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# DC Motor Analysis 42D29Y401 for System Optimization through LQR and LQT Approaches

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**ABSTRACT**

DC motors are one of the control systems used to control, manage, and control the condition of a system. Especially in DC motors it is used to convert direct current (DC) into kinetic energy. This DC motor has two poles, namely positive (+) and negative (-) poles that function so that they can be active. DC motors have the advantage of being easy to regulate speed in a wide range with various methods used which makes this DC Motor widely used in Industry, especially Modern Industry. Not specifically in a Modern Industry, but various kinds of Modern Industries use this DC Motor with various variations depending on the needs and needs of the industry. One of the methods that can be used to adjust the speed of the DC Motor and to suit the needs of the tool working system is to use *a speed control device*. Thus, the performance optimization experiment of DC Motors can be carried out using mathematical modeling and control systems supported by Software. One of the software that can be used and is in accordance with the experiment is the Matlab software. The optimization system methods used for the optimal occurrence of a system in this problem are LQR (Linear Quadratic Regulator) and LQT (Linear Quadratic Tracking). Thus, in this study, the representation and simulation of DC motors with and without a series of optimizations are carried out.

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

## I. INTRODUCTION

Due to its ease in various applications, DC motors are often used. Not only used for industrial needs, but can also be used in household appliances, toys, daily tools, and as one of the components in electronic systems. The presence of two poles on a DC motor requires direct current to activate it[1]. DC motors have the ability to convert electrical energy into mechanical energy[2]. There are several types of DC Motors that operate in the presence of an interaction between a magnetic field and a conductor, which will conduct current to cause the motor to spin. The rotor and stator are also the components that make up the DC Motor, which can be seen in figure 1[3]

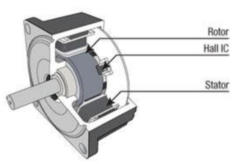


Figure 1. DC Motor Parts

Due to the high industrial demand for DC motors, an analysis and calculation process is needed to find the most optimal solution used to implement control system optimization[4][5]. A control system can be defined as the process of regulating one or more variables or parameters so that it reaches a certain value or a certain range. In different contexts, it is often referred to as a control technique, a regulatory system, or a control system. In terms of equipment and instruments used, the control system involves various physical components that function to show the direction of energy flow to a certain machine or process to achieve the desired results[6].

There are two types of control systems, namely *open-loop control systems* and *closed-loop control systems[7][8].* An open-loop control system is a type of control in which the output signal does not affect the control action. This can occur due to the absence of a feedback mechanism from the output signal to the input signal in an *open-loop control system*. A model of this open-loop control system can be seen in figure 2[9].


Figure 2. Open Loop Control System

A closed-loop *control system* is a type of control system in which the output signal directly affects the control actions in the system[10][11]. This can happen because of the feedback mechanism in this system. A model of this closed-loop control system can be seen in figure 3.

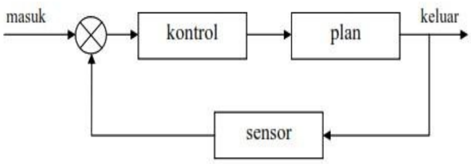


Figure 3. Closed Loop Control System

In this study, the authors utilize a *closed-loop* control system to investigate the response of IG 22GM type DC Motor in order 1 mathematical techniques when used as a plant in a system. The simulation was carried out using LQR and LQT Techniques in the IG 22GM type DC Motor[12]. *Linear Quadratic Regulator* (LQR) is one of the state space control techniques that requires comprehensive system information. To optimize the gain value, weighting is needed as Q and R values in LQR[13][14]. On the other hand, *Linear Quadratic Tracker* (LQT) is the main technique for tracking problems in linear systems. LQT is designed to design optimal control so that the linear control system can follow a set reference path. By minimizing the specified square function, optimal control can be obtained. LQT consists of feedback and *feedforward* components calculated using *the Algebraic Riccati Equation* (ARE)[15].

The author uses Simulink to simulate the system created by the LQR and LQT methods in this study. Simulink is a graphical extension of Matlab that is used to create models and run system simulations. In Simulink, the system is symbolized as a block diagram, which *includes transfer functions*, *summing junctions*, as well as *input and output virtual* devices such as *Oscilloscopes* and *Function Generators[16].*

Mathematical modeling is a technique for describing complex systems into Mathematical Languages. This language or mathematical model is expected to represent the conditions of these complex systems. The DC Motor 42D29Y401 datasheet is used as a reference for the author to perform calculations to obtain 1st order mathematical modeling which is used as a transfer function from the plant, which is a mathematical relationship between the input and output of the control system components[17][18].

The purpose of this study is to analyze the output behavior response caused by the variation of the input signal or *step response* in the DC Motor type 42D29Y401 under two conditions, namely without noise and the other with *noise* in the system output[19][20].

## II. METHODOLOGY

### 1. Research Process

The following is *a flowchart* that illustrates the stages carried out in this study:

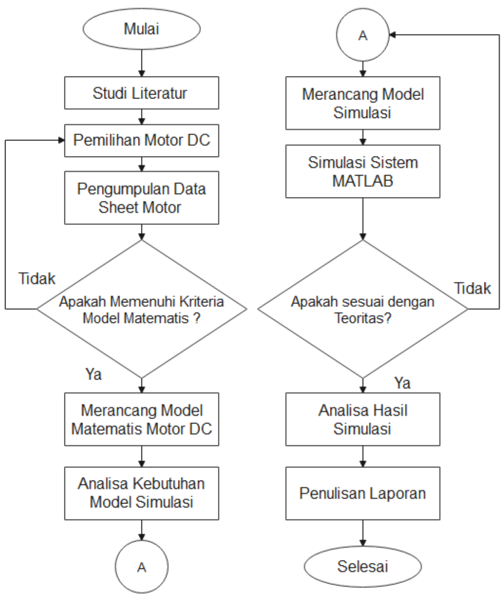


Figure 4. Simulation Stage Flowchart

### 2. Preparation of Mathematical Models of Systems and Sensors

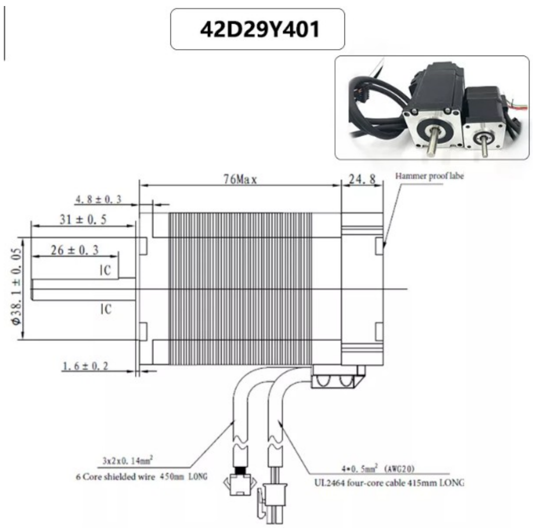


Figure 5. DC Motor 42D29Y401

Table 1. DC Motor 42D29Y401 Datasheet

| Electrical Characteristics | | 6.Phase inductance | 1. 4mH ± 20% (1kHz 1V rms) |
|---|---|---|---|
| 1.Phase number | 2 Phase | 7. Holding torque | 2. 2N. m Min (两相通电) |
| 2. Step angle | 1. 8° | 8. Rotor inertia | 300g. cm^2 |
| 3.Rated voltage | 2. 31V | 9. Motor weight | 680g Ref. |
| 4. Rated current | 4. 2A | 10. Insulation resistance | 100MΩ Min. (DC 500V) |
| 5. Phase resistance | 0. 54Ω ± 10% (20° C) | 11. Insulation class | B (130° C) |

Known:

- Motor Name = DC Motor 42D29Y401
- $\tau$ = 2.2 N/m
- Rated Current = 4.2 A
- Voltage = 31 V
- Speed = 6000 rpm or 628.32 m/s

With the data that is already known, it can be obtained the general form of the order 1 transfer function:

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

- Order 1 DC Motor
  With the data known from the DC motor datasheet, it can be found that the 1st order equation : namely $\tau$ = K. i which causes

$$K = = \frac{\tau}{i}\frac{2{,}2}{4{,}2} = 0.523 \quad (2)$$

Equivalent values of order 1 DC motors:

$$G(s) = \frac{0{,}523}{2{,}2s+1}$$

(3)

- Mathematical depictions of the 2nd Order
  General form of order 2nd order transfer function

$$G(s)=\frac{\omega n^2}{s^2+2\varsigma\omega n s+\omega n^2}$$
(4)

$$G(s)=\frac{2\pi f^2}{s^2+2\varsigma(2\pi f)s+2\pi f^2} \quad (5)$$

$$G(s)=\frac{(2\pi 50)^2}{s^2+2(300)(2\pi 50)s+\text{¿¿}} \quad (6)$$

$$G(s)=\frac{98596}{s^2+188400s+98596} \quad (7)$$

In a system with multiple outputs, a current sensor switching function is required as feedback in the system to measure the current generated by the DC Motor 42D29Y401. This block of current sensor switching functions is depicted as seen in Figure 6.

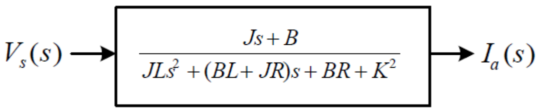


Figure 6. Current Sensor Switch Function Block

A speed sensor switch function block is required to measure the speed value of the DC Motor 42D29Y401 as seen in Figure 7.

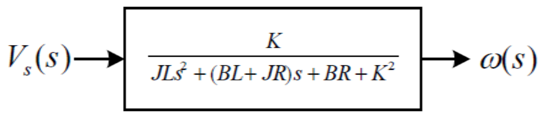


Figure 7. Speed Sensor Switch Function Block

- Moment of inertia (J) = 30 Kg.m2
- Damping of mechanical systems (B) = 0.14 Nms
- Motor constant (K) = 0.298 Nm/A
- Resistance (R) = 0.54 ohm
- Inductance (L) = 0.0014 H

Mathematical description of the current sensor switching function:

$$\frac{Js+B}{JLs^2+(BL+JR)s+BR+K^2}$$
(8)

$$\frac{30s+0{,}14}{(30)(0{,}0014)s^2+\text{¿¿}}$$
(9)

$$\frac{30s+0{,}14}{0{,}042s^2+16{,}2001s+0.0756+0{,}0888}$$
(Current Sensor Switch Function)
(10)

Mathematical description of the speed sensor switching function:

$$\frac{K}{JLs^2+(BL+JR)s+BR+K^2}$$
(11)

$$\frac{0{,}298}{(30)(0{,}0014)s^2+\text{¿¿}}$$
(12)

$$\frac{0{,}298}{0{,}042s^2+16{,}2001s+0{,}0756+0{,}0888}$$
(Speed Sensor Switch Function) (13)

## 3. Writing MATLAB Script Programs

In the practicum of system optimization of the DC Motor 42D29Y401 using the LQR and LQT methods, a MATLAB program script is needed to simulate the system on Simulink. Here is the script of the MATLAB program used.

**1.System Optimization with LQR Method on DC Motors**

```
% OPTIMIZATION OF LQR SYSTEM ON DC
MOTORS
Clear; CLC;
% DC Motor Models
J = 30 ; % J = Moment of Inertia
b = 0.14 ; %b = Damping Ratio
K = 0.0298 ; %K = Constant
R = 0.54 ; %R = Resistance
L = 0.0014 ; %L = Inductance

A = [-b/J K/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)];

% Matrix LQR
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. System Optimization with LQT Method on DC Motors**

```
Clear;
CLC;
% DC Motor Models
J = 30 ; b= 0.14 ; K= 0.0298 ; R= 0.54 ; L = 0.0014 ;
% J = Moment, b = Ratio, K= constant, R= resistance, L=Inductance
A = [-b/J K/J; -K/L -R/L];
B = [0; 1/L];
C = [1 0]
Q=10; R=0.0000000001; %0.000000000000001
W=C'*Q; %
[S,o,m,n]=care(A,B,C'*Q*C,R) %m=v(t) %S=P
K=inv(R)*B'*S %feedback Gain
ACL=(A-B*K)'
L=inv(R)*B' %model following gain
```

## 4. System Needs Analysis

The LQR and LQT paper methods use Simulink from MATLAB Software. The following are the components needed as shown in table 2.

Table 2. Simulink Components List

| | |
|---|---|
| Add | Gain |
| Step | Integrator |
| Random Number | Scope |

## 5. Creating a System Inside the Simulator

**1.DC Motor Series 42D29Y401 In Order 1**

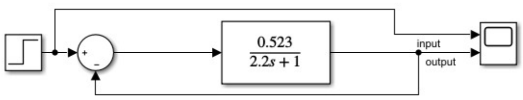


Figure 8. DC Motor Series 42D29Y401 Order 1

**2.LQR Network**

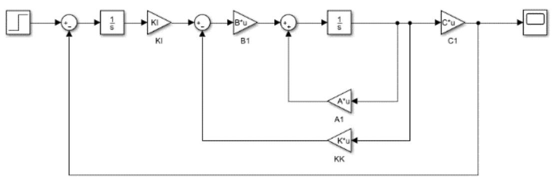


Figure 9. LQR Network

**3. Noise LQR Subsystem Network**

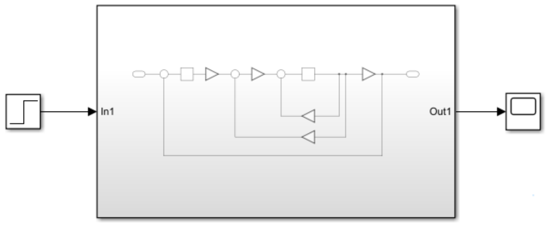


Figure 10. Noiseless LQR Subsystem Series

#### 4. LQR Subsystem Network with Noise

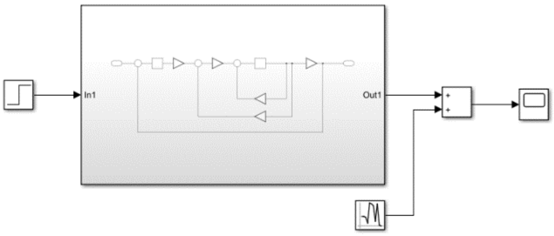


Figure 11. LQR Subsystem Array with Noise

#### 5.LQT Network

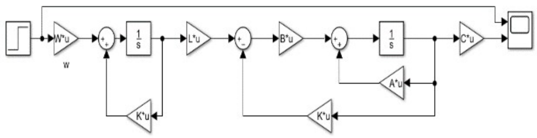


Figure 12. LQT Network

#### 6. Noise LQT Subsystem Network

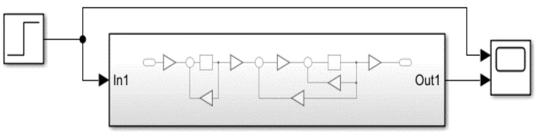


Figure 13. Noiseless LQT Subsystem Series

#### 7. LQT Subsystem Circuit with Noise

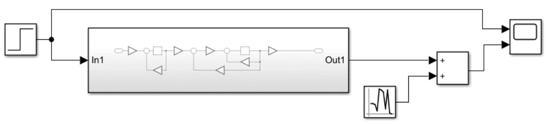


Figure 14. LQT Subsystem Circuits with Noise

## III. RESULTS AND DISCUSSION

#### 1. Simulation Output Analysis of DC Motor 42D29Y401 Order 1

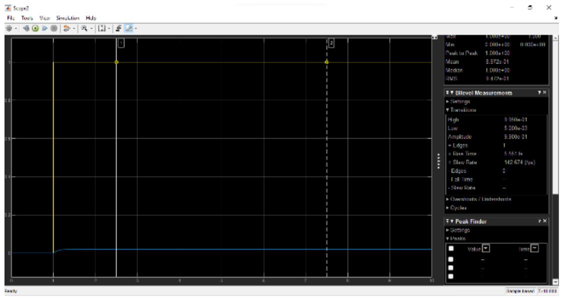

Figure 15. SISO Step Response Display

In Figure 15, there is a graph of the step response of the DC 42D29Y401 motor in the SISO system order 1. In the graph, there are two curves, namely the yellow curve that represents the input given to the system (often referred to as a setpoint) and the blue curve that represents the DC 42D29Y401 motor step response. From the graph, it can be seen that the output curve shape of the SISO order 1 system has not reached the desired setpoint value. The curve shows stability with an amplitude of 0.0204 and an elevation time of 231.789 ms. In addition, the system shows an overshoot of 0.505% and an undershoot of 0.499%.

#### 2. Analysis of the Results of the Simulation of LQR Motor System DC 42D29Y401 without interference (Noise)

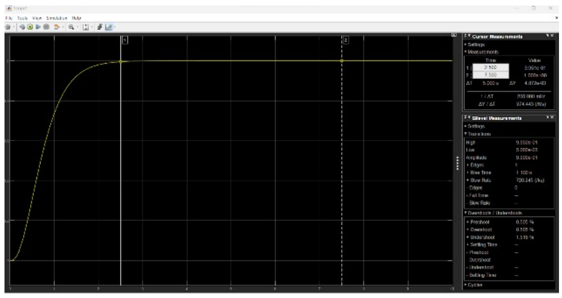

Figure 16. LQR Step Response Display without Noise

In Figure 16, there is a step response graph of the DC motor 42D29Y401 which has been optimized using the LQR method without any interference (noise). It can be seen that the output step response of the LQR optimization system on the DC motor 42D29Y401 reaches an amplitude of about 0.99 which can be estimated as 1, reaching the specified setpoint. The system has a maximum climb time of about 3.11 seconds and shows an overshoot of about 0.501% and an undershoot of about 1.98%.

## 3. Analysis of the Results of the Simulation of LQR Motor System DC 42D29Y401 with Noise

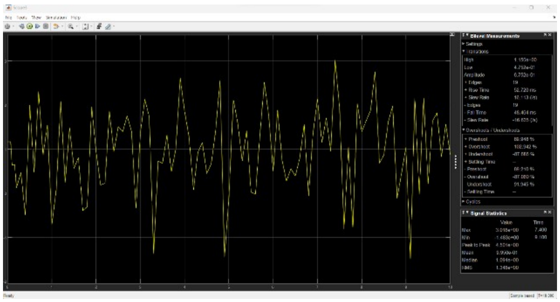

Figure 17. LQR Step Response Display with Noise

In Figure 17, there is a step response graph of the DC 42D29Y401 motor that has been optimized using the LQR method with noise. It can be seen that the output step response of the LQR optimization system on the DC motor 42D29Y401 shows fluctuations caused by noise. The system has an amplitude of about 0.67 and a climb time of about 52.72 ms, and shows significant overshoot and undershoot with an overshoot of about -87.06% and an undershoot of about 91.94%.

## 4. Analysis of LQT System Optimization Simulation Results on DC Motor 42D29Y401 without interference (Noise)

Figure 18. LQT Step Response Display without Noise

In Figure 18, there is a step response graph of the DC motor 42D29Y401 which has been optimized using the LQT method without any noise. It can be seen that the output step response of the LQT optimization system on the DC 42D29Y401 motor shows an amplitude of about 0.99 and a climb time of about 7.43 ms. This system also shows an overshoot of 1.53% and an undershoot of 0.45%.

## 5. Analysis of LQT System Optimization Simulation Results on DC Motor 42D29Y401 with Noise

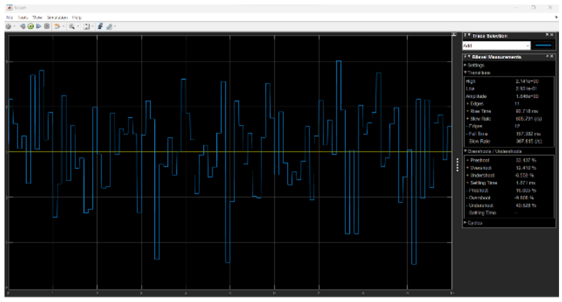

Figure 19. LQT Step Response Display with Noise

In Figure 19, there is a step response graph of the DC motor 42D29Y401 which has been optimized using the LQT method with noise. It can be seen that the output step response of the LQT optimization system on the DC motor 42D29Y401 shows fluctuations caused by noise. This system has an amplitude of about 0.18 and a climb time of about 92.71 ms. There is also a significant overshoot of around

12.41% and an undershoot of about -6.55%.

### 6. Simulation Result Data

The following is the experimental simulation data obtained on the Simulink MATLAB 2018B platform listed below.

Table 3. Simulation Data

| No. | System Model | Amplitude | *Rise Time (s)* | *Overshoot (%)* | *Undershoot (%)* |
|---|---|---|---|---|---|
| 1. | SISO Order 1 | 3.40 | 3.11 | 0.501 | 1.98 |
| 2. | Noiseless LQR | 0.99 | 1.1 | 0.505 | 1.518 |
| 3. | LQR with Noise | 0.67 | 52.72 | -87.06 | 91.94 |
| 4. | Noiseless LQT | 0.99 | 7.43 | 1.53 | 0.45 |
| 5. | LQT with Noise | 0.18 | 92.71 | 12.41 | -6.55 |

## IV. CONCLUSION

1. In order to obtain the mathematical model of a 1st order DC motor and the variables required in the LQR method, the specification data of the DC motor must be available in the form of a datasheet that includes information such as moment of inertia, motor constant, damping ratio, resistance, and inductance. Using 1st order mathematical modeling calculations, we can generate a transfer function. Furthermore, through the execution of the MATLAB script using the LQR method, we can calculate variables A, B, C, K_lqr, and so on that will appear in the workspace.

$$G(s)=\frac{0,523}{2,2s+1}$$

2. The step response results of the DC motor 42D29Y401 with order 1 show a stable step response graph with an amplitude of about 3.40, which indicates that this response reaches the desired setpoint value. The rise time in this case is about 3.11 seconds, and the system has an overshoot of 0.501% and an undershoot of 1.98%.
On the other hand, the step response results of the DC 42D29Y401 motor that has been optimized using the LQR method show an amplitude of about 0.99, which can be considered as 1, thus reaching the specified setpoint. The rise time in this case is quite optimal, which is about 1.1 seconds, and the system shows a fairly small overshoot and undershoot, about 0.505% each.

3. From the results of the response of the second step of the system, it can be compared and it is concluded that the use of the LQR method in the DC motor 42D29Y401 produces more optimal performance than the DC motor 42D29Y401 with order 1. With LQR, the step response of the DC 42D29Y401 motor reaches a setpoint, shows high stability, has a fast rise time, and has a low magnitude overshoot and undershoot. However, the step response generated by the LQT system shows superior performance compared to the previous two systems.

## V. CLOSING

## 1. Awards

The researcher realized that the preparation of this community service journal was impossible to achieve without the support of various parties. Therefore, on this occasion, the researcher would like to express his great gratitude to all parties who have participated. This can be adjusted by adding or listing the parties you want to appreciate.

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