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THEORETICAL AND EXPERIMENTAL INVESTIGATION OF DC SERVO-MOTOR

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ABSTRACT

In this paper the proportional integral derivative (PID) controller is designed and used to control the DC servo motor. The PID parameters are optimized by the trial and error method. The controller is verified on the loaded DC servo motor by SIMULINK program. The controller SIMULINK model is verified experimentally. Acceptable agreement is obtained between theoretical and experimental results. Simulation and experimental results verify the effectiveness of the PID controller of the DC servo motor.

Keywords—DC Servo Motor, Proportional-Integral- derivative, Ziegler-Nichols method, Particle swarm optimization

1.INTRODUCTION

Electric motors can be classified by their functions as servomotors, gear motors, and so forth, and by their electrical configurations as (direct current) DC and (alternating current) AC motors. A further classification can be made as single phase and poly phone with synchronous and induction motors in terms of their operating principles for AC motors, and permanent magnet (PM) and shunt DC motors for DC's.

Although DC motors are preferred dominantly in the variable speed applications, increasing use of AC motors can be seen prior to improvements in solid state components. Servomotor is a motor use for position or speed control in closed loop control systems. The requirement from a servomotor is to turn over a wide range of speeds and also to perform position and speed instructions given DC and AC servomotors applications are seen by considering their machine structure in general [1].

DC servo motors have been used generally at the computers, numeric control machines, industrial equipment, weapon industry, speed control of alternators, control mechanism of full automatic regulators as the first starter, optimal design of nonlinear profile for jumping robot.[2], automatic solar tracker robot [3], starting systems quickly and Correctly[4].

In the field of control of mechanical linkages and robots, research works are mostly found on DC motors. While some properties of DC servo motors are the same, like inertia, physical structure, shaft resonance and shaft characteristics, their electrical and physical constants are variable.

The velocity and position tolerance of servo motors which are used at the control systems are nearly the same. So they must be controlled according to the control system needs.

For this aim; it has implemented proportional–integral–derivative PID and fuzzy logic system respectively to the simulation model, which has prepared at the Simulink /Matlab software package for improvement the servo motor performance [4].

Utilizing the sampling frequency affect the performance of a direct neural controller (DNC), which is applied to a DC motor speed control system is studied in [5]. A DNC of self-tuning strategy is proposed as a speed regulator to keep the motor in constant without the specified reference model.

Reference [6] presents the design of a robust optimal control system for a DC servo motor. The design procedure is done via a linear convex combination of all

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controllers minimizing mixed H_2 / H_∞ norm of the closed loop transfer function under parametric uncertainties and some constraints.

A neuro -fuzzy controller of the DC servo motor is designed in[7].The designed controller does not produce the overshoot such as PID controller, does not produce steady state error of fuzzy logic controller, and shortened about 10% of settling time.

A fuzzy logic controller applied for control the position of dc servo motor is presented in[8]The position of the angle location is limited at $-\pi$ to π radian. The results of experiment on the real plant demonstrate that the proposed fuzzy logic controller is able to sensitivity to variation of the reference position attention. Comparing the time specification performance between conventional controller
and fuzzy Logic controller in position control system of a DC motor is presented in [9].

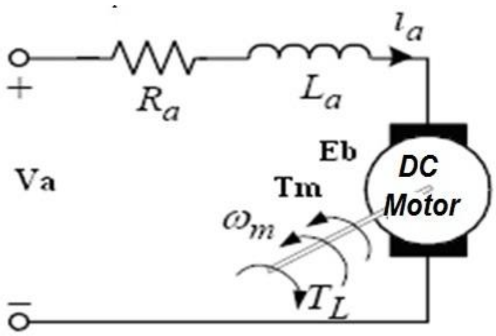
Two types of controller namely PID and fuzzy logic PID controller used to control the output response.3.Methods of genetic algorithm (GA) and evolutionary programming (EP) are used in [10] to find the optimal PID control gain constants for the position of DC servo motor. Fuzzy logic control is added to fine tuning the gain constants.

The experimental and simulation results are conducted using PC-based interface. A design of a fuzzy control system to control the position of a DC motor is presented in [11]The motor was modeled and converted to a subsystem in Simulink.

First, a crisp proportional-derivative (PD) controller was designed and tuned using a Simulink block instead of conventional tuning methods such as hand-tuning or Ziegler-Nichols frequency response method. Then a fuzzy proportional-derivative (FPD) controller was designed and system responses of FPDs with different defuzzification methods were investigated. A disturbance signal was also applied to the input of the control system. FPD controller succeeded to reject the disturbance signal without further tuning of the parameters where by crisp PD controller failed.

2. Mathematical Model of DC Servo Motor:

The velocity of the DC servo motor is controlled by changing the supply voltage. According to this theory subjects 2 voltage and moment equations:



Laplace transforms of (1) and (2) are:

$$V_a(s) = R_a I_a(s) + L_a I_a(s).s + k_b.w(s) \quad (3)$$

$$K_t.I_a(S) = J_m.w(s).s + B_m.w(s) \quad (4)$$

If current is obtained from (4) and substituted in (3) we have:

$$V_a = \omega(s)\frac{1}{K_b}[L_a J_m S^2 + (R_a J_m + L_a B_m) + (R_a B_m + K_b K_t) \quad (5)$$

Then the relation between rotor shaft speed and applied armature voltage is represented by transfer function:

$$\frac{W(s)}{V_a(s)} = \frac{K_t}{L_a J_m.S^2 + (R_a.J_m + L_a.B_m).s + (R_a.B_m + K_b K_t)} \quad (6)$$

The relation between position and speed is:

$$\theta(s) = \frac{\omega(s)}{s} \quad (7)$$

Then the transfer function between shaft position and armature voltage at no-load is:

$$\frac{\theta(s)}{V_a(s)} = \frac{K_t}{[L_a J_m.S^2 + (R_a.J_m + L_a.B_m).s + (R_a.B_m + K_b K_t)]s} \quad (8)$$

Figure 2 shows the DC servo motor model built in Simulink. Motor model was converted to 2-in and 2-out subsystem. Input ports are armature voltage (Va) and load torque (T load) and the output ports are angular speed in (w) and position (Ө) [11].

Where:

V_a= armature voltage (V) ,R_a= armature resistance (Ω)
L_a= armature inductance (H) ,I_a= armature current(A)
E_b= back emf (V) ,ω =angular speed (rad/s)
T_m= motor torque (N-m) ,Ө = angular position of rotor shaft (rad) ,J_m= rotor inertia (kg-m^2)

B_m= viscous friction (N-ms/rad)

K_t= torque constant (N-m/A) ,K_b= back emf constant (vs. /rad) ,

Let us combine the upper equations together:

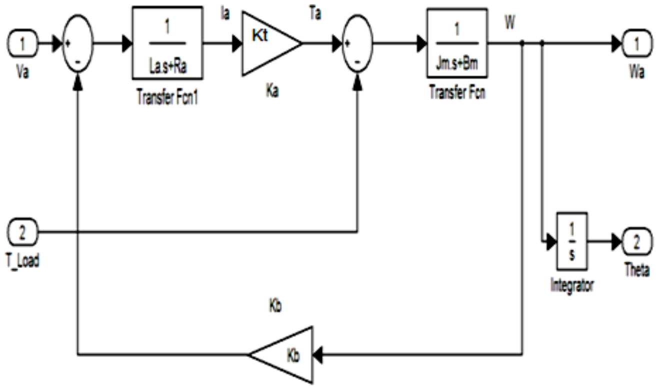


Fig 2:The DC Servo-motor Simulink Modle

3 - Basic Method of PSO:

Kennedy and Eberhart [12] developed a PSO concept the PSO is basically developed through simulation of bird flocking in two-dimensional space. The position of each agent is represented by XY axis position and also the velocity is expressed by v_x and v_y in the *x* and *y* direction respectively. Modification of the agent position is realized by the position and velocity information. Bird flocking optimizes a certain objective function. Each agent knows its best value so far (pbest), and its xy position. This information is analogous to the personal experience of each agent. Moreover, each agent knows the best value so far in the group (gbest) among the obtained pbests.

This information is analogous to knowledge of how other agents in the group have performed. Namely, each agent tries to modify its position. Position modification can be represented by the concept of velocity. The velocity of each agent can be modified by the following equation (9)

$$\mathrm{v_i}^{k+1} = \mathrm{k}\,[\mathrm{v_i}^{k} + \mathrm{v_i}^{k} + \mathrm{c_1 rand_1} * (\mathrm{pbest_i} - \mathrm{s_i}^{k}) + \mathrm{c_2 rand_2} * (\mathrm{gbest} - \mathrm{s_i}^{k})] \tag{9}$$

Where,

K= the constriction factor = $\frac{2}{\left|2-\varphi-\sqrt{\varphi^2-4\varphi}\right|}$,

and $\varphi = c_1 + c_2$, $\varphi > 4$

v_i^k: velocity of agent i at iteration k ,

c_i : weighting factor ,

$rand_i$: random number between 0 and 1,

s_i^k: current position of agent i at iteration k ,

$pbest_i$:pbest of agent i ,

gbest : gbest of the group.

current position (searching point in the solution space) can be modified by the following equation:

$$s_i^{k+1} = s_i^k + v_i^{k+1} \tag{10}$$

4. Performance Evaluation

In order to provide the efficiency of the proposed PID-based PSO controller, it is evaluated through a comparison of its response with that of the PID-based signal constrained block, which introduced in[11].

4.1. PID-based Signal Constrained block

PID Control (proportional-integral-derivative) is by far the widest type of automatic control used in industry. Even though it has a relatively simple algorithm/structure, there are many subtle variations in how it is applied in industry. A proportional integral derivative controller (PID controller) is a generic control loop feedback mechanism widely used in industrial control systems.

A PID controller will correct the error between the output and the desired input or set point by calculating and give an output of correction that will adjust the process accordingly. A PID controller has the general form

$$u(t) = k_p e(t) + k_i \int_0^t e(t)dt + k_d \frac{de}{dt} \tag{11}$$

Where K p is proportional gain, K i is the integral gain, and K d is the derivative gain. The PID controller calculation (algorithm) involves three separate parameters; the Proportional, the Integral and Derivative values.

The Proportional value determines the reaction to the current error, the Integral determines the reaction based on the sum of recent errors and the Derivative determines the reaction to the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, the power supply of a heating element or DC motor speed and position [2].

Designing The PID Controller for the Estimated Model the PID controller in a closed loop control system is shown below

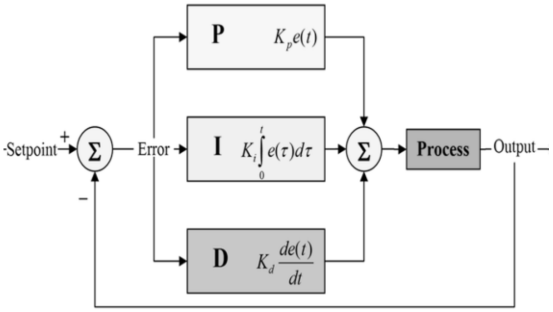


Fig. 3:. PID control system.

Controller parameters were tuned using Signal Constraint block of Simulink Response Optimization Toolbox instead of conventional methods.

Performance criteria were specified as:
Rise time $(t_r) \le 1s$
Settling time $(t) \le 2s$
Maximum overshoot $(M_p) \le 10\%$,
Steady state error $(e) \le 1\%$

The objective in control system design is to find a control signal that satisfies the performance requirements.

The obtained PID gains are as follows:
$k_p = 5.065$, $k_I = 9.586$, $K_D = 0.338$

5. Simulation Results

The simulation results PID controllers are widely used in industrial control applications due to their simple structures, comprehensible control algorithms and low costs. Fig.4 shows the schematic model of a control system with a PID controller.

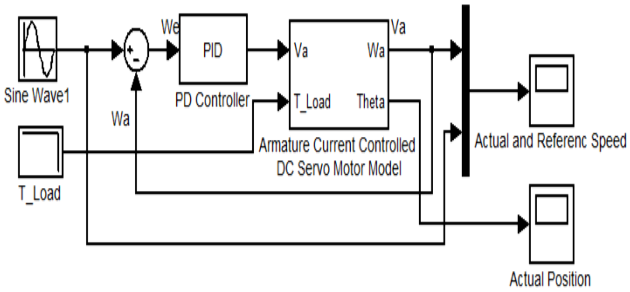


Fig 4: DC Servo Motor Simulink Model with PID Control

Fig. 5 illustrates the shape of the DC servo motor actual speed and the reference speed, in case of no load. Certainly the actual speed is low than the reference speed .

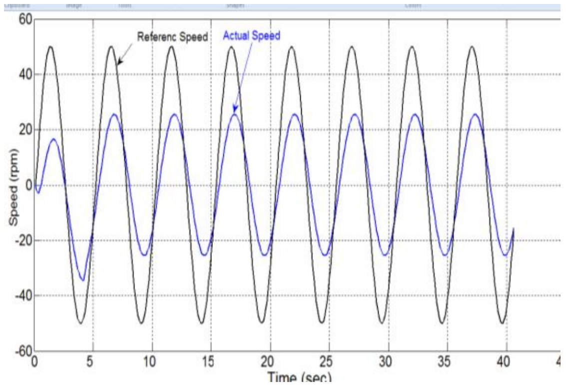


Fig.5 Actual and Reference Speed Controlled DC Servo Motor Model at no load

Fig.6 shows the speed curve of the DC servo motor actual speed and reference speed. At no load, the PID controller is applied in atrial to enhance the actual speed curve. Thais overshot is completely vanished due to PID implementation and the actual speed is almost similar to the reference speed.

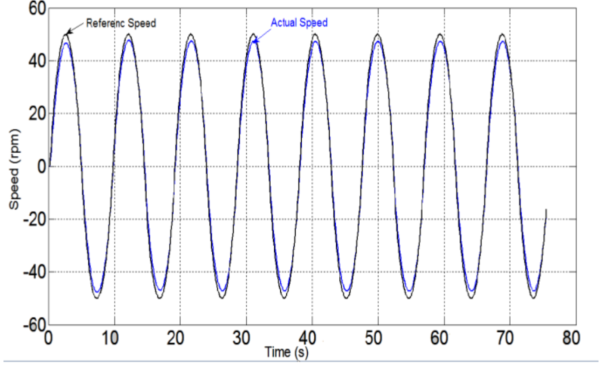


Fig 6: Signal Constrained block-Based PID controller response at no load

Fig. 7 shows the actual speed curve of the DC servo motor and reference speed at full-load. There is no significant difference between no-load and full-load condition due to implementation of PID controller.

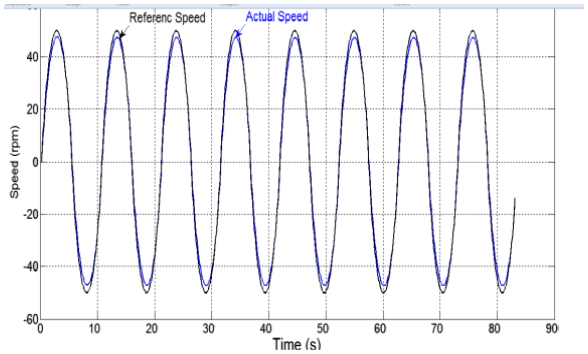


Fig 7. Signal Constrained block-Based PID controller response at full load

6. Experimental Verifications

The Digital Servo Fundamentals Trainer combines hardware and software to from an integrated, experiment-based, learning environment. The courseware for the trainer comprises a number of Assignments, each of which covers a particular topic. The main emphasis is on practical work, the software is is not simply a textbook on a computer screen.

6.1. Experimental Results

Fig.8 showing overall experimental work consists of system frame, A power supply, Mechanical Unit, Digital Unit, USB Interface Unit, Connecting cables, Computer and Printer.

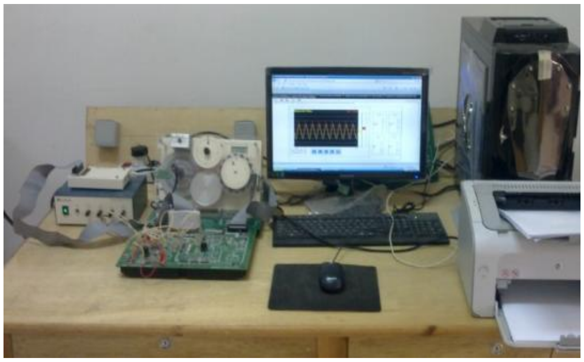


Fig.8 Experimental setup

Fig. 9 illustrates the shape of the DC servo motor actual speed and the reference speed, in case of no load. Also, fig. 9 shows overshoot in the form of speed.

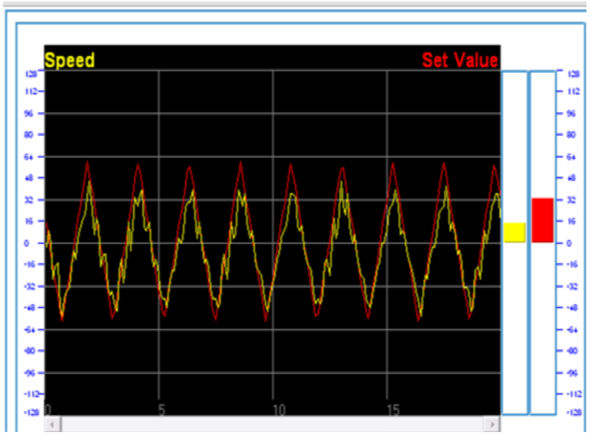


Fig 9 The relationship between actual speed and speed reference in the case of no load

Fig. 10 illustrates the shape of the DC servo motor actual speed and the reference speed, in case of full load. this presence of overshooting in the speed form. Certainly the actual speed is low than the reference speed

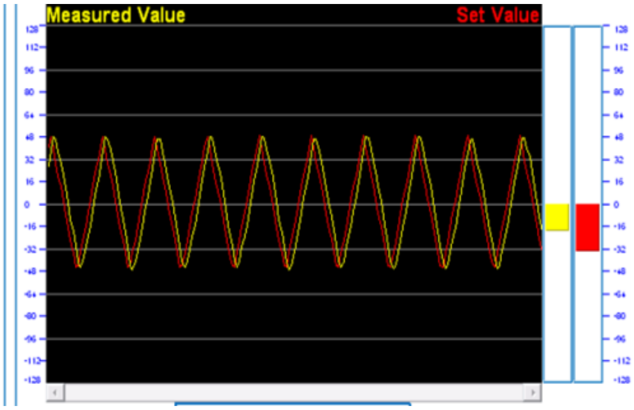


Fig.10 The relationship between actual speed and speed reference in the case of full load

Fig. 11 shows the actual speed curve of the DC servo motor and reference speed at full-load. There is no significant difference between no-load and full-load condition due to implementation of PID controller

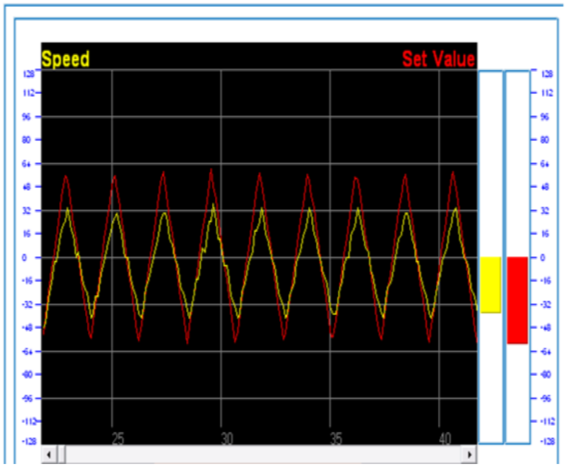


Fig.11The relationship between actual speed and speed reference in the case of controlled using PID at full load

Fig.12 show the variation of actual speed and reference speed of DC servo motor during the load torque. The load is set at 20% of full-load torque. As mentioned before, the overshot is completely vanished due to PID implementation. The actual speed is almost similar to reference speed, but it's seems experience phase shifting over reference speed due to loading.

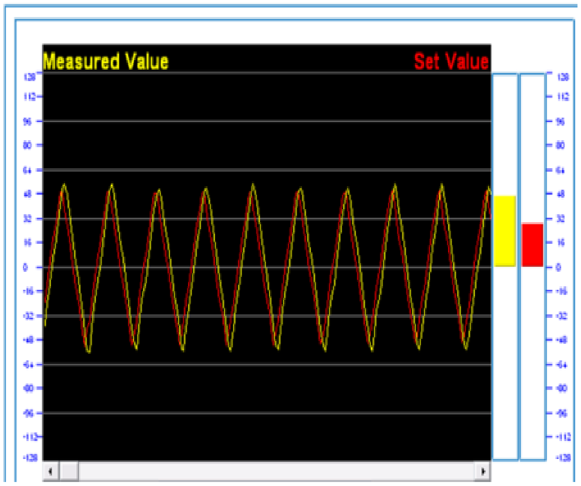


Fig.12 The relationship between actual speed and speed reference in the case of controlled using PID at 20% load

7 .CONCLUSION:

The results obtained for speed control of DC servo motors using PID controller and the mat lab software model are efficient. Acceptable agreement is obtained between theoretical and laboratory results. The control without any knowledge of speed is coming out of the DC servo motor in the case of no-load and full load.

Application of PI control system is to know the form of speed of the DC servo motor in the case of no-load and full load. The application of PID control system is more accurate and fast response for speed control of the DC servo motor at no load and different loads.

The design of a PIDPSO-based controller for the speed of DC servo-motor is presented in this work and good results are achieved. The DC servo-motor with the proposed PIDPSO controller is compared with the PID-based signal constrained block of the mat lab /Simulink.

The proposed PIDPSO- based controller has much faster response than that of the other controller. However the PIDPSO is much better in terms of the peak value and the settling time than the PID-based Signal Constrained block.

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