Improving the Output Circuit System through the LQR and LQT Methods on the RS PRO 454-0883 DC Motor

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ABSTRACT

DC motors are components that are often found in everyday life, requiring direct voltage and current to operate. This electric motor is an electromechanical device that can convert electrical energy into mechanical energy. This paper discusses two methods, namely LQR and LQT, and considers noise, to examine the impact of noise on the system. This study uses a DC motor RS PRO 454-0883 to observe the effects of noise on the motor system. Modeling of various plant configurations, such as SISO, SIMO, MISO, and MIMO, is needed to describe the plant response graphically using software. MATLAB is used to conduct the study, including mathematical modeling of the motor to obtain the 1st and 2nd order Transfer Functions. Furthermore, simulations are carried out on each circuit for analysis. Finally, the output signals from the circuits are compared. The results show that noise has a significant impact on the 37GB500 DC motor, so an optimization method is needed to reduce noise in the motor. However, the second-order motor shows better performance compared to the first-order, as seen in the condition after the raise time

Keywords*:*LQR, LQT, DC Motor, Noise

I.INTRODUCTION

In this paper, the author reviews a system method used to improve the output performance of LQR (Linear Quadratic Regulator) and LQT (Linear Quadratic Tracking) motors, which is one of the topics in the Automation Engineering course at PPNS, namely "System Optimization". Previously, DC motors were one of the components often found in everyday life, where DC motors require voltage and direct current to operate[1][2]. This electric motor itself is an electromagnetic device that is capable of converting electrical energy into mechanical energy[3][4][5].

The next method is Linear Quadratic Tracker (LQT). LQT is a linear control system where the system follows a desired reference path [6]. The way Linear Quadratic Tracker works is by controlling tracking based on a model that uses state feedback to provide optimal control efforts [7]. LQT consists of the usual state feedback of a linear dynamic system, along with additional feedforward control [8]. The Linear Quadratic Tracker method is usually used to solve optimization problems in systems related to tracking [10][11]

By using both optimization methods, in the System Optimization course at the Surabaya State Polytechnic of Shipbuilding Automation Engineering, an experiment was conducted to test the impact of the LQR and LQT methods on the output response generated by a DC motor. The experiment also involved adding noise to the system to check whether the LQR and LQT methods could make the motor response unaffected by the added noise or whether the motor response was still affected by the noise [12] [13]. In addition, the study also aims to understand the differences between the

LQR and LQT optimization methods on the same type of DC motor [14][15].

II.METHODOLOGY

2.1 Research Stages

Based on the introduction, the following research stages were obtained:

1. Literature Study
   The initial stage in this research is to conduct a literature study. At this stage, a search for references related to the Linear Quadratic Regulation and Linear Quadratic Tracker system optimization methods is carried out [16]. References are used as a guide to solving problems. References are obtained from two sources, namely scientific journals/articles and datasheets.
2. Mathematical Modeling
   The creation of a mathematical model involves a theoretical calculation process to produce a 1st and 2nd order mathematical model based on the information in the datasheet obtained [17]. The mathematical model is used as a transfer function of the circuit to be simulated.
3. System Circuit Creation
   At this stage, each series of systems to be simulated is created. MATLAB software was used to conduct this experiment. Four circuits are created: LQT circuit, LQT circuit with noise, LQR circuit, and LQR circuit with noise[18][19].
4. System Output Response Analysis
   At this stage, an evaluation of the system simulation signal output response is carried out. The focus of the analysis in this study is on the comparison or comparison of the two system optimization methods.
5. Conclusion
   The final stage in this research involves drawing conclusions based on the results of the analysis that has been carried out.

2.2 Mathematical Model of RS PRO 454-0883 DC Motor

The mathematical model consists of several stages as follows::

2.2.1 Datasheet for DC Motor RS PRO 454-0883

Specifications :

Output speed	145 rpm
Supply Voltage	12V DC
Maximum Output Torque	10000 g.cm
DC Motor Type	Brushed
Shaft Diameter	6mm
Power Rating	19.8 W
Gearhead Type	Planetary
Length	89.3mm
Width	35.8mm
Current Rating	2.81 A
Weight	305g

Figure 2.2 RS PRO 454-0883 DC Motor Datasheet

2.2.2 First Order Mathematical Modeling

Mathematical modeling of the 1st order RS PRO 454-0883 DC motor is as follows:

It is known:

$$\tau=0{,}98\, i=2{,}81\, K=\frac{\tau}{i}=\frac{0{,}98}{2{,}81}=0{,}35\, Persamaan\, U$$

:

$$G(s)=\frac{K}{\tau s+1}\, G(s)=\frac{0{,}314}{0{,}98\, s+1} \quad (1)$$

2.2.3 Mathematical Modeling of Order 2

$$G(s)=\frac{\omega\pi^2}{s^2+2\varsigma\omega n s+\omega\pi^2}$$

$$G(s)=\frac{2\pi f^2}{s^2+2\varsigma(2\pi f)s+2\pi f^2}$$

$$G(s)=\frac{2\pi 50^2}{s^2+2100(2\pi 50)s+2\pi 50^2}$$

$$G(s)=\frac{98.596}{s^2+13.816s+98.596} \quad (2)$$

2.3 Optimal Control of Linear Quadratic Regulator (LQR)

In contemporary control theory, the linear quadratic regulator (LQR) is the approach used. The state space approach is used to perform the analysis of such systems. This is due to the fact that this approach is a simplified version of the state space method and is used by systems that have many inputs and outputs[20]. The general state space equation of the system is as follows:

$$X=AX+Bu \quad (3)$$

Basically, the LQR method tries to find a control signal that minimizes the performance index J.

$$J=\int (X^T Q_X+U^T ¿ R_a)dt ¿ \quad (4)$$

The LQR method finds the optimal control input rule i*. The constraints imposed by the Q and R matrices are used to minimize the performance index. The optimal closed-loop control law is defined as follows:

$$u=-Kx \quad (5)$$

Where the matrix K represents the optimal feedback gain matrix. This gain matrix plays a role in minimizing the performance index. This matrix determines the optimal closed-loop pole placement to achieve this goal. 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), where the matrix P is a symmetric and positive definite matrix resulting from the solution of the ARE and is defined as follows:

$$A^T P+PA-PBR^{-1}B^T P+Q=0 \quad (6)$$

$$x=AX-BKx=(A-BK)x \quad (7)$$

Substitute equations (8) and (9) to become:

$$x=AX-BKx=(A-BK)x \quad (8)$$

A block diagram showing the LQR configuration is shown in Figure 2.3.

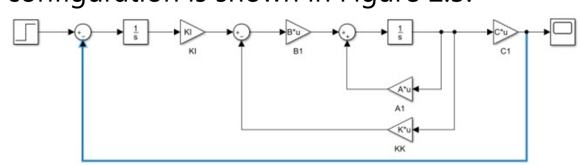


Figure 2.3. Linear Quadratic Regulation (LQR) Block Diagram

2.4 Matlab Linear Quadratic Regulation (LQR) Program on DC Motor RS PRO454-0883

```
% LQR SYSTEM OPTIMIZATION ON RS PRO 454-0883 DC MOTOR
clear; clc;
% DC Motor Models
J=0.00000838 ; b=0.1 ; K=0.0143 ; R=0.848 ; 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)

Linear Quadratic Tracker (LQT) has two control terms feedforward and the usual state feedback of a linear dynamic system. The reference signal vector, r(t), determines the feedforward control term. The vector r(t) is represented in:

$$r(t)=¿ \tag{9}$$

The reference voltage signal that changes over time is called Vref. To produce optimal control decisions, the LQT scheme minimizes the squared performance index. The equation can be found below:

$$J=\frac{1}{2}\int_{0}^{T} ¿¿ \tag{10}$$

Q and R are the states between the control and weighting matrices. They are chosen because Q = QT ≥ 0 and R = RT ≥ 0. The control signal is proportional to the squared variation of the equation due to the quadratic nature of the cost function. Therefore, if there is a significant state-level difference, minimization will occur, which means convergence will occur faster.

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

$$d(t)=-Kx(t)+K_{ff}v_{ref}(t) \tag{11}$$

Where

$$K=R^{-1}B^{T}P \tag{12}$$

$$K=R^{-1}B^{T}¿ \tag{13}$$

K, the gain vector, helps to move the poles of the system to synthesize the best controller. The vector obtained in the best way depends on the symmetric positive definite matrix, P, shown in (12). The matrix for a given system can be obtained by solving the Riccati Algebra Equation, shown in.

$$A^{T}P+PA-PBR^{-1}B^{T}P+H^{T}QH=0 \tag{14}$$

2.6 Matlab Linear Quadratic Tracker (LQT) Program on RS PRO 454-0883 DC Motor

```
clear
```

```
clc

%MSD system parameters

m=2;

k=8;

b=6;

%Matrix on state

A=[0 1;k/m -b/m];

B=[0;1/m];

C=[1 0];

%weight

Q=[1 0;0 1];

R=10;

[S,eig,G] = care(A,B,G) %riccati 0=A'S+SA-SB(inv R)B'S+Q

Kx=inv(R)*B'*S %feedback 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]

%hat weight

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 Circuit Simulation in Matlab

2.7.1 First Order DC Motor Circuit

The original response output of the RS PRO 454-0883 DC motor is determined by a first-order circuit without changing the noise or optimization method.

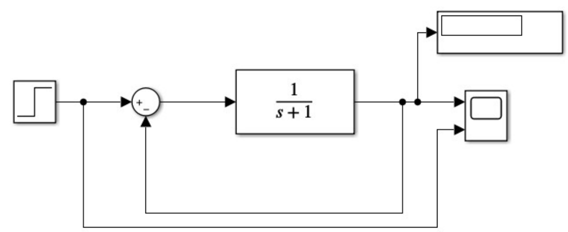


Figure 2.4 DC Motor First Order Circuit

In Figure 2.4 there is a first-order DC motor circuit consisting of one input and one output. The input uses a step signal type. The transfer function in this circuit represents the model of the first-order RS PRO 454-0883 DC motor. The output response is displayed on the scope screen to monitor the response results.

2.7.2 Linear Quadratic Regulation (LQR) Circuit for DC Motor RS PRO 454-0883

The RS PRO 454-0883 DC Motor Circuit with LQR optimization method is used to examine the output response of the DC motor when the LQR optimization method is applied in the Matlab Simulink environment.

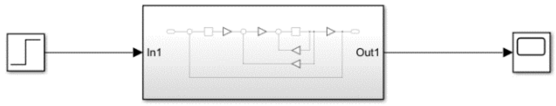


Figure 2.5 LQR Circuit of RS PRO 454-0883 DC Motor

2.7.3 Linear Quadratic Regulation (LQR) Circuit of 37-GB500 DC Motor with Noise

LQR Motor DC RS PRO 454-0883 involving LQR optimization method and noise addition is used to evaluate the output response of a DC motor when LQR optimization method is applied and noise is added into the system, all of this is done through Matlab Simulink.

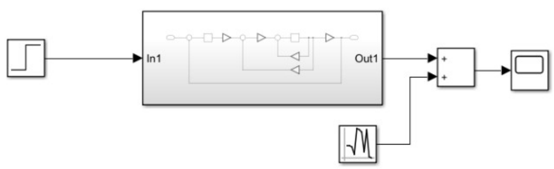


Figure 2.5 LQR Circuit of DC Motor RS PRO 454-0883 with Noise

2.7.4 Linear Quadratic Tracker (LQT) Circuit of DC Motor 37-GB500

The RS PRO 454-0883 DC Motor Circuit with LQT optimization method is used to evaluate the output response of the DC motor when the LQT optimization method is applied through Matlab Simulink.

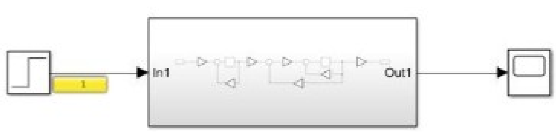


Figure 2.6 LQT DC Motor Circuit RS PRO 454-0883

2.7.5 Linear Quadratic Tracker (LQT) Circuit of RS PRO 454-0883 DC Motor with Noise

LQT DC Motor RS PRO 454-0883 involving LQT optimization method and noise addition is used to observe the output response of DC motor when LQT optimization method is applied and noise is added into the system, all of this is done through Matlab Simulink.

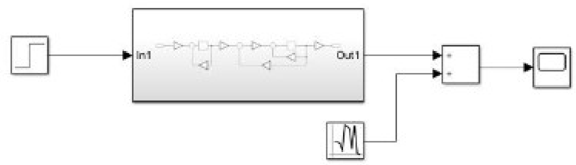
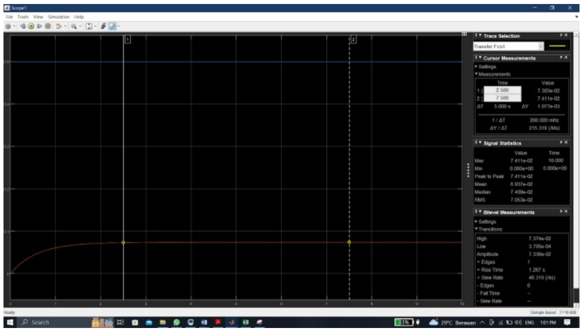


Figure 2.7 RS PRO 454-0883 LQT Motor Circuit with Noise

III.RESULTS & DISCUSSION

The output response graph of the RS PRO 454-0883 DC motor with a first-order mathematical model, with the addition of the Linear Quadratic Regulation (LQR) method, Linear Quadratic Tracker (LQT), and the addition of noise are the results of the experiment. From the results of the experiment, a comparison of the motor output response will be carried out.

3.1 First Order Response Results of RS Pro 454-0883 DC Motor



In Figure 3.1, the first-order response output shows a response graph with the output significantly far from the set point. The orange waveform represents the motor response, while the blue waveform represents the set point. The set point value is 0.5, while the motor response only reaches 0.07, which is far below the set point. The RS PRO 454-0883 DC motor shows linear characteristics with no waves or fluctuations in its signal. The motor response reaches steady state at 2 seconds. However, this response is considered slow in the context of optimization.

Figure 3.1 Response Results of the RS PRO 454-0883 First Order DC Motor

3.2 Response Results of RS PRO 454-0883 DC Motor with LQR Method

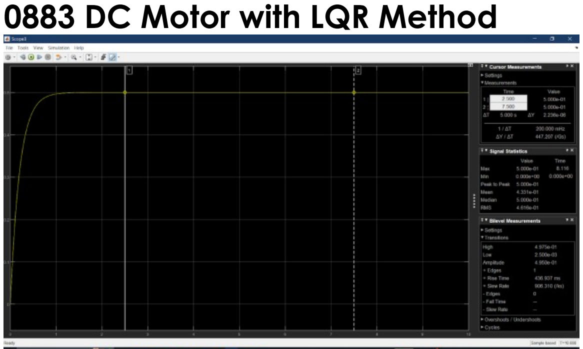


Figure 3.2 Results of DC Motor Response 37-GB500 with LQR Method

The response graph of the RS PRO 454-0883 motor shows that the output of the LQR circuit is the same as the desired set point value, as shown in Figure 3.2. The response of the RS PRO 454-0883 DC motor with the Linear Quadratic Regulation (LQR) method is better than the first order motor. Its response reaches the set point to 1.2 in seconds without overshut or undershut.

3.3 Comparison Results of DC Motor Response 37-GB500 with LQR Method and Without Method

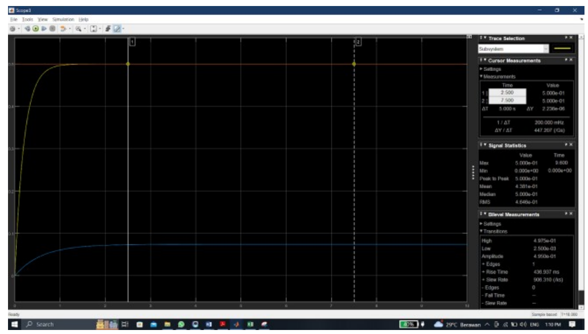


Figure 3.3 Comparison Results of the Response of the RS PRO 454-0883 DC Motor with the LQR Method and Without Using the Method

The output response comparison graph (Figure 3.3) between the use of the LQR method and without the method shows a significant difference. The orange wave line depicts the desired set point, while the blue line depicts the motor response without using the LQR method, and the yellow line depicts the motor response with the use of the LQR method. From Figure 3.3, it can be seen that the motor response with the LQR method is much better compared to the response without any method. In addition to the response approaching the set point, the motor response also reaches the steady state value faster.

3.4 Results of DC Motor Response 37-GB500 LQR Method with Noise

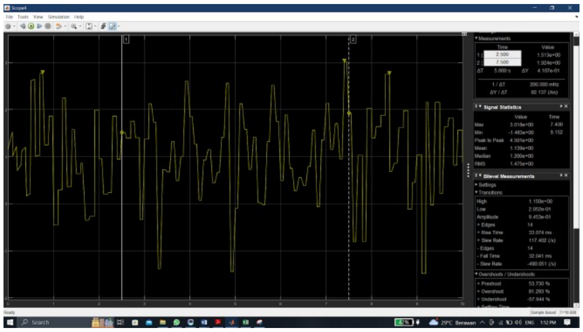


Figure 3.4 Results of the Response of the RS PRO 454-0883 DC Motor with the LQR Method when Given Noise

Figure 3.4 shows the output response of the LQR circuit with disturbance where the yellow signal changes shape before the disturbance is given. The signal shape experiences many ripples and duplicates the shape of the disturbance given. The resulting signal is no longer linear and far from the steady state condition at the given set point.

3.5 Response Results of RS PRO 454-0883 DC Motor with LQT Method

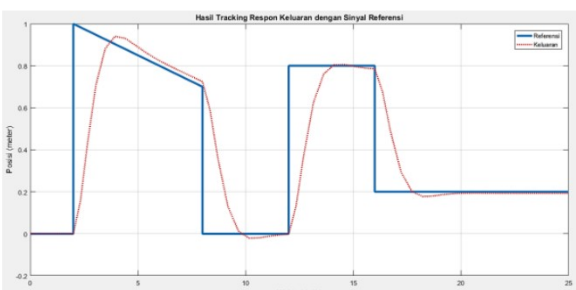


Figure 3.5 Results of the RS PRO 454-0883 DC Motor Response with the LQT Method

The 37-GB500 motor response graph shows that the output of the LQT response circuit is the same as the desired set point value, as shown in Figure 3.5. With a set point of 0.5, the motor response successfully reaches the set point to 1.2 in seconds without overshut or undershut. Unlike the first-order motor response, the RS PRO 454-0883 DC motor response with the Linear Quadratic Tracker (LQT) method is better.

3.7 Response Results of DC Motor RS PRO 454-0883 LQT Method with Noise

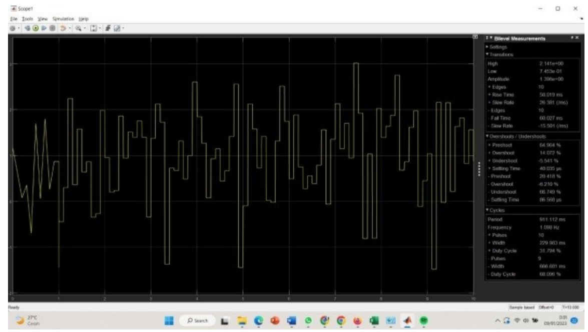


Figure 3.7 Results of the Response of the RS PRO 454-0883 DC Motor with the LQT Method when Given Noise

In Figure 3.7, the output response of the LQT circuit with added noise (yellow waveform) shows a change in shape before the noise. The signal undergoes many small repeating waves and displays a shape that is duplicated from the added noise signal. The resulting signal no longer exhibits linear characteristics and is far from reaching the steady state condition at the predetermined set point.

IV.CONCLUSION (14 pt)

The simulation results using MATLAB on the RS PRO 454-0883 DC motor in several circuits concluded that the two methods used, namely Linear Quadratic Regulation and Linear Quadratic Tracker, have a significant effect on the motor response. The output signal shape of the circuit using the LQR, LQT, and first-order methods shows a significant difference. However, it should be noted that when noise is added to the circuit, there are many fluctuations in the output signal.

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.

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