Planetary Gear

CS 285 Solid Modelling (FALL 2011)

Eric Lu and Jessie Jin

Abstract

Planetary gear is one of the epicyclic gear, which is a gear system consisting of one or more outer gears, or planet gears, revolving about a central, or sun gear. And it can be wildly used in industry, such as printing lathe, automation assembly, semiconductor equipment and automation system. Since its commercial value, our project is aimed to build a 3D model of multiple layers of planetary gear by using Solidworks software. And with the help of COS- MOSMotion, visual movement simulation can be realized more efficiently. Moreover, using FDM machine, solid model of a sophisticated planetary gear can be built successfully.

1. Introduction

Planetary gear trains are one of the main subdivisions of the simple epicyclic gear train family. The epicyclic gear train family in general has a central "sun" gear which meshes with and is surrounded by planet gears. The outermost gear, the ring gear, meshes with each of the planet gears. The planet gears are held to a cage or carrier that fixes the planets in orbit relative to each other. Planetary gear is a widely used industrial product in mid-level precision industry, such as printing lathe, automation assembly, semiconductor equipment and automation system. Planetary gearing could increase torque and reduce load inertia while slowdown the speed. To compare with traditional gearbox, planetary gear has several advantages. One advantage is its unique combination of both compactness and outstanding power transmission efficiencies. A typical efficiency loss in a planetary gearbox arrangement is only 3% per stage. This type of efficiency ensures that a high proportion of the energy being input is transmitted through the gearbox, rather than being wasted on mechanical losses inside the gearbox. Another advantage of the planetary gearbox arrangement is load distribution. Because the load being transmitted is shared between multiple planets, torque capability is greatly increased. Greater load ability, as well as higher torque density is obtained with more planets in the system. The planetary gearbox arrangement also creates greater stability due to the even distribution of mass and increased rotational stiffness.

Based on so many advantages of planetary gear above, we did our 3D model of multiple layers of planetary gear to get the speed reduction. And by using COS-MOSMotion, we achieve the visual movement simulation of it. Also we build the solid model using FDM machine. Finally, we hope our product can be used in industry in the future.

2. Planetary gear generation

By using SolidWorks software to build the 3D model of planetary gear, there are some things to do first, such as keeping a constant velocity ratio between two adjacent gear teeth, generating involute curve and set parameters of spur gear.

2.1 Constant Velocity Ratio

To get a constant velocity ratio, the common normal to the tooth profiles at the point of contact must always pass through a fixed point (the pitch point) on the line of centers. In figure 1, although the two profiles have different velocities at the contact point K, their velocities along N_1N_2 that is passing through the pitch point P are equal in both magnitude and direction. Otherwise the two tooth profiles would separate from each other. Therefore, we get the velocity ratio, which is equal to the inverse ratio of the diameters of these two tooth profiles. This is called fundamental law of gear-tooth action. For each two mating gearing tooth profiles, they should satisfy the fundamental law to get a constant velocity ratio.
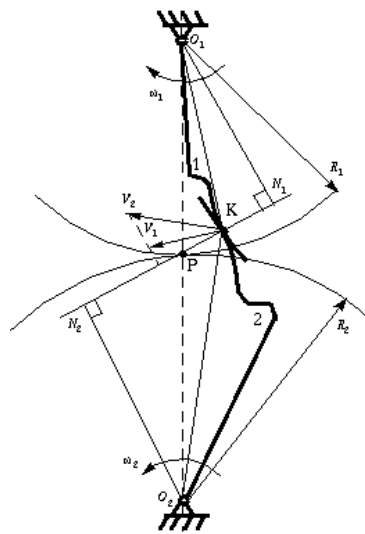

Figure 1. Constant Velocity Ratio

2.2 Generation of Involute Curve

The first step of generation a single tooth of the gear is to generating the involute curve. This involute curve is the path traced by a point on a line as the line rolls without slipping on the circumference of a circle. In Figure 2, let line MN roll in the counterclockwise direction on the circumference of a circle without slipping. When the line has reached the position M'N', its original point of tangent A has reached the position K, having traced the involute curve AK during the motion. As the motion continues, the point A will trace the involute curve AKC.
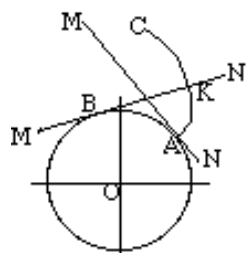

Figure 2. Involute Curve

2.3 Generation of Spur Gear

Usually we use the involute curve to generate a spur gear. The involute has important advantages -- it is easy to manufacture and the center distance between a pair of involute gears can be varied without changing the velocity ratio. Thus, we generate the involute curve to generate a spur gear.

To generate a spur gear, some terminologies of the gear should be taken into consideration. The most important parameters in modeling we need to set the planetary gear are numbers of tooth, module, pitch circle diameter, pressure angle, basis circle diameter, addendum and dedendum. Figure 3 shows these terms. And Table 1 lists the standard tooth system for spur gears. In our design of planetary gear, we choose our pressure angle to be $\alpha = 20°$
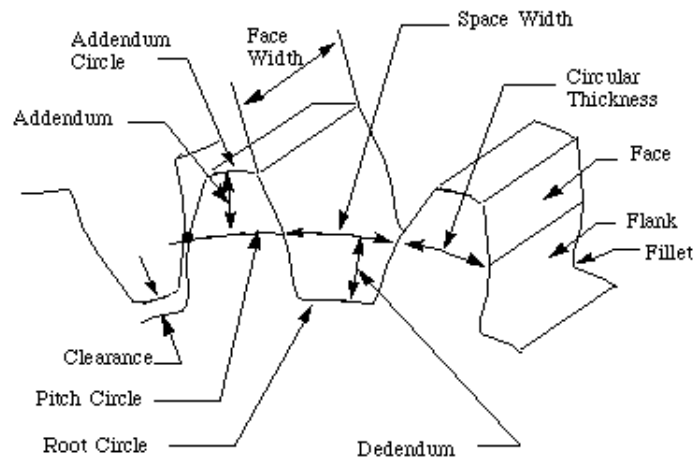

Figure 3. Spur Gear System

Tooth system	Pressure angle α , deg	Addendum a	Dedendum
Full depth	20	$\frac{1}{P_t}$ or 1.0m	$\frac{1.25}{P_t}$ or 1.25m
			$\frac{1.35}{P_t}$ or 1.35m
	$22\frac{1}{2}$	$\frac{1}{P_t}$ or 1.0m	$\frac{1.25}{P_t}$ or 1.25m
			$\frac{1.35}{P_t}$ or 1.35m
	25	$\frac{1}{P_t}$ or 1.0m	$\frac{1.25}{P_t}$ or 1.25m
			$\frac{1.35}{P_t}$ or 1.35m
Stub	20	$\frac{0.8}{P_t}$ or 0.8m	$\frac{1}{P_t}$ or 1m

Table 1. Standard Gear System

Based on the above parameter, we can start to generate the gear model in SolidWorks, and there are several important equations that define the gear:

$$\text{Pitch Circle: } r_p = \frac{1}{2}mZ$$

$$\text{Basic Circle: } r_b = r_p \cos\alpha$$

$$\text{Addendum Circle: } r_a = r + h_a$$

$$\text{Dedendum Circle: } r_f = r - h_f$$

Start with the Y axis, we generated the involute curve based on the basic circle. Each involute curve is unique to the basic circle. For generating the involute curve, we used the parametric method which has the highest accuracy. The equation for the involute curve is:

$$R_{b2} = (\frac{mZ}{2}) \times \cos 20°$$

$$\theta = 45t$$

$$x = R_b \times \cos(\frac{\pi\theta}{180}) + R_b \times \sin(\frac{\pi\theta}{180}) \times (\frac{\pi\theta}{180})$$

$$y = R_b \times \sin(\frac{\pi\theta}{180}) - R_b \times \cos(\frac{\pi\theta}{180}) \times (\frac{\pi\theta}{180})$$

$$z = 0$$

$$\text{where } t \in (0,1)$$

After generating the first involute curve, turned the axis to the certain angle $\tan\alpha - \alpha + \frac{\pi}{2}(\frac{1}{2} + 4\frac{\tan\alpha}{\pi z})$, then draw the other involute curve. Use the addendum circle and the dedendum circle to cut the two involute curves, and add the curve between them, extrude them to the certain width, then we have one tooth. Use the symmetry to arrange the tooth to the entire circle, and we have done with the gear model. The process of generating gears can be shown in Figure 4.
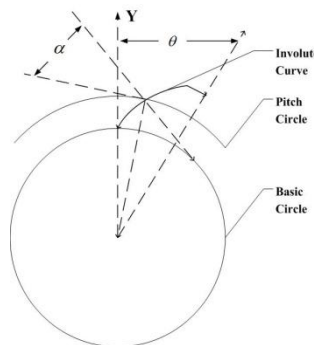

Figure 4. Generating Gears

2.4 Gear Meshing

In order to get a correct meshing the distance of K_1K_2 on gear 1 should be the same as the distance of K_1K_2 on gear 2, as is shown in Figure5. As K_1K_2 on both gears are equal to the base pitch of their gears, so $p_{b1} = p_{b2}$. And since

$p_{b1} = p_1 \cos \alpha_1 = \dfrac{\pi}{P_1} \cos \alpha_1$ and $p_{b2} = p_2 \cos \alpha_2 = \dfrac{\pi}{P_2} \cos \alpha_2$, thus we have

$\dfrac{1}{P_1} \cos \alpha_1 = \dfrac{1}{P_2} \cos \alpha_2$. To satisfy this equation, the pair of meshing gears must satisfy the following condition:

$$\begin{cases} P_1 = P_2 \\ \alpha_1 = \alpha_2 \end{cases}$$

In the above equations, p stands for circular pitch where $p = \dfrac{\pi N}{D}$, and P stands for diametral pitch where $P = \dfrac{N}{D}$. The diametral pitch is the number of teeth of a gear per inch of its pitch diameter.
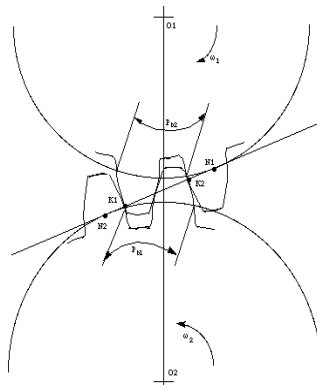

Figure 5. Gear Meshing

2.5 Gears Generated

Based on the above method and parameter, we generated our planetary gear system, which contains one ring gear, two sun gears and four planet gears. The following figures show the generated gears:
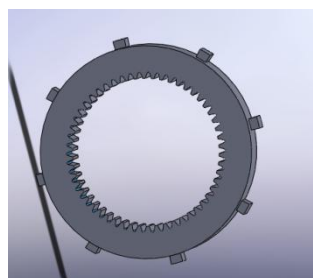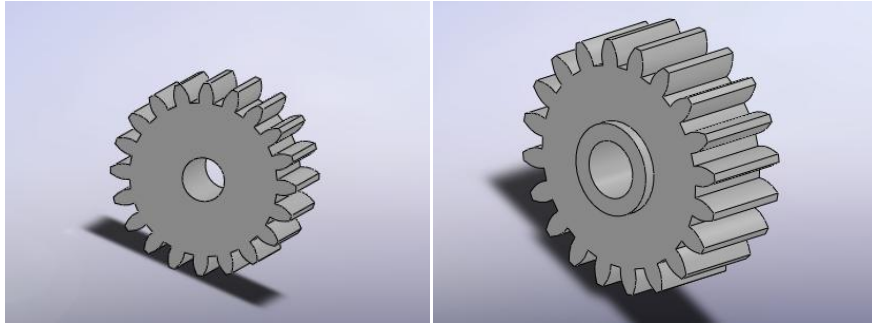
Figure 6. Ring Gear
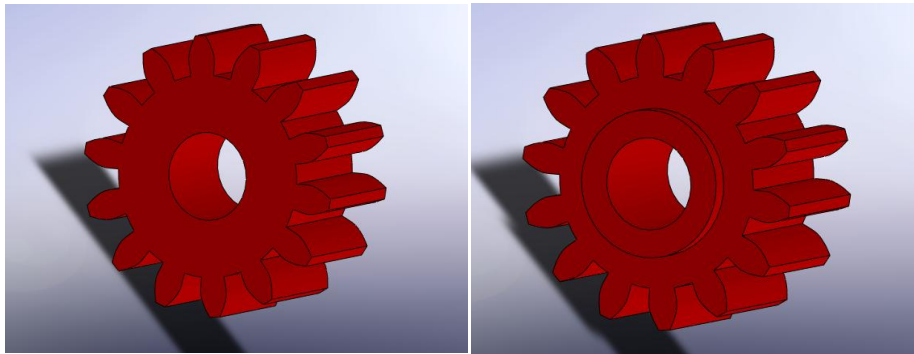

Figure 7. Planet Gears

Figure 8. Sun Gears

3. Gear Assemble

There are several assemble conditions and restrictions, which is one of the technical challenges for our project. In order to prevent the collision between gears, there must be space between each gears, so we have the conjugate condition:

$$O_2O_2' > 2r_{a2} = d_{a2}$$

In the planetary gear system, the center axle and main axle are coincide with each other, so in order to make the ring gear, sun gear and the orbits of the planet gear concentric, we should have the concentric condition:

$$z_2 = (z_3 - z_1) / 2$$

And in order to improve the system's carrying capacity, we usually assemble the planet gears symmetrically surrounding the sun gear, so it should also follow the assemble condition:

$$(z_1 + z_3) / K = N$$

The steps for assemble our gears together could be summarized as follows:

- First Fix the ring gear, set the ring gear and sun gear to be concentric.

- Then Adjust the sun gear, make the gear midline collinear to the ring gear

- Finally Import plant gears, set them to be concentric to the plant shaft and the gear midline collinear to the ring gear.
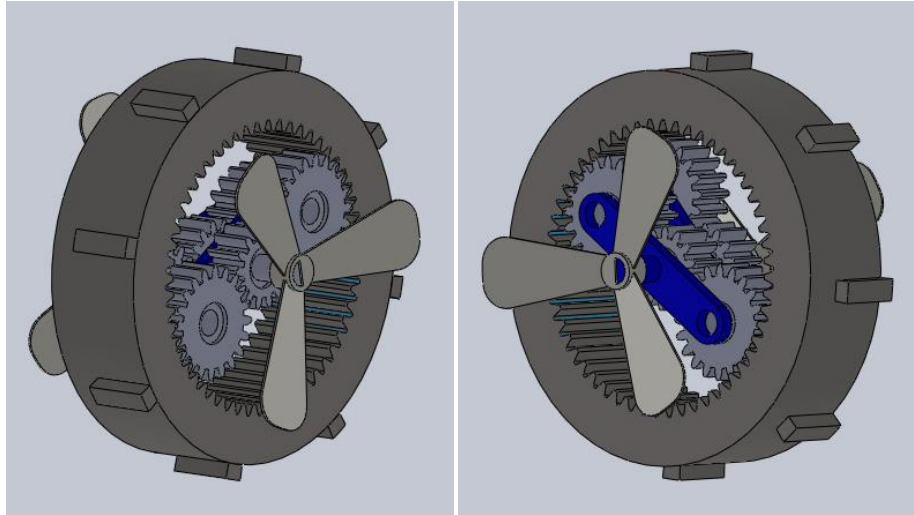
The assembled planetary gears system is shown in figure 9.

Figure 9. Assembled Planetary Gear System

4. Deliverable

After one month's effort for this project, our final deliverable contains:

- A multiple-layer CAD model of the planetary gear system

- A demo video to demonstrate the speed reduction

- A solid model using FDM machine

5. Conclusion

In this project, we have created a CAD model, a simulation video and a solid model of a two-layer planetary gear system using SolidWorks. We have learned the solid modeling technique, assembling knowledge and the simulation process through the project. We think our project could be extended to more layers of gear system and more planet gears per system. We believe our project covered the majority lesson learned in CS285 classes and is of great potential commercial value.