Failure Analysis of the Aircraft Accessories Graphite Seal Ring

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Abstract. After 1300 hours of operation, the aircraft accessories graphite seal ring parts were overhauled with the aircraft engine. Then the seal assemblies were reinstalled on the engine. The graphite seal ring fractured 1 hour of used. The failure cause of the graphite seal ring was analyzed by appearance inspection, structure relationship analysis of the seal parts, surface and fracture observation, physical performance testing and composition examination. The analysis results show that the physical performance of the failed graphite seal ring met the requirement, and no abnormality was observed in the structural composition. But in the long-term used process, there was mutual wear between the fixing groove of the graphite seal ring and the limiting bracket of the metal static ring seat. As a result, the operating space of graphite seal ring was increased. The overall coordination stability decreases after the secondary assembly. Therefore, when the engine starts, the fluctuating friction occurs between the graphite seal ring and the friction pair, and the lubrication condition was poor, resulting in the graphite ring carrying capacity was too large, and then led to the graphite ring fracture in a short time after maintenance. This leads to fracture of graphite ring in a short time after overhaul. In order to prevent the failure from happening again, this paper gives the corresponding improvement suggestions.

Keywords: graphite seal ring; fracture; rubbing; vibrated.

1. Introduction
The carbon Graphite material has many excellent properties, such as the wear resistant, unique self-lubricity, chemistry stability, high transmit heat and low friction coefficient etc. These excellent performances have to make its got the extensive application in mechanical seal, and the technical development along with the mechanical seal technique, it can not be the substitute act in the trade [1-3]. But the material and special structure of graphite seals often cause their wear and fracture, easy to cause the failure of mechanical seal. According to statistics, since 2010, there have been more than 50 oil leakage faults in a certain type of aircraft accessory casing caused by fracture of graphite sealing ring. For the leakage fault of graphite seal, there is no specific solution and elimination method at present. It
is mainly eliminated by replacing seals, which not only increases the trouble shooting cycle, but also consumes a lot of manpower, material and financial resources [5-7]. Therefore, it is of great significance to study the fracture rule and failure reason of graphite seal ring, and to put forward the corresponding improvement and prevention measures.

In this case, the graphite sealing ring of the aircraft accessory casing with fracture fault was overhauled along with the engine after being used for 1300 hours. Oil leakage was found one hour after the overhaul, and the graphite sealing ring was found to be fractured after the inspection after decomposition. The total life of the graphite seal ring is 2000 hours, of which it is overhauled with the engine every 500 hours or so. During the overhaul, the sealing components will not be replaced. The sealing surface of graphite ring and friction pair will be ground only according to the sealing test.

In this paper, the appearance inspection, fracture observation, physical performance detection and structural component analysis are carried out to analyze the causes of the fracture of the graphite seal ring, and provide reference for the fault resolution and prevention of the graphite seal ring.

2. Experimental Materials and Procedure

Graphite seal components are mainly composed of static ring components (graphite ring, spring, rubber seal ring, static ring seat) and moving ring components (friction pair). The assembly process is: first in the static ring seat into the wave form spring and rubber ring, and then the graphite ring is fixed to the static ring seat, when the friction pair rotates and graphite is in a static state.

2.1. Experimental section

2.1.1. Macroscopic morphology observation. The surface damage state of the failed seal assembly was examined by means of naked eye and stereo light microscope.

The fracture of the graphite seal ring occurred in the fixed groove and the non-fixed groove, and the fracture direction was along the axial direction of the graphite seal ring. Its sealing surface was worn and shiny, no signs of damage were seen on its inner and outer surfaces, as shown in figure 1. There is obvious wear and discoloration on the sealing surface of the friction pair corresponding to the failed graphite sealing ring, and the color of different areas is obviously uneven. A large area near the edge of the outer ring of the friction area has become discolored and yellowed. Among them, three symmetrical areas separated by an angle of 120° are the most severely discolored and have become blue-purple, the morphology is shown in figure 2.

![Fig. 1 Appearance of the graphite seal ring](image1)
![Fig. 2 Appearance of the friction pair](image2)

In the area near the sealing surface of the outer surface of the graphite sealing ring, it can be seen that some droplets spattered have coked or even carbonized, forming spots of oil droplets, as shown in figure 3. There are wear grooves about 0.5mm wide and 0.7mm deep on the right side of the two fixed
grooves. The location of the grooves corresponds to the depth of the limit bracket protruding from the metal mounting base. The surface of the grooves is smoother than the machined surface of the fixed grooves, and the surface is also attached with black graphite wear powder, as shown in Figure 4. The sealing surface of the graphite sealing ring has been rough due to wear, and the whole surface presents a ring, fine and continuous grooves wear morphology, with the characteristics of ploughing wear. The wear grooves on both sides of the two fracture sites are continuous without any signs of interruption, as shown in Figure 5. In addition, the inspection of the entire sealing surface did not find the presence of metal chips, sand particles and other foreign bodies.

Fig. 3 External surface of the graphite seal ring

Fig. 4 Wear groove of the graphite seal ring limit slot

Fig. 5 Wear morphology of the fracture location
The inspection revealed slight signs of wear up and down on the inner surface of the static ring seat. The protruding limiting bracket on the metal mounting base and the corresponding surface of the graphite ring grooves were worn and adhered to black powder. The surface on the side of the metal bracket not in contact with the graphite was more smooth and clean, with no powder adhesion and no wear marks, as shown in figure 6.

The friction surface of the friction pair corresponding to the failed graphite sealing ring has been discolored and the color was uneven. There was a ring wear zone in the center of the sealing surface, which was corresponding to the width of the graphite sealing surface. The areas with severe discoloration were also more severely worn. Areas with light discoloration also wear less, as shown in figure 7. The side of the friction pair showed no obvious discoloration, which indicated that the temperature change of the metal was caused by the friction with the graphite seal ring.

2.1.2. Fracture observation. The fracture morphology of the graphite seal ring was observed by using the stereo light microscope and scanning electron microscope.

The fracture characteristics of the two fractures of the graphite ring are the same: the overall fracture was relatively flat, no wear signs are seen on the surface of the fracture, the fracture originates from the step position on the inner surface, the source area was linear source, and obvious tearing edges can be seen on the source area and the whole fracture, which was the brittle overload fracture characteristics, as shown in Fig. 8. No damage morphology such as impact and wear was seen in the fracture source area, and no obvious material defects such as pores, inclusions and micro-cracks were seen, as shown in Fig 9.
2.1.3. Material and performance check. The elements on the sealing surface and fracture surface were analyzed by energy dispersive spectrometer (EDS). The results show that the elements on the sealing surface of the failed graphite ring are C, O; and trace element Na, P, Ca, Fe. The C and O elements were mainly from graphite, Fe from the friction pair, and the Na, P, Ca elements were from oil. No abnormal elements were found on the wear surface. The fracture is mainly composed of C and O elements, and there was a trace of Na locally. Analysis suggested that Na came from oil, and no abnormality was found in the elements on the fracture, as shown in Table 1.

Table 1. EDS test results of the graphite ring (wt%)

| Element  | C   | O   | Na  | P  | Ca | Fe  |
|----------|-----|-----|-----|----|----|-----|
| Sealing surface | 88.29 | 10.46 | 0.58 | 0.25 | 0.8 | 0.23 |
| Fracture surface | 91.23 | 8.55 | 0.22 | -  | -  | -   |

X-ray fluorescence spectrometer (XPS) and X-ray diffractometer (XRD) were used to compare the elements and structures of the newly produced and failed graphite seal rings. The results showed that the XPS curves and XRD curves of the failed graphite seal rings were exactly the same, and only contained C and O elements. The chemical elements and structures of the failed graphite seal rings were not abnormal.

Graphite seal rings of the same batch as the fault parts were taken and physical properties were tested according to the technical requirements of HB 5366-1986. The results are shown in Table 2. It shows...
that the physical properties of graphite sealing ring, such as hardness, compressive strength, bending strength, void fraction, density and friction coefficient, meet the standard requirements.

| Table 2. Physical performance of the graphite ring |
|-----------------------------------------------|
| Performance                  | Requirement | Result of test | |
| Surface hardness (HR10/60)   | 110 ~ 125   | 115.5         |
| Compressive strength/MPa     | ≥98         | 106.4         |
| Bending strength/MPa         | ≥44         | 60.2          |
| Open porosity/%              | ≤7.0        | 2.88          |
| Density/(g·cm\(^{-3}\))     | ≥1.8        | 1.96          |
| Friction coefficient         | ≤0.15       | 0.08          |

In addition, the rubber seal ring and wave form spring in the failed seal assembly were rechecked. The results showed that the surface of the rubber seal ring was intact, and the size and hardness met the requirements. The waveform spring showed no obvious signs of extrusion deformation and discoloration, and the size and elasticity of the spring also met the design requirements.

3. Results and discussion

There were two cracks in the graphite seal ring, both of which were overload fractures, both originated from the inner surface, the line source, and no obvious defects and damages were found at the fractures. The chemical elements and structure of the graphite seal ring were not abnormal, and the physical properties meet the design requirements. There was continuous grooving wear on the sealing surface of the graphite ring, and the wear on both sides of the fracture site was coherent, and no obvious signs of falling blocks are found. The fracture was an overload fracture and no obvious wear signs were seen on the surface. The graphite ring should be worn first and then fractured. And the fracture reason had nothing to do with the material and performance of the graphite sealing ring, but was mainly caused by the excessive load.

Graphite sealing ring sealing surface did not see obvious inclusion defects, no signs of foreign material into the resulting in abnormal friction and lateral surface also not seen obvious impact damage, but the graphite ring in near friction pair surface for signs of lubricant coking, carbide friction pair and graphitization contact surface has become rough, but the side of the friction pair and no obvious change color, install no obvious signs of damage, rubber seal did not see signs of high temperature damage, waveform spring in good condition, analysis of lubricating oil, carbide and friction pair of anti-coking discoloration for sealing surface caused by friction heat up.

There were obvious groove wear and powder adhesion on the sealing surface of the graphite ring, no signs of peeling off blocks. There were abrasion marks and discoloration on the surface of the corresponding friction pair, as well as adhesion of black powder. There was no obvious oil adhesion, mainly showing the characteristics of dry friction, which will significantly increase the friction coefficient and lead to wear aggravation. Normally, the sealing surface of the graphite sealing ring should have oil splash, thus forming an oil film, showing lubricating wear characteristics. The actual sealing surface presents dry friction characteristics, which is related to the fact that the engine has just started and the oil has not yet spilled on the sealing surface.

There were grooves on the edges of the two fixed grooves of the graphite ring caused by mutual wear with the metal support of the static ring seat. Wear signs in the upper and lower directions can be seen on the inner surface of the static ring seat of the graphite ring. There was also a certain degree of wear on the lower surface of the graphite ring, which indicates that there was relative movement between the graphite ring and the static ring seat. During the operation, the friction pair rotates and the graphite seal ring remains stationary. However, the actual wear marks indicate that the graphite ring had undergone an obvious up-down movement.

There were three areas of serious discoloration and wear with an interval of 120° each other on the sealing surface of the friction pair, that is, the discoloration and wear degree are not uniform, indicating
that different areas of the sealing surface are subjected to uneven forces. In addition, the severe wear zone is distributed at an interval of 120°, which indicates that there is a periodic regional contact between graphite ring and friction pair, rather than a uniform surface-surface contact. There are two reasons for the interval wear: (1) the graphite ring and the friction pair periodically fluctuate in contact with each other; (2) the contact surface was not smooth, and there was a bulge phenomenon in the area with serious wear. Since no abnormality was found in the front friction pair during the overhaul and the flatness was checked during the overhaul, the possibility of intermittent wear caused by uneven contact surface is ruled out. Combined with the working process, analysis fluctuating impact wear is the fundamental cause of uneven wear.

The lack of oil lubrication and cooling between the graphite ring and the friction pair will increase the friction coefficient between the sealing ring and the friction pair. The higher the load is, the stronger the friction resistance will be, resulting in the temperature rise, resulting in excessive wear of the graphite ring. The graphite ring and the friction pair are in fluctuating contact with each other, and the wear is uneven, which intensifies the mutual wear of the graphite ring and the friction pair, thus making the temperature rise and the friction pair discolor and the oil droplets coking. Therefore, wear grooves and uneven wear on the surface of graphite ring and friction pair appeared in a short period (1 hour and 22 minutes) after overhaul. The serious wear is caused by the lack of oil lubrication on the sealing surface and the channeling of graphite ring.

The graphite ring moves up and down in a static ring, which accelerates the impact wear between the graphite ring and the inner wall of the static ring seat and increases the radial load of the graphite ring. At the beginning of engine start, the lack of oil lubrication between the graphite ring and the friction pair also increases the friction of the graphite ring to some extent. The combined action of the two makes the graphite ring bear too much load and fracture, resulting in oil leakage.

Because the metal bracket of the sealing ring static ring seat is designed to be in right-angle shape structure and tends to expand outward (Fig. 4a), when there is relative movement between the seal ring and the graphite ring, it is easy to wear the fixed groove of the graphite ring, which leads to the increase of the movement space of the graphite change and the increase of the instability. Graphite sealing ring is to rely on the elastic force of the spring to push the friction pair, when the graphite ring bearing load is greater than the spring elastic force, will produce relative movement, resulting in channeling or fluctuation. In addition to the secondary assembly after overhaul, will also cause the loss of coordination among the components, especially just startup speed is not stable, lubrication conditions are relatively poor, resulted in the shaking of graphite seal ring, thus forming periodic impact wear and friction clothing, lead to friction surface roughness increases at the same time, increase the friction, eventually lead to graphite sealing ring fracture. This was also the main reason for the fracture of graphite seal ring at the beginning of application after the second assembly.

The main purpose of fault analysis is to improve product quality and avoid the recurrence of similar fault events. Therefore, under the principle of changing the original structure as little as possible, this paper puts forward the following two suggestions [8-10]:

1. Before assembly or before factory use, the graphite sealing ring is immersed in lubricating oil for a period of time. Because graphite is a porous material, the oil can be absorbed into the graphite seal ring by immersion treatment, and the oil is gradually released to the sealing surface to form an oil film during the use process, thus reducing the friction coefficient. It can effectively avoid the phenomenon of dry friction and excessive wear caused by the lack of oil lubrication on the sealing surface of the graphite ring caused by the oil circuit or the abnormal speed in the process of starting. Figure 12 is a good proof of this rule.
2. The right angle between the metal bracket of the graphite ring mounting base and the contact position of the graphite ring is processed into an R angle with radian, which can effectively reduce the wear damage of the graphite ring fixing groove.

**Fig. 13** Structural improvement of metal fixed bracket

**Conclusions**

The metal bracket of the seal ring static ring seat is designed as a right-angle structure. When there is relative movement between the static ring seat and the graphite ring, it is easy to wear the graphite ring, which leads to the increase of the movement space of the graphite ring and the increase of the instability. Overhaul after secondary assembly, will also cause the loss of coordination among the components, especially just startup speed is not stable, lubrication conditions are relatively poor, resulted in the shaking of graphite seal ring, thus forming periodic impact wear and friction clothing, leading to the friction surface roughness increases at the same time, increase the friction, eventually leading to graphite sealing ring fracture. This is also the graphite sealing ring in the second assembly, the main reason for the early use of fracture. It is suggested that: (1) the metal bracket of the static ring seat should be improved into an curved structure with R angle; (2) the graphite sealing ring should be immersed in the lubricating oil before assembly.

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