Experiment 7

Rotational Dynamics

7.1 INTRODUCTION

In this experiment, you will study angular acceleration and torque in a rotating system, and you will determine the moment of inertia of a rotating platter. The analysis will also draw on ideas you have used in a number of earlier labs this semester. If you are stuck on a particular analysis step, you should look back through your lab notebook and see if perhaps you solved a similar problem earlier in the semester.

The apparatus consists of two platters which rotate about a fixed vertical axle, and a small mass tied to a string wrapped around the hub of the platter and draped over a pulley (as shown in the photograph, Figure 7.1).

The string tension force, F_{T}, is applied at a distance r from the axis of rotation, producing a torque of magnitude $\tau = rF_{\mathrm{T}}$ on the platter. You can vary the torque by varying the mass attached to the string and hence varying the tension force. Alternatively, you can vary the torque by varying the radius at which the force is applied. Newton's laws predict that you should find a relationship between that torque and the angular acceleration of the cylinder,

$$\sum \tau = I\alpha \ ,$$

where I is the moment of inertia of the cylinder-hub combination and α is the angular acceleration.

In this experiment, you will measure α for a range of different torques, and you will use that data to determine I.

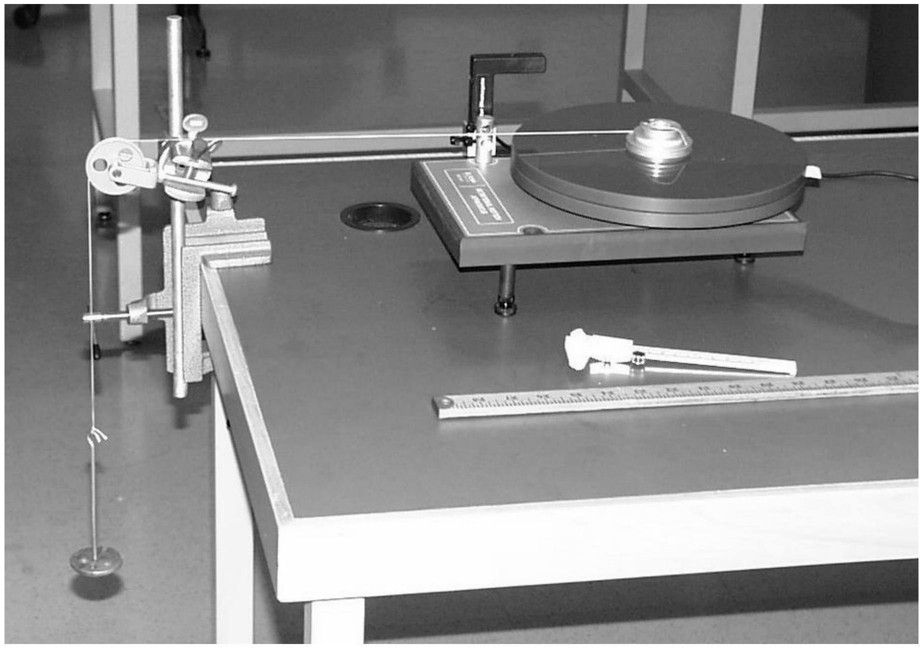

Figure 7.1: Photograph of the Rotational dynamics apparatus.

7.2 DATA ACQUISITION

7.2.1 Angular Position vs. Time

1. First, measure the masses and radii of the platters and make an *estimate* I_{est} of the moment of inertia of the apparatus. Convert everything to SI units (meters, kilograms). Recall that for a solid disk $I_{disk} = \frac{1}{2}MR^2$. (The moment of inertia of the metal hub is only about $90\,\mathrm{g\,cm}^2$, so it may safely be ignored for this estimate.) If you have previously completed the Rotational Energy experiment, you can check this result in your lab notebook.

2. Ensure the string is aligned parallel to the table.

3. You will determine the angular acceleration α by using a photogate to time successive passes of a small flag attached to the outer edge of the platter. Launch `LoggerPro`, then select `File`→`Open`→`Probes & Sensors`→`Photogates`→`Motion Timer Picket Fence`. When prompted by the pop-up box, click `Connect` to enable the photogate.

4. The default setup is for linear measurements, rather than angular measurements. To change this, select `Experiment`→`Set up Sensors`→`LabQuest Mini:1` and then click on the photogate icon in the `DIG/SONIC1` box. Choose `Set Distance or Length`, click on the little down arrow, and select `User Defined`. Type 6.2832 (i.e. 2π) in

the first box and change the units to radians (rad). We will not use the calculated velocity or acceleration plots, so you should just ignore them. (Deleting them is more trouble than it's worth.)

5. Spin the disk around (gently) and press the `Collect` button. Note that `LoggerPro` records the times corresponding to successive passages of the flag through the photogate. Experiment with the set-up until you are confident you understand what the data in the data table means.

6. Carefully wind the string around the hub. Ensure to minimize overlaps; overlapping the string will cause the radius at which the torque is applied to change by a small amount as the wheel rotates. A total hanging mass of about 100 g usually works well for a starting value.

7. Record the hanging mass m and the radius r. Note that the relevant radius is that at which the string applies the force; it is not the outer radius of the hub. Look carefully at the hub—there is an overhang. You want to be sure to measure the radius where the string is actually applying the force.

8. Release the platter from rest with the flag about 1 cm behind the photogate. (That is, it should not be blocking the photogate, and it should pass through the gate shortly after you release the platter. You can rotate the bottom platter independently to line it up properly.) Note carefully when the mass hits the floor or when you run out of string, and stop the platter at that time. If any stray timings occur after the mass hits the floor, note which rows are bad so that you can delete them later.[1]

   Ensure that the placement of the apparatus and the length of the string are such that you get at least 5 data points before the mass hits the floor. As you move the string to the smaller hubs, the number of data points will increase. Be sure that the string is always tangent to the hub throughout your run. You can move the platter closer to the pulley, if necessary.

7.2.2 Angular Acceleration

Use the plot of your measured angles (in radians) vs. time to determine the angular acceleration. You can do the fit directly in `LoggerPro`. It is *critical* that all your data be visible on your graph—`LoggerPro` will only fit the displayed data. Use `Analyze`→`AutoScale Graph`→`Autoscale from 0`. You may also have to manually set the scales by clicking on the minimum and maximum numbers on the graph axes. If in doubt, please ask.

Click on the graph and then select `Analyze`→`Curve Fit`. Select a quadratic curve, select `Automatic` fit, and then select `Try Fit`. Record your results and determine the angular acceleration of the platter. (If you did the Free Fall experiment earlier this semester, you

[1] To delete data, highlight it and then select `Edit`→`Strikeout Data`.

did a very similar fit. Check your notes for that experiment if you are unsure what to do. If you are stymied, consult with your instructor.) Print out one sample graph and include it in your notebook. Thereafter, you only need to include the relevant parameters from the fit in your notebook. Don't forget to include the uncertainties in the fit parameters.

7.2.3 Additional Runs

Repeat the above procedure to get a total of at least six different combinations of mass and radius, ensuring a wide range of torques.

7.3 ANALYSIS

The analysis will proceed in two stages: First, for each run, you will use the measured angular acceleration, along with the value of the hanging mass, to compute the torque applied to the disk. Second, you will plot applied torque *vs.* angular acceleration to determine I.

7.3.1 Determining Torque

Use the relationship $a = \alpha r$ to determine the linear acceleration a for each of your trials. Does your use of this relationship require any assumptions about the string and how it is attached? If so, record those assumptions in your notebook.

The magnitude of the torque applied to the cylinder is $|\vec{\tau_{app}}| = |\vec{r} \times \vec{F_T}| = rF_T$, since the vectors $\vec{r}$ and $\vec{F_T}$ are perpendicular in this case. However, F_T is not simply equal to mg. Apply Newton's laws to the small hanging mass, and work out the algebraic relationship for F_T in terms of m, g, and a. This should involve the drawing of a free-body diagram of the hanging mass. You can neglect the mass of the little plastic pulley that the string goes over. Show your work clearly in your notebook. Watch your signs!

7.3.2 Determining I

Use curve-fitting to assess whether your data for τ_{app} and α have the expected relationship by plotting τ_{app} vs. α. Do you get a straight line as the best fit to your data? If so, does the slope agree with the expected value? (Check this agreement using the statistical methods you have learned this semester.) Does your line pass through the origin? If not, what physical quantity does the intercept represent? If there are any deviations from the expected relationship, can you think of sources of uncertainty that would produce the deviations you find? Can you think of any ways to test your ideas?

As always, discuss sources of uncertainty and ways in which the experiment or write-up could be improved.