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Tuning of PID Controller for Speed Control of DC Motor Using Genetic Algorithm

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Abstract— *DC motors are frequently used in the industry, especially where speed control applications such as steel mills, electric trains, cranes. The reason why these motors have been used as controllers in speed control applications for many years; the simplicity of the structure and ease of use of these structures. Setting the PID parameter values correctly and appropriately is of great importance for the control system to operate successfully. PID parameters are generally determined by trial-and-error method or by using traditional Ziegler-Nichols method. However, the determined parameters may not always give the best performance, especially the complexity of the system makes it difficult to determine the parameters. In this study, the gain values of the PID controllers are optimized using Genetic Algorithm (GA). The simulation results by MATLAB/Simulink show more stable and higher performance for speed control of separately excited DC motor using GA is performed.*

Keywords— Genetic Algorithm; PID controller; DC motor; IAE ; Ziegler-Nichols.

1. Introduction

DC motors have been widely used in industry for many years, especially in the control field. The reasons for this are that it has many good features such as high starting torque characteristic, fast response performance, linear control characteristic [1].

In order to control any system, the mathematical model of the system must be known. In addition to creating a mathematical model for the control of the DC motor's variables such as current, speed and position, it is necessary to add a control system that will bring the value of the feedback loop error closer to zero.

Proportional, Integral and Derivative controllers (PID), which are traditional control systems, are one of the control methods frequently used in industries. It is still widely used because of its simple structure and good performance for many systems of different structures. However, the good performance of these controllers is possible with the appropriate selection of KP, KI and KD coefficients. When trying to determine the coefficients using the trial-and-error method, many difficulties are encountered and the system may be damaged during this process. For this purpose, methods such as the Ziegler-Nichols [2-3] method developed and published in the literature are used to determine the coefficients. Apart from these traditional methods, it is seen that optimization methods based on artificial intelligence have been used recently [4-6]. In addition, when the literature is examined, there are studies conducted with many types of approaches and methods to determine the coefficients of the PID controller, such as programmable logic controllers (PLC) [7] and Krill Herd optimization (KHA) algorithm [8].

In this study, optimum values were tried to be obtained by optimizing the controller coefficients with the genetic algorithm in order to control the DC motor speed.

2. Separately Excited DC Motor

Separately excited DC motors are the leading motors used in speed control applications in industry. The excitation flux and armature voltages in separately excited motors can be controlled independently of each other. For a medium-sized free-excited DC motor, the decrease in speed from no-load to full-load state is about 5%. For this reason, freely excited DC motors are often used in applications that require good speed regulation or variable speed regulation.

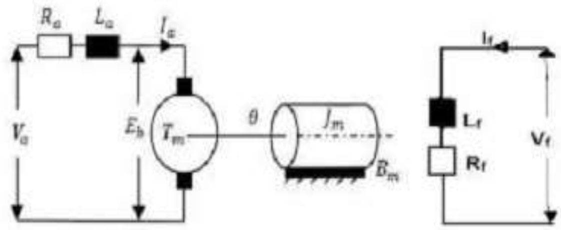

Fig.1. Schematic diagram of Separately excited DC motor

The equations describing the dynamic behavior of the DC motor whose schematic diagram is given in Figure 1 are given in (1) and (2).

$$V_a(t) = R_a . i_a(t) + L_a . \frac{di_a(t)}{dt} + e_b(t)$$
(1)

$$e_b(t) = K_b . \omega(t) \quad (2)$$

The connection between the load torque, torque and angular velocity produced by the DC motor is given in (3) and (4).

$$T_m(t) = K_T . i_a(t) \quad (3)$$

$$T_m(t) = J_m . \frac{d\omega(t)}{dt} + B_m . \omega(t) + T_L \quad (4)$$

The closed loop transfer function of the system is given in (5).

$$\frac{\omega(s)}{V_a(s)} = \frac{(K_m / L_a . J_m)}{S^2 + ((R_a . J_m + L_a . B_m)/L_a . J_m) . S + ((R_a . B_m + K_b . K_T)/L_a . J_m)} \quad (5)$$

Where:
V_a = Armature voltage (V).
i_a = Armature current (A).
R_a = Armature resistance (Ω).
L_a = Armature inductance (H).
e_b = Back emf (V).
K_b = Back emf constant (V.s/rad).
K_T = Motor torque constant (N.m/A).
J_m = Rotor inertia (Kg. m^2).
B_m = Viscous friction coefficient (N.m.s/rad).
T_m =Motor torque (N.m).
T_L = Load torque (N.m).
ω = Angular speed (rad/s).

The MATLAB / Simulink model of the separately excited DC motor to be used in simulation studies is given in Figure 2, and the motor parameters are listed in Table 1.

Table 1: Parameter values

Parameters	Value
R_a	2 Ω
L_a	0.5 H
J_m	0.02 Kg.m^2
K_b	0.01 V.s/rad
K_T	0.015 N.m/A
B_m	0.2 N.m.s/rad
V_a	220 V

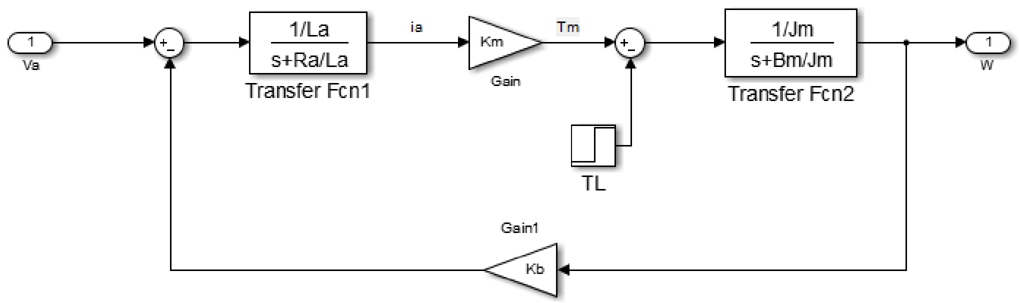

Fig.2. MATLAB/Simulink model of DC motor.

3. PID CONTROLLER

The general structure of the PID controller, which is frequently used in the industrial field, is given in Figure 3. The error (difference between reference and feedback) signal E(s) at the input of the PID controller and the control signal U(s) at its output are given in (6).

$$G(s) = \frac{U(s)}{E(s)} = K_P + \frac{K_I}{s} + K_D.s \quad (6)$$

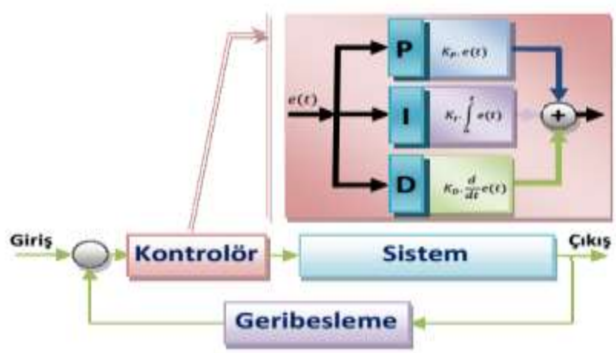

Fig.3. Feedback control system and PID controller.

4. GENETIC ALGORITHM

John Holland, a psychology and computer science specialist at the University of Michigan, was the first to work on genetic algorithms. Holland, who works on machine learning, was influenced by Darwin's theory of evolution and thought to carry out the genetic process in living things in a computer environment [9]. In the process of applying the theory of evolution in nature to artificial systems, three methods emerged under the title of evolutionary calculations: Genetic Algorithms (GA), Evolutionary Programming (EP) and Evolutionary Strategies (ES). Among these, the most known and most used method today is Genetic Algorithms.

Genetic Algorithms are based on the rules of natural selection and natural inheritance. Natural selection means that the living things that have adapted to the environmental conditions continue their lives, and that those that cannot adapt are eliminated, that is, they die. Natural inheritance, on the other hand, can be briefly summarized as the breeding of selected individuals to produce new offspring by mating with each other. In solving problems in Genetic Algorithms, n individuals that will form the first population are determined completely randomly. Later stages can be gathered under two roofs.

a) Genetic operations: crossover and mutation

b) Evolutionary process: selection

Genetic Algorithms, which start problem solving from the population of points, first encode these points. Each structure that makes up the solution set (population) is called a "chromosome" or "individual". Chromosomes are made up of strings of symbols called genes. For example, in Figure 4, the "individual" consisting of the symbols 0 and 1 with a binary coding structure is seen.

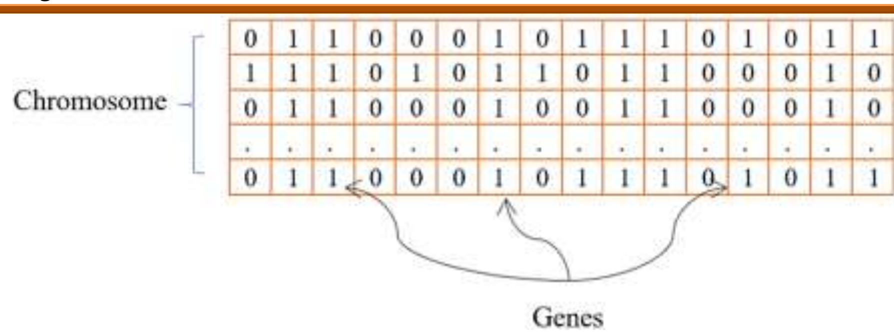

Fig.4. The individual in the binary coding structure

In this study, a separate algorithm was used to individually adjust the parameters, and the general population encompasses all levels of readiness. The general population is made out of chromosomes, Figure 5 shows the structure of the chromosome consisting of three gains (KP, KI and KD). Chromosomes are associated with the DC drive system and dynamic execution properties of the construct are resolved for each chromosome.

Fig.5. The structure of the chromosome consisting of three gains

GA general flow diagram is given in Figure (6). First, the initial population is randomly generated. The other stages are the determination of fitness function, selection, crossover, mutation and transfer of elite individuals to the next generation. Finally, if the termination conditions are met, the algorithm is finished, and if the condition is not met, it is returned to the fitness function stage.

5. GA Based Optimization

The fitness function is the best approach to using the Genetic Algorithm. The most important step in applying the GA tuning method is to accept the target study used to review the health assessment of each chromosome. In this study, target limits are used and their execution is examined. The solution depends on the infinite integral of the absolute error (IAE) document. The objective function (target limit) is given as:

$$IAE = \int_0^T |e(t)|dt \quad (7)$$

The GA parameters used in this study are given in Table 2.

Table 2: Values of GA parameters

Parameters	Value
Generations	50
Population	100
Lower Limit	[0 0 0]
Upper Limit	[300 300 300]
Population Type	Double Vector
Crossover	Constraint Dependent
Mutation	Constraint Dependent
Selection	Stochastic Uniform
Elite Count	5

The codes are written to determine the transfer function of the system (DC Motor), the initial values of the population, the limits of the variables, the transfer function of the controller and the target function. Figure 7 shows the GA initialization code.

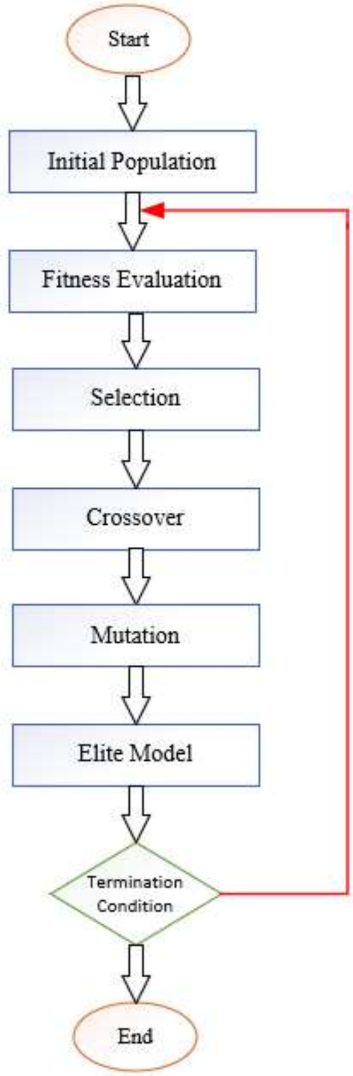

Fig.6. GA flowchart for PID tuning

```
function [J]= pidtun_opti_DCmotor(x)
_______________________________%%
% Plant transfer fonksiyonu (DC Motor)
s = tf ('s');
plant = 1/(s^2+14*s+40.02);
_______________________________%%
% genetik algoritma oluşturma
Popsize=100;                    %  Populasiyon saysı
bound=[0 300;0 300;0 300];      % değişken sını
% kp, kd, ki  hesaplamanın başlatılması
kp=x(1)
ki=x(2)
kd=x(3)
% kontrol transfer fonksiyonu
cont= kp+ ki/s+ kd*s;
% Kapalı döngü
step (feedback(plant*cont,1));
dt=0.001;
t= 0:dt:1;
e= 1-step(feedback(plant*cont,1),t);
% Hedef fonksiyonu
J= sum(t'.*abs(e)*dt);
```

Fig.7. Genetic Algorithm initialization code

6. Simulation Results

The transfer function of the system is modelled by two methods using MATLAB. The first method is carried out using the transfer function of the system by Equation 5 and is given in (8).

$$T(s) = \frac{w(s)}{V_a(s)} = \frac{1}{S^2+14\,S+40.02} \tag{8}$$

In the second method, the DC motor is modelled in MATLAB/SIMULINK environment as shown in Figure 2. In order to see the response of the uncontrolled DC motor system, the response of the system to which the unit step input is applied is given in Figure 8. The gains of the PID controller are calculated using the Ziegler - Nichols method.

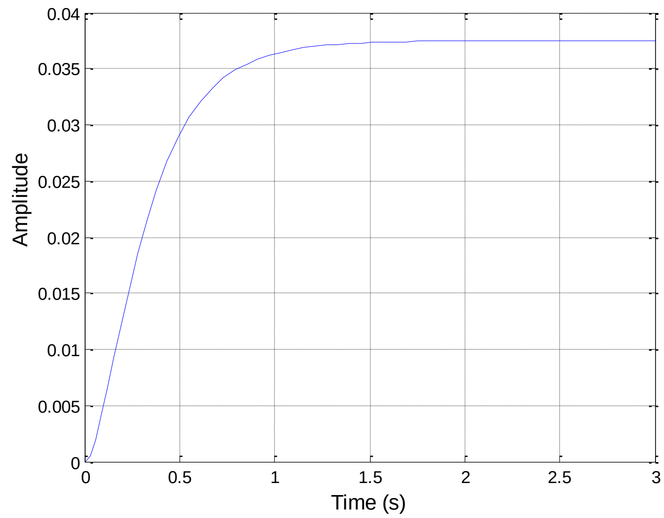

Fig.8. Step input response of uncontrolled DC motor

In this study, the limits of KP, KI and KD were chosen separately between 0 and 300. Optimum values of KP, KI and KD gains are obtained. Figure 9 shows the simulation results while applying the PID gains obtained in both methods (traditional Z-N and optimization GA) and the results are analyzed and compared as seen in Table 3.

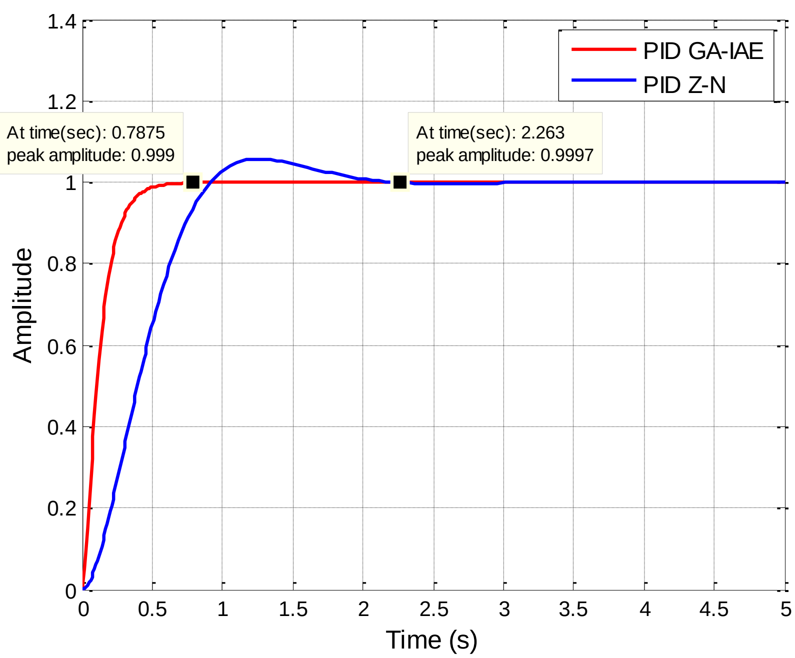

Fig.9. unit step response of the system in both methods

Table 3: Performance comparison of PID controller between GA and Z-N

Parameters	Tuning method	
	Conventional PID (Z-N)	***Genetic Algorithm***
K_P	15.17	299.6
K_I	105.70	295
K_D	0.55	27.5
Peak	1.057	0.9999
Overshoot (%)	5.7	0
Settling time (s)	2.263	0.7875
Rise time (s)	1.214	0.5615

7. Conclusion

In this study, a PID controller has used to effectively control the separately excited DC motor. The values of the PID controller used were found by the traditional Ziegler-Nichols method and optimized GA. Simulation results of both methods were obtained in MATLAB and the results were compared. The obtained simulation results seen that the PID values obtained as a result of the optimization study with the Genetic Algorithm give better results and better control than the PID values obtained with the traditional Ziegler-Nichols method. Better rise time, Minimum overshoot and Minimum settling time values were obtained with the optimized values. By optimizing PID values with GA, more stable and high-performance PID controllers can be obtained.

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