XI'AN JIAOTONG-LIVERPOOL UNIVERSITY

西 交 利 物 浦 大 学

COURSEWORK

SUBMISSION COVER Page

Lab Date (tick √)	Week 10 Tuesday Week 10 Thursday √
Team Number	T06
Students' ID Number	2251625 2252439 2251676 2251619 2253907
Module Code	CAN102
Assignment Title	Coursework2
Submission Deadline	23:59 2024/05/05 for D2/1 23:59 2024/05/07 for D2/2

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Contribution:

Part A is completed by (write down the ID number): 2251625 2252439 2251676 2251619 2253907

B1-B3 is completed by (write down the ID number): 2251625 2252439 2251676 2251619 2253907

B4-B6 is completed by (write down the ID number): 2251625 2252439 2251676 2251619 2253907

B7&B8 is completed by (write down the ID number): 2251625 2252439 2251676 2251619 2253907

Please list the ID number who does NOT contribute at all: None

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Signature YiFei Wu 2251619

Signature Qiyuan Cai 2253907

Date 2024/5/2

Part A

TASK A:

The cross-sectional view of a 230 V series dc motor is given in Figure A. The rated operating speed n_m is 1500 rpm and the armature current I_a is 15 A. The armature resistance R_a and the field resistance R_f are 0.9 Ω and 1.0 Ω respectively. Assume the motor as magnetically linear and neglecting the armature reaction.

a) Determine the number of poles of the given dc motor (1 mark).
b) Identify the components' names of P1-P4 (rotor, stator, armature windings, field windings) in Figure A (4 marks).
c) Draw an equivalent circuit of the given series dc motor. Currents, resistances, and voltages should all be clearly labelled on your drawing (you may draw this by hand or using software) (5 marks).
d) Determine the value of the induced torque τ_{ind} supplied by the series dc motor (5 marks).
e) Given the relation between the loss torque (frictional torque) τ_L of the series dc motor and the shaft speed ω_m is $\tau_L = 0.001\omega_m$, determine the value of the shaft torque τ_s (5 marks).

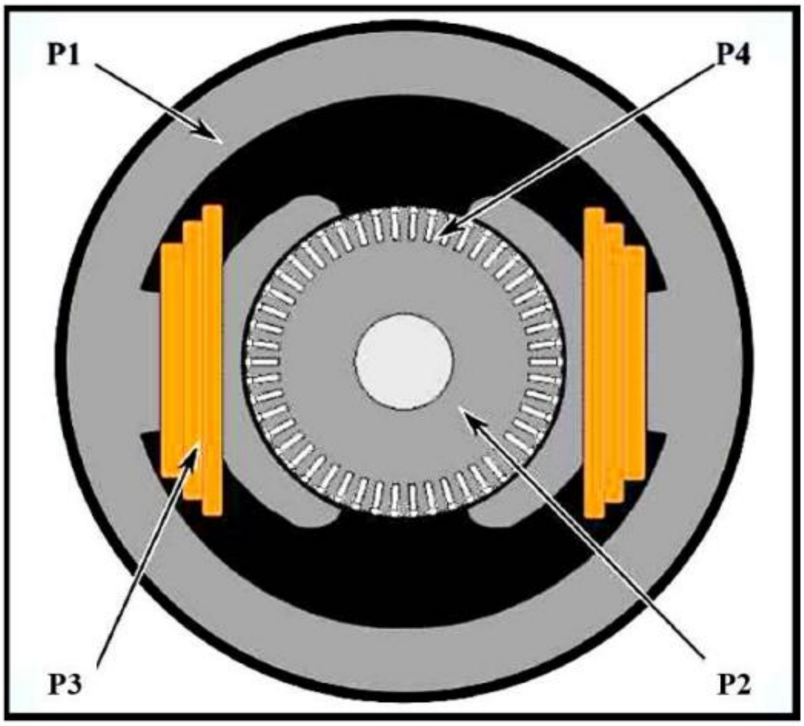


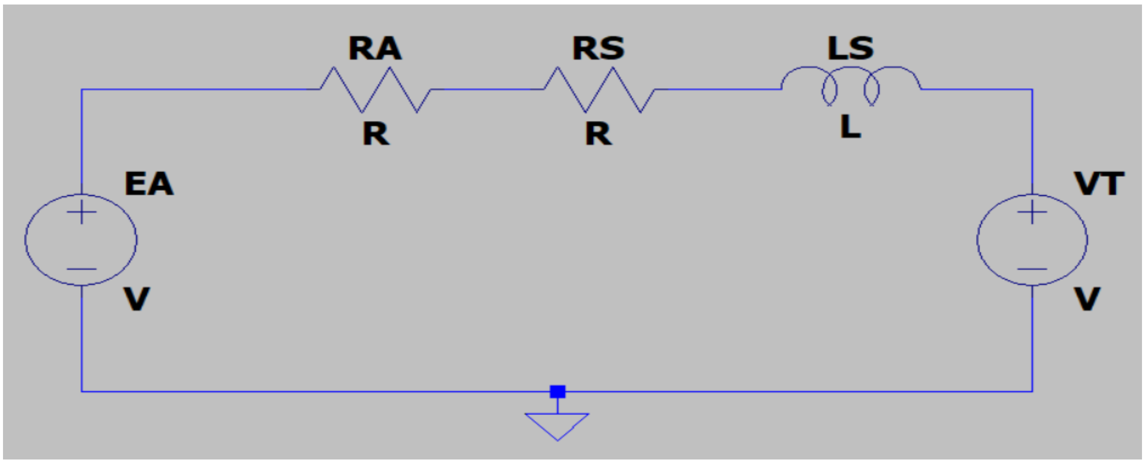
Figure A: A cross-sectional view of a series dc motor.

Answer A:

(a) There are 2 poles for the given dc motor.

(b) P1: stator; P2: rotor; P3: field winding; P4: armature winding

(c) Drawn in ***LTSPICE***



(d) From the formula of induced torque and known information

$$\tau ind = k\Phi \mathrm{Ia}$$

We have to find $k\Phi$ by

$$Ea = k\Phi\omega$$

To find EA, we have to write a KVL equation

$$VT = Ea + Ia(RA + RF)$$

$$VT = 230V; Ia = 15A; Ra = 0.9\Omega; Rf = 1.0\Omega$$

Thus

$$EA = 201.5V$$

To find ω, we've known the relationship between angular velocity and speed per minute as below

$$\omega = 2\pi * \frac{nm}{60}$$

$$nm = 1500\ rpm$$

Therefore

$$\omega = 50\pi\ rad/s$$

In summary

$$\tau ind = 19.2418\ N * m$$

(e) We know that

$$\Phi = \mathrm{C} * \mathrm{Ia}$$

Thus

$$\mathrm{K}\Phi = \mathrm{KC} * \mathrm{Ia}$$

$$\mathrm{KC} = \frac{\mathrm{K}\Phi}{\mathrm{Ia}} = \frac{EA}{\omega * Ia} = \frac{201.5}{50\pi * 15} = 0.0855$$

Then

$$\sqrt{KC} = \sqrt{0.0855} = 0.2924$$

According to Lecture 17 P25

$$\omega m = \frac{VT}{\sqrt{KC * \tau ind}} - \frac{Ra + Rf}{KC}$$

Hence

$$\omega m = \frac{230}{0.2924 * \sqrt{19.24}} - \frac{0.9 + 1.0}{0.0855} = 157.1057\ rad/s$$

To find τL

$$\tau L = 0.001 * \omega m = 0.1571\ N * m$$

By the relation of torque

$$\tau ind = \tau shaft + \tau loss$$

Then

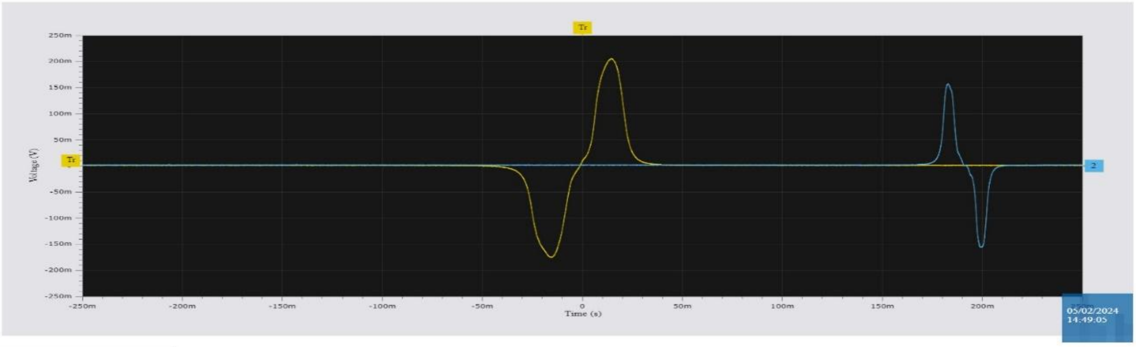
$$\tau s = \tau shaft = 19.2418 - 0.1571 = 19.0847\ N * m$$

Part B

Task B1:

Determine the North and South ends of your magnet set and stick a sticker on the North end. Describe how you made your determination in your assignment (2 marks; check onsite sticker, 3 marks explanation).

Answer B1:



General Settings	
Trigger Type	Analog edge
Trigger Source	Channel 1
Trigger Slope	Rising
Trigger Level	10 mV
Time Per Division	50 ms
Sampling Mode	Decimate
Repetitive Sampling Mode	Off

Advanced Trigger Settings	
Acquisition Delay	Disabled
Trigger Position	0 s

Channels

Name	State	Coupling	Probe Attenuation	Vertical Offset	Vertical Position	Volt Per Division
Channel 1	Enabled	DC	1x	0 V	0 V	50 mV
Channel 2	Enabled	DC	1x	0 V	0 V	50 mV
Channel 3	Disabled					
Channel 4	Disabled					

Reference Channels

Name	State	Reference Mode	Source File Name	Source File Channel	Vertical Position	Volt Per Division
Reference 1	Disabled					
Reference 2	Disabled					
Reference 3	Disabled					
Reference 4	Disabled					

Reference Channels

Name	State	Reference Mode	Source Circuit	Source Probe	Trigger Source Checked	Vertical Position	Volt Per Division

Additional Channels - FFT	
Name	FFT
State	Disabled

Additional Channels - Math	
Name	Math
State	Disabled

Channel Measurements Data

Channel Name	VPP	RMS	Frequency	Period
Ch 1	382.3 mV	41.62 mV	- - - Hz	- - - s
Ch 2	314.1 mV	21.53 mV	- - - Hz	- - - s

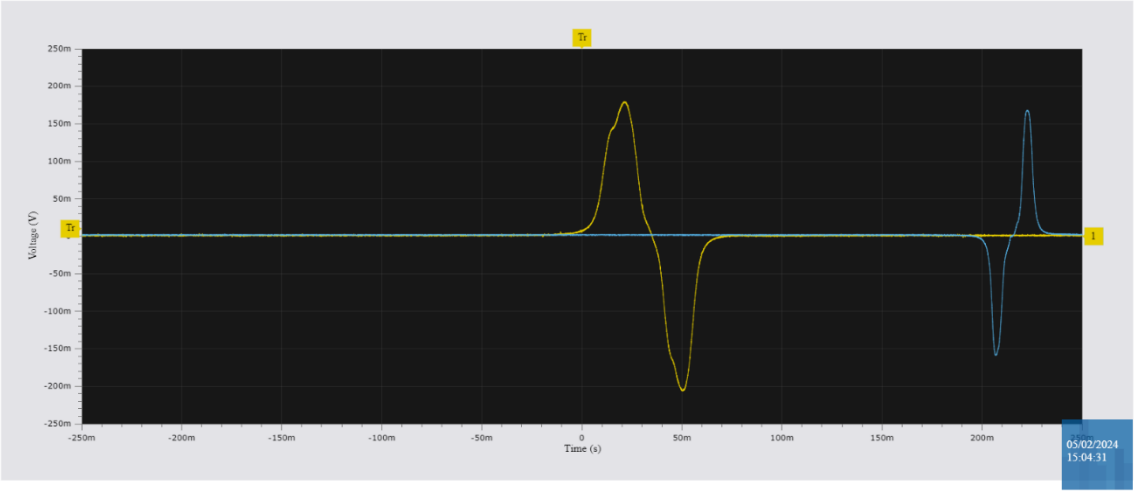
Finished onsite successfully, marked by TA during the lab.

The first peak shown in the figure is negative, and the current flows out of the marker; We go around in a clockwise direction; According to Lenz's law right-hand rule; It can be judged that the North Pole of the induced magnetic field is down; This shows that when you enter the magnetic field, the South Pole of the magnet faces down

Task B2:

When you drop your magnet set 1 North end first, was the induced emf in coil 1 positive or negative for approach? Was the induced emf in coil 2 positive or negative for approach? Explain the reasons with a figure of voltage vs. time obtained from the experiment (10 marks).

Answer B2:



General Settings	
Trigger Type	Analog edge
Trigger Source	Channel 1
Trigger Slope	Rising
Trigger Level	10 mV
Time Per Division	50 ms
Sampling Mode	Decimate
Repetitive Sampling Mode	Off

Advanced Trigger Settings	
Acquisition Delay	Disabled
Trigger Position	0 s

Channels						
Name	State	Coupling	Probe Attenuation	Vertical Offset	Vertical Position	Volt Per Division
Channel 1	Enabled	DC	1x	0 V	0 V	50 mV
Channel 2	Enabled	DC	1x	0 V	0 V	50 mV
Channel 3	Disabled					
Channel 4	Disabled					

Reference Channels						
Name	State	Reference Mode	Source File Name	Source File Channel	Vertical Position	Volt Per Division
Reference 1	Disabled					
Reference 2	Disabled					
Reference 3	Disabled					
Reference 4	Disabled					

Reference Channels							
Name	State	Reference Mode	Source Circuit	Source Probe	Trigger Source Checked	Vertical Position	Volt Per Division

Additional Channels - FFT	
Name	FFT
State	Disabled

Additional Channels - Math	
Name	Math
State	Disabled

Channel Measurements Data				
Channel Name	VPP	RMS	Frequency	Period
Ch 1	386.5 mV	41.41 mV	- - - Hz	- - - s
Ch 2	327.3 mV	21.55 mV	- - - Hz	- - - s

According to the voltage vs. time diagram, when the magnet is near the coil 1, the induced electromotive force is positive, and when it is near the coil 2, the induced electromotive force is negative. This is because when the magnet with the North Pole facing down falls, according to Lenz's law, the induced electromotive force generated by the coil will generate a magnetic field that prevents its fall, and then the right-hand rule can be used to deduce that the induced electromotive force is positive at this time.

Task B3:

Explain the reasons why two peaks of opposite polarity are always observed as the magnet passes through a coil (10 marks).

Answer B3:

When the magnet falls freely into the plastic tube, the magnetic field around the magnet changes. According to Faraday's law of electromagnetic induction, a changing magnetic field can induce an electromotive force in a coil. The copper coils around the plastic tube will sense changes in the magnetic field, and thus induce an electric current. According to Lenz's law, the direction of an induced electromotive force always tends to cancel out its cause. When the magnet enters around the coil, the magnetic field is enhanced, and the current induced in the coil will have a specific direction. When the magnet moves away from the coil, the magnetic field weakens and the current induced in the coil moves in the opposite direction. This is the reason why two peaks of opposite polarity are always observed when the magnet passes through the coil.

Task B4:

Explain the reasons why the maximum induced emf for approach is always less than that for recession (10 marks).

Answer B4:

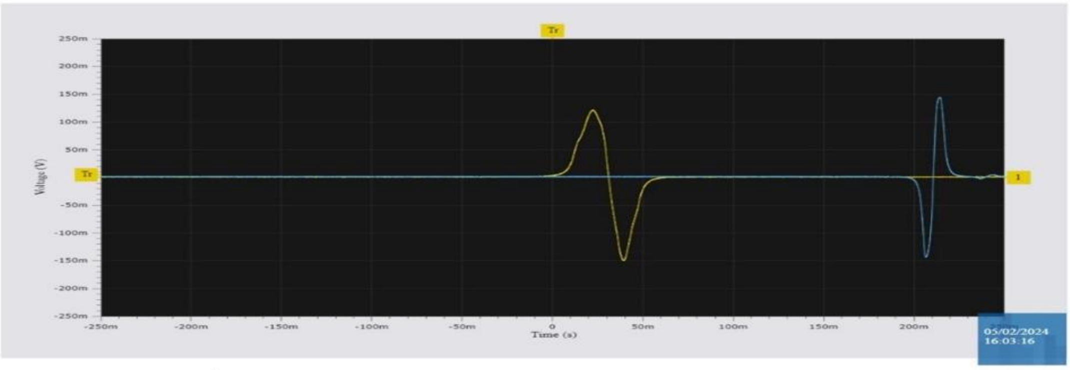
The reason why the maximum induced electromotive force at approach is always less than the maximum induced electromotive force at decay is the difference in the rate of change of the magnetic field. According to Faraday's law of electromagnetic induction, $\varepsilon = -\frac{d\Phi}{dt}$. The peak value of induced electromotive force is smaller when the changing rate of magnetic field is small, and the peak value of induced electromotive force is larger when the changing rate of magnetic field is large. As the magnet approaches the coil, the magnetic field is strengthened at a slower rate, resulting in a smaller rate of change in the magnetic flux and thus a smaller peak in the induced electromotive force. When the magnet is far away from the coil, the weakening rate of the magnetic field is faster, and the rate of change of the magnetic flux is larger, so the peak value of the induced electromotive force is larger.

Task B5:

With the aid of diagrams and what you've learned from CAN102, explain the reasons why there is a moment the induced emf is zero as the magnet passes through the coil. Assume the mass of the magnet set is m and the gravity is g (10 marks).

Answer B5:

✧ Graph



General Settings	
Trigger Type	Analog edge
Trigger Source	Channel 1
Trigger Slope	Rising
Trigger Level	5 mV
Time Per Division	50 ms
Sampling Mode	Decimate
Repetitive Sampling Mode	Off

Advanced Trigger Settings	
Acquisition Delay	Disabled
Trigger Position	0 s

Channels						
Name	State	Coupling	Probe Attenuation	Vertical Offset	Vertical Position	Volt Per Division
Channel 1	Enabled	DC	1x	0 V	0 V	50 mV
Channel 2	Enabled	DC	1x	0 V	0 V	50 mV
Channel 3	Disabled					
Channel 4	Disabled					

Reference Channels						
Name	State	Reference Mode	Source File Name	Source File Channel	Vertical Position	Volt Per Division
Reference 1	Disabled					
Reference 2	Disabled					
Reference 3	Disabled					
Reference 4	Disabled					

Reference Channels							
Name	State	Reference Mode	Source Circuit	Source Probe	Trigger Source Checked	Vertical Position	Volt Per Division

Additional Channels - FFT	
Name	FFT
State	Disabled

Additional Channels - Math	
Name	Math
State	Disabled

Channel Measurements Data				
Channel Name	VPP	RMS	Frequency	Period
Ch 1	272.7 mV	26.06 mV	- - - Hz	- - - s
Ch 2	288.6 mV	18.55 mV	- - - Hz	- - - s

✧ Explanation

Through the B-8 experiment, the induced electromotive force (emf) obtained by magnet M-2 passing through two coils changes over time. We can observe that the induced emf approaches zero volts around 125ms. Proceeding with the analysis and neglecting the counteracting forces from Ampere's force and air resistance, the magnet is in free fall, leading to a velocity $v\_m2 = \sqrt{2gh}$, where h is assumed to be the distance from the starting point of the fall to the top end of the magnet. As the magnetic Induction Iine are oppositely directed at each end of the magnet and symmetrically distributed, if we consider either the North pole (N) or South pole (S) individually, the rate of change of magnetic flux through the coil would continually increase. However, the graph shows that the induced emf does not keep increasing but reaches a positive peak followed by a negative peak.

According to Faraday's Law of Electromagnetic Induction, $\varepsilon = -\frac{d\phi}{dt}$. Given the opposite and symmetric distribution of the magnetic lines at the N and S poles, when the North pole first enters the coil, the induced emf is primarily generated by the interaction of the North pole with the coil. As the South pole also enters the coil, the oppositely directed magnetic Induction Iine from both poles enter the coil, which decreases the resulting induced emf (they cancel each other out). When the magnet is exactly at the center of the coil, the completely opposite and symmetrical distribution of the magnetic Induction Iine results in the total induced emf within the coil being zero at that moment.

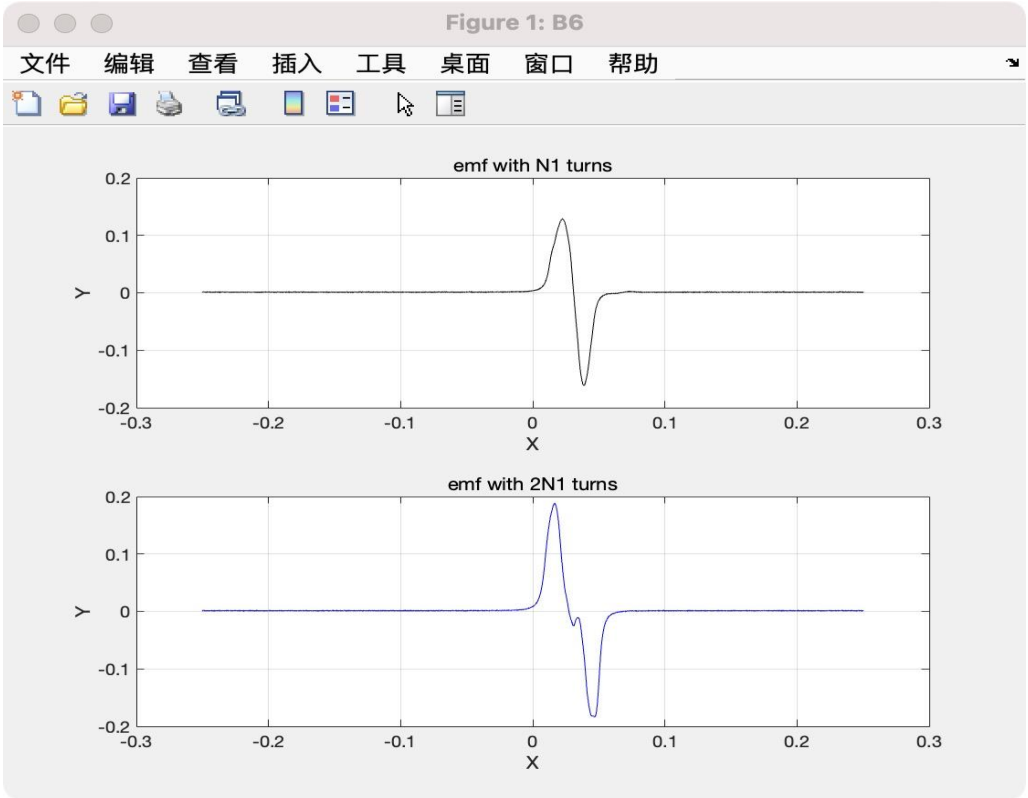
Task B6:

(10 marks): Set up the apparatus as shown in Fig. B-6 and drop your magnet set 2 North end first. Save the data of the induced emf vs. time. If you double the turns of coil 1 and drop your magnet set 2 from the same position again, analyses the differences between these two scenarios and plot both traces in the same figure:

Trace 1: emf with N1 turns (black color) Trace 2: emf with 2N1 turns (blue color)

Answer B6:

✧ Graph



✧ Analysis

When comparing two scenarios involving coils, it's evident that increasing the number of turns in a coil leads to a higher induced voltage, as per Faraday's law of electromagnetic induction: $\text{emf} = -N\frac{d\phi}{dt}$. This increase occurs because the magnetic flux passing through the coil is directly proportional to the number of turns. Consequently, the induced electromagnetic force (emf) follows a similar trend in both scenarios, starting from the largest positive value, decreasing to the largest negative value, and nearing zero. However, the scenario with more turns exhibits a higher peak emf due to the increased number of coils, resulting in a greater total induced emf.

Task B7:

Set up the apparatus as shown in Fig. B-6 and drop your magnet set 2 North end first. Calculate the area of the approach peak and the area of the recession peak with MATLAB, and evaluate the results by applying Faraday's law. Note: please provide your MATLAB code with sufficient comments as Appendix A in your submission (Code format: Arial with the font size 9, line spacing is single).

Answer B7:

✧ Analysis

Following Faraday's law, the number of magnetic induction lines emitted and received by the north and south poles of a magnet is consistent and symmetrical. The induced electromotive force (emf) can be computed using the formula $A = \int_b^a \mathrm{emf}\, dt$, where 'a' and 'b' denote the starting and ending time points of the peak, respectively. During the falling of the magnet set, the magnetic flux within the copper coil experiences an increase followed by a decrease, inducing a counter voltage (or current) in the copper wire. By applying Faraday's law, when comparing the procedure of magnetic flux increase and decrease, the number of coil turns 'N', and the change in flux, all remain constant, as the same magnet set is utilized. Consequently, the area under the approach peak and recession peak should be identical.

Task B8:

(10 marks): When you dropped your magnet set 2 North end first from the same position as you dropped the magnet set 1, summaries and analyses all of the differences between these two scenarios and plot four traces on the same figure:

Trace 1: emf through coil 1 with magnet set 1 (black color)

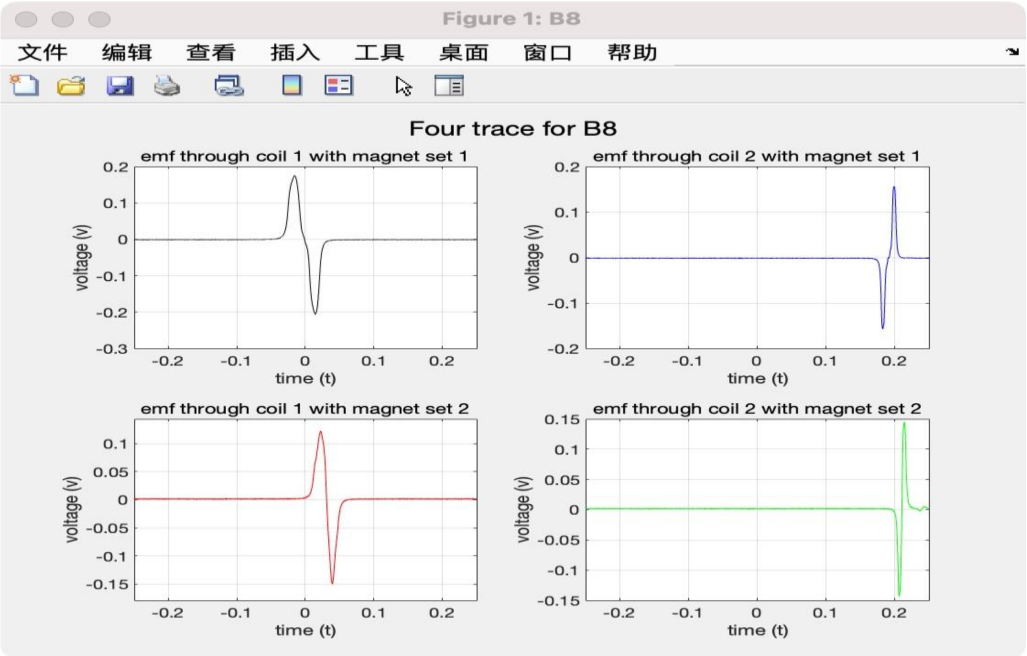
Trace 2: emf through coil 2 with magnet set 1(blue color)

Trace 3: emf through coil 1 with magnet set 2 (red color)

Trace 4: emf through coil 2 with magnet set 2 (green color)

Answer B8:

✧ Graph



✧ MATLAB Code:

✧ Analysis

The differences between the scenarios in both diagrams can be analyzed based on the concepts of electromotive force (EMF) and Faraday's law. The induced emf in the coil is directly proportional to the rate of change of magnetic flux. The magnetic field strength of Magnet Set 2 is stronger than that of Magnet Set 1. The greater magnetic field strength and potentially higher rate of fall due to increased gravitational force should result in a higher induced emf and a larger rate of change in magnetic flux for Set 2, shown as a higher peak in the figure and larger slope. The time interval between two peaks for Set 2 should be less than Set 1 due to this faster fall rate.

Comparing Trace 1 and Trace 3, and Trace 2 and Trace 4, we can see that an increase in the number of magnets (from Set 1 to Set 3, and Set 2 to Set 4) results in an increase in the electromotive force, represented as a larger amplitude. However, Trace 1 starts slightly earlier than Trace 3 and Trace 2 starts slightly earlier than Trace 4 due to environmental influences on the magnets. Comparing Traces 1 and 2 with Traces 3 and 4, we also find that coil 1 and coil 2 exhibit opposite polarities of the induced voltage due to differing winding directions.

In addition, we find that coils of different heights result in different induced electromotive forces, and the peak value of the induced voltage also changes. This is because as the coil accelerates and reaches a lower height, its speed is faster, leading to an increased induced voltage, according to

Faraday's law. The resultant higher emf and increased magnetic flux can be observed as greater amplitudes in the graph. This intricate interplay of forces and variables demonstrates the dynamic nature of electromagnetic phenomena.

Appendix

MATLAB Coding:

B6:

```
% load two data
data = readtable('T06.csv');

data2 = readtable('T06B62N1.csv');

% Create 'B6'

figure('Name', 'B6');

% Create a 2x1 subplot and place two plots

% First

subplot(2, 1, 1);

plot(data.X__Trace1___CH1_, data.Y__Trace1___CH1_, 'k');

% Plot the graph with a black line

title('emf with N1 turns');

% Set the title

xlabel('time (t)');

% Set the x-axis label

ylabel('voltage (v)');

% Set the y-axis label

grid on;

% Display grid lines

% Second

subplot(2, 1, 2);

plot(data2.X__Trace1___CH1_, data2.Y__Trace1___CH1_, 'b');

% Plot the graph with a blue line

title('emf with 2N1 turns');

% Set the title

xlabel('time (t)');

% Set the x-axis label

ylabel('voltage (v)');

% Set the y-axis label

grid on;

% Display grid lines
```

B7:

```
% Load data from CSV file
data = readtable('T06.csv');
% Create 'B7'
figure('Name', 'B7');
% Create a 2x1 subplot and place two plots
% First
subplot(2, 1, 1);
plot(data.X__Trace1___CH1_, data.Y__Trace1___CH1_, 'k');
% Plot the graph with a black line
title('emf with N1 turns');
% Set the title
xlabel('time (t)');
% Set the x-axis label
ylabel('voltage (v)');
% Set the y-axis label
grid on;
% Display grid lines
% Time and EMF data
time = data.X__Trace1___CH1_; % define time
emf = data.Y__Trace1___CH1_; % define EMF
% Define time ranges for simplification based on the figure shown above
simple_start = -0.02;
simple_end = 0.06;
% Find zero crossings within the time range
% First, reduce the dataset to the time range of interest
mask_time_range = (time >= simple_start) & (time <= simple_end);
time_filtered = time(mask_time_range);
emf_filtered = emf(mask_time_range);
% Find zero crossings in the filtered data
%diff(sign(emf...)) to find the zero point
zero_cross_diff = diff(sign(emf_filtered));
zero_point = time_filtered([false; zero_cross_diff ~= 0]); % Adjust indexing due to diff
% Select data for from peak start to Zero Point
mask_peak_to_zero = (time >= simple_start) & (time <= zero_point);
time_peak_to_zero = time(mask_peak_to_zero);
emf_peak_to_zero = emf(mask_peak_to_zero);
% Select data for from Zero Point to valley end
mask_zero_to_valley = (time >= zero_point) & (time <= simple_end);
```

```
time_zero_to_valley = time(mask_zero_to_valley);
emf_zero_to_valley = emf(mask_zero_to_valley);
% Calculate area under the curve for both ranges
area_peak_to_zero = trapz(time_peak_to_zero, emf_peak_to_zero);
area_zero_to_valley = trapz(time_zero_to_valley, emf_zero_to_valley);
% Display the results
disp(area_peak_to_zero);
disp(area_zero_to_valley);
% the result will be     0.0019
%
%                        -0.0018
```

B8:

```
data = readtable('T06B8M1.csv');
data2 = readtable('T06B8M2.csv');
% Create a 2x2 subplot and place four plots for this question B8
figure('Name','B8');
% First
subplot(2, 2, 1);
plot(data.X__Trace1___CH1_, data.Y__Trace1___CH1_,'k');
%Plot from imported datathe graph with a black line
title('emf through coil 1 with magnet set 1');
% Set the title
xlabel('time (t)');
% Set the x-axis label
ylabel('voltage (v)');
% Set the y-axis label
grid on;
% Display grid lines
% Second
subplot(2, 2, 2);
plot(data.X__Trace2___CH2_, data.Y__Trace2___CH2_,'b');
% Plot the graph with a blue line
title('emf through coil 2 with magnet set 1');
% Set the title
xlabel('time (t)');
% Set the x-axis label
```

```
ylabel('voltage (v)');
% Set the y-axis label
grid on;
% Display grid lines
% Third
subplot(2, 2, 3);
plot(data2.X__Trace1___CH1_, data2.Y__Trace1___CH1_,'r');
% Plot the graph with a red line
title('emf through coil 1 with magnet set 2');
% Set the title
xlabel('time (t)');
% Set the x-axis label
ylabel('voltage (v)');
% Set the y-axis label
grid on; % Display grid lines
% Fourth
subplot(2, 2, 4);
plot(data2.X__Trace2___CH2_, data2.Y__Trace2___CH2_,'g');
% Plot the graph with a green line
title('emf through coil 2 with magnet set 2');
% Set the title
xlabel('time (t)');
% Set the x-axis label
ylabel('voltage (v)');
% Set the y-axis label
grid on;
% Display grid lines
% Set the overall title for the entire question
sgtitle('Four trace for B8');
```