Study on intense vibration of local structures of Zhanghewan pumped-storage powerhouse

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Abstract. Vibration of the powerhouse has an important influence on safe operation of hydropower station and health of operation personnel. In the present paper, intense vibration of local structures of Zhanghewan pumped-storage powerhouse is studied, and the reason of intense vibration is illustrated through analyzing the main excitation sources and the natural frequencies of local structures. The revelation from the research process and conclusions is that the entirety resonance of the powerhouse should be avoided absolutely during the process of design, and the resonance between local structures and the main excitation sources should be avoided as well.

1. Introduction
Vibration of the powerhouse has an important influence on safe operation of hydropower station and health of operation personnel. It is known that the excitation sources of the vibration come from the hydropower unit, but the relationship between the excitation sources and local structures of the powerhouse shall be researched synthetically.

The measurement of the shaft displacement, the vibration of the unit components and the pressure fluctuation in the unit passage is often carried out to estimate the status of the hydropower unit. Through further analysis, the main frequency of the shaft displacement, the vibration and the pressure fluctuation can be obtained[1-4]. In order to estimate the status of the hydropower powerhouse, the vibration of its structures can be measured as well[5].

When the vibration of local structures of the hydropower powerhouse is intense, it is necessary to verify the resonance possibility between the excitation sources and the local structures, and the natural frequency of the local structures shall be measured to compare with the main frequency of the excitation sources, while the related research is rarely reported in public.

2. Analysis and Discussion

2.1. Case study and instrumentation
Four vertical reversible pump-turbines are installed in Zhanghewan pumped-storage hydropower station, and rated output for each unit is 250 MW. The main parameters of the unit are as follows \[^6\].

There was strong noise and vibration of local structures such as upright columns and stairs from commercial operation of this hydropower station, inducing some screw bolts loosened and some components worn down, which influenced safe and stable operation of the unit \[^7\].

In order to find out the reason of strong noise and vibration, on-site test was performed. Three kinds of sensors were used during the test.

1. Force balance type sensor: its sensitivity is 2.5 V/g, and its frequency linearity is 0-100 Hz. It can show three direction (X, Y, Z) vibration signals, and it is diamagnetic.

2. Piezoelectric sensor: its sensitivity is 1.5 V/g, and its frequency linearity is 0-2kHz.

3. Pressure fluctuation sensor: its sensitivity is 400 kPa/\(\text{mA}\), and its frequency linearity is 0-1 kHz.

Four sensors were used to measure pressure fluctuation at the inlet of spiral case, at the +X and +Y directions of vaneless area, under the head cover separately.

The positions of all sensors are illustrated as Figure 1.

| Table 1. Main parameters of the unit |
|-------------------------------------|
| Rated speed (rpm) | 333.3 | Number of runner blades | 9 |
| Nominal diameter of the runner (m) | 4.641 | Rated gross head (m) | 305 |
| Number of stay vanes | 20 | Maximum gross head (m) | 346 |
| Number of guide vanes | 20 | Minimum gross head (m) | 291 |

(a) Test points on the generator floor

\(\Theta\) - Force balance type sensor

(b) Test points on the busbar layer floor
2.2. Measurement results and analysis
The data acquisition frequency was 800 Hz, and the test conditions were as follows.

(1) 150 MW output was for unit 3 and unit 4, and the other two units were standstill.
(2) 200 MW output was for unit 3 and unit 4, and the other two units were standstill.
(3) 250 MW output was for unit 3 and unit 4, and the other two units were standstill.

The variation of vibration acceleration amplitude versus unit output was shown in Figure 2, and vibration spectrums of different test points were shown in Figure 3. Two conclusions could be obtained as below.

(1) When the unit output increased from 150 MW to 200 MW, the variation of vibration acceleration was very small; when the unit output increased from 200 MW to 250 MW, the vibration acceleration increased obviously.

(2) Under three operating conditions, the dominant frequency of vertical vibration of the floor was 100 Hz, as shown in Figure 3.
(b) Y-direction vibration acceleration amplitude under three operating conditions

(c) Z-direction vibration acceleration amplitude under three operating conditions

Figure 2. Vibration acceleration amplitude variations under three operating conditions

(a) Vibration spectrums of channel 3 under no. 1 (left) and no. 3 (right) operating conditions
The rotational frequency of the unit is 5.555 Hz, and the number of guide vanes and runner blades is 20 and 9 respectively. According to $K = m \times Z_g - n \times Z_r = 1 \times 20 - 2 \times 9 = 2$, leading to dominant RSI frequency corresponding to two times the runner blade passing frequency. The runner blade passing frequency is 50 Hz, and its harmonic frequency is 100 Hz.

As for the pump-turbine, the pressure fluctuation induced by the interaction of the guide vanes and the runner is always the main excitation source for the vibration of the unit and the hydropower station. The pressure fluctuation spectrums under three operating conditions (averaged gross head was 316.23 m) were shown as Figure 4, and it was seen that 50 Hz and 100 Hz components existed in the pressure fluctuation spectrums at the inlet of spiral casing, under the cover and at the vaneless area obviously.

Then, why the dominant frequency of the floor under three operating conditions was 100 Hz? Why the component of 50 Hz was so small? There was only one reason that the component of 100 Hz was magnified intensively because of the interaction between the excitation source and the vibration parts. In order to make sure this deduction, the natural frequency test of the column was performed.

Two thick columns and one thin column on the turbine floor were selected to perform the natural frequency test, and 12 sensors were installed on three columns, as shown in Figure 5. The total number of striking test was 18, and the vibration spectrums of 10 measuring points were illustrated in Figure 6, where “X, Y” denoted signal direction, and “mid” denoted the middle of the column, and “oppo” denoted the striking position was opposite to the measuring point.
Figure 4. Pressure fluctuation spectrums under three operating conditions
**Figure 5.** The measuring points of the columns on the turbine floor.
It was seen from Figure 6 that the first stage main frequencies of 10 measuring points on the columns were close to 100 Hz, especially the measuring points from no. 1 to no. 8. When the excitation source from the pressure fluctuation transferred to the columns, the influence of 100 Hz component was increased intensively, inducing severe vibration of the columns. The columns were installed in the floor, so the intensive vibration of the columns promoted the vibration of the floor.

3. Conclusions
The main conclusions and suggestions were as follows:

(1) The intensive pressure fluctuation at the vaneless area was the excitation source inducing intense vibration of local components of this pumped-storage power station.

(2) The X-direction natural frequencies of the columns in turbine floor are close to twice passing frequency of the runner (100 Hz), and it showed that the local resonance phenomena existed, which aggravated the vibration of the floor.

(3) The entire resonance of the hydropower station should be avoided absolutely during the process of designing, and resonance of local structures should be avoided as well.

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