



Vibration analysis of large bulb tubular pump house under pressure pulsations

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Abstract: A 3D finite element model of the Huaiyin third pumping station of the Eastern Route of the South-to-North Water Transfer is described in this paper. Two methods were used in the calculation and vibration analysis of the pumping station in both the time domain and the frequency domain. The pressure pulsation field of the whole flow passage was structured on the basis of pressure pulsations recorded at some locations of the physical model test. Dynamic time-history analysis of the pump house under pressure pulsations was carried out. At the same time, according to spectrum characteristics of the pressure pulsations at measuring points and results of free vibration characteristics analysis of the pump house, the spectrum analysis method of random vibration was used to calculate dynamic responses of the pump house. Results from both methods are consistent, which indicates that they are both reasonable. The results can be used for reference in anti-vibration safety evaluation of the Huaiyin third pumping station.

Key words: pump house; pressure pulsation; time-history analysis; random vibration spectrum analysis

1 Introduction

The problem of vibrations of large pumping stations has attracted a lot of attention for a long time. This kind of long-term continuous vibration greatly influences devices in the pump house as well as the bodies of staff who control and monitor these devices, and severe vibrations affect the safety and reliability of the hydro-turbine. Hydraulic exciting vibration is a main reason for pumping station vibration. However, the interaction between the flow and structure is very complicated. Reasonable calculation of vibration responses under pressure pulsations of the pump house and correct evaluation of anti-vibration safety of the pump house have always been the research emphases.

At present, methods used to calculate the dynamic responses of the pump house mainly include the resonant check method, pseudo-static method, harmonic response method, and dynamic time-history method (Ohura et al. 1990; Ma et al. 2004; Ouyang et al. 2005). Of these, the dynamic time-history method is most commonly used because it can obtain more

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reasonable vibration responses. However, no matter which method is selected, load characteristics of flow pulsations should be known before calculation. There are mainly two means of obtaining the load characteristics of pressure pulsation: physical model tests, and numerical model calculation. It is difficult to decide whether it is suitable and reasonable to simulate the practical problem as well as to determine the resemblance between the calculated results and practical observation. Therefore, the means of the physical model tests are usually used to obtain pressure pulsation data, especially for large and important projects. In this study, on the basis of the pressure pulsations measured in the physical model test of the Huaiyin third pumping station, the time-history method was used to calculate the dynamic responses of the pump house in the time domain. At the same time, based on spectrum characteristics and relativity analysis (Wang et al. 1998), the spectrum analysis method of random vibration (Zhao et al. 2005) was used to calculate the root mean square value of pump house vibration. The results of the two methods are compared to show the rationality of these calculations.

2 Random vibration spectrum analysis

The finite element method (FEM) dynamic analysis equation is

$$\mathbf{K}\boldsymbol{\delta} + \mathbf{C}\dot{\boldsymbol{\delta}} + \mathbf{M}\ddot{\boldsymbol{\delta}} = \mathbf{F} \quad (1)$$

where $\boldsymbol{\delta}$, $\dot{\boldsymbol{\delta}}$, and $\ddot{\boldsymbol{\delta}}$ are the column vectors of the nodal displacement, nodal velocity, and nodal acceleration, respectively; and $\mathbf{K}$, $\mathbf{C}$, $\mathbf{M}$, and $\mathbf{F}$ are the global stiffness matrix, the global damping matrix, the global mass matrix and the nodal load column vector, respectively. $\mathbf{M}$ includes the added mass matrix of the water. In fact, these global matrices are assembled with their element matrices.

At first, free vibration characteristics of the structure that relate to the interaction between the structure and the water, that is, the vibration mode of the lowest p steps $\boldsymbol{\varphi} = (\boldsymbol{\varphi}_1, \boldsymbol{\varphi}_2, \dots, \boldsymbol{\varphi}_p)$ and corresponding frequency $\boldsymbol{\omega} = (\omega_1, \omega_2, \dots, \omega_p)^T$, should be obtained. Based on the expansion method of the vibration mode, $\boldsymbol{\delta}$ can be expressed by the function of generalized coordinates, $\boldsymbol{\delta} = \boldsymbol{\varphi}\mathbf{Y}$, which can lead to the FEM dynamic equation of the discrete structure. The dynamic equation remains to be multiplied by $\boldsymbol{\varphi}^T$:

$$\mathbf{K}^*\mathbf{Y} + \mathbf{C}^*\dot{\mathbf{Y}} + \mathbf{M}^*\ddot{\mathbf{Y}} = \mathbf{F}^* \quad (2)$$

where $\mathbf{K}^*$, $\mathbf{C}^*$, $\mathbf{M}^*$ and $\mathbf{F}^*$ are the generalized stiffness matrix, generalized damping matrix, generalized mass matrix and generalized force vector, respectively.

When proportional damping theory is used, the orthogonality equation (Eq. (2)) can be decoupled to form

$$\ddot{\mathbf{Y}}_j(t) + 2\xi_j\omega_j\dot{\mathbf{Y}}_j(t) + \omega_j^2\mathbf{Y}_j(t) = \frac{\mathbf{F}_j^*}{m_j^*} = f_j(t) \quad (3)$$

where the subscript j is the j th step vibration mode; ξ_j , ω_j , m_j^* , $\mathbf{F}_j^*$ are the damping ratio, the frequency, the generalized mass and the generalized force vector of the j th step, respectively; and $\mathbf{Y}_j(t)$ is the generalized coordinate of the j th step at time t .

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