SCUPI

Sichuan University - Pittsburgh Institute

ME 1042

Mechanics/Materials
Lab

Geared Systems

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Mechanical Engineering Department

<u>Goal</u>: (1) To determine the mechanical efficiency of a simple and compound geared system and to consider the advantages/disadvantages of a compound system. (2) To experimentally determine the rotational inertia of a shaft with friction and compare to a value found from geometry.

<u>Equipment Needed</u>:
TecQuipment TM18 Geared Systems Control Unit
TM18 Dynamometer Motor and Brake
TM18 Winding Drum
TM18 Gear Box

1 Introduction and Basic Theory

1.1 *Mechanical Efficiency of a Gear System*

The purpose of a geared system (such as the drive train in a car) is to increase or decrease rotational speed, increase torque or reverse the direction of torque, or reverses the direction of rotation. Unfortunately mechanical losses in the form of friction are incurred in this process. In an ideal geared system the power out of the system would be equal to the power in, i.e. 100% efficient. However, this is never the case, due to friction in the shaft bearings and between the meshing of the gear teeth. Friction can be reduced by the use of very low friction bearings, tight tolerances and fine surface finishes on running components, although the added cost can outweigh the increase in efficiency gained. The apparatus used for the first part consists of a motor, three shafts with four gears, and a brake. A schematic of the gear box can be seen in Figure 1.

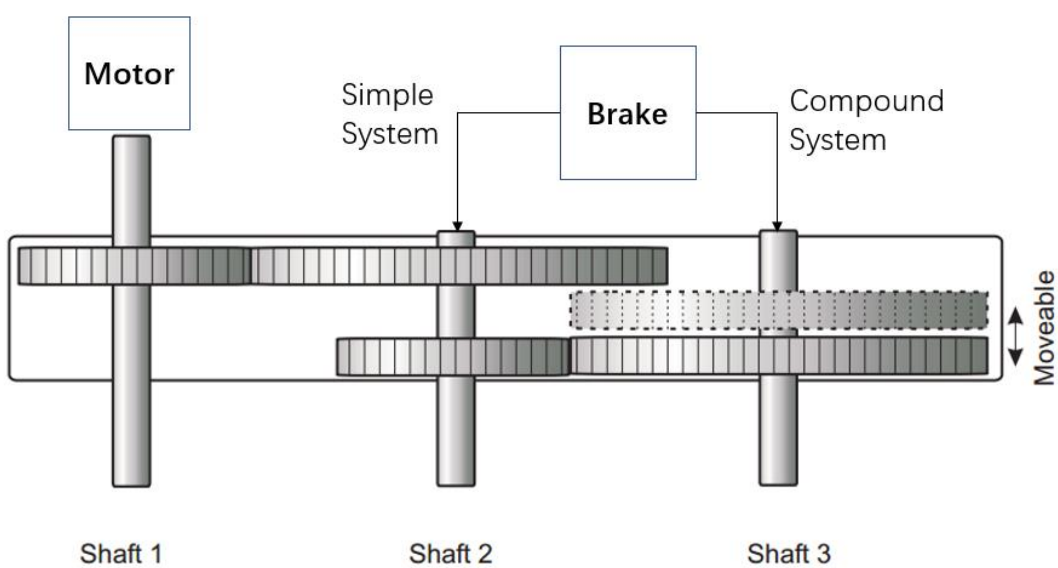

Figure 1: Layout of the Gear Box.

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A description of the gear unit is:

- **Shaft 1** – 1 gear (D) of 80 teeth and a Pitch Circle Diameter (PCD) of 64 mm
- **Shaft 2** – 2 gears, one (B) of 60 teeth and a PCD of 48 mm, the other (C) with 120 teeth and a PCD of 96 mm
- **Shaft 3** – 1 gear (A) of 120 teeth and a PCD of 96 mm.

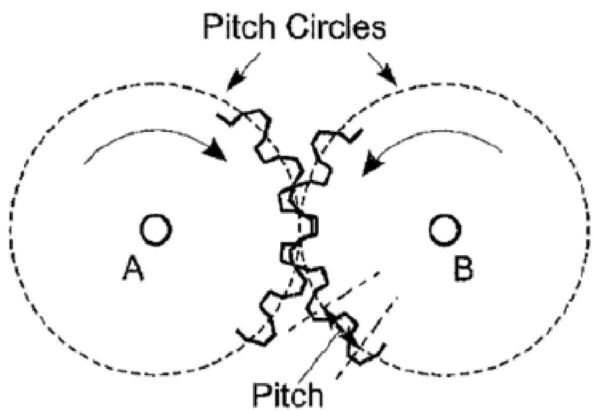

Figure 2: Pitch depictions of driver A and follower B.

Velocity ratios can be determined for a simple system by the following equation:

$$\frac{Speed\ of\ driver\ A}{Speed\ of\ follower\ B} = \frac{Number\ of\ teeth\ on\ follower\ B}{Number\ of\ teeth\ on\ driver\ A}$$

The power of a rotating shaft is a product of the torque and angular velocity of the shaft:

$$Power = Torque \times Angular\ Velocity$$

The efficiency of a mechanical system is defined as the ratio of the output and input power:

$$\varepsilon(\%) = \frac{P_{out}}{P_{in}} \times 100$$

1.2 Rotational Inertia of a Shaft with Friction

The inertia of a rotating component is it's resistance to being accelerated up to speed. The torque required to accelerate a rotating mass is the product of the inertia and angular acceleration. Whether you want to start a car engine, accelerate a washing machine drum or a flywheel, the inertia of the rotating parts must be known to determine how much torque is required to accelerate it up to speed in a reasonable time. In this part of the experiment we will find the inertia of a shaft with friction and compare this to the value calculated from its geometry.

The inertia of a mass rotating about axis (X-X) is:

$$I_{xx} = mr^2/2$$

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Where m = mass (kg) and r = radius (m). If all masses are not rotating about the same axis, the parallel axis theorem can be used to 'translate' the inertia to the appropriate axis.

$$I_{xx} = I_{yy} + md^2$$

Where d is the perpendicular distance of the geometric axis (yy).

In order to find the inertia experimentally, we will wind a string attached to a mass around the drum and drop the mass. Gravity will cause the drum to accelerate, which will be measured. A free body diagram of the system can be seen in Figure 3, where Tf is torque due to friction.

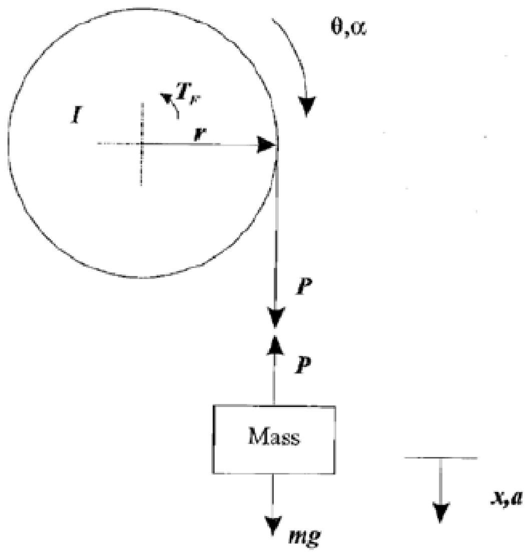

Figure 3: Free body diagram of the winding drum - falling mass system.

2 Experiment 1: Mechanical Efficiency of a Geared System

This experiment will determine the mechanical efficiency of a simple and compound geared system. Experiment 1 will be split into two parts: 1) simple system and 2) compound system. The speed of the motor must remain constant throughout both parts of the experiment to ensure accurate results.

2.1 Procedure for Simple Geared System

Ensure that the system is set up as seen in Figure 4 (consult the Lab Engineer if it is not), and be sure gears C and D are engaged and gears A and B are disengaged. Three people will be needed to adjust the brake, adjust the motor, and take torque readings. Use Table 1 to record data. For power inputs, calculate the values. Do not use the displayed power.

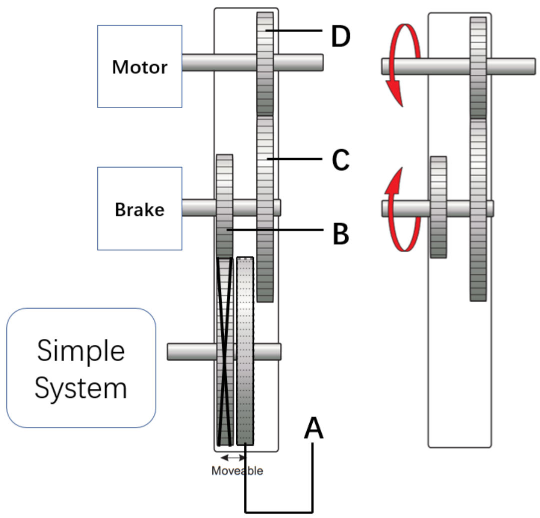

Figure 4: Set-up for Experiment 1: Simple System

Table 1: Data for Experiment 1: Simple System

Nominal Motor Torque (mN m)	Actual Motor Torque (mN m)	Motor Speed (rad/s)	Brake Torque (Nm)	Brake Speed (rad/s)
10				
20				
30				
40				
50				
60				
70				

Work through the following procedure:

1. Prior to starting the experiment, work out the velocity ratio of the simple system and make a note of it.
2. Switch on the control unit via the switch on the rear panel. All displays should display data.
3. Using the "set zero" control on the motor and brake, zero out the force and torque readings on each respective component. ***This procedure should be done every time when the system stops***.
4. Make sure the speed control dial is turned fully counter-clockwise.
5. Press the motor button and slowly increase motor speed to 600 + 10 rev/min. Note the speed of shaft 2. Does it agree with your calculation of velocity ratio?
6. Allow the system to warm up for a minute and take readings for the 10mN m torque case (first row of Table 1).
7. Begin to load the system in approximately the increments shown in Table 1, using the brake. The motor operates under constant power, so when you apply a load to the system the motor speed will slow. To compensate for this, apply a small increment in

load and then adjust the motor speed back to 600 rev/min. Do this until the target motor torque is achieved.

8. Record values for Motor Torque and Load Torque. ***You will calculate the power and efficiency using the previously described relations in Section 1.1***.

2.2 Procedure for Compound System

The procedure for part 2 is the same for part 1 except the initial set-up is different. See Figure 5 and consult the Lab Engineer for initial set-up procedure. Be sure all gears are engaged.

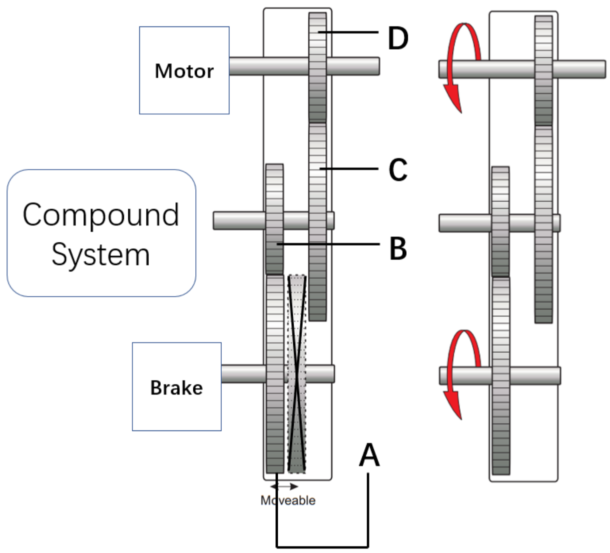

Figure 5: Set-up for Experiment 1: Compound System

Follow the same procedure as experiment one, and record your data in Table 2.

Table 2: Data for Experiment 1: Compound System.

Nominal Motor Torque (mN m)	Actual Motor Torque (mN m)	Motor Speed (rad/s)	Brake Torque (Nm)	Brake Speed (rad/s)
10				
20				
30				
40				
50				
60				
70				

2.3 Analysis of Recorded Data

Plot the Actual Motor Torque (y) vs. the Brake Torque (x) for the simple and compound systems on the same axis and develop an appropriate curve fit for each (should be linear). Physically, what does the slope and intercept represent? Discuss the similarities/differences between the slope and intercept for a simple and compound system. In a separate figure, plot the efficiency (%) (y) vs. Motor Torque (x) for both systems on the same axes. Discuss the differences in each system, and why such differences occur. What are the disadvantages/advantages of using a compound system over a simple system?

3 Experiment 2: Inertia of a Shaft with Friction

The winding drum assembly is connected inline to a flywheel with the component details shown in Figure 6. Since all components are rotating about a common axis, the total inertia is just sum of the individual component inertias. Table 3 shows a summary of the components:

Table 3: Winding drum assembly breakdown.

Flywheel Assembly		**Load Pulley**	
Part	Details	Part	Details
A (Steel Shaft)	r = 4 mm m = 35.94 g $I=2.8752 \times 10^{-7}$ kgm^2	A (Brass Collect)	Inner r = 4 mm Outer r = 6 mm m = 7.54 g
B	r = 48 mm m = 568.2 g	B (Solid Body)	r = 15 mm m = 169.65 g
C	r = 20 mm m = 78.9 g	F = Missing Hole	r = 6 mm m = 13.57 g
F = Missing Hole	r = 5 mm m = 6.2 g		
G = Missing Hole	r = 4 mm m = 7.1 g		

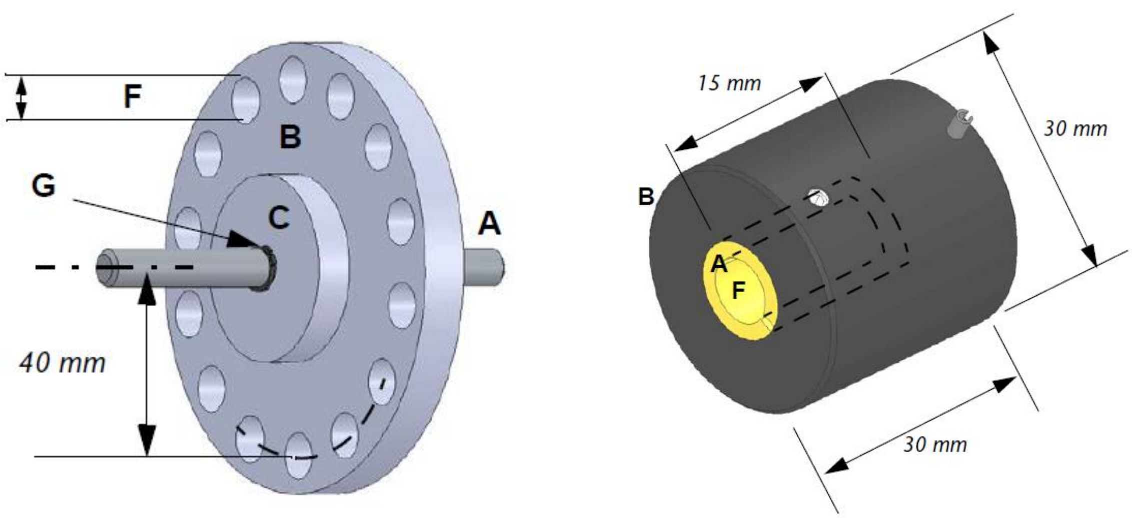

Figure 6: Flywheel and load pulley dimensions.

You are to determine the inertia of the winding drum assembly based on Figures 3 and 6, and Table 3. The winding drum assembly consists of three discs and two extrusions, minus a recess, a bore and 14 timings holes. The recess, bore and 14 timing holes will need to be subtracted from the inertia of the three discs and extrusions.

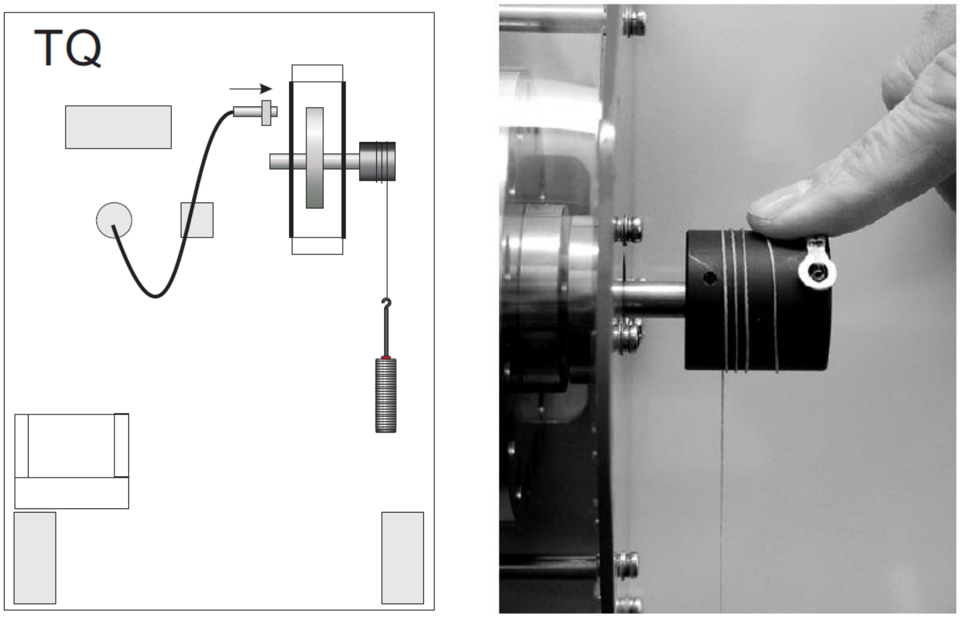

Figure 7: Flywheel inertia test setup.

3.1 Procedure for Experiment 2

The set-up for Experiment 2 is shown in Figure 7. Consult the Lab Engineer for the initial set-up procedure. Once the system is set up, follow the step-by-step procedure to complete the experiment and use Table 4 to input results.

Table 4: Results for Experiment 2.

Angular Acceleration (rad/s^2)					
Mass (g)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
100					
150					
200					
250					
300					

1. Fit a cord and weight hanger as shown in Figure 7. Wrap the cord neatly around the load pulley, for at least four turns. The direction is not important.
2. Add 90 g of masses to the Weight Hanger, giving a total of 100 g load.
3. Hold the Loading Pulley to prevent it from turning. For best results, hold it so that the sensor is between holes. This will help prevent any false starts.
4. Briefly press the pushbutton, then release the Loading Pulley. The display will count the pulses from the tacho sensor as the Flywheel accelerates over a period of two revolutions, then it will produce a value of angular acceleration.
5. Briefly press the pushbutton to reset the display. Repeat the test to confirm the value. Enter the value into your results table.
6. Repeat for increased load values as shown in the results table.

3.2 Analysis of Recorded Data

Using Newton's 2nd law develop a relationship between (mg-ma) and a. For this system, Newton's 2nd law will result in two equations (linear and rotational). You will combine these equations by expressing angular acceleration as a combination of other parameters. After some manipulation you should now have one equation of the form (mg-ma) = m(a) + b. Plot this equation (mg – ma) vs. a, and fit a linear equation. Use your fit parameters and your original equation to solve for I and T_f. You will have 5 curves, and therefore 5 values of *I* and T_f.

Use the information given to calculate a value of inertia for the winding drum assembly based off of geometry. There is 1% uncertainty in the dimension measurements. Perform an uncertainty analysis to come up with the total uncertainty in your calculated inertia for the winding drum assembly. Assume the values of inertia for the other components in the system (given in Table 3) have zero uncertainty. Determine whether the mean value for experimental inertia is statistically different from the theoretical value (conduct a two-tailed t-test).

4 For the Report

In this experiment you have gained firsthand knowledge of advantages and disadvantages of using various geared systems and how inertia effects the acceleration of a rotating shaft with friction. In this experiment 1 we kept the speed of the motor constant, further experiments could vary the speed to determine the effect on efficiency. Knowledge of inertia is imperative to the design of any accelerating rotating system. Further experiments may examine different ways to reduce inertia and friction.

In order to accurately analyze the data the following plots need to be made:

a) Motor Torque vs. Brake Torque for both systems (on same axes) along with a linear fit for both. Be clear labeling sets of data.
b) Efficiency vs. Motor Torque for a simple and compound system (on same axes)
c) (mg – ma) vs. a. for the Experiment 2, along with a linear fit. (only plot one trial)

Along with the plots you will need to discuss the results, using Section 2.3 and Section 3.2 as a guide. Include your process for calculating inertia (a table would help) and an uncertainty analysis (These should be in an Appendix). Do a t-test for the data from Experiment 2 and use a 95% confidence. Show your analysis and a clear explanation of results.

The form of the report should be an extended memo. This will include a few paragraphs of introduction to state the purpose of the study (no theory is needed) and a description of the experiments, followed by results and discussion. Be sure to format your figures properly step the reader through your conclusions.