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Digital Controller Design to Control the Direct Current Motor System

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Abstract

The direct current motor is one of the first machines devised to convert electrical power into mechanical power, and its origins can be traced to the disc-type machines conceived and tested by Michael Faraday. Its primary goal is to design a digital Proportional-Integral-Derivative (or PID) controller in a PLD's devices environment to control the speed of DC motor system. This paper attempts to address two major problems by means of a PID controller. The first problem was system non-linearity that arose due to the nature of the hardware. The second problem was system unreliability when the DC motor load was varied.

***Keywords** : digital controller, proportional, integral, derivative*

1. Introduction

1.1 Feedback Control System and Motor

Its primary goal is to implement a digital PID controller to control the speed of a DC(Direct Current) motor system using feedback techniques. The use of feedback in a closed-loop system has a number of advantages, including increased accuracy and reduced effects of external disturbances and variations. DC motors are used in many industrial applications that require adjustable speed which can be controlled smoothly down to zero, followed immediately by acceleration in the opposite direction. Also, due to high torque-to-inertia ratio, DC motors respond quickly to control signal changes. DC motors in all but fractional and low integral horsepower sizes, have wound fields and are categorized as shunt-wound, series-wound, or compound-wound motors. In fractional and low integral horsepower sizes, permanent magnets are used instead of wound fields in many motor designs, this type is used as motor coupled with typical generator. DC motor can also be classified into Brush and Brushless type. In this paper, Brush type is chosen to implement the DC Motor system because it's high controllability and low cost.

1.2 Digital Controller System

The control system proposed in this paper is a type of digital controller, we have chosen a digital PID (Proportional[1-3], Integral[4] and Derivative) speed controller, which is the most common controller, widely used in all applications of control (90% of all control problems) and an essential element of more sophisticated controllers. This PID controller[5-6] depends on the PID algorithm[7-10] which used close loop techniques to compensate an existing system, with three forms of compensations Proportional(P), Integral(I) and Derivative(D). Its behavior can be roughly interpreted as the sum of these three term actions, which increases system performance in a variety of ways. Proportional

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control can both increase gain margin and stabilize a potentially unstable system and give a rapid control response. Integral control can minimize steady state error. A derivative control has the effect of increasing the stability of the system, reducing the overshoot, and improving the behavior of the control system during transients. Figure 1 shows the proposed system, which is considered to be the starting point of this 1.2.

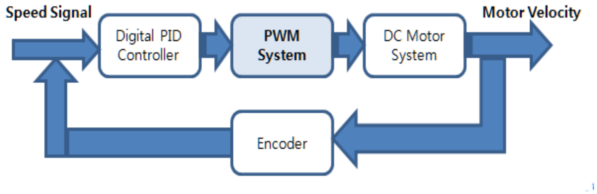


Figure 1. Proposed System Block Diagram

2. System Environment

Implementation of the digital controller consist of Microcontroller’s, DSP or PLD's devices. This paper will attempt to find a median between two extremes of performance and cost. The proposed solution is to design a special-purpose computer whose only purpose is to quickly execute the PID algorithm. This computer designed using the VHDL (Very High Speed Integrated Circuit Hardware Description Language), and implemented on an PLD's devices like CPLD (Complex Programmable Logic Device) or FPGA(Field Programmable Gate Array) to obtain, high energy efficiency, flexibility in control, quick response, light weight & compact control unit, less ripple in the armature current, small discontinuous conduction region in the speed-torque plane, small discontinuous conduction region improves the speed regulation and transient response of the drive, less amount of machine losses due to fewer ripples in the armature current, ability to control down to very low speeds.

3. Algorithms

The PID algorithm is the most popular feedback controller used within the process industries. It has been successfully used for over 50 years. It is a robust easily understood algorithm that can provide excellent control performance despite the varied dynamic characteristics of process plant. A PID control method, as its name suggests, the PID algorithm consists of three basic modes, the Proportional mode, the Integral and the Derivative modes. When utilizing this algorithm it is necessary to decide which modes are to be used P, I D and then specify the parameters (or settings) for each mode used. Generally, three basic algorithms are used P, PI or PID.

3.1 Proportional Controller

The action may be either direct or reverse. In a direct acting control loop an increase in the process measurement causes an increase in the output to the final control element. In a reverse acting control loop an increase in measurement causes a decrease in the output. The proportional only equation is *output = gain x error + bias*. The bias is sometimes known as the manual reset. Some control systems products, use proportional band rather than gain. The proportional band and the gain are related by ;

$$Gain = \frac{100\%}{Proportional - band} \qquad Proportional - band = \frac{100\%}{Gain}$$

3.2 Integral Controller

Integral controller depends on the integral of the error signal over time. The T_I integral time constant is the adjustable controller parameter with units of time.

$$u(t) = \frac{1}{T_I}\int_0^t e(t)dt = K_I\int_0^t e(t)dt$$

The primary advantage of integral control is that it eliminates offset. This happens because *u(t)* will change until the error signal is zero, thus eliminating a deviation between the controlled variable and setpoint in the steady-state. The disadvantage of integral-only control is that the controller will not respond until the error signal has persisted.

3.3 Derivative Controller

The third term of PID control is derivative, also known as Pre-Act, and rate. With derivative action, the controller output is proportional to the rate of change of the measurement or error. The controller output is calculated by the rate of change of the measurement with time

$$u(t) = T_D\left[\frac{de(t)}{dt}\right] = K_D\left[\frac{de(t)}{dt}\right]$$

K_D:derivative gain, T_D : the derivative time constant.

Derivative action can compensate for a changing measurement. Thus derivative takes action to inhibit more rapid changes of the measurement than proportional action. When a load or set-point change occurs, the derivative action causes the controller gain to move the "wrong" way when the measurement gets near the setpoint. Derivative is often used to avoid overshoot. Derivative action can stabilize loops since it adds phase lead. Generally, if you use derivative action, more controller gain and reset can be used.

3.4 Proportional-Integral-Derivative Controller

Proportional-integral-derivative (PID) controller combines the advantages of each individual mode of controllers. The ideal PID controller output equation is

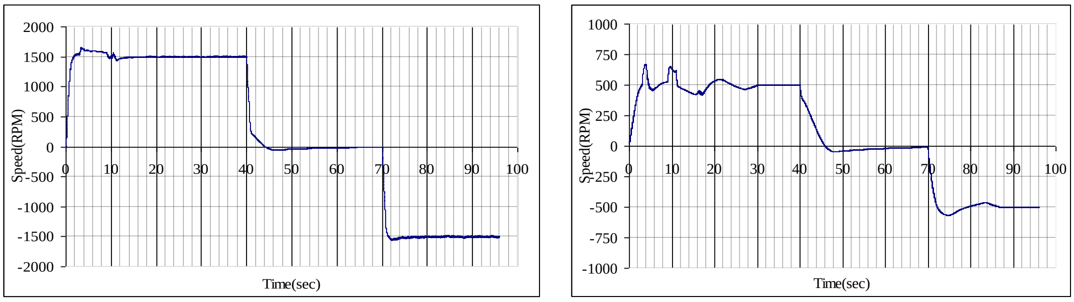
$$u(t) = K_p e(t) + K_I\int_0^t e(t)dt + K_D\left(\frac{de(t)}{dt}\right) = K_p\left[e(t) + \frac{1}{T_I}\int_0^t e(t)dt + T_D\left(\frac{de(t)}{dt}\right)\right]$$

The PID controller provides quick acting corrective control of most process variables. Adding integral control to a proportional controller will eliminate the steady state error, but will increase overshoot and settling time. However, by adding derivative control, the overshoot and settling time can be reduced. A PID controller is not used for highly noisy control variables like flow control, because the derivative response will amplify the random fluctuations in the system.

4. System

4.1 DC Motor

Controlling the speed of a DC motor requires a variable voltage DC power source. Taking DC motor and applying full power to it will cause the motor to rotate, gradually building up speed. Since motors do not respond immediately, it will take a shot amount of time to reach full speed. Likewise, there will be a time when the power is removed and when the motor armature stops revolving. Switching the power *ON* and *OFF* quickly enough will enable the motor to run at some speed part way between zero and full speed. Pulse Width Modulation (PWM) does exactly this, switching the motor on in a series of pulses. To control the motor speed, it varies (modulates) the width of the pulses, hence Pulse Width Modulation.



(a)Setpoint changed from 0 rpm to 1500rpm, from 1500rpm to 0rpm, and from 0rpm to -1500rpm

(b)Setpoint changed from 0 rpm to 500 rpm, from 500rpm to 0rpm, and from 0rpm to -500rpm

Figure 2. DC Motor Response with PID (K_P=3, K_I =1, K_D =1) Controller

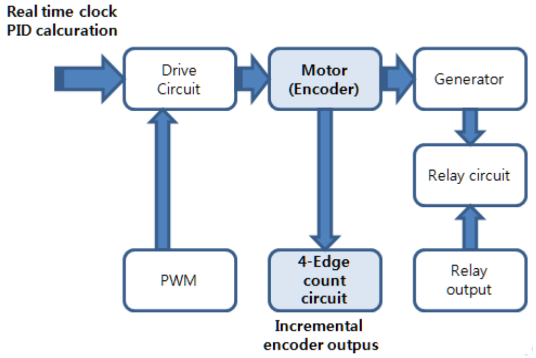
The DC motor System which is used in this paper is contained two similar DC motor coupled together, one act as motor and other act as generator or load, this load controlled from the controller to be in work through relay (sp-st). When the load out of working we considered no losses in motor and the speed is constant, but when the load in working the motor speed need to be treated by correction method. Simulation Figure 2 show how the optimal parameters value for K_P ,K_I and K_D can be attained, this values are considering the real system conditions, when implementing PID algorithm with VHDL which is not support the floating point, large values are needed with keeping the proportional factor between it, considering the system response, performance and stability. Incremental Encoder used in this paper has low resolution (423 p/rev), to solve this problem and obtain high resolution 4-edge count is used, this 4-edge count is implemented on PLD's device.

4.2 The PWM System

The PWM can be generated from different sources, Microcontroller or from PLD's device , but in all it will consider the control system needs which is here is PID controller and the feedback element, this consideration appear in the relationship between the *duty cycle* of PWM and the DC motor speed(RPM), which have to be a unity relationship ,that just to enable PID algorithm to be implemented in the PLD's device only, this lead to generating PWM with resolution of 12 bit, but the maximum counter value is 3000 which is equaled the maximum DC motor speed . From this technique desired speed is equal to *duty cycle*, also the output of PID calculation part is added or subtracted directly from the *duty cycle.*

4.3 Configuration

The two main parts in this system are controller and motor system. The controller includes the PID calculation, PWM generator 4-edge count, encoder pulse counter and relay controller. The motor system configuration includes drive circuit, DC motor[11], Rotary encoder, Generator and Relay shown in Figure 3. The input signals to controller are incremental encoder outputs. The signals are treated with a 4-edge count circuit to obtain DOWN and UP signals, Encoder pulse counter counting the DOWN or UP pulse every 30msec (Sampling time T_S)to determine actual motor speed. When speed is determined (the PID calculation part) compares demand speed with actual motor speed to update the PWM duty cycle. The control signals produced by controller are (Enable, Direction, PWM and Relay (ON/OFF)). This procedure is start initial controller. Determine desired motor speed and direction. PWM generating SET DIR(0 or 1). Input ENC-A, ENC-B to 4-edge count. Count down or up pulse. Calculate error and implement PLD algorithms. If error=0 new motor setting and update duty cycle.



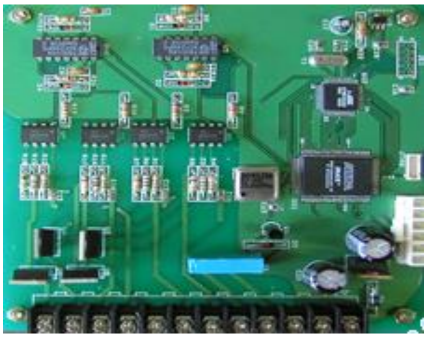


Figure 4. System Configuration **Figure 5. Main Board of Digital Controller**

To implement the previous system configuration, a Microcontroller and a CPLD are used. The main board of digital controller is shown in Figure 5. The PID calculation is programmed using C++ language in the Microcontroller. The PWM system and the Feedback system are designed in CPLD using VHDL[12] with ALTERA MAX PLUS 2 is used as Simulation tool. Microcontroller has ability to generate a PWM as well. So if this ability used, two different PWM sources are available.

4. Conclusion

In this paper digital controller is implemented and designed using VHDL, in the PLD's device. The PID parameter value are obtained by *trail and error method* from DC motor simulation program. This system considered to be a "closed-loop" system because information was fed back to the controller by the incremental encoder, its resolution 432 p/rev, which is increased by 4-edge count circuit designed in the PLD's devices, to reach 1728 p/rev, that to express purpose of improving system performance to reach:

- Steady State Error in range of 5% for command input.
- Percent Overshoot ≅ 5%, Phase Margin > 50

Future work can be done in this paper includes;

- Improve the PID parameters selection method to compatible with changing in setpoint especially each setpoint has optimal value of PID parameters.

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