Analysis of movable guide vane inversion and limited block dropping of hydropower plants

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Abstract. The fracture signal of shear pin occurs in the process of short time load reduction of AGC. During the stop site inspection, it is found that the shear pin was broken, the guide vane limit block fell off, and the movable guide vane was reversed. The analysis shows that the installation and welding mode of the limited block is wrong. Therefore, when the guide vane is subjected to additional load, the position of the fixed guide vane cannot be effectively limited, which leads to the inversion of the fixed guide vane.

1 Fault description

When the fracture signal of shearing pin was reported in the process of AGC short-term load reduction, the maintenance personnel noticed the abnormal sound of the crew, the obvious vibration of the factory building and the office building. The operator rushed the crew off the gate and immediately inspected on site as quickly as possible. The on-line vibration monitoring system of the unit shows that the vibration value of the instantaneous top cover of the unit is 3700 μm and the water conductivity is above 900 μm , which seriously exceeds the standard.

The lower connecting plate of the guide vane has fallen off, and the pressure plate and fixing bolt of the lower connecting plate have fallen (as shown in Figure 1). The pin hole of the connecting plate has been seriously deformed due to impact. The inner hole changes from circular to square (as shown in Figure 2). The guide vane arm and the guide vane journal drive pin sleeve have been squeezed out, and the fixed position of the guide vane arm and guide vane has been mispositioned.

Figure 1 the pressure plate and fixing bolt have fallen

2 Detection and analysis

2.1 Appearance inspection

2.1.1 Guide vane control device

Figure 2 deformation of the pin hole and the extrusion cracking of the pin sleeve

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2.1.2 Guide vane protection device

No. 17, 18, 19 guide vane arm and pin sleeve with guide vane journal drive deform. The shear pin of guide vane breaks, as shown in Figure 3. It is found that the cut pin

is smooth, which is caused by the result of impact fracture. No. 18 and 19 guide vane closing side limiting device fall off.

Figure 3 the breakout of the shear pin and the falling of the guide vane closing side limiting device

2.1.3 Moving guide vane and fixed guide vane

When entering the volute, it is found that there are obvious scratches at the gap between the top cover and the movable guide vane (as shown in Figure 4). There are also obvious scratches on the influent edge of the movable guide vane. No. 18 movable guide vane rotates

more than 180° . The outlet edge of the movable guide vane is reversed and the position of the movable guide vane is higher than that of the fixed guide vane. There are extrusion marks at the outlet edge of the fixed guide vane and the outlet edge of the movable guide vane.

Figure 4 the scratch of the top cover and the movable guide vane rotating more than 180°

2.2 Physical and chemical analysis

The cutting pin is made of 45 steel. The metallographic structure of shear pin was inspected. It is found that the

ferrite is distributed on the grain boundary and is feather-like, with the characteristics of Weiss structure (as shown in Figure 5).

Figure 5 the microstructure of the cutting pin

The mechanical properties of the sample are analyzed by sampling on the shear pin and the strength of the sample is shown in Table 1. According to the service characteristics of shear pin, the mechanical properties of shear pin should be uniform. Therefore, it is necessary to carry out heat treatment. Normalizing treatment is generally used to obtain good comprehensive mechanical properties of 45 steel. According to GB/T 699 *High Quality Carbon Structural Steel*[1], the tensile strength and post-break extension rate of the shear pin meet the requirements of the standard.

Table 1 the mechanical properties of the Shear pin

No	Rm (MPa)	A (%)	Standard
1	826	19.2	Rm $\geq$ 600MPa
2	830	24.2	A (%) $\geq$ 16%

The impact test was carried out by the sample on the cut pin. The impact work detection data are dispersive. In each group of test results, one sample has a test value below the standard requirements (Table 2). Therefore, impact work does not meet the requirements of the standard.

Table 2 Impact property of the shear pin

No	A _{KU2} (J)	Standard
1	40.0, 52.5, 31.5	A _{KU2} $\geq$ 39J
2	47.8, 44.5, 32.5	

The shear pin hardness is shown in Table 3. The hardness value is higher than the standard requirement.

Table 3 the hardness value of the shear pin

No	hardness value				Average	Standard
1	241	244	244	243	243	Annealed state hardness value $\leq$ 197HB
2	243	245	244	244	244	Non-heat treated state $\leq$ 229HB

2.3 Analysis of welding quality of limited block

By checking the welding quality of the limited block, it can be seen that there are five sides and four sides of the limit block. A side in which the limit block collides with the guide vane arm is fitted with a rubber block. There is no welding on this side. The field welding mode of the limit block is shown in Figure 6a and the red area in the figure is the actual welding position. It is found that the weld has no groove, the welding height is about 8 ~ 10 mm, and the welding quality is poor. Looking at the design and construction scheme provided by the manufacturer, it is seen that the actual welding mode of the limit block is completely wrong and the welding of the limit block should open the full groove and weld through. As shown in Figure 6b, the red area is the welding position.

Figure 6 The actual welding mode (a) and the designing welding mode (b) of the limit block

The guide vane protection device is composed of a shear pin, a friction limit device and a guide vane limit block. The functions of the device are shown as follows:

When the guide vane is jammed by a foreign body in the process of closing and the bearing stress of the guide vane. The transmission parts reach a certain stress level

and it is not destroyed. The shear pin first breaks to ensure that the other guide vane continues to close. The function of shear pin is to break automatically when the transmission mechanism exceeds the preset load, which protects the guide vane and transmission mechanism [2]. Each guide vane is equipped with a friction limit device to prevent the guide vane from swinging repeatedly after the action of the protective device. Each guide vane has a friction limited device to prevent the guide vane from swinging repeatedly after the action of the protective device. If there are obstacles between any pair of guide vane, the device will not prevent the control loop from moving on or off [3].

Each guide vane has a guide vane limit block, which is designed according to the maximum water torque and impact force that may be applied to the guide vane limit block under the most unfavorable working conditions. The limited block is arranged between the top cover and the inflection arm to limit the motion angle of the guide vane and to prevent the loose guide vane from interfering with the motion of the adjacent guide vane or runner under the condition of the action of the protective device [4]. When the shear pin is broken and the friction pair is ineffective, the guide vane swings between the full shut and the full open limit block, which protects the guide vane and wheel. When the limited block fails, the guide vane might collide with the fixed guide vane or runner, resulting in the destruction of the guide vane and runner [5].

During the accident, the surface of the rotating wheel is scratched, which indicates that foreign matters can enter the rotating wheel and the blocking of the guide vane is possible. The shear pin first breaks and the torque of the guide vane is larger than that of the friction pair, which causes the guide vane arm to impact directly on the limit block. The welding mode of the limited block is

wrong and the welding quality is poor. Therefore, the limited block is impacted off, the guide vane is subjected to hydraulic impact and the position is not limited, which leads to the inversion of the guide vane, the dislocation of the position, and the impact deformation of the connecting plate during the impact process.

3 Conclusions and treatment measures

3.1 Conclusions:

The main cause of this accident is the failure of the guide vane protection device. The failure of the protection function of the limited block leads to the direct cause of the accident when the active guide vane and the fixed guide vane collide. In the installation stage of the unit, the limited block of the guide vane arm is not welded according to the design requirements, which leads to the great reduction of the weld strength and the failure of the limited block. The guide vane arm could not be protected effectively when the guide vane arm rotates. The important factors leading to the accident include the poor microstructure, poor mechanical properties of the cutting pin and the sliding of the guide vane friction device after the cutting of the guide pin.

3.2 Treatment measures:

1. The microstructure of the shear pin has the characteristics of Weiss structure and the hardness is on the high side. The impact absorption work does not meet the requirements of the standard. Therefore, it is suggested that all shearing pins of the unit should be replaced.
2. All the existing limit blocks need welding again and the welding method should be in accordance with the way of full penetration.

References

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