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System Optimization Study on IG-22GM DC Motor Plant with LQR and LQT Analysis Approach

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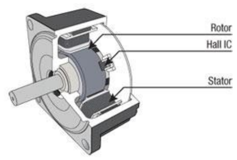
ABSTRACT

A control system, or commonly known as a control system, is a device used to monitor, instruct, and manage the condition of a system. A DC motor, on the other hand, is a device that continuously converts electrical energy into kinetic energy or mechanical motion. DC motors have two terminals, namely the positive terminal and the negative terminal, which require voltage in order to operate. The use of DC motors is very common in a variety of modern industrial systems, with various specifications tailored to the needs of specific industries. One of the main reasons why DC motors are a top choice in modern industry is due to their ability to regulate rotational speeds over a wide range, thanks to the wide variety of speed control methods that can be applied. One common method used to regulate the speed of a DC motor is to use a speed control device, which allows the speed adjustment according to the needs of the device's working system. Therefore, experiments are needed to optimize the operation of DC motors through mathematical modeling and control systems using Matlab software. In the context of this problem, the two optimization methods used in this system are Linear Quadratic Regulation (LQR) and Linear Quadratic Tracking (LQT) to ensure optimal system operation. Therefore, in this study, we modeled and simulated an upgraded DC motor with optimized and non-optimized circuits.

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. DC motors have the ability to convert electrical energy into mechanical energy[1][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[3]. The rotor and stator are also the components that make up the DC Motor, which can be seen in figure 1[4].



:s

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[5][6]. 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[7][8]. 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[9][10].

There are two types of control systems, namely *open-loop control systems* and *closed-loop control systems[11]*. 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.

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[12]. 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.

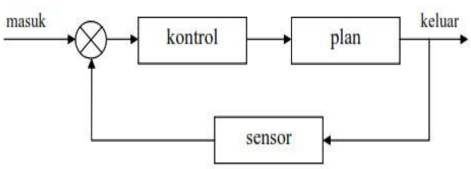


Figure 3. Closed Loop Control System

In this study, the authors used a *closed-loop* control system to investigate the response of the IG-22GM DC Motor in 1st order mathematical techniques when used as a plant in a system[13][14]. The simulation was carried out using LQR and LQT Techniques in the IG-22GM DC Motor.*Linear Quadratic Regulator* (LQR) is one of the state space control techniques that requires comprehensive system information[19][20]. To optimize the gain value, weighting is needed as Q and R values in LQR. 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).

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.*

Mathematical modeling is a technique for describing complex systems into Mathematical Languages[15][16]. This language or mathematical model is expected to represent the conditions of these complex systems. The IG-22GM DC Motor 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].

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 IG-22GM DC Motor in two conditions, namely without noise and the other with noise in the system output[18].

II. METHODOLOGY

1. Research Process

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

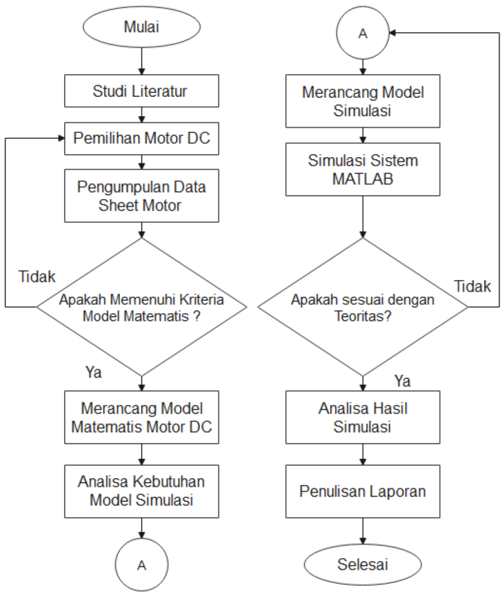


Figure 4. Simulation Stage Flowchart

Specification of IG-22GM type DC Motor	
Rated Torque (τ)	105 mNm = 0.105 Nm
No Load Current(A)	448 mA = 0.448 A
Rated Current(A)	4.87 A
Voltage (V)	18V
Speed (rpm)	441 rpm = 46.18 m/s
Rotor Inertia (J_R)	$23\ gcm^2$
Resistance (R)	0,199 Ω
Inductance (L)	0.113 mH
Mechanical System Damping (B)	0.1 Nms

2. Preparation of Mathematical Models of Systems and Sensors

In the context of this study, it is necessary to use DC motors that have phase to phase inductance and phase to phase resistance characteristics that can be used as parameters in modeling DC motors using LQR and LQT methods. Therefore, this study utilizes an IG 22GM type DC motor with an input voltage of 18V which has different variations in phase to phase inductance and phase to phase resistance values in each variation of voltage input used.

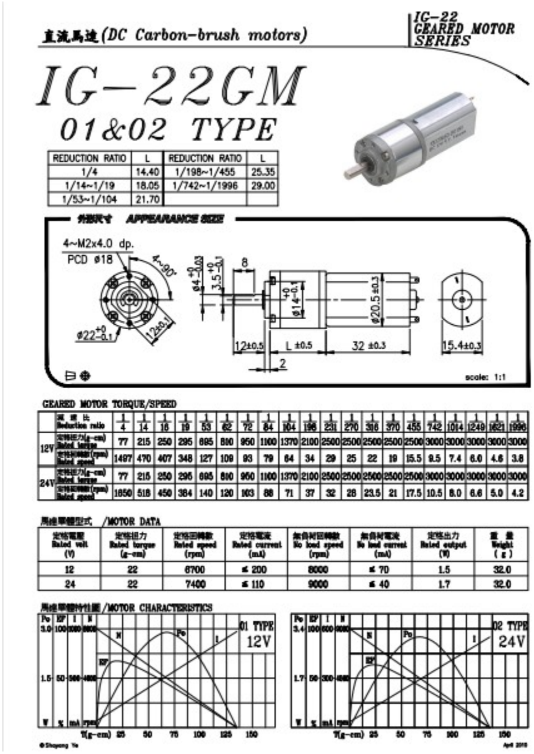


Figure 5. Motor DC IG-22GM

Table 1. Datasheet Motor DC IG-22GM

From the perspective of the mathematical model of a system, the order of the system can be determined through the power of the variable s in the Laplace transform. A system is considered to be one-order if its transfer function has the highest power of the variable s being one. We will now explain more about the modeling of a one-order system.

General equation of order 1 transfer functions:

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

Information:

G(S) = Reinforcement

τ = Torque

K = Constant

Based on the *above datasheet*, order 1 can be obtained:

Where so that the equation of the 1st order of dc motors is obtained: $\tau = K.i$

$$K=\frac{\tau}{i}=\frac{0{,}105}{4{,}87}=0{,}014 \quad (2)$$

$$G(s)=\frac{0{,}021}{0{,}105s+1} \quad (3)$$

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)];
```

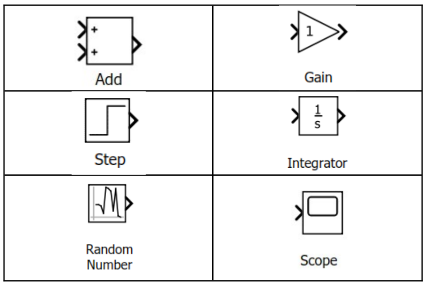
2. System Optimization with LQT Method on DC Motors

```
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; %0.0000000000000001
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



5. Creating a System Inside the Simulator

1.IG-22GM DC Motor Series On Order 1

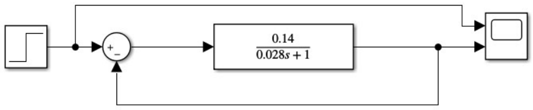


Figure 6. IG-22GM DC Motor Series Order 1

2.LQR Network

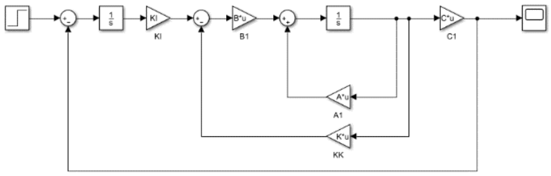


Figure 7. LQR Network

3. Noise LQR Subsystem Network

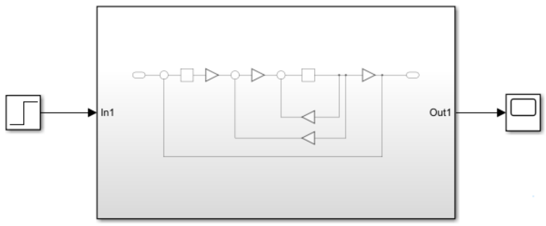


Figure 8. Noiseless LQR Subsystem Series

4. LQR Subsystem Network with Noise

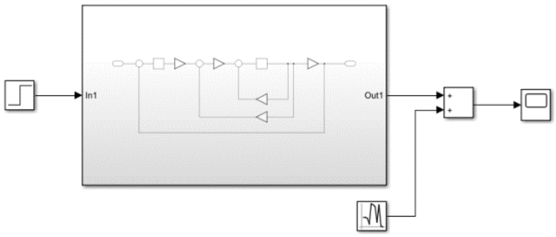


Figure 9. LQR Subsystem Array with Noise

5.LQT Network

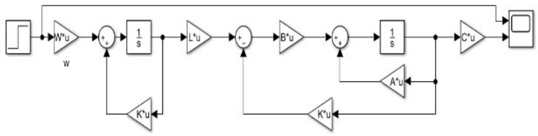


Figure 10. LQT Network

6. Noise LQT Subsystem Network

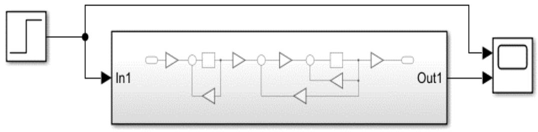


Figure 11. Noiseless LQT Subsystem Series

7. LQT Subsystem Circuit with Noise

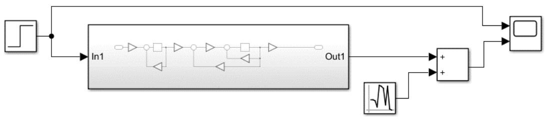


Figure 12. LQT Subsystem Circuits with Noise

III. RESULTS AND DISCUSSION

1. Simulation Output Analysis of IG-22GM DC Motor Order 1

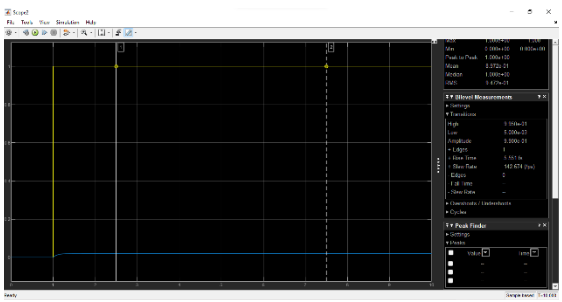


Figure 13. SISO Step Response Display

In Figure 13 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)

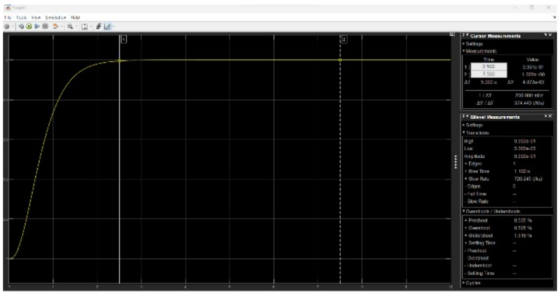


Figure 14. LQR Step Response Display without Noise

In Figure 14, This is the step response of the IG 22GM DC motor that has been optimized using the LQR method without any interference. From this graph, it can be seen that the output step response of the LQR-optimized system on the IG 22GM DC motor reaches an amplitude of 0.99, which can be rounded to 1, according to the specified setpoint. The system has a rise time of about 1.1 seconds, and also has an overshoot of 0.505% and an undershoot of 1.518%.

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

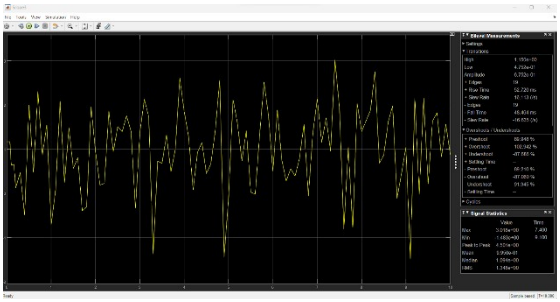


Figure 15. LQR Step Response Display with Noise

In Figure 15, This is the step response of the IG 22GM DC motor that has been optimized using the Linear Quadratic Regulation (LQR) method with additional noise. It can be seen that the output step response of the LQR system on the IG 22GM DC motor shows graph fluctuations caused by the influence of noise that has been fed into the system. In this response, the amplitude reached 2.34 and the rise time was 84.96 ms, with a significant overshoot of 41.735% and an undershoot of 35.093%.

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

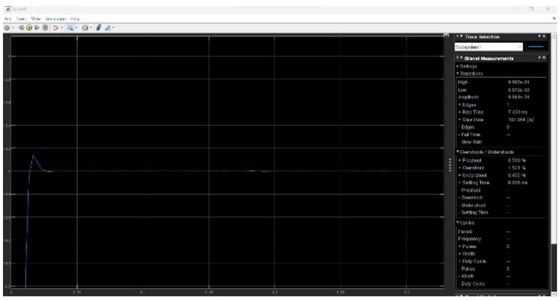


Figure 16. LQT Step Response Display without Noise

In Figure 16, there is a step response graph of the IG 22GM DC motor that has been optimized using the LQT method without any interference. It can be seen that the output step response of the LQT optimization system on the DC IG 22GM motor shows an amplitude of about 0.99 and a rise 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

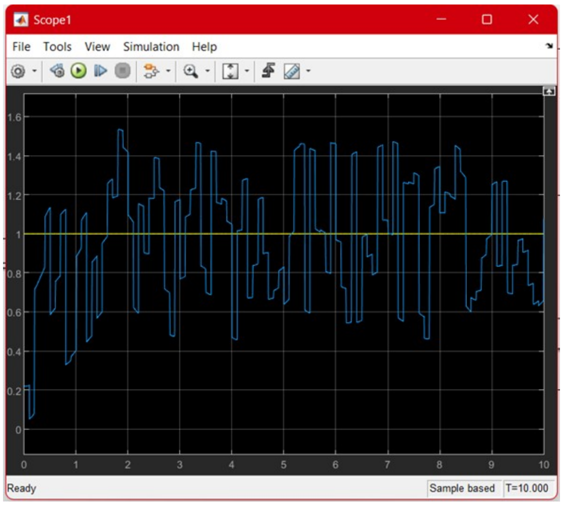


Figure 17. LQT Step Response Display with Noise

After the simulation process, the authors can analyze the response of each DC motor model. The simulation results show that this motorcycle model is not able to achieve the desired set point value. This fact is confirmed by only reaching about 33% of the expected responses. Therefore, this type of motor has a low level of efficiency and has an error of about 77% of the set point value.

However, after being given a Linear Quadratic Tracker (LQT) circuit on the DC motor model, the system's response has changed significantly. The singal response is able to reach the set point value in about 0.8 seconds after the trigger or input is given. In addition, after reaching the set point, the system response does not oscillate and remains stable in the Steady State condition.

In addition, the study also evaluated the system's response when exposed to a disturbance. In experiments without the use of LQT, the singal results of the system's response are severely oscillated and tend to follow the interference signal. However, after applying the LQT circuit, the response signal still oscillates, but it is different from a system without LQT. The response signal in the system reinforced with LQT remains better isolated, and the error value is minimal, or it can be said that there is better attenuation in the system response.

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				
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

In the step response results of the IG-22GM DC motor with order 1, a stable step response graph with an amplitude of 0.124 was found. This means that the bike reaches a setpoint value of 1 with a rise

time of about 5.497 seconds, and the system experiences an overshoot of around 0.501% and an undershoot of around 1.985%.
Meanwhile, the output step response of the IG-22GM DC motor upgraded by the LQR method reached an amplitude of about 0.99, which can be rounded to 1, indicating that the motor reached the desired setpoint. In addition, this response has an excellent climb time, around 1.109 seconds, as well as a fairly small overshoot and undershoot, around 0.505% each.

V. CLOSING

1. Awards

The researcher realized that the preparation of this community service magazine would not have been carried out without the support of many parties. Therefore, on this occasion, the researcher would like to express his deepest gratitude to all parties who have participated.

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