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Control Of A Dc Motor Using Active Disturbance Rejection

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ABSTRACT:

This paper presents the design of a proportional integral derivative control strategy applied to the speed control of a direct current motor, this was measured the ability of the system to follow a reference signal of step type. The measurement was made in the frame of the mean square error percentage where the degree of the polynomial with which the disturbance is approximated was varied, giving as a result for m=2 a mean square error percentage of 2.35%, for m=4 a mean square error percentage of 1.23% and finally for m=6 a mean square error percentage of 0.87%.

Keywords: Active disturbance rejection, control, modeling, speed control, tracking error

INTRODUCTION

Due to the variety of technical configurations, direct current (DC) motors are an integral part of various applications and are used in different industries (Guerrero et al., 2020). Especially the relatively simple speed and torque control, precise controllability and efficiency enable a wide range of applications (Zhu, 2022). As a conventional and proven motor type, brushed DC motors require few or no external components, which also makes them more useful under harsh environmental conditions (Sahana et al., 2016). Suitable applications include rotating and grinding machines, conveyor systems and vacuum cleaners. In addition, brushed DC motors can be used to drive compressors, rotating machines and elevators (Buzi & Marango, 2013; Lu Renquan et al., 2008; Mozaffari Niapour et al., 2014; Sadiq et al., 2013). For the case study a DC motor with a constant magnetic field is presented as shown in Figure 1.

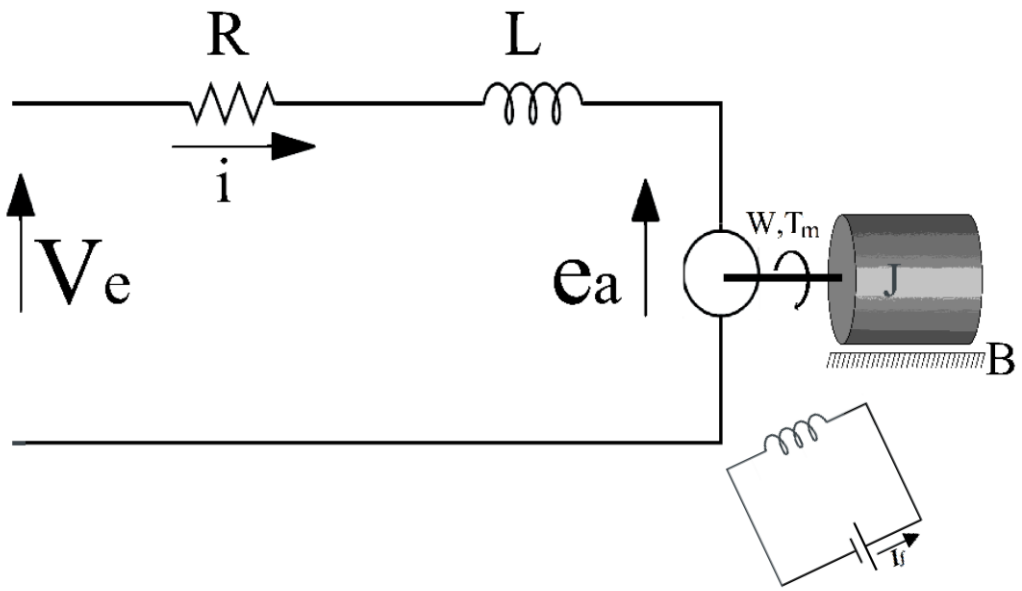

Figure 1. Schematic diagram of direct current motor

MATERIALS AND METHODS

This section presents the mathematical model of the DC motor, figure 1 shows the schematic diagram of a direct current motor where the DC motor armature is modeled as having a constant resistance R in series with a constant inductance L representing the inductance of the armature coil, and a power supply V, representing the voltage generated in the armature, which for this case R=0.8Ω,L=750mH. Where E_a (t) is the counterelectromotive force, by applying Kirchhoff's voltage law the circuit equation is as follows.

$$v(t) = Ri(t) + L\frac{di(t)}{dt} + E_a(t)$$

$$L\frac{di(t)}{dt} = v(t) - Ri(t) - E_a(t) \quad (1)$$

The equation of the mechanical section is given by the model

$$T_m(t) = J\frac{d\omega(t)}{dt} + B\omega(t)$$

$$J\frac{d\omega(t)}{dt} = T_m(t) - B\omega(t) \quad (2)$$

Where $T_m(t)$ is the torque of the DC motor, B is the coefficient of friction equivalent to the DC motor and load mounted on the motor shaft, J is the total moment of inertia of the rotor and load relative to the motor shaft, ω(t) is the angular velocity of the motor and $\frac{d\omega(t)}{dt}$ is the angular acceleration. For this case B=0.15N.m.s, J=0.01Kg.m^2

The angular velocity has a direct relationship with the counterelectromotive force, this is given by equation 3 where K_a is known as the counterelectromotive constant which in this case is $K_a = 2.8 \times 10^{-3} \frac{V}{rad/s}$.

$$E_a(t) = K_a\omega(t) \quad (3)$$

In the same way the current has a direct relationship with the touch given by equation 4 where K_m is the torque constant which in this case is $K_m = 1.2 \times 10^{-3} \frac{N.m}{A}$.

$$T_m(t) = K_m i(t) \quad (4)$$

Moving to the frequency domain, applying the Laplace transform, the transfer function of the angular velocity as a function of the input voltage is given.

$$\frac{\omega(s)}{V(s)} = \frac{K_m}{LJs^2 + (RJ + LB)s + RB + K_m K_a} \quad (5)$$

Thus the transfer function of the proposed DC motor is given by:

$$\frac{\omega(s)}{V(s)} = \frac{0.0012}{0.0075s^2 + 0.1205s + 0.12} \quad (6)$$

GPI CONTROL DESIGN AND SIMULATION RESULTS

According to (Regino et al., 2019) equation (5) has the structure of a perturbed linear system represented by equation 7, where $\kappa = \frac{Km}{L.J}$ and $\xi(t)$ groups the unmodeled dynamics, endogenous and exogenous perturbations of the system (Lee & Kwok, s/f).

$$y^{(n)}(t) = \kappa u(t) + \xi(t) \quad (7)$$

For the generalized proportional-integral (GPI) control strategy the control action U is given by equation 8 (Regino-Ubarnes et al., 2019).

$$U = \frac{1}{\kappa}\left[y^{*(n)} + \left(\frac{K_{n+m}s^{n+m} + \cdots + K_1 s + K_0}{s^{m+1}(s^{n-1} + K_{2n+m-1}s^{n-2} + \cdots K_{n+m+1})}\right)(y^* - y)\right] \quad (8)$$

Where n represents the order of the system, which in this case n=2, m is the order of the polynomial with which the disturbance is approximated, y^* is the reference signal and y is the output of the system, which in this case is the angular velocity of the direct current motor. Initially the control strategy will be designed for an order of the polynomial of approximation of the disturbance m = 2, then equation 8 is as follows.

$$U = \frac{1}{\kappa}\left[y^{*(2)} + \left(\frac{K_4 s^4 + K_3 s^3 + K_2 s^2 + K_1 s + K_0}{s^3(s^1 + K_5)}\right)(y^* - y)\right] \quad (9)$$

Figure 2 represents the system response to a step-type signal, where the poles of the characteristic polynomial are [-7.5 -12.5 -17.5 -22.5 -22.5 -27.5 -30]. To measure the signal tracking, the percent mean square error (PECM) between the reference signal data and the output was applied resulting in a percent error of 2.35%.

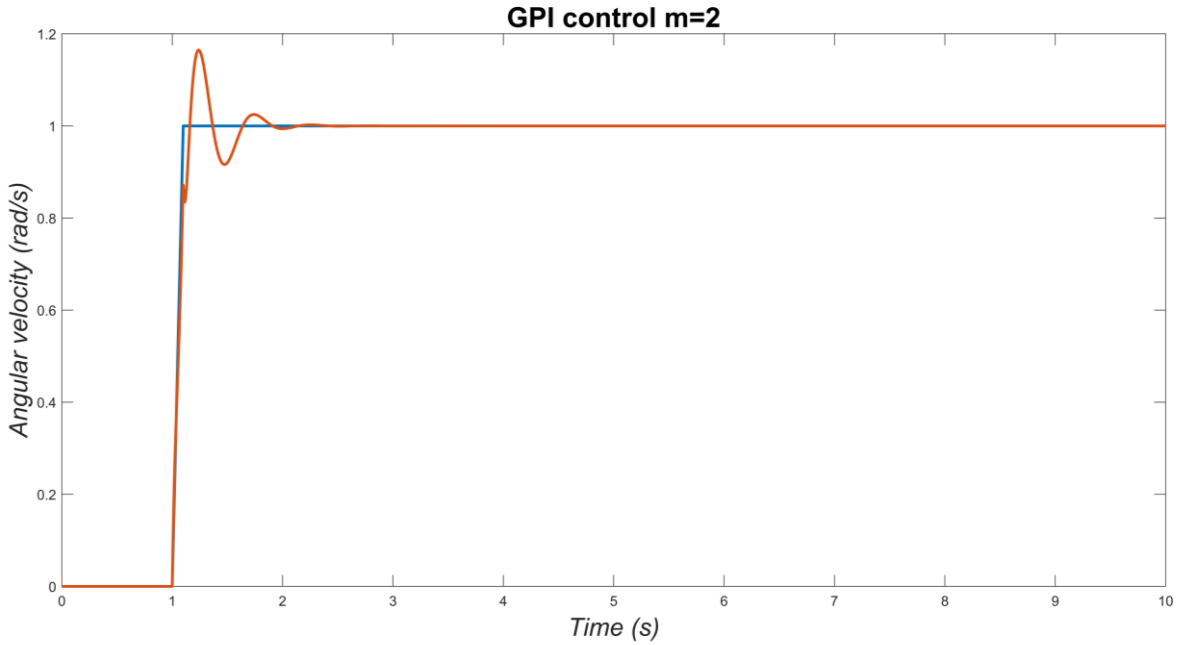

Figure 2. The system response to a step-type signal for m=2

The control strategy for an order of the polynomial of approximation of the perturbation m=4, is as follows.

$$U = \frac{1}{K}\left[y^{*(2)} + \left(\frac{K_6 s^6 + K_5 s^5 + K_4 s^4 + K_3 s^3 + K_2 s^2 + K_1 s + K_0}{s^5(s^1 + K_7)}\right)(y^* - y)\right] \quad (10)$$

Figure 3 represents the system response to a step type signal, where the poles of the characteristic polynomial are [-15 -25 -35 -45 -55 -55 -60 -65 -70], resulting in an error percentage of 1.23%.

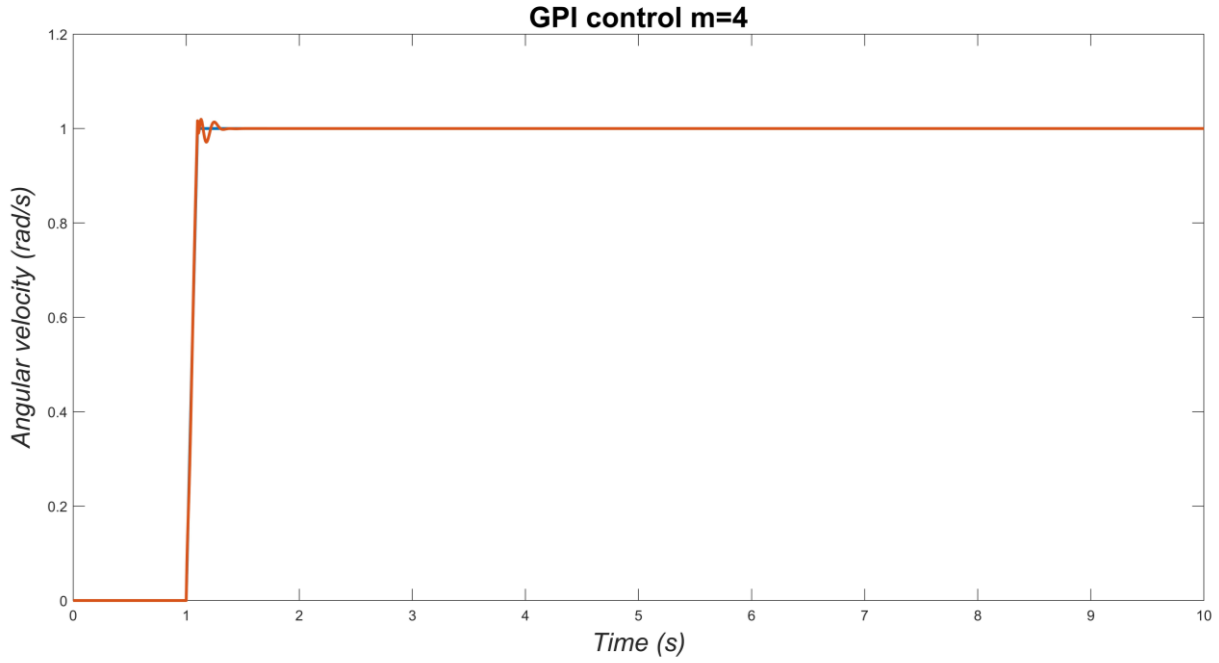

Figure 3. The system response to a step-type signal for m=4

The control strategy for an order of the polynomial of approximation of the perturbation m=6, is

as follows.

$$U = \frac{1}{K}\left[y^{*(2)} + \left(\frac{K_8 s^8 + K_7 s^7 + K_6 s^6 + K_5 s^5 + K_4 s^4 + K_3 s^3 + K_2 s^2 + K_1 s + K_0}{s^7(s^1 + K_9)}\right)(y^* - y)\right] \quad (11)$$

Figure 4 represents the system response to a step type signal, where the poles of the characteristic polynomial are [-15 -25 -35 -45 -55 -55 -60 -65 -70 -75 -80], resulting in an error percentage of 0.87%

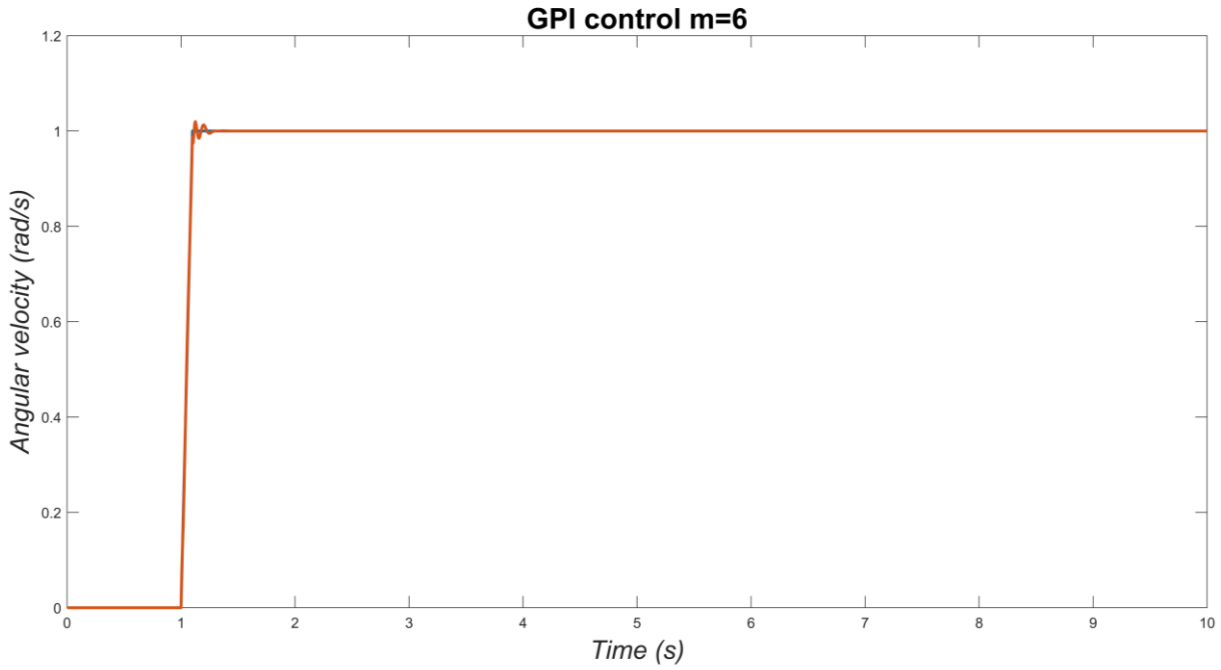

Figure 4. The system response to a step-type signal for m=6

CONCLUSIONS

The control strategies based on the active rejection of disturbances such as GPI control, have substantial advantages over a traditional control strategy such as PID control, this is evidenced in the tracking error, where the GPI control obtained a percentage of mean square error less than unity.

The two control strategies meet the objectives, in terms of parameter variation the GPI control has a superior performance, since with a variation of 50% in the model, the mean square error percentage was less than 3%. This is a good indicator of robustness to the uncertainty that the system model could present.

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