Split Comb Teeth Seal of High Speed Shaft of Wind Power Gearbox

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Abstract. This paper analyzed the reasons for the oil leakage of the high-speed shaft of the wind power gearbox, regarding the common radial labyrinth seal and axial labyrinth seal oil leakage problems, the corresponding structural optimization was carried out. Furthermore, a new split-type comb-tooth seal device suitable for the high-speed shaft of the wind power gearbox was proposed, and a fluid analysis of the seal gap was performed. Finally, this optimization was applied to practice, the results showed a significant performance improvement, thus, the sealing effectiveness of the device after optimization was verified.

Keywords: Wind Power, Gear Box, Oil Leakage, Labyrinth Seal, Comb Tooth Seal

1. Introduction

Except for the lubrication of smaller power gearboxes (such as 200kW and 250kW wind power speed-increasing gearboxes) using splash lubrication, gearboxes with a power greater than 300kW require forced lubrication. Therefore, a high-power wind power gearbox requires an external lubrication system [1]. Forced lubrication is a type of circulating lubrication. The working characteristics of the oil circulation require that there is enough free space in the gear box. Therefore, the depth of the lubricating oil in the gear box is not too high, and its highest position is usually below the plane of the main shaft.

Seals made of fluororubber can adapt to the working conditions of long-term immersion in lubricating oil and severe friction. The disadvantage of this contact seal is that the service life of various rubber seals in different environments is also very different. And its life expectancy is more difficult, especially in places with high altitude, sand, dust and extreme temperature changes, its working life is short, and it will usually be aged and damaged in two or three years. In addition, the reliability of the contact seal has a great relationship with the assembly process. At present, this type of sealing is rarely used in wind turbine gearboxes. Labyrinth seals are used by more and more wind power projects[2], which is a typical non-contact seal.

However, despite the improvement in the life of the sealing components, the labyrinth seals used in the high-speed shafts of the existing gearboxes have good sealing performance when the machine is
running, and lubricant leakage often occurs during shutdown. The newly developed split comb-tooth seal of this paper overcomes this shortcoming. It can take into account that the equipment runs and shuts down without leakage, and can achieve long-term continuous sealing.

2. Structural Improvement of Sealing Parts

2.1. Labyrinth Seal of General Wind Power Gearbox
In some types of machinery, the gap between the shaft and the cavity is neither filled with liquid nor subjected to pressure from any direction, but it is exposed to random liquid splashes or directional liquid drops. For such cases, due to bearing life considerations, it is necessary to restrict liquid from entering the sealing system adjacent to the bearing [3]. This actual demand has led to a large number of intuitive design forms similar to labyrinth seals-splash-proof non-contact shaft seals, which are also often referred to as labyrinth seals. However, there are few structural forms that can fully meet the requirements of this sealing type, and more only play a mitigating role [4].

For the consideration of processing technology and production cost, the existing wind power gear box labyrinth seals also often use splash-proof non-contact shaft seals.

![Labyrinth seal with oil slinger](image)

**Figure 1.** Labyrinth seal with oil slinger

Taking into account factors such as thermal deformation and radial runout of the high-speed shaft, this structure will deliberately increase the gap between the oil slinger and the end cover in practical applications, rather than make it labyrinth like the labyrinth seal used for gas sealing, whose size of the channel is very narrow, and its purpose is to leave room for the above-mentioned deformation. Splashed lubricating oil often breaks through multiple seal defense lines through loose cogging and gathers in the labyrinth channel. When the rotation speed of the rotating shaft is too low or is stopped, the lubricating oil liquid that has lost enough centrifugal force will quickly accumulate at the lower end of the labyrinth channel, and some of the liquid will not be able to return to the gear box. After flowing through the small and tight gap, the lubricating oil liquid will eventually lead to leakage [5].

2.2. Design of Split Comb Seal
The split comb-tooth seal studied in this paper is a sealing device used in a high-speed shaft of a 1.5MW wind turbine gearbox. The working parameters of the entire system are shown in Table 1.

| Input speed /rpm | Speed ratio | Output speed /rpm | Shaft diameter /mm | Line speed /(m/s) |
|------------------|-------------|-------------------|--------------------|-------------------|
| 17.3             | 100.48      | 1700              | 130                | 11.83             |
| Lubrication method | Oil pressure /bar | seal medium | Original seal |
|-------------------|------------------|-------------|--------------|
| Spray             | 1~3              | Thin oil    | labyrinth    |

Although contact seals, such as skeleton oil seals, can be considered because the line speed of the equipment is not high[6], but spray lubrication determines the lubricating oil level at the lower end of the rotating shaft and does not immerse the rotating shaft, so the sealing object is splashed liquid. In order to achieve a splash-proof gap seal, the entire sealing system must have the following working functions: shield the approaching liquid into the gap; collect the liquid that has bypassed the shield layer; and drain the collected liquid back.

On the basis of the three-point function described above, the service life of the seal, the convenience of installation, the sealing during operation and shutdown must be considered. This paper proposed a non-contact split comb-tooth seal system, which integrates the functions of oil rejection, liquid accumulation and drainage. The specific structure is composed of a static ring, a moving ring, a locking ring, and a connecting bolt. The sealing component All the parts and their positional relationship are shown in Figure 2.

**Figure 2.** The parts of the split comb tooth seal and their positional relationship

It can be seen from the figure that this split comb seal has three sealing barriers. When the lubricating oil enters the first barrier, it will be quickly collected by centrifugal action, and the rotating ring will throw the adhering liquid to static ring surface, then drain back to the sealed gearbox internal space through the drainage channel. This paper believes that it has the following advantages:

First of all, this design integrates the sealing system of oil rejection, liquid accumulation and drainage, and the sealing performance has nothing to do with the speed;

Secondly, it adopts a non-contact design, without touching and rubbing the rotating shaft, without the energy loss caused by friction, and can adapt to the high speed;

Third, the split design is adopted, and there is no need to disassemble the equipment during installation.

It can be used for maintenance and replacement at any time, and can also be used for initial installation of equipment.

In addition, the material selection of the device can be diversified. For example, in mass production, engineering plastics can be used for injection molding to achieve lightweight products and improve its economy. For special non-standard customized specifications, aluminum alloy machining can be used to shorten the development cycle.
3. Numerical Simulation of Split Comb Seal

Using the cfx module in ANSYS software, this new type of seal was numerically calculated. First, according to the three-dimensional model of the seal shown in Figure 3, the flow field of the comb-tooth sealed labyrinth space should be extracted. The result is shown in Figure 4. The flow field consists of the seal cavity, the labyrinth of the seal-tooth and the atmosphere. The seal comb The tooth is in the middle of the sealed cavity and the atmosphere, and the volume of the atmospheric region and the sealed cavity is much larger than that of the comb tooth labyrinth.

![Figure 3. 3D model of the sealing part](image)

![Figure 4. The flow field domain of the sealed labyrinth space](image)

Furthermore, the three-dimensional model of this flow field was imported into meshing software for meshing, and finally the boundary conditions were set in cfx for calculation. The grid of the analyzed seal area is shown in Figure 5, and the boundary condition parameter settings are shown in Table 2. It is worth noting that in order to obtain a more realistic flow field analysis result, the κ-ε double equation turbulence model with a low Reynolds number is used for calculation[7], and the temperature of the sealed cavity is set to 341k.

![Figure 5. Mesh elements of the flow field of the comb seal](image)
Table 2. Boundary condition parameters

| Atmospheric end surface | Seal cavity end surface | Atmospheric outer boundary | Sealed cavity outer boundary | Inner boundary of the maze |
|-------------------------|-------------------------|----------------------------|------------------------------|----------------------------|
| outlet                   | inlet                   | wall                       | wall                         |                            |
| Labyrinth               | Labyrinth               | Atmospheric end surface    | Sealed cavity boundary       | Sealed cavity inner boundary |
| high-pressure boundary  | low-pressure boundary   |                            |                              |                            |
| interface               | interface               | Interface                  | interface                    | wall                       |

Under the condition that the pressure of the sealing cavity is $5 \times 10^5$ Pa, the sealing effect is shown in Figure 6, so that the flow field in the atmosphere is not affected by the high pressure of the sealed cavity, which shows that the sealing effect is excellent.

The pressure change cloud diagram in the labyrinth of the comb teeth is shown in Figure 7. On the outside of the comb teeth, the pressure extension decreases uniformly from the interface of the seal cavity to the atmospheric interface. However, when measured inside the comb teeth, the opposite situation occurs: the pressure The direction from the seal cavity interface to the atmospheric interface increases uniformly, but the highest pressure on the inside is only about $3 \times 10^5$ Pa.

![Figure 6](image1)

**Figure 6.** Sealing effect under the condition that the pressure of the sealed cavity is $5 \times 10^5$ Pa

![Figure 7](image2)

**Figure 7.** The pressure change cloud diagram in the labyrinth of the comb teeth

Figure 8 shows the radial pressure change inside the comb-tooth labyrinth. The change is concentrically distributed, with slight doping and turbidity. This phenomenon is caused by the
medium-speed rotation of the moving ring of the comb seal, indicating that the reliability of the sealing device in the radial pressure distribution.

Figure 9 is the distribution of pressure gradient in the flow field domain. In the sealed cavity and the atmospheric domain, the pressure gradient is distributed in a typical Fano curve, with no obvious changes. However, inside the comb-tooth labyrinth, the pressure gradient changes drastically, from the highest value to the lowest value, which has no obvious effect on the atmosphere. It can be seen that the reliability of this sealing device.

![Figure 8. The radial pressure change inside the comb-tooth labyrinth](image1)

![Figure 9. The distribution of pressure gradient in the flow field domain](image2)

4. Application Test of Split Comb Seal
The high-speed shaft end of the gearbox of multiple wind power factory located in northwestern China had serious oil leakage. The original seal of wind turbine shaft was a traditional labyrinth seal. The sealing situation before the improvement is shown in Figure 10. According to the method proposed by this paper, maintenance personnel borrowed the bolt holes on the end surface of the equipment, added a transition flange, and assembled a split comb seal, which successfully solved the oil leakage problem. The on-site picture after installation is shown in Figure 11 below.
Figure 10. The original seal lubricant leakage of the equipment

Figure 11. Sealing situation after applying split comb tooth seal

5. Summary
Aiming at the situation that the traditional labyrinth seal is used in the high-speed shaft of the fan gear box and the leakage often occurs during shutdown, a split comb-tooth seal system was developed. Through the analysis of ANSYS software and the practical application of a wind field, the superiority of this structure to the labyrinth seal used in traditional wind power gearboxes is verified. This new design provides a new solution for the sealing of the high-speed shaft of the fan gear box. It is foreseeable that the split S-type multi-comb tooth seal will become a new generation of sealing technology after the traditional maze sealing.

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