On Line Speed Control of PMDC Motor Using Auto Tuning PID through LabVIEW

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Abstract—**This paper presents a new method of controlling the speed of PMDC motor with the auto tuning of parameters of the PID controller in the on-line speed control and also extracting the model of the closed loop system through LabVIEW. PID controllers provide robust and reliable performance for most systems if the PID parameters are tuned properly. This objective is achieved by using an auto tuning PID in three steps. In the first step, the PMDC motor-generator set is interfaced to Laptop using NI USB-6008 DAQ card. In the second step, the closed loop system is extracted through the LabVIEW system identification toolkit. In the third step, the PID parameters are obtained through the auto tuning procedure and speed controlling is done. The designed auto tuning PID controller realize a good dynamic behaviour of the DC motor, a perfect speed tracking with less rise and settling time, minimum overshoot, minimum steady state error and give better performance compared to the manual tuning PID controller.**

Index Terms—**PMDC motor, auto tune PID, NI USB-6008 DAQ card, LabVIEW, system identification tool kit, state-space model.**

I. Introduction

Development of high performance Permanent Magnet D.C motor (PMDC) drives is very essential for industrial applications. A high performance motor drive system must have good dynamic speed command tracking and load regulating response. DC motors provide excellent control of speed for acceleration and deceleration [1]. The power supply of a DC motor connects directly to the field of the motor which allows for precise voltage control, and is necessary for speed and torque control applications. D.C motor is considered as a SISO (Single Input and Single Output) system having torque/speed characteristics compatible with most mechanical loads. This makes a D.C motor controllable over a wide range of speeds by proper adjustment of the terminal voltage.

Large experiences have been gained in designing trajectory controllers based on self tuning and Proportional Integral Derivative (PID) control. In order to adjust the speed of the system PID controller is widely used. This method is most useful when a mathematical model of the process or control is too complicated or unknown [1]. Tuning of PID parameters should be done in order to get the optimal response. The PID based speed control has many advantages like fast control, low cost and simplified structure. This paper mainly deals with closed loop controlling of DC motor speed using auto tuning PID as speed and current controller with Labview.

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II. Theory

A. Closed Loop Control Systems

Closed loop control system uses feedback to determine the actual input to the system. Feedback means that the information about the current states (e.g. position, velocity) of the system is used by the controller to continuously correct the actual input to the system in order to reach the desired states. Most commonly used type of controllers [2] P, PI and PID controllers. In this paper the PID controller is used to achieve the desired speed.

B. PID Controller

The PID controller compares the set point (SP) to the process variable (PV) to obtain the error (*e*) [2].

$$e= SP-PV \tag{1}$$

Then the PID controller calculates the controller action, *u*(*t*), where *Kc* is controller gain.

$$u(t) = K_C(e + \frac{1}{T_i}\int_0^t edt + T_d\frac{de}{dt}) \tag{2}$$

If the error and the controller output have the same range, 100% to 100%, controller gain is the reciprocal of proportional band [1]. *Ti* is the integral time in minutes, also called the reset time, and T_d is the derivative time in minutes, also called the rate time. The following formula represents the proportional action [3].

$$u_p(t)=K_ce \tag{3}$$

The following formula represents the integral action.

$$u_I(t) = \frac{K_C}{T_i}\int_0^t edt \tag{4}$$

The following formula represents the derivative action.

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$$u_D(t) = K_c T_d \frac{de}{dt} \tag{5}$$

Controller output is the summation of the proportional, integral, and derivative action, as shown in the following formula.

$$u(k) = u_p(k) + u_I(k) + u_D(k) \tag{6}$$

The actual controller output is limited to the range specified for control output [3].
If

$$u(k) \geq u_{max} \text{then} u(k) = u_{max} \quad \text{and} \tag{7}$$

$$u(k) \leq u_{max} \text{then} u(k) = u_{min} \tag{8}$$

The following formula shows the practical model of the PID controller.

$$u(t) = K_c \left[(SP - PV) + \frac{1}{T_i} \int_0^t (SP - PV)dt - T_d \frac{dPV_f}{dt} \right] \tag{9}$$

The default ranges for the parameters SP, PV, and output correspond to percentage values.

PID controllers have some drawbacks that limit their effectiveness. One of the current difficulties with PID controllers is the gain tuning. Often, many controllers are poorly tuned. As a result, some controllers are either too aggressive or too sluggish. PID controllers are difficult to tune when the process dynamics or disturbances are unknown.

In the present work, an auto tuning PID controller is implemented so that the parameters of the PID controller are automatically tuned through LabVIEW

C. *The Auto Tuning Algorithm*

The tuning principle is to automatically change the setpoint stepwise, and to calculate the controller parameters from the response. The autotuner requires that the control loop is stable initially (with P, PI or PID controller). Once the system is in steady state the tuning process starts [3]. When a limit cycle exists with the required number of cycles, new PID parameters are evaluated, then PID controller parameters are updated and the auto-tuning process is stopped.

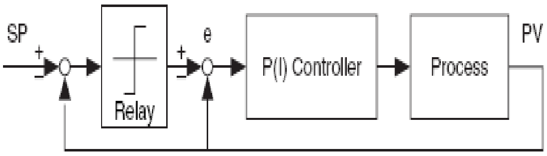


Figure 1. Process under PID Control with Setpoint Relay

Fig. 1 illustrates the auto tuning procedure excited by the set point relay experiment, which connects a relay and an extra feedback signal with the set point. The existing controller remains in the loop.

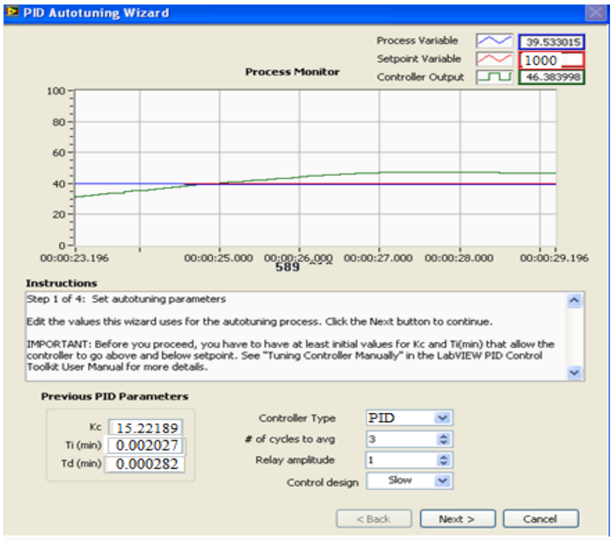
For most systems, the nonlinear relay characteristic generates a limiting cycle, from which the auto tuning algorithm identifies the relevant information needed for PID tuning. If the existing model is PID, the auto tuning algorithm identifies the dead time and time constant T_p, which are two parameters in the integral-plus-dead time model [3].

This auto tuning PID uses Ziegler and Nichols' heuristic methods for determining the parameters of a PID controller. The tuning formula used for the PID control to this paper is given in Table I [3].

TABLE I. TUNING FORMULA UNDER AUTO TUNE PID CONTROL

Controller	**K_c**	**T_i**	**T_d**
P	$0.26T_p/\tau$	-	-
PI	$0.24T_p/\tau$	5.33τ	-
PID	$0.32T_p/\tau$	4τ	0.8τ

When the auto tuning procedure runs, an auto tuning wizard opens as shown in Fig. 2 and a local variable updates the PID gains control. After the control loop is complete, the VI writes the current PID gains.



Process Variable 39.533015
Setpoint Variable 1000
Controller Output 46.383998

Instructions

Step 1 of 4: Set autotuning parameters

Edit the values this wizard uses for the autotuning process. Click the Next button to continue.

IMPORTANT: Before you proceed, you have to have at least initial values for Kc and Ti(min) that allow the controller to go above and below setpoint. See "Tuning Controller Manually" in the LabVIEW PID Control Toolkit User Manual for more details.

Previous PID Parameters

Kc 15.22189
Ti (min) 0.002027
Td (min) 0.000282

Controller Type PID
# of cycles to avg 3
Relay amplitude 1
Control design Slow

Figure 2. Autotuning wizard

D. *System Identification*

System identification is a technique of building mathematical models of a dynamic system based on a set of measured stimulus and response data samples. And also System identification is an iterative process that includes acquiring, formatting, processing, and identifying raw data from a real-world system based on the selected mathematical model [4]. Then determine if the resulting model fits the observed system behavior. If the results are unsatisfactory, revise the parameters and iterate through the process. System identification is fundamental for communication and control engineering, and it also plays important roles in many other areas, such as meteorology and economics [4].

One of the biggest advantages of using the System Identification Toolkit is the integration with LabVIEW, NI data acquisition hardware, and NI-DAQ [5].

After acquiring and preprocessing the data from a linear time-invariant system, the next step in the system identification process is to estimate the model.

❖ *Identification methods*

It is necessary to identify a system that must operate in a closed-loop fashion under some type of feedback control. This may be due to safety reasons, an unstable plant that requires control, or the expense required to take a plant offline for test. In these cases it is necessary to perform closed-loop identification.

There are three basic approaches to closed-loop identification. These approaches are direct, indirect, and joint input-output [4].

1. The first method of interest is the **Direct Approach**. In this method, the existence of feedback is neglected and the recorded data are treated as if the system were operating in open loop, and not using the reference signal, to obtain the model. This can be used for SISO, MIMO and MISO systems.
2. The second method of interest in closed-loop identification is the **Indirect Approach**. In this method Identify the closed loop system from the reference input to output and retrieve from that the open loop system, making use of the known feedback law.
3. The last method is the **Joint Input-Output Approach**. Consider y and u as outputs of a system driven by reference signal v and noise. Recover the knowledge of the system and the regulator from this joint model.

Both the Indirect and Joint identification can be used only for SISO systems. In this paper, only information on stimulus and response signal is known hence only direct identification approach is used. In this, State space estimation method is used since it does not assume zero correlation between input signal and output noise. It is often necessary to perform identification under closed-loop conditions to increase safety or reduce the costs of the modeling. The three approaches outlined in this paper provide accurate estimations of plant dynamics under feedback control using simple measurements. The LabVIEW System Identification Toolkit provides the necessary identification algorithms to aid in these closed-loop identification problems [4].

III. Experimental Setup

A. Hardware

1) Optical switch arrangement

MOC7811 is a slotted Opto isolator module, with an IR transmitter and a photodiode mounted on it. Performs Non-Contact Object Sensing. This is normally used as positional sensor switch or as Position Encoder sensors used to find position of the shaft. It consists of IR LED and Photodiode mounted facing each other. When light emitted by the IR LED is blocked because of alternating slots of the encoder disc logic level of the photo diode changes. This change in the logic level can be sensed by the microcontroller or by discrete hardware. This sensor is used to give position feedback to the robot or as Limit switches [6].

The optical switch for producing pulse for speed measurement is shown in Fig. 3.

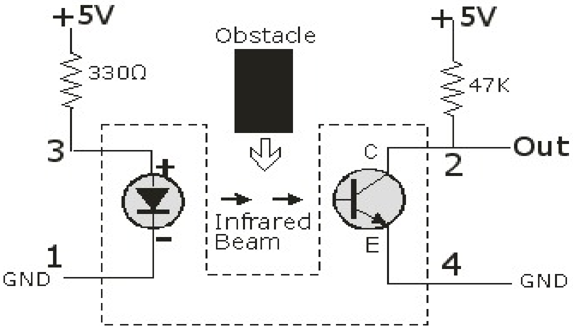


Figure 3. Optical switch circuit

2) Frequency to voltage converter

The frequency to voltage converter can be used for any application that requires measurement of a repeating event, such as a wheel making a complete rotation [6].

The LM2907 is frequency to voltage converter with a high gain op amp/comparator used for measuring the speed of the motor when the input frequency reaches or exceeds a selected rate. Input to this converter is given as pulses which are produced from the optical switch. LM2907 converts the given input pulse frequency to a proportional voltage. The circuit connection for 2907 is shown in Fig. 4.

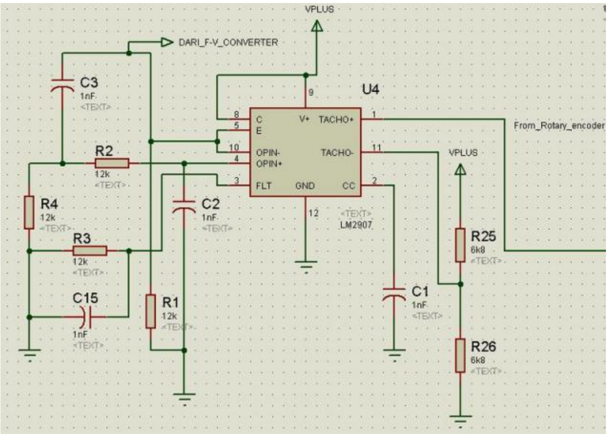


Figure 4. Frequency to voltage converter circuit

3) Motor driver circuit

The PID controller output is given as an analog signal of range 0-5V through the motor driving circuitry for driving the motor. This circuit consists of 2 stages [6].

- Voltage amplification
- Current amplification

The output obtained from the DAQ card is in the range of 0-5V to 0-12V and .To meet the voltage specification of the motor, the output voltage from the DAQ [5] needs to be amplified, which is done using IC 741. Since the output current of the IC 741 is in the range of milli Amperes, we need to amplify the current for driving the motor. This amplification is done by connecting the TIP122 NPN power transistor in common collector configuration. The property of the common collector configuration is that the voltage gain is unity and the current gain is equal to the maximum current gain of the transistor. Therefore, the current amplified output is given to the motor from the emitter junction of the TIP122. By this way, the motor can be driven properly and circuit connection is made as shown in Fig. 5.

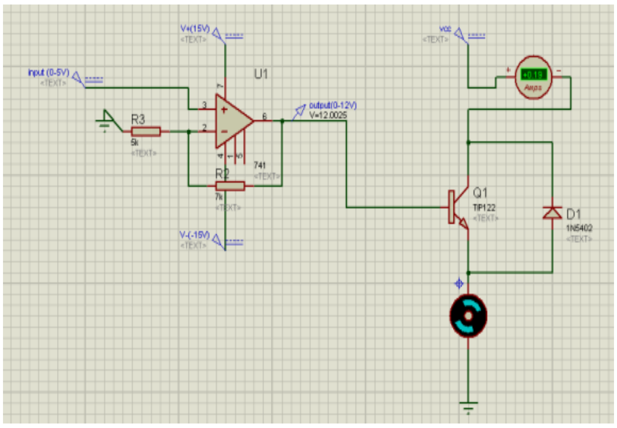


Figure 5. Voltage and current amplification circuit

B. *Software*

A LabVIEW platform is used to interface the auto tuning PID controller with the DC motor for controlling the speed of the motor through NI DAQ card USB-6008. With the use of the LabVIEW the system identification and speed controlling of the PMDC motor is performed on the same platform [5].

1) *Closed loop PID speed control*

The set up for controlling the speed of the motor is done as shown in functional block diagram of closed loop system in Fig. 6.

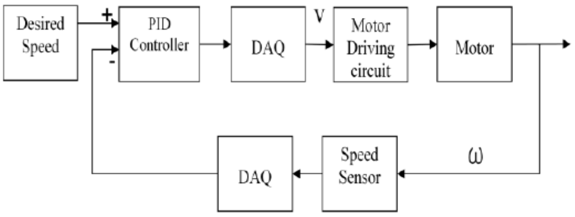


Figure 6. Functional block diagram of closed loop speed control system of DC motor

The desired speed is obtained from the user and the actual speed of the motor is received through the DAQ card from the speed measurement circuitry. The desired speed, the actual speed and the PID gains calculated from the ultimate gain method [7] are given as inputs to the PID controller which in turn produces the controller output in the range of 0-5V through the DAQ card. The PID Control Input Filter is used to filter high-frequency noise from measured values i.e., process variable values as they are measured using a DAQ device [8].

The LabVIEW block diagram of closed loop speed control system is shown in Fig. 7.

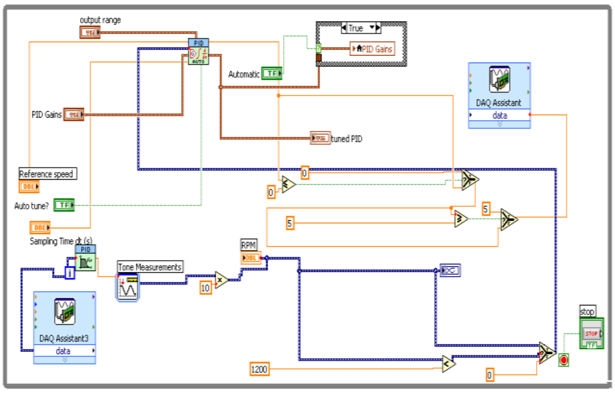


Figure 7. LabVIEW block diagram of closed loop speed control system

The tuned PID gains obtained are as follows:

Kp=15.2289 ;

Ti=0.002027 s ;

Td=0.000282 s;

The hardware setup and driver circuit are shown in Fig. 8 and Fig. 9 respectively.

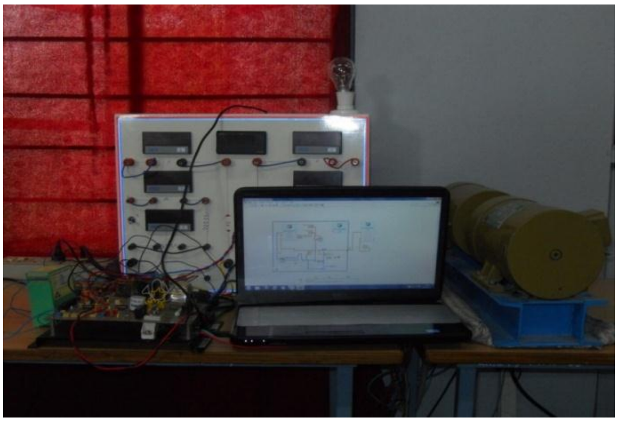


Figure 8. Hardware setup

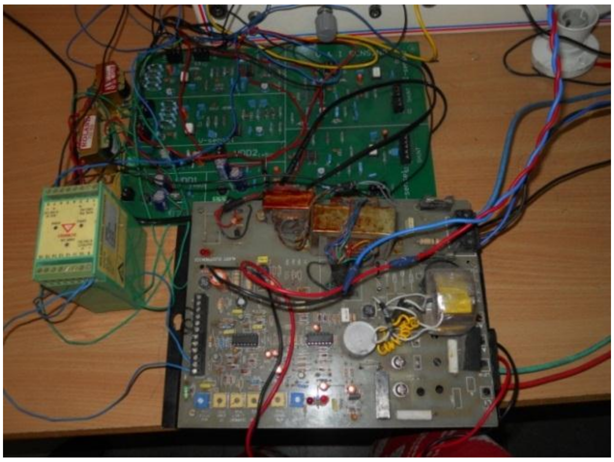
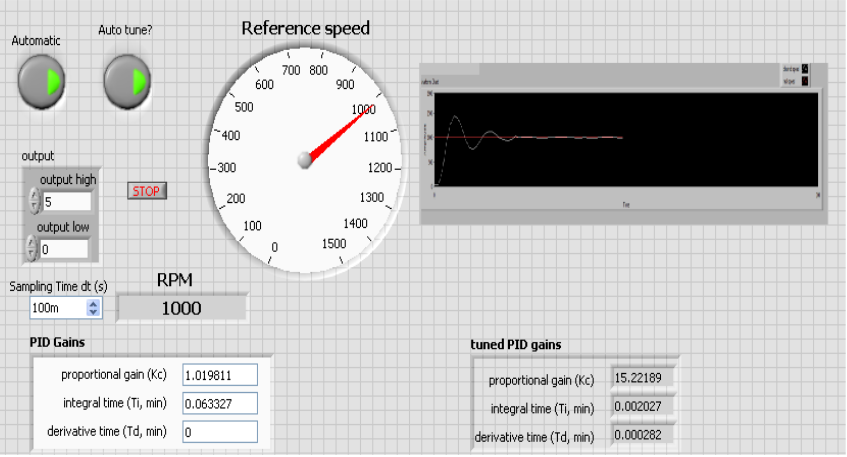


Figure 9. Driver circuitary

The result with the front panel is as shown in Fig. 10.


Automatic

Auto tune?

output

output high 5

output low 0

STOP

Sampling Time dt (s) 100m

RPM 1000

PID Gains

proportional gain (Kc) 1.019811

integral time (Ti, min) 0.063327

derivative time (Td, min) 0

tuned PID gains

proportional gain (Kc) 15.22189

integral time (Ti, min) 0.002027

derivative time (Td, min) 0.000282

Figure 10. Output shown in LabVIEW front panel

2) System identification

System identification [7] procedure is used to identify the model of the closed loop speed control system. Since the parameters of the PMDC motor and the system is unknown, we perform the subspace system identification method. This procedure includes 3 steps. They are

- Data logging
- Model estimation
- Model validation

Procedure is as follows [4]:

i. From the speed control system, the actual speed (i.e.) the input (u) and the desired speed (i.e) output (y) are logged into the measurement file.

ii. From the measurement file, the input and the output are extracted. These extracted data are given to the split signal block for splitting the data into user defined proportions.

iii. The first proportion of data is given to the state space estimation.vi and the output will be the state space model of the system. This completes the model estimation stage.

iv. The identified model and is given as the input to the model simulation.vi, the output of the simulation and the real-time logged data are compared in waveform graphs.

v. By changing the user defined order, the optimum model can be obtained and model validation is done.

System identification block diagram is shown in Fig. 11.

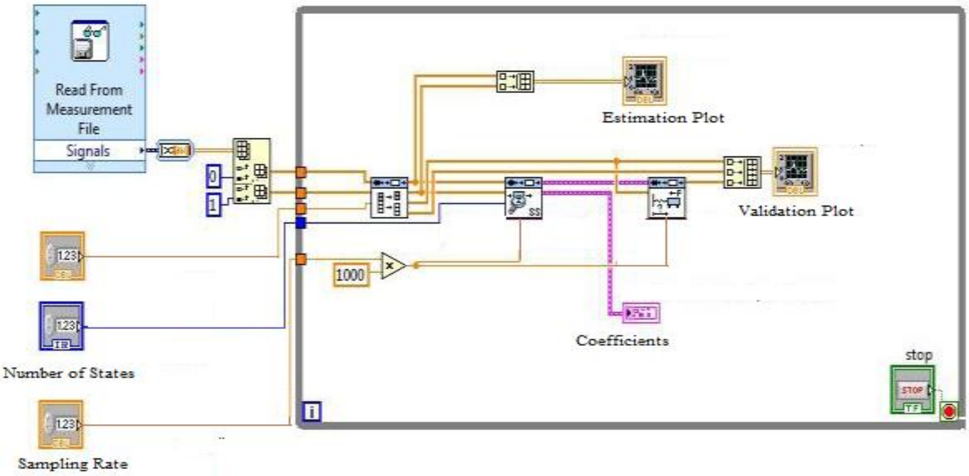


Figure 11. LabVIEW block diagram of system identification

The output state space model determined from the system identification procedure is as follows:

$$A = \begin{bmatrix} -0.894 & -0.0584 \\ 1 & 0 \end{bmatrix} \;;\; B = \begin{bmatrix} 1 \\ 0 \end{bmatrix};$$
$$C = [0 \quad 0.1596] \;;\; D = [0]$$

The simulation output is as shown in Fig. 12. The comparision is made between the desired speed and output speed.

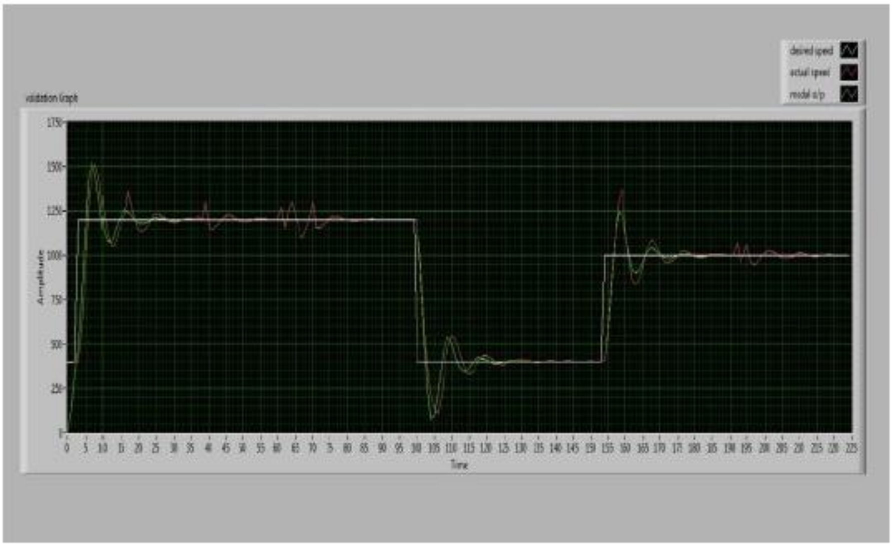


Figure 12. Model Simulation Output

IV. Conclusions

In this paper an auto tuning PID controller is designed for controlling the speed of the PMDC motor using LabVIEW. The closed loop system is identified to determine the initial parameters of the PID. From the simulation result with LabView both in command following control and disturbance rejection control, it was found that PID controller could control plants that consist of the first order delay and the integrator element. The system's response shows the fast rise time, fast setting time as well as fast recovering time.

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