

Real Time Cascade PI Control for Position Monitoring of DC Brushed Motor

Mazree Ibrahim, Sy. Najib Sy. Salim, M. Nizam Kamarudin, Aminurrashid Noordin

Abstract— This paper depicts the development of real time motor drive system. The modeling of Direct Current (DC) motor is vital in this work and hence is discussed in brief. Experimental setup consists of DC motor, rotary encoder, interface card and personal computer is thoroughly configured to obtain useful data such as control signal, speed and position of the motor. User interface and control algorithm is developed using Microsoft Visual C#. Proportional-Integral (PI) algorithm is developed to perform cascaded control of the DC motor. The system equipped with fixed inner current loop control parameters while the outer speed and position loop is varied to obtain the most satisfied position and speed of such motor. Through comparison of demanded speed and position, literal analysis of real time speed and position is thoroughly discussed.

Keywords— Proportional-Integral (PI) Control, DC brushed motor, position control, Cascade control.

I. INTRODUCTION

Since data collection and systems monitoring are vital in industrial environment, development of real time facilities for control systems has become needed for engineers and technologists. As such, this paper focuses on the real time development of DC motor drive systems. According to [1], a cascade control of DC motor is the most effective for DC drives as it uses fast inner current loop and enclosed by outer speed loop. However, for industrial needs such as robotics arm or pick and place systems, it is desired to attach position loop to the system. Therefore, this paper proposed a newly implemented real time cascade control system without inner current loop as shown in Fig. 1.

The system consists of primary and secondary loop so-called speed and position loop respectively. All variables abbreviated as CO2, PV2, PV1 and SP1 represent secondary control output, secondary process variable, primary process variable and primary set point respectively. Note that D2 represents a disturbance that impacts the PV2 before they impact PV1. Fig.2 shows the system configuration where PIC microcontroller from Microchip is used to build the decoder.

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The purpose of decoder is to decode signal from rotary encoder. The outputs of the rotary encoder are sets of pulses train. Specifically, the decoder is named quadrature decoder [2].

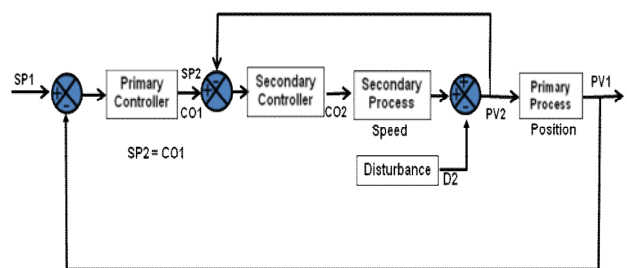


Fig. 1. Cascade control of DC motor with inner speed and outer position loop

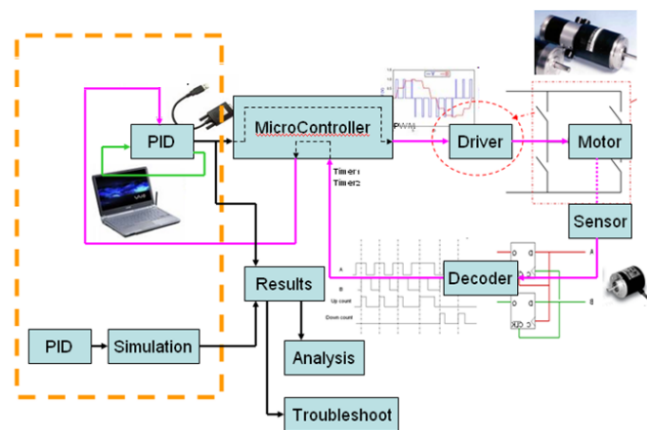


Fig. 2. System configuration

II. DC MOTOR MODEL

A separately excited DC motor is used because it has an independent voltage supplies to the field and armature windings. This type of structure gives advantage of more control over the motor performance [1]. A brushed M586TE motor manufactured by McLennon is used in this project. The parameters are listed in Table 1. Motor back emf and load torque makes the motor equation non-linear. As such, the state space equations (1), (2) and (3) is derived to provide the simplicity of modeling task. The model is depicted in fig. 3.

TABLE I
DC MOTOR PARAMETERS

Specifications	Value
Rotor inertia (Kgm ²)	3.87 x 10 ⁻⁵
Torque Constant (Nm/A)	0.056
Viscous friction (Nm/(rad/s))	8 x 10 ⁻⁶
Voltage constant (V/1000 rpm)	5.56
Terminal resistance (Ohm)	2.40
Rotor inductance (mH)	1.576

$$\frac{di_a(t)}{dt} = \frac{1}{L}(v_a - i_a(t)R_a + E_b) \quad (1)$$

$$\frac{d\omega(t)}{dt} = \frac{1}{J}(T_e(t) - T_L(t)) \quad (2)$$

$$\frac{d\theta(t)}{dt} = \omega(t) \quad (3)$$

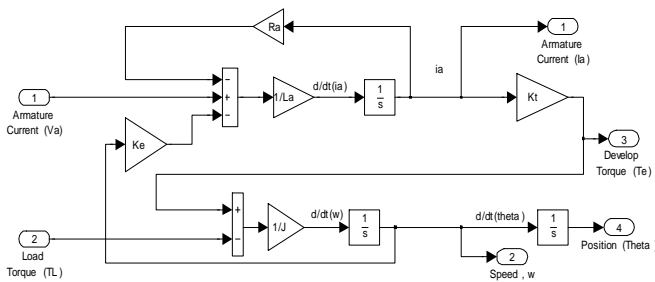


Fig. 3. DC motor model

III. CONTROLLER DESIGN

During the real time implementation phase, a simulation of overall system is developed beforehand. The simulation model is used to preliminarily tune inner speed loop controller as well as the outer position loop controller. Paper [3] provides procedure for cascade control tuning method where it mentions that for any multi-loop control scheme, the dynamics of all loop need to be taken into account while designing a controller. For this system, a proportional – integral (PI) controller is employed for both speed and position controllers because of several practical advantages. PI controller offers simple structure as well as robust performance [1]. The speed of the motor is actually controlled by adjusting the width of the pulse width modulation (PWM) signal through the power switching devices in the DC/DC converter circuit. Therefore, the use of derivative term for motor drive which equipped with DC/DC converter is unnecessary as some signals will have discontinuities or ripple that would result in spikes when being differentiated [4].

Equations (4) and (5) explain PI controller mathematically while fig. 4 shows a model of PI controller in SIMULINK environment. The overall model of the system is illustrated in fig. 5

$$y(n) = K_p \varepsilon(n) + K_i x(n) \quad (4)$$

$$x(n+1) = x(n) + \varepsilon(n) \quad (5)$$

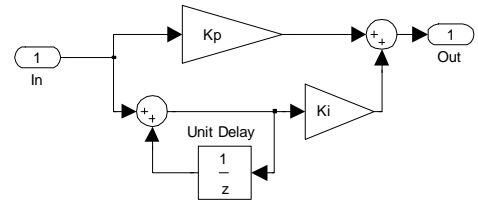


Fig. 4. Digital PI Controller

IV. SYSTEM IMPLEMENTATION

The actual system is shown in fig. 5. The system is equipped with motor driver circuit, encoder and decoder circuit. A PIC from Microchip is used to build the decoder which decodes a pulses train from rotary encoder. Specifically, the decoder is named quadrature decoder shown in fig. 6. This circuit is taken from “AN718: Brush-DC Servomotor Implementation using PIC17C756A” [5].

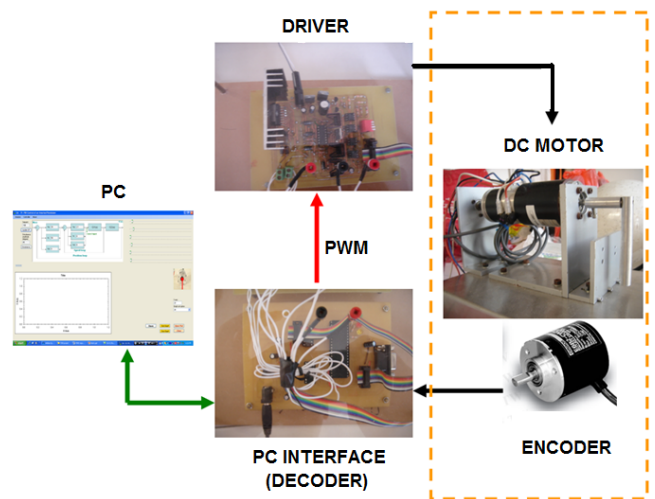


Fig. 5. Real time Cascade PI Control for Position Monitoring of DC Brushed Motor

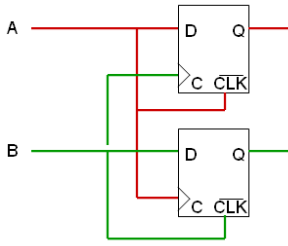


Fig. 6. Simple quadrature decoder using flip-flop

H-Bridge DC-DC converter drives the motor forward and reverse. Besides, it realizes 4 quadrant operations for braking and motoring function. In the simulation phase, the DC-DC converter is modeled in SIMULINK as it is non-linear due to their inherent switching operation [6,7]. In real time implementation, the regulation of the speed and position is achieved by the pulse width modulation (PWM) technique. The PWM switch the power MOSFET ON and OFF. As such, speed is varied by controlling the ON time of the pulse. As the position is obtained by integrating the speed with time, it is therefore possible to control the position of the DC motor by controlling the speed at a very first time. The correct selection of power semiconductor devices for the drive circuit is vital to ensure nearly perfect systems. The MOSFET is used based on its low switching loss and it's also could be operated in frequency more than 1 Mega Hertz [1]. A graphical user interface (GUI) for the system is developed in C# environment. The GUI is shown in fig. 7.

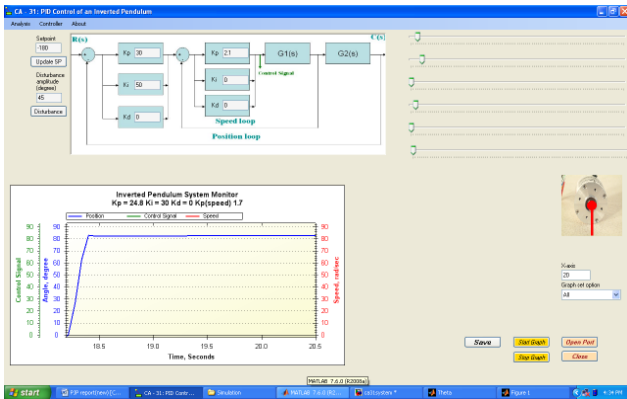


Fig. 7. User interface appear on host PC.

The parameter of the PI controller is tuned using Zigler-Nichols method. In the cascade control system, an inner loop is tuned first before the outer loop is engaged [1]. The parameters determine the transient response of the system such as rise time and settling time. The integral gain on the other hand ensure low steady error [8] while the value of proportional gain is constrained to from further increase to avoid the closed loop system become unstable.

V. RESULT

The system performance is measured by testing the system with various demanded input. The most satisfactory control parameters are listed in table 2 whereas table 3 shows the experimental result.

TABLE 2
CONTROL PARAMETERS

Parameters	Controller (Speed)	Controller (Position)
Kp	1.7	24.8
Ki	-	30

TABLE 3
MAPING OF REAL TIME INPUT – OUTPUT POSITION

Demand position	Actual Position		Absolute error	
	no load	with load	no load (%)	with load (%)
45°	44.64°	45.73°	0.8	1.62
90°	89.64°	91.68°	0.4	1.87
135°	135.01°	136.56°	0.01	1.16
180°	181.66°	176.56°	1.98	1.91
225°	227.16°	221.67°	0.96	1.48
270°	272.38°	274.4°	1.73	1.63
315°	312.48°	317.72°	0.8	0.86
360°	357.4°	357.2°	1.83	0.78

Fig. 8 and fig. 9 show a response for demanded 90° position for no-load and without load respectively. Ideally, the system reaches demanded position at 0.2 seconds. Slight delay occurred when the load is attached to the system as it reached demanded position at 4 seconds. Moreover, the system with load suffered 37.2% overshoot as well as sluggish settling time in the transient start up. This phenomenon happened because starting a large motor is determined not only by the torque, but also by the inertia of the rotor coupled with load. inertia of the rotor.

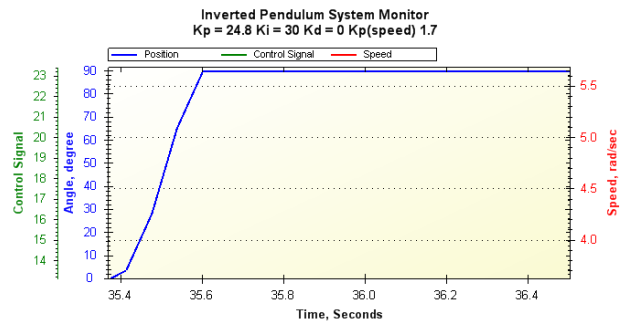


Fig. 8. Position without load

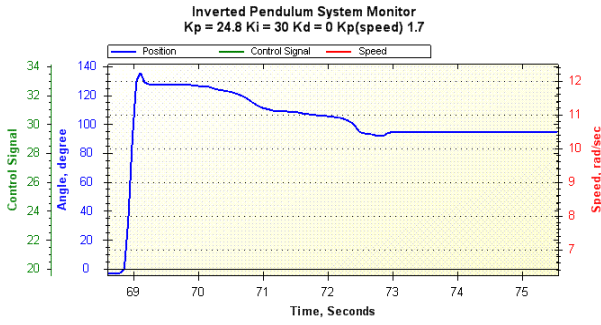


Fig. 9. Position with load

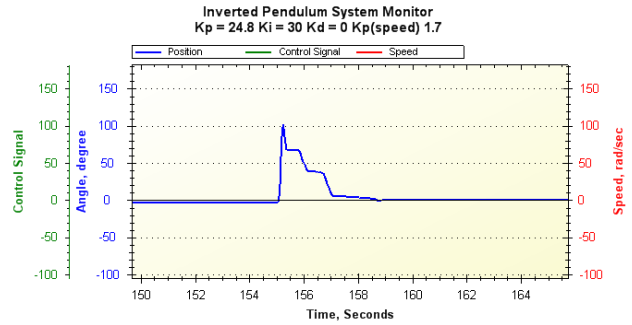


Fig. 11. Disturbance at 180°

The system is injected with -180° and 180° during steady state running at 0° . Result shown in fig. 10 and fig. 11 indicate that the system managed to recovered as soon as 1.27 seconds and 1.28 seconds respectively. The algorithm managed to avoid disturbance when it can ensure that the peak response below than applied disturbance. The result is tabulated in table 4.

TABLE 4
RESULT FOR INJECTED DISTURBANCE

Disturbance	Peak Response	Settling Time, Ts
-180°	-90°	1.27
180°	100°	1.28

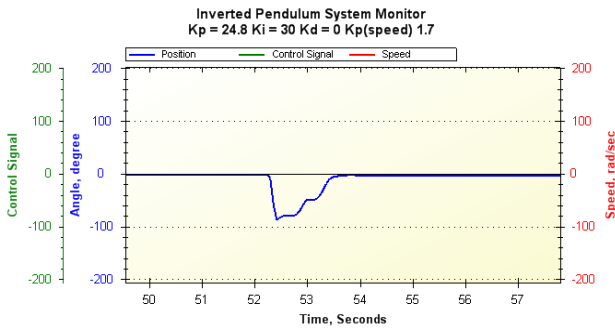


Fig. 10. Disturbance at -180°

VI. CONCLUSION

In this paper, the real time cascade PI control for position monitoring of DC brush motor was considered. A state space equation was derived to provide the simplicity of modeling task and had been used to facilitate the controller design. The experimental apparatus was constructed and the controller with GUI was implemented. An experimental result was presented to demonstrate the effectiveness of the designed controller.

From the result, it was concluded that the newly implemented real time cascade control without inner current loop perform as good as the conventional cascade control. The system tries to recover when the system is injected with external interruption making the system insensitive to disturbance. However, several improvements can be pondered to improve the transient.

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