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Experimental Research on Self-repairing of Diverging Stepped Magnetic Fluid Seals with Single Magnetic Source

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To improve the self-repairing capability of common magnetic fluid seal structures after rupture due to excessive differential pressure in small clearance conditions and to verify the superiority of diverging stepped magnetic fluid seals, a diverging stepped magnetic fluid seal device with single magnetic source was tested. The effect of injection volume, clearance and numbers of teeth on the self-repairing performance of a diverging stepped magnetic fluid seals was investigated experimentally and compared with a common magnetic fluid seal. The experimental results indicate that the self-repairing performance of one stepped magnetic fluid seal device is better. The repair rate of a diverging stepped magnetic fluid seal structure decreases first and then increases with the increase of injection volume, and a minimum value is reached near the saturation value. The smaller the sealing gap and the fewer the number of bore teeth, the higher the repair rate of this structure.

Keywords : self-repairing, magnetic fluid, seal, diverging, single magnetic source

1. Introduction

Magnetic fluid seal is one kind of technology that uses the response characteristic of magnetic fluid to the external magnetic field to produce the sealing ring, so that to resist the differential pressure between the two sides of the sealing structure. The seal has the advantages of zero leakage, long life and low friction [1-5]. When it ruptures under a too large pressure difference magnitude, magnetic fluid will automatically recover and reseal after the differential pressure drops to a certain degree, which is known as the self-repairing function of a magnetic fluid [6, 7]. Szczech [8, 9] has investigated the effects of the performance of magnetic fluid on the error between the theoretical pressure tolerance of the magnetic fluid seal and experimental results using numerical and experimental methods. It is concluded that the influence of manufacturing error can be reduced with the increase of the volume and the saturation magnetization of the magnetic fluid in the sealing phase, thus the difference between simulation and experimental results will be reduced accordingly. Based on the research results, the theoretical pressure resistance formula of magnetic fluid seal was also modified to trim down the error of theoretical pressure resistance and experimental results. Using the finite element method and statistical analysis, Parmar *et al.* studied the design parameters affecting the magnetic fluid rotary seal. It demonstrates that the particle volume fraction does not contribute much to the field in the radial clearance, but has significant effect on pressure differential capacity. Liu *et al.* investigated the effect of key factors such as compression rate, times of rupture, sealing magnetic field gradient, sealing tooth rank and magnetic pole rank on the loading capacity of the magnetic fluid seal after self-repair. The results unfold that the loss can be compensated well with the application of the multi-magnetic and minimally toothed seal structure, and the self-repairing capability of the magnetic fluid seal can be improved. G.Hong analyzed the repair process of the magnetic fluid after rupturing and explored the influence of the factors leading to the rupture on the degree of self-repair. It is shown in the results that the self-repairing capability can be greatly improved by increasing the supply after magnetic fluid loss. Multipole-multistage sealing structure should be adopted to have a better self-repairing effect and ensure enough repair time. Whereas, because the repair performance of common magnetic fluid seal decreases with the increase of the rupture number, which does not exert too much positive effect in actual operation, the self-repairing rate of magnetic fluid

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seal has not been studied for a long time, while the research on stepped magnetic fluid seals with large clearance has been carried out. In 2014, Yang and Li *et al.* began to conduct numerical analysis and experimental research on the stepped magnetic fluid seal with large clearance. They compared and analyzed the pressure-resistant performance of the common magnetic fluid seal, of which the results display that the stepped magnetic fluid seal is an effective method to enhance the performance of the magnetic fluid seal when there is a large clearance. Xiaolong Yang *et al.* - proved that the anti-pressure capability of the diverging and polymerizing stepped magnetic fluid seal decreases with the increase of radial clearance width using sealing theory and experiment. Different from common magnetic fluid seals, it can change the leakage path and make it is possible to improve the self-repairing performance of the magnetic fluid seals.

In order to study the influence of loading capacity of the diverging stepped magnetic fluid seal structure after self-repair, the effects of key factors such as injection volume, radial clearance, axial clearance, axial teeth number and radial teeth number on the self-repairing capability of diverging stepped magnetic fluid seals have been investigated. The results can provide valuable experimental guidance to the design of highly reliable diverging stepped magnetic fluid seal structures with small clearance.

2. Design of Diverging Stepped Magnetic Fluid Seal with Single Magnetic Source

A diverging stepped magnetic fluid seal with single magnetic source structure is shown in Fig. 1. By definition, diverging stepped magnetic fluid seal refers to the sealing structure in which the sealed medium leaks along the direction of increasing axial diameter when the seal fails. The magnetic circuit mainly consists of permanent magnet, pole shoe, magnetic fluid and rotating shaft. The magnetic fluid is bound to the clearance formed with the

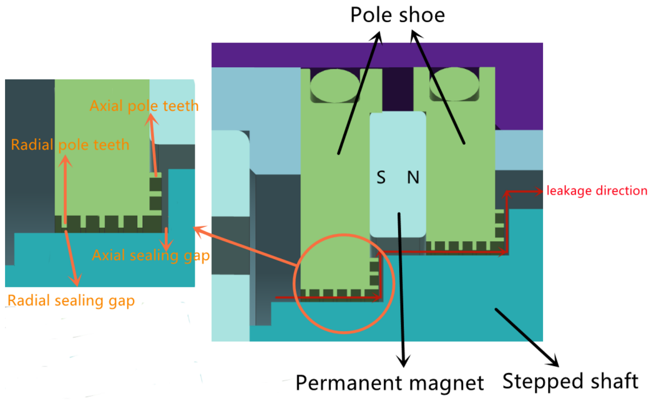

Fig. 1. (Color online) Two-dimensional graph of diverging stepped magnetic fluid seal with single magnetic source.

step axis and the pole shoe by the magnetic field generated from the permanent magnet, the magnetic source of the whole magnetic circuit. To achieve the purpose of blocking the leakage path, the fluid resists differential pressure on two sides of the seal by the magnetic field force. The sealing clearance is divided into radial sealing clearance and axial sealing clearance, where the radial sealing clearance is formed by the space between the round surface of the pole shoe and the round surface of the step shaft; while the axial sealing clearance is formed by the space between the end face of pole shoe and the end face of step shaft shoulder. Pole teeth includes axial pole teeth and radial pole teeth, in which axial pole teeth are in the axial sealing clearance, while radial pole teeth are in the radial sealing clearance. The basic parameters of the diverging stepped magnetic fluid seal with single magnetic source structure and the common magnetic fluid seal structure with single magnetic source are shown in Table 1 and Table 2, respectively. The permanent magnet is installed between the two pole shoes. The coercion and permeability of the permanent magnet are 1.356×10^6 A/m and 1.05 respectively. The pole shoe and step shaft are made of 45# steel, and the BH curve is shown in Fig. 2. The sealing medium is oil-based magnetic fluid, and its saturation magnetization curve is demonstrated in Fig. 3.

Table 1. Parameters of diverging stepped magnetic fluid seal with small clearance structure.

Parameters	Value	Parameters	Value
Inside radius of the first pole shoe /mm	13	Radial clearance height /mm	0.1-0.4
Outside radius of the first pole shoe /mm	30	Axial clearance width /mm	0.1-0.4
Axial length of the first pole shoe /mm	5.3	Pole tooth width /mm	0.3
Inside radius of the second pole shoe /mm	17	Groove depth /mm	0.8
Outside radius of the second pole shoe /mm	30	Tooth width /mm	0.7
Axial length of the second pole shoe /mm	5.3	Number of radial teeth	1-5
Number of axial teeth	1-3		

Table 2. Parameters of common magnetic fluid seal with small clearance structure.

Parameters	Value	Parameters	Value
Inside radius of the first pole shoe /mm	13	Axial length of the second pole shoe /mm	5.3
Outside radius of the first pole shoe /mm /mm	30	Radial clearance height /mm	0.1-0.4
Axial length of the first pole shoe /mm	5.3	Pole tooth width /mm	0.3
Inside radius of the second pole shoe /mm	17	Space depth /mm	0.8
Outside radius of the second pole shoe /mm	30	Space width /mm	0.7

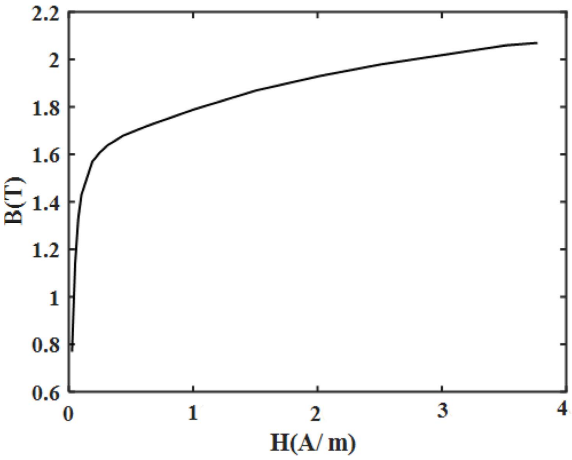

Fig. 2. Magnetization curve of 45 steel.

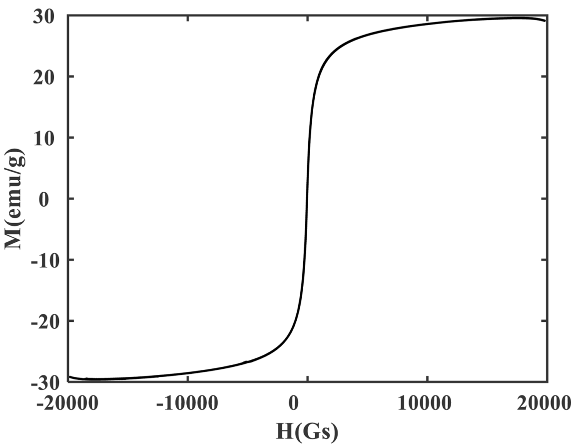

Fig. 3. Magnetization curve of oil based magnetic fluid.

In accordance with Fig. 2, the saturation magnetization of the magnetic fluid is calculated as 29.5 KA/m.

Generally, Bernoulli's equation for magnetic fluid can be expressed as following

$$p+\frac{1}{2}\rho_f gh-u_0\int_0^H MdH=C \tag{1}$$

Where p is the pressure of the magnetic fluid at certain position; ρ^f is the density of the magnetic fluid; V is the velocity of the magnetic fluid at a certain point; g is the acceleration of gravity; h is the height of the magnetic fluid at a certain point; u_0 is the vacuum permeability; M is the magnetization of the magnetic fluid; H is the strength of the external magnetic field strength; C is a constant. In terms of magnetic static fluid seals, the influence of velocity and gravity on the magnetic fluid seal can be ignored. Therefore, the sealing performance of the magnetic fluid seal can be simplified as follows:

$$DP=P_1-P_2=u_0\int_{H_2}^{H_1} MdH=u_0M_s\Sigma_{i-1}^{N}(H^i_{\max}-H^i_{\min})$$
$$=M_s\Sigma_{i-1}^{N}(B^i_{\max}-B^i_{\min}) \tag{2}$$

Where M_s is the saturation magnetization of magnetic fluid; $H^i_{\max}$ and $H^i_{\min}$ are the maximum and minimum values of magnetic field strength of the working clearance under grade i pole teeth in the sealing structure, respectively; $B^i_{\max}$ and $B^i_{\min}$ are respectively the maximum and minimum magnetic flux density of the working clearance under grade i pole teeth in the sealing structure; N is the total sealing series.

The anti-pressure formula of diverging stepped magnetic fluid seal is :

$$\Delta P=\sum_i^N (P_{jr}+\lambda P_{ja}) \tag{3}$$

Where P_{jr} and P_{ja} are the critical seal pressure of magnetic fluid in the radial seal clearance and axial seal clearance formed by the jth pole boot and the step shaft, respectively. If P_{jr} is less than P_{ja}, it is 1; otherwise, 0. P_{jr} and P_{ja} can be calculated by equation (2).

3. Experiment Process and Method

The experimental setup is shown in Fig. 4, which includes nitrogen cylinders, sealing cavity, pressure gauge and valve. Gas was used as the sealing medium in the cavity sealed by magnetic fluid. Experimental process is as follows. The stepped magnetic fluid seal device was assembled and injected with the right amount of magnetic fluid. The sealing device was fixed on the end face of the cavity by the threaded connection. The sealing cavity was pressurized with the application of the nitrogen cylinders, and the gas flow in and out of the sealing cavity unit time

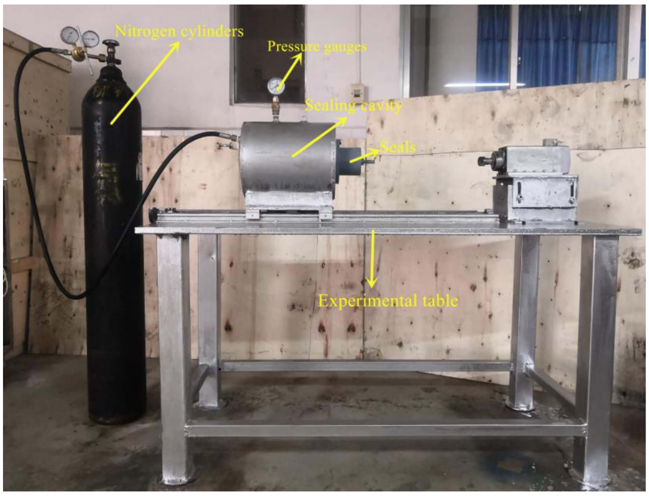

Fig. 4. (Color online) Diverging stepped magnetic fluid seal test bed.

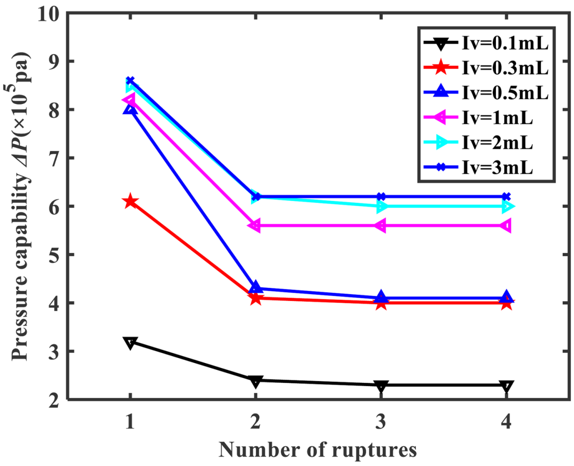

Fig. 5. (Color online) Effects of the number of ruptures on anti-pressure capability of diverging stepped magnetic fluid seal structure. Iv:Injection volume.

volume was adjusted by the valve, with the compression rate of 0.5 atm per 30 seconds, so that the pressure of the magnetic fluid seal device can be controlled. The pressure imposed into the magnetic fluid seal device was shown on a pressure gauge. To observe the gas leakage at the seal, soapy water was sprayed continuously on the left of the sealing device close to the atmosphere pressure. The reading of the pressure gauge was recorded when the magnetic fluid seal device failed, which is the critical value of sealing pressure resistance. Then the cavity was re-pressured to the critical pressure, the repair limit pressure, of which the process was repeated three times, symbolizing that the experiment was completed. The experiment should be repeated 2-3 times. After the experiment, the sealing structure was removed and cleaned carefully, and then reassembled as well as installed to obtain new parameters and used for the next set of experiments.

4. Results and Discussion

The main requirement for the self-repair of magnetic fluid seals after rupturing is that it must keep enough sealing bearing capacity. The degree of self-repair of magnetic fluid seals after rupturing is represented with the usage of the ratio of the maximum differential pressure that can be sustained after self-repair (repair limit differential pressure) to the maximum differential pressure that can be sustained before rupturing (limit differential pressure), which depends on the process of sealing failure and the self-repairing ability of the magnetic fluid.

4.1. Effect of the injection volume of magnetic fluid on the self-repairing performance of diverging stepped magnetic fluid seal

The self-repairing performance of diverging stepped magnetic fluid seal is related to the injection volume of magnetic fluid, which makes the research of the effect of the injection volume of magnetic fluid on the self-repairing performance of diverging stepped magnetic fluid seal have the ability to provide important experimental basis for the design of diverging stepped magnetic fluid seal.

When number of axial teeth and number of radial teeth are both 3, and the axial sealing clearance and radial sealing clearance are 0.2 mm and 0.1 mm respectively, the anti-pressure capability and self-repair ratio of diverging stepped magnetic fluid seal with single magnetic source under different injection volume of magnetic fluid are as shown in Fig. 5 and Fig. 6. The self-repair ratio is usually represented by the ratio of the increase in the repair ultimate pressure difference to the ultimate pressure difference. As the injection volume increases, the pressure increases. The larger the injection is, sealing pressure to a certain extent will appear leakage. When the seal is broken, if the pressure is stopped accordingly, the pressure in the sealing chamber will be slightly reduced, the leakage will be stopped, and the pressure gauge indicator in the sealing chamber will be quickly restored to the highest pressure, which is the limit differential pressure of the magnetic fluid seal.

What can be seen from Fig. 5 is that the critical pressure of the diverging stepped magnetic fluid seal decreases first and then maintains the stability with the increase of the number of ruptures of the magnetic fluid seal. This is because the leakage of magnetic fluid is

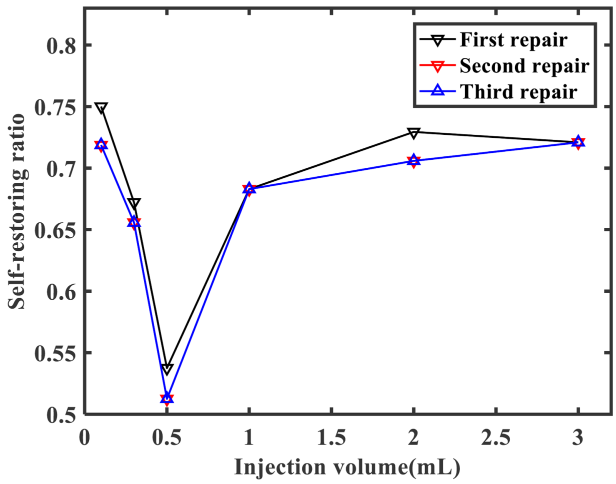

Fig. 6. (Color online) Effect of the injection volume of magnetic fluid on self-repair ratio of diverging stepped magnetic fluid seal structure.

prevented by the shaft shoulder when the critical pressure of diverging stepped magnetic fluid seal structure is reached and there is no outflow or ejection of magnetic fluid. When the pressure is removed, the pressure-resistant properties of the pole teeth close to the shaft shoulder will restore quickly. On the contrary, for the pole teeth far from the shaft shoulder, only partial pressure-resistant properties can restore themselves. Therefore, when the second pressure reaches the critical pressure, the anti-pressure capacity of diverging stepped magnetic fluid seal will decrease sharply. Due to the bewildering amount of magnetic fluids on the axial shoulder, when the pressure is removed for the second time, the effect of the magnetic force of pole teeth on the magnetic fluid will return to the state at the time when the first pressure is removed. Therefore, the anti-pressure capacity of the diverging stepped magnetic fluid seal remains unchanged or slightly decreases when the third pressure reaches the critical pressure. What is indicated as well in Fig. 5 is that the anti-pressure capability increases first and then remains stable with the increase of the magnetic fluid injection. Saturation is reached when the volume of the magnetic fluid is 0.5 mL. In order to reduce the influence of loss and strengthen the sealing function of magnetic fluid, 1 mL magnetic fluid was injected to verify the anti-pressure performance of different diverging stepped magnetic fluid seal structure in the experiment.

As can be seen from Fig. 6, the self-repair ratio of diverging stepped magnetic fluid seal decreases first and then increases with the increase of injected volume of magnetic fluid. It achieves the minimum when the injection volume is 0.5 mL, which is because when there is an increase in the injection volume of diverging stepped magnetic fluid seal, the increase of repair limit differential pressure is less than that of limit differential pressure. Thus, when the injection volume is less than 0.5 mL, the self-repair ratio of diverging stepped magnetic fluid seal will decrease with the injection of magnetic fluid. At the same time, the diverging stepped magnetic fluid seal reaches the saturation value at 0.5 mL of injection volume. When the injection volume is more than 0.5 mL, the repair limit differential pressure increases continuously, but the limit differential pressure remains unchanged and the self-repair ratio of diverging stepped magnetic fluid seal grows accordingly. Therefore, the self-repair ratio of diverging stepped magnetic fluid seal achieves a negative relationship with the injection of magnetic fluid first, and then a positive one.

4.2. Effect of seal clearance on self-repairing performance of diverging stepped magnetic fluid seal

The self-repairing performance of diverging stepped magnetic fluid seal is related to its sealing clearance. The research of the effect of radial sealing clearance and axial sealing clearance on self-repairing performance of diverging stepped magnetic fluid seal can provide important theoretical basis for the design of diverging stepped magnetic fluid seal with high self-repairing performance.

When number of axial teeth is 3 with radial teeth of 3 as well, and the axial sealing clearance is 0.2 mm, the self-repairing performance of diverging stepped magnetic fluid seal with different radial sealing clearance are shown in Fig. 7 and Fig. 8.

It is shown in Fig. 7 that the self-repairing ratio of diverging stepped magnetic fluid seal decreases when there is an increase in radial sealing clearance. Owing to the growth of radial sealing clearance which can cause the

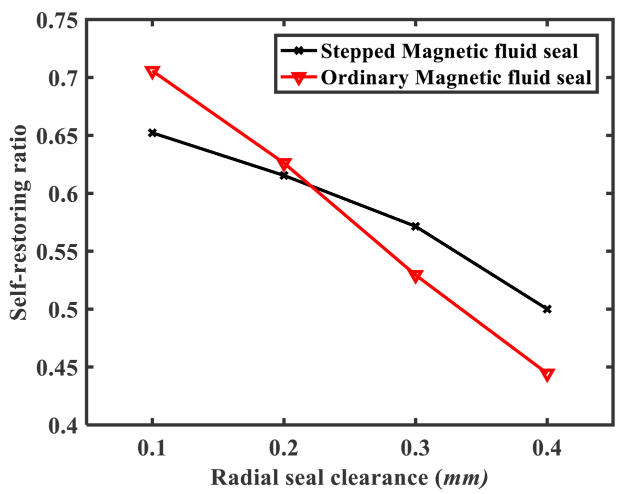

Fig. 7. (Color online) Effect of radial sealing clearance on self-repairing ratio.

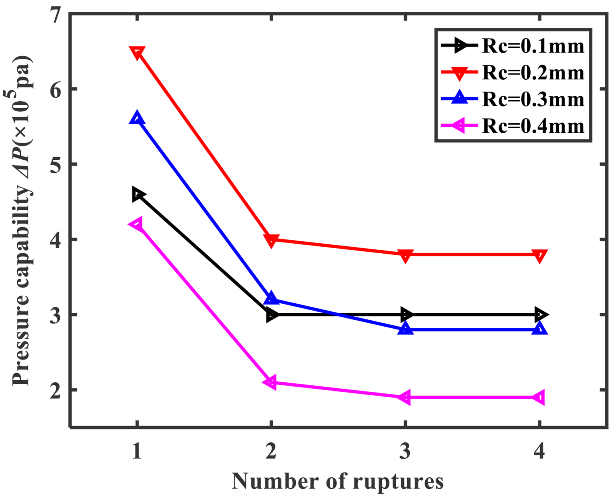

Fig. 8. (Color online) Effect of the number of ruptures on anti-pressure capability of diverging stepped magnetic fluid seal structure with different radial sealing clearance. Rc: Radial seal clearance.

increase in magnetic resistance of radial sealing clearance, the magnetic resistance of the whole magnetic circuit increases, and the magnetic flux of the magnetic circuit is reduced. Because the magnetic resistance of axial sealing clearance is constant, and in accordance with the magnetic circuit theory, the magnetic resistance of radial magnetic circuit increases much faster than the magnetic potential, so the radial magnetic flux density decreases with increasing clearance, and the force of radial pole teeth on the magnetic fluid decreases with the growth of clearance. Therefore, the self-repairing ratio of diverging stepped magnetic fluid seal decreases with the increase of radial clearance.

It is indicated in Fig. 8 that when number of axial teeth and number of radial teeth are both 3, and the axial sealing clearance is 0.2 mm, the decreasing speed of self-repairing ratio of diverging stepped magnetic fluid seal with the increase of radial sealing clearance is much smaller than that of common magnetic fluid seal structure. When the radial sealing clearance exceeds 0.2 mm, the self-repairing ratio of diverging stepped magnetic fluid seal will be better than that of common magnetic fluid seal, of which the reason is that the residual magnetic fluid in the tooth space and the groove of the permanent magnet is the main factor for the self-repairing capability of magnetic fluid seal after rupturing. As for the common magnetic fluid seal structure, the magnetic fluid is ejected directly, but the magnetic fluid in the diverging stepped seal structure is prevented by the shaft shoulder and does not overflowing. It participates in the repair even after removal. Therefore, the decreasing speed of self-repairing ratio of diverging stepped magnetic fluid seal with the increase of radial sealing clearance is much smaller than that of common magnetic fluid seal structure. When the axial sealing clearance is 0.2 mm, the radial sealing clearance is less than 0.2 mm and number of axial teeth and number of radial teeth are both 3. On the one hand, according to the stepped magnetic fluid seal pressure assistance theory (3), axial pole teeth of diverging magnetic fluid seal structure has no sealing effect; on the other hand, according to the magnetic circuit theory, the magnetic potential is unchanged, and some magnetic flux in diverging stepped magnetic fluid seal are distributed to pole teeth. Thus, the magnetic flux density in radial pole teeth of diverging stepped magnetic fluid seal is less than that of common magnetic fluid seal, and the self-repairing ratio will be lower as well. When the axial sealing clearance is 0.2 mm and the radial sealing clearance is larger than 0.2 mm, according to the magnetic fluid seal pressure assistance theory (3), the axial pole teeth of diverging stepped magnetic fluid seal plays a role in seals and the magnetic fluid obstructed at the shaft shoulder also serves as a repair. Hence the self-repairing ratio of the diverging stepped magnetic fluid seal structure is larger than that of the common type.

When the number of axial teeth is 3 with the number of radial teeth of the same, and the radial sealing clearance is 0.2 mm, the effect of different axial sealing clearance on self-repairing ratio of diverging stepped magnetic fluid seal is shown in Fig. 9.

It is indicated in Fig. 9 that the self-repairing ratio of diverging stepped magnetic fluid seal decreases when there is an increase in axial sealing clearance. As the growth of axial sealing clearance increases the magnetic resistance of axial sealing clearance, the magnetic re-

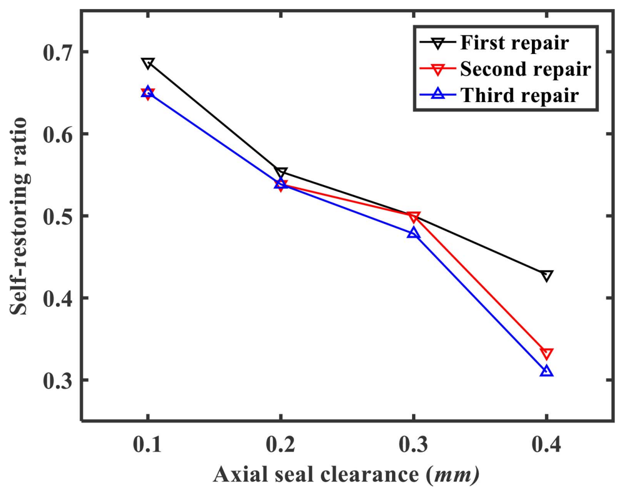

Fig. 9. (Color online) Effect of axial sealing clearance on self-repairing ratio.

sistance of the whole magnetic circuit increases, and the magnetic flux of the magnetic circuit is reduced. Because the magnetic resistance of radial sealing clearance is constant, and according to the magnetic circuit theory, the magnetic resistance of radial magnetic circuit will increase much faster than the magnetic potential, the radial magnetic flux density decreases with increasing clearance. Therefore, the self-repairing ratio of diverging stepped magnetic fluid seal achieves negative correlation with axial clearance. Fig. 9 also shows that the number of ruptures has little influence on self-repairing ratio of diverging stepped magnetic fluid seal, which verifies the superiority of divergent stepped magnetic fluid seal again.

4.3. Effect of the number of pole teeth on self-repairing performance of diverging stepped magnetic fluid seal

There is a relation between self-repairing performance of diverging stepped magnetic fluid seal and the number of pole teeth. Researching the effect of the number of pole teeth on self-repairing performance of diverging stepped magnetic fluid seal can provide essential theoretical basis for the design of diverging stepped magnetic fluid seal with high self-repairing performance.

When the axial sealing clearance and the radial sealing clearance are both 0.1 mm, and the number of axial teeth is 2, the effect of different number of radial teeth and ruptures on diverging stepped magnetic fluid seal and common magnetic fluid seal are demonstrated in Fig. 10 and Fig. 11.

It is shown in Fig. 10 that the self-repairing ratio of magnetic fluid seal decreases when the number of radial teeth increases, which is because the increase of the number of radial teeth can cause the decrease in magnetic resistance of radial teeth, so that the magnetic resistance of the whole magnetic circuit is also reduced, leading to the increase in magnetic flux of the magnetic circuit. According to the magnetic circuit theory, even when there is a decrease in the magnetic flux through axial pole tooth reluctance and an increase in the magnetic flux through radial pole tooth reluctance, the flux density allocated to each pole tooth will still be reduced on account of the increase of radial teeth. Number of Pole teeth have less effect on the magnetic fluid. Therefore, the self-repairing ratio of magnetic fluid seal decreases with the increase of the radial teeth number. Comparing with diverging stepped magnetic fluid seal, the common magnetic fluid has a higher self-repairing ratio. The reason is that when number of axial teeth is 2 and number of radial teeth is less than 2, according to the stepped magnetic fluid seal pressure assistance theory (3), axial pole teeth of stepped magnetic fluid seal structure has sealing effect, so the self-repairing ratio of stepped magnetic fluid seal is similar to that of the common type. When number of axial teeth is 2 and number of radial teeth is more than 1, according to the stepped magnetic fluid seal pressure assistance theory (3), radial pole teeth of diverging magnetic fluid seal structure expresses no sealing effect. According to the magnetic circuit theory, the magnetic potential is constant, and some magnetic flux in diverging stepped magnetic fluid seal are distributed to pole teeth by the shaft. Thus, the magnetic flux density in radial pole teeth of diverging stepped magnetic fluid seal is less than that of common magnetic fluid seal, and the self-repairing ratio of is lower as well.

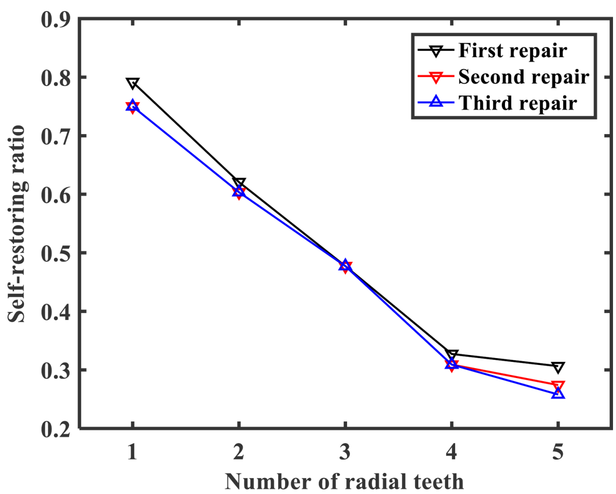

Fig. 10. (Color online) Effect of the number of radial pole teeth on self-repairing ratio.

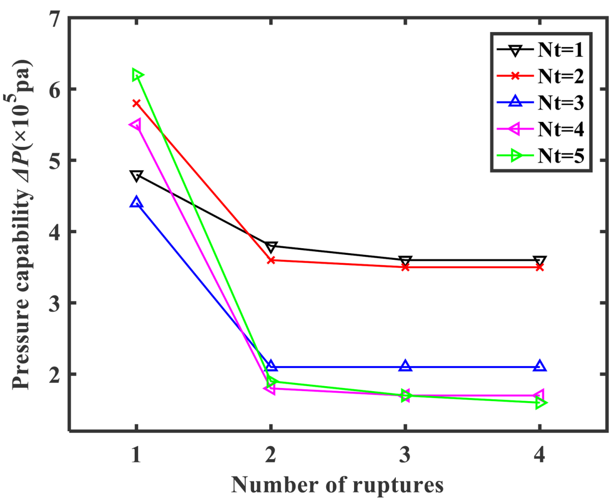

Fig. 11. (Color online) Effect of the number of ruptures on anti-pressure capability of diverging stepped magnetic fluid seal with different radial teeth number. Nt: Number of radial teeth.

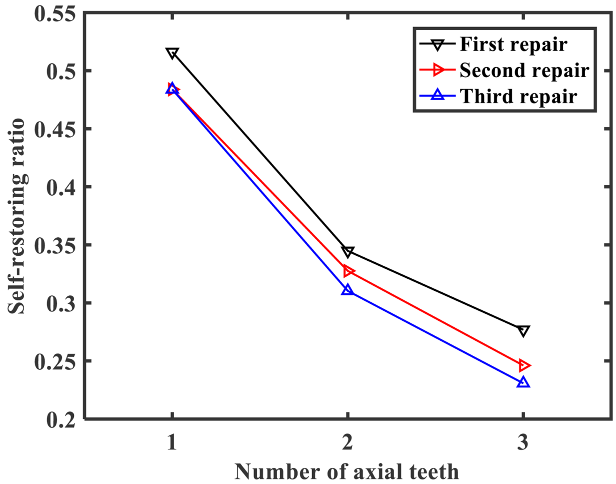

Fig. 12. (Color online) Effect of the number of axial pole teeth on self-repairing ratio.

Fig. 11 displays that the limit differential pressure of diverging stepped magnetic fluid seal increases first, then decreases and then increases with the increasing radial teeth number, while there is a decrease in the repair limit differential pressure when the number of radial teeth increase. Consequently, for diverging stepped magnetic fluid seal, choosing a structure with higher limit anti-pressure capacity is not the best way to improve the comprehensive capacity of the magnetic fluid.

When the axial sealing clearance and the radial sealing clearance are both 0.1 mm and the number of radial teeth is 2, the effect of different number of axial teeth and ruptures on the diverging stepped magnetic fluid seal and a common magnetic fluid seal is shown in Fig. 12.

What is shown in Fig. 12 is that the self-repairing ratio of diverging stepped magnetic fluid seal decreases when the number of axial teeth increases. This is because the increase of the number of axial teeth can cause the decrease in magnetic resistance of axial teeth, so that the magnetic resistance of the whole magnetic circuit is also reduced, resulting in the increase in magnetic flux of the magnetic circuit. Under the guidance of the magnetic circuit theory, even there is a decrease in the magnetic flux through radial pole tooth reluctance and an increase in the magnetic flux through axial pole tooth reluctance, the flux density allocated to each pole tooth is reduced because of the increase of axial teeth. The number of pole teeth has less effect on the magnetic fluid. Hence, the self-repairing ratio of magnetic fluid seal decreases with the increase of the axial teeth number.

Fig. 13 Fig. 14

when the diverging stepped magnetic fluid seal fails, the phenomenon of magnetic fluid flowing out or ejecting with the leakage of the sealed medium is not found, as shown in Fig. 13. According to what is shown in Fig. 14, when the ordinary magnetic fluid seal fails, a large amount of magnetic fluid will be ejected with the leakage of the sealed medium. This is because the diverging stepped magnetic fluid seal has a unique stepped structure compared with the ordinary magnetic fluid seal. In the sealed path, not only does the step structure change the leakage direction, but it also enhances the magnetic focusing effect, making it difficult for the magnetic fluid to eject. Nevertheless, the leakage path of ordinary magnetic fluid seal is single and the magnetic accumulation effect is poor.

Fig. 13. (Color online) Diverging stepped magnetic fluid seal failure.

Fig. 14. (Color online) Common magnetic fluid seal failure.

5. Conclusions

In this study, a diverging stepped magnetic fluid seal was constructed with single magnetic source, where the effects of injection volume, radial clearance, axial clearance, radial teeth number and axial teeth number on the self-repairing performance of the diverging stepped magnetic fluid seals and a common magnetic fluid seal were investigated experimentally. The conclusions are as follows.

1. The self-repairing ratio of diverging stepped magnetic fluid seal achieves negative correlation with teeth number and sealing clearance.

2. When the axial pole teeth of diverging stepped magnetic fluid seal has no sealing effect, magnetic separation of axial pole teeth performs as a substantial reason that diverging stepped magnetic fluid seal has lower self-repairing ratio than common magnetic fluid seal. When the axial pole teeth of diverging stepped magnetic fluid seal has sealing effect, because the radial magnetic fluid at shaft shoulder can be quickly involved in repairing when the pressure is removed, diverging stepped magnetic fluid seal has higher self-repairing ratio than that of common magnetic fluid seal.

3. The limit differential pressure of diverging stepped magnetic fluid seal increases first, decreases subsequently and then increases with the increasing radial teeth number. There is a decrease in the repair limit differential pressure when the number of radial teeth increase. Therefore, choosing a diverging stepped magnetic fluid seal structure with higher limit anti-pressure capacity is not the best way to improve the comprehensive capacity of the magnetic fluid.

4. When the diverging stepped magnetic fluid seal structure reaches the critical pressure, no outflow nor ejection of the magnetic fluid is presented, which is an expressive reason that diverging stepped magnetic fluid seal structure has a much higher self-repair capacity than the common magnetic fluid seal structure.

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