Design and Mechanical Efficiency Improvement of Micro Reducer

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Abstract—Micro reducer is widely used, but its mechanical efficiency is not high. Selecting metal materials and engineering plastics to form the motion pair can reduce friction and wear. Selecting new materials in the design of the reducer and adopting new molding technologies can improve the precision of gear transmission and reduce noise and vibration. For a reducer with a large transmission ratio and many transmission stages, rational allocation of the transmission ratios at all levels in the structural design can improve the efficiency of the reducer. Different planetary gear structural designs will also affect the mechanical efficiency, and the structural design is optimized so that the reducer can better take into account the relationship between load and mechanical efficiency.

1. Introduction

The micro reducer is an important part of the micro motor, which converts the speed of the motor into the speed required by the working machine. The miniature reducer is small in size and has a large transmission ratio. It usually uses an internal meshing multi-stage planetary reducer. It consists of a series of gears. It has many product types and compact structure. It is often used in new automatic rolling shutters, projection screens, high-end automatic window shutters and other occasions. Micro reducers can act as torque amplifiers and can be used in robot arms.

Mechanical efficiency is an important parameter for evaluating machine mechanics. Compared with ordinary reducers, miniature planetary reducers have many types and large transmission ratios. The materials of planetary reducers include steel, aluminum alloy, powder metallurgy materials, engineering plastics and other materials. Therefore, the mechanical efficiency of planetary reducers and ordinary reducers is very different. In terms of structure, the micro reducer usually adopts multi-stage transmission, and when the speed ratio is large, it adopts 3-4 stage transmission. The miniature planetary reducer has a large number of planetary gears, each stage of transmission generally has 3-4 planetary gears, and usually adopts multiple symmetrical arrangements, which is very different from the structure of ordinary reducers. At present, there is no good method or empirical formula to calculate, and the mechanical efficiency is usually obtained by testing equipment. The research and analysis of the influence of the material and structure of the micro reducer on the mechanical efficiency can provide a basis for the research and development of new products, the improvement of structural design, and the improvement of mechanical efficiency and product quality.
2. The structure and mechanical efficiency of the micro reducer

2.1 Composition and structure of micro reducer

Micro reducer usually adopts planetary reducer, which consists of sun gear, planetary gear, planet carrier and rack. The axis of the center wheel is fixed, and the fixed axis rotates. The axis of the planet carrier is fixed, one end is fixed to rotate, and the other end is connected to the planetary gear, which is the axis of the planetary gear. In order to reduce the volume and mass, the micro reducer adopts internal meshing planetary gear transmission.

There are many types of miniature reducers, large transmission ratio range, small size, and wide application. Commonly used miniature reducers are divided into single-stage reducers, two-stage reducers, and many-stage reducers. Fig. 1 is a schematic diagram of the composition of a three-stage planetary reducer. The three-stage miniature reducer is divided into three stages of transmission, each stage is a planetary gear transmission, and the center wheel 1 is an external gear, meshing with the planetary gear 2, the central wheel 3 is an internal gear, and 4 is a planet carrier, forming a planetary gear train. The axes of the six central wheels of the three-stage planetary gear train are collinear, and the internal gear of the three-stage transmission is usually made into one part, that is, the three-stage planetary transmission shares a large ring gear - the casing (frame) of the reducer.

![Fig.1 Schematic diagram of the composition of the three-stage planetary reducer](image)

2.2 Mechanical efficiency of micro reducer

Mechanical efficiency is an important indicator to measure the mechanical performance of reducer machine. The factors affecting the mechanical efficiency of the micro reducer include three aspects: (1) The gear meshing efficiency, which is the power loss caused by the friction and wear of the gear teeth during gear transmission, is the main influencing factor. For micro reducers, the structure of micro reducers is usually complicated, and the number of meshing gears generally ranges from a few pairs to a dozen pairs. The meshing efficiency of multi-stage reducers with large transmission ratios is low (2) Bearing efficiency, which is determined by the power loss caused by the friction and wear of the bearing, the bearing efficiency of the micro reducer is not high. (3) Other power loss efficiency, micro reducer materials are diverse, and are affected by materials and precision, but there is no specific data for reference. Therefore, the formula for calculating the mechanical efficiency of ordinary reducers cannot be used. As yet, there is no formula or method for calculating the efficiency of micro-planetary gearing. The mechanical efficiency of the micro reducer is usually measured by the specially developed mechanical efficiency test equipment of the micro reducer.

3. Design and Mechanical Efficiency of Micro Reducer

3.1 Material selection of planetary reducer

The material selection of the miniature planetary gear reducer requires that the planetary gear transmission has the advantages of compact structure, small volume, light weight, large transmission ratio, etc., and at the same time, it has a very small installation and operating space to obtain a large torque increase function. Therefore, the selection of manufacturing materials for transmission parts of
micro reducer is constantly researched and innovated. At present, the commonly used materials are steel, powder metallurgy materials, engineering plastics and aluminum alloys. Gear meshing with metal and non-metal materials can reduce friction and wear, reduce noise and vibration, and improve mechanical efficiency.

The internal gears in the miniature planetary reducer are usually made of engineering plastics. PA66 is a kind of polyamide with higher melting point, which belongs to a semi-crystalline-crystalline material, and can maintain strong strength and stiffness at higher temperature\(^1\).

The planetary gear in the reducer can also be made of engineering plastics. Commonly used materials are engineering plastics POM and engineering thermoplastic elastomers. POM has good comprehensive properties and is the hardest among thermoplastics. It is one of the plastic materials with the closest mechanical properties to metals. Thermoplastic elastomers are high-strength, high-performance materials. Properly designed components can withstand millions of bending cycles after being subjected to repeated tension and compression. Impact strength. Good toughness even at low temperature\(^2\). Commonly used in high-speed planetary gears of micro reducers. The planetary gear can also be made of powder metallurgy materials. The internal pores of the material are crisscrossed and connected to each other, and have self-lubricating properties by dipping and lubricating in the pores of the material\(^3\).

The planet carrier is usually made of aluminum alloy. In order to ensure the mechanical precision and surface quality, the planet carrier is made of aluminum alloy die-casting.

Table 2 shows the materials of a three-stage planetary reducer, and you can see the diversity of gear selection materials in the three-stage transmission. The primary and secondary transmissions are at the higher speed end and the torque is small, and the planetary gears can be made of different engineering plastic materials. The three-stage transmission has large torque and large load, and is manufactured by powder metallurgy. The material selection of sun gear 1 is different. The primary sun gear is made of steel connecting gear, the secondary sun gear is made of aluminum alloy, and the third-stage transmission sun gear is made of powder metallurgy\(^4\).

| serial number | Components | Primary drive | Secondary drive | three-stage transmission |
|---------------|------------|---------------|-----------------|------------------------|
| 1             | sun gear 1 | 45° steel     | Aluminum alloy  | powder metallurgy       |
|               | Planetary 2| thermoplastic elastomer | POM           | powder metallurgy       |
| 3             | Internal gear 3 | Nylon PA66    | Nylon PA66     | Nylon PA66             |
| 4             | Planet carrier H | Aluminum alloy | Aluminum alloy  | Aluminum alloy         |

\(3.2\) Transmission ratio distribution of micro reducer

The transmission efficiency of the miniature planetary gear is related to the transmission ratio. The transmission efficiency value changes with the transmission ratio. Generally, the larger the transmission ratio, the lower the mechanical efficiency. In practical applications, especially in robots and intelligent equipment, planetary reducers are required to be small in size and large in transmission ratio range. Multi-stage planetary reducers are usually used. For the calculation of the transmission ratio of the multi-stage planetary reducer, the transmission ratio of each stage can be calculated separately, and the total transmission ratio can be multiplied by the transmission ratio of each stage. The transmission ratio range of the miniature reducer is large. The mechanical efficiency of the micro reducer decreases with the increase of the transmission ratio. The more stages of the reducer, the larger the transmission ratio, the more power loss, and the lower the mechanical efficiency\(^5\).

The transmission ratio of the multi-stage reducer is the continuous product of the transmission ratio of each stage of the reducer. Therefore, the distribution of the speed ratio of each stage of the reducer is very important to the reducer and is the main content of the overall design. Usually, a larger transmission ratio is selected for the first-stage transmission of the high-speed stage, because the torque of the first stage is the smallest, and the subsequent transmission ratios can be reasonably allocated according to
the specific situation. As shown in Fig. 1, the total transmission ratio of a three-stage micro reducer is
\[ i_T = 72 \]
and the transmission ratio distribution of the three-stage transmission is:
\[ i_T = i_1 \times i_2 \times i_3 = 6 \times 3 \times 4 = 72. \]

### 3.3 Structural design of micro reducer

Reducer takes the micro reducer shown in Fig. 2 as an example. The inner gear ring outside the micro reducer is the center wheel of the transmission, which is shared by the multi-stage transmission. The planetary gears are symmetrically arranged with three (or four) identical gears, which can share the load. The planet carrier is integrated with the central wheel of the next-stage transmission to simplify the structure and facilitate installation and assembly. The inner ring gear of the center wheel adopts a shared structure. In order to share the load, each stage of the planetary transmission of the micro reducer is composed of a plurality of evenly distributed planetary gears symmetrically arranged.

![Fig.2 Three-dimensional diagram of the overall structure design of the planetary reducer](image)

In order to improve the bearing capacity, the planetary gear of the reducer is usually arranged symmetrically with several planetary gears, and the load is shared by several planetary gears. Usually, 2 to 4 planetary gears can be used according to the size of the load, and usually 3 or 4 evenly distributed in the micro reducer. As shown in Fig. 3, the planetary reducer adopts the structure design of 3 \( \times \) 120 ° uniform distribution, and 4 \( \times \) 90 ° structure design.

![Fig.3 The structure of planetary gears and the planet carrier](image)

### 4. Conclusion

The structural design of the micro reducer has many factors affecting the mechanical efficiency of the reducer. In the design of the reducer, we improve the mechanical efficiency of the reducer through three methods. (1) Micro reducer parts use various materials. With the development of material science, new materials continue to emerge. Choosing new engineering plastics as the material for internal gears and planetary gears can improve the mechanical efficiency of the micro reducer and reduce noise and vibration. (2) In the overall structural design, the mechanical efficiency can be improved by selecting the appropriate transmission ratio distribution and selecting a larger transmission ratio for the high-speed stage. (3) In the selection and arrangement of the number of planetary gears, select an appropriate method to improve the bearing capacity of the reducer, while taking into account the mechanical improvement. In addition, factors such as the accuracy level of the gear, the positioning of the sun gear and the shaft in a fixed manner, and the installation and cooperation of the planetary gear and the planet carrier will also affect the mechanical efficiency of the micro reducer.

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