ME370: KINEMATICS & DYNAMICS OF MACHINERY LAB

Department of Mechanical Engineering
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Lab 6: Motor Spin Down Test using Arduino IDE

Group: 5
Section: A

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1. Aim of the Experiment

- Study of a practical example of a first-order dynamic system, namely the decay response of a DC motor provided with an initial angular velocity.
- Finding the Coefficient of Damping for the system using appropriate curve fitting by observing the best model for the motor.

2. Apparatus Used

- Motor
- Laptop with MATLAB, Putty, and Arduino IDE
- Arduino UNO microcontroller
- Connecting wires

3. Introduction

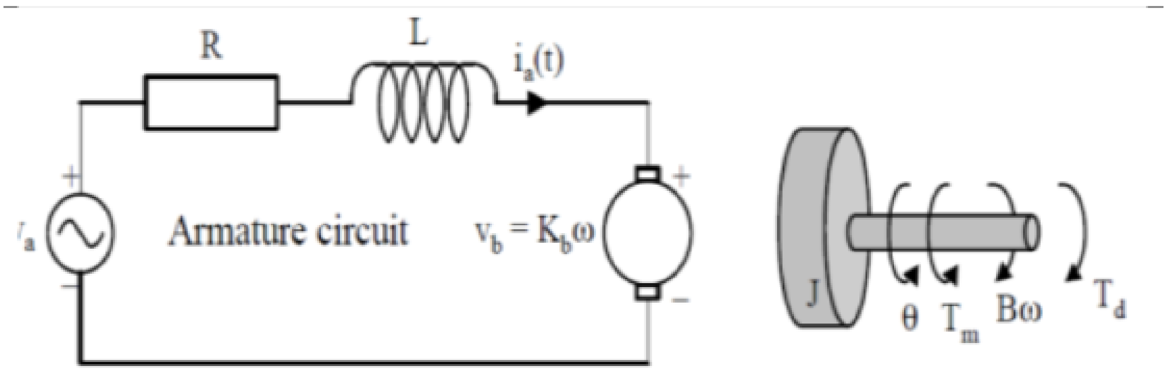


Figure 1

- A motor spin-down test is conducted to evaluate the deceleration rate of a motor after it has been powered off. This assessment is pivotal in gauging the motor's overall functionality and condition.
- Through experimental measurements, the deceleration rate is determined and compared against the manufacturer's specifications to identify any potential maintenance or repair requirements. For instance:
  i. Prolonged deceleration time beyond expectations could indicate issues with the motor's bearings or other internal components.

ii. Conversely, excessively prolonged deceleration may signify heightened friction caused by misalignment or mechanical irregularities.

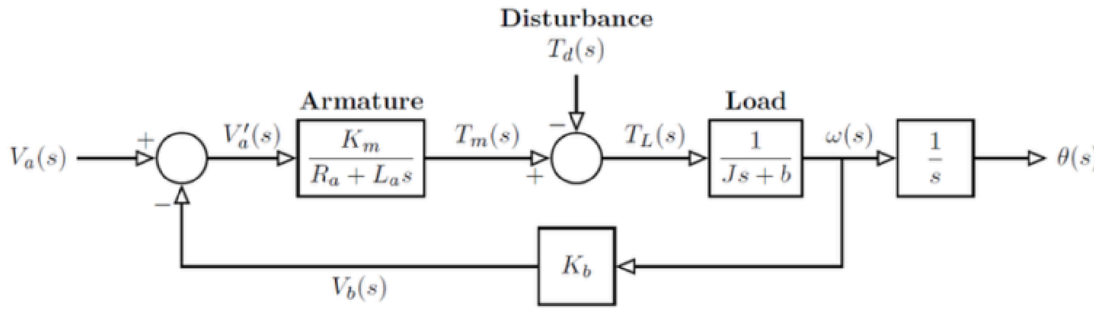


Figure 2

- Given the motor's susceptibility to various friction types, it becomes imperative to explore diverse models to ascertain the most effective governing mechanism for the system.

  Types of Friction Description

  1. **Static** The friction when the two surfaces are sticking
  2. **Coulomb** Coulomb friction is independent of velocity.
     - This friction component is only dependent on the direction of motion, in such a way that it is in the direction opposite to the velocity.
     - The magnitude of Coulomb friction depends on the properties of the surfaces in contact and the normal force.
     - Coulomb friction is also known as kinetic friction
  3. **Viscous** Viscous friction is dependent of the velocity.
     - At zero velocity the viscous friction is zero and the viscous componentincreases with the increase of velocity.
  4. **Stribeck** Friction arises from the usage of fluid lubrication.
- The angular velocity of a DC motor can be described by the following first order differential equations:

  Here, the terms J,$Tm(t)$, $Tf(t)$,$TL(t)$,Kt,Kb,$va(t)$ & $vb(t)$ 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.

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

- In our scenario, with no load present, $TL(t)=0$.
  Upon disconnecting the power supply, $va(t)=0$, leading to a gradual decrease in the circuit's current from its initial value to zero.
  However, for the sake of simplification in our mathematical representation, we assume $ia(t)=0$.
  Consequently, $Tm(t)=0$, resulting in the simplified equation: $J\dot{\omega}=-Tf(t)$
- Assuming the angular speed at $t=0$ to be $\omega 0$, the friction torque can be modeled using different models as follows:

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: $T_f(t) = c_3\omega(t) + c_4$	$\omega(t) = \omega_0 e^{-\frac{c_3 t}{J}} + \frac{c_4}{c_3}\left(e^{-\frac{c_3 t}{J}} - 1\right)$

4. Methodology

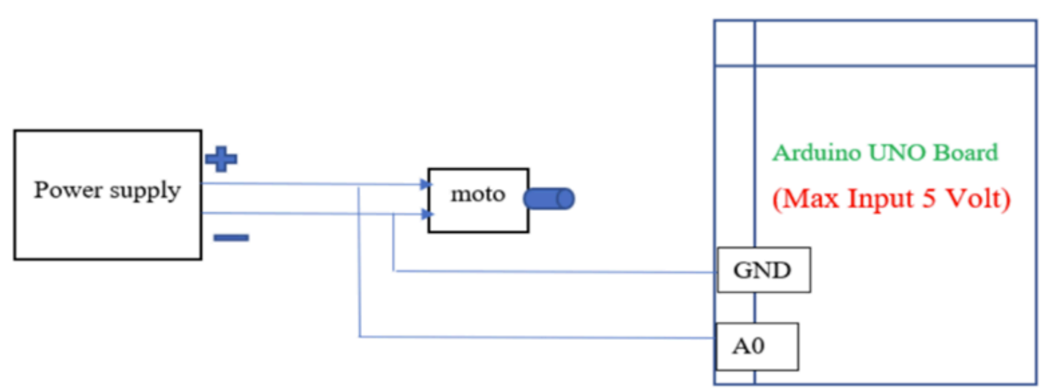


Figure 3

1. According to the above figure, we've connected the positive terminal of the power supply to the Positive end of the motor, and the ground of the power supply to the Ground end of the motor using the breadboard provided.

2. Next, we've linked the Positive and Ground ports on our Arduino board to the corresponding Positive and Ground terminals on the breadboard using jumper wires. This completes the essential connections.
3. The Arduino board was linked to the laptop via a USB cable. Subsequently, we launched the Arduino Uno desktop application and configured the port connection to channel COM7. Following this, we uploaded the provided code for data acquisition onto the Arduino interface. We then activated the Serial Monitor tool to monitor the real-time data output.
4. The power supply was activated, and the voltage was gradually increased from 0V to 3V using the fine voltage tuning key until the motor reached a stable state.
5. Next, we initiated the automated data storage software, Putty, on our laptop and adjusted the necessary logging settings to 'All Session Output'.
6. Once the Putty terminal was active, we powered off the supply. Voltage readings were recorded until the voltage stabilized at zero.
7. These readings were then transferred to an Excel sheet for further analysis. Any initial readings captured during the time gap between opening the Putty terminal and shutting down the power supply were disregarded.

8. The inertia of the system was estimated by calculating the inertia of the cylindrical mass and locating the inertia of the rotor from the motor datasheet as follows:

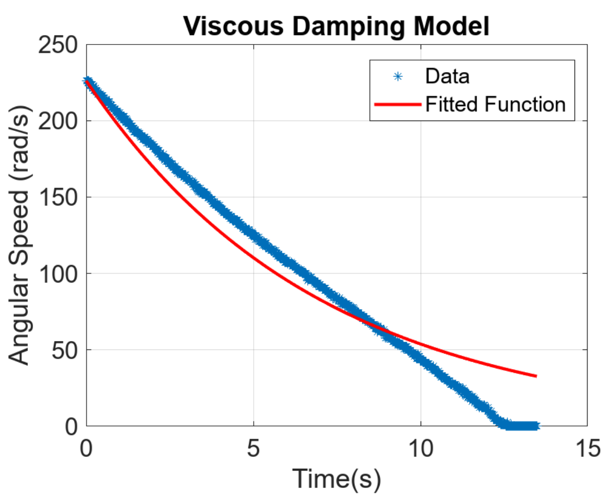
$\mathrm{I}_{\mathrm{motor}} = 10.9\ gcm^2$
Radius = 2 cm
Height = 1.5 cm
Density = 2700 kg/ m^3

$$I_{system} = I_{motor} + \frac{mR^2}{2} = \frac{10.9}{10^7} + \frac{(\rho \pi R^4 H)}{2} = \frac{112.69}{10^7}\ \mathrm{kg/m^2}$$

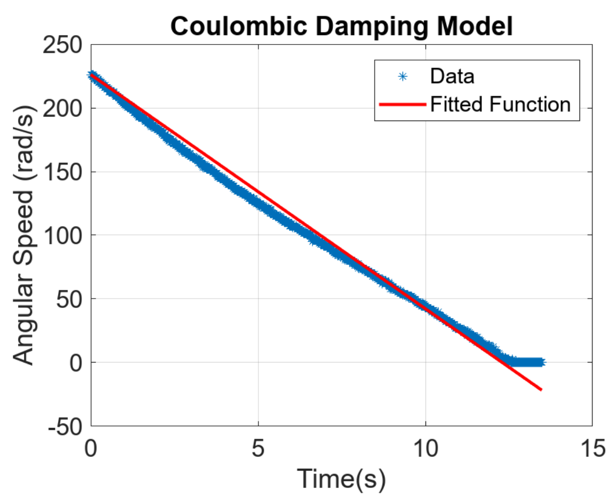
K_b = 1180 RPM/V from the datasheet
The values of Angular Velocity were obtained using the equation $V_b(t) = K_b w(t)$

9. The angular velocity values were plotted against time, and a best-fit curve was generated. Subsequently, this curve was compared with the analytical solution to derive our constant of proportionality.

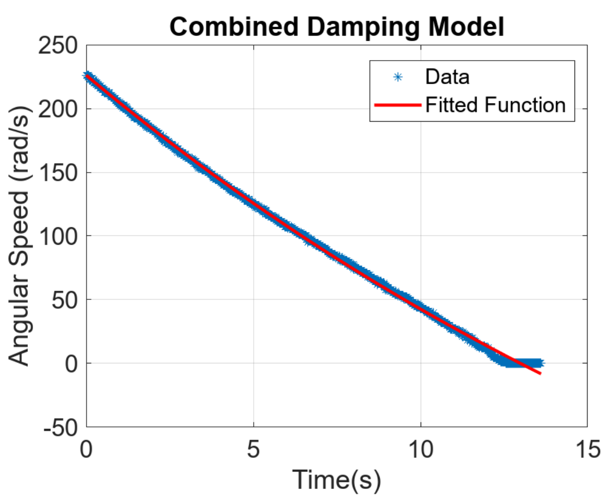
5. **Results**



$C_1 = 0.6102\times10^{-5}$

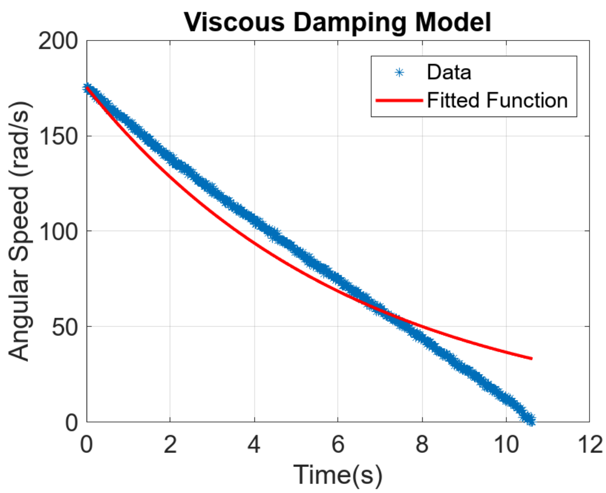


$C_1 = 0.7815\times10^{-3}$

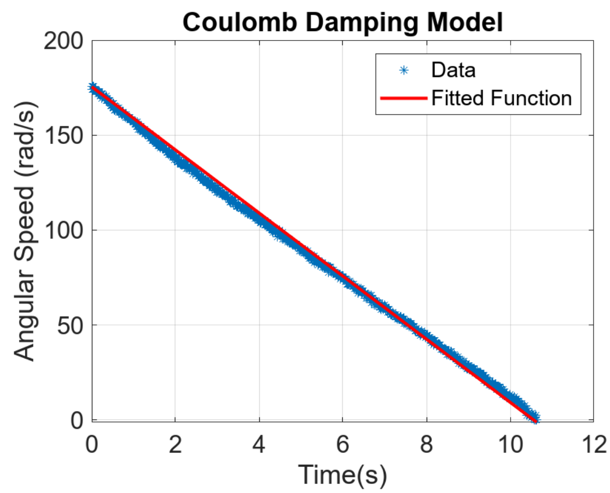


$C_1 = 0.1578\times10^{-5}$, $C_2 = 0.5776\times10^{-3}$

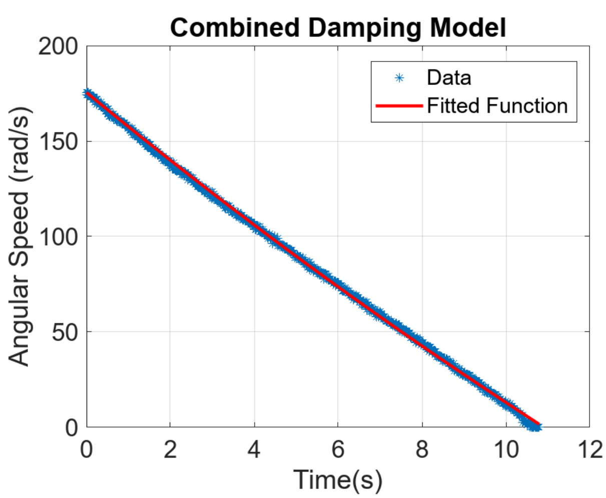
Dataset 1



$C_1 = 0.6656\times10^{-5}$

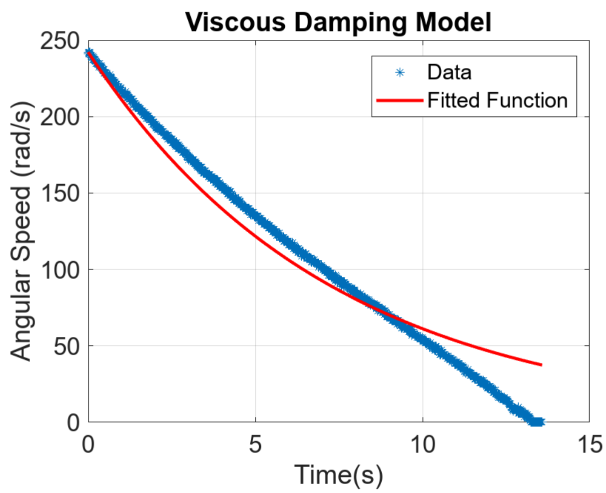


$C_1 = 0.7063\times10^{-3}$

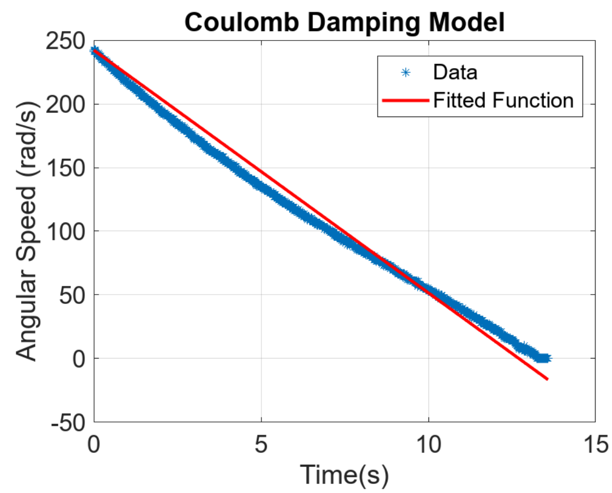


$C_1 = 0.1291\times10^{-5}$, $C_2 = 0.5984\times10^{-3}$

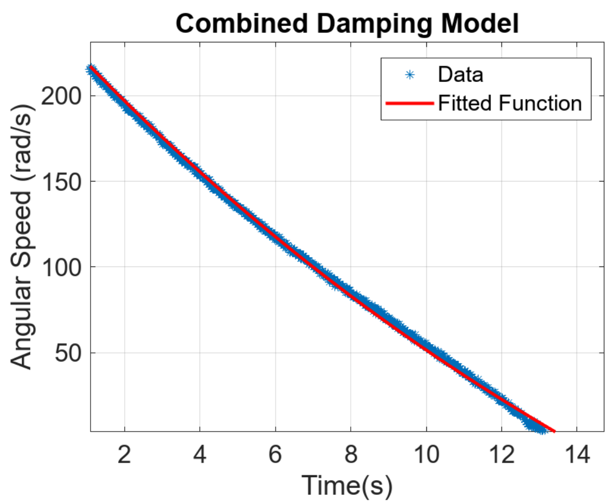
Dataset 2



$C_1 = 0.5848 \times 10^{-5}$

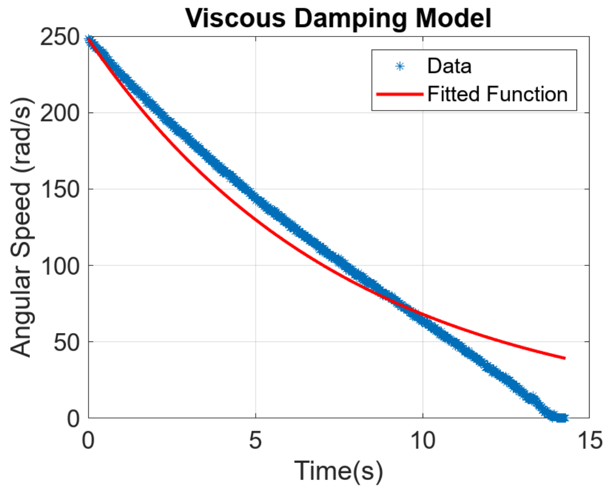


$C_1 = 0.8102 \times 10^{-3}$

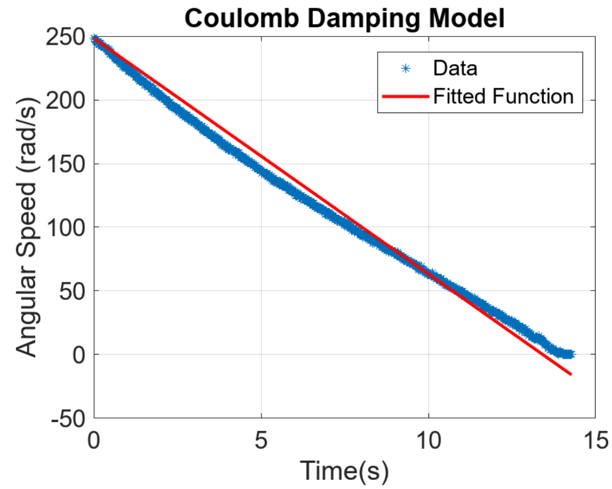


$C_1 = 0.19 \times 10^{-5}$, $C_2 = 0.5399 \times 10^{-3}$

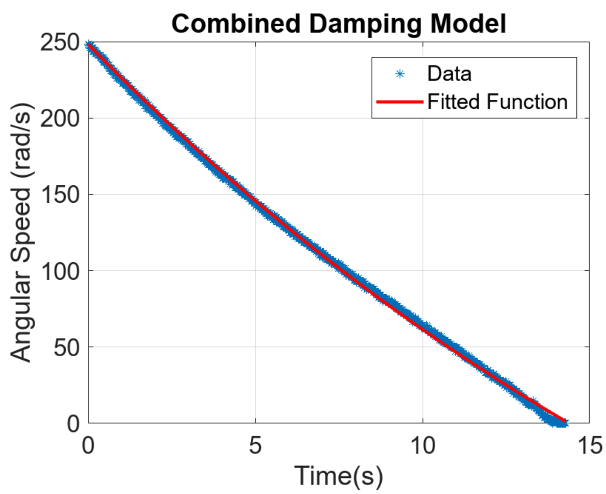
Dataset 3



$C_1 = 0.57\times10^{-5}$



$C_1 = 0.7875\times10^{-3}$



$C_1 = 0.17\times10^{-5}$, $C_2 = 0.5471\times10^{-3}$

Dataset 4

Average Damping Coefficients -

Combined	Viscous	Coulomb
0.5471×10^{-3}, 0.161725×10^{-5}	0.60765×10^{-5}	0.771375×10^{-3}

6. **Discussion**

- Given the small variation between our best fit curve and the analytical solution compared to the other two models, the Combined Damping Model appears to be the most suitable model for representing the friction encountered by the system for all of our data sets.

- In the Combined Damping Model, the values of the constants c_3 are also larger than the constants c_4 for each data set indicating that a closeness to linearity in our solution is favourable. However, purely linear does not capture the nonlinearity present in the damping.

- Using viscous damping is not recommended as there is a large deviation present in all the datasets. The Coulomb damping model does perform well on our data but the combined model gives near-perfect fitting.

7. **Conclusion**

- The mean combined damping coefficients are $c_1 = 0.5471\times10^{-3}$, $c_2 = 0.161725\times10^{-5}$

- The combined damping friction model can be used to best describe the friction conditions experienced by the motor whereas the viscous model is the least accurate for our dataset.
- Using these parameters, one can estimate the friction forces for complex systems using the same motor very accurately.

8. **Sources of Error**

- The measured EMF fluctuates because to system vibrations and is not stable even when the power supply is on.

- Due to the quick rate of voltage drop, turning off the power source before opening the Putty Terminal will cause the initial voltage readings to be lost.

- Because of approximations made during estimation, such as using a best fit curve and assuming zero current, the calculated damping coefficients are not 100% accurate.

- Existence of loose connections between the components of the electrical circuit

- Any human errors in execution of methodology such as Voltage adjustment, use of softwares, or round-off errors in calculations.

9. **Contributions**

Sr No.	Name	Contribution
1	Yash Salunkhe	Results, Discussion, Data processing
2	Sanika Wagh	Introduction
3	Kavan Vavadiya	Methodology
4	Shreya Biswas	Conclusion, Sources of error
5	Samiksha Patel	Calculations
6	Mudit Sethia	MATLAB plots

10. **Bibliography**

- https://en.wikipedia.org/wiki/Viscous_damping
- https://en.wikipedia.org/wiki/Coulomb_damping
- Arduino, MATLAB scripts shared by Prof. Salil Kulkarni