Vibration Response Testing and Evaluation of A Hydropower Station’s Gate

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Abstract. We use standard vibration source to verify the method that vibration displacement was obtained by filter and integral in frequency domain. The feasibility and reliability of this method was confirmed. A gate’s vibration response such as acceleration, dynamic stress and displacement was tested. The vibration acceleration is less than 3 m/s², the vibration displacement is less than 0.25 mm, and the dynamic stress is less than 153.2 MPa. In the initial stage of the gate lifting, the maximum vibration displacement over the standard requirements. Vibration evaluation of the gate was given by the acceleration, displacement and dynamic stress.

1. Introduction
The hydropower station is located on the mainstream of Hongshui River in Guangxi Zhuang Autonomous Region. Eight bulb tubular hydro generators with a single unit capacity of 57 MW and a total installed capacity of 456 MW are installed. The project started construction in March 2005 and all 8 units were put into production in 2009. The power station has been running safely for 10 years. According to the relevant requirements, the metal structure of the power station needs to be inspected safely. Entrusted by the competent department of the power station, the water conservancy machinery quality inspection and testing center of the Ministry of Water Resources shall undertake the safety inspection work of the sluice gate of the power station. According to the operation management personnel, the 1# gate of the power station can feel obvious vibration during opening and closing, so it needs to be added to the vibration test.

"Hydraulic steel gate and hoist safety detection technical specification "(SL101, DL835), structural vibration detection mainly includes vibration response detection and dynamic characteristics detection. The vibration response detection includes vibration displacement, velocity, acceleration, and dynamic stress[1,2]. This test is mainly for vibration response detection.

2. Vibration Acceleration Test
When the gate is opened and closed, the forced vibration is mainly caused by the water flow, and the corresponding vibration acceleration and vibration energy are formed[3]. The IMI608A11 acceleration...
sensor is used to measure the vibration of the gate. The sensor is arranged in the middle position of the gate span. The acceleration value of the gate is collected from the closed state to the opening degree 1 m to the opening degree 2 m to the opening degree 3 m. Three acceleration sensors are arranged on the main beam flange of the middle part of the gate span respectively. The relationship between acceleration acquisition point (time) and voltage (acceleration) is shown in figure 1.

1#—3# maximum acceleration at each opening among 0.89 m/s²-32.55 m/s². Among them, the acceleration values of the gate in the process of holding at a certain opening are all relatively small, and the maximum acceleration of the three channels in the process of holding at three openings is less than 3 m/s². A maximum acceleration occurs when the gate is raised from close to 1 m opening. 32.55 m/s² is maximum. Based on relevant literature [4-9], the vibration acceleration of the gate is in the safe range.

3. Displacement test
The displacement test mainly depends on the displacement sensor or acceleration integral mode. Through the test and analysis, it is found that the layout of the gate displacement sensor is inconvenient and coincides with the test position of the vibration acceleration sensor. The displacement value data of the system software integral is too large. Therefore, it is necessary to study the form of acceleration integral displacement, and finally determine that by converting acceleration signal to a frequency domain, Fourier transform is carried out, the quadratic integral is carried out after frequency domain filtering, and then Fourier inverse transform is carried out to time domain. To test the reliability of the transformation method, the data acquisition and analysis are carried out by a standard vibration source.

3.1. Standard Vibration Source Test
The model of standard handheld vibration source is Model 394C06, its working frequency is 159.2 Hz(±1%), and the effective value of vibration acceleration is 9.81 m/s²(±3%), the effective value of vibration velocity is 9.81 mm/s, the effective value of vibration displacement is 9.81 μm. The standard vibration source test acceleration is shown in figure 2.
According to the standard vibration source acceleration curve, the effective value of acceleration is 9.815m/s², the frequency is 1159.1Hz. They are consistent with the nominal value of the vibration source. Through spectrum analysis of acceleration signal and setting minimum cutoff frequency 80 Hz, maximum cutoff frequency 300 Hz, frequency domain filtering, the displacement curve obtained after Fourier inverse transformation is shown in figure 3.

From figure 3, the effective value of the displacement curve obtained by quadratic integration after filtering in the frequency domain is 9.822μm, which is consistent with the nominal value of the standard vibration source. The feasibility and reliability of frequency domain integration are verified by the test of the standard vibration source.

3.2. Gate testing
Using the measured vibration acceleration data and the integration process of 2.1, the maximum vibration displacement of the gate is less than 0.5mm, and the effective value of the vibration displacement is less than 0.25mm. When the gate is opened, the instantaneous value of vibration displacement is 0.715mm, when the gate is opened to 1m, the instantaneous value of vibration displacement is 0.541mm, and the instantaneous value of vibration displacement is 2.459mm during the gate descent.

Based on the displacement of vibration hazard of Arkansas river gate[10-15], a severe vibration occurs when the average displacement is greater than 0.508mm. Therefore, the overall vibration displacement of the gate meets the requirements of the standard, and the maximum displacement of individual operating states only in the initial stage of hoisting exceeds the standard requirements.

4. Dynamic stress testing
The gate vibration stress is generated under pulsating water pressure, using the "strain electric measurement method". The signal is obtained by the resistance strain gauge pasted on the force position, and the remote measurement is realized by wireless transmission. When testing, the upstream water level of the gate is 82.87m, the downstream water level is 65.51m, the design head is 24m, the actual action head of the gate is 17.36m.
For three-way strain gauges:

\[
\sigma_{1,2} = \frac{\eta E}{2\eta_1} \left[ \varepsilon_x + \varepsilon_y \pm \frac{1}{1 - \mu} \sqrt{2(\varepsilon_x - \varepsilon_y)^2 + 2(\varepsilon_{xy} - \varepsilon_y)^2} \right]
\]

Principal stress

\[
\theta = \frac{1}{2} \tan^{-1} \left[ \frac{2\varepsilon_{xy} - (\varepsilon_x + \varepsilon_y)}{\varepsilon_x - \varepsilon_y} \right]
\]

Equivalent stress

\[
\sigma = \frac{\eta E}{2\eta_1} \sqrt{\frac{(\varepsilon_x + \varepsilon_y)^2 + 6(\varepsilon_x - \varepsilon_{xy})^2 + (\varepsilon_{xy} - \varepsilon_y)^2}{(1 - \mu)^2}}
\]

\(\sigma_{1,2}\) in the formula is maximum principal stress and minimum principal stress; \(\eta\) is sensitivity coefficient of strain gauge; \(\eta_1\) is sensitivity coefficient of strain gauge; \(E\) is modulus of elasticity \((2.06 \times 10^5 \text{MPa})\); \(\mu\) is Poisson’s ratio \((0.3\) in steel); \(\varepsilon_x, \varepsilon_y, \varepsilon_{xy}\) are \(0^\circ, 90^\circ, 45^\circ\) direction strain value; \(\theta\) is the angle of principal stress direction.

5. Vibration evaluation

Combined with the acceleration test, displacement test, and dynamic stress test of the gate, the vibration acceleration and dynamic stress of the gate do not exceed the limit value. The maximum displacement of gate vibration displacement only in the initial stage of hoisting exceeds the relevant reference value, and the effective value of gate vibration displacement meets the requirements. The comprehensive evaluation of the vibration of the gate meets the requirements. It is suggested that the observation should continue in the process of opening and closing. When there is obvious vibration, special vibration detection can be done, and the resonance of the gate can be analyzed.

6. Conclusion

Acoustic emission monitoring technology has high sensitivity to crack growth monitoring and can be well positioned according to sensor arrays. As safe monitoring means of the hydraulic test of steel bifurcation pipe, it is advantageous and necessary. It can warn the dangerous situation in the process of raising pressure and keeping the pressure of hydraulic test of retaining branch pipe and ensure the safety of test effectively.

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