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Design of Control Systemfor DC motor

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ABSTRACT: *This document describes the procedure carried out to find transfer function of a DC motor by means of the system identification technique from speed data obtained,, and by means of mathematical modeling, taking into account the parameters of the DC motor. Then, PIDcontroller for the speed of the system is designed by finding the constants Kp, Ki and Kdwith the help of Sisotool tool from MATLAB®. Finally, controller is tuned and its correct operation is verified.*

KEYWORDS –*Controllers design, DC motor, PIDcontrol,sintonization,transfer function,*

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I. INTRODUCTION

Overthepastfewyears, mechanization of productionprocesses, manufacturing, and othersectors of theeconomy and modernindustryhavesought a goal, to free manfromexcessivephysicaleffort and toincreaseeffectiveness, speed, and profitability of each of thesesectors. Alltheseneedshavegivenrisetosignificantimprovementsusingelectronic, electrical, pneumatic and hydraulicdevices [1]. Whichhaveachievedexcellentresults in terms of informationprocessing and storagecapacity, speed and agility in repetitiveprocesses and durability of thematerialsused in automatedsystems [2].

On the other hand, the controllers defined as additional elements in the initial configuration of a system, are intended to improve the characteristics of the response of the system, in order to meet the specific operating requirements of the original system [3]. These specifications must be met in a stable state and in a transitory state.

One of the first step carried out is the gain adjustment, which corresponds to the constant or proportional control, however, modifying this characteristic alone is not enough to comply with the optimal operation of the system, so other elements must be added or controllers. There are three types of controllers, the proportional (P), the integral (I) and the derivative (D) [3].

Controllers can complement each other, taking into account the requirements of the system. In this case, a PID controller is designed to control the speed of DC motor. This type of control is the most common due to its simplicity and high functionality that applies to almost all control systems, especially when the mathematical model of the plant is not known [4].

The general configuration of PID controller is found in figure 1, where it can be stated that it´s a closed-loop system that uses a sensor to feedback the system. The function of this feedback is to compare the output with the reference, that is, with the desired behavior, so that, if necessary, the correction of the controlled process is carried out and an optimal output is obtained.

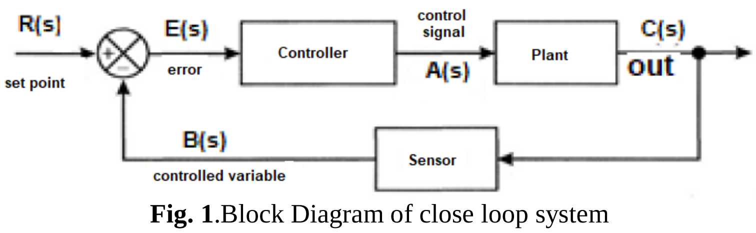

Fig. 1.Block Diagram of close loop system

DC motor is a dynamic system that transforms electrical energy into mechanical energy. To drive a DC motor it´s necessary to apply a supply voltage. They are widely used for their high functionality in motion generation, robotics, automation, among others [5]. Figure 2 shows relationship between electrical component and mechanical component that generates movement of DC motor.

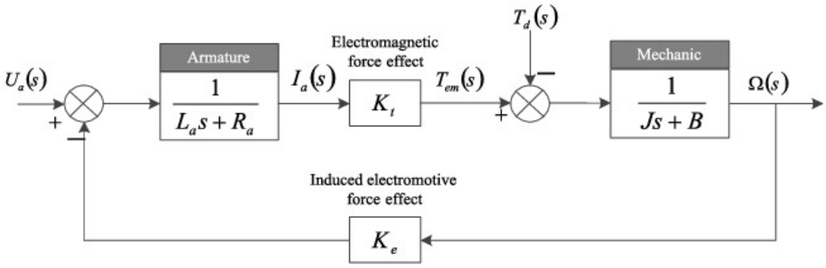

Fig. 2. Relation between electrical and mechanical components of DC motor

Once the controller has been identified, it´s important to mention that there are various design methods, including Ziegler Nichols Tuning rules, which is based on the response of the open-loop system to a step signal [6].

Use of sensors in technology, both in the industrial and domestic fields, the measurement of mechanical, thermal, electrical and chemical magnitudes has become common in sectors such as automated industries, robotics, experimental engineering, energy saving, environmental control, automobiles, electrical appliances, computers, are tasks that would be unthinkable without the application of sensors [7].

II. METHODOLOGY

A. Motor parameters

First phase consists of analyzing parameters of DC motor. Table 1 lists these parameters so that they can be used in mathematical modeling.

Table 1. Motor´sparameters

Parameter	VALUE
Inductance(L)	70e-3 H
Resistance(R)	2.7 Ω
Torque constant (Kt)	16.4e-3 N.m/A
fem constante (Ke)	16.4e-3 V/rad/s
Inertia momento (J)	0.44e-3 Kg.m^2
Viscousfrictionconstant (B)	1.93-3 N.m.s/rad
Tau	0.23 s
Angular speed (wn)	200 RPM
Nominal Voltage (Vn)	6 V
Nominal Torque (Tn)	34.5e-3 N.m
Nominal Current (In)	0.48 A

B. Data Acquisition

Once theory has been reviewed and the DC motor parameters considered, system data is acquired. In this case, three variables are modified, these are Sampling time, Duration and Voltage.

In order to have an orderly way of acquiring data, fixed voltage is established, initially 3V, and then modifying sampling time by 20 ms, 50 ms and 100 ms, with 3 seconds of duration.

Once these data are available, voltage is increased to 5 V and 6 V, varying sampling time in the same way. Finally, nine data tables are obtained that relate time to output of the system, which is DC motor speed.

In order to design appropriate PID controller for the system, and to get specific requirements, two methods are used to find transfer function of the system, which are briefly described below: Mathematical modeling, which uses DC motor parameters theoretically. Transfer function is found when output of the system is the speed. Taking transfer function as equation (1), DC motor parameters are replaced, obtaining in equation (2) transfer function proper to this DC motor.

$$\omega(s) = \frac{K_m}{LJs^2 + (RJ + LB)s + RB + K_m K_e} \qquad (1)$$

$$\frac{\omega(s)}{v(s)} = \frac{0.0164}{3.08e-05\ s^2 + 0.001321\ s + 0.005399} \qquad (2)$$

Once transfer function is obtained, it´s necessary to proceed to check it in MATLAB®, for this, theoretical nominal voltage is applied as input, that is, 6 volts, and it´s observed that output corresponds to the angular speed theoretical motor, in this case approximately 180 RPM.

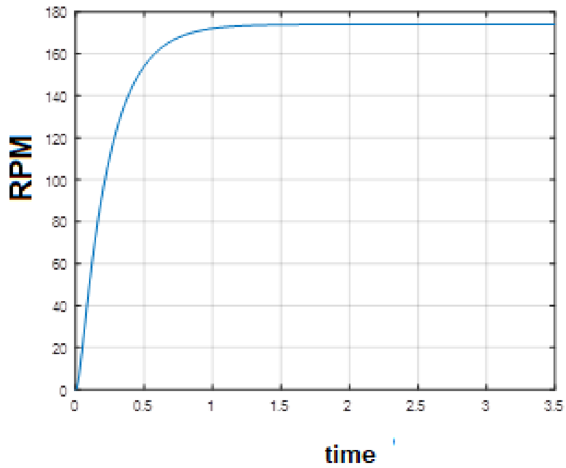

Fig. 3. Verification of transfer function found by mathematical modeling.

Identification of systems uses data obtained in data acquisition, which contains values of time and motor speed for each case. In the identification of systems, data is processed through MATLAB®. Data is imported and transfer function is created from them, entering the number of poles and zeros desired. Transfer function that has a high percentage in the best data fit is probably the closest representation.

In this case, transfer function was found for each of the data obtained in data acquisition. Three of them are shown below in equations (3), (4) and (5), since, in general, equations are of the same order. It was taken into account that adjustment percentage was above 80%, which is an acceptable value:

- Ts = 20 ms, Duration = 3 seconds, Voltage = 3V, *BestFit* = 88.01 %

$$G1 = \frac{2.704}{s + 0.09575} \qquad (3)$$

- Ts = 30 ms, Duration = 3 seconds, Voltage= 3V, *BestFit* = 91.16 %

$$G2 = \frac{6.246}{s + 0.2318} \qquad (4)$$

- Ts = 20 ms, Duration = 3 seconds, Voltage= 5V, *BestFit* = 82.75 %

$$G3 = \frac{0.8572}{s^2 + 0.318\, s + 0.02985} \qquad (5)$$

For controller design, data is processed in MATLAB®. With system transfer function, design is done using Sisotool tool. Characteristics that system response must have are created.

For the case of transfer function found with mathematical modeling, information of the function is analyzed against a step input. These data are shown in table 2:

Table 2. Informationforstep input

CHARACTERISTICS	VALUE
RISETIME	0.4861
SETTLING TIME	0.8829
SETTLINGMIN	2.7341
SETTLINGMAX	3.0323
OVERSHOOT	0
UNDERSHOO	0
PEAK	3.0323
PEAKTIME	1.4159

When wanting to improve these response values, it was decided to make them faster, so lower values listed as follows were introduced as parameters for the control design:

Rise time = 0.2 s
Settling time = 0.6 s
Overshoot percentage <5%

By means of Sisotool, values of the constants were found as follows: Kp = 0.977, Ki = 4.11, Kd = 0.0262. Then, they are entered into transfer function for PID controller, as presented in equation (6).

$$C = \frac{0.026211(s + 32.42)(s + 4.836)}{s} \quad (6)$$

To check that system works correctly, block diagram is implemented in Simulink with controller and a small disturbance as shown in figure 4.

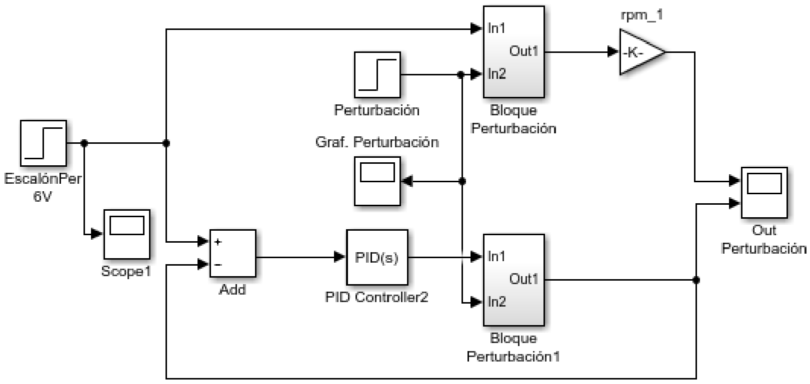

Fig.4. Configuration in Simulink to test controller with transfer function found with mathematical modeling.

III. RESULTS AND DISCUSSIONS

As shown in equation (6), response of the system with disturbance and without control, DC motor shuts down, but when controller is included, signal is initially lowered, but PID acts and manages to carry the signal of output to desired value, in this case 6volts of the input step, as can be seen in figure 5.

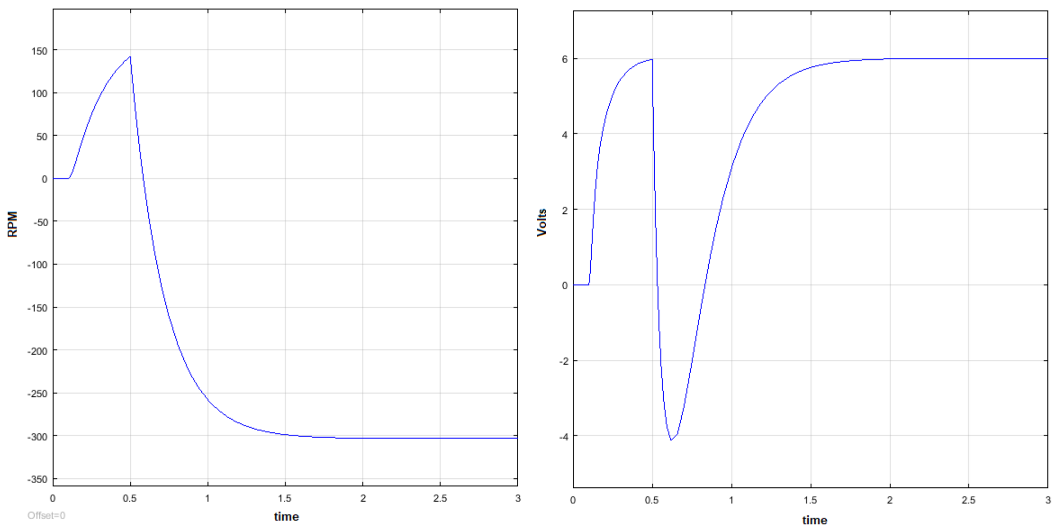

Fig. 5. System Output withdisturbance. No controller (left). Withcontroller(right).

Controllers designed using system identification method for transfer function, have very similar values in their constants. Table 3 lists values found for G1, G2 and G3, in that order. Figure 6 shows response of the controller with gains G1 and G2, and Figure 7 shows response of the system with G3.

It´s important to remember that time response of a control system consists of two parts: the transient response and steady state response. Transient response refers to the one that goes from initial state to the final state. By steady state response we mean the way the output of the system behaves as t tends to infinity [8].

Table 3. PID Controllerconstants

Kp	Ki	Ki
3.66	0.0088	0
0.084	0.0143	0
0.0935	0.0096	0.227
2.5	1	0

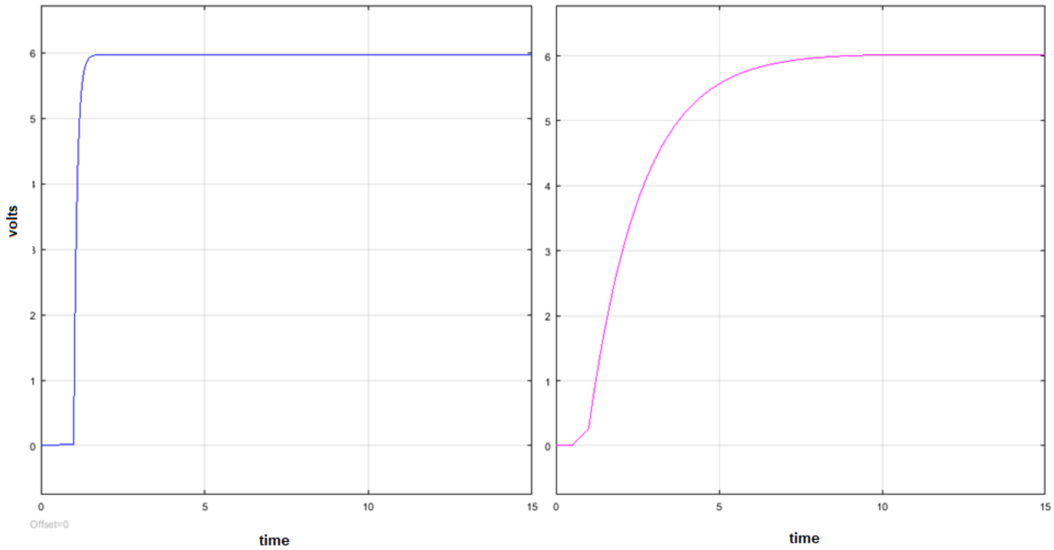

Fig. 6. System response withcontrollerusingconstants G1 and G2.

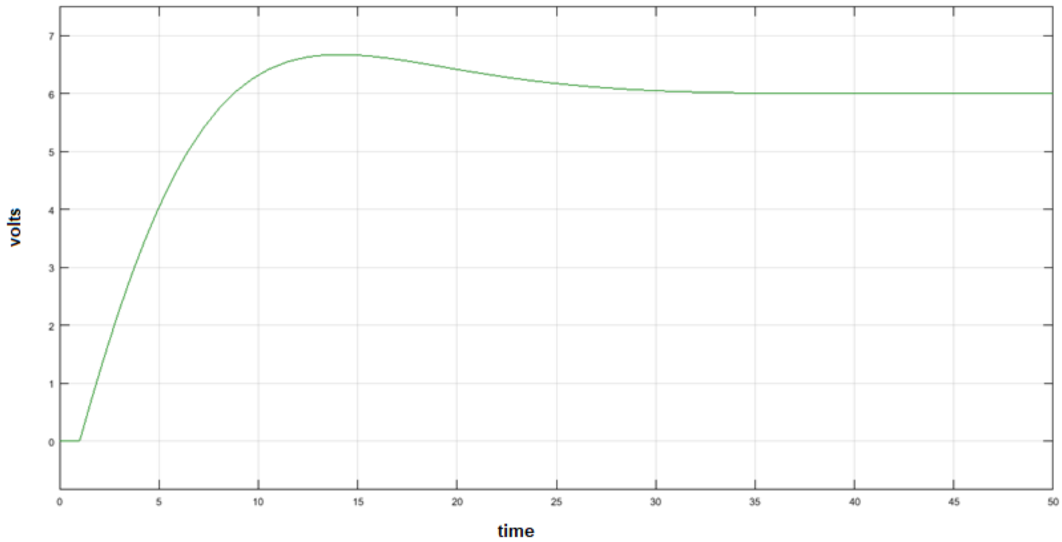

Fig. 7. System response withcontrollerusingconstant G3

As shown in figures above, first two controllers behave in a suitable way, causing DC motor to reach voltage signal of the input, in this case 6 volts, however, controller of G2 is slower, which doesn't make it that efficient. Last controller is much slower, and signal stabilizes in approximately 35 seconds, which causes DC motor to take a long time, and in an application where process is required to be fast, it could not be applied.

Once the controllers are designed, proceed to tune constants in DC motor and analyze behavior of the real system. To perform these tests, setpoint value is set at 1000, this means that reference speed is a square wave between 50 and 100 RPM.

a) First, controller constants are tested for transfer function found with mathematical modeling, as shown in Figure 8.

Fig.8. System response forcontrollerdesignedwithmathematicalmodeling transfer function.

Speed (red) does follow speed reference, however it doesn´t do so perfectly, but it does follow reference speed relatively quickly. This indicates tha control action is working.

a) Now, introducing constants with systems identification transfer function.

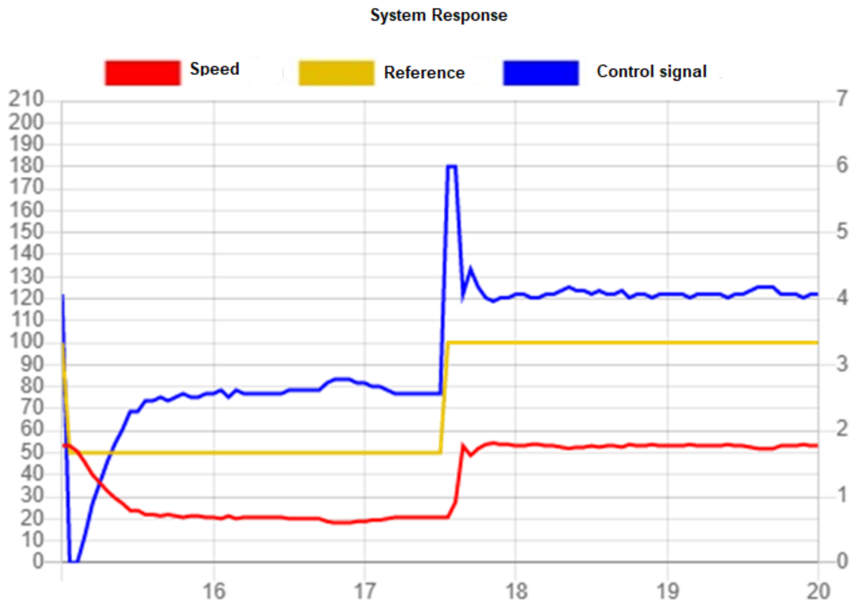

Fig. 9. System response forKp = 3.66 and Ki = 0.0088.

In figure 9, speed fails to reach reference value that it must follow, although it follows the waveform, it doesn´t reach desired revolutions.

Finally, with controller whose constants are of a very low value, DC motor doesn´t start, control action is very low, and it doesn´t manage to control movement of DC motor, so this controller doesn´t actually fulfill its function. Figures 10 and 11 show that speed is not controlled either, since it doesn´t follow reference.

Fig. 10. System response forKp = 0.084 and Ki = 0.0143.

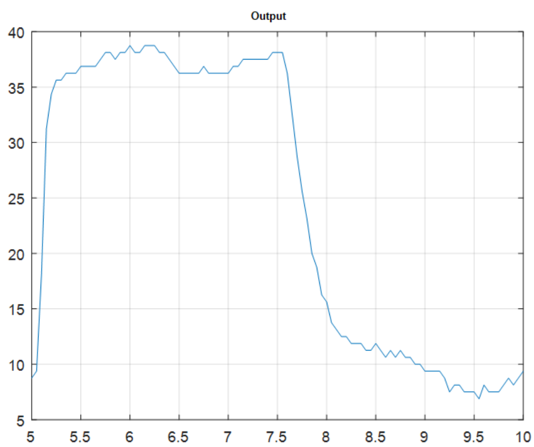

Fig. 11. System response forKp = 0.084 and Ki = 0.014

Finally, as a random test, and observing behavior of the signals with designed controllers, constants are modified again, but randomly, in the same order in which system should work visually. The following values were entered:

$$Kp = 2.5, Ki = 1, Kd = 0$$

And it was obtained as a result that speed of the system tries to follow reference, and control action works by helping speed of the system to follow reference.

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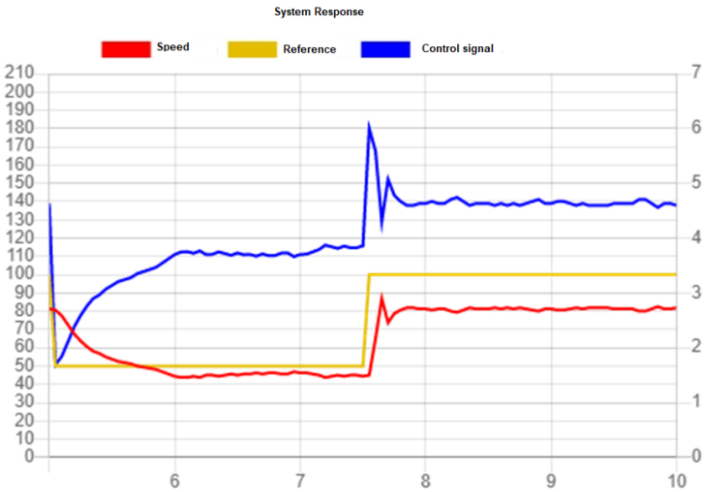

Fig. 12. System response forKp = 2.5 and Ki = 1.

IV. CONCLUSIONS

It´s important to know DC motor parameters so that transfer function is adjusted as possible to the behavior of the system, since this guarantees that output signal will be the desired one, or very close to the ideal values.

When data analysis is done, it´s important that they are taken in an orderly manner and that it´s taken into account that number of samples influences the adjustment of transfer function, since, when obtained in a graphical way, several important data describing the proper behavior of the system signals.

For system identification process, it´s important that data contain dynamics of the system, so it´s appropriate that variations are made in terms of speed changes, both in slow responses and in fast responses of the DC motor. This tool is very useful to find linear model of DC motor, since data comes from actual operation of the machine.

Controllers design must be tested with simulation tool that gives an approximation of how the system would actually work, and factors such as external disturbances, their amplitude, and reaction time must be taken into account within the simulation that DC motor should have, as this depends on the application for which it´s being designed.

After testing controllers, it´s concluded that only control action of two of them works properly. The system with controller that best follows reference speed is the one designed from the DC motor parameters, this because, having them, transfer function adjusts much more to the behavior of the system, therefore, controller will be more efficient and it will control speed better in the event of a disturbance.

When transfer function is found from data obtained, and controller is designed, it should also respond appropriately by making DC motor speed follow reference, however, it must be taken into account that the amount of data taken influences considerably. If little data is collected, not enough information is available for the model to fit the system.

Constants being of a very small value are not enough to control the system. Once designed constants were tested, random variation of the constants was performed, tuning controller with values close to those of the controller that did work. It could be observed that when increasing Ki and decreasing the value of Kp, speed tends to follow reference, and it´s tested with random values, in this case Kp = 2.5, Ki = 1 and Kd = 0.

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