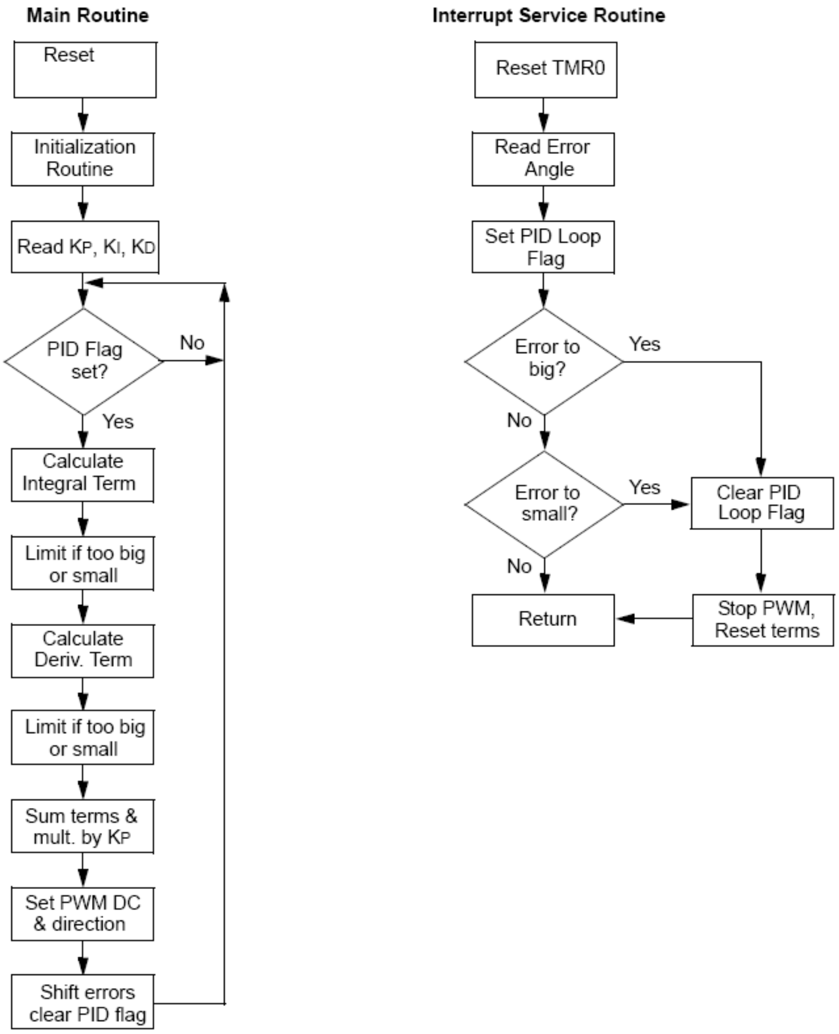

Figure 3: Software Routine Flowcharts

Tuning Techniques

Proper tuning of a controller is not only essential to its correct operation but will also greatly improve product quality, reduce scrap, shorten down-time and save money. Procedures for tuning conventional PID controllers are well established and simple to perform. Any time a sensor is replaced, the new set point must be retuned, which can be difficult under certain running conditions. This controller have digital settings for the three control parameters: Proportional Band, Integral time constant and Derivative time constant. This feature makes it simple to reproduce the correct parameter settings when replacing an sensors.

There are several established techniques for tuning control loops. The two most common techniques are the Process Reaction Curve technique and the Closed-Loop Cycling method. These two methods were first formally described in an article by J.G. Ziegler and N.B. Nicholls in 1942. They were initially proposed as being equal in their ability to be used for tuning but, as will be seen, one technique is superior to the other. It should also be understood that "optimal tuning", as defined by J.G. Ziegler and N.B. Nicholls, is achieved when the system responds to a perturbation with a 4:1 decay ratio. This definition of "optimal tuning" may not suit every application, so the trade-offs must be understood.

Experimental results:

The experimental model was tested using INOE 2000 IHP`s test rig. All the parameters were collected using a DAS 1700 KEITHLEY acquisition board.

In Figure 4 is presented the variation of pressure depending on flow.

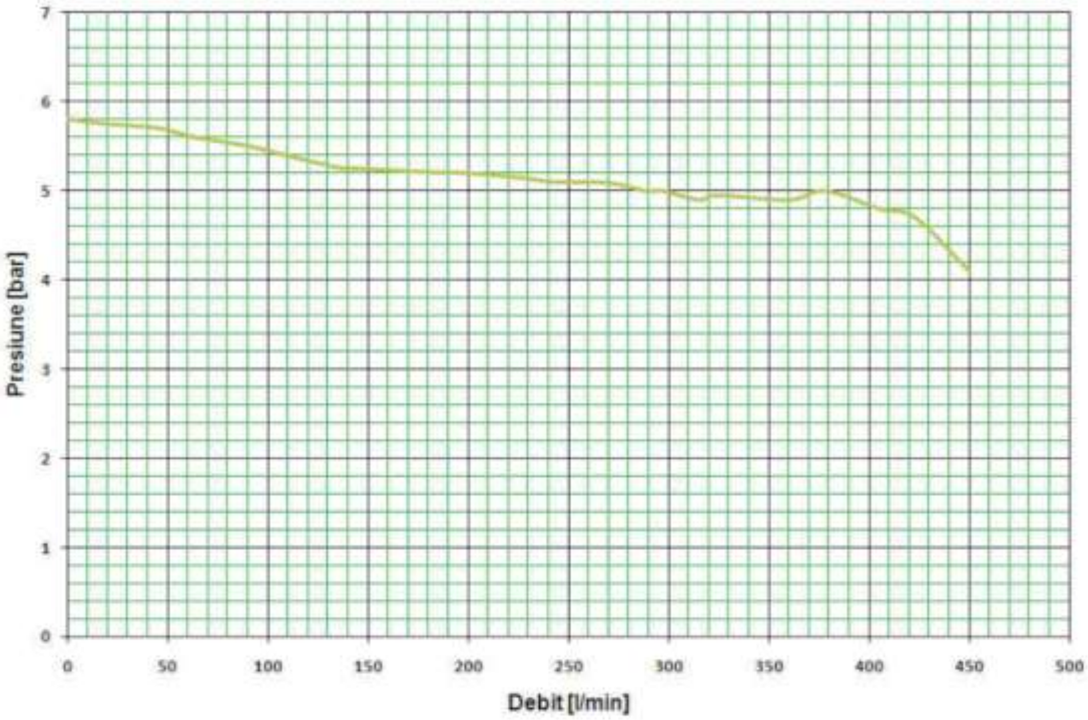

Figure 4: Pressure - Flow chart

In Figure 5 is presented the relation between the size of the command current and the air pressure at the exit hole and it is relieved a good stability and the liniarity in case of accidental increases or decreases of the pressure on pneumatic consumer circuit.

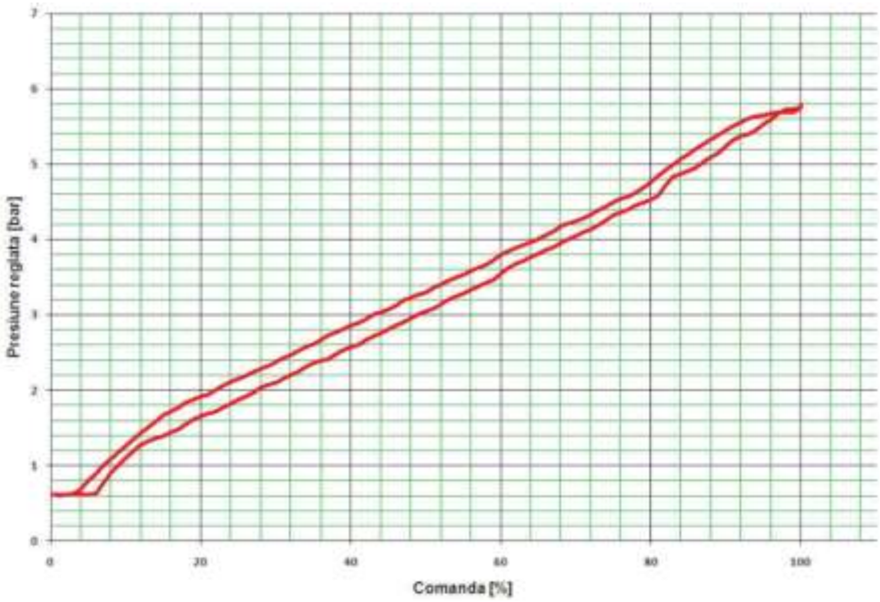

Figure 5: Hysteresis chart

Conclusions

PID controllers have been broadly used in process control since the 1940s. Despite a simple structure, they can effectively control a very large group of industrial processes. Furthermore, this controller is often categorised as an almost robust controller; as a result, they may also control uncertain processes. Due to their popularity, many research works have been carried out during the past sixty years to obtain the best formulas for tuning PID parameters, but every method has had a disadvantage or limitation. Dimensional analysis and numerical optimization methods were used to simplify the procedure of obtaining optimal relations. It was shown that the proposed formulas have a clear advantage to Ziegler-Nichols and Cohen-Coon methods - the most popular techniques in tuning PID controllers. Our future research is targeted at obtaining optimal formulas for tuning PID controllers for a second order plus time delay model.

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