Experiment 6: Motor Spin Down Test

Section D (S4), Group 1

Arnav Kalgutkar (210100025)
Aryan Bhosale (210040024)
Nayantara Ramakrishnan (210100099)
Saukhya Telge (210100135)
Vora Jay Bhaveshbhai (21D100023)

Introduction:

We shall perform a 'Motor Spin Down Test' to determine the rate at which the angular velocity decreases after power supply to it is stopped. This is done to perform analysis of motor health and performance.
The experimental rate (of the motor slowing down) is compared to specifications provided by the manufacturer. This can help us know if the motor needs repair or maintenance. A diagram showing a motor in action is attached.

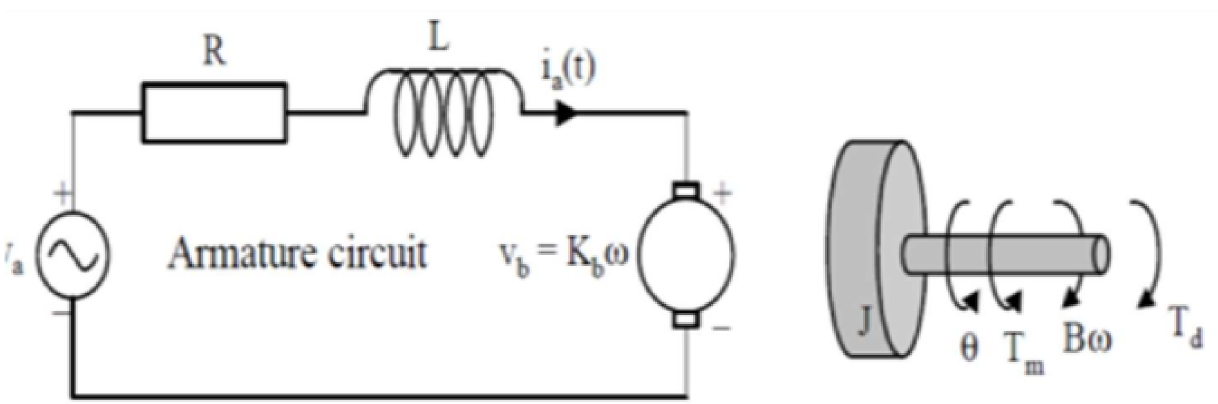


Fig 1: Circuit in a motor (along with torque on the motor)

The experimental rate (of the motor slowing down) is compared to specifications provided by the manufacturer. This
Examples of diagnosis on performing Motor Spin Down Test:

1. If the motor takes too long to slow down: may be a sign of
   high value of friction caused due to misalignment or other mechanical issues
2. If a motor takes too long to come to a complete stop, it may mean that there is a problem with the motor's bearings or other internal components.

Types of Friction	Description
Stribeck Friction	o Friction arises from the usage of fluid lubrication.
Static Friction	o Friction when the two surfaces are sticking
Coulomb Friction	o Coulomb friction is independent of velocity o This friction component is only dependent on the direction of motion, in such way that it is in the direction opposite to the velocity. o The magnitude of Coulomb friction depends on the properties of the surfaces in contact and the normal force. o Coulomb friction is also known as kinetic friction
Viscous Friction	o Viscous friction is dependent of the velocity. o At zero velocity the viscous friction is zero and the viscous component increases with the increase of velocity.

The above table contains different types of friction the motor may experience. We must also decide which model can describe our situation best. Transfer functions for the motor have been noted below:

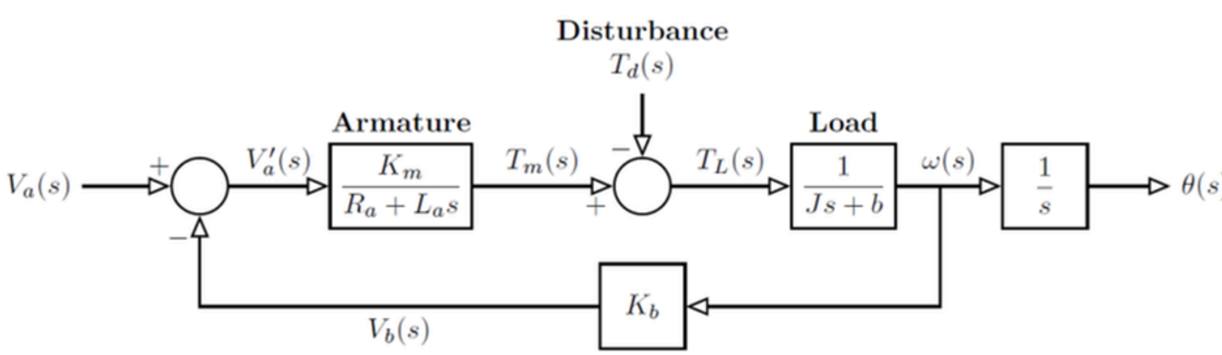


Fig 2: Transfer function diagram for a motor

The angular velocity of a DC motor can be described by the following first-order differential equations:

$J\dot{\omega} = T_m(t) - T_f(t) - T_L(t)$	$v_b(t) = K_b\omega(t)$
$\frac{L\,di_a(t)}{dt} + Ri_a(t) = v_a(t) - v_b(t)$	$T_m(t) = K_t i_a(t)$

Here, the terms J,T_m(t),T_f(t), T_L(t),K_t,K_b,v_a(t) and v_b(t) indicate the moment of inertia, Motor Torque, Torque due to Friction, Load Torque, Torque Constant, Back EMF Constant, Applied Voltage and Back EMF generated respectively.

T_L(t) = 0 (No load is applied)
v_a(t) = 0 (power supply disconnected)
Current decreases from initial value to zero.
We assume i_a(t) = 0
Thus, T_m(t) = 0 (from the above equations)
Thus our equations reduce to a simpler solution
Simplified Equation:

$$J\dot{\omega} = -T_f(t)$$

Assuming angular speed at t=0 to be ω_0, we can model friction torque using the following models:

Friction Models Used	Analytical Solution
○ Viscous Damping: $T_f(t) = c_1\omega(t)$	$\omega(t) = \omega_0 exp\left(\frac{-tc_1}{J}\right)$
○ Coulomb Damping: $T_f(t) = c_2$	$\omega(t) = \omega_0 - \frac{tc_2}{J}$
○ Combined Damping: $T_f(t) = c_3\omega(t) + c_4$	$\omega(t) = \omega_0 e^{-\frac{c_3 t}{J}} + \frac{c_4}{c_3}\left(e^{-\frac{c_3 t}{J}} - 1\right)$

Objectives:

- To perform a study of a practical example of a first order dynamic system - the decay response of a DC motor provided with an initial angular velocity.
- To provide students exposure to Arduino IDE and Putty softwares for data acquisition.
- To find the Coefficient of Viscous Damping for the system using appropriate curve fitting assuming the system experiences pure Viscous Damping, with negligible Coulomb friction.

Methodology:

1. Setup Putty and Arduino IDE on your laptop. Putty is used for easy data logging and Arduino IDE will be used for uploading the code to the Arduino board
2. Make the connection to the Arduino. The DC power supply powers the motor. The laptop powers the Arduino. The motor is also connected to one of the Analog pins for reading the back EMF.
3. Now connect the Arduino to the laptop and select the appropriate port on the Arduino IDE. Upload the given code to the board.
4. Open Putty and set appropriate settings for data logging. The save location must be specified manually, or the data will not be saved anywhere.
5. Start the motor and start data logging on Putty on your laptop, and switch the power supply to the motor off after it reaches a steady speed.
6. Immediately after the motor is switched off, connect the analog pin to the motor to take input of the back EMF readings. Take readings till the motor stops completely.
7. Stop the putty terminal. The data readings can now be imported and analysed in MATLAB or Python.

The given code and its working are described below:

```
/*
* A basic program to log voltage data from sensor using arduino
* KDoM Lab 2023
* prepared by: abhilash
* Instructors: prof. Salil Kulkarni, Prof. Darshan shah
*
*/
float data;
void setup() {
//Starting the communication between PC and Arduino with baud rate (speed) of 9600
//bits per seconds
Serial.begin(9600);
}
void loop() {
data=analogRead(A0); //read the voltage at pin named A0
// measured output is ranging from o to 1023
//(2^10) represents 0 to 5 Volts
data=data*5/1023; // converting into voltage
// printing or sending measured data and time value
Serial.print(millis());
```

```
Serial.print('\t');
Serial.println(data);
delay(20); // set appropriate delay (in milliseconds) as
//per required sampling rate
}
```

- A variable 'data' is defined to store the back EMF values
- Baud rate is the rate of communication between Arduino and laptop, which is set as 9600 here. The same value should be used while setting up Putty for data logging.
- Back EMF is read from analog pin A0 and is scaled by appropriate value to account for mapping of value to actual voltage
- Data and time value are printed on the serial monitor.
- Delay is set as 20 ms as per required sampling rate

Results:

The total moment of inertia of the system is equal to the sum of the individual moments of the motor and the Aluminium cylinder.

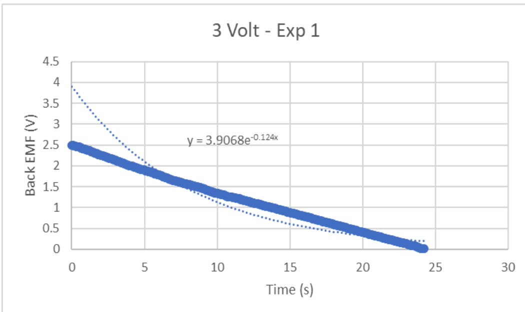
Estimation of the moment of inertia of the Aluminium cylinder:
The measured dimensions of the Aluminium cylinder are as follows:
Radius = 2 cm, Height = 1.5 cm, Density (ρ) = 2700 kg/m^3 (Aluminium)
Mass of the cylinder $m = \rho\pi R^2 H$ = 0.0508938 kg.
Using the formula for the moment of inertia of a cylinder: $I = \frac{mR^2}{2}$ = 1.01787602 $\times 10^{-5}$ kg m^2.

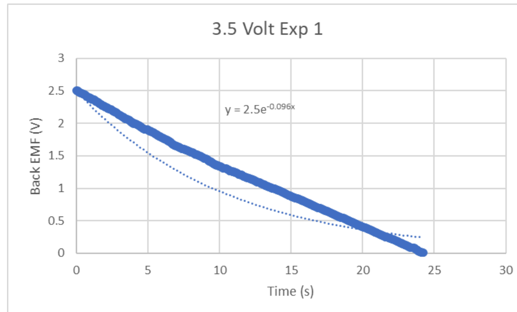
From the motor datasheet (part number 110947):
Moment of inertia of the rotor = 10.9 g cm^2 = 10.9 $\times 10^{-7}$ kg m^2.
Motor speed constant ($1/K_b$) = 1180 rpm/V = 123.569311 rad s^{-1} V^{-1}.
Hence, the total moment of inertia of the system:
$I = I_{cylinder} + I_{rotor}$ = 1.12687602 $\times 10^{-5}$ kg m^2 = 112.687602 g cm^2

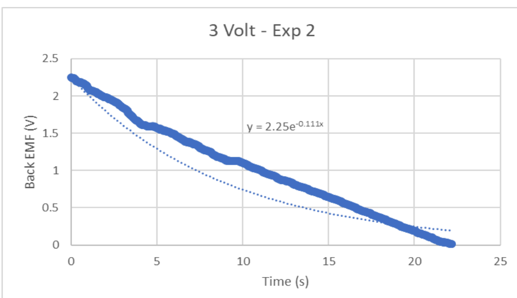
For Viscous damping:

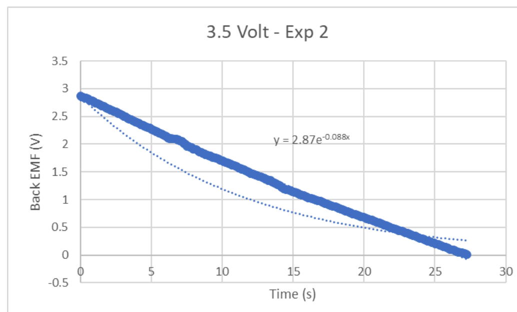
Curve : $y = Ae^{-Bx}$

Keeping A also a variable for curve fitting gives the adjacent graph hence, it was set manually for below graphs.









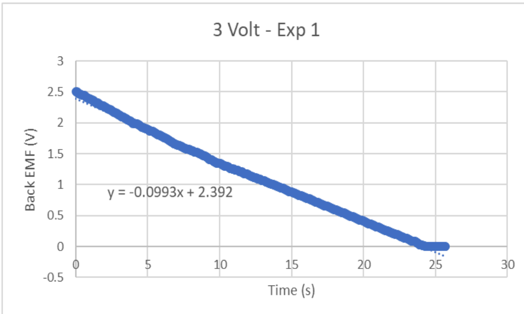
The equation used to describe viscous damping is $T_f(t) = c_1\omega(t)$, or the torque experienced is proportional to the angular velocity of the motor shaft. Hence, the graph describing the angular velocity with respect to time for a perfectly viscous system is exponentially decreasing, i.e., $\omega(t) = \omega_0 exp(-\frac{c_1 t}{I})$.

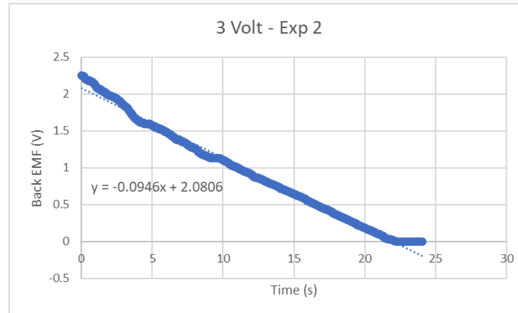
For the back EMF in Volts, $\omega_0 = \frac{e_b(0)}{K_b}$ where $e_b(0)$ = A. To determine the coefficient of viscous damping, $B = \frac{c_1}{I}$, hence $c_1 = BI$.

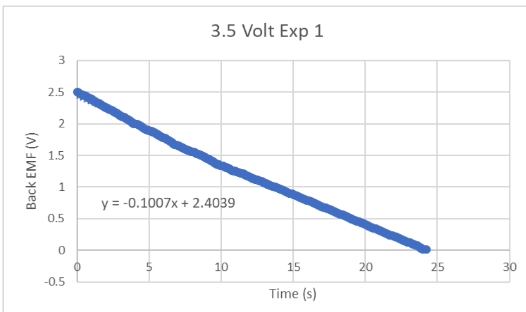
Experiment	Value of B (in s^{-1})	Corresponding Value of c_1 (in g cm^2 s^{-1})
3 Volt: Experiment 1	0.124	13.973
3.5 Volt: Experiment 2	0.096	10.818
3 Volt: Experiment 1	0.111	12.508
3.5 Volt: Experiment 2	0.088	9.917

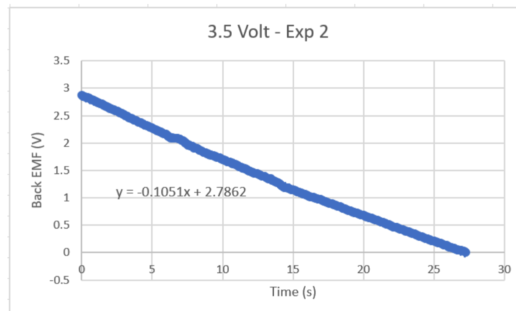
For Coulomb damping:

Curve : $y = Ax + B$









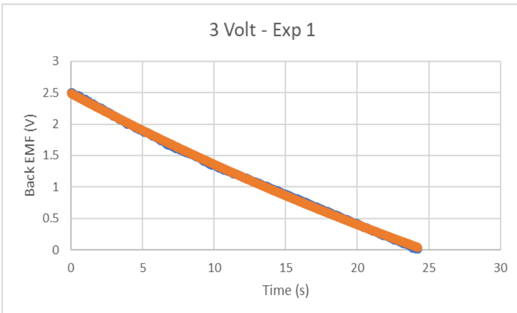
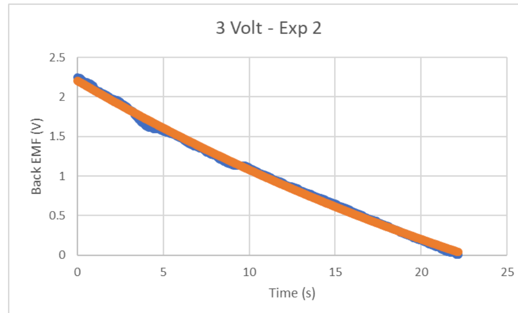
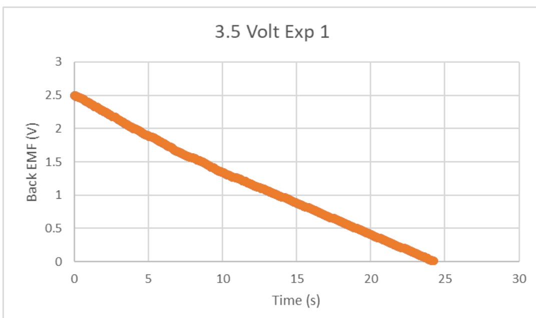
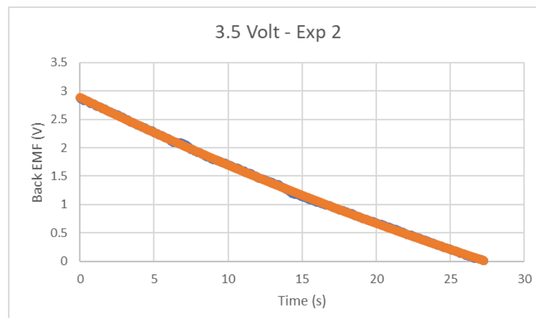
In the Coulomb friction model, there is a constant value of the torque due to friction opposing the motion of the motor shaft. The equation for the friction torque is as follows: $T_f(t) = c_2$, where c_2 is opposing torque due to Coulomb friction. Hence, the equation for the motor shaft angular velocity versus time is a linearly decreasing curve, or $\omega(t) = \omega_0(t) - \frac{c_2 t}{I}$.

As in the previous friction scheme, $\omega_0 = \frac{e_b(0)}{K_b}$, where $e_b(0)$ is the initial value of the back EMF produced by the motor in Volts. Here, $e_b(0) = B$ and $A = -\frac{K_b c_2 t}{I}$, so $c_2 = -\frac{AI}{K_b}$ (the values of the back EMF in Volts must be divided by K_b to obtain the angular velocity in rad/s).

Experiment	Value of A (in V/s)	Value of c_2 (in g cm^2 rad s^{-2})
3 Volt: Experiment 1	-0.0993	1382.726
3.5 Volt: Experiment 2	-0.0946	1317.279
3 Volt: Experiment 1	-0.1007	1402.220
3.5 Volt: Experiment 2	-0.1541	2145.801

For Combined Damping:

Curve : $y = A + Be^{Cx}$ (Red line shows the fitted curve)

 $A = -5.0581,\ B = 7.5448,\ C = -0.01617$	 $A = -2.8813,\ B = 5.0883,\ C = -0.02505$
 $A = -5.13509,\ B = 7.6205,\ C = -0.01597$	 $A = -5.7502,\ B = 8.6369,\ C = -0.01484$

For combined viscous damping and Coulomb friction, the opposing torque on the motor shaft is equal to a combination of a viscous component proportional to the angular velocity and a constant Coulomb friction torque. This is represented in the equation for the motor dynamics: $T_f(t) = c_3\omega(t) + c_4$, where c_3 is the coefficient of viscous damping and c_4 is the Coulomb friction term. By comparing the values of $c_3\omega(t)$ and c_4 at a particular instant, the relative contributions of each friction mode can be determined. Upon using the relation $T_f(t) = -I\frac{d\omega(t)}{dt}$ and integrating the motor dynamics differential equation, the law for the angular velocity ω(t) is obtained as follows: $(c_3\omega_0 + c_4)exp(-\frac{c_3 t}{I}) = (c_3\omega(t) + c_4)$.

Alternately, as $\omega(t) = -\frac{c_4}{c_3} + (\omega_0 + \frac{c_4}{c_3})exp(-\frac{c_3 t}{I})$.

For the particular curve fitting scheme used, three coefficients namely A, B, and C are obtained. First, the values of the measured back EMF in Volts must be divided by K_b to obtain the values of the angular velocity in rad/s. Hence, coefficients A and B must be divided by K_b before proceeding. Here, $\frac{A}{K_b} = -\frac{c_4}{c_3}$, $\frac{B}{K_b} = (\omega_0 + \frac{c_4}{c_3})$ or $\frac{B}{K_b} = (\omega_0 - \frac{A}{K_b})$, and $C = -\frac{c_3}{I}$, where A and

B are in rad/s. As discussed previously, $\omega_0 = \frac{e_b(0)}{K_b}$, where $e_b(0)$ is the initial value of the back EMF produced by the motor in Volts.

To determine c_3 and c_4, $c_3 =- CI$ and $c_4 =- \frac{Ac_3}{K_b} = \frac{ACI}{K_b}$.

Experiment	Value of A (in V)	Value of C (in s^{-1})	Value of c_3 (in g cm^2 s^{-1})	Value of c_4 (in gm cm^2 rad s^{-1})
3 Volt: Experiment 1	-5.0581	-0.01617	1.822	1138.89633
3.5 Volt: Experiment 2	-2.8813	-0.02505	2.823	1005.039132
3 Volt: Experiment 1	-5.13509	-0.01597	1.800	1141.930672
3.5 Volt: Experiment 2	-5.7502	-0.01484	1.672	1188.238483

Discussions:

1. The large deviation between the measured values of the back EMF and the best fit curve assuming viscous damping indicates that this dissipation model alone cannot be used to describe the system.
2. Assuming purely Coulomb friction, the deviation between the best fit curve and the experimentally obtained data decreases drastically. However, there is a small amount of non-linearity observed in the measured values, so this is also inadequate.
3. On combining both these models, there is almost no deviation. Hence, it is determined that both viscous damping and Coulomb friction are present in the motor.
4. Coulomb friction is observed to be more dominant since the back EMF versus time is almost linear.
5. The viscous dissipation component helps capture the non-linear behaviour. Since the viscous damping torque is proportional to the motor speed, the contribution of viscous forces and hence the deviation from the linear trend is greater initially.

Conclusions:

1. Viscous damping is usually present in motors because of lubrication to reduce friction and avoid vibrations. It has a very small effect in this system.
2. Coulomb damping, a result of dry friction/ sliding between the two surfaces in contact, is observed to be dominant, indicating low lubrication inside the motor.
3. A mix of two friction models is usually the right solution for any real-life case.

Limitations of the Current Experimental Setup:

1. The sampling frequency decides the accuracy of the readings. We need to make sure it is larger than twice the motor frequency.
2. The digital to analog converter's resolution also affects the accuracy/quality of readings.
3. Other vibrations, wind etc may affect the motor's speed.

Improvements to the Current Experimental Setup:

1. Set the sampling frequency large enough after taking the first reading of motor frequency
2. Use a rotary encoder instead of this setup to finely control sampling frequency and get direct digital values, avoiding the error due to analog-to-digital conversion.
3. Isolate the system from vibrations and turn off the fan/ close nearby windows.

Contributions:

1. Introduction and Objectives - Aryan Bhosale
2. Methodology - Saukhya Telge
3. Data Plotting - Vora Jay Bhaveshbhai
4. Results and Discussions - Arnav Kalgutkar
5. Conclusions (Including Limitations and Improvements) - Nayantara Ramakrishnan