Fracture Failure Analysis of Flameproof Enclosure of Hydraulic Pump Regulator

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Abstract. A flameproof enclosure of hydraulic pump regulator has undergone a durable vibration fatigue test. Lugs have been found dropped during the test before the expected life. Failure analysis has been carried out by means of macro and micro observation, energy dispersive spectrum analysis, metallographic examination and hardness test. The reason of the failure is the fatigue resistance of this flameproof enclosure is not enough to endure the test. According to suggestions, a new structure flameproof enclosure has been improved to instead of the flanging lugs. The improved new one has passed the vibration test successfully.

1. Background

The hydraulic pump is an important power component of the hydraulic system. It provides energy for the entire hydraulic system and requires extremely high reliability and long life [1]. The hydraulic pump regulator can adjust the oil pressure and is the core component of the hydraulic pump. Therefore, the flameproof enclosure is made of 12Cr18Ni9 stainless steel, which has the function of fire insulation and protect the wire from damage. To do the failure analysis of the fractured flameproof enclosure and propose improvement measures have great significance and value for protecting the normal operation of the hydraulic pump regulator.

12Cr18Ni9 is an austenitic stainless steel with the tensile strength \(\sigma_b \geq 520 \text{ MPa}\). The chemical composition is shown in Table 1. In addition to good corrosion resistance, it has high ductility and mechanical strength, which is facilitate to be manufactured and maintained permanently.

Table 1. Chemical compositions of 12Cr18Ni9 stainless steel (wt.%)  

| Elements | C | Si | Mn | S | P | Cr | Ni | Fe |
|----------|---|----|----|---|---|----|----|----|
| Contents | \(\leq 0.12\) | \(\leq 1.00\) | \(\leq 2.00\) | \(\leq 0.030\) | \(\leq 0.035\) | 17.00–19.00 | 8.00–10.00 | Bal. |

2. Physical and chemical test

2.1. Macro observation

The entire hydraulic pump with the flameproof enclosure had undergone a durable vibration test. The flameproof enclosure lugs had been found to fall off before the expected life. The hydraulic pump had been disassembled, and the failure parts are shown in Figure 1. It was found that the middle position on the left side and the lower right lugs of flameproof enclosure were broken and fell off at the bending line (marked with circle). In order to facilitate the description of the fracture direction, the interior of the flameproof enclosure is defined as internal (inner side) and the outer surface is defined as external (outer side) in this paper.
The fracture surfaces of failure lugs were observed using stereo microscope, which is shown in Figure 2. The fracture surfaces of two lugs are flat and appear silver-gray. The arc features can be seen, mainly extending from the inner side to the outer side.

![Failure lug](image)

**Figure 1.** Macroscopic observation of the flameproof enclosure

![Inner side](image) ![Outer side](image)

**Figure 2.** Fracture morphology of the flameproof enclosure. a) Left fracture and b) right one.

### 2.2. Micro observation

Microscopic observation of the fracture surface of failed lugs was using by scanning electron microscope (SEM). The fracture of the left lug is flat. Crack originates from both the inner side and the outer side, of which the inner one is the main origin, as shown in Figure 3a; no defects were found in the origin region. The fracture shows cleavage-like features (Figure 3b); crack extension region also shows cleavage-like features, and the fatigue striation can be observed after zooming in (Figure 3c); the outer side is the secondary origin, which expands inward, and the extension ridge is clear, as shown in Figure 3d [2-4]. The fracture surface of the right lug has almost the same features as the left one, which is shown in Figure 4.

![Inner side](image) ![Outer side](image)

**Figure 3.** Microscopic observation of the left fracture. a) Low magnification morphology, b) inner side initiation, c) crack propagation zone of inner side, d) outer side initiation.
2.3. Energy Spectrum Analysis

Energy spectrum analysis (EDS) of the left lug fracture surface was performed on the inner side and outer side initiation areas. The positions of the selected area are shown in Figure 5, and the results are shown in Table 2. It can be seen that the composition of the material basically meets the requirements of 12Cr18Ni9 material. There are no obvious abnormality features in the crack initiation area.

2.4. Metallographic examination

The microstructure near the fracture position of the flameproof enclosure was examined using by optical microscope (OM), see Figure 6. The material structure is austenite, and the grains are relatively uniform and equiaxed. Deformation streamlines of sheet metal can be seen clearly, and no metallurgical defects have been found [5].
2.5. **Hardness test**

The specimen near fracture surface had been chosen for hardness testing, and the results are shown in Table 3. It can be seen that the hardness values are uniform and in the standard range [6].

| Position | 1  | 2  | 3  | Ave. |
|----------|----|----|----|------|
| Hardness | 212| 217| 218| 216  |

3. **Analysis and discussion**

The fracture surfaces of the two failed lugs are clean and flat, without any plastic deformation features. From macro and micro observing, it is revealed that the cracks initiated linearly from both inner and outer side. Expansion ridges and fatigue striation can be seen clearly in the extended region. From the above typical features, the fracture mode can be inferred as fatigue failure [3]. The inner expansion regions of the two lugs are larger than the outer expansion region, which means the inner side is the main initiation. There were no abnormalities in the microstructure and hardness of the material near fracture, which can be judged that the cracking of lugs is not caused by material [7].

The break position of the flameproof enclosure is located at the bending position of the lugs on the left and right folded sides. This position has undergone plastic deformation through the bending process, the effective bearing cross-section is small, which may induce stress concentration in the bending place. The inner side of the bend is the location of tensile stress concentration, and the outer side is the compressive stress concentration. Fracture observation shows that the inner side is the main crack initiation, which coincides with the location of tensile stress concentration. The flameproof enclosure was subjected to horizontal vibration before breaking, which is consistent with the maximum stress direction of the two lugs. The crack initiated linearly, and no defect was found in the initiation area. The occurrence of fracture was mainly caused by vibration stress superimposed on the structural stress concentration.

4. **Conclusion and recommendation**

Through comprehensive analysis of the fracture characteristics of the flameproof enclosure, the failure mode is bi-directional vibration fatigue fracture. The reason for the fracture is that the bending area of the lugs were subjected to overload fatigue stress. The recommendation is as follows:

1. Check whether there is any abnormality of the loading fatigue stress during the test. Find out the cause of the abnormality and prevent it;
2. If there is no abnormal load, check whether the fatigue strength of the structure is sufficient or not. If not, it is recommended to replace material or improve the existing material fatigue resistance; or change the enclosure structure to reduce the stress concentrations, in order to increase the overall fatigue performance of the flameproof enclosure.
5. Follow-up rectification

According to the above suggestions, the manufacturer has modified the structure of the flameproof enclosure: changed the original lug structure to a non-bend structure with holes, which is shown in Figure 7. The modified flameproof enclosure was assembled in a hydraulic pump and subjected to a vibration fatigue test. No cracks on the edge of the hole were found after reaching the expected life.

Figure 7. Macroscopic observation of modified flameproof enclosure

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