Failure analysis of sensor diaphragm cracking

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Abstract: The sensor diaphragm cracked during the test project. Through macro and micro morphology observation, metallographic examination and hardness test, the diaphragm failure properties and reasons were determined. The results showed that the failure nature of the faulted diaphragm was bidirectional bending fatigue cracking. 1# crack failure was related to the greater bending stress borne at the bottom of the outermost corrugation. 2# crack failure was related to the greater stress borne by the root at the boundary between the outermost corrugation and the outer edge, the appearance of grain boundaries caused by the pickling process promoted the initiation and propagation of 2# crack.

1. Introduction

With the rapid development of science and technology, industries such as precision instrumentation industry, atomic energy technology, modern aviation remote control and telemetry technology, and radio technology have put forward higher requirements on the properties of elastic alloys, so that the research on elastic alloys with special purposes is becoming more extensive and in-depth [1,2]. As a corrosion-resistant high-elasticity precision alloy, 3J1 material is made into plates, strips, wires and rods through special smelting, forging, rolling and other technological methods. It has five characteristics: (1) high elastic limit, low inelastic behavior; (2) good anti-relaxation stability; (3) excellent corrosion resistance in various corrosive media and under oceanic and tropical climate conditions; (4) non-magnetic; (5) the maximum operating temperature is 250°C. 3J1 elastic alloy is mainly used to make bellows, coil springs, pressure sensors, etc. in automation instruments [3].

The failure sensor diaphragm was assembled, the product performed pressure alternating test between -55 °C ~ 185 °C, while pressure alternating between compressed air 0 to 1.77 MPa. The alternating test was designed for 50,000 times. After the fault product experienced 37,000 alternatives, the product was abnormal and the dismantling examination found that the diaphragm cracked. The diaphragm material was precision 3J1 alloy. Through macro and micro morphology observation, metallographic examination and hardness test, the diaphragm failure properties and reasons were
determined. This failure case provided reference to preventing similar fault.

2. Test process and results

2.1. Macro observation
The faulty diaphragm was observed. An obvious pit damage could be seen in the outer edge of the faulty diaphragm, the size of the damage was about 4mm×4mm, as shown in figure 1. There were two cracks in the faulty diaphragm, which were recorded as 1# and 2# cracks. 1# crack was located at the bottom of the outermost corrugation of the diaphragm when viewed from the concave surface, with a length of about 6mm. 1# crack extended along the bottom of the corrugation, as shown in the figure 2. 2# crack length was about 3mm, located at the root of the boundary between the outermost corrugation and the outer edge (the edge of the pit), and expanded along the outermost corrugation arc (the arc of the pit). The crack was small and bifurcation was visible, as shown in the figure 3.

Figure 1 Overall appearance of the failure diaphragm

Figure 2 Macro appearance of 1# crack
2.2. Microscopic observation

2.2.1. Microscopic observation of crack morphology

Obvious grain boundary appearance morphology could be seen on the surface of the faulty diaphragm, which was a phenomenon produced by the diaphragm after the pickling process. Grain boundaries appeared on the surface of the faulty diaphragm, which was essentially intergranular corrosion. Intergranular corrosion is the corrosion of metal materials along grain boundaries in a specific corrosive medium, and is a common localized corrosion. Intergranular corrosion destroys the bonding force between the grains, increases the brittleness of the material, and reduces the toughness and fatigue resistance of the material[4].

The relationship between the crack direction of the faulty diaphragm and the grain boundary was observed. The propagation path of 1# crack was tortuous. 1# crack on the concave side showed continuous, while on the convex side showed distributed intermittently. 1# crack propagation path presented the characteristics of a large amount of transgranular with a little amount of intergranular morphology, as shown in Figure 4. 2# crack was small, and the propagation path was tortuous. From the concave side or the convex side, 2# crack showed obvious bifurcation and aggregation. 2# crack propagation path presented the characteristics of a large amount of intergranular and a little amount of transgranular morphology, as shown in Figure 5.
2.2.2. Microscopic observation of crack fracture morphology

Crack fractures microscopic morphology were observed.

1# crack fracture was smooth and no obvious plastic deformation was seen. The fracture had both concave and convex origins. The fatigue area on the side close to the concave was larger, accounting for about 4/5 of the entire fracture. The fatigue source presented the characteristics of multiple small line sources, and a large number of fatigue steps and ridges could be seen in the expansion area. The main fatigue zone and the secondary fatigue zone had similar cleavage characteristics, and fine fatigue bands could be seen under high magnification, as shown in Figure 6.

The micro morphology of 2# crack fracture was basically the same as that of 1# crack fracture. The fracture had no obvious plastic deformation; the fracture presents both concave and convex origins, and the fatigue area on the side close to the concave is larger, accounting for about 3/5 of the entire fracture; the fatigue source is composed of multiple small line sources, and a large amount of fatigue could be seen in the expansion area. Steps and ridges. The main fatigue zone and the secondary fatigue zone show cleavage-like features, and dense fatigue bands could be seen under high magnification, as shown in Figure 7.

The artificial fracture was taken on the faulted diaphragm to observe the microscopic morphology, and the typical dimple morphology could be seen.
2.3. Metallographic examination

The microstructure of the diaphragm after corrosion was checked. The diaphragm microstructure was uniform, with visible grain morphology and artificial aging phase, and no metallurgical defects could be seen, as shown in Figure 8.

2.4. Hardness test

The hardness of the diaphragm was required to be higher than 360HV. The micro vickers hardness test was carried out on the metallographic sample with a load of 200g. The test results were shown in table 1. From the results in table 1, it could be seen that the hardness of the faulty diaphragm was uniform, which met the technical requirements.

| Test sample        | Test values | Average value | Requirement |
|--------------------|-------------|---------------|-------------|
| faulty diaphragm   | 425.51      | 403.06        | 424.42      | 417.66      | ≥360HV      |

3. Analysis and discussion

The fatigue of materials and components seriously threatens the safety of modern industrial equipment. Factors, such as pressure fluctuations and complex external forces, causes fatigue damage to components. Once a component is damaged, it will cause great harm. Two-way bending fatigue is more complicated than unidirectional bending fatigue, which is the fatigue failure that occurs when two basically opposite directions bear alternating bending loads. There are many reports in aviation,
Through the observation of the macro and micro morphology of the fault diaphragm fracture, it could be seen that two crack fractures characteristics of the fault diaphragm were the same: two fractures had no obvious plastic deformation; two fractures showed the characteristics of both concave and convex sides; fatigue sources were composed of multiple small line sources. A large number of fatigue steps and ridges could be seen in the expansion zone. Fine fatigue bands could be seen under high magnification in the fatigue zone. Artificially broken fracture was the characteristics of dimples. It could be seen that the failure nature of the failed diaphragm was bidirectional bending fatigue cracking.

1# crack of the faulty diaphragm was located at the bottom of the outermost corrugation of the diaphragm, and it mainly spread through the crystal. No obvious processing defects and damage traces was seen in the source area. The initiation of 1# crack had little to do with the surface quality of the diaphragm. Diaphragm crack had multiple sources and multiple fatigue steps. These characteristics indicated that the fatigue crack initiation stress was relatively large, which was caused by the bending deformation of the diaphragm surface. The crack presented the characteristic of bidirectional origin. The distribution and propagation of the crack on the concave side was relatively uniform, which was the main fatigue zone, while the crack on the convex side was distributed intermittently, which was the secondary fatigue zone. It was inferred from this that the diaphragm was subjected to bidirectional bending stress. The bending stress on the concave side should be derived from the working stress, and the bending stress on the convex side may be derived from the vibration caused by the deformation and recovery of the diaphragm.

2# crack of the faulty diaphragm was located at the root of the boundary between the outermost corrugated arc and the outer edge of the diaphragm. It mainly spread along the grain and originated from the acid-washed grain boundary. The crack presented the characteristic of two-way origin. The concave side is the main fatigue zone, and the convex side is the secondary fatigue zone. The diaphragm was subjected to two-way bending stress. The diaphragm had multiple sources and multiple fatigue steps. These characteristics indicated that the fatigue crack initiation stress was relatively high. This may be related to the stress concentration at the root of the boundary. After the 2# crack cracked, the degree of freedom increased, and dents and deformation occurred under the action of residual stress and working stress. The comparison between the faulty diaphragm and the intact diaphragm showed that there was no obvious difference in the morphology and depth of the surface grain boundaries. Based on this, it was inferred that the grain boundary appearance factor caused by the pickling process was not the decisive factor, but was the promoting factor. 2# crack failure was related to the great stress on the root of the boundary between the outermost corrugation and the outer edge. The appearance of the grain boundary caused by the pickling process promoted the initiation and propagation of the crack.

In summary, the failure nature of the failed diaphragm was bidirectional bending fatigue cracking; 1# crack failure was related to the greater bending stress borne by the bottom of the outermost corrugation; 2# crack failure was related to the greater stress borne by the root of the outermost corrugation and outer edge. The major concern was that the appearance of grain boundaries caused by the pickling process promoted the initiation and propagation of 2# crack.

4. Conclusions

(1) The failure nature of the failed diaphragm was bidirectional bending fatigue cracking;
(2) 1# crack failure was related to the greater bending stress borne by the bottom of the outermost corrugation;
(3) 2# crack failure was related to the greater stress borne by the root of the outermost corrugation and outer edge, and the appearance of grain boundaries caused by the pickling process promoted the initiation and propagation of 2# crack.
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