Design and Experiment of a Teaching Tool for Oval Gears with Variable Transmission Ratio

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Abstract. The basic theory of oval gear is studied. The teaching tool with variable transmission ratio of oval gear is designed. On the premise that the center distance remains unchanged, the parameter law of oval gear is clarified, and finally oval gear mechanism parameters of meeting the constraint conditions of box body are obtained. The effectiveness of the teaching tool design method is verified by experiments, which facilitates the standardized design and application of oval gear.

1. Introduction
When the driving wheel of the non-circular gear mechanism rotates at a constant speed, the speed of the driven wheel changes. Noncircular gear has the advantages of general cylindrical gear [1]. At present, people have done a lot of research on the design, manufacture and application of oval gears [2]. In the actual design process of oval gear, the size and variation law of transmission ratio are determined first, then eccentricity is calculated, modulus and number of teeth are selected, and finally other parameters, such as center distance, are determined [3]. However, people usually put the oval gear into the reducer [4]. Therefore, the design of oval gear reducer will face the situation that the center distance remains unchanged and other parameters of oval gear are designed. In this paper, the teaching tool with variable transmission ratio of oval gear is designed, and the effectiveness of the teaching tool design method is verified by experiments.

2. Transmission Design of Teaching Tool
The design flow chart is shown in Fig. 1. In this paper, the box of existing reducer teaching aid model is selected as the box of non-circular gear reducer, which is shown in Fig. 2. On this basis, the input-output device and other transmission mechanisms are designed. The center distance is 70mm.
3. Design of Oval Gears
Taking the oval gear mechanism as an example, the design method of oval gear is studied in this paper.

3.1. Basic Theory of Oval Gear
The pitch curve of the oval gear can be expressed as:

\[
R_1 = \frac{a(1 - e^2)}{1 + e \cos \phi_1}
\] (1)

Here, \(a\) is major semi-axis, \(\phi_1\) is polar angle, \(e\) is eccentricity, and \(R_1\) is the polar diameter [5].

The oval gear structure diagram is shown in Fig. 3. The transmission ratio can be calculated as:

\[
i_{21} = \frac{1 - e^2}{1 + 2e \cos 2\phi_1 + e^2}
\] (2)

According to [6], in order to avoid concave pitch curve, eccentricity should meet the following requirements:
$e \leq \frac{1}{3}$  \hspace{1cm} (3)

In order to ensure the distribution of two teeth on the major axis and two slots on the minor axis, the number of teeth of oval gear should be guaranteed:

$$z = 4n + 2$$  \hspace{1cm} (4)

Here, $n$ is positive integer.

The circumference of the pitch curve can be obtained:

$$L = \pi nz$$  \hspace{1cm} (5)

Here, $z$ is number of teeth and $m$ is modulus.

The pitch curve arc length can be obtained:

$$S = 4a \sqrt{1 + 3e^2} \int_0^\frac{\pi}{2} \sqrt{1 - \frac{4e^2}{1 + 3e^2} \sin^2 \phi} d\phi$$  \hspace{1cm} (6)

According to $L=S$, we can get from Eq (5) and Eq (6):

$$a = \frac{\pi nz}{4\sqrt{1 + 3e^2} \int_0^\frac{\pi}{2} \sqrt{1 - \frac{4e^2}{1 + 3e^2} \sin^2 \phi} d\phi}$$  \hspace{1cm} (7)

3.2. Criteria for Selecting Parameters of Oval Gears Oriented to Fixed Center Distance

When designing the basic parameters of oval gears, the basic dimensions of the box body should also be satisfied, that is, the center distance $a=70$mm.

Normally, the standard modulus $m$ can take 1.0, 1.5, 2.0, 2.5 and so on, while Eq (4) shows that $z$ can take 22, 26, 30, 34, 38, 42, 46... The eccentricity should be $0 < e < 0.33$.

Based on Eq (7), the value range of teeth and modulus can be obtained when $e$ varies in the range of values, as shown in Fig.4.

![Graph showing the value range of teeth and modulus for different $e$ values](image-url)
Fig.4 shows that the basic parameters of center distance $2a = 70\text{mm}$ are not satisfied. Therefore, only oval gears with non-standard modulus can be selected. Finally, $a$-$e$ curves of $m=1.1$, $z=66$ and $a$-$e$ curves of $m=2.4$ and $z=30$ are calculated, as shown in Fig.5.

![Figure 4](image1)

**Figure 4.** The value range of $a$ corresponding to different modulus and teeth.

![Figure 5](image2)

**Figure 5.** The $a$-$e$ curves of non-standard modulus.

From Fig.5, it can be seen that the basic parameters of reasonable oval gear satisfying the center distance of $2a = 70\text{mm}$ are shown in Table.1. Finally, the second group of data parameters is selected.

| Table 1. Reasonable parameters of oval gear. |
|---------------------------------------------|
| Parameter | The first group | The second group |
|-----------|----------------|-----------------|
| $m$       | 1.1            | 2.4             |
| $z$       | 66             | 30              |
| $e$       | 0.28           | 0.2442          |
| $a$       | 35             | 35              |
| $b$       | 33.6           | 33.9404         |
| $c$       | 9.8            | 8.547           |

4. Experiment of the Teaching Tool

The teaching tool experiment is shown in Fig. 6. Firstly, the experiment was carried out with elliptical gear, and then the experiment was carried out with oval gear. The change curve of transmission ratio is obtained by two kinds of noncircular gears. In this way, students can intuitively feel the change law of transmission ratio of oval gears.

Figure 6. Teaching tool experiment.

5. Conclusion

In this paper, the basic theory of oval gear is studied. The teaching tool with variable transmission ratio of oval gear is designed. On the premise that the center distance remains unchanged, the parameter law of oval gear is clarified, and finally oval gear mechanism parameters of meeting the constraint conditions of box body are obtained. The effectiveness of the teaching tool design method is verified by experiments, which facilitates the standardized design and application of non-circular gear.

Acknowledgments

This work was financially supported by Natural Science Foundation of Liaoning Province (2020-MS-363) and Innovation Talent Support Program for College and Universities in Liaoning Province (LR2019036).

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