Fracture Analysis of the Main Valve Stem in the Steam Turbine

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Abstract. The failure analysis of the main valve stem in the steam turbine made of 2Cr12NiMo1W1Vis presented. The failure of the main valve stem in the steam turbine occurred at 11 operating years. Several examinations were carried out to identify the main valve stem failure’s root cause: macroscopic inspection, chemical composition analysis, hardness test, metallographic analysis, mechanical properties analysis. It is found that there are multiple cracks in the fracture of the valve stem. From the lines, it can be seen that the cracks develop from the inner wall of axial and radial holes to the outer diameter of the valve stem, and finally break in the outer wall of the four quadrals. The material performance of the valve stem is lower than the reference standard GB/T 8732-2014 and the manufacturer's requirements, which is the internal factors of the valve stem fracture. The axial cross opening of the valve stem and the center of the axial inner hole do not coincide with the valve stem center. Local stress concentration and additional stress are the external (mechanical) factors of the valve stem fracture. It is suggested to contact steam turbine manufacturers to optimize the valve stem structure, to avoid the influence of axial cross orifice stress concentration, and to avoid the factor that may produce additional stress. Check and accept valve stem in strict accordance with manufacturer's standard, including but not limited to valve stem material quality certificate, geometric dimension review, spectrum, etc.

1. Introduction
A thermal power plant has 2 sets of 254MW (E) gas turbine - steam combined cycle generator sets. Each generator set consists of 1 gas turbine, 1 steam turbine, 1 gas turbine generator set, 1 steam turbine generator set, 1 dual-pressure waste heat boiler and auxiliary equipment, both units were put into production in June 2008, and by April 3, 2019, and unit 2 had accumulated 62218 hours.

The model of the steam turbine produced by Shanghai steam turbine co., ltd. is lzc80-7.80/0.65/0.15. The front part of the cylinder (level 1 to 5) is a double-layer structure, followed by a single-layer structure. The typical operating parameters are shown in table 1. The steam turbine is equipped with two main steam valve and two high pressure regulating steam valve, one main steam valve and one high pressure regulating steam valve form a group, which is arranged on both sides of the high pressure cylinder. The new steam from the boiler enters the main steam valves on both sides of the engine room in two ways, and then enters the high pressure regulating valve. It is connected with the front cylinder main steam inlet through the main steam pipe through the outlet of the two high pressure regulating valves. Each set of main steam valve and regulating steam valve set has an independent seat support.
2Cr12NiMo1W1V steel is a reinforced 12% Cr martensitic heat resistant stainless steel, which is equivalent to c-422 and AISI616 steel. The steel has high strength, good comprehensive performance, low endurance sensitivity, good vibration absorber and anti-relaxation performance. It is widely used for bolts and stem with operating temperature not exceeding 540°C [1]. However, several problems, such as fatigue failure, pitting corrosion, stress corrosion cracking, and inter-granular corrosion occasionally, occur in these stems [2–6]. Accidents resulting from such problems can lead to injury or even death to those nearby, as well as considerable property damage.

In this research, the reason leading to the failure of the main valve stem in the steam turbine stems were investigated. Based on the critical root causes of the valve stem failure, the structural reliability of valves may be improved in the power plant field [7].

| Working condition of the summer | Maximum continuous output | Pure coagulation condition | Rated heating extraction condition | Maximum extraction condition |
|--------------------------------|---------------------------|---------------------------|----------------------------------|-----------------------------|
| The output (kW)                | 73950                     | 80963                     | 81550                            | 57354                       |
| Heat consumption of turbo-generator (kJ/kWh) | 3729.6               | 3726.2                     | 3740.0                            | 3749.6                       |
| High pressure steam pressure (MPa) | 7.565                    | 7.648                      | 7.718                             | 7.778                        |
| High pressure steam temperature (°C) | 530.0                    | 518.3                      | 523.9                             | 519.0                        |
| High pressure steam flow (kg/h) | 233380                   | 238270                     | 239425                            | 242222                       |

2. Experimental procedure
The objects to investigate into were the main valve stem obtained from the plant. After an extensive visual examination, chemical analysis of the valve stem material was carried out by spectral analysis method. A portion of the failed valve stem cross section was cut for metallography. The metallographic samples were prepared by using standard metallographic techniques and etched with reagent Ferric chloride and hydrochloric acid during 15s at room temperature. The brinell hardness test and vickers hardness test were carried out on the cross section of the valve stem. Brinell Hardness Testing Machine with bearing of 2.5mm in diameter under a load of 1840 N. Micro-hardness Vickers tests were performed with a 200 g load and an indentation time of 15 s. Micro-indentation tests were also carried out on defined areas of the sample. The applied load was 1960 mN. Machining longitudinal sample in stem to conduct mechanical performance tests.

3. Results and discussion

3.1. Visual inspection
The valve stem was completely broken during maintenance, as shown in fig.1(a), the overall fracture is located at a stem diameter of approximately 20mm in the radial opening position, as shown in fig1(c), which stem diameter was about 37.8 mm, phi axial hole there is no roundness, the measured maximum diameter is 12.6 mm, the measured minimum diameter is 12.2 mm, Axial bore center does not coincide with stem center, cross section in the radial hole measured the length of the minimum value is 11.4 mm, the measured maximum length is 14.0 mm, s shown in fig1(b),It indicates that the bearing area of the four quadrants of the valve stem is different during service, and the force is uneven as well.

The whole fracture has been oxidized and no obvious metallic luster has been seen, indicating that the valve stem has been broken for a period of time before maintenance. There are several cracks in the
fracture. From the fracture extension pattern, it can be faintly seen that the crack develops from the inner wall of axial and radial holes to the outer diameter of the valve stem, and finally breaks in the outer wall of the four quadrants (red arc position) with obvious shear lip. The predicted crack growth direction is indicated by the arrow in fig.1 (b).

![Fracture condition and morphology](image1)

(a) general fracture condition  (b) macroscopic fracture morphology

![Stem fracture length position](image2)

(c) stem fracture length position

Figure 1. Main steam valve stem fracture

### 3.2. Chemical analysis

Thermo ARL8860 spectrometer was used for spectral analysis, and the analysis results were the average of the three test results, as shown in table.2. It is generally believed that low content of element C in steel will reduce hardness and strength and improve toughness, low content of element Mo will reduce thermal strength and creep strength, and low content of element W has secondary hardening effect, which will reduce mechanical properties and thermal strength (the effect is similar to Mo). According to the 2Cr12NiMo1W1V requirements in GB/T8732-2014, the content of elements C, Mo and W is slightly lower than the standard requirements, which will slightly reduce the strength index of the valve stem, and the content of other elements meets the requirements.

Table 2. Spectral analysis results (wt %).

| Elements | C   | Si  | Mn  | P   | S   | Ni   | Cr    | Mo   | W   | V   | Cu  |
|----------|-----|-----|-----|-----|-----|------|-------|------|-----|-----|-----|
| Result   | 0.19| 0.28| 0.74| 0.019| 0.005| 0.63 | 11.52 | 0.88 | 0.89| 0.26| 0.14|
| GB/T8732-2014 | 0.20~0.2 | ≤0.5 | 0.50~1.0 | ≤0.03 | ≤0.02 | 0.50~1.0 | 11.00~12.5 | 0.90~1.2 | 0.90~1.2 | 0.20~0.3 | ≤0.3 |

### 3.3. Hardness test

Brinell hardness test and Vickers hardness test were carried out on the cross section of the valve stem. The hardness test locations are shown in fig2. Brinell hardness test results are shown in table 3 and Vickers hardness test results are shown in fig3. It can be seen that the tested Brinell hardness exceeds the requirements provided by the standard and manufacturer. The distribution trend of Vickers hardness of the valve stem cross-section presents an upward trend from the center to the edge. The minimum
measured base value is 278HV, and the hardness range of the nitride layer is 640–660HV, which is lower than the requirement that the nitride layer hardness of the manufacturer is ≥800 HV.

![Figure 2. Location of hardness measuring point](image)

![Table 3. Brinell hardness test results (HBW)](table)

![Figure 3. Vickers hardness test results](image)

3.4. Microscopical investigation

The cross section of the valve stem was examined for metallographic structure, as shown in fig 3. It can be seen that the metallographic structure of the cross section was tempered martensite, meeting the standard requirements. The average thickness of the stem surface nitride layer is about 507 microns, exceeding the manufacturer's requirement of 200-350 microns.
3.5. Mechanical property test

Tensile test and impact test at room temperature were carried out on the valve stem. The results are shown in Table 4. The tensile strength, specified plastic extension strength and elongation after fracture are all lower than the reference standard and manufacturer's requirement.

|                  | Rp0.2 (MPa) | Rm (MPa) | A (%) | AKV (J) |
|------------------|-------------|----------|-------|---------|
| Result           | 707         | 906      | 4.0   | 27      |
| GB/T8732-2014    | ≥760        | ≥930     | ≥12   | 11      |
| Manufacturer's requirement | ≥760        | ≥930     | ≥14   | /       |

4. Conclusion

In summary, there are multiple cracks in the fracture of the valve stem. From the lines, it can be faintly seen that the cracks develop from the inner wall of axial and radial holes to the outer diameter of the valve stem, and finally break in the outer wall of the four quadrants. The material performance of the valve stem is lower than the reference standard and the manufacturer's requirements which is the internal factors of the valve stem fracture. The axial cross opening of the valve stem and axial bore center does not coincide with stem center, Local stress concentration and additional stress are the external factors of the valve stem fracture.

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