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Optimization of LQR and LQT Control System Performance on RS PRO 834-7641 DC Motor with and Without Disturbance

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ABSTRACT

DC motors are the most commonly used type of motor compared to other electric motors. The advantages of this motor include simple, sturdy construction, relatively cheap price, and require uncomplicated maintenance. However, the main focus in this discussion is to keep the motor speed constant. When there is a change in the load on the DC motor with a certain value of the nominal load, its response can change even though the controller has been given. To overcome this problem, the optimal control techniques used are Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT). In this study, the author uses a closed-loop control system to understand how the RS PRO 834-7641 type DC motor responds with mathematical modeling of order 1 and order 2 when integrated into a system. Furthermore, simulations are carried out using MATLAB Simulink software to analyze the risetime, overshoot, undershoot responses under normal conditions, and when there is noise in the system. This study requires a DC motor with a terminal inductance phase to phase and terminal resistance phase to phase values, which are used to create mathematical modeling of speed and current sensors as feedback functions in a system with dual outputs. The LQR controller has two parameters, namely the Q and R weight matrices, which must be determined to produce optimal control actions as expected. Examples of implementation of the LQR and LQT methods include speed control of induction motors, frequency control in generator power plants, to quadcopter drones. The combination of the LQR and LQT methods with the discipline of system optimization is very important to achieve optimal points and reduce errors in a device, so that device performance can be adjusted according to user wishes.

Keywords : *RS PRO 834-7641, LQR, Overshoot, Rise Time*

I.INTRODUCTION

The production system in industry is a complex and dynamic system, so that in such conditions, the process often experiences undesirable results. This is due to the lack of control system capability to keep the process running as expected. [1] Therefore, an optimization technique is needed to achieve the best desired results. According to Anthony (2014), optimization is a method carried out to achieve the best desired results. Sugioko (2013) also explains that optimization is a discipline in mathematics that focuses on systematic efforts to find the minimum or maximum value of a function, opportunity, or other value searches in various situations. [2]

DC motors are devices that can convert electrical energy into mechanical energy or motion [3]. To function, they require voltage and direct current [4]. Therefore, the application of control system optimization is a process of analysis and calculation to obtain the best solution. The process of regulating or controlling one or more quantities, such as parameters or variables, so that they are at a certain value or in a range of values is known as a control system. Control systems are also referred to as control techniques, control systems, or control systems. Control systems consist of various combinations of physical components, in terms of the equipment and instruments used, which are used to direct the flow of energy to a machine or process to achieve the desired results.

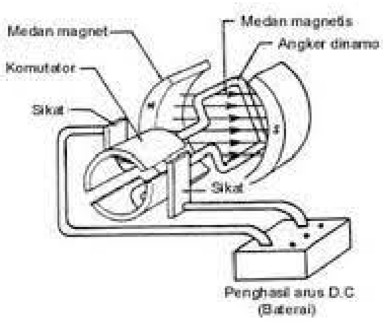


Figure 1.1 DC Motor Parts

However, the use of direct current (DC) in motors does not reach the optimal level because the motor output contains quite significant noise. Noise is a signal that has an impact on the output value of a system, in this case, the motor [5][19]. Noise signals that affect the motor can be caused by various factors such as the condition of the surrounding magnetic field, the installation between the controller and the computer, or even by the motor components themselves [6][20]. In this study, noise will be represented by random values.

Control in a system becomes important because of the feedback network [7][18]. The closed loop control system model or closed loop control system can be found in Figure 1.2.

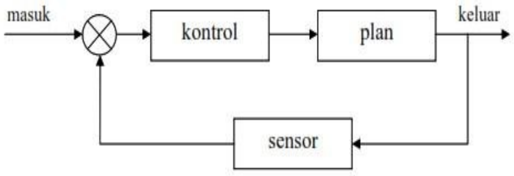


Figure 1.2 Closed Loop Control System [8].

System optimization involves various types of circuits, including SISO (single input single output), SIMO (single input multi output), MISO (multi input single output), MIMO (multi input multi output), noise, LQR, LQT, and so on. In this study, the author uses a closed-loop control system to observe the response of the RS PRO 834-7641 type DC motor with 1st order mathematical modeling when integrated into a system. Simulations are carried out using the LQR and LQT methods on the RS PRO 834-7641 type DC motor. LQR (Linear-Quadratic Regulator) is one of the state space control methods that requires information from the entire system. To achieve the optimal gain value, weights need to be applied to the Q and R values in the LQR [9]. LQT (Linear-Quadratic Tracker), on the other hand, is a key method for tracking problems in linear systems. LQT is designed to develop optimal control so that the linear control system can track a predetermined reference trajectory. This optimal control is achieved by minimizing a predetermined quadratic value function. LQT consists of feedback and feed-forward parts which are calculated using the Algebraic Riccati Equation (ARE) [10][17].

In this study, the author uses Simulink to simulate a system constructed using the LQR and LQT methods. Simulink is a Graphical Extension of Matlab that is used to model and simulate a system. In Simulink, the system is illustrated as a block diagram, including transfer functions, sum junctions, and also virtual input and output devices such as function generators and oscilloscopes [11]. Mathematical modeling is a technique for describing a complex system into a mathematical model. Thus, the formulated mathematical model is expected to be able to explain the complex situation being observed [12]. The author makes calculations by referring to the RS PRO 834-7641 DC motor data sheet to formulate a 1st order mathematical modeling. This modeling is used as a plant transfer function, which is a mathematical relationship between the input and output of the control system components [13].

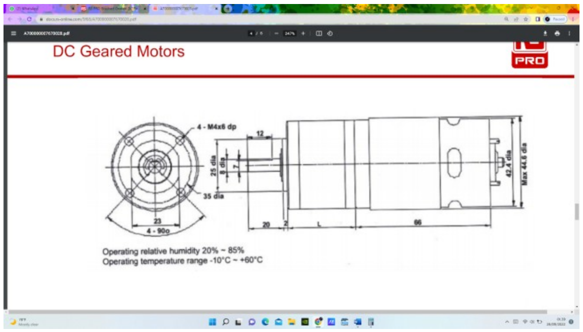
The purpose of this study is to examine the step response or change in output behavior to changes in the input signal of the RS PRO 834-7641 DC motor, both with noise-free treatment and with noise at the system output [14].

II.METHODOLOGY

2.1 Research Stages

1. Literature review
   In this step, a search for relevant literature related to system optimization is conducted. References are used as a guide to overcome existing problems. References are obtained from two main sources, namely scientific journals/articles and datasheets.
2. Mathematical Modeling
   In this phase, theoretical calculations are performed to obtain mathematical models of order 1 and order 2 based on the collected datasheets. This mathematical model functions as a transfer function of the circuit to be simulated.
3. Network Creation
   The circuit creation is done using the help of MATLAB software. Some types of circuits created include SISO, SIMO, MISO, MIMO, SISO noise, SIMO noise, MISO noise, and MIMO noise.
4. Analysis of Results and Discussion
   The results analysis and discussion stages are carried out by analyzing the results of the series that have been created using MATLAB. Comparisons are made between circuits with noise and without noise through the use of a scope.
5. Conclusion
   At this stage, the author draws conclusions based on the results and discussions that have been conducted. There are several key points noted by the author in the conclusion, which are a description or result of this research.

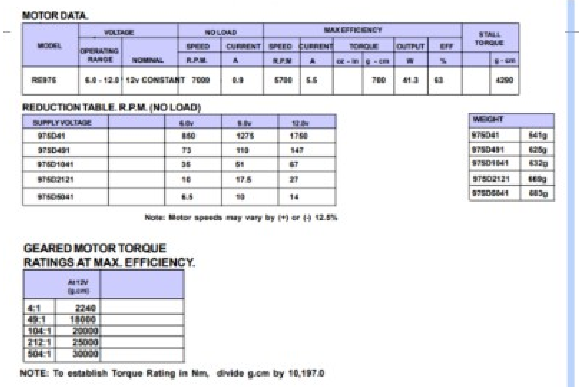
2.2.1 RS PRO 834-7641 DC Motor Datasheet



DC Geared Motors

Operating relative humidity 20% ~ 85%
Operating temperature range -10°C ~ +60°C

Figure 2. 2 RS PRO 834-7641 DC Motor



MOTOR DATA.

MODEL	VOLTAGE		NO LOAD		MAX EFFICIENCY						STALL TORQUE	
	OPERATING RANGE	NOMINAL	SPEED	CURRENT	SPEED	CURRENT	TORQUE		OUTPUT	EFF		
			R.P.M.	A	R.P.M	A	oz - in	g - cm	W	%		g - cm
RE976	6.0 - 12.0	12v CONSTANT	7000	0.9	5700	5.5		700	41.3	63		4290

REDUCTION TABLE. R.P.M. (NO LOAD)

SUPPLY VOLTAGE		6.0v	9.0v	12.0v
975D41		850	1275	1750
975D491		73	110	147
975D1041		35	51	67
975D2121		16	17.5	27
975D5041		6.5	10	14

Note: Motor speeds may vary by (+) or (-) 12.5%

WEIGHT	
975D41	541g
975D491	625g
975D1041	632g
975D2121	669g
975D5041	683g

GEARED MOTOR TORQUE
RATINGS AT MAX. EFFICIENCY.

	At 12V (g.cm)	
4:1	2240	
49:1	18000	
104:1	20000	
212:1	25000	
504:1	30000	

NOTE: To establish Torque Rating in Nm, divide g.cm by 10,197.0

Figure 2.3 RS PRO 834-7641 DC Motor Specifications

Motor Name = RS PRO 834-7641 DC Motor
t = 1.8 N/m
No load current = 900 mA = 0.9 A
Rated Current = 5500 mA = 5.5 A
Voltage = 12V
Speed = 143 rpm or 14.97 m/s
Reduction Ratio = 1:49

2.2.2 Order 1 and Order 2 Calculations

1st Order Modeling

General form of first-order transfer function [15]

$$G(s)=\frac{K}{\tau s+1}$$

Order 1 DC motor

Based on the DC motor datasheet, the first order equation is obtained:

Where τ = Ki so that

$$c$$

First order equation of DC motor:

$$G(s)=\frac{K}{\tau s+1}=\frac{0{,}32}{1{,}8+1}$$

2.3 Optimal Control LQR (Linear Quadratic Regulator)

Linear Quadratic Regulator (LQR) is a method used in modern control theory. Analysis of this system is done by utilizing the state space approach. Due to the simplicity of the state space method approach, systems with multi-input multi-output can be solved using this method. The state space equation for the system is generally expressed as:

$$x=AX+Bu$$

In principle, the LQR method searches for a control signal u that minimizes the performance index J.

$$J=\int (X^T Q_x \text{¿} + U^T R_a)\, dt\, \text{¿}$$

LQR produces the optimal control input rule u*. The constraints imposed by the Q and R matrices aim to minimize the performance index. The optimal control rule for the closed loop is formulated as:

$$u^{\text{¿}}=-Kx$$

Where K reflects the optimal feedback gain matrix. This gain matrix serves to reduce the performance index. The presence of this gain matrix ensures the optimal placement of closed-loop poles to reduce the index. The feedback gain matrix K depends on the matrices A, B, Q, and R. The feedback gain matrix K is found by solving the Riccati Algebraic Equation (ARE), with P as a symmetric and positive definite matrix obtained as a solution to the ARE, which is then defined as:

$$A^T P+PA-PBR^{-1}B^T P+Q=0$$

$$K=AX-BK_x=(A-BK)x$$

Substitute equations (8) and (9) to get

$$x=AX-BKx=(A-BK)x$$

The block diagram showing the LQR configuration is shown in Figure

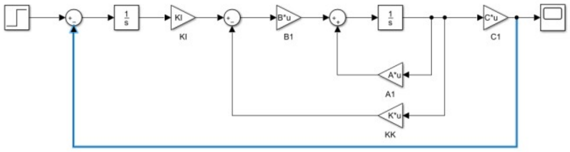


Figure 2.4 LQR Block Diagram

2.4 Matlab LQR Program on RS PRO 834-764 DC Motor

```
% LQR SYSTEM OPTIMIZATION ON DC MOTOR
clear; clc;
% DC Motor Models
J=0.00000242 ; b=0.1 ; K=0.0167 ; R=0.343 ; L
= 0.00018 ;
% J = Momentum, b = Damping ratio, K =
constant, R = resistance, L =
% Inductance
A = [-b/JK/J; -K/L -R/L];
B = [0;1/L];
C = [1 0];

AA = [ A zeros(2,1); -C 0];
BB = [B;0];
% Pole Placement
J = [-3 -4 -5];
K = acker(AA,BB,J)
KI = -K(3);
KK = [K(1) K(2)];
% LQR Matrix
Q = [1 0 0;
   0 1 0;
   0 0 1000];
R = [1] ;
K_lqr = lqr(AA,BB,Q,R)
KI2=-K_lqr(3);
KK2=[K_lqr(1) K_lqr(2)];
```

2.5 Optimal Control of Linear Quadratic Tracker (LQT)

LQT involves the conventional state feedback of a linear dynamical system, along with an additional feedforward control term. This feedforward control term depends on the reference signal vector, r(t). The vector representation of r(t) is given by:

$$r(t)=\text{¿}$$

With Vref as a reference voltage signal that changes over time, the LQT scheme aims to reduce the quadratic performance index, resulting in an optimal control decision that can be expressed in the following equation [16].

$$J=\frac{1}{2}\int_{0}^{T} ¿¿$$

With Q and R as the weight matrices for the state and control respectively. These matrices are chosen carefully; Since the cost function is quadratic, the control signal is correlated with the quadratic variation of the equation. Therefore, if the state variation is large; the reduction and, consequently, the convergence rate becomes faster.

$$Q=Q^{T}\geq 0\, dan\, R=R^{T}>0$$

The optimal affine control decision is evaluated through the mathematical expression shown in [16],

$$d(t)=-Kx(t)+K_{ff}v_{ref}(t)$$

Where

$$K=R^{-1}B^{T}$$

$$K_{ff}=R^{-1}B^{T}¿$$

The gain vector, K, serves to shift the position of the system poles in the optimal control synthesis process. The acquisition of this optimal vector depends on the positive definite symmetric matrix, P, which is stated in (14). The matrix P for a particular system can be obtained by solving the Riccati Algebra Equation, as shown in

$$A^{T}P+PA-PBR^{-1}B^{T}P+H^{T}QH=0$$

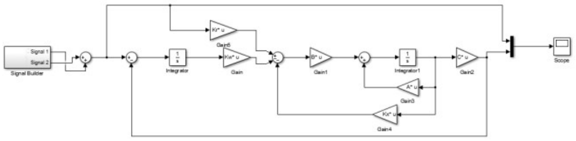
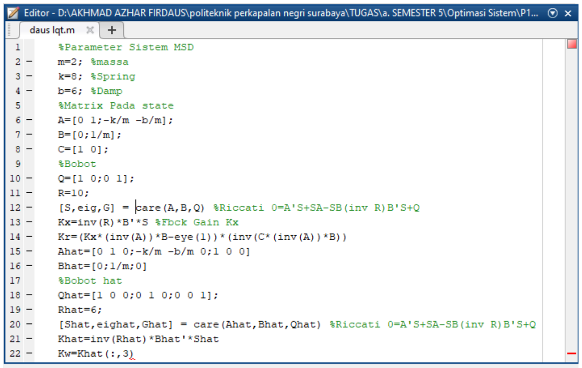


Figure 2.5 LQT Block Diagram

2.6 ogram MATLAB LQT on DC motor RS PRO 834-7641



```
%Parameter Sistem MSD
m=2; %massa
k=8; %Spring
b=6; %Damp
%Matrix Pada state
A=[0 1;-k/m -b/m];
B=[0;1/m];
C=[1 0];
%Bobot
Q=[1 0;0 1];
R=10;
[S,eig,G] = care(A,B,Q) %Riccati 0=A'S+SA-SB(inv R)B'S+Q
Kx=inv(R)*B'*S %Fbck Gain Kx
Kr=(Kx*(inv(A))*B-eye(1))*(inv(C*(inv(A))*B))
Ahat=[0 1 0;-k/m -b/m 0;1 0 0]
Bhat=[0;1/m;0]
%Bobot hat
Qhat=[1 0 0;0 1 0;0 0 1];
Rhat=6;
[Shat,eighat,Ghat] = care(Ahat,Bhat,Qhat) %Riccati 0=A'S+SA-SB(inv R)B'S+Q
Khat=inv(Rhat)*Bhat'*Shat
Kw=Khat(:,3)
```

2.7 System Block Diagram

2.7.1 Block Diagram of First Order DC Motor RS PRO 834-7641

The first order motor block diagram is used to observe the actual response of the RS PRO 834-7641 DC motor without involving additional methods in the simulink software.

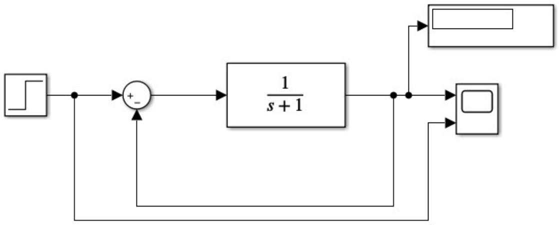


Figure 2. 7.1 First Order Block Diagram of DC Motor

Figure 2.7.1 shows a block diagram of a first-order DC motor involving one input and one output. The type of input applied is a step response. The transfer function in the diagram can include modeling of a first-order DC motor. The response results will be visualized on the scope and display to determine the maximum response value that occurs.

2.7.2 Block Diagram of LQR DC Motor RS PRO 834-7641

LQR block diagram for RS PRO 834-7641 DC Motor is used to observe the response of DC motor when LQR optimization method is applied using simulink software.

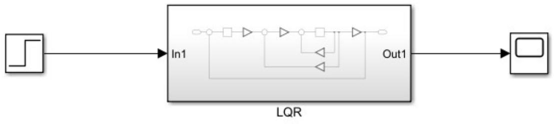


Figure 2.7 Block Diagram of LQR DC Motor RS PRO 834-7641

2.7.3 Block Diagram of LQR DC Motor RS PRO 834-7641 with Noise

The LQR block diagram of the RS PRO 834-7641 DC Motor with noise is used to observe the response of the DC motor when the LQR and noise optimization methods are added to the system using simulink software.

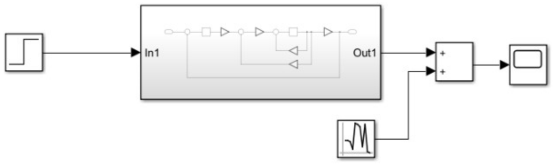
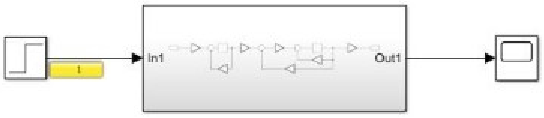


Figure 2. 8 Block Diagram of LQR DC Motor RS PRO 834-7641 with noise

2.7.4 Block Diagram LQT DC Motor RS PRO 834-7641

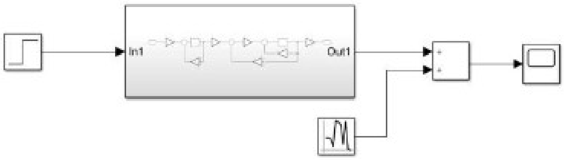
The purpose of the LQT block diagram of the RS PRO 834-7641 DC Motor is to determine the response results of the DC motor if the LQT optimization method is added to the Simulink software to the DC motor.



Gambar 2. 9 Diagram Blok LQT Motor DC RS PRO 834-7641

2.7.5 Block Diagram of LQT DC Motor RS PRO 834-7641 with Noise

The LQT RS PRO 834-7641 DC Motor System with noise was created to observe the response of the DC motor when the LQT optimization method and noise were added to the system using Matlab Simulink.



Gambar 2.7 Rangkaian LQT Motor RS PRO 834-7641 dengan *Noise*

III.RESULTS & DISCUSSION

Figure 3.1 Results of the Response of the RS PRO 834-7641 DC Motor in First Order Mathematical Modeling

In the first-order modal response output depicted in Figure 3.1, it can be seen that the first-order motor response graph shows an output that is far from the desired set point value. The orange waveform depicts the motor response results, while the blue waveform shows the desired set point, which is 0.5. However, the motor response only reaches a value of 0.07. The observed RS PRO 834-7641 DC motor shows linear characteristics with a non-fluctuating signal. The motor response reaches a steady state condition in ±2 seconds after the motor is turned on, and the response is quite slow.

3.2. Response Results of RS PRO 834-7641 DC Motor Using LQR Method

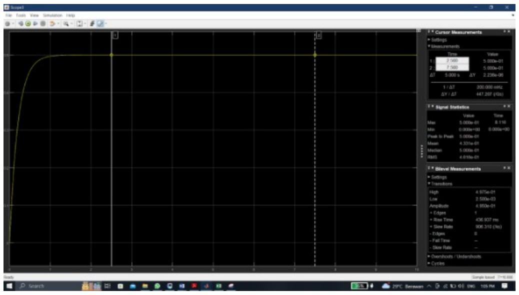


Figure 3.2 Results of the RS PRO 834-7641 DC Motor Response with the LQR Method

In the modal response output in Figure 3.2, it can be seen that the response graph of the RS PRO 834-7641 Watt DC motor with the application of the LQR method produces an output that matches the desired set point value. The desired set point value is 0.5, and the motor response successfully reaches the set point value at ±1.2 seconds without any overshoot and undershoot. The use of the LQR method improves the performance of the RS PRO 834-7641 DC motor response, producing better results compared to conditions without the application of the LQR method.

3.3. Comparison Results of RS PRO 834-7641 DC Motor Response Using the LQR Method and Without the LQR Method

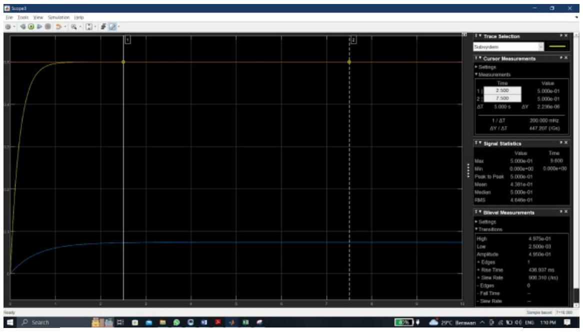


Figure 3.3 Comparison Results of the Response of the RS PRO 834-7641 DC Motor with the LQR Method and Without

In the modal comparison response output in Figure 3.3, it can be seen that the response graph of the RS PRO 834-7641 DC motor with and without the application of the LQR method shows the difference in response output. The orange waveform shows the desired set point value, while the blue waveform depicts the motor response without the application of the LQR method, and the yellow waveform is the motor response with the LQR method. Figure 3.3 clearly shows that the response of the RS PRO 834-7641 DC motor with the LQR method produces a superior response compared to the condition without the LQR method. In addition to having a response value that matches the desired set point without overshoot and undershoot, the motor response also reaches a steady state value faster.

3.4. Response Results of RS PRO 834-7641 DC Motor Using LQR Method with Noise

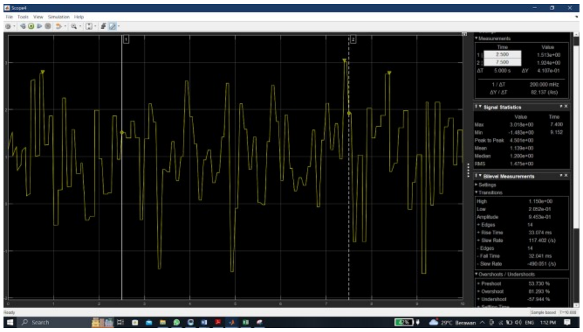


Figure 3.4 Results of the Response of the RS PRO 834-7641 DC Motor with the LQR Method When Given Noise

The results of Figure 3.4 show that the yellow signal, which is the result of the response of the RS PRO 834-7641 DC motor with the LQR method, has changed shape compared to the previous noise signal. The signal shape experiences a lot of ripples and imitates the shape of the given noise signal. The resulting signal is no longer linear and far from the steady state or stable condition at a certain set point.

3.5. Maxon RS PRO 834-7641 DC Motor Response Results Using the LQT Method

In the response results of the LQT system (Figure 3.5), it can be seen that the RS PRO

834-7641 motor response graph shows an output that matches the desired set point value. This set point value is 0.5. The motor response successfully reaches the set point at 1.2 seconds without overshoot or undershoot. The motor response of the RS PRO 834-7641 DC Motor with the application of the Linear Quadratic Tracker (LQT) method shows better performance when compared to the first-order motor response.

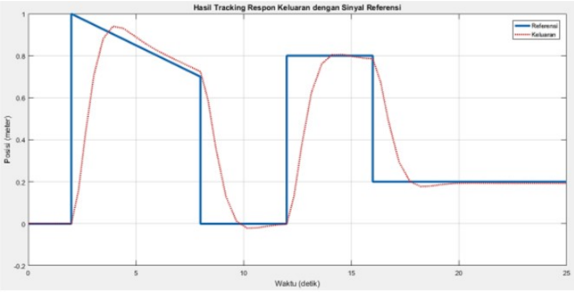


Figure 3.5 Results of the RS PRO 834-7641 DC Motor Response with the LQT Method

3.6. Comparison Results of RS PRO 834-7641 DC Motor Response Using the LQT Method and Without the Method

The results of the comparison response (Figure 3.6) between the use of the LQT method and without the use of the method show the difference in the response graph. The orange wave shows the desired set point value, while the blue one illustrates the motor response without the application of the LQT method, and the yellow one is the motor response with the LQT method. Figure 3.6 shows that the motor response with the LQT method has the most optimal performance compared to conditions without any method. In addition to having a response according to the set point, the motor response also reaches a steady state value faster.

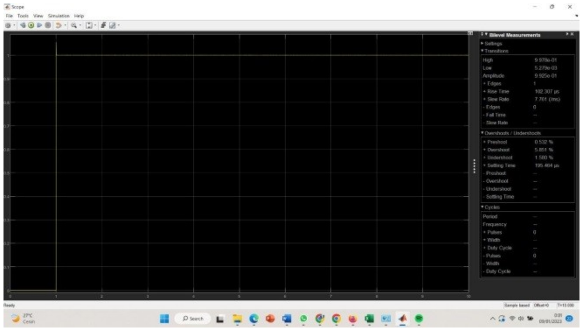


Figure 3.6 Comparison Results of the Response of the RS PRO 834-7641 DC Motor with the LQT Method and Without Using the Method

3.7. Response Results of RS PRO 834-7641 DC Motor Using LQT Method with Noise

In the response results of the LQT system with noise (Figure 3.7), it can be observed that the yellow signal changes shape before the addition of noise. The signal shape experiences many waves that are folded and imitate the shape of the added noise signal. The resulting signal is no longer linear and far from reaching a steady state condition at the set point value that has been set.

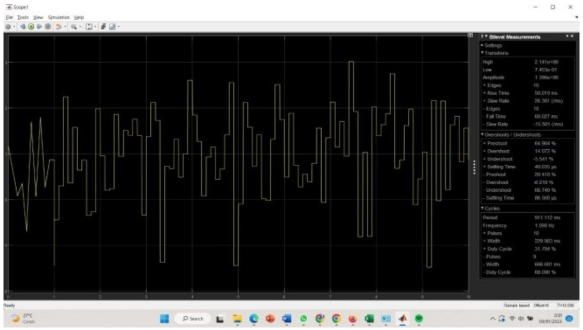


Figure 3.7 Results of the Response of the RS PRO 834-7641 DC Motor with the LQT Method when Given Noise

IV.CONCLUSION

From the experimental results on the PRO 834-7641 DC motor, it is proven that the use of the LQR method provides better response results. This can be seen from the response ability of the PRO 834-7641 DC motor to reach the desired set point value in a short time when using the LQR method. Conversely, without using the LQR method, the motor response is far from the desired set point value, and reaching the steady state value takes quite a long time. This confirms that the theory that the LQR optimization method can improve the response of DC motors is true. However, when the system is given noise, the LQR method cannot maintain its response results. The response of the PRO 834-7641 DC motor with LQR when given noise produces a response that follows the noise signal, so that the resulting response is no longer linear. Controller testing on the system is carried out under different conditions, assuming that the disturbance or shock to the suspension system varies. The simulation results show that the blue line represents the set reference value, while the red line shows the system response with the LQT controller. From the test results, it is known that the system with the LQT controller is able to track the position according to the set reference value. The transient response of the system shows that the steady state error value is 3%, indicating good conditions. The average steady state error of 3% indicates that when there is a shock to the vehicle that causes a change in position in the suspension system, the applied controller can bring the suspension system to track the position accurately, so that the disturbance or shock that occurs can be dampened properly.

V.CLOSING

1.Awards

research, especially those who funded your research. Include individuals who have helped you with your study: Advisors, Financial Supporters, or perhaps other supporters such as Proofreaders, Typists, and Suppliers who may have provided materials. The researcher realizes that without the support of various parties, the compilation of this community service journal will never be realized. So on this occasion the researcher would like to express many thanks to the various parties who have participated. (This point can be adjusted again by adding words or including the party who wants to be appreciated)

2. Bibliography

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