

structural mechanics and dynamics 3 MECE09036  
  
Dynamics lab EXPERIMENTS   
STUDENT REPORT

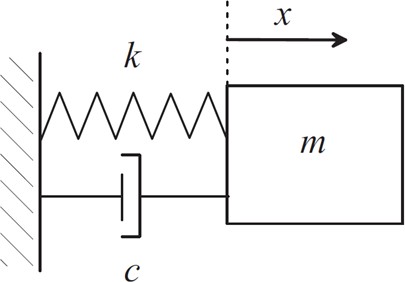
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LAB REPORT

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## Dynamics: Experiment 1 – Mass Spring damper (MSD)

**D1.1 Mass-spring-damper theory (student should familiarise with the theory before attending the lab)**

Figure D1.1 shows an ideal mass-spring-damper system. Find the damping coefficient of the system if a mass m is used in combination with a spring with stiffness k = 17 N/m. The system has a damped period of oscillation Td.

*Figure D1.1: Schematic of spring mass damper*

#### QUESTIONS TO ADDRESS IN THE REPORT:

|  |  |
| --- | --- |
| **To prepare for the experiments, address the following questions (these will be included in the lab report):**  Answer the questions below for the system shown in Figure D1.1, if the system is released from rest, 5 cm from its equilibrium point at t0 = 0 s and using the following parameters:   1. mass m = 150 g and period Td = 590.37 ms 2. mass m = 380 g and period Td = 950.90 ms | |
| **Q1.1** Calculate the damping ratio 𝛿 and damping coefficient c (include all the calculation steps) for conditions a) and b) (assume viscous damping). | [10] |
| **Q1.2** For condition a) plot the response 𝑥(𝑡) for the time interval [0,10] s, and describe how 𝑥(𝑡) was obtained. | [10] |
| Marks for MSD theoretical part [20] | |

**Any code should be included in the appendix at the end of the report. All plots should have clear axis labels and measurement units.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Q1.1** Calculate the damping ratio and damping coefficient c (include all the calculation steps) for conditions a) and b) (assume viscous damping). | | |  |
| *kx*   1. ***m = 150g , Td = 590.37ms***   Equation from FBD ends up being , after comparing with the canonical solution of free damped vibrations  *,* the terms in each equation can clearly be equated to yield  Using Td we can find rad/s, and from known theory, comparing and we see that the natural frequency of the system is larger than the damped one, meaning the system is **underdamped**  Since the system is underdamped, we may determine the damping ratio δ using δ = 0.02374  To find the damping ratio c we refer back to our original free body equations to obtain the relation and after rearrangement this gives us a damping coefficitent c = 0.   1. ***m = 380g, Td = 950.90ms***   We follow a similar process to part (a) where we first must find the natural and damping frequencies, compare and then sue the appropriate equations to find δ and c.  & so clearly the system is again **underdamped** since the natural frequency is larger than the damping frequency.  We can now find δ using which gives δ =  We can find c using our equations from the free body diagram, leaving us with and this yielding c = 0.7879kg/s | | |  |
|  | Damping ratio  (numerical result, 4 dec. places) | Damping constant c  (numerical result, 4 dec. places) |  |
| a) | 0.0237 | 0.0758 |  |
| b) | 0.1552 | 0.7879 |  |
| **Q1.2** For condition a), plot the response for the time interval [0,10] s, and describe how was obtained. | | |  |
| **Plot**    Time (s) | | |  |
| Describe how 𝑥(𝑡) was obtained (max 3 lines).  x(t) was obtained by taking the general eq. for underdamped vibrations and applying the boundary conditions at t = 0, x(0) = 5 cm and after finding the derivative of x(t) which yields A = 0.0012, B = 0.05. The plot was obtained using python code. | | | /Lines  1  2  3 |

**Experiments performed**

1. mass m = 150 g (60° inclination)
2. mass m = 250 g (60° inclination) + damper on Teflon side (130 g)

#### QUESTIONS TO ADDRESS IN THE REPORT:

|  |  |
| --- | --- |
| Answer the questions below utilising the data collected during the experiment and for the two sets of different experimental conditions (a, b): | |
| **Q1.3** Plot the response x(t) of the tested system, find the frequency and period of oscillation of the mass. | [10] |
| **Q1.4** Compare the response obtained with the experiments and the one obtained in the theory section. What are the similarities and differences in the response? Explain and discuss any difference. | [20] |
| Marks for MSD experimental part [30] | |

**Any code should be included in the appendix at the end of the report. All plots should have clear axis labels and measurement units.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Q1.3** Plot the response x(t) of the tested system, find the frequency and period of oscillation of the mass. *(Explain in the appendix the method and procedure used for plotting: Python, Excel, MATLAB or other software?)* | | |  |
| **Plot**   1. **Undamped System Experiment**      1. **Damped System Experiment** | | |  |
|  | Period  (numerical result, 2 dec. places) | Frequency  (numerical result, 2 dec. places) |  |
| a) | 0.56 | 11.19 |  |
| b) | 1.03 | 6.10 |  |
| **Q1.4** Compare the response obtained with the experiments and the one obtained in the theory section. What are the similarities and differences in the response? Explain and discuss any difference. (Max 15 lines) | | |  |
| **Answer (max 15 lines)**  Theoretical values had differing values for damping coefficient and frequency due to the difference in mass between the two, the same can be said about the experimental data (150g and 380g). All systems were underdamped, and case (a) and real underdamped had a much lower period of oscillation than (b) and real damped, largely due to the mass difference. (a) also had a damping coefficient of 1 order of magnitude lower than (b), ~ 0.07 << ~ 0.7. The experimental cases had similar results relative to the theory. (a) and the undamped case had similar periods of 0.59s and 0.56 and frequencies of 10.64 and 11.19. Despite it being theoretically undamped, the system was still lightly damped via pulley friction, since the graph of x(t) showed an underdamped shape. If we do the numerical analysis, the predicted underdamped frequency for this case is larger than the natural frequency (11.18>10.65) which is not possible if we assume the system to be underdamped. An assumption could be that the given spring constant of 17N/m is actually higher (closer to 18.8N/m) for the system to be underdamped which is possible since the spring could have been previously subjected to frequent loading/unloading cycles which might alter its length/microstructure. Another possibility is an error in the method for obtained T value. The real damped case and (b) had similar frequencies of 6.1 and 6.6rad/s since they had the same mass. However, due to the frictional damping in the pulley as well as the Teflon block and surface, the real case had a lower frequency than (b). | | | Lines  1  2  3  4  5  6  7  8  9  10  11  12  13  14  15 |

**Dynamics: Experiment 2 – Damped harmonic oscillations (DDHO)**

**D2.1 Damped harmonic oscillator theory (student should familiarise with the theory before attending the lab)**

Figure D2.1 shows the schematic model of the experimental setup: an oscillating system consisting of a disk connected to two springs (torsion pendulum). The equivalent torsional spring constant is *keq* = 0.00259 Nm/rad, and the torsional damping coefficient is b = 9.68 x 10-5 Nms/rad. The disk has a mass *M* = 118.4 g and the radius *R* = 4.76 cm.



*Figure D2.1: Schematic model of the experimental setup and equivalent model (torsion pendulum)*

#### QUESTIONS TO ADDRESS IN THE REPORT:

|  |  |
| --- | --- |
| **To prepare for the experiments, address the following questions (these will be included in the lab report):**  Answer the questions below for the system shown in Figure D2.1 | |
| **Q2.1** Write the equation of motion for the system without forcing, calculate the moment of inertia I of the disk about the perpendicular axis through its centre and the natural frequency 𝜔0 of the system. | [10] |
| **Q2.2** Plot the magnitude of the angular displacement as a function of the forcing frequency (the system has a static angular displacement 𝜃0 = 0.362 rad) | [10] |
| Marks for DHO theoretical part [20] | |

**Any code should be included in the appendix at the end of the report. All plots should have clear axis labels and measurement units.**

|  |  |
| --- | --- |
| **Q2.1** Write the equation of motion for the system without forcing, calculate the moment of inertia I of the disk about the perpendicular axis through its centre and the natural frequency of the system. |  |
| **Equation of motion (show also free body diagram with forces)**    **EQUATIONS OF MOTION:** |  |
| **Calculate the moment of inertia *I* of the disk about the perpendicular axis through its centre (give the formula used and numerical result)** |  |
| **Calculate the natural frequency of the system (give the formula used and numerical result)** |  |
| **Q2.2** Plot the magnitude of the angular displacement as a function of the forcing frequency (the system has a static angular displacement = 0.362 rad). |  |
| **Plot (complete curve until it the angular displacement is 0)** |  |
| **Explain how to get the angular displacement (max 3 lines)**  Angular displacement = wherein represents the system torque which would be equal to and plotted this graph starting with until our value for angular displacement reached zero. | Lines  1  2  3 |

**Experiments performed**

* Undamped free oscillations (Procedure 1), magnet far away from disk;
* Damped free oscillations (Procedure 2), magnet at 4 mm;
* Damped forced oscillations (Procedure 3), magnet at 4 mm.

#### QUESTIONS TO ADDRESS IN THE REPORT:

|  |  |
| --- | --- |
| Answer the questions below utilising the data collected during the experiment: | |
| **Q2.3** Plot the angular displacement as function of time obtained with Procedure 1, and compare theoretical and experimental natural frequencies. | [10] |
| **Q2.4** Give the estimated values for the damped frequency and damping coefficient obtained with Procedure 2 (unforced system) and with Procedure 3 (forced system). Discuss and explain any difference between the values obtained using the two procedures, and between the estimated damped frequency and natural frequency. | [10] |
| **Q2.5** Examine the graphs of the driving oscillation versus time and the disk oscillation versus time. Measure the phase difference between these oscillations at high frequency (at the beginning of the time interval), resonance frequency (at the time when the disk oscillation is greatest), and at low frequency (at the end of the time interval). At resonance, which peaks first? Do these phase differences agree with the theory? | [10] |
| Marks for DHO experimental part [30] | |

**Any code should be included in the appendix at the end of the report. All plots should have clear axis labels and measurement units.**

|  |  |
| --- | --- |
| **Q2.3** Plot the angular displacement as function of time obtained with Procedure 1, and compare theoretical and experimental natural frequencies. |  |
| **Plot (complete curve until the angular displacement is very close to 0)** |  |
| **Compare theoretical and experimental natural frequencies (max 3 lines)**  in line with expected results. Natural frequency refers to undamped frequency, this would be smaller than theoretical case since friction naturally damps the system and thereby makes it oscillate slower. | Lines  1  2  3 |
| **Q2.4** Give the estimated values for the damped frequency and damping coefficient obtained with Procedure 2 (unforced system) and with Procedure 3 (forced system). Discuss and explain any difference between the values obtained using the two procedures, and between the estimated damped frequency and natural frequency. |  |
| **Damped frequency and damping coefficient (Procedure 2)**  *given in produced graph, calculated using B=0.456*  *b = I\*B = 1.223\** Nms/rad   |  |  | | --- | --- | | *A* | *26.8* | | *B* | *0.456* | | *C* | *-0.0014* | | *φ* | *1.1* | |  |
| **Damped frequency and damping coefficient (Procedure 3)**  Driven damped oscillator equation compared with the relation given in the graph produced and after comparing we obtain C = and  D = allowing us to easily compute b and ω, which leaves us with b = 1.213\*  Nms/rad, and ω = 0.668\*2π = 4.197 rad/s via inspection from the graph local peak at  ~0.668Hz   |  |  | | --- | --- | | *A* | *0.553* | | *C* | *0.668* | | *D* | *0.144* | |  |
| **Discuss and explain any difference between the values obtained using the two procedures, and between the estimated damped frequency and natural frequency (max 4 lines).**  4.53% difference between experimental and theory values for . Procedures 2 and 3 had percentage difference of 3.96% if using undriven ω=4.37 calculated using B, or 1.25% if the given ω=4.25 used. Minimal differences in all cases likely due to either electrical noise in lab equipment, or frictional forces, in line with expectations. | Lines  1  2  3  4 |
| **Q2.5** Examine the graphs of the driving oscillation versus time and the disk oscillation versus time. Measure the phase difference between these oscillations at high frequency (at the beginning of the time interval), resonance frequency (at the time when the disk oscillation is greatest), and at low frequency (at the end of the time interval). At resonance, which peaks first? Do these phase differences agree with the theory? |  |
| **Estimated phase at high frequency (>> resonance)**  High frequency phase difference at t = 0s, φ ~ -π by inspection |  |
| **Does it agree with the theory? (max 2 lines)**  We assume r approaches infinity in this stiffness region where r approaches infinity, so it aligns with theory. | Lines  1  2 |
| **Estimated phase at resonance**  Graphs seem half-way shifted between the -π and 0 phase shift cases, indicating visually the phase difference φ ~ -π/2 |  |
| **Does it agree with the theory? (max 2 lines)**  Theory claims that in a r/φ graph, around the middle in the damping region we expect r = 1 and therefore phase difference to be equal to -π/2. This aligns with theory. | Lines  1  2 |
| **Estimated phase at low frequency (<< resonance)**    Graphs almost coincide perfectly, indicating minimal phase difference near the amplitude peak of the disk, so φ ~ 0 |  |
| **Does it agree with the theory? (max 2 lines)**  Yes, theory dictates when inertia region is reached, r = 0 and φ ~ 0 so by inspection this aligns with the theory. | Lines  1  2 |

**APPENDIX (max 3 pages)**

**1.2**

import numpy as np

import matplotlib.pyplot as plt

from scipy.signal import find\_peaks

delta = 0.02374

omega = 10.6458

v = 10.6428

t = np.linspace(0, 10, 1000)

x\_t = np.exp(-delta \* omega \* t) \* (0.0012 \* np.sin(v \* t) + 0.05 \* np.cos(v \* t))

peaks, \_ = find\_peaks(x\_t)

plt.figure(figsize=(8, 6))

plt.plot(t, x\_t, label=r"$x(t) = e^{-\delta \omega t}\left(0.0012 \cdot \sin(vt) + 0.05 \cdot \cos(vt)\right)$")

plt.plot(t[peaks], x\_t[peaks], "ro", label="Peaks")

plt.title("Graph of $x(t)$ against $t$ in the time interval [0,10]s")

plt.xlabel("Time $t$")

plt.ylabel("$x(t)$")

plt.legend()

plt.grid(True)

plt.show()

**1.3 UNDAMPED**

import pandas as pd

import numpy as np

from scipy.signal import find\_peaks

import matplotlib.pyplot as plt

data = pd.read\_csv(r'c:\Users\thodi\Desktop\SMD3\Group 14 - 1, undamped(lvtemporary\_390961).csv')

data.columns = ['Time (s)', 'Pulley Movement (cm)']

filtered\_data = data[data['Time (s)'] >= 10.5]

peaks, \_ = find\_peaks(filtered\_data['Pulley Movement (cm)'])

if len(peaks) > 3:

    peak\_times\_after\_third = filtered\_data['Time (s)'].iloc[peaks[3:]].values

    peak\_values\_after\_third = filtered\_data['Pulley Movement (cm)'].iloc[peaks[3:]].values

    plt.figure(figsize=(10, 6))

    plt.plot(filtered\_data['Time (s)'], filtered\_data['Pulley Movement (cm)'], label="Pulley Movement")

    plt.scatter(peak\_times\_after\_third, peak\_values\_after\_third, color='red', label='Peaks', zorder=5)

    plt.title('Pulley Movement vs. Time for an Undamped Oscillator')

    plt.xlabel('Time (s)')

    plt.ylabel('Pulley Movement (cm)')

    plt.grid(True)

    plt.legend()

    plt.show()

    periods = np.diff(peak\_times\_after\_third)

    mean\_period = np.mean(periods)

    oscillation\_frequency = 2 \* np.pi / mean\_period if mean\_period > 0 else 0

    print(f'Mean Period (after first 3 peaks): {mean\_period:.4f} seconds')

    print(f'Oscillation Frequency (after first 3 peaks): {oscillation\_frequency:.4f} rad/s')

**1.3 DAMPED**

import pandas as pd

import numpy as np

from scipy.signal import find\_peaks

import matplotlib.pyplot as plt

data = pd.read\_csv(r'C:\Users\thodi\Desktop\SMD3\Group 14 - 1, damped(Group 14 - 1, damped).csv')

data.columns = ['Time (s)', 'Pulley Movement (cm)']

peaks, \_ = find\_peaks(data['Pulley Movement (cm)'])

if len(peaks) > 0:

    peak\_values = data['Pulley Movement (cm)'].iloc[peaks].values

    max\_peak\_index = peaks[np.argmax(peak\_values)]

    data\_after\_max\_peak = data.iloc[max\_peak\_index:]

    peak\_times\_after\_max = data['Time (s)'].iloc[peaks[peaks >= max\_peak\_index]].values

    peak\_values\_after\_max = data['Pulley Movement (cm)'].iloc[peaks[peaks >= max\_peak\_index]].values

    plt.figure(figsize=(10, 6))

    plt.plot(data\_after\_max\_peak['Time (s)'], data\_after\_max\_peak['Pulley Movement (cm)'], label="Pulley Movement")

    plt.scatter(peak\_times\_after\_max, peak\_values\_after\_max, color='red', label='Peaks', zorder=5)

    plt.title('Pulley Movement vs. Time for a Damped Oscillator')

    plt.xlabel('Time (s)')

    plt.ylabel('Pulley Movement (cm)')

    plt.grid(True)

    plt.legend()

    plt.show()

    periods = np.diff(peak\_times\_after\_max)

    mean\_period = np.mean(periods)

    oscillation\_frequency = 2\*np.pi / mean\_period if mean\_period > 0 else 0

    print(f'Mean Period: {mean\_period:.4f} seconds')

    print(f'Oscillation\_Frequency: {oscillation\_frequency:.4f} rad/s')

**2.2**

import numpy as np

import matplotlib.pyplot as plt

theta\_o = 0.362

I = 0.0001341

omega\_forcing = np.linspace(0,20,500)

omega\_natural = 4.394

b = 9.68e-5

k\_eq = 0.00259

tau\_o = k\_eq\*theta\_o

theta\_value = (tau\_o / I) / (np.sqrt((omega\_forcing\*\*2 - omega\_natural\*\*2)\*\*2 + (b / I)\*\*2 \* omega\_forcing\*\*2))

plt.plot(omega\_forcing,theta\_value)

plt.xlabel('Forcing Frequency')

plt.ylabel('Theta')

plt.title('Angular Displacement as a Function of the Forcing Frequency')

plt.grid(True)

plt.show()

**2.3**

import pandas as pd

import matplotlib.pyplot as plt

from scipy.signal import find\_peaks

import numpy as np

data = pd.read\_csv(r'C:\Users\thodi\Desktop\SMD3\Run 1.csv')

time = data['Time (s)']

angular\_displacement = data['Disk Angle (rad)']

filtered\_data = data[data['Time (s)'] >= 2]

time = filtered\_data['Time (s)']

angular\_displacement = filtered\_data['Disk Angle (rad)']

flattened\_region = angular\_displacement[-int(0.1 \* len(angular\_displacement)):]

offset = np.mean(flattened\_region)

adjusted\_angular\_displacement = angular\_displacement - offset

plt.figure(figsize=(10, 6))

plt.plot(time, adjusted\_angular\_displacement, label='Adjusted Disk Angular Displacement', color='b', marker='o')

plt.xlabel('Time (s)')

plt.ylabel('Angular Displacement (rad)')

plt.title('Shifted Down Disk Angular Displacement as a Function of Time')

plt.legend()

plt.grid(True)

plt.show()

interval\_mask = (time >= 5) & (time <= 20)

time\_interval = time[interval\_mask]

adjusted\_displacement\_interval = adjusted\_angular\_displacement[interval\_mask]

peaks, \_ = find\_peaks(adjusted\_displacement\_interval)

peak\_times = time\_interval.iloc[peaks].values

time\_diffs = np.diff(peak\_times)

average\_time\_period = np.mean(time\_diffs)

print("Offset:", offset)

print("Average Time Period after Offset Adjustment:", average\_time\_period)

**2.5**

**Interval 0-10s**

import pandas as pd

import matplotlib.pyplot as plt

from scipy.signal import find\_peaks

data = pd.read\_csv(r'C:\Users\thodi\Desktop\SMD3\Run 3.csv')

Applied to all intervals

time = data['Time (s)']

disk\_angular\_velocity = data['Disk Angular Velocity (rad/s)']

driver\_angular\_velocity = data['Driver Angular Velocity (rad/s)']

disk\_peaks, \_ = find\_peaks(disk\_angular\_velocity)

driver\_peaks, \_ = find\_peaks(driver\_angular\_velocity)

mask\_0\_10 = (time >= 0) & (time <= 10)

time\_0\_10 = time[mask\_0\_10]

disk\_angular\_velocity\_0\_10 = disk\_angular\_velocity[mask\_0\_10]

driver\_angular\_velocity\_0\_10 = driver\_angular\_velocity[mask\_0\_10]

plt.figure(figsize=(10, 6))

plt.plot(time\_0\_10, disk\_angular\_velocity\_0\_10, label='Disk Angular Velocity (rad/s)', color='b')

plt.plot(time\_0\_10, driver\_angular\_velocity\_0\_10, label='Driver Angular Velocity (rad/s)', color='r')

plt.plot(time\_0\_10[disk\_peaks[(time[disk\_peaks] >= 0) & (time[disk\_peaks] <= 10)]],

         disk\_angular\_velocity\_0\_10[disk\_peaks[(time[disk\_peaks] >= 0) & (time[disk\_peaks] <= 10)]], 'bo', label='Disk Peaks')

plt.plot(time\_0\_10[driver\_peaks[(time[driver\_peaks] >= 0) & (time[driver\_peaks] <= 10)]],

         driver\_angular\_velocity\_0\_10[driver\_peaks[(time[driver\_peaks] >= 0) & (time[driver\_peaks] <= 10)]], 'ro', label='Driver Peaks')

plt.title('Disk and Driver Angular Velocity (0 to 10 seconds)')

plt.xlabel('Time (s)')

plt.ylabel('Angular Velocity (rad/s)')

plt.legend()

plt.grid(True)

plt.xlim(0, 10)

plt.show()

**Interval 300-320 seconds**

mask\_300\_320 = (time >= 300) & (time <= 320)

time\_300\_320 = time[mask\_300\_320]

disk\_angular\_velocity\_300\_320 = disk\_angular\_velocity[mask\_300\_320]

driver\_angular\_velocity\_300\_320 = driver\_angular\_velocity[mask\_300\_320]

plt.figure(figsize=(10, 6))

plt.plot(time\_300\_320, disk\_angular\_velocity\_300\_320, label='Disk Angular Velocity (rad/s)', color='b')

plt.plot(time\_300\_320, driver\_angular\_velocity\_300\_320, label='Driver Angular Velocity (rad/s)', color='r')

plt.plot(time\_300\_320[disk\_peaks[(time[disk\_peaks] >= 300) & (time[disk\_peaks] <= 320)]],

         disk\_angular\_velocity\_300\_320[disk\_peaks[(time[disk\_peaks] >= 300) & (time[disk\_peaks] <= 320)]], 'bo', label='Disk Peaks')

plt.plot(time\_300\_320[driver\_peaks[(time[driver\_peaks] >= 300) & (time[driver\_peaks] <= 320)]],

         driver\_angular\_velocity\_300\_320[driver\_peaks[(time[driver\_peaks] >= 300) & (time[driver\_peaks] <= 320)]], 'ro', label='Driver Peaks')

plt.title('Disk and Driver Angular Velocity (300 to 320 seconds)')

plt.xlabel('Time (s)')

plt.ylabel('Angular Velocity (rad/s)')

plt.legend()

plt.grid(True)

plt.xlim(300, 320)

plt.show()

**Interval 400-410 seconds**

disk\_peaks, \_ = find\_peaks(disk\_angular\_velocity)

driver\_peaks, \_ = find\_peaks(driver\_angular\_velocity)

mask\_400\_410 = (time >= 400) & (time <= 410)

time\_400\_410 = time[mask\_400\_410]

disk\_angular\_velocity\_400\_410 = disk\_angular\_velocity[mask\_400\_410]

driver\_angular\_velocity\_400\_410 = driver\_angular\_velocity[mask\_400\_410]

plt.figure(figsize=(10, 6))

plt.plot(time\_400\_410, disk\_angular\_velocity\_400\_410, label='Disk Angular Velocity (rad/s)', color='b')

plt.plot(time\_400\_410, driver\_angular\_velocity\_400\_410, label='Driver Angular Velocity (rad/s)', color='r')

plt.plot(time\_400\_410[disk\_peaks[(time[disk\_peaks] >= 400) & (time[disk\_peaks] <= 410)]],

         disk\_angular\_velocity\_400\_410[disk\_peaks[(time[disk\_peaks] >= 400) & (time[disk\_peaks] <= 410)]], 'bo', label='Disk Peaks')

plt.plot(time\_400\_410[driver\_peaks[(time[driver\_peaks] >= 400) & (time[driver\_peaks] <= 410)]],

         driver\_angular\_velocity\_400\_410[driver\_peaks[(time[driver\_peaks] >= 400) & (time[driver\_peaks] <= 410)]], 'ro', label='Driver Peaks')

plt.title('Disk and Driver Angular Velocity (400 to 410 seconds)')

plt.xlabel('Time (s)')

plt.ylabel('Angular Velocity (rad/s)')

plt.legend()

plt.grid(True)

plt.xlim(400, 410)

plt.show()