Time-frequency domain identification of dynamic loads on hydropower station

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Abstract: In this study the wavelet-based analysis technique is proposed for analyzing its time-frequency characteristics, and identifying its maximum dynamic loads with genetic algorithm. The signals extracted by wavelet analysis are furthermore used for estimating the modelling parameters and loads. It is also indicated that the load amplitudes estimated with the extracted data by wavelet analysis can provides more detailed and finer information than those by Fourier analysis technique. This study is a valuable reference for investigating the vibrating source rule and predicting the dynamic response of powerhouse structures.

1. Introduction
The vibration of powerhouse structure is an important problem during its design and operation. The significant dynamic modal parameters include damping ratio, material parameters, boundary conditions and dynamic loads. However, direct measuring of these components will be quite difficult because of their complicated mechanism and the giant structure. Therefore, it is very valuable for finding out an efficient method to set up a rational parametric model utilizing the dynamic response measurements of the structure and the system identification theory [1, 2].

Most of the dynamic analysis for hydropower plant’s supporting structure is based on the Fourier Transformation technique (FFT) previously. But the FFT is more appropriate in linear systems than nonlinear systems. Wavelet transform is a fundamentally different approach from Fourier theory [3]. In this novel transformation, a signal is not decomposed into its harmonics, which are global functions that have support on [-∞, +∞], but into a series of local basis functions called wavelets, which are of a waveform of effectively limited duration and having an average value of zero. At the finest scale, the wavelets may be very long. By wavelet
transform, any particular local features of signals could be detected and identified from the scale and the position of the wavelets.

In this paper, combining the finite element analysis and field test of Xilongchi Pumped-storage Power Station located on the Shanxi province in China, the selection of the wavelet transform for its loads analysis and identification is discussed. The purpose of this paper is to provide the advanced technology that is conducted on vibratory analysis of the powerhouse structure by wavelet analysis.

2. Analysis of field experiments

In this study, we used 8 transducers on different positions of the powerhouse, by radial and vertical directions on different floors, piers and airhoods, as shown in figure 1. The frequency range of vibration-measuring device is $0.5\text{Hz} \sim 125\text{Hz}$. This study identifies chiefly the loads involved in the 50MW partial load operation condition.

Firstly, measured variation signals are analyzed by Fourier transform. The result shows the most important dynamic loads on hydropower plant’s supporting structure are 58.08Hz hydraulic pulsation caused by the non-uniform wave of turbine blades; the other loads include hydraulic pulsations as white noise in spiral case and tailrace, the 50Hz or 100Hz unbalanced magnetic pull, and the 8.33Hz rotating unbalanced loads.

Subsequently, by applying wavelet function of Daubechies of order 2 (db2), all signals are decomposed into level 12. The time-frequency signals of 58.08Hz can be extracted from level 2 detail (D2), with example of the radial signal of DA4 shown in figure 2. Table 1 contrasts its maximum amplitude of wavelet analysis in confidence 97% with the amplitude of the Fourier transform. It is revealed that the amplitude by wavelet analysis is much higher than that by the Fourier transform. This also indicates that the 58.08Hz hydraulic pulsation of turbine blades is quite unstable, and its amplitude varies severely with time.
Table 1. Contrast of maximum amplitude of wavelet analysis in confidence 97% and of the Fourier transform (cm/s²)

| points | wavelet analysis | FFT analysis | wavelet analysis | FFT analysis |
|--------|------------------|--------------|------------------|--------------|
| DA8    | 19.64            | 5.44         | 16.18            | 2.06         |
| DA7    | 16.53            | 4.56         | 15.18            | 4.93         |
| DA6    | 8.30             | 1.59         | 12.86            | 4.16         |
| DA5    | 9.08             | 2.06         | 8.26             | 2.37         |
| DA4    | 11.02            | 2.27         | 9.83             | 1.27         |
| DA3    | 6.22             | 0.78         | 7.36             | 1.17         |
| DA2    | 6.15             | 1.34         | 5.63             | 0.45         |
| DA1    | 5.56             | 1.29         | 2.80             | 0.25         |

3. Identification of 58.08Hz hydraulic pulsation

The previous study in Ref.[5] shows that the acting mode of 58.08Hz hydraulic pulsation caused by turbine blades has three ways: the first is hydraulic vibration acting on the spiral case and stay ring etc. directly; the second is concentrated forces acting on lower bracket-arms transmitting from turbine axis; and the another is concentrated forces acting on upper bracket-arms.

3.1 Identifying method

The proposed identifying procedure shown in figure 3 provides a method to transform a parametric identification into an objective function optimization. By iterative calculating and modifying identified parameters to achieve the minimum of the objective function, the optimum load value is obtained. It is implemented by using the software ANSYS and Genetic algorithm. ANSYS is used to generate the FEM model (shown in figure 4), computing structural dynamic response. Genetic algorithm is applied to optimum identifying the loads.
The objective function of Genetic algorithm is as following:

$$
\mathcal{E} = \frac{1}{M} \sum_{i=1}^{M} \left[ \frac{(A_m(i) - A_e(i))}{A_m(i)} \right]^2
$$

Where $A_m(i)$ and $A_e(i)$ are the measured amplitude and the calculated amplitude respectively; $M$ is the total of survey points.

3.2 Identified results and analysis

Using the radial datum of all measuring points to identify, the load results are obtained as following:

Based on the wavelet analysis, the single amplitude of 58.08Hz hydraulic vibration in spiral case is 17.6KN/m$^2$ (equal to 1.8m head pressure); the single amplitude of resultant force on lower bracket-arms is 57KN; the single amplitude of resultant force on upper bracket-arms is 1.12KN.

Otherwise, based on the Fourier analysis, the single amplitude of 58.08Hz hydraulic vibration in spiral case is 4.83KN/m$^2$ (equal to 0.5m head pressure); the single amplitude of resultant force on lower bracket-arms is 8.28KN; the single amplitude of resultant force on upper bracket-arms is 0.352KN.

The identified results show that the load values of hydraulic vibration caused by turbine blades are smaller during the 50MW partial load operation condition. The primary transmitted load resulting to the powerhouse vibration is hydraulic excitation acting on the spiral case liner, the secondary load excitation source is acting on the lower bracket-arms, and the load acting on the upper bracket-arms is relatively very small.

The identified load values based on the wavelet analysis are much greater than the values based on the Fourier analysis. Respectively, the values of hydraulic load acting on the spiral case and the force on lower bracket-arms identified from wavelet analysis are 3.6 and 6.9 times greater than the values identified from Fourier analysis. So the time-frequency analysis of wavelet transformation can provides more detailed and finer information about non-stationary signals than traditional Fourier analysis in the dynamic analysis of the powerhouse structures.
4. Summary and conclusion

In this paper, with the field test of Xilongchi Pumped-storage Power Station, the selection of the wavelet transform for its loads analysis and identification is discussed. The important hydraulic load of turbine blades is identified and analyzed. It shows that the amplitude of certain frequency load on the plant concrete structure is not invariant with the time varying, and it is not a standard harmonic. The traditional Fourier analysis cannot obtain the real maximum values of loads. So the advanced time-frequency analysis of wavelet transform is very important and significant for investigating the vibrating source and predicting the dynamic response of powerhouse structures.

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