Design of a Proportional Integral Derivative (PID) Controller for An Industrial Seminar

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Abstract

A Proportional Integral Derivative (PID) controller was designed and built for a seminar on process controls for local industry. The PID controller was designed to illustrate both the effect of the individual controllers on a system and the proper settings for the controller in various industrial applications.

The objectives of this paper are to discuss the educational aspects of the design and to qualify the effectiveness of the controller. A comparison is made between the observed results and the ideal theoretical results.

Introduction

A standard design for a PID controller has proportional gain provide the input for derivative gain and integral gain (Figure 1). This design is appropriate for industrial applications because proportional gain must always be active. However, for educational purposes, this design presents limitations. For example, the oscillatory nature of integral control or the 100% steady state error for a unit step input with derivative control cannot be observed. To observe the stand-alone effects of the controller, a different design is needed.

To study the individual characteristics of proportional, integral, and derivative controls, a PID controller (Figure 2) was designed and built for a seminar for local industry. An objective of the seminar was to provide a hardware demonstration that supported computer simulations of the PID controlled process.

The performance improvements of a second order plant are presented in this paper, and the accuracy of the design of the PID controller is examined. The output responses of the closed loop system are compared with the results obtained using MATLAB.

The Closed Loop System

For the seminar, the closed loop system consisted of two cascaded blocks, the PID controller and a critically damped, second order plant with an undamped natural frequency of two. The closed loop system used unity feedback to achieve stability. Both the plant and controller were constructed with op-amps, resistors, and capacitors. A block diagram of the system is illustrated in Figure 3.

Test and Analysis

Objectives of the seminar included determining system performance under various circumstances and developing a methodology of tuning the PID controller to achieve various responses. The input stimulus for each case was a step input.

The effect of proportional control was examined. As proportional gain (K_P) was increased, the steady state error was reduced but never reached zero. Some residual error was always present. Large amounts of K_P produced an output with an oscillatory response.

Stand-alone derivative control (K_D) produced a steady state error of 100%, as shown if Figure 4. This steady state error explains why derivative control is never used in a stand-alone mode. The other problem associated with derivative control is its susceptibility to external noise.

Integral control (K_I), used in a stand-alone mode, produced an output response with overshoot and oscillations. However, the steady state error eventually decreased to zero when the system was allowed to run for an extended time.

Since steady state error, rise time, settling time, and percent overshoot are concerns in an industrial control system, these parameters were analyzed in a simulated plant environment. With all three gains present, proportional gain produced a faster rise time and settling time. If K_P exceeded a certain value, overshoot and ringing occurred. Integral control decreased the steady state error and the settling time but, if set too high, also increased percent overshoot. Derivative control had the effect of improving rise time.

Various combinations of K_P , K_I , and K_D were examined for different design criteria. If settling time is not critical and overshoot is not allowed, controller values of K_P=6.8, K_I=.5, and K_D=.001 produce the response illustrated in Figure 5. If settling time must be minimized and overshoot is allowed, values of K_P=6.8, K_I=10, and K_D=.001

produce the response illustrated in Figure 6.

A methodology of tuning the PID controller to obtain the responses shown in Figures 5 and 6 consists of:

1. increase K_P until ringing occurs, then reduce proportional gain until the response has no ringing,

2. increase K_I until the design criteria (settling time, overshoot, etc.) are met, and

3. add a very small amount of K_D. If the plant is in a noisy environment, consider setting derivative control to zero.

For many desired system responses, there is no unique combination of controller settings. A different combination of K_P , K_I , and K_D could produce a similar system output.

The MATLAB Response

A MATLAB simulation of the closed loop system was conducted to determine the accuracy of the PID controller. The controller was modeled by   .

$$(1) \qquad G_1(s) = K_P + K_D s + \frac{K_I}{s}$$

and the plant was modeled by

$$(2) \qquad G_2(s) = \frac{1}{(s^2 + 4s + 4)}$$

The purpose of this comparison was to qualify the accuracy of the controller. MATLAB was used to determine the theoretical response for the controller values that produced Figures 5 and 6. A MATLAB response for the condition where overshoot is allowed and settling time must be minimized is illustrated in Figure 7.

The MATLAB code used to model the system is shown below:

```
>>Kp=6.8; Ki=10; Kp=.001;
>>num1=[Kp Kp Ki];
>>den1=[0 1 0];
>>num2=[0 0 1];
>>den2=[1 4 4];
>>[num3,den3]=series(num1,den1,num2,den2);
>>[num4,den4]=cloop(num4,den4,-1);
```

```
>>t=[0:0.0001:8];
>>[y,x,t]=step(num4,den4,t);
>>plot(t,y)
```

Conclusions

The MATLAB results indicate that the PID controller produces accurate responses. A close examination of Figures 6 and 7 reveals no discernable difference between the two graphs' settling times or percent overshoots. The excellent correlation of the graphs is probably due to the use of resistors and capacitors with 1% tolerance for fixed values. Decade resistors were used for variable components, ie. to set component gains. By measuring the value of the decade resistors and equating the values to the calculated gains, the decade resistors contributed to very accurate results.
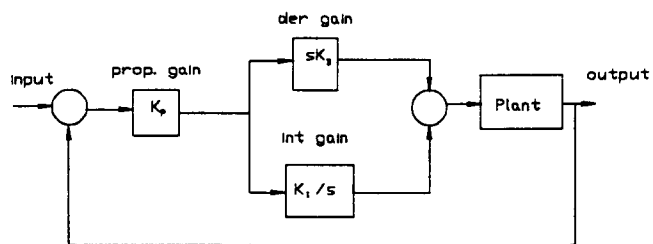
Figure 1: Block Diagram of a Typical PID Controller

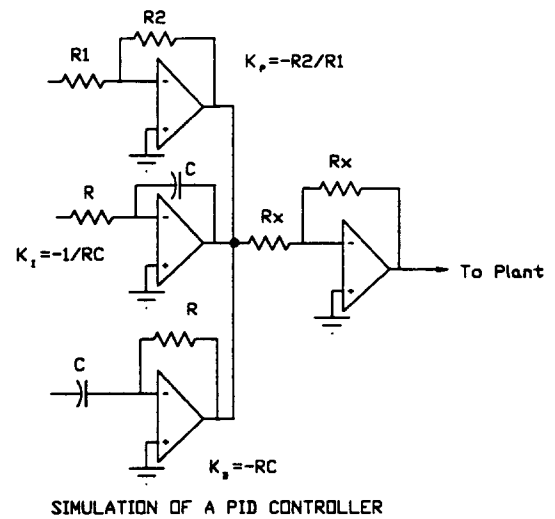SIMULATION OF A PID CONTROLLER

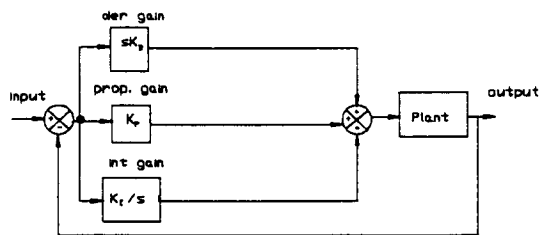Figure 2: Op-amp Design of the Controller
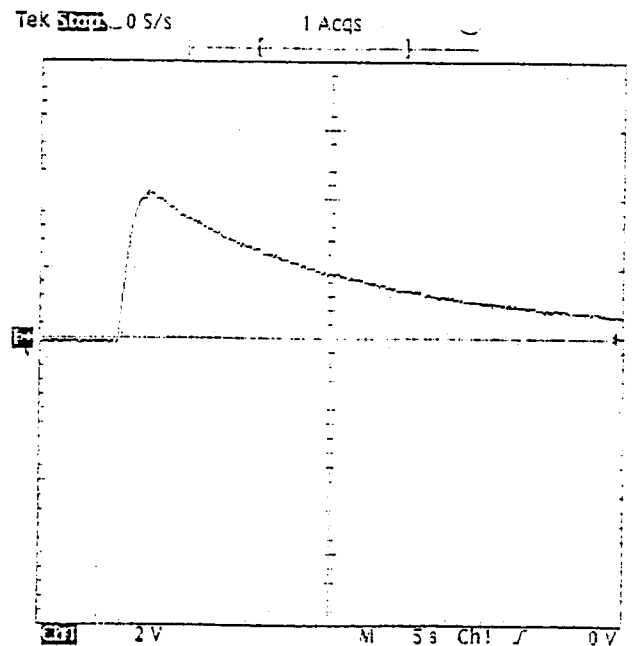

Figure 3: Block Diagram of the System

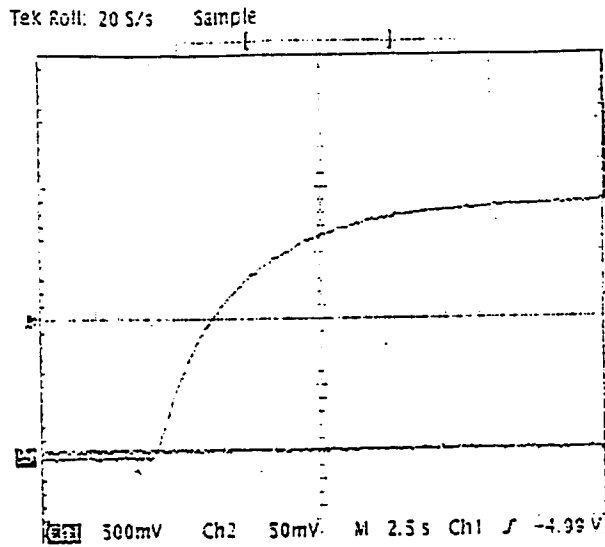Figure 4: System Response with
Derivative Control

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Figure 5: system Response with
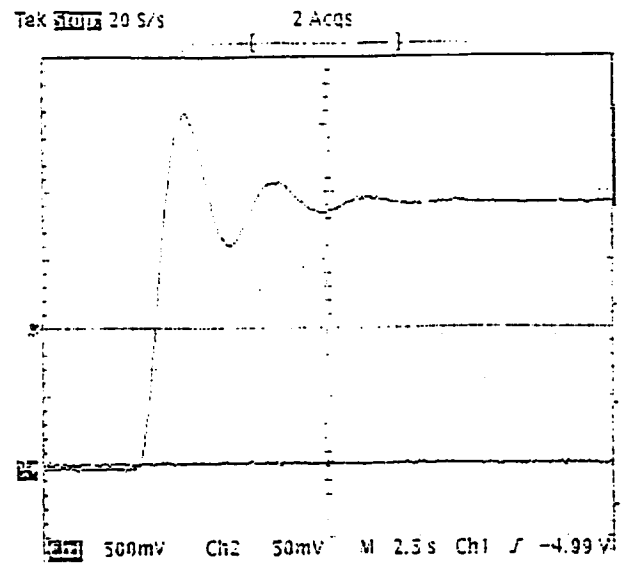K_P=6.8, K_I=.5, and K_D=.001

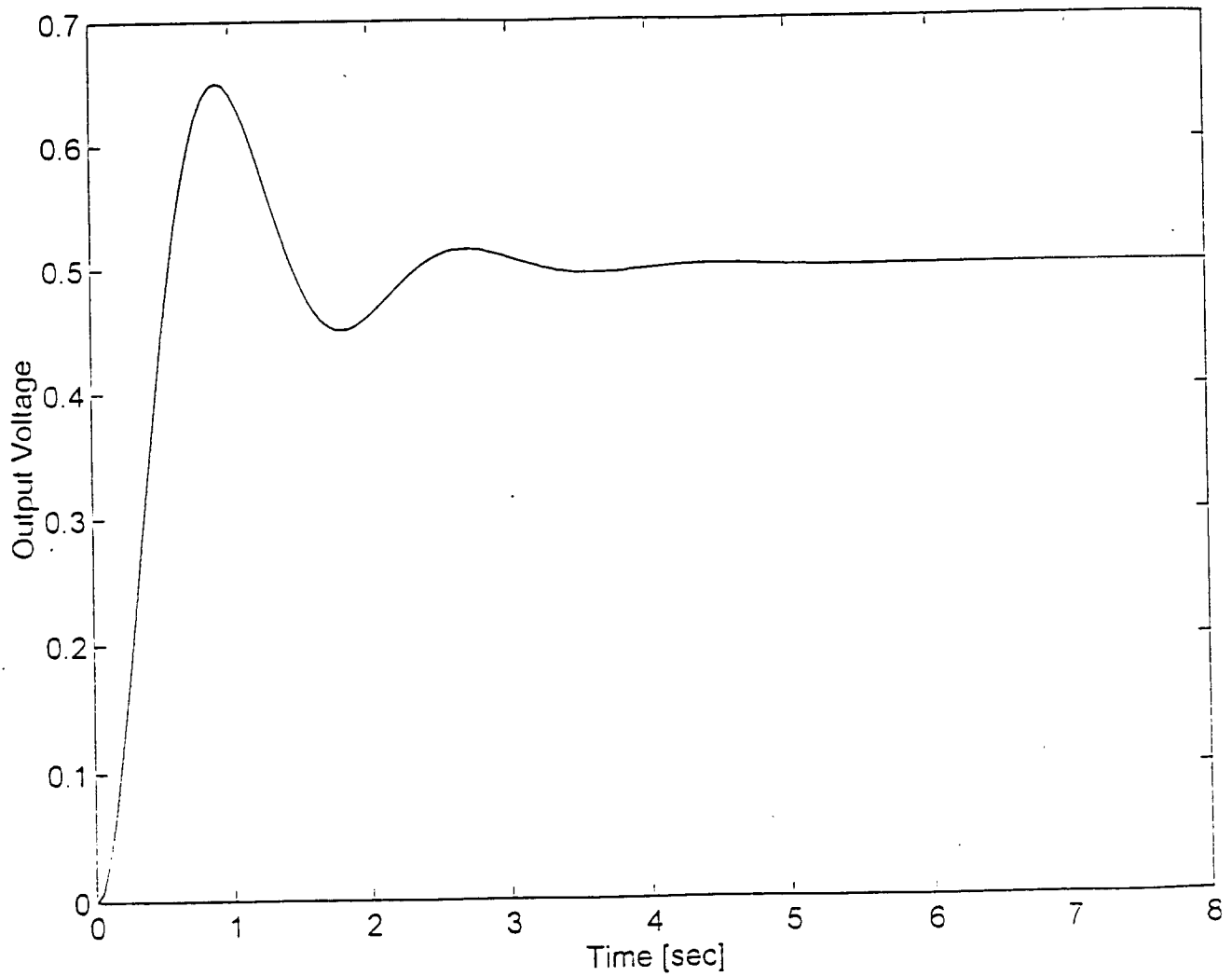Figure 6: System Response with
K_P=6.8, K_I=10, and K_D=.001

Figure 7: System Response with K_P=6.8, K_I=10, and K_D=.001

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