Analysis and Treatment of Abnormal Vibration of Steam Feed Pump Towards 660MW Steam Turbine

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Abstract. The driving end of B steam feed pump vibrates greatly when steam turbine is in normal operation. Through fault diagnosis and analysis, reasons for vibration were checked and solution found. It mainly caused by mass imbalance of feed pump rotor. A kind of solution has been proposed, and potential equipment safety hazard were eliminated successfully.

Keywords. steam feed pump; Abnormal vibration; Fault diagnosis; Fault treatment.

1. Overview of equipment
A power plant ultra-supercritical 660MW steam turbine, the water supply system is equipped with two sets of 50 percent BMCR capacity steam feed pump A and B. The steam turbine is NK63/71 which produced by hangzhou steam turbine co., LTD., and the feed pump steam turbine is of single-cylinder, axial flow and reaction-type pure condensation type. Exhaust steam directly to the main engine condenser, rated speed of 5500r/min, working speed range of 3000 ~ 5990r/min, the first order critical speed of more than 7000r/min. The steam pumps of A and B are horizontal multi-stage barrel core enveloping structure, and the shaft end sealing type is labyrinth sealing. The rated speed of the feed pump is 5500r/min. The steam turbine and the steam pump adopt flexible laminated coupling for torque transfer. B steam pump group, a total of four bearing support, each journal is installed on the same section have two are 90 ° vibration of X and Y to the eddy current sensor, used to measure the axial vibration.

The connection type of shaft system of steam pump B can be seen from figure 1.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{The connection type of shaft system of steam pump B}
\end{figure}
2. Description of fault phenomenon

On June 1, 2018, B steam pump normal operation, when the speed reached 5266r/min, vibration value began to increase in 3X and 3Y direction, the frequency value reached 40 and 31μm respectively; The vibration values also began to increase in 2X and 2Y direction, the direct frequency values reached 19.6 and 18.1μm respectively.

Then the variable load test of B steam pump group was carried out. With the increase of rotating speed, the vibration value also increased gradually. When the rotating speed reached 5588r/min, the direct frequency values reached 65.8 and 70.1μm respectively in 3X and 3Y direction, the direct frequency values in 2X and 2Y direction also increased gradually, reached 28.8 and 24.7μm respectively. There was a slight increase in the vibration value of 4X and 4Y.

3. Analysis of Fault cause

3.1. Vibration monitoring of B steam pump

The main operating parameters of B steam pump were all excellent and no maintenance has been carried out since put into operation on July 13, 2017. SKVMA12 vibration detector is used for diagnosis and analysis when the vibration value of B steam pump increases. When the rotating speed reached 5266r/min, the vibration value of #1-#4 bearing can be seen from Table 1.

| Measuring point | Direct frequency value | Base frequency | double frequency |
|-----------------|------------------------|----------------|-----------------|
| 1X direction    | 18.3                   | 14.6 ∠3°       | 1.53 ∠138°      |
| 1Y direction    | 11.9                   | 6.42 ∠117°     | 1.73 ∠296°      |
| 2X direction    | 19.6                   | 13.7 ∠142°     | 1.41 ∠202°      |
| 2Y direction    | 18.1                   | 11.4 ∠260°     | 2.4 ∠5°         |
| 3X direction    | 40.2                   | 34.7 ∠4°       | 3.22 ∠24°       |
| 3Y direction    | 31.4                   | 26.5 ∠80°      | 1.96 ∠131°      |
| 4X direction    | 17.3                   | 12.2 ∠105°     | 1.88 ∠94°       |
| 4Y direction    | 18.7                   | 12.6 ∠204°     | 1.61 ∠284°      |

Vibration monitoring instrument is used to monitor the frequency spectrum of the vibration value of the feed pump and the driving end of the small machine. When the speed of the B steam pump is 5266r/min, the measured frequency spectrum is shown in figure 2 to figure 5.

![Figure 2. Spectrum in 3X direction](image-url)
The vibration value is mainly of base frequency in 3X and 3Y direction, the direct frequency value is 40.2μm and 31.4μm, base frequency is 34.7μm and 26.5μm respectively in 3X and 3Y direction. The base frequency accounts for 86.3% of the direct frequency value in 3X direction and 84.4% in 3Y direction and the phase angle is stable.

The vibration value is also mainly of base frequency in 2X and 2Y direction, the direct frequency value is 19.6μm and 18.1μm, base frequency is 13.7μm and 11.4μm respectively in 2X and 2Y direction. The base frequency accounts for 69.9% of the direct frequency value in 2X direction and 63% in 2Y direction and the phase angle is stable.

![Figure 3. Spectrum in 3Y direction](image1)

![Figure 4. Spectrum in 2X direction](image2)

![Figure 5. Spectrum in 2Y direction](image3)

When the vibration value of B steam pump increases, it happens to be in the peak season of power load in summer. Affected by the power load of the power grid, no empty load test can be conducted.
Instead, variable load test can only be conducted for B steam pump group to monitor the vibration of B steam pump group under different loads for more accurate fault diagnosis and analysis. After communicating with the operation department in the factory, variable load test was carried out, and the variation range of speed was 5006-5592 r/min. Vibration monitoring instrument was also used to measure the vibration of B steam pump group. The variation trend of the vibration value of the feed pump and the driving end of the small machine with the speed is shown in figure 6 to figure 9.

![Figure 6. Trend diagram of variable speed in 3X direction](image6)

The vibration value increases with the increase of working speed of B steam pump group in 3X and 3Y direction.

![Figure 7. Trend diagram of variable speed in 3Y direction](image7)

![Figure 8. Trend diagram of variable speed in 2X direction](image8)
When the working speed of B steam pump group is below 5526 r/min, the vibration value in 2X direction is basically stable. When the working speed is 5526 ~ 5580 r/min, the vibration value increases with the increase of the working speed.

![Figure 9. Trend diagram of variable speed in 2Y direction](image)

When the working speed of the B steam pump group is below 5494 r/min, the vibration value in the 2Y direction is basically stable. When the working speed is 5494 ~ 5580 r/min, the vibration value increases with the increase of the working speed.

Variable load test is carried out on the B steam pump group, when the speed is 5588 r/min, the vibration value of the B steam pump group reaches the maximum. The vibration value of #1 ~ #4 bearing is shown in Table 2.

| Measuring point | Direct frequency value | Base frequency | double frequency |
|-----------------|------------------------|---------------|-----------------|
| 1X direction    | 16.2                   | 12.4 ∠3°      | 0.826 ∠138°     |
| 1Y direction    | 11.9                   | 6.61 ∠117°    | 1.01 ∠296°      |
| 2X direction    | 28.8                   | 22.7 ∠142°    | 1.27 ∠202°      |
| 2Y direction    | 24.7                   | 18.2 ∠260°    | 1.77 ∠5°        |
| 3X direction    | 65.8                   | 55 ∠4°        | 2.20 ∠24°       |
| 3Y direction    | 70.1                   | 56.8 ∠80°     | 6.59 ∠131°      |
| 4X direction    | 21.2                   | 15.5 ∠106°    | 1.80 ∠94°       |
| 4Y direction    | 22.1                   | 14.9 ∠209°    | 1.96 ∠284°      |

3.2 Analysis on vibration of B steam pump

According to the vibration data and frequency spectrum of B steam pump detected by the vibration monitor as well as the variation trend diagram of rotation speed, the vibration of B steam pump has the following characteristics:

1) The vibration value in 1X and 1Y direction changes little and is not affected by the working speed change of B steam pump. The vibration values in 2X and 2Y directions vary with the working speed, but the range of change is not large. The vibration values in 3X and 3Y directions vary with the working speed and have good reproducibility. The vibration value increases when the working speed increases and decreases when the working speed decreases. The vibration value in 4X and 4Y direction does not vary greatly with the working speed.

2) When the speed of B steam pump is 5266 r/min, the base frequency vibration accounts for 86.3% of the direct frequency value in 3X direction, and 84.4% in 3Y direction. When the working speed
reaches 5588 r/min, the base frequency vibration accounts for 86.3% of the direct frequency value in 3X direction, and 81% in 3Y direction. The rest of the vibration components are small.

3) The vibration phase angle does not change with the working speed of B steam pump, and it is very stable. The vibration phase angle is 4° in 3X direction and 80° in 3Y direction when the working speed changed from 5266 r/min to 5588 r/min.

According to the vibration characteristics of the B steam pump, the preliminary analysis suggests that the reason for the large vibration of the B steam pump may be the common forced vibration caused by the unbalanced mass of the feed pump rotor [1, 2]. Considering the factors causing the mass imbalance of the feed pump rotor, there are mainly three situations:

1) There is a certain amount of original quality imbalance after on-site installation of the equipment.
2) In the normal operation of B steam pump group, sudden mass imbalance occurs.
3) With the accumulation of running time of B steam pump, the gradual mass imbalance appears [3, 4].

The vibration value of the feed pump is always excellent since put into operation, the original mass imbalance of the rotor of the feed pump can be eliminated. In addition, the vibration value of the B steam pump group increases with the continuous gradual increase in speed rather than a sudden sharp rise, which can eliminate sudden mass imbalance. Therefore, it can be inferred that the increase of vibration value of B steam pump is caused by the gradual mass imbalance.

3.3 Analysis of mass imbalance of B steam pump
Vibration is mainly in 3X and 3Y direction of B steam pump, that is the feed pump bearing vibration at the drive end and in the feed pump inlet position. It may be because the water quality of the feed water is poor, contains some impurities, uneven scaling on the rotor, or impurities on the blade and impeller surface to produce different degrees of wear and corrosion, resulting in unbalanced quality of the feed water pump rotor [5].

4. Treatment measures and effects
The B steam pump group is dynamically balanced on site to eliminate the mass imbalance of the rotor itself, reduce the vibration value, and ensure the safe and stable operation of the equipment.

1) Reduce the load of the unit and stop the B steam pump;
2) In order to reduce the on-site maintenance workload, shorten the downtime of B steam pump group and ensure the normal load of the unit, it is decided to carry out on-site weight balancing at the coupling of B steam pump group. According to the experience of vibration treatment of turbo-generator set, it is decided to carry out on-site weight balancing on the connecting bolt of the wheel of the feed pump coupling (near the side of the feed pump). Through calculation and analysis, it is decided to increase 310g in the direction of 130°, increase the way to increase the nuts and washers on bolt, weight in order to achieve the quality requirements.

The vibration frequency of #1 ~ #4 bearings is decreased to 37μm after additional weight balance, and up to excellent.

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