New Tuning Technique of the PID Controller for Speed Control of a DC Servomotor

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***Abstract* - The problem associated with tuning techniques of the PID controller is considered in this paper. Many tuning methods such as Ziegler-Nichols, Cohen-Coon, and Lambda have been proposed to tune the gains of PID controllers, but being trial and error method they are time-consuming and cannot be implemented online. In this paper, a PID controller was tuned using estimated parameters of moment of inertia and friction coefficient of a DC servomotor under dynamic load variation. Several simulations were run to evaluate the performance of the system. The comparative analysis between parameter estimation based PID controller and Ziegler-Nichols based PID controller shows that, the Parameter Estimation based PID controller rises faster and settles quicker. For instance, rise time and settling time of the Parameter Estimation based PID controller are 0.3s and 0.6s respectively, while the rise time and settling time of the Ziegler-Nichols based PID controller are 1.2s and 2s respectively with desired speed of 4000rpm under 0.5Nm load torque. Robustness to load changes and disturbance were achieved together with fast error convergences when compared with Ziegler Nichols based PID controller.**

***Keywords*: Derivative gain, friction coefficient, moment of inertia, PID controller, proportional gain, servomotor**

I. INTRODUCTION

A servomotor is a rotary or linear actuator that consists of a suitable motor, gear arrangement and sensor circuit [1]. DC servomotors are characterized by high torque, low inertia, and good linearity [2]. They are found in many applications including; Industrial robot manipulators [3], Camera Auto Focus, Solar Tracking Systems, Conveyor Belts, Metal Cutting and Metal Forming, Antenna Positioning and Automatic Door Openers and so on [4]. In fact, under good control effort, these motors exhibit accurate speed and position control [5]. Several control methods have been used to achieve the speed or position control of servomotors, such techniques are Fuzzy logic and Neural Network are approaches that are gaining interest in both the academic world and industrial fields. Fuzzy logic has the capability of mimicking human mind [6] and it is well known as universal system approximator. Designing Fuzzy logic however, requires expert knowledge of the process [7]. Thus, it is associated with knowledge bottle neck. Neural Network on the other hand adds learning capability to systems[8] but the training phase usually consumes a lot of time [9]. Another controller such as Variable Structure Control (VSC) is applied to speed or position control. This method provides systematic approach to maintain desired performance specification in the face of uncertainties and disturbances caused by load changes. One major drawback in the Sliding mode approach however, is undesired phenomenon of chattering due to high frequency switching of control signal, which will often excite undesired dynamics, leading in practice to unwanted oscillations that can result in low control accuracy and high heat loss in electric power circuit. Moreover, its insensitivity to parameter variation has a limit [10]. PID controller is the most widely used of all due to its simplicity, ease of understanding and efficiency. PID controller has demonstrated acceptable performance in several systems so long as the system parameters do not vary beyond its operating conditions. Load disturbances can cause variations in system parameters and degrade PID performance unless its gains are retuned. Many tuning methods/algorithms such as Ziegler-Nichols, Cohen-Coon, and Lambda [11] have been proposed to tune the gains of PID controllers, but being trial and error method they are time-consuming [12] and cannot be implemented online. Therefore, the needs for a simple and efficient tuning mechanism that is less time-consuming and can be implemented online still remain in the literature. The performance of controller depends largely on how accurate its parameters are tuned. Several tuning techniques have evolved over the years with the sole aim of improving controller performance. For instance; [13] developed a scheme to control the speed of DC motor with time delay using LQR-PID controller. The state weighting matrices of the LQR are used for finding the set of optimal PID gains. The comparisons were made with the previously developed method and the results show that LQR-PID controller gives more close to the desired damping ratio and natural frequency. However, increasing the value of the time delay, the closed loop system becomes more oscillatory and finally leads to instability. Furthermore, [14] controlled Quadrator UAV using a Fuzzy system for tuning PID controller gains in hovering mode. Simulation, analyses and performance comparison have been made between the proposed controller and classical PID controller. The results indicate that the self-tuning PID controller performed better than the classical PID controller. However, the selection of the membership functions and the rules of the Fuzzy logic controller are based on the experience of the designer and furthermore, using a few trial and error approach. In 2017, [15] tuned the fuzzy logic controller parameters using kalman algorithm for conical tank system. The kalman algorithm which employs fuzzy logic rules and adjusted the controller parameters automatically during the operation process of the system and the controller used to reduce the error in noisy environments. The results obtained show that the technique displayed acceptable performance when compared with Fuzzy logic controller and PID controller. However, the method used consumed a lot of time due to the iterative nature of kalman filter algorithm. Moreover, [16] estimated the parameters of permanent magnetic DC motor and tuned the PI controller from the estimated parameters using differential evolution. The result presented a good dynamic response with a minimum error for speed control. However, the estimation was not performed in real-time because temperature or magnetic variation may affect real-time parameter estimation. It was, therefore, estimated only in no-load or short time (2 sec). In this paper, a suitable parameter update mechanism based on the relationship between servomotor parameters and PID controller gains will be developed and used to update the PID parameters online. The Performance of the tuned PID controller will be analyzed and compared against those of other PID controller that are tuned using Ziegler Nichols methods.

II. SYSTEM DESCRIPTION

The System Comprises of a PID controller, DC servomotor, load arrangement, Parameter estimator, PID Tuner (gain scheduler) as shown in fig.(3.1). The PID controller controls the speed of the motor, while the estimator determines some parameters of the DC servomotor such as friction coefficient (B) and moment of inertia (J) that vary with load, and the PID tuner computes and schedules the new gains (proportional gain-K_p, integral gain-K_i and derivative gain-K_d) of the PID controller based on the estimated parameters for the proper speed control of the motor. The model equations of the Servomotor and PID controller are shown in (1) and (2) respectively.

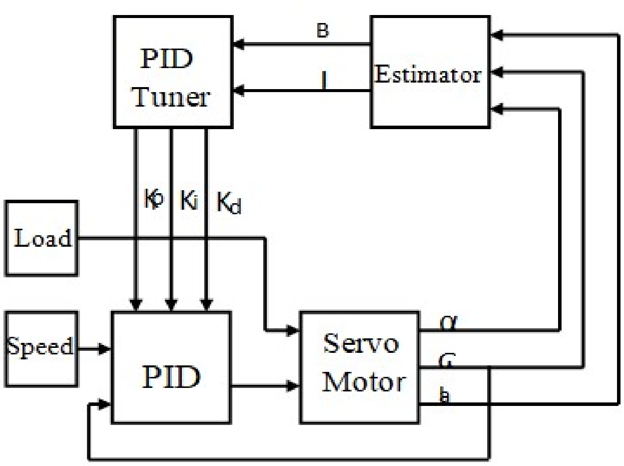

Fig. 3.1 Block Diagram of a DC Servomotor Speed Control System

III. CONTROLLER TUNING AND ONLINE UPDATING

The PID controller tuning algorithm was developed using (3), (4) and (5), they are derived relationship between the dc servomotor parameters and the PID controller gains which will applied in tuning the gains of the controller online.

$$\frac{\omega(s)}{V(s)} = \frac{K_T}{[(Js+B)(R_a+sL_a)+k_bK_f]} \qquad 1$$

Where;

K_T is torque constant

R_a is armature resistance

L_a is armature inductance

J is moment of inertia

B is friction coefficient

K_b is back emf constant

$$u(t) = K_p\left\{e(t) + \frac{1}{T_i}\int_0^t e(\tau)\,d\tau + T_d\frac{d\,e(t)}{dt}\right\} \qquad 2$$

Where:

K_p is proportional gain

T_i is integral time constant

T_d is derivative time constant

e(t) is error

$$\Delta K_p = \frac{B\,\omega(S)}{E(s)} \qquad 3$$

$$\Delta K_i = 0 \qquad 4$$

$$\Delta K_d = \frac{J\,\omega(S)}{E(s)} \qquad 5$$

The PID controller uses (6), (7) and (8) for its online updating scheme:

$$K_p = K_{p\,(int)} + \Delta K_p \qquad 6$$

$$K_i = K_{i\,(int)} + \Delta K_i \qquad 7$$

$$K_d = K_{d\,(int)} + \Delta K_d \qquad 8$$

IV. SIMULATION RESULTS AND DISCUSSIONS

So many simulations were run to evaluate the performance of the system. The results obtained shows that, the change in Proportional gain of the PID controller is directly proportional to the friction coefficient of the motor as illustrated in fig. 1. The graph clearly shows that the higher the friction coefficient of the motor, the higher the Proportional gain needed to maintain acceptable performance of the system. Also, fig.2 shows that, the change in derivative gain of the PID controller varies linearly with the moment of inertia of the motor; this graph illustrated that the higher the moment of inertia of the motor, the higher the change in derivative gain of the PID controller needed to maintain acceptable performance of the system. Moreover, the performance of the parameter estimation based PID controller was analysed and compared to that of Ziegler Nichols based PID controller for DC servomotor speed control on the desired speeds of 4000rpm and 3000rpm, with load torque of 0.5Nm. Fig. 3 and fig. 4 show that the PID controller tuned using estimated parameters rises faster and settles quicker than the Ziegler Nichols tuned PID controller (The parameters of interest in this analysis are: Rise time (t_{r1}) and settling time (t_{s1}). The subscripts 1 and 2 indicate parameter estimation based PID controller and Ziegler Nichols based PID controller respectively). Furthermore, the speed of error convergence of the tuned PID controller using estimated parameters is analysed and compare to that other PID controller tuned using Ziegler Nichols method. Fig. 5 and fig. 6 show that the error converges faster (with desired speed of 4000rpm and 3000rpm under 0.5Nm load torque) under the tuned PID controller using estimated parameters.

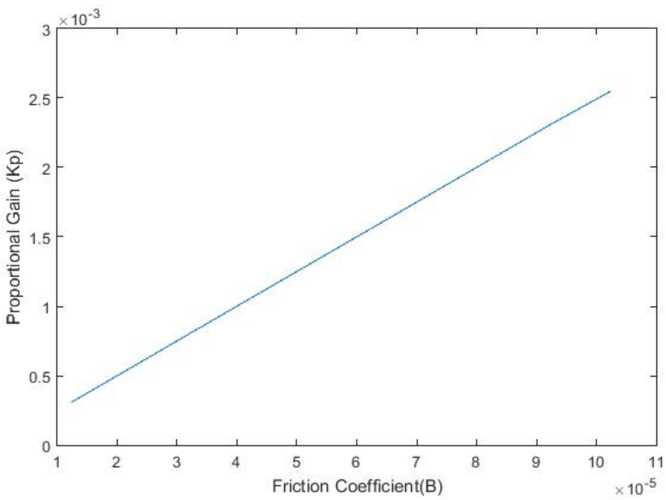

Fig.1 Proportional gain against Friction Coefficient

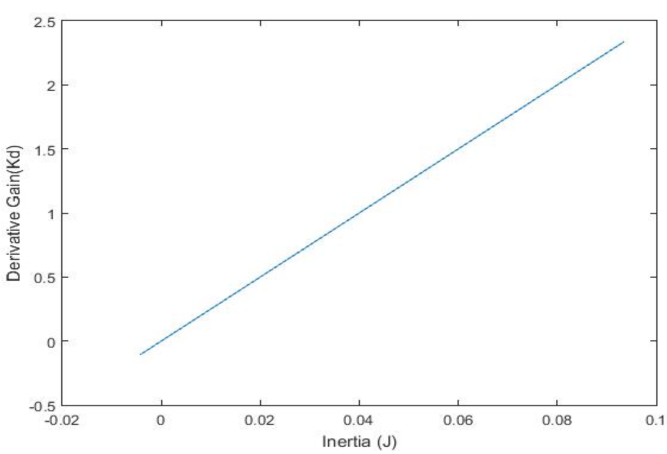

Fig. 2 Derivative gain against Moment of Inertia

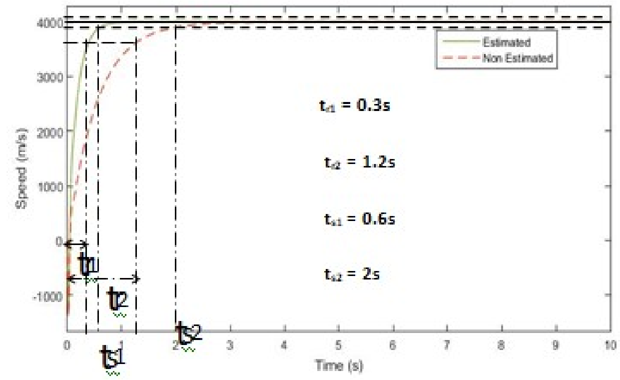

Fig.3 Responses of both controllers with desired speed of 4000rpm under 0.5Nm load torque

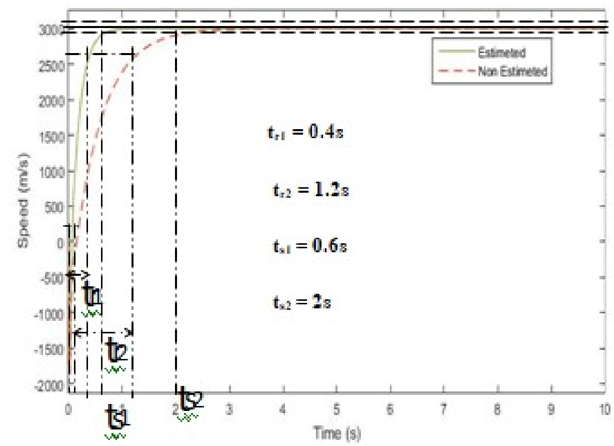

Fig.4 Responses of both controllers with desired speed of 3000rpm under 0.5Nm load torque

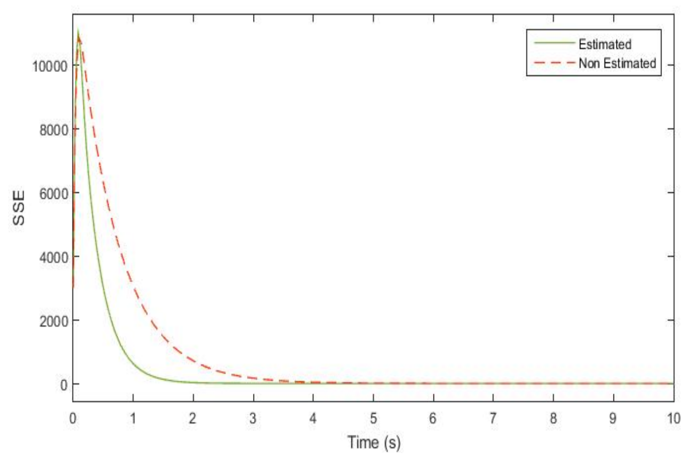

Fig.5 Steady state Error of both controllers with desired speed of 4000rpm under 0.5Nm torque

V. CONCLUSIONS

The desired performance specification of the system was achieved using parameter estimation based PID controller. The PID parameter updating mechanism accurately schedules the gains of the controller accordingly. Strong robustness to uncertainties and external load disturbances is achieved. When compared with other PID controller tuned using Ziegler Nichols method, the parameter estimation based PID controller rises faster and settles quicker. Additionally, the convergence analysis shows that, the error converges faster under the PID controller tuned using estimated parameters than that of the PID controller tuned using Ziegler Nichols method.

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