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**Research Article**

# SPEED CONTROL FOR SEPARATELY EXCITED DC MOTOR WITH PID CONTROLLER, GA, AND PSO

**Ayam M[2]*., liqaa S M[1] and Raoof T H[2]**

[1]Electrical Engineering Department, Al-Mustansiriyah University, Baghdad, Iraq
[2]Computer Engineering Department, Al-Mustansiriyah University, Baghdad, Iraq

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**ABSTRACT**

DC motor one of the important parts used in different applications. DC motor speed control one of the important aspects for these applications. In this paper the speed control of the DC motor was done by using PID controller, the tuning of PID parameters was done using different algorithms named robust PID, genetic and particle swarm optimization, and each one of these algorithms done in two different ways which were MATLAB and LABVIEW.



## INTRODUCTION

This section explains the general introduction and the theory needed in this paper.

### *DC motor*

The speed of DC motors can be adjusted within wide boundaries so that this provides easy controllability and high performance. DC motors used in many applications such as steel rolling mills, electric trains, electric vehicles, electric cranes and robotic manipulators require speed controllers toper form their tasks (Waleed and Khearia, 2012). DC drives are less complex with a single power conversion from AC to DC. Again the speed torque characteristics of DC motors are much more superior to that of AC motors. A DC motors provide excellent control of speed for acceleration and deceleration. DC drives are normally less expensive for most horsepower ratings. DC motors have a long tradition of use as adjustable speed machines and a wide range of options have evolved for this purpose (S. Tharani *et al*, 2014).

### *Particle swarm optimization*

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Eberhart and Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling. The PSO method is a member of the wide category of Swarm Intelligence methods. PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations (Sudhir *et al*, 2011).

In PSO, instead of using genetic operators, individuals called as particles are “evolved” by cooperation and competition among themselves through generations. A particle represents a potential solution to a problem. Each particle adjusts its flying according to its own flying experience and its companion flying experience. Each particle is treated as a point in a D-dimensional space.

- The i-th particle is represented as $x_i = (x_{i1}, x_{i2}, \ldots, x_{iD})$.
- The best previous position (giving the minimum fitness value) of any particle is recorded and represented as $P_i = (p_{i1}, p_{i2}, \ldots, p_{iD})$, this is called pbest.
- The index of the best particle among all particles in the population is represented by gbest.
- The velocity for the particle i is represented as $V_i = (v_{i1}, v_{i2}, \ldots, v_{iD})$. The particles are updated according to the following equations: [Mahmud *et al*, 2011]

$$v_{id}(t+1) = \omega . v_{id}(t) + c_1 r_1 (Pbest_{id} - x_i(t)) + c_2 r_2 (gbest_d - x_i(t))$$

$$x_{id}(t+1) = x_{id}(t) + v_{id}(t+1)$$

**Corresponding author:* ***Ayam M***
*Electrical Engineering Department, Al-Mustansiriyah University, Baghdad, Iraq*

Where w, c1 and c2 are called the coefficient of inertia, cognitive and society study, respectively. The r1 and r2 is uniformly distributed random numbers in [0, 1]. (Mickael *et al*, 2012). The PSO algorithm is shown in (Fig 1). (Abdelelah *et al*, August 2013).

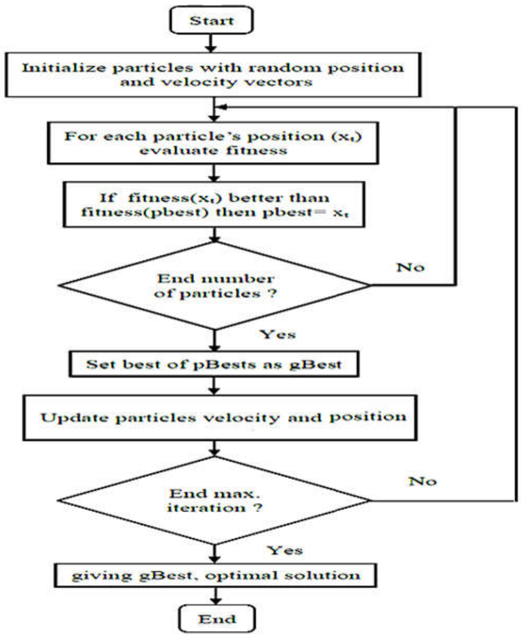



**Figure 1**PSO algorithm

***Genetic algorithm***

Genetic Algorithm is related to biological background, in sense that it follows Darwin theory of natural evolution "the survival of the fittest". The genetic algorithm is first proposed by John Holland in1975. In genetic algorithms there are some terminologies must be understood. Main terms are gene, chromosome, individual, population. Gene is smallest unit of information, Individual is a set of genes carrying information and further set of individuals is population, chromosome and individual are synonym (Gopesh, 2014).

The simplest form of genetic algorithm involves three types of operators: selection, crossover (single point), and mutation as follows:

- ***Selection:*** This operator selects chromosomes in the population for reproduction. The fitter the chromosome the more times it is likely to be selected to reproduce
- ***Crossover:*** This operator randomly chooses a locus and exchanges the subsequences before and after that locus between two chromosomes to create two offspring. For example, the strings 10000100 and 11111111 could be crossed over after the third locus in each to produce the two offspring 10011111 and 11100100. The crossover operator roughly mimics biological recombination between two single chromosome (haploid) organisms.
- ***Mutation:*** This operator randomly flips some of the bits in a chromosome. For example, the string 00000100 might be mutated in its second position to yield 01000100. Mutation can occur at each bit position in a string with some probability, usually very small (e.g., 0.001)

***Simple genetic algorithm***

Given a clearly defined problem to be solved and a bit string representation for candidate solutions, a simple GA works as follows:

1. Start with a randomly generated population of n bit chromosomes (candidate solutions to problem).
2. Calculate the fitness $f(x)$ of each chromosome x in the population
3. Repeat the following steps until n offspring have been create:
   a. Select a pair of parent chromosomes from the current population, the probability of selection being an increasing function of fitness. Selection is done "with replacement," meaning that the same chromosome can be selected more than once to become a parent.
   b. With probability $p_c$ (the "crossover probability" or "crossover rate"), cross over the pair at a randomly chosen point (chosen with uniform probability) to form two offspring. If no crossover takes place, form two offspring that are exact copies of their respective parents.
   c. Mutate the two offspring at each locus with probability pm (the mutation probability or mutation rate), and place the resulting chromosomes in the new population. If n is odd, one new population member can be discarded at random.
4. Replace the current population with the new population.
5. Go to step 2 (Mitchell, 1999).

***Mathematical Model***

***Speed Control of Separately Excited DC Motor without Controller***

***Open Loop (Without Controller)***

In (Fig 2) the Separately DC Motor without Controller for open loop and the armature voltage equation is given by:

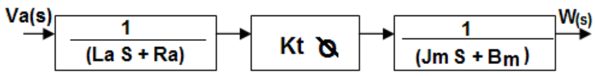



**Figure 2** the Separately DC Motor without Controller for Open Loop

$$G(s) = \frac{K_t\ \phi}{(L_a S + R_a)(J_m S + B_m)}$$

After simplifying the above motor model, the overall transfer function will be:

$$G(s) = \frac{K_t\,\phi}{(L_a.J_m)S^2 + (R_a.J_m + L_a.B_m)S + (R_a.B_m)}$$

Where:
V= Armature Voltage (V).
Kt= Motor Torque Constant (Nm/A).
La= Motor inductance (H).
Jm= Armature moment of inertia (Kg – m2).
Ra = Armature Resistance (Ω).
Bm =Viscous – Friction Coefficient (N-m/Rad/Sec).
ϕ= Field Flux.
Kb = Back EMF Constant (V/Rad/Sec).

### *Close Loop (Without Controller)*

In (Fig 3) the Separately DC Motor without Controller for close loop and the armature voltage equation is given by:

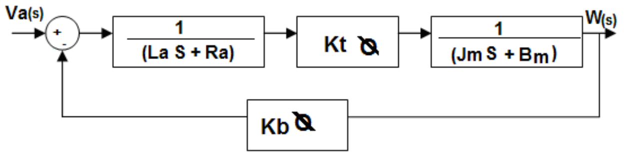



**Figure 3** the Separately DC Motor without Controller for Close Loop

$$T.F = \frac{G_p(s)}{1 + G_P(s).H(s)}$$

$$T.F = \frac{\dfrac{K_t\ \phi}{(L_a.J_m)S^2 + (R_a.J_m + L_a.B_m)S + (R_a.B_m)}}{1 + \dfrac{K_t\ \phi}{(L_a.J_m)S^2 + (R_a.J_m + L_a.B_m)S + (R_a.B_m)}\quad K_b\ \phi}$$

After simplifying the above motor model, the overall transfer function will be:

$$T.F = \frac{K_t\ \phi}{(L_a.J_m)S^2 + (R_a.J_m + L_a.B_m)S + (R_a.B_m) + K_t\ \ K_b\phi^2}$$

### *Speed Control of Separately Excited DC Motor with Controller*

### *Open Loop (With Controller)*

In (Fig 4) the Separately DC Motor with Controller for open loop and the armature voltage equation is given by:

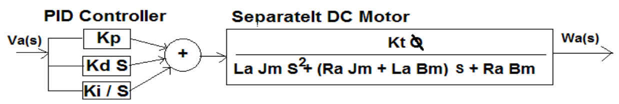



**Figure 4** the Separately DC Motor with Controller for Open Loop

$$G_c(s).G_p(s) = (K_p + \frac{K_i}{S} + K_dS)\quad \frac{K_t\ \phi}{(L_a.J_m)S^2 + (R_a.J_m + L_a.B_m)S + (R_a.B_m)}$$

### *Close Loop (With Controller)*

In (Fig 5) the Separately DC Motor with Controller for close loop and the armature voltage equation is given by:

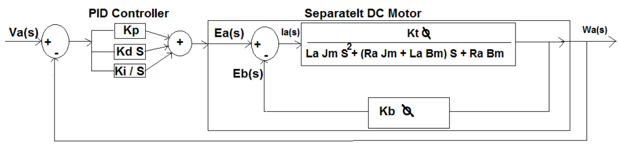



**Figure 5** the Separately DC Motor with Controller for Close Loop

$$T.F = \frac{G_c(s).G_p(s)}{1 + G_c(s).G_p(s).H(s)}$$

$$T.F = \frac{(K_p + \frac{K_i}{S} + K_dS)\quad \dfrac{K_t\ \phi}{(L_a.J_m)S^2 + (R_a.J_m + L_a.B_m)S + (R_a.B_m) + K_t\ \ K_b\phi^2}}{1 + \left(K_p + \frac{K_i}{S} + K_dS\right)\quad \dfrac{K_t\ \phi}{(L_a.J_m)S^2 + (R_a.J_m + L_a.B_m)S + (R_a.B_m) + K_t\ \ K_b\phi^2}\quad 1}$$

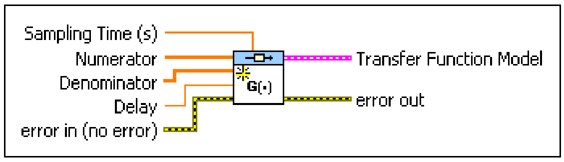
After simplifying the above motor model, the overall transfer function will be

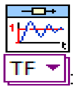
$$T.F = \frac{(K_pS + K_i + K_dS^2).K_t\,\phi}{(L_a.J_m)S^3 + (R_a.J_m + L_a.B_m + K_t.K_d\ \phi)S^2 + (R_a.B_m + K_t.K_P\phi + K_t.K_b\ \phi^2)S + K_t.K_i\ \phi}$$

### *Lab view program*

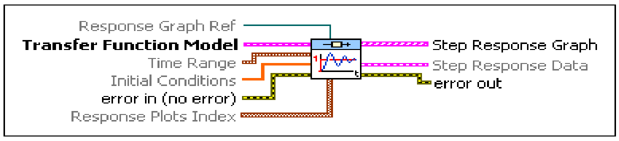
LABVIEW (Laboratory Virtual Instrument Engineering Workbench) is a program consists of two major components: Front Panel (FP) and Block Diagram (BD). A Front Panel provides a graphical user interface while a Block Diagram contains building blocks of a system resembling a flowchart (N. KIM, N. KEHTARNAVAZ, and M. TORLAK, 2006). Many Icons applied in this paper are:

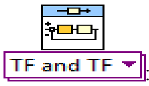

: CD Construct Transfer Function Model (SISO).



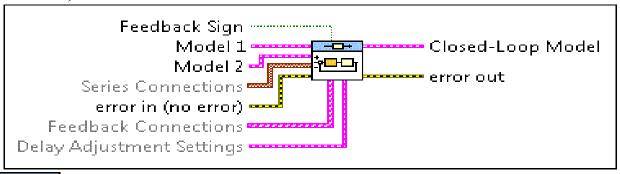



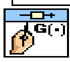

: Step Response (Transfer Function).



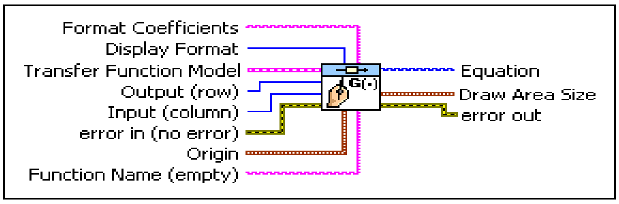




: CD Unit Feedback (Transfer Function and Transfer Function).

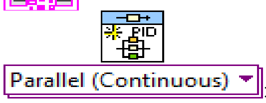


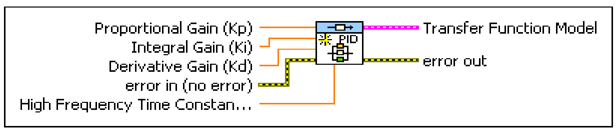

: CD Draw Transfer Function Equation (Transfer Function).




Step Response Graph




: CD Construct PID Model (Parallel, Continuous).





: Create SubVI for Separately Excited DC- Motor.


: Create SubVI for PID Controller.

**CASE STUDY**

In this paper used the plant of Separated Excited DC- Motor is: G(s)=0.5/(0.002 S2+0.005S+0.625).

And the motor parameter values are: Kt=0.5 Nm/A, La=0.02 H, Jm=0.1 Kg.m2, Ra=0.5 Ohm, Bm=0.008 N.m/rad/sec, Phi= 1, Kb=1.25 V/rad/sec,Va= 200 v.

In (Fig 6) represented the output result by using LABVIEW program 2013 of DC – motor with controller.

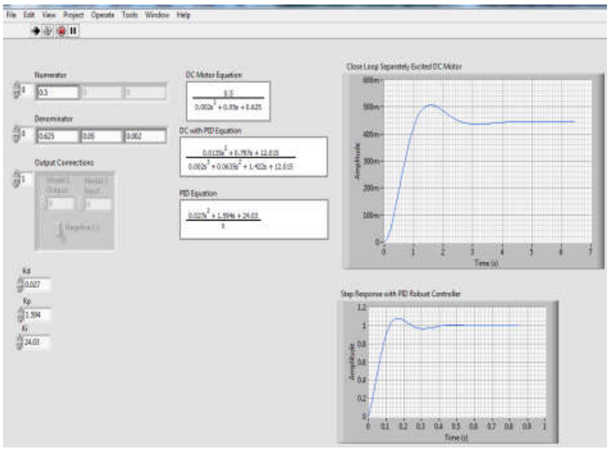


**Figure 6** Block Diagram of Separated Excited DC Motor with PID Controller

In (Fig 7) represented the simulation of DC – motor with controller using LABVIEW program 2013.

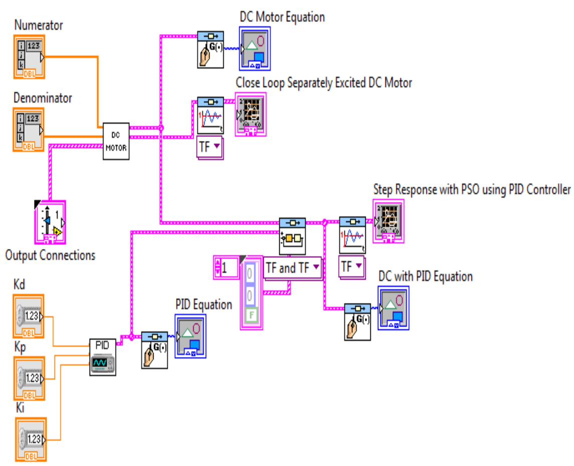
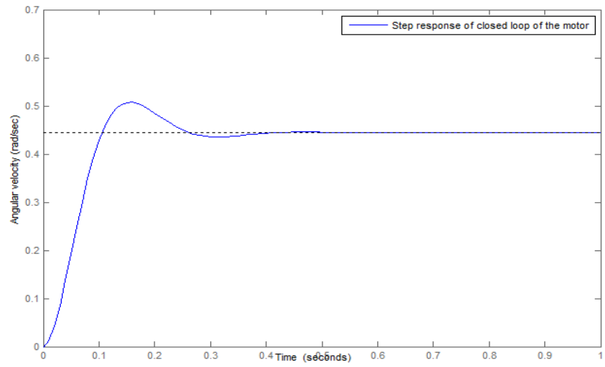



**Figure 7** Front Panel of Separated Excited DC Motor with PID Controller

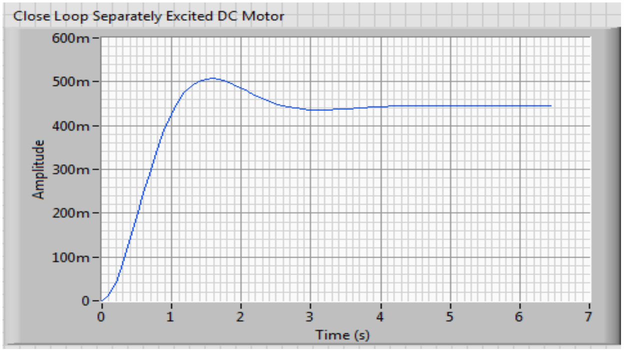
## SIMULATION AND RESULTS

Applied the simulation of the system with different type of methods (Robust PID, PSO, GA) are shown here. The represented of the system controller using MATLAB & LABVIEW program are being applied.

The response of the dc motor as shown in (Fig 8) .This figure contains the closed loop of (angular speed) response of the motor without using controller.




**A** With MATLAB




**B With LABVIEW**

**Figure 8** The closed loop response of the motor without controller.

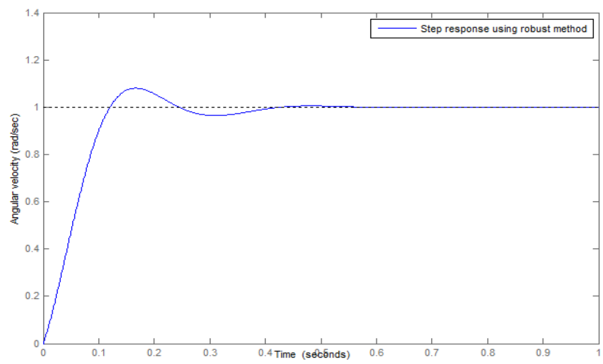
Table (1) shows the characteristics of closed loop response of the motor without controller. From (Fig 8) and table (1), the closed loop response of the motor without controller contains error steady state and overshoot and the response is slow.

**Table 1** The characteristics of closed loop response of the motor without controller

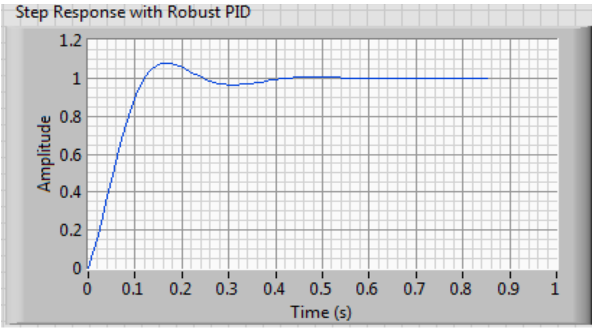
| Closed loop response | Rise Time ($t_r$) (sec.) | Overshoot $M_p$ % | Peak Time ($t_p$) (Sec.) | Settling Time ($t_s$) (Sec.) | Delay Time ($t_d$) (Sec.) |
|---|---|---|---|---|---|
| | 0.0714 | 14.2497 | 0.1553 | 0.3193 | 0.137 |

(Fig 9) shows the response of the motor with PID controller using robust method.

The parameters of PID controller are ($K_p$=1.594, $K_i$=24.03, $K_d$ = 0.027).




**A** With MATLAB




**B** with LABVIEW

**Figure 9** The closed loop response of the motor with PID controller using robust method.

To overcome the difficulty of choosing the parameters of PID by trial and error genetic algorithm is used. The optimization process is driven by the maximization of the fitness function F, defined as the mean error between the current value of the position and the desired reference:

$$MSE = \frac{1}{t}\int_0^t (e(t))^2\, dt$$

Fitness=1 / (MSE)

To apply GA, the elements of the chromosome must be set. From (Fig 10), three parameters (Kp, Kd, Ki) for PID controller will be constituted.

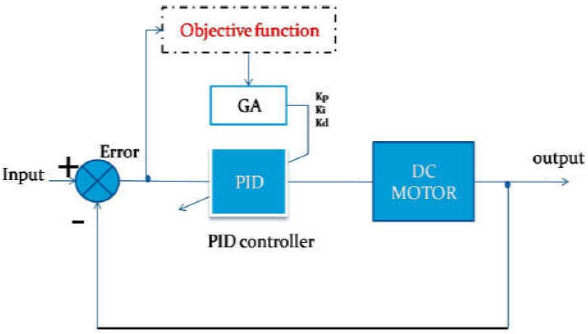
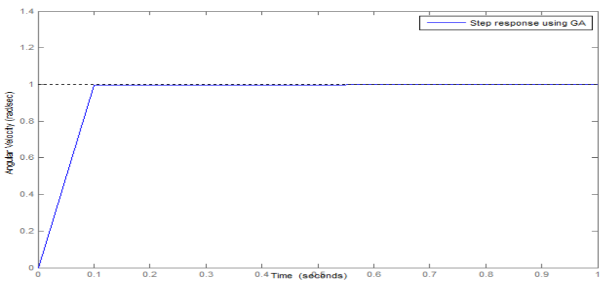


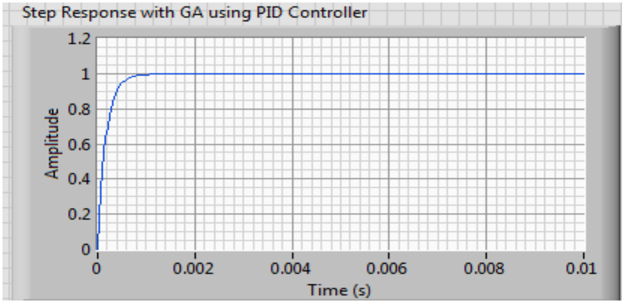

**Figure 10** General block diagram for tuning PID using GA.

The selection method is roulette wheel, arithmetic crossover, mutation is uniform mutation, the Elitism strategy is used to retain best individual and the stopping condition for GA is either the maximum number of generation is achieved or the value of fitness is fixed for next generations.

(Fig 11) shows the response of the motor with PID controller using GA. The parameters of PID controller are ($K_P$= 160.0609, $K_i$= 481.1030, $K_d$ =23.5304). Elapsed time is 20.081012 seconds.




**A** With MATLAB




**B** with LABVIEW

**Figure 11** The closed loop response of the motor with PID controller using GA.

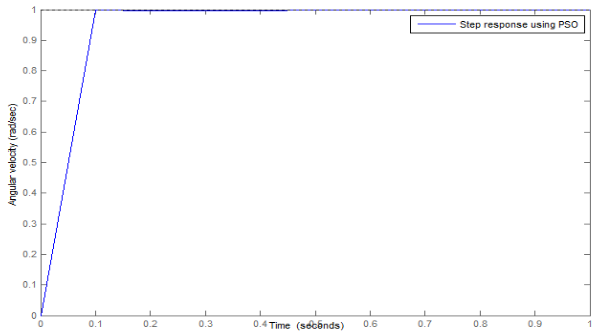
To apply the PSO method for searching the controller parameters, the "individual" was used to replace the "particle" and the "population" to replace the "group". Since we have three parameters ($K_p$, $K_d$, $K_i$) for PID controller, hence, there are three members in an individual. These members are assigned as real values. If there are n individuals in a population, then the dimension of a population is n 3. The optimization process is driven by the maximization of the fitness function F.

Initializing the values of the parameters of PSO algorithm is shown in table (2).

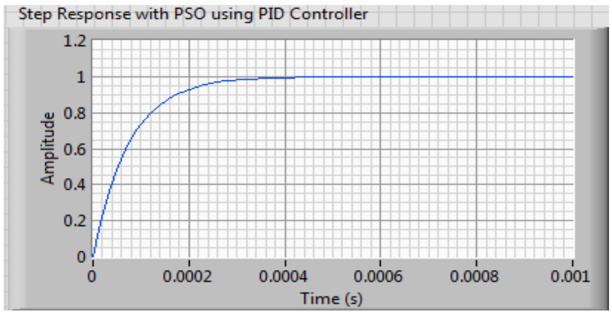
**Table 2** PSO parameters

| **Population size** | **80** |
|---|---|
| Number of iterations | 50 |
| Velocity constant,c1 | 0.12 |
| Velocity constant,c2 | 1.2 |

(Fig 12) shows the response of the motor with PID controller using PSO algorithm. The parameters of PID controller are ($K_p$= 317.0316, $K_i$= 429.4377, $K_d$ = 53.8708). Elapsed time is 1.972462 seconds.




**A** with MATLAB




**B** with LABVIEW

**Figure 12** The closed loop response of the motor with PID controller using PSO algorithm.

Table (3) shows the characteristics of closed loop response of the motor with PID controller using robust method, GA and PSO algorithm. From table (2), the closed loop response of the motor with PID controller using PSO algorithm not contains error steady state and no overshoot and the response is fast.

**Table 3** The characteristic of closed loop response of the motor with PID controller

| Controller type | Rise Time ($t_r$ ) (sec.) | Overshoot $M_p$ % | Peak Time ($t_p$ ) (Sec.) | Settling Time ($t_s$ ) (Sec.) | Delay Time ($t_d$ ) (Sec.) |
|---|---|---|---|---|---|
| PID Controller using robust method | 0.0874 | 8.0296 | 0.1676 | 0.3687 | 0.0528 |
| PID Controller using GA | 3.7715e-004 | 0 | 0.0013 | 6.9097e-004 | 0.0502 |
| PID Controller using PSO | 2.1003e-004 | 0 | 0.0010 | 3.6663e-004 | 0.05 |

## CONCLUSIONS

In this paper the speed of a DC motor is controlled using PID controller, tuning the parameters of PID controller using robust method, GA and PSO algorithm. The results are obtained using MATLAB and LABVIEW. The results show that settling time, peak time and control performance has been improved greatly by using PSO algorithm for tuning the parameters of PID controller. The response of the system has no overshoot when using GA and PSO algorithm for tuning the PID controller, but the tuning with PSO algorithm take less time than using GA.

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