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A Real Time IMC Tuned PID Controller for DC Motor

M. Saranya, D. Pamela

***Abstract**: This paper presents a Internal Model Control(IMC) tuned PID controller method for the DC motor for robust operation. IMC is a process model approach to design the PID controller parameter to obtain the optimal setpoint tracking and load disturbance rejection. This method of control which is based on the accurate model of the process, leads to the design of a control system that is stable and robust. The results of the IMC tuning method when compared with the Ziegler Nichols (ZN) closed loop tuning provides a commendable improvement in the overshoot, rise time and settling time of the system. Simulated results in LabVIEW and Matlab using the PID and IMC are presented and also the same has been implemented and tested for a 12volt DC motor.*

***Keywords**: Controller; DC motor speed control system; Internal Model Control; Z-N Tuning.*

I. INTRODUCTION

Electric motor converts electrical energy into the mechanical motion and are broadly classified into two different categories: DC (Direct Current) motor and AC (Alternating Current) motor. DC motors are widely used in industrial system, such as robotic manipulators, because their control is relatively simple and they are reliable for a wide range of operating conditions. DC motors are usually modeled as linear systems and then linear control approaches are implemented. However, most linear controllers have unsatisfactory performance due to the changes of motor-load dynamics and due to nonlinearities introduced by the armature reaction. Neglecting the impact of external disturbances and of nonlinearities may risk the stability of the closed loop system. For this reason, the DC motor control using the conventional PID controllers are inadequate and more effective control approaches are needed. Hence, IMC (Internal Model Control) controller has been used to overcome this Difficulties. The IMC controller is used because, for practical applications or an actual process in industries PID controller is simple and robust to handle the model inaccuracies. Hence IMC tuned PID controller provides a clear tradeoff between closed loop performance and robustness to model inaccuracies with a single tuning parameter. The IMC controller allows good tracking ability and good load disturbance rejection. For many process control applications, disturbance rejection is much more important than setpoint tracking hence IMC controller that emphasizes disturbance rejection rather than setpoint tracking can be implemented. But the sophisticated part of IMC controller design relys on the order of the model, performance requirements of the system and the optimum filter has to be designed. The controller should work for the filter tuning parameter to achieve the desired response.

Here, the test system with conventional PID controller tuned by Ziegler Nichols method is compared with the IMC tuned PID controller. The results with IMC tuned controller has been found to outperform the Ziegler Nichols tuned PID controllers.

The paper is organized as follows, a simple mathematical model of DC motor in section II. The IMC-PID controller is explained in section III. Simulation and results are given in section IV. Hardware implementation in section V. Conclusions in section VI.

II.MATHEMATICAL MODELLING OF A DC MOTOR

A simple model of DC motor is shown in Fig.1.

Let, Ra-Resistance of the armature(Ω).

Va- Armature voltage(V).

Eb-Back emf(V).

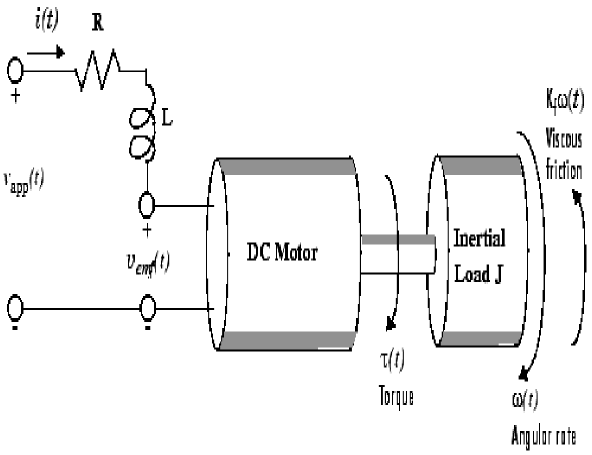

Fig 1.A simple of DC motor driving inertial load

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f0-viscous friction.

J- Moment of inertia(Kgm^2).

Ia - Armature current(A).

La- Inductance of the armature(H).

T-Torque developed(Nm).

Kb-Back emf constant(V/rad/sec)

Kt-torque constant(Nm/A)

Kf-viscous coefficient(Nm/rad/sec)

The back emf is proportional to angular displacement and is given by,

$$Eb = Kb\omega(s) \tag{1}$$

The difference equation of armature is,

$$\mathbf{L\frac{dIa}{dt} + RaIa + Eb = Va}$$

By taking laplace transform of the above equation,it gives

$$\mathbf{LsIa(s) + RaIa(s) + Eb(s) = Va(s)} \tag{2}$$

Torque equation is,

$$\mathbf{J\frac{d\omega}{dt} = -Kf\omega + KtIa}$$

The laplace transform of the above equation is

$$\mathbf{Js\omega(s) = -Kf\omega(s) + KtIa(s)} \tag{3}$$

From Equ(2),

$$Ia(s) = \frac{\mathbf{Va(s)-Eb(s)}}{\mathbf{(Ls+Ra(s))}} \tag{4}$$

From Equ(3),

$$\omega(s) = \frac{\mathbf{KtIa(s)}}{\mathbf{Js+Kf}} \tag{5}$$

Substitute (4) in (5)

$$\omega(s) = \frac{\mathbf{Kt}}{\mathbf{(Js+Kf)}} \frac{\mathbf{(Va(s)-Kbs)}}{\mathbf{(Ls+Ra(s))+KbKt}} \tag{6}$$

On solving the equ(6) gives

$$\frac{\boldsymbol{\omega}\mathbf{(s)}}{\mathbf{V(s)}} = \frac{\mathbf{Kt}}{\mathbf{(Ra+sLa)(Js+f0)+(KbKt)}} \tag{7}$$

Equ(7) gives the transfer function of the DC motor.

III. IMC TUNED PID CONTROLLER

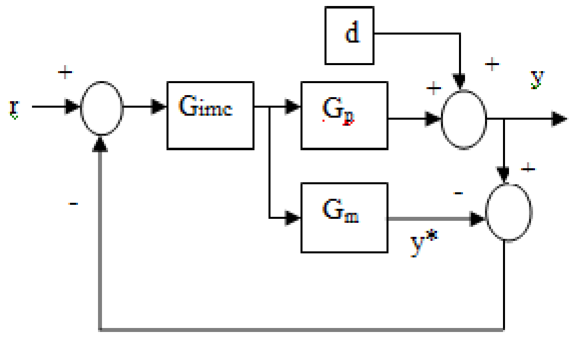

Fig 2.Basic structure of IMC controller

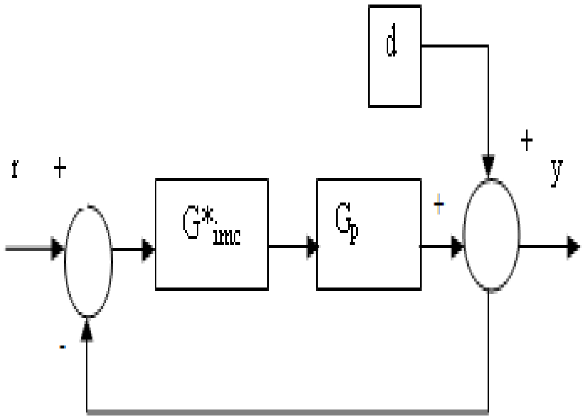

Fig 3.Structure equivalent to conventional control.

The typical internal model controller structure is given in Fig. 2. Where G_p is the actual process to be controlled, G_m refer to the model of the process, and G_{imc} is the IMC controller, *r*, *y* and *y** refer to the input, output of the actual process and the output of the model of the process. *d* is the disturbance of the system.Fig.2 has been rearranged and by replacing the inner loop with a single block gives the structure as shown in Fig.3 The process model G_m is separated into two terms as,

$$G_m = G_{ma}G_{mm} \tag{8}$$

where,G_{ma} is a transfer function of an all pass filter and G_{mm} is a transfer function that has minimum phase characteristics.For a step change in disturbance G_{imc} is determined by,

$$G_{imc} = 1/G_{mm} \tag{9}$$

To obtain a practical IMC controller,G_{imc} is multiplied by a transfer function of the filter,f(s).The simplest form of the filter is given by

$$f(s) = \frac{1}{(\lambda s+1)^n} \tag{10}$$

where λ is the filter parameter

n is the integer.

The practical IMC controller can be expressed as

$$G_{imc} = \frac{f(s)}{Gmm} \tag{11}$$

IV. SIMULATION AND RESULTS

A standard 12V DC motor was modeled and simulated using Matlab and LabVIEW.The simulated results of the DC motor control with ZN tuning and IMC based PID tuning was analysed.Fig.4 shows the block diagram of DC motor driving an inertial load.

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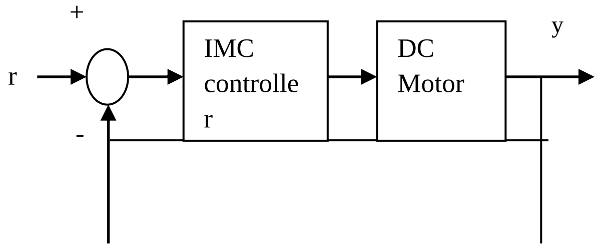


Fig 4.Block diagram of DC motor speed control system.

The DC Motor specification:

- Rated voltage:12volt
- Rated current:1.5A
- Rated speed:1500rpm.
-

The DC motor parameters obtained through experiments are

R= 8.8 Ω
L=3.005mH
K_b = 0.0777 V.sec/rad
K_t = 0.0777 Nm/A
J = 0.000132 kg.m^2.

The transfer function of the DC motor is obtained by substituting these values in equ (7) and is given as

$$G(s) = \frac{\omega(s)}{v(s)} = \frac{0.0777}{0.000000397s^2+0.001162s+0.00649}$$

A.Ziegler-Nichols based tuning

To achieve such a system of speed controller PID system, the Fig.4 is simulated in Matlab simulink and LabVIEW.The gain values of the PID controller are calculated using the Ziegler Nichols tuning formula.The response are shown below.

B. Internal Model Control (IMC) based tuning

The IMC controller is designed by approximating the model for the process and multiplying the model with the filter transfer function. The λ and n values of the filter are chosen by trial and error method for the equ(10).It is clear from the response that using IMC tuned PID controller the overshoot is reduced to a greater extent when compared to the PID controller.

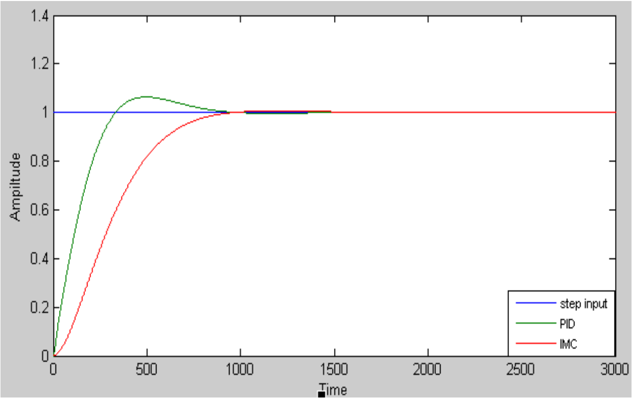


Fig.5.Response of IMC compared with PID controller in Matlab simulation.

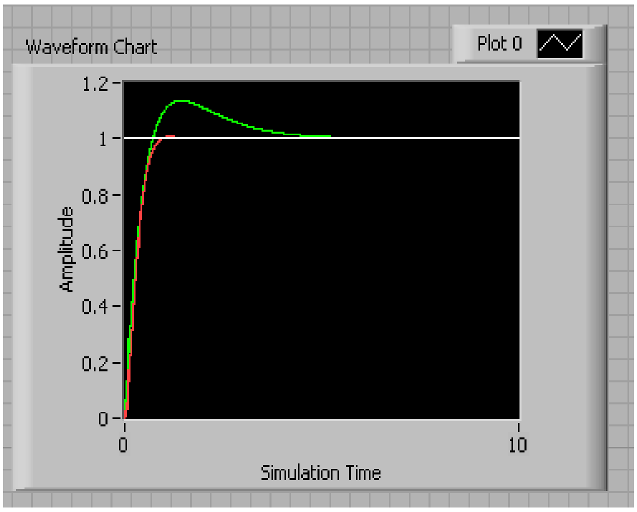


Fig.6.Response for IMC compared with Ziegler Nichols tuned PID in LabVIEW simulation

TABLE I Comparison of PID with IMC controller

Parameter	PID	IMC
Overshoot	High	Less
Rise time	2.4s	0.9s
Settling time	4.8s	1.8s

V.HARDWARE IMPLEMENTATION

This designed controllers are implemented in real time for 12volt,1500rpm,1.5A DC motor. The motor is interfaced through DAQ card to LAbVIEW and was thus controlled.The hardware components used are as follows.

A.Encoder

Optical encoders are devices that convert a mechanical position into a representative electrical signal by means of a patterned disk or scale, a light source and photosensitive elements. With proper interface electronics, position and speed information can be derived. Encoders can be classified as rotary or linear for measurements of respectively angular and linear displacements. Rotary encoders are available as housed units with shaft and ball-bearings or as "modular" encoders which are usually mounted on a host shaft (e.g. at the end of a motor).

B.Speed sensor

The sensor is always ON, meaning that the IR led is constantly emitting light.This design of the circuit is suitable for counting objects, or counting revolutions of a rotating object, that may be of the order of 15,000 rpm or much more. However this design is more power consuming and is not optimized for high ranges.In this design,the distance range can be from 1 to 10 cm, depending on the ambient light conditions.

The sender is composed of an IR LED (D2) in series with a 470 Ohm resistor, yielding a forward current of 7.5mA.The receiver part is more complicated, the two resistors R5 and R6 form a voltage divider which provides 2.5V at the anode of the IR LED.When IR light falls on the LED (D1), the voltage drop increases, the cathode's voltage of D1 may go as low as 1.4V or more, depending on the light intensity. This voltage drop can be detected using an Op-Amp (operational Amplifier LM358).Adjust the variable resistor (POT),R8 so that the voltage at the positive input of the Op-Amp (pin No. 5) would be somewhere near 1.6 Volt.The output will go HIGH when the volt at the cathode of D1 drops under 1.6V. So the output will be HIGH when IR light is detected, which is the purpose of the receiver.

C.Driver circuit

The circuit is built around an LM324 low power quad-operational amplifier. Of the four op-amps available, two are used for triangle wave generator and one for comparator. Op-amp N2 generates a 1.6KHz square wave, while op-amp N1 is configured as an integrator. The square wave output of N2 at its pin 14 is fed to the inverting input (pin 2) of N1 through R1. As N1 is configured as an integrator, it outputs a triangular wave of the same frequency as the square wave. The triangular wave is fed to a scaling circuit and the output of the scaling circuit is given to pin 5 of op-amp N3, which is configured as a comparator. The triangular wave applied at pin 5 of N3 is compared with the reference voltage at its pin 6. The output at pin 7 is about +12V when the voltage at pin 5 is greater than pin 6. Similarly the output at pin 7 is about -12V when the voltage at pin 5 is lower than the voltage at pin 6. The output from comparator N3 is the gate voltage for n-channel MOSFET (T1). T1 switches on when the gate voltage is positive and switches off when the gate voltage is negative. The reference voltage output which comes from DAQ therefore controls the pulse width of the motor. When T1 is switched on for a longer period, the pulse width will be wider, which means more average DC component and faster speed of the motor. Speed will be low when pulse width is small.

D.Scaling circuit

The scaling circuit consists of a potential divider circuit and a clamping circuit. The potential divider circuit is designed in such a way that it reduces the amplitude of the triangular wave. Output of this section is given to a clamping circuit which clamps the triangular wave positively at +0.6V. The output of clamping circuit is given to the drive circuit.

The hardware setup is shown below

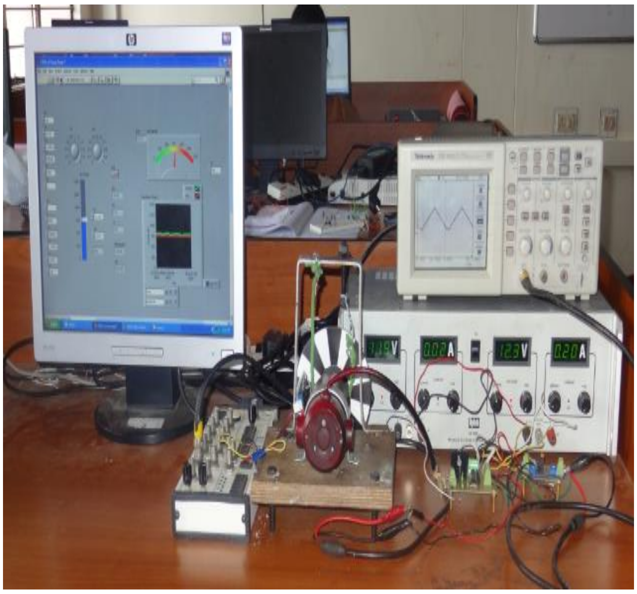
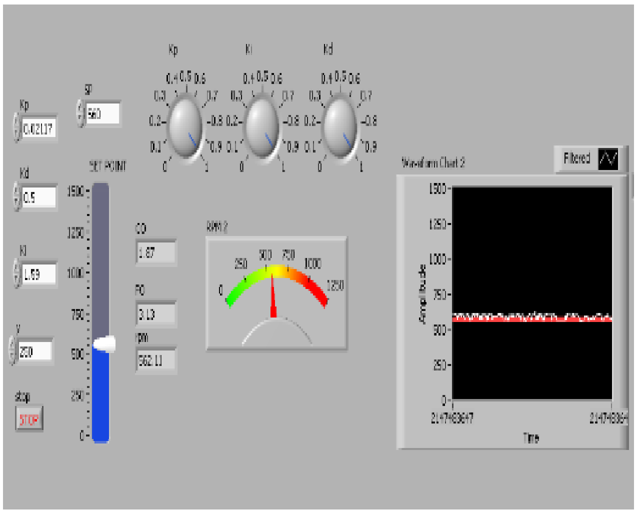
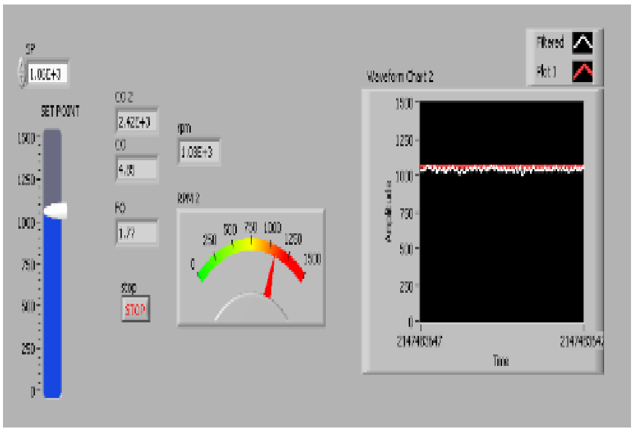


Fig.7.Hardware arrangement



Kp 0.02117
SP 560
Kd 0.5
Ki 1.59
y 250
CO 1.87
PO 3.13
rpm 562.11

Fig.8.Response of the system for PID controller



SP 1.00E+3
CO 2 2.42E+3
CO 4.05
PO 1.77
rpm 1.08E+3

Fig.9. Response of the system for IMC controller

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VI. CONCLUSIONS

A Robust IMC tuned PID controller was designed and implemented in real timefor a 12V DC motor.IT is observed from the response that the IMC tuned PID controller show a better performance in overshoot,rise time and settling time and thus proving its robustness.

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