The Analysis of Variations in Peak Time Values With Disturbance on DC Motors Using Robust Tracking Control

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Abstract: DC motors are actuators that have very popular functionality in the industry. DC motors can easily design and implement actuators using robust tracking control methods. This study aims to achieve a stable output signal according to the desired reference and remain robust against interference by using robust tracking. In this research, Matlab R2022a is used for system analysis and simulation. Variations of various peak time values are implemented in the simulation to observe changes in the output signal from the controlled system. The simulation results reveal oscillations within the system due to the utilization of a fourth-order in the robust tracking approach. However, the signal output consistently maintains stability with respect to the desired reference (Ess=0), even when subjected to disturbances. The Simulink results show that the robust tracking method is a successful tracking, even in the presence of disturbances, of the desired reference signal. Therefore, the robust tracking method is well-suited for maintaining system stability while accurately tracking the desired reference.

Keywords: robust tracking, disturbance, DC motor control, peak time, matlab.

1 Introduction

DC motors have easy linear control. Subsequently, they have advantageous functionality and include highly controlled actuators in the industry [1]. Speed and direction/position control are advantages of a DC Motor. This study aims to analyze the output signal through simulation using Simulink within the Matlab application. This

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approach makes the DC motor function as a solid regulator of the output signal in accordance with a given reference, even in the presence of interference.

Some controllers, such as; Fuzzy Logic Controller [2], PID Controller [3][4], and Integral state feedback [5], have been implemented into the DC motor system. Since it is uncomplicated and not difficult to be used in a real hardware system, the PID controller is one of the best-known among other controllers [6], [7], [8]. Integral state feedback is an alternative to a controller with straightforward and easily implementable features for achieving tracking control in a DC motor. The application of integral state feedback has been observed in various systems, including inverters [9], buck converters [10], quadcopters [11], AC induction motors [12], boost converters [13], magnetic levitation systems [14], [15], level control of a two-tank System [16], inverted pendulums [17], and DC to DC converters [18]. Robust control is proposed for two configurations of the DC motor system because of its active disturbance rejection and differential flatness [19].

Robust tracking control involves the design of a controller to generate a stable and robust output signal by almost perfectly tracking the desired reference. This objective holds true even when faced with initial conditions and external interference. The concept of 'almost perfectly tracking' refers to the controller's capacity to reach a reference within a specified settling time, even in the presence of external disturbances and initial conditions [20][21].

2 Research Methods And Controller Design

2.1 Research Methods Result

In this study, the varying peak time values on DC motors are controlled by the robust tracking method to achieve a specified reference signal. The simulations are conducted using Simulink within the Matlab R2022a application. Alterations in the peak time value affect the value of ω_n, which is subsequently utilized in generating the output signal. Additionally, an examination of signals with certain peak time criteria is carried out in the presence of disturbances to observe their output signals. A comparative analysis and discussion of the output results are performed for each simulated peak time, both with and without disturbances.

2.2 Controller Design Result

1) Determination of DC Motor Transfer Function

By utilizing a potentiometer to track the rotation of the DC motor, the Toolbox System Identification in Matlab was used to build a DC motor model. The acquired results, thought to be the most precise fits, reflect the features of the DC motor and produce the following overtone values.

TABLE I. TEST RESULTS FOR THE DETERMINATION OF THE TRANSFER FUNCTION

Gain	Set Point	Best Fits (%)
10	10	1.78
10	15	80.63
15	10	89.05
15	15	92.12

The test's results elucidated that the best-fitting result had an accuracy of 92.12%. The system's obtained transfer function is shown in the following.

$$G(s) = \frac{83.54}{s^2 + 13.81s + 83.54} \quad (1)$$

2) Determination of Robust Tracking Parameters

To achieve the intended performance of the system, system design criteria are established. The system acts as a yardstick for figuring out what is required to bring the initial system into alignment with the intended system. The favoured standards for system design are Peak Time (Tp) is 0.5 seconds, Max. Overshoot (Mp) is 10%, Tracking reference is 1, and Error Steady State (Ess) is 0.

The following attributes can be determined using the design criteria as a guide:

$$M_p = e^{-\left(\frac{\zeta}{\sqrt{1-\zeta^2}}\right)\pi} \quad (2)$$

$$\zeta = 0.59 \quad (3)$$

$$T_p = \frac{\pi}{\omega_n \sqrt{1-\zeta^2}} \quad (4)$$

$$\omega_n = 7.78 \tag{5}$$

$\alpha + \beta = \chi.$ (1) (1)

The conditions for maximum overshoot and peak time variation are taken into account, and it is discovered that the damping constant Equation (3) is equal to 0.59, and the natural frequency constant Equation (5) is equal to 7.78. As a result, the following equation can be used to explain the features of the resulting system Equation (7).

$$s^2 + 2\zeta\omega_n s + \omega_n^2 = 0 \tag{6}$$

$$\alpha_c(s) = s^2 + 9.1804s + 60.5284 \tag{7}$$

We can get it based on robust tracking system equations [22]

$$|sI - F + GK| = s^4 + (10.18 + 60.53\,K_0)s^3 + (69.71 + 60.53\,K_1 + 60.53\,K_0)s^2 + (60.53 + 60.53\,K_{e0} + 60.53\,K_1)s + 60.53\,K_{e1} \tag{8}$$

According to the robust tracking system equation [22], the third and fourth order is required. The desired poles are produced by multiplying by 10x ($-\zeta\omega_n$) and 10x ($-\zeta\omega_n$)+1, and the desired characteristic equation is as follows.

$$\alpha_c(s) = s^3 + 27.5412s^2 + 120.4818s + 347.2968 \tag{9}$$

$\alpha + \beta = \chi.$ (1) (1)

3 Result and Discussion

3.1 DC Motor System Response without Controller

Figure 1 and Table 2 elucidates a DC motor system's signal response without a controller.

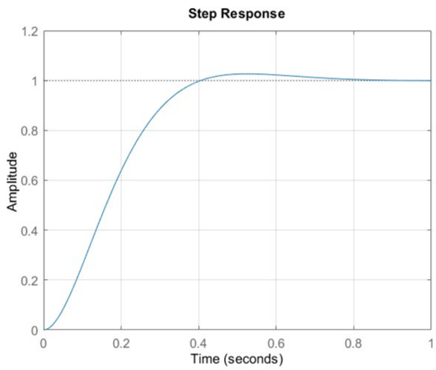

Fig. 1. Signal Response without robust tracking.

The simulations in Matlab elucidate that the response signal can "track" stably at a value of 1, which is the reference signal, with a steady state error value of 0.

TABLE II. TEST RESULTS FOR THE DETERMINATION OF THE TRANSFER FUNCTION

Data	Open Loop System
SettlingTime	0.6224
RiseTime	0.2524
Peak	1.0267
PeakTime	0.5269
Overshoot	2.6711%

Conversely, if the system model is given a disturbance, the response signal cannot track a reference signal shown in Figure

2 and also show the steady-state error value of the uncontrolled signal output is at the value 0.332, which is still far from the reference signal.

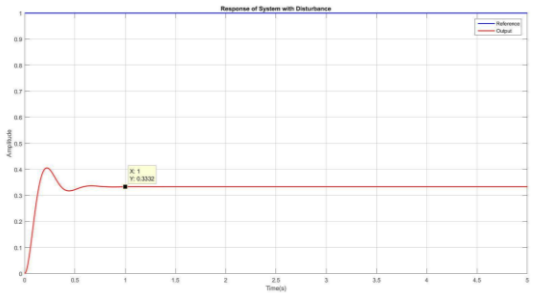

Fig. 2. Response signal with disturbance without robust tracking.

3.2. DC Motor System Response with Robust Tracking Controller

The robust tracking method is embedded into the Simulink model to test the output signal's steadiness and eliminate steady-state errors on signals that are given disturbance. The Simulink model embedded with Robust Tracking is shown in Figure 3 and with additional disturbance in Figure 4.

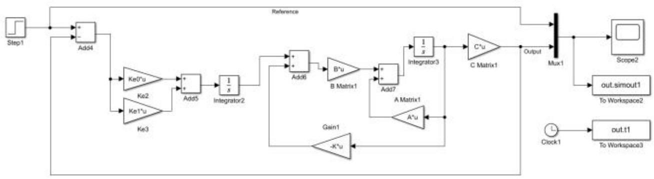

Fig. 3. The Simulink Robust Tracking model.

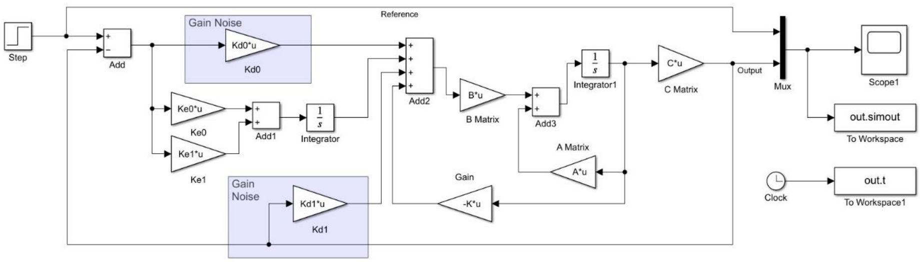

Fig. 4. The Simulink Robust Tracking model with disturbance.

System analysis and simulation are carried out in Simulink by determining various desired peak time values. The desired maximum overshoot value is 10%. From the calculation of peak time and max overshoot, the value of ωn is obtained and entered into the Matlab calculations as one of the variables for analyzing the signal response. The simulation results are shown in Simulink in graphical form, with the X-axis representing time (seconds) and the Y-axis representing the signal output amplitude. Figure 5-10 elucidate the graphs generated by Simulink, which take input data from calculation results in Matlab. In this study, the value of

1 as the desired reference signal is shown on a blue graph, while the robust control simulation results are shown on a red graph. Figure 5-9 elucidates the signal output without disturbance added, and Figure 10 is the signal output from the Simulink model with disturbance.

The value of the natural frequency constant (ω_n) changes based on the desired peak time criterion specified in the previous section. The novel transfer function is obtained from the characteristic Equation (8-9), and the controlling constant values are determined. The values from that equation are then applied to the Robust Tracking model and simulated in Simulink.

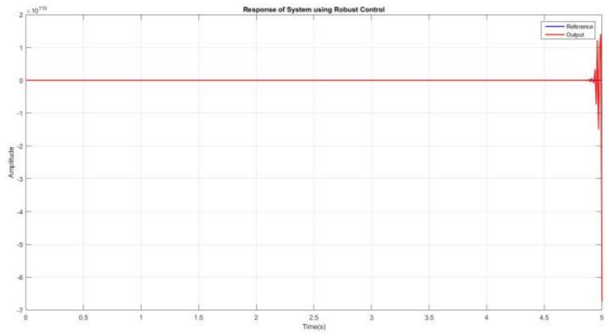

Fig. 5. Signal response of DC motor system with robust tracking and without disturbance at the peak time setting of 0.1 seconds.

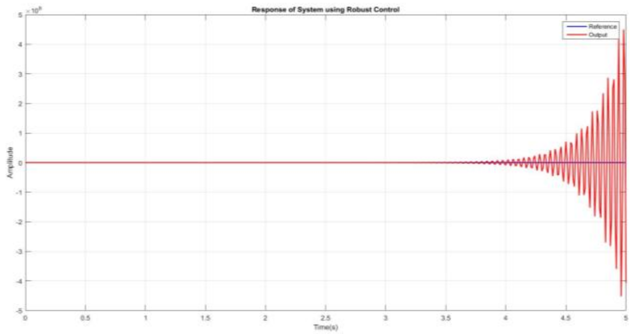

Fig. 6. Signal response of DC motor system with robust tracking and without disturbance at the peak time setting of 0.2 seconds.

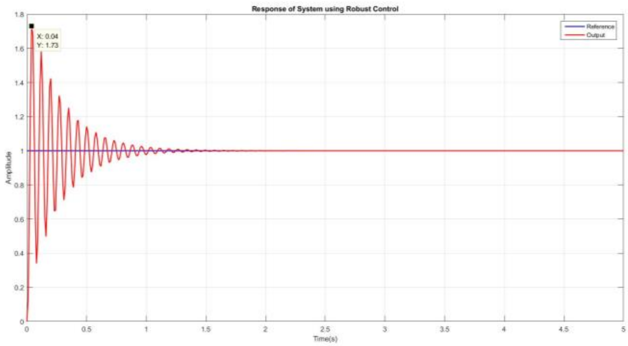

Fig. 7. Signal response of DC motor system with robust tracking and without disturbance at the peak time setting of 0.3 seconds.

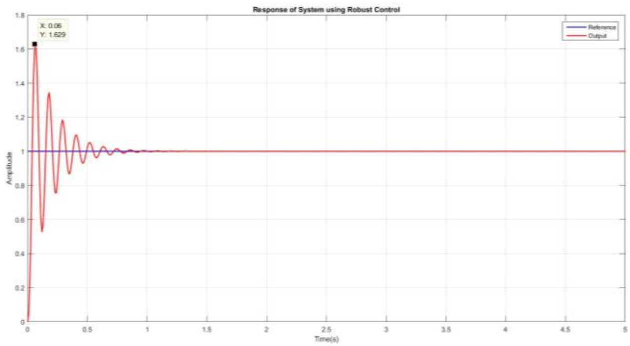

Fig. 8. Signal response of DC motor system with robust tracking and without disturbance at the peak time setting of 0.4 seconds.

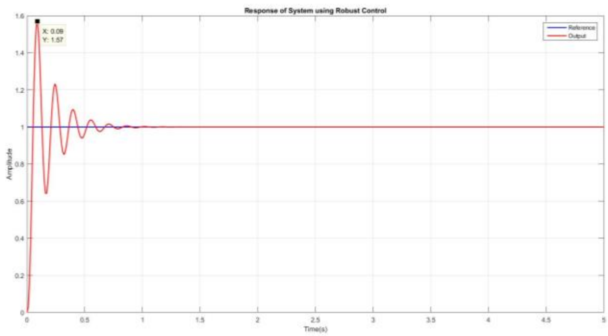

Fig. 9. Signal response of DC motor system with robust tracking and without disturbance at the peak time setting of 0.5 seconds.

Table 3 elucidates the data obtained based on the simulation results in Figure 5, 6, 7, 8, and 9.

TABLE III. ROBUST TRACKING SIMULATION RESULTS

Desired Peak Time (Tp)(s)	ωn	Amplitude	Time (s)
0.1	38.91	oscillation and unstable	
0.2	19.45		
0.3	12.97	1.73	0.04
0.4	9.73	1,629	0.06
0.5	7.78	1.57	0.09

According to Table 3, the design criteria for robust tracking with the desired peak time of 0.1 seconds (Figure 5) and 0.2 seconds (Figure 6) produce an output signal that experiences oscillations. Robust tracking with desired peak times of 0.3 seconds (Figure 7), 0.4 seconds (Figure 8), and 0.5 seconds (Figure 9) achieved much faster peak times of 0.04, 0.06, and 0.09 seconds, respectively. Even though the desired peak time value is met, the amplitude of the maximum overshoot exceeds the maximum overshoot limit set in the design criteria. Despite having the fastest peak time, the model with the desired peak time of 0.3 seconds demonstrates an overshoot amplitude of 1.73—marking the highest overshoot compared to models with the desired peak time of 0.4 and 0.5 seconds. Moreover, the amount of overshoot and undershoot can be seen more in the model with the desired peak time of 0.3 seconds compared to the other models before eventually converging to track the signal reference.

In contrast, the signal output from the model with the desired peak time of 0.5 appears to have fewer overshoots and undershoots before successfully tracking the reference signal. In Robust Tracking, the equation with the fourth order is used to determine the error prevention constant subsequently that tracking remains according to the reference. The oscillations in the signal output are caused by the high order used in robust tracking.

TABLE IV. ROBUST TRACKING WITH DISTURBANCE SIMULATION RESULTS

Disturbance		Amplitude	Time (s)
Kd0	Kd1		
1	1	1.53	0.09
1	5	1,614	0.09
5	1	1,451	0.09
5	5	1,528	0.09

In the context of the robust tracking simulation in Simulink, the model configured to achieve a desired peak time of 0.5 seconds is intentionally subjected to disturbances represented by Kd0 and Kd1. The model simulation results using robust tracking with disturbances are summarized in Table 4.

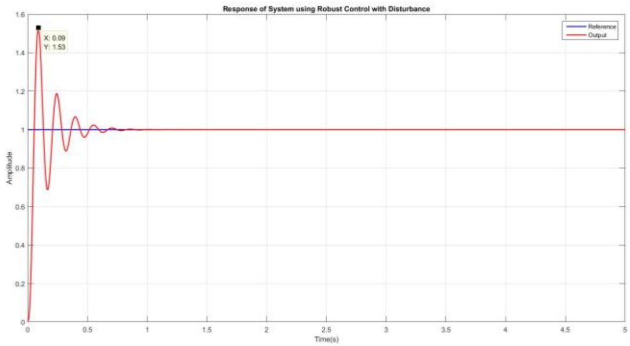

Fig. 10. Signal response of DC motor system with robust tracking and added disturbance at the peak time setting of 0.5 seconds.

The graphical representation in Figure 10 emphasizes that, despite the introduced disturbances, the signal output adheres to the reference signal. An interesting observation emerges when comparing this result to the undisturbed model, as depicted in Figure 9: the presence of disturbances leads to a reduced maximum overshoot and undershoot, indicating the efficacy of the robust tracking methodology.

4 Conclusions

The output signal generated by a DC motor system utilizing a robust tracking method with different peak time value criteria can attain a reference signal. Conversely, it may not satisfy all the specified system design criteria. The Simulink simulation results demonstrate that the robust tracking method is a potent controller, enabling successful tracking of the desired reference signal even in the presence of disturbances. Therefore, the robust tracking method for DC motors appears suitable for maintaining reference signals when unforeseen disturbances affect the system.

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