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Power Efficiency of Planetary Gear System

Kinetic A

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1 Background

1.1 Introduction

As the team is currently building the final design, a mastery of the mechanical components is a must. The primary gear set, the planetary gear system, is the source of aesthetics for this sculpture. The gear ratios and power efficiencies will determine the overall aesthetics for the sculpture. By using engineering methods and calculations, the team can produce an educating sculpture.

1.2 Contemporary Issue

One of the customer's needs the team needed to account for was the aesthetic of the sculpture. It also needs to display at least three engineering characteristics. By using a gear system, the team can achieve these simultaneously. The power efficiency calculated can be used to determine the revolution of the Archimedes screw, thus determining the flow rate of the oil being cascaded over the main gear system.

2 Calculations

2.1 Equations

In order to calculate the power efficiency, the input power and output power were needed. The equation for power is as follows:

$$P = T\omega \quad [1]$$

Where *P* is the power of the gear with units of foot-pound per second. *T* is the torque produced by the gears with units of inch-pound. The rotational velocity, ω, is measured in revolutions per minute. This calculation was done several times, starting with the worm gears known torque, and ending with the planetary gear. To find the torque of the following gear, the torque of the first gear, which is known, is multiplied by the gear ratio of the two gears meshing. This is seen in equation 2 below.

$$T_2 = GT_1 \quad [2]$$

Where, T_2 is the torque of the next gear. The gear ratio between the two gears is represented as *G*. The known torque of the meshing gears is represented by T_1. Since the size of the meshing gears is proportionate to the torque and rotational velocity [1], this equation gives a shortcut for finding the torques. Through analysis of the pulley and gear system leading to the worm gear gives the first known torque for Equation 2. Using the known torque, the out power could be calculated. Once the input and output powers were calculated, the power efficiency can be calculated using Equation 3 below.

$$\eta = \frac{P_{out}}{P_{in}} * 100\% \quad [3]$$

Where, η will be the power efficiency of the gear system. P_{out} and P_{in} represent the power at the inner planetary gear and the worm gear, respectively.

2.2 Assumptions

The equations above do not account for friction between the gears. Since the gears will be made of aluminum and cascaded with oil, friction should be negligible. Assuming T_1 from the worm gear as 0.75 inch-pounds, Equation 2 can be solved for the remainder of the gear set.

3 3D Printed Model

This section will detail the planetary gear system being analyzed. The worm gear, ring gear, planetary gears, and sun gear can be seen in Figure 1 below.

Figure 3.1: Planetary Gear System

The worm gear driving the ring gear rotates at a 50 revolutions per minute. The gear ratio between the worm gear and the ring gear is 25:1, which means the worm gear will rotate 25 times as the ring gear completes one revolution. The ring gear has 25 outer teeth and 55 inner teeth. The inner teeth of the ring gear drive the outer planetary gears. The ratio between these two is 0.218, which indicates the ring gear will complete 0.218 of its rotation as the planetary gear completes one complete revolution. The inner set of planetary gears rotates faster than the outer set. The outer and inner planetary gears rotate at 2.1 and 3.3 revolutions per minute, respectively.

4 Results and Discussion

4.1 Torque and Power

The torque that each gear provides directly correlates to the amount of power it produces. The amount of power will determine the longevity of this sculpture. The higher the power, the more likely it is to wear and eventually fail. The torques of each gear was found by using Equation 2. The gear ratios were found by finding the number of teeth of the driven gear and diving that value by the number of teeth of the driving gear. The resulting torque value was then input into Equation 1. The angular velocities were known from the CADD model design. The calculations and results can be seen below in Table 1.

Table 1: Torque and Power Calculations

Gear	Torque (ft*lb)	Power (ft*lb/s)
Worm	0.063	0.327
Ring	1.563	0.327
Outer Planet	0.341	0.075
Inner Planet	0.341	0.118

The planetary gears produced the same amount of torque due to a gear ratio of 1. However, these gears produced different power outputs due to the difference in rotational velocity. The outer planetary gears produce less power since they rotate at a slower velocity.

4.2 Efficiency

The efficiency of the gear set will determine the rotational velocity of the Archimedes screw, thus, determining the flow rate of the oil. This is important for the aesthetics of the sculpture. A low efficiency indicates the team will need to add more components to ensure proper rotational velocity of the screw. A high efficiency indicates the gear system can directly rotate the screw. Using equation 2, the efficiency was calculated to be 36% from the input to output, worm gear and inner planetary gear, respectively.

5 Conclusions

The torque and power calculations were necessary to provide the team insight on the design. The low efficiency highlighted the need to add a set of gears before the screw to ensure proper output. This is done by placing a bevel gear on the back of the planetary gear holder, as seen below.

Figure 5.1: Bevel gear on Carrier

The pinion gear is connected to a rod. The other end of the rod includes a small two gear system that directly rotates the Archimedes screw. The desired velocity of the screw was created by the addition of different types of gear sets. Gear sets are an effective measure to manipulate power for a desired outcome.

6 References

[1] "8.4: Gear Ratios," *1.3: What is the Engineering Design Process? | VEX EDR Curriculum*. [Online]. Available: https://curriculum.vexrobotics.com/curriculum/mechanical-power-transmission/gear-ratios.html. [Accessed: 27-Feb-2019].