https://doi.org/10.52326/ic-ecco.2021/CE.03

Synthesis the PID Control Algorithm for Speed Control of the DC Motor based on the Genetic Algorithm

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***Abstract*—In this paper, it is proposed to use the genetic algorithm for synthesis the PI and PID control algorithms for speed control of the DC motor, according to the imposed performance, namely settling time. The obtained results were compared with maximum stability degree method with iterations and to demonstrate the efficiency of proposed algorithm the computer simulation was done. The designed algorithm searches for the controller tuning parameters: k_p, k_i, and k_d, so that performance for the closed-loop step response to be satisfied.**

Keywords*—PID controller; genetic algorithm; automatic control system; maximum stability degree method with iterations

I. INTRODUCTION

The industrial or technological process, directed to achieve a specified goal, represents an organized and ordered set of activities, or operations, which are divided into two main categories: actuation operations and control operations. Actuation operations include activities that are necessary to carry out a process according to the nature laws, which are carried out on the technological installations that involves mass and energy transfer. In order to achieve the correct dynamic of the process and ensure the high performance, there are required the control operations. Both operations types can be developed on the automation equipment.

An important element in terms of actuation on the industrial or technological process are the electrical motors, which are used as actuator elements [5-7].

Electric motors have a wide range of applications in the fields of servo automation and robotics. Electric motors can be classified by the type of electric current: DC motors and AC motors. Due to the linearity of its features and relatively simple speed control methods, DC motor is a power actuator which transforms electrical energy into mechanical energy and it is the most used motor as actuator or as a control object in the automatic control systems, where in both situations it is necessary to control its speed, which is solved by using a typical control algorithm.

One of the most used control algorithms in industrial applications is the PID control algorithm and its variation P, PI, PD. Proportional-Integral-Derivative (PID) control algorithm has been used for several decades in different industrial applications, due to its simplicity, good robustness and performance, that it ensures to the automatic control systems.

The PID control algorithm is characterized by three parameters - proportional (P), integral (I) and derivative (D). The proportional component P depends on the present error, the integral component I depends on the accumulation of past error, and the derivate component D presents the prediction of the future error, based on current rate of error change, Fig. 1 [8].

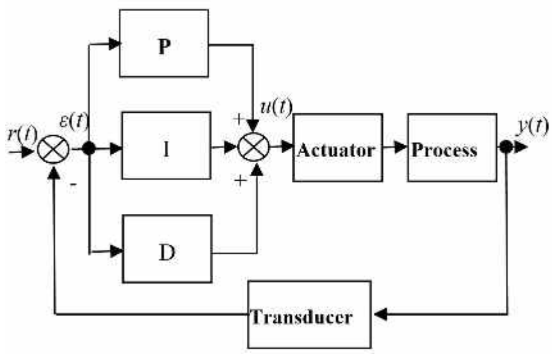

Fig. 1. Block scheme of the automatic control system

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Nowadays, there are developed many methods for synthesis the typical control algorithms as: experimental methods; the graph-analytical methods, which involves to be known the mathematical model that approximates the industrial process; the optimization methods and the artificial intelligence approaches such as evolutionary algorithms are widely used in case of optimization problem of synthesis the PID control algorithm [1-2].

In this paper, it was proposed to use the genetic algorithm for synthesis the PI and PID control algorithms for speed control of the DC motor, according to the imposed performance. The designed algorithm searches for the controller tuning parameters: k_p, k_i, and k_d, so that the performance imposed to the system to be satisfied.

II. Description of the Designed System

As DC motor, it was used the FK130SH motor for testing several reaction wheels. The system was implemented based on the NUCLEO-F303K8 platform from ST Microelectronics and the reaction wheel is coupled directly to the motor, Fig. 2. The speed of the motor coupled with the reaction wheel is controlled by the STM32F303K8 microcontroller. As the speed sensor, the EE-SX4235A-P2 transmissive photo microsensor is used.

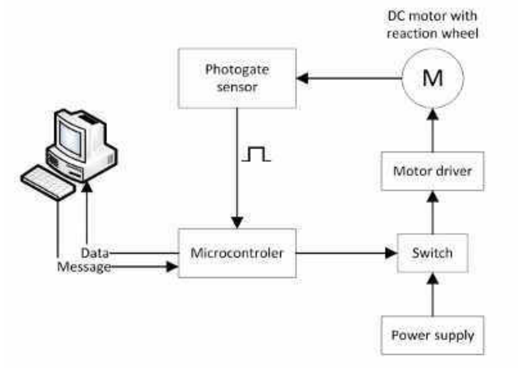

Fig. 2. Block diagram of the designed system

It was proposed to be done the experimental identification of the mathematical model that approximates the dynamics of the DC motor. It was done the data acquisition, so that the experimental variation of the DC motor speed at the reference speed of 8500 rpm is presented in the Fig. 3.

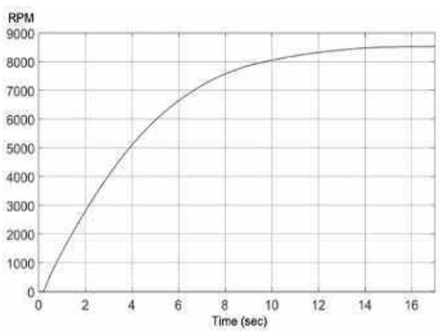

Fig. 3. Experimental curve

To estimate the mathematical model, it was proposed to be used the System Identification Toolbox from MATLAB. The experimental curve it was approximated with model of object with inertia second order [4]:

$$H(s)=\frac{k}{(T_1 s+1)(T_2 s+1)}=\frac{1.0069}{3.1695s^2+5.0289s+1}. \quad (1)$$

III. Synthesis of the PI and PID Control Algorithms using Genetic Algorithm

Genetic algorithm (GA) is inspired by biological phenomena (principles of natural selection and genetics) and particle swarm optimization algorithm. It has a strong search capability being a stochastic global search method, that mimics the process of natural evolution, where is evolving a population of candidate solutions to a target problem.

Genetic algorithm manipulates not just with one potential solution to a problem but with a collection of potential solutions, that are known as population. Every solution corresponds to a chromosome and each parameter represents a gene, where genetic algorithm evaluates the fitness of each individual in the population using a fitness (objective) function. The genetic algorithm use the genetic operators such as selection, crossover and mutation for the generation of the new chromosomes from the existing population. Genetic algorithm consists from the following steps:

Step 1. Random generation of the populations of n chromosomes.

Step 2. Evaluating of the success of each x chromosome using the fitness function $f(x)$.

Step 3. Creating a new population by applying the following evolutionary operations until the new population is complete:

- Selection - Selection of two parents chromosomes from a population according to the function $f(x)$.

- Crossover - Two individual agents combine to produce an offspring. The main objective of crossover is to explore new areas within the search space.

- Mutation - During mutation individual agents endure the small random changes of genes that lead to the generation of new individuals.

Step 4. The above-mentioned steps are repeated until the swarm converges to an optimal or sub-optimal solution [3].

The synthesis procedure implementation of the PI and PID control algorithms based on the genetic algorithm, starts with definition of the chromosome representation.

It was used the PI control algorithm in the standard form that is described by the following transfer function:

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$$H_{PID}(s) = k_p + \frac{k_i}{s} = \frac{k_p s + k_i}{s}, \qquad (2)$$

where k_p, k_i, k_d – are the tuning parameters of the PID control algorithm.

It was used the PID control algorithm in the standard form, that is described by the following transfer function:

$$H_{PID}(s) = k_p + \frac{k_i}{s} + k_d s = \frac{k_d s^2 + k_p s + k_i}{s}, \qquad (3)$$

where k_p, k_i, k_d – are the tuning parameters of the PID control algorithm.

In this case, the chromosome is formed by the following parameters that correspond to the tuning parameters: k_p, k_i – for PI control algorithm; k_p, k_i, k_d – for PID control algorithm [2].

The objective function is proposed to be settled according to the settling time that was proposed to be equal with 2 seconds.

The obtained results of tuning the PID controller by the genetic algorithm were compared with maximum stability degree method with iterations (MSD).

The values of the tuning parameters of the PI and PID control algorithm are presented in the Table I and the obtained performance of the automatic control system is presented in the Table II.

TABLE I. TUNING PARAMETERS

No	Controller	Method	Iterations	Tuning parameters		
				k_p	k_i	k_d
1	PI	GA	200	4.891	1.07	
2	PI	MSD		1.64	0.46	
3	PID	GA	55	20.402	4.58	9.12
4	PID	MSD		10.226	4.07	5.29

TABLE II. PERFORMANCE OF AUTOMATIC CONTROL SYSTEM

No	Controller	Method	Performance of the system			
			t_r	t_s	σ	λ
1	PI	GA	1.39	4.56	12.044	1
2	PI	MSD	3.66	11.55	3.55	1
3	PID	GA	0.55	2.00	3.99	1
4	PID	MSD	0.93	5.039	7.83	1

The simulation results of control system with PI and PID control algorithms are presented in the Fig. 4 and 5, where curve 1- for the case of tuning the controller by the genetic algorithm, curve 2 – for the case of tuning the controller by the maximum stability degree method with iterations.

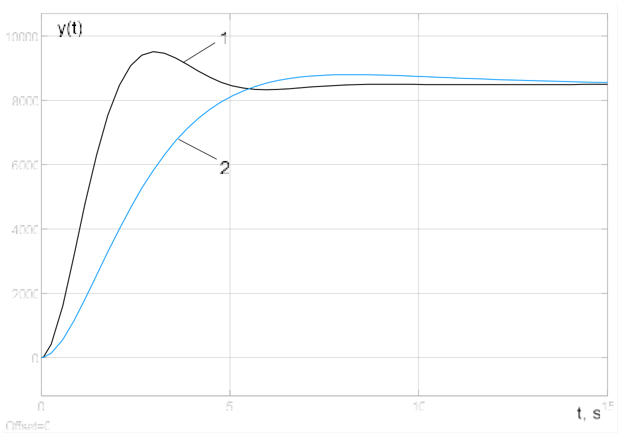

Fig. 4. The step responses of the control system with control object (1) and PI control algorithm

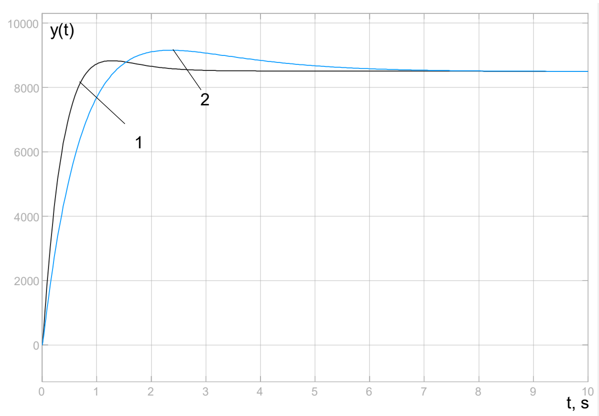

Fig. 5. The step responses of the control system with control object (1) and PID control algorithm

In the Fig. 6 and 7, it is presented the distribution of poles and zeros of the closed loop system with PI and PID controller in the complex plan, where the numbering of the poles 1- for the case of tuning the PI controller by the genetic algorithm, 2 – for the case of tuning the PID controller by the maximum stability degree method with iterations.

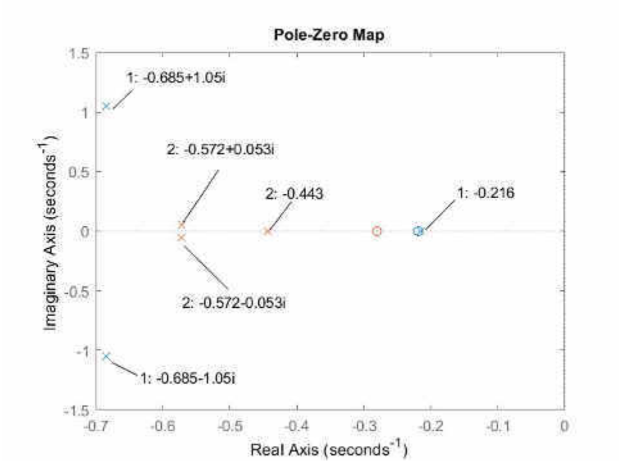

Fig. 6. The distribution of poles-zeros of the closed loop system

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with PI controller

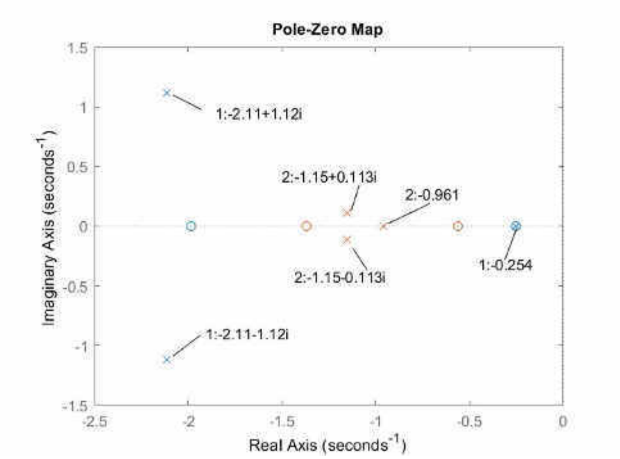

Fig. 7. The distribution of poles-zeros of the closed loop system with PID controller

IV. CONCLUSIONS

In this work, it was proposed to use the genetic algorithm for speed control of the DC motor. As DC motor it was proposed to use the FK130SH motor and the system was implemented based on the NUCLEO-F303K8 platform from ST Microelectronics. It was done the experimental identification of the mathematical model, that approximates the dynamics of the DC motor and to the obtained model of object was tuned the PI and PID controller by the genetic algorithm. It was done the comparison of the obtained results with maximum stability degree method with iterations.

Analyzing the obtained results, it was observed that for the case of tuning the PI and PID controllers by the genetic algorithm it was obtained the transient processes that satisfied the imposed performance. But for the case of using the MSD method the control system didn't satisfy the imposed performance, but it has the higher robustness in comparison with genetic algorithm.

ACKNOWLEDGMENT

This work was supported by the project 20.80009.5007.09 "Elaboration and launches of the nanosatellites series with research missions from the International Space Station, the monitoring and its post operation, promotion of space technologies".

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