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Volume calculation of RV reducer

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Abstract. At present, the volume of RV reducer has been limited to the volume calculation of cycloid gear, and the main transmission parts of RV reducer have not been fully calculated. In this paper, according to the structural characteristics and transmission principle of RV reducer, the volume calculation formula of the first decelerator sun gear, planetary gear, second decelerator cycloid gear, needle gear, crankshaft, Planetary frame Ⅰ and planet frameⅡ in the planetary frame are derived respectively, and the total volume formula of the RV reducer is calculated. . The 3D model of RV reducer is built in SolidWorks, and the volume of the said parts is calculated by using relevant commands in SolidWorks. Comparing the volume calculated by the formula with the volume of the three dimensional model, the accuracy of the derived formula is verified. The error between the RV reducer volume calculated by the above formula and the volume of 3D model in SolidWorks is not more than 1.5%, and the maximum error of component volume contrast is 3.49%.

1. Introduction

RV reducer is a decelerator widely used in robot and medical equipment. It is developed on the basis of traditional needle and pendulum planetary transmission. It not only overcomes the shortcomings of ordinary needle and pendulum transmission, but also has small volume, light weight, large transmission ratio, long life, high precision, and high efficiency. A series of advantages such as dynamic stability and so on. Taking the smallest volume of the main transmission parts of the RV reducer and improving the volumetric efficiency of the RV reducer, it has always been the main direction of the structural optimization of the RV reducer. However, the volume of RV reducer has been limited to the volume calculation of cycloid gear, and the main transmission parts of RV reducer have not been fully calculated. In this paper, based on the structural characteristics and transmission principle of the RV reducer, The formulas for calculating the volume of the first decelerator, the sun gear, the planetary gear, second deceleration, the cycloid gear, the needle gear, the crankshaft, planetary frame, the planetary frame Ⅰ and the planet frame II are derived respectively. and the total volume formula of the RV reducer is calculated. The 3D model of RV reducer is built in SolidWorks, and the volume of the said parts is calculated by using relevant commands in SolidWorks. Comparing the volume calculated by the formula with the volume of the three dimensional model, the accuracy of the derived formula is verified[1].

In this paper, we take the volume of each transmission part of the RV reducer as the research object, and propose the volume modeling method of each part of the RV reducer. The volume model is

used to optimize the structure of the RV reducer in the following work, so as to achieve the ultimate goal of increasing the volume efficiency ratio of the RV reducer.

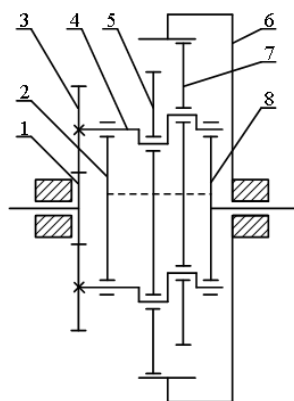## 2. Transmission principle of RV reducer

Figure 1. transmission diagram of RV reducer.

The RV transmission system is a closed differential gear train, which is made up of two parts, which are the first stage involute planetary gear transmission and the second stage cycloid gear drive. The transmission diagram is as shown in 1. The first stage involute gear drive consists of the sun gear 1 and the planetary gear 3; the second level needle cycloid drive includes two cycloid gears5 (7), the needle gear 6, and the crankshaft 4, which are arranged on the 180 "symmetric phase", the planetary frame I 2 and the planetary frame II 8.

The complete transmission process of the RV reducer is (assuming the input speed direction is counterclockwise):

The active sun gear 1 is fixed with the input shaft of the motor, and the sun gear 1 is driven after the motor is started and turns around the clockwise direction. Then the sun gear is engaged with the planetary gear 3 to make the planetary gear revolve around the sun axis and rotate clockwise at the same time, and then the crankshaft 4, which is fixed with the planetary gear, also rotates at the same speed[2]. After the first deceleration, the movement passes to the crank shaft and enters the transmission part of the needle cycloid gear. The two cycloid gear is revolving to form its rotation, and the cycloid gear will engage with the needle teeth which are half buried inside the outer shell, and then the rotation of the cycloid gear will cause the rotation of the cycloid gear after the reverse direction. The rotation direction is reverse clockwise. Finally, the output mechanism of the supporting shaft which drives the crank shaft rotates with the rotation of the cycloidal gear to complete the whole process of motion transmission.

3. Volume calculation

A suIn this paper, the volume calculation of the main transmission parts of the RV reducer includes the first deceleration sun gear of the RV reducer, the planetary gear, the second deceleration cycloid gear, the needle gear, the crankshaft, the star frame in the planetary frame and the volume calculation formula of the planet frame two.

3.1. Volume calculation of the first deceleration

The first deceleration part of the RV reducer is a spur gear deceleration mechanism, which is composed of a sun gear and a planet gear distributed around the sun gear. In this paper, the dividing circle method is used to calculate the volume of spur gear. The indexing circle method is a traditional method of calculating the volume of the spur gear. The volume of the spur gear can be considered as the sum of the hub volume and the volume of the tooth[3]. In the calculation, the cylindrical volume of

the tooth root circle is used as the inner diameter and the diameter of the dividing circle as the outer diameter and the height of the tooth width as the gear volume.

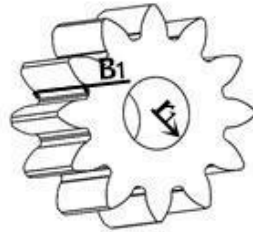### 3.1.1. Calculation of the volume of the sun gear

Figure 2. sun gear 3D model.

As shown in the figure 2 sun gear 3D model, the volume formula of the sun gear is,

$$V_1 = \pi B_1 \left(\frac{1}{4} m_1^2 Z_1^2 - r_1^2 \right) \tag{1}$$

In the formula, V_1 is the sun gear volume, Z_1 is the number of sun gear teeth, m_1 is the number of the sun gear, r_1 is the inner diameter of the sun gear, B_1 is the thickness of the sun gear.

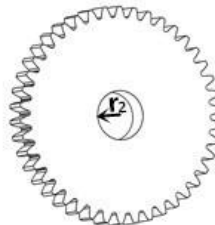### 3.1.2. Calculation of the volume of the planetary gear

Figure 3. three dimensional model of planetary gear.

The above figure 3 shows the volumetric formula of the planet gear as shown in the 3D model of the planet gear,

$$V_2 = \pi B_1 \left(\frac{1}{4} m_1^2 Z_2^2 - r_2^2 \right) \tag{2}$$

In the formula, V_2 is the volume of the planet gear, Z_2 is the tooth number of planetary gears, r_2 is the inner diameter of the planetary gear.

3.2. Volume calculation of second deceleration section

The second decelerator in the RV decelerator is a cycloid deceleration mechanism. The crankshaft connected with the first gear of the first decelerator becomes the input of the second deceleration section. The eccentric part of the crankshaft is mounted by the roller bearing two cycloid gears, and the inner side of the needle gear shell is inlaid more than the cycloid gear, and arranged at the same pitch.

3.2.1. Volume calculation of cycloid gear. When calculating the volume of the cycloid gear, the average circle method is used to calculate the average value of the radius of the tooth top circle and the radius of the tooth root circle, which is used as the outer diameter of the cycloid gear, the radius of the tooth root circle as the inner diameter, and the cylindrical volume of the height taking the tooth width as the tooth volume[4].
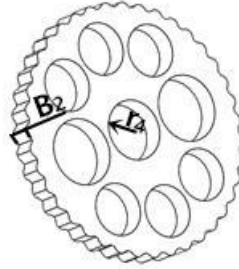

Figure 4. three dimensional model of cycloid gear.

As shown in the 3D model of the cycloid gear above Figure 4, the volume calculation formula of the cycloid gear is,

$$V_3 = \pi B_2[(r_p - r_{rp})^2 - 6(r_8 + a)^2 - 2r_3^2 - r_4^2] \tag{3}$$

In the formula, V_3 is the volume of the cycloid gear, B_2 is the thickness of the cycloid gear, r_p is the center circle radius of the needle gear, r_{rp} for the needle gear radius, r_8 for the two pin radius of the planet frame, a for the crankshaft eccentricity, r_3 for the outer diameter of the roller bearing, r_4 for the inner aperture of the cycloid gear.
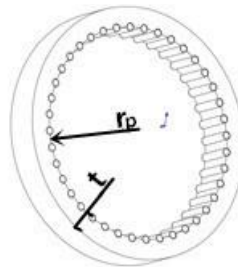
3.2.2. Calculation of the volume of needle gear

Figure 5. three dimensional model of a needle gear.

As shown in Figure 5, the volume of the pingear is calculated as follows:

$$V_4 = \pi B_2 \left(4tr_p + 2t^2 + r_{rp}^2 Z_3\right) \tag{4}$$

In the formula, V_4 is the volume of the needle gear, t is the thickness of the needle gear shell, Z_3 is the number of the needle gear.

*3.2.3. Calculation of the volume of crankshaft .*As shown in Figure 6, the crankshaft volume is calculated as follows:

$$V_5 = \pi r_2^2 (B_1 + 2B_3) + 2\pi r_5^2 B_2 \tag{5}$$

In the formula, V_5 is the volume of the crankshaft, B_3 is the width of the thrust bearing , and the r_5 is the inner diameter of the roller bearing.
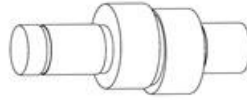

Figure 6.three dimensional model of crankshaft.

3.3. The calculation of the volume of the planetary frame
The planet frame is one of the main components of the RV reducer, and its structure is very important and complex. As the basic component of the planetary frame, it is the largest component bearing the external torque in the mechanism, so its structure size design determines the transmission quality of the RV reducer[5]. In the volume calculation, the planetary frame structure should be simplified to meet the transmission requirements of the structure while ensuring the accuracy of volume calculation[6].

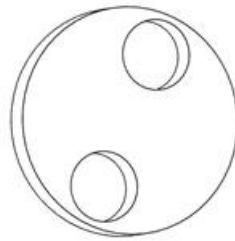*3.3.1. One volume calculation of the planetary frame*

Figure 7.three dimensional model of a planetary frame I.

As shown in the three dimensional model in Figure 7 above, the formula for calculating the planetary frame I,

$$V_6 = \pi r_6^2 B_4 - 2\pi r_7^2 B_3 \tag{6}$$

In the formula, V_6 is a volume of planet carrier, r_6 is angular contact bearing inner diameter, B_4 is angular contact bearing width, r_7 is thrust bearing outer diameter.

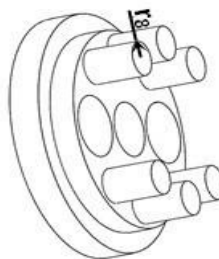*3.3.2. volume calculation of the planetary frame II*

Figure 8. three dimensional model of the planet frame II .

If the three dimensional model of the planet frame II is shown in Figure 8 above, the formula for calculating the volume of the planet frame II is,

$$V_7 = \pi r_9^2 (B_1 + B_3 - B_4) + 12\pi B_2 r_8^2 + \pi r_6^2 B_4$$
$$-[\frac{1}{4}\pi m_1^2 (Z_1^2 + 2Z_2^2)B_1 + 2\pi r_7^2 B_3 + \frac{1}{4}\pi m_1^2 Z_1^2 B_3] \tag{7}$$

In the formula, V_7 is the volume of planet frame II, r_9 is the inner diameter of the oil seal.

3.4.The volume of RV reducer

Combining the volume calculation formula of the first deceleration part in 3.1, 3.2 and 3.3, the volume calculation formula of the second deceleration part and the planetary frame volume formula, combined with the working principle of the RV reducer, the volume of the RV reducer is obtained.

$$V_8 = V_1 + nV_2 + 2V_3 + V_4 + nV_5 + V_6 + V_7 \tag{8}$$

4. Verification of volume formula

In order to check the accuracy of the formula, the formula calculated data are compared with the volume of three-dimensional model in SolidWorks.

The results of volume contrast are shown in Table 1 as shown below.

Table 1. The result of Volume contrast.

Model volume			calculate volume
First deceleration	Sun gear	461.67mm^3	467.31mm^3
	Planetary gear	6503.87mm^3	6534.51mm^3
Second deceleration	Cycloid gear	38169.76mm^3	38354.13mm^3
	Needle gear	68933.68mm^3	68989.37mm^3
	crankshaft	8982.36mm^3	8669.22mm^3
Planetary frame	Planetary frame I	61424.07mm^3	61434.47mm^3
	Planetary frame II	140711.47 mm^3	137249.12mm^3
	Total volume	325186.88mm^3	321698.13mm^3

From table 1, it can be found that the volume contrast between the RV reducer volume calculated in the above formula and the three-dimensional model in SolidWorks is not more than 1.5%, and the maximum error of the component volume comparison is 3.49%. So the derived formula is available.

5. Conclusions

1) According to the structure and working principle of the RV reducer, the volume of the transmission components in the RV reducer is deduced, and the volume of the RV reducer iscalculated.
2) In order to test the accuracy of the formula, the accuracy of the formula is verified by comparing the calculated data with the volume of the three-dimensional model in SolidWorks.
3) The calculation of the volume of the RV reducer lays a foundation for optimizing the structure of the RV reducer and improving the volumetric efficiency of the RV reducer.

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