Analytical Task Assignment

Torque Required to Turn Planetary Gear

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18F02-Kinetic Sculpture

The main component of our Kinetic sculpture is the planetary gear that sits in the front of our design. We plan to use a worm gear to rotate the ring gear in planetary gearset. We plan to use a weight attached to a pulley that will transmit the power through multiple gear sets in order to rotate the worm gear. However without a proper analysis, there is no way to find out what weight spring needs to be purchased. To find what that weight needs to be, a series of machine design formulas were used to find the force needed to turn the original planetary gearset.

A CADD model was first drawn in Solidworks to secure the general geometry of all the gears to be used. Once that was complete, some of the needed specifications were already known such as; the mean gear diameter (Dm) is 15 inches, the number of teeth on the gear (Ng) is 25, the mean diameter of the worm gear (dw) is 4 inches, the worm gear was a single thread worm gear (Nw) and the pressure ratio (ɸ) is 14.5°. From these I was then able to calculate the gear ratio (mg) using equation (1), the diametral pitch (Pt) using equation (2), the circular pitch (px) using equation (3), and the lead (L) using equation (4) .

$$mg = Ng * Nw \quad (1)$$
$$Pt = mg/Dm \quad (2)$$
$$px = \pi/Pt \quad (3)$$
$$L = pc * Nw \quad (4)$$

Once that was completed the gear ratio (mg) was 25, the diametral pitch (Pt) was 1.67, the circular pitch (px) was 1.884, and the lead (L) was 1.844 as well. I was then able to find the lead angle (λ) which was 8.53 degrees, the sliding velocity (Vs)which was 79.4 feet per minute, the tangential worm gear speed (Vg) which is 11.8 feet per minute, and the coefficient of friction(f) which was .059 .

$$\lambda = tan^{-1}(L/\pi * dw) \quad (5)$$
$$Vs = (\pi * dm * nw) \quad (6)$$
$$Vg = \pi * Dm * (nw/mg)/12 \quad (7)$$
$$f = .103e^{(-.11*Vs^{.45})} + .012 \quad (8)$$

From these I was then able to find the worm gear efficiency (ew), the gear tangential force (Wtg), the worm tangential force (Wtw), and finally the worm gear torque (Tw) I also decided that the pressure angle (ϕ) was 14.5 degrees, a design factor (nd) of .8 , the application factor (Ka) was .8 , and because it requires an output horsepower so i decided to set that very low at .01 because the gear will spin very slow.

$$ew = \frac{cos(\phi)-f*tan(\lambda)}{cos(\phi)+f*cot(\lambda)} \quad (9)$$
$$Wtg = \frac{33000*nd*Ho*Ka}{Vg*ew} \quad (10)$$
$$Wtw = Wtg * \frac{cos(\phi)*sin(\lambda)+f*cos(\lambda)}{cos(\phi)cos(\lambda)-f*sin(\lambda)} \quad (11)$$
$$Tw = Wtw/dw \quad (12)$$

Using these equations I found out that the worm gear efficiency (ew) was .71, the gear tangential force (Wtg) was 12.6 pounds, the worm tangential force (Wtw) was 2.7 pounds, and the worm gear torque (Tw) was .67 pounds per inch. If we were to then attach the constant torque spring to the worm gear, the sculpture would only spin for about 15-30 seconds. In order to lengthen this duration of operation we then added 4 additional gear sets and a pulley. Doing this we added a 67:1 gear ratio and increased the duration of operation to approximately 15-30 minutes. We were able to find this by using equations 13-16 for each of the gear sets to get an ultimate torque of 45.4 pounds per inch at the input shaft. Figure (1) shows a description of how the gears are going to be laid out.

$$D1 = N1/P1 \tag{13}$$

$$D2 = N2/P2 \tag{14}$$

$$F1 = Tw/D1 \tag{15}$$

$$T2 = F1 * D2 \tag{16}$$

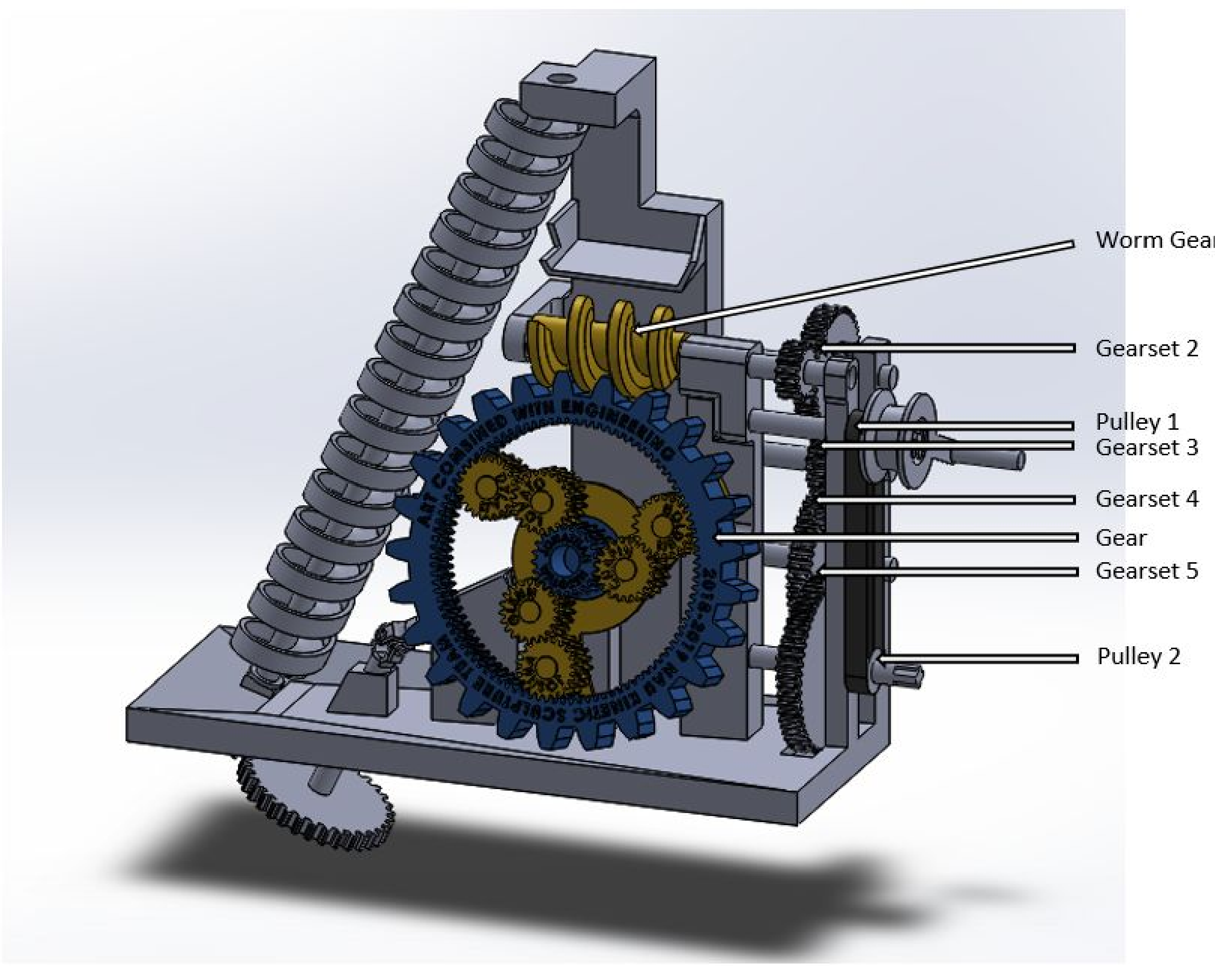

Figure 1: An Image of the Intended Gear Layout

Below is Table 1 thru 3 of part of the calculations used to calculate the final torque.

Table 1: Worm Gear set Calculations

Worm Gear set		
Dm	15	Mean Gear Diameter (inches)
nw	75	RPM of Worm Gear (RPM's)
dw	4	Mean Worm Gear Diameter (inches)
Nw	1	Single Thread Worm Gear
Ng	25	Gear Teeth
phi	14.5	Pressure Angle (degrees)
mg	25	Gear Ratio
Pt	1.666666667	Diametral Pitch (Teeth/inche)
Px	1.884	Circular Pitch (inches)
L	1.884	Lead (inches)
Lamda	0.1488899476	Lead Angle (radians)
Vs	79.37821253	Sliding Velocity (feet/minute)
Ho	0.01	Output Horsepower
Ka	0.8	Application Factor
Vg	11.775	Tangential Worm Gear Speed (Feet/Minute)
f	0.0588623696	Coefficient of Friction
nd	0.8	Design Factor
ew	0.7050959398	Worm Gear Efficiency
Wtg	12.64681635	Gear Tangential Force (Pounds)
Wtw	2.69044586	Worm Tangential Force (Pounds)
Tw	0.672611465	Wotm Gear Torque (Pounds*Inch)

Table 2: Gear Set 2 Calculations

Second Gear Set		
N1	16	Gear 1 Teeth
N2	38	Gear 2 Teeth
Ratio	2.375	
P1	8	Gear Pitch
P2	8	Gear Pitch
D1	2	Gear 1 Diameter
D2	4.75	Gear 2 Diameter
T1	0.672611465	Torque at Gear 1
F1	0.3363057325	Force at Gear 1
F2	0.3363057325	Force at Gear 2
T2	1.597452229	Torque at Gear 2

Table 3: Fifth Gear Set and Pulley Calculations

Fifth Gear Set				Pulley		
N1	16	Gear 1 Teeth		D1	1	Gear 1 Teeth
N2	54	Gear 2 Teeth		D2	1	Gear 2 Teeth
Ratio	3.375			Ratio	1	
P1	8	Gear Pitch		T1	45.4057076	Torque at Gear 1
P2	8	Gear Pitch		T2	45.4057076	Torque at Gear 2
D1	2	Gear 1 Diameter				
D2	6.75	Gear 2 Diameter				
T1	13.45354299	Torque at Gear 1				
F1	6.726771497	Force at Gear 1				
F2	6.726771497	Force at Gear 2				
T2	45.4057076	Torque at Gear 2				

What this all adds up to is we need to attach a weight on a rope to the 2” diameter ratchet that weighs 45.4 pounds and we will be able run our sculpture for a maximum of 30 minutes.

References

R. G. Budynas, J. K. Nisbett, and J. E. Shigley, *Shigley's mechanical engineering design*, 10th ed. New York, NY: McGraw-Hill Education, 2015.