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lab 1 report

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# Simulation 1 (Open loop)

## Question 1

***When the duty cycle is fixed at 0.5 and no external mechanical load torque is applied, observe the corresponding motor torque, speed, current and voltage waveforms and provide detailed explanations of your observations.***

Chart, treemap chart

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Figure 1a. Armature voltage graph

Chart, histogram, scatter chart

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Figure 1b. Armature current graph

Chart

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Figure 1c. Zoomed armature voltage graph

Chart, line chart, scatter chart

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Figure 1d. Zoomed armature current graph

Chart

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Figure 1e. Motor speed graph

Chart, histogram

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Figure 1f. Motor torque graph

At t=0s, the armature current is observed in Figure 1b to increase to its peak value and then decrease back to a value of 0A. This is due to the motor being required to overcome its own inertia and be of a greater value than the load to accelerate.

Since where is the motor torque, is the field flux, and is the armature current; the shape of the motor torque waveform (Figure 1f) and the armature current (Figure 1b) are similar as k and are constant.

The motor continues to accelerate (Figure 1e) until the motor torque is equal to the inertia where the motor speed remains at constant because there is no external mechanical load torque, and the motor torque drops back to 0.

## Question 2

***Investigate the performance of the drive system when the duty cycle is step-changed from 0.5 to 0.8 at t = 2 sec and from 0.8 to 0.2 at t = 4 sec. Please note that no external mechanical load is applied.***

Chart, histogram

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Figure 2a. Armature voltage graph

Chart, scatter chart

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Figure 2b. Armature current graph

Chart

Description automatically generated

Figure 2c. Zoomed armature voltage graph

Chart, line chart

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Figure 2d. Zoomed armature current graph

Chart, scatter chart

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Figure 2e. Motor speed graph

Chart, line chart, scatter chart

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Figure 2f. Motor torque graph

When the duty cycle increases from 0.5 to 0.8 at t=2s, the armature current increases as shown in Figure 2b, and thus, increases as shown in Figure 2f. As a result, and the motor accelerates as observed in Figure 2e. Since , when the armature current increases (Figure 2b), the armature voltage temporarily drops as observed in Figure 2a.

When duty cycle decreases from 0.8 to 0.2 at t=4s, the armature current drops as shown in Figure 2b and thus, a negative torque is applied on the motor, causing forward braking. Energy stored in the armature inductor together with the rotational kinetic energy is sent back to the source, resulting in the temporal spike in the armature voltage (Figure 2a). The motor decelerates (Figure 2e) as the net torque decreases due to the negative torque applied to the motor.

## Question 3

***Investigate the performance of the drive system when the load torque is step-changed from 0 to 0.5 N.m at t = 2.0 sec and from 0.5 N.m to 0.2 N.m at t = 4.0 sec. Please note that the duty cycle is kept constant at 0.5.***

Chart

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Figure 3a. Armature voltage graph

Chart, line chart, histogram

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Figure 3b. Armature current graph

Chart

Description automatically generated

Figure 3c. Zoomed armature voltage graph

Chart, line chart, scatter chart

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Figure 3d. Zoomed armature current graph

Chart

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Figure 3e. Motor Speed graph

Chart, line chart

Description automatically generated

Figure 3f. Motor torque graph

When the load torque is increased from 0 to 0.5 Nm at t = 2s, , and hence, , causing the motor to decelerate as shown in Figure 3e. Hence, decreases and armature current increases as shown in Figure 3b while armature voltage decreases until it reaches steady state as shown in Figure 3a (difficult to see as the drop is very small, need to zoom in).

When the load torque decreased from 0.5 Nm to 0.2 Nm at t = 4s, , and hence, , causing the motor to accelerate. Hence, increases and armature current decreases (Figure 3b) while armature voltage increases until it reaches steady state (Figure 3a; difficult to see as the drop is very small, need to zoom in).

# Simulation 2 (Closed loop)

## Question 1

***Run “design\_pi\_con\_currentloop.m”, file to obtain the PI controller parameters for inner current control loop, use the same parameters (please enter the DC Machine parameters) for outer speed control loop as calculated in simulation-2.***

From the MatLab Simulink model, the following parameters are obtained:

DC input voltage of chopper = ≈ 561.2969 V (where )

Machine inductance = 0.39 H

Machine winding resistance = 29

Mechanical inertia of machine = 0.0024

Switching frequency of chopper = 2000 Hz

Mutual inductance between field and armature = 1.8072 H

Field voltage applied = 240 V

Field voltage applied = 697

From these parameter values, the following parameters of the controller are obtained:

## Question 2

***When the reference speed is fixed at 800 rpm and no external mechanical load is applied, observe the corresponding motor torque and speed waveforms and explain the results.***

Chart

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Figure 4a. Armature voltage graph

Chart

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Figure 4b. Zoomed armature voltage graph

Chart, line chart, scatter chart

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Figure 4c. Armature current graph

Chart, scatter chart

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Figure 4d. Reference and actual speed graph

Chart, scatter chart

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Figure 4e. Reference and actual torque graph

The controller increases the motor speed (Figure 4d) and the motor torque (Figure 4e) to their reference values by increasing the armature current, from which, the motor speed and motor torque remains relatively constant as no external mechanical torque is applied. It can be observed that the motor speed and motor torque reach steady state faster for the closed loop control relative to the open loop control (simulation 1).

## Question 3

***Investigate the performance of the drive system when the load torque has step-changed by a disturbance of 0.5 N.m at t = 2 sec. Please note that the reference speed is kept constant at 800 rpm.***

Chart

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Figure 5a. Armature current graph

Chart, histogram

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Figure 5b. Zoomed armature voltage graph

Chart, line chart, scatter chart

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Figure 5c. Armature current graph

Chart, scatter chart

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Figure 5d. Reference and actual speed graph

Chart

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Figure 5e. Reference and actual torque graph

The disturbance of 0.5Nm at t=0.2s, causes motor speed to dip and deviates from the reference value before correcting itself back to the reference speed as observed in Figure 5d. This is different from the open loop control where the motor speed will not restore back to the original speed (Figure 2e).

The armature current increases in responds to the perturbation and the armature voltage drops as observed in Figures 5c and 5a. The reference torque increases and the actual torque increases to match the reference torque as observed in Figure 5e. This contrasts with the open loop control where the armature current and motor torque peaks and returns to their original levels.

# Experiment 1-A

The DC motor/generator field current is first set to its nominal value (300mA) using the field rheostat. Then the voltage knob in the power supply is adjusted to 100% position and the input voltage to the chopper is increased to about 240V.

The duty cycle of the Chopper is adjusted to 25%, and an image of the oscilloscope waveforms are taken (Figure 6a). This is repeated for 45% duty cycle and 60% duty cycle (Figure 6b and Figure 6c respectively).

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Automatisch generierte Beschreibung Graphical user interface

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Figure 6a. Oscilloscope waveforms for 25% duty cycle Figure 6b. Oscilloscope waveforms for 45% duty cycle

Graphical user interface, application

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Figure 6c. Oscilloscope waveforms for 60% duty cycle

## Question 1

**Explain the relationship between the PWM duty cycles and the DC motor voltage and speed. Try to discuss about how the current changes when increasing speed or decreasing the motor speed.**

A higher PWM Duty Cycle means a higher DC motor voltage since and thus motor speed is higher. When the motor speed is increasing, the current is increasing and when the motor speed is decreasing, the current is also increasing but in the opposite direction.

## Question 2

**Plot the torque – speed characteristics of the motor for the two duty cycles and discuss about the nature these curves.**

The duty cycle of the Chopper is adjusted to 30%. The load is then increased from 0 to 0.8 to 1.4 and then to 1.88 Nm and the motor speed at the different loads were recorded. Then the duty cycle is increased to 50% and the experiment is repeated for 0, 0.8, 1.4 and 3.04 Nm. The values are recorded in tables 1a and 1b below.

|  |  |
| --- | --- |
| 30% Duty Cycle | |
| Load [Nm] | Speed [rpm] |
| 0 | 385 |
| 0.8 | 303 |
| 1.4 | 248 |
| 1.88 | 199 |

|  |  |
| --- | --- |
| 50% Duty Cycle | |
| Load [Nm] | Speed [rpm] |
| 0 | 656 |
| 0.8 | 573 |
| 1.4 | 513 |
| 3.04 | 283 |

Table 1a. Motor speed for various loads at 30% duty cycle Table 1b. Motor speed for various loads at 50% duty cycle

The values are then plotted in the graph in Figure 7 below.

Figure 7. Oscilloscope waveforms for 60% duty cycle

The torque-speed curves in Figure 7 share similar gradients for both the 30% and 50% duty cycle. However, the 50% duty cycle curve sits higher than the 30% duty cycle curve, indicating a higher motor speed across all loads.

This is due to the higher duty cycle supplying more armature voltage which contributes to a higher motor speed. Hence, armature voltage control is effective for controlling the motor speed for speeds below the base speed.

# Experiment 1-B

## Question 3

**Plot the torque – speed characteristics of the motor for two field currents and discuss about the nature these curves.**

The load is set to 0Nm. With the duty cycle is set at 50%, the field current is adjusted to 150 mA and the motor speed is recorded. While maintaining the duty cycle at 50%, the field current is adjusted to 200mA and 300mA and their corresponding motor speeds are recorded in the table 2 below.

|  |  |
| --- | --- |
| Field current (mA) | Speed (r/min) |
| 150 | 850 |
| 200 | 745 |
| 300 | 654 |

Table 2. Motor speed for various field currents with no load

Maintaining the 50% duty cycle, the field current is set to 150mA, and the load is adjusted to 4 different values and their corresponding motor speeds are recorded in table 3 below. The experiment is repeated for 300mA field current and the corresponding motor speeds are recorded in the same table.

Table 3. Motor speed for various field currents with various loads

|  |  |  |
| --- | --- | --- |
| Field current (mA) | Load (Nm) | Speed (r/min) |
| 150 | 1.04 | 561 |
| 0.8 | 643 |
| 0.48 | 731 |
| 0 | 838 |
| 300 | 1.37 | 462 |
| 0.62 | 571 |
| 0.27 | 609 |
| 0 | 648 |

The torque-speed characteristics for the 150mA and the 300mA field currents are plotted in the graph as shown in Figure 8 below.

Figure 8. Graph of speed against load

From the 2 curves plotted in Figure 8, the 300mA field current curve has a steeper curve than that of the 150mA field current curve. This indicates that for the same torque, lower field current corresponds to a higher motor speed and hence, the ineffectiveness of field flux control to control motor speed for speeds below the base speed.