Experimental research on Ferrofluid Combined rotary Sealing of High Power Motor

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Abstract. It was designed a ferrofluid combined rotary sealing structure for a high power motor in this paper. In addition, it was calculated the magnetic field distribution of the structure by Ansys at different gaps, the result showed that the magnetic field distribution trend was generally the same. In the sealing experiment, it was concluded that when the maximum gap was 0.6mm, the single-stage sealing pressure capacity reached at 36.7KPa, and the sealing capacity remained stable with speed increasing. The experiments showed that the design was suitable for sealing high-power motors in corrosive environments.

1. Introduction
Ferrofluid sealing is a new type of non-contact sealing [1]. Magnetic grease is a special Ferrofluid. Its base carrier fluid is high-viscosity non-Newtonian sealing grease. The advantage of magnetic grease sealing is that it has higher pressure resistance and better compatibility with liquid media, but in dynamic sealing, the power loss is higher[2], so the sealing life is affected more than other magnetic fluid[3].

This paper intends to solve the sealing problem of Freon (F113), which is the cooling medium for high-power motors. Due to the large sealing shaft diameter of the high-power motor (rated power is MW class) and the large lateral and axial vibration in some working environments, the sealing is required to be able to adapt the vibration, the sealing gap is reaching at 0.6~0.7mm. At the same time, factors such as humidity, mold, salt spray, and corrosive media must also be considered.

2. The design of sealing structure
It was showed the magnetic liquid combined rotary sealing and the partial structure and in Fig 1. The sealing device included a sealing cavity, permanent magnets, pole shoes, pole teeth, etc.
Fig.1. The magnetic fluid combined sealing structure and Partial image.
1. Fastening bolt 2. Pole shoe 3. Permanent magnet 4. Pole teeth
5. Rotating shaft 6. Outer casing 7. Bearing

Fig.2. The sealing device and the photo of the experimental bench

The sealing device used 5 permanent magnets, each permanent magnet had corresponding pole shoes pairs and eight pole tooth, which formed some multiple magnetic circuits. The tooth shape was rectangle, and the number of tooth was 12. The size of teeth was all the same, forming 5 Slot 6 poles 12 teeth sealing structure. The tooth-shaped structure used one pole shoe-four rectangular pole teeth to form the multiple magnetic circuits. The rectangular tooth were easy to make, it had guarantee performance, it also had a larger magnetic field gradient, so it can effectively reduce the magnetic resistance, which was expected to greatly improve the enable sealing voltage.

Before working, it was injected approximately 10ml of magnetic liquid into the inner ring of each permanent magnet, and injected 2mg of magnetic grease into the pole ring which was contacted the F113. The sealed cavity shell was made of non-magnetic material 304 stainless steel; the permanent magnet was made of neodymium iron boron material which had large magnetic energy product and high magnetic field strength; the magnetic pole material was made of electrical pure iron; the shaft material was 1Cr13, we can obtain different sealing gaps by machining the central shaft. The magnetic pole and the non-magnetic shell were sealed with an "O"-shaped sealing ring.

3. Finite element analysis

3.1. Description of finite element analysis
The ANSYS was used to analyze the magnetic field distribution characteristics, we got the magnetic induction intensity, the magnetic field line equivalent distribution of the magnetic circuit and the magnetic field intensity vector distribution\cite{4}. The ferrofluid sealing device was a three-dimensional solid model. Since the entire device was axisymmetric, the magnetic circuit was simplified into a cross-sectional plane figure that crosses the central axis. The physical environment of the sealing structure mainly included the determination of various units and options, such as the input of the performance data of non-magnetic materials, permanent magnet materials, magnetic poles, magnetic liquids, rotating shafts, and air\cite{5}.
After the analysis model is established, the physical environment of the sealed structure is determined. The physical environment of the sealed structure mainly includes the determination of various units and options, such as the input of performance data of non-magnetic materials such as permanent magnet materials, magnetic poles, magnetic liquids, rotating shafts, and air. First, set the reference frame to Magnetic-Nodal and use PLANE53 plane element. The material performance data can be input through the material model dialog box or directly from the defined material performance database. The permanent magnet selected in this article is the BH curve of Nd-Fe-B.

![Fig.3 The two-dimensional model of the large gap magnetic fluid sealing](image)

![Fig.4 The magnetic field distribution](image)

3.2. Result analysis

It is seen from the results shown in Fig.5 To define the axial trajectory in the ANSYS post processor. The change of the axial magnetic field intensity directly affected the sealing ability. The value of the magnetic field strength $H_{max}$ was mapped on this trajectory. In order to see the change of the magnetic field at the pole teeth more clearly, when defining the axial trajectory, we defined a point at the end of each pole tooth, point interpolation number 20 into the two adjacent, the trajectory length was $s$, as shown in the Fig.5. It can be seen from the Fig.5 that the magnetic field intensity of two poles outside
was significantly smaller than that was in inside, so the main seal effect was the magnetic field intensity generated under the middle four pole shoes. When the gap increased, the magnetic field intensity value of the rectangular tooth under each pole shoe tended to be smooth.

![Graph showing magnetic field distribution](image)

**Fig.5 The axial magnetic field distribution of different large gap**

### 4. Experimental verification

In the experiment, we used ester-based magnetic liquid, and we added to the inner ring of each permanent magnet a total 3ml magnetic liquid. Different sealing gaps were obtained by machining the center shaft. Since the high power motor’s shaft rotated at 3000 rpm in actual normal operation, we recorded the pressure value when the magnetic liquid was filled. The sealing test is shown in Fig. 6.

![Image of magnetic fluid rotation sealing structure](image)

**Fig.6 Magnetic fluid rotation sealing structure (one side)**

After each breaking, kept the motor running and recorded the passing pressure capacity and repairing time after self-repairing.

| Sealing gap/mm | 0.4 | 0.5 | 0.6 | 0.7 |
|----------------|-----|-----|-----|-----|
| Maximum pressure/MPa | 0.34 | 0.24 | 0.22 | 0.18 |
| Self-healing pressure/MPa | 0.18 | 0.11 | 0.15 | 0.08 |
| Theoretical pressure/MPa | 0.55 | 0.47 | 0.41 | 0.33 |
| Self-repair time/s | 5 | 4 | 5 | 6 |

According to the data in Table.1, for a typical sealing gap of 0.15mm, the pressure of a single-stage sealing capability can reach about 22KPa. The author designed a rotary sealing structure for high-power motors in military equipment. When the maximum gap was 0.6mm, the single-stage sealing pressure capacity reached at 36.7KPa.
5. Conclusion
According the experiment, we can get the following results:

(1) It was designed a ferrofluid combined rotary sealing structure for a high power motor in this paper, the sealing structure was suitable for practical application.

(2) For a typical sealing gap of 0.15mm, the pressure of a single-stage sealing capability can reach about 22KPa. The sealing structure designed by author for high-power motors in military equipment, when the maximum gap was 0.6mm, the single-stage sealing pressure capacity reached at 36.7KPa.

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