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DESIGN AND SIMULATION OF MODEL-FREE LAG-LEAD CONTROLLER FOR DC MOTOR SPEED CONTROL

MONJENGUE, DAVID
RUA DE SANGA, Q.34, CASA 20, ZIMPETO
MAPUTO-MOZAMBIQUE
E-MAIL: bmonjengue@yahoo.com
TEL: 258 842854173

ABSTRACT

This paper presented a new Model-free Controller for speed control of Direct-Current (DC) motors. The design objectives were to combine the benefits of proportional-integral-derivative (PID) controllers (simplicity in the structure and the usage) and performances of the advanced controllers such as linear-quadratic regulator (LQR), Fuzzy Logic Controllers (FLC), with the advantage of not depending on the model. The Model free Lag-Lead controller (MFLL) is compared against the Fuzzy, LQR, PI controllers for speed regulation of DC Motor and showed the ability to produce better performances. The MFLL is also easy to design and to tune without any special rule, and can be implemented by non-professional.

KEY WORDS: Direct current (DC) motor, Fuzzy Logic controller (FLC), Linear-quadratic regulator (LQR), Model-free controller, Proportional Integral Derivative controller (PID).

INTRODUCTION

The fast development of Technology and the growing usage of its applications in industry as well as for domestics use, such as Electro-mechanics home appliances, Electric Vehicles, robotics, machines tools etc., play an important part of the global world development.

Many of these applications used DC motors and demand adjustable speed regulation, frequent starting, braking and reversing. To match these demanded industrial criteria a robust and high-performance motor control system should be designed (Mohammed, & Abdulla, 2018).

DC servo-motor systems are indispensable in modern industry. Although many advanced control techniques such as Self turning control, model reference adaptive control, sliding mode control and fuzzy control, have been proposed to improve systems performances, the conventional PI/PID controllers are still dominant in majority of real world servo-systems (Bindu & Namboothiripad, 2012, Li & Tsang, 2007). This is because of their simple structure and robust performances in a wide range of operation conditions (Loucif, 2005).

Gédouin and Al (2011) said, in order to realize the process control, part of the process modelling represents 90% of the project global time and requires a true know-how in control and about the process to be controlled. Besides that, precise mathematical model of the system is very hard to obtain.

Model-free control is a convenient approach for application in industry where systems are much more complex than models in the laboratory due to some unpredictable effects, such as changes of environment (Xu & Al, 2013).

The rapid development of science and the increase need of technology in day to day activities implies the development of new types of controllers that should be simple and efficient, easy to use for all categories of users from expects to neophyte. PID controllers are suitable for the industry, but the tuning of the parameters is not straightforward and need many tries. Manual tuning of PID is very tedious; we need to find the value of three parameters, which increase the complexity of the manual search.

The Model-free controller we intended to designed here aimed to have an easy to use and implement controller as PID, simple in structure, which can be easily tune manually to reach good performance (compare to performances obtained with advanced controllers), the tuning complexity should be smaller compare to PID.

The objectives of this study are:

- Design a model-free controller for speed control of DC motor which should combine the advantages of PID controllers in terms of simple structure and easy to tune;
- The controller´s performances should be good compare to advanced techniques, which shall be taken as the based for our comparison. (The performances to reach or to overpass).

II. Model free Lead-Lag Compensator (MFLL)

It is common in control system to make the controller inside the closed loop system. In this way, the controller will react to any changes in the output.

The Model Free Lead/Lag controller is different because; it reposes on the idea of conditioning or modifying the input signal (the reference) so that it will force the closed loop system to produce the desired output.

The Lag/Lead compensator is used for the purpose of conditioning the input signal of the DC motor.

Let $G_{NL}(s)$ be the transfert function of the DC motor system.

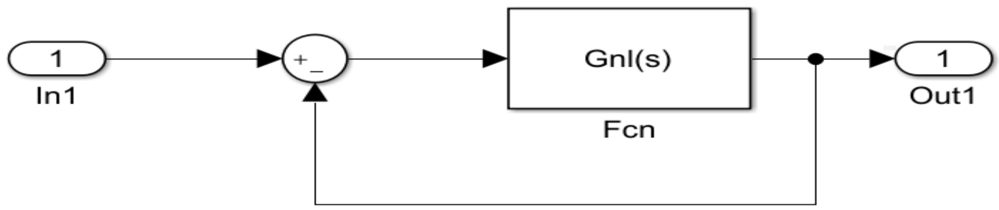

Figure 1: Close-loop system

Assumption

1- The closed-loop system is stable;
2- The system is assumed to be linear.

Applying the final value theorem on the system, we have:

$$\lim_{s \to 0} s.\frac{G_{NL}(s)}{1+G_{NL(s)}} = L \qquad (1)$$

L: is a positive non null number ($L \in R_+^*$).

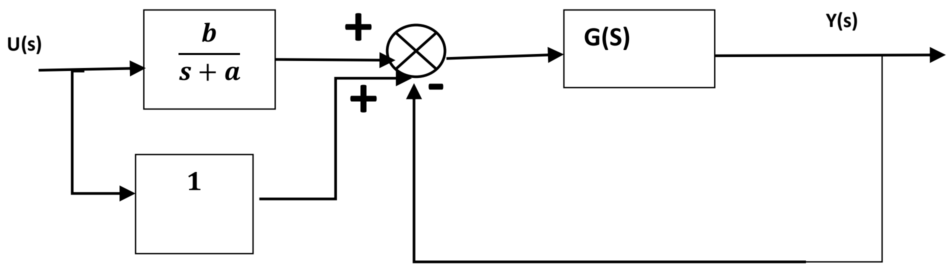

Figure 2: Close-loop system with compensator

The transfer function of fig.2 is:

$$\frac{Y(s)}{U(s)} = \frac{s+a+b}{s+a} * \frac{G_{NL}(s)}{1+G_{NL(s)}} \quad (2)$$

Stability Analysis

The system is stable:

$$\text{If } \begin{cases} \frac{G_{NL}(s)}{1+G_{NL(s)}} stableand \\ \frac{s+a+b}{s+a} \; stable \end{cases} \quad (3)$$

$\frac{G_{NL}(s)}{1+G_{NL(s)}}$is stable (our initial assumption)

$\frac{s+a+b}{s+a}$ is stable if $a \geq 0$

The compensator can be a Lead or a Lag compensator depending on the value of the parameters "***a***" and "***b***".

Determining Lead-lag parameters (a, b)

Applying the final value theorem to (2), we obtain:

$$\lim_{s \to 0} s. \frac{s+a+b}{s+a} . \frac{G_{NL}(s)}{1+G_{NL(s)}} . \frac{1}{s} = \lim_{s \to 0} s. \frac{G_{NL}(s)}{1+G_{NL(s)}} . \frac{s+a+b}{s+a} = V_f$$
(4)

(1) In (4) gives:

$$V_f = \frac{L(a+b)}{a} \rightarrow V_f . a = L. a + L. b \leftrightarrow b = a. \frac{(V_f - L)}{L}$$
(5)

If we want the output (V_f) to follow the reference input (V_{ref}), then (5) becomes:

$$b = a. \frac{(V_{ref} - L)}{L}$$
(6)

This value of "b", guarantees that $V_f = V_{ref}$, whatever is the value of "a".

(6) shows that to find the value of "b", we need to know the value of "a" and "L".

Since "a" and "b" are our controller parameters, we can fix the value of "a" and determine the value of "b". The only external parameters to our controller is "L". When the system operates without any controller then its final value is the value of "L", assuming the system is stable.

The parameter "a" is then the only parameter necessary to be tuned in order to have the system reach desired specifications.

The designed controller has a simple structure (easy to implement and only one parameters needs to be tuned), does not required to know system parameters, only the final value of the system closed loop.

III. Results/Simulations

The simulation was conducted using DC Motor parameter model as described by P. Kumar (2017), the software used was Scilab:

Armature inductance (L) = 0.1215 H

Armature resistance (R) = 11.3 Ω

Mechanical inertia (J) = 0.02215 Kg.m2

Friction coefficient (B) = 0.002953 N-m/rad/sec

Back emf constant K_b= 1.28 V/rad/sec

Motor torque constant K_t= 1.28 N.m/A

The open loop transfer function is given by:

$$G(s) = \frac{1.28}{0.002691s^2 + 0.2507s + 1.672}$$

Test 01

<u>*Controller parameters*</u>:

$a = 1; L = 0.43;\ \ b = 1.30625\ (from\ eqs. 6)$

The below figure shows the step response obtained.

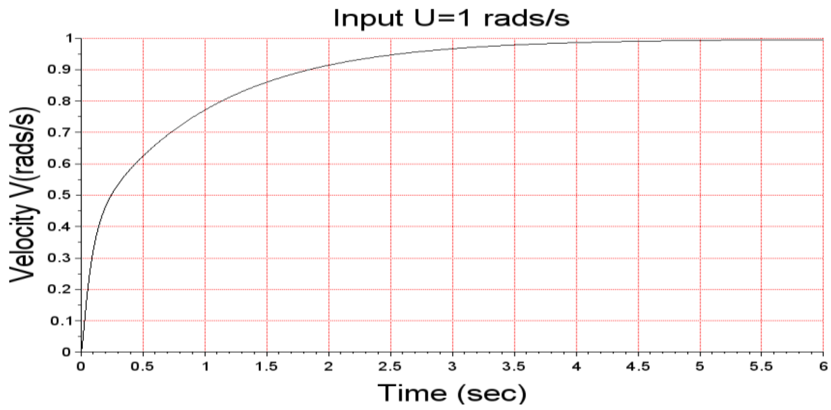

Figure 3: Step response of the system with the model free controller.

Test 02

The parameter of "$\boldsymbol{a}$" was increased in order to increase the system performances.

<u>*Controller parameters*</u>:
$a = 5; L = 0.43;\ \ b = 6.53125\ (from\ eqs. 6)$

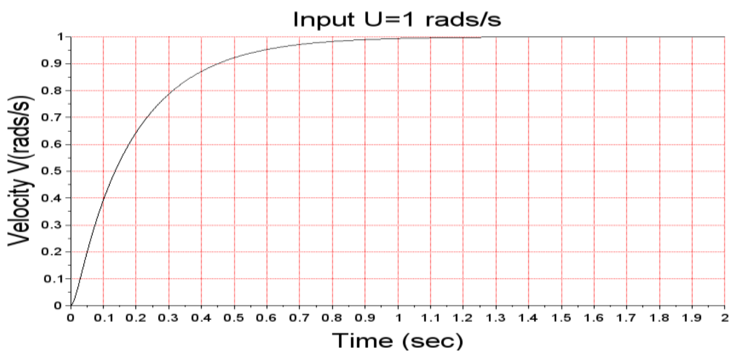

Figure 4: Step response of the system with the model free controller after refining the parameter "a".

The below table is a comparative table for the performances of three controllers, Fuzzy logic, LQR controllers as designed by P. Kumar (2017) and the model free controller proposed in this study.

Table 1: Comparative table on different controllers

Parameter	**Fuzzy**	**LQR**	**MFLL (simulation 1) a=1, b=1.30625, L=0.43**	**MFLL (simulation 2) a=5, b=6.53125, L=0.43**
Tr (s)	0.76	0.498	1.793	0.441
Ts(s)	2.62	0.881	3.43	0.774
OS (%)	0.008	0	0	0

CONCLUSION

In this study, we designed a new controller based on a Lag/Lead compensator and on model free approach, which has the advantages to be simple structure as PID, no model is required and better performances than advanced controllers like LQR, fuzzy logic etc. The structure of the model-free controller is simple, as it is only a lag/lead compensator attached to the system in a feedback form. The simplicity of this model-free controller is also reinforced by the fact that few parameters need to be tuned in order to reach the desired performances, and parameters for the DC motor used for simulation. The complexity to reach optimum parameters is reduced compare to PID. The design time is minimal and the MFLL can be implemented by hardware or by software. When needed to refine the system parameters to meet some specifications, no need of specialist, as the tuning is only related to the increase or decrease of the parameter "a". The future works will be to make the model-free adaptive to system variation without manual intervention.

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