Analysis on vibration of small-scale hydroelectric generating unit

Liying Wang*, Lisha You

School of Water Conservancy and Hydropower, Hebei University of Engineering, Handan 056021, China

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Abstract

An analytical model for the vibrations of operating conditions of small-scale hydroelectric generating unit is developed based on frequency domain and time domain. Firstly the vibration of unit 2 in Xida hydropower station is tested by using intelligent data logger, where the DASP10 software is used to collect the data and analyse them; and then the data are analysed by the time domain analysis, shaft centreline orbit analysis and auto-spectrum analysis respectively. Finally some instructive conclusions on the exceedance of shaft degrees and the overweight phenomena are drawn, which may assist an overhaul to raise the operating efficiency and the power output.

Keywords: Hydroelectric Generating Unit, Vibration, Time Domain Analysis, Shaft Centreline Orbit, Auto-spectrum Analysis

1 Introduction

In recent years, a large number of small hydropower stations have sprung up in many urban and rural areas, it has become an indispensable part of residential living electricity and industrial electricity in China, but the small-scale hydrocelectric generating units have a poor performance in the quality and efficiency at present due to low investment, the limitation of technical level and there is often lack of the monitoring and analysis of unit vibration, which causes many units damage [1]. At present, the analysis and research methods, which are used in turbine vibration have the following kinds: fluid numerical calculation, model test, real machine test, and system modelling identification study [2-5]. In this paper, according to the reality and other factors, the real machine test method is used to monitor and analyse the vibration of unit 2 in Xida hydropower station, meanwhile the obtained data are analysed by the time domain analysis, shaft centreline orbit analysis and auto-spectrum analysis respectively, some instructive and important conclusions on the exceedance of shaft degrees and the overweight phenomena are drawn.

Xida hydropower station located in She county of Handan was founded in the late 1980s, and it belongs to the typical small hydropower, its rated power is 500kw, its rated speed is 375r/min. In the daily operation process, the engineering technicians find that there exists an abnormal vibration and a higher oil temperature in the bearing of units after excitation.

2 Experimental test systems

2.1 MONITORING POINT ARRANGEMENT

Unit 2 in Xida hydropower station is the test object, the X, Y directions of large shaft flange and water guide bearing all decorate eddy current transducers, and the X, Y, Z directions of upper bracket, lower guide bearing, water guide bearing and the head cover respectively arrange acceleration sensors. Figure 1 is the test site arrangement.

FIGURE 1 Test site arrangement

2.2 WORKING CONDITIONS SET

The test is divided into 12 working conditions which are as follows: the boot, plus exciting ,synchronization, load increasing to 250kw, load increasing to 500kw, load increasing to 600kw, keeping 600kw, load reducing to 500kw, load reducing to 250kw, splitting, reducing excitation, shutdown.

3 The basic analysis method

3.1 TIME DOMAIN ANALYSIS METHOD

Time domain analysis method is most commonly used in vibration signal analysis, the waveform is generated by the original waveform signal, which has a strong intuitive, and can accurately show the change trend of the signal amplitudes with the time [6, 7].

* ***Corresponding author*** e-mail: 2000wangly@163.com

In vibration measurement, there are three basic parameters: displacement, velocity and acceleration, the formulas are given below respectively:

$$x = A\sin(\omega t + \phi), \quad (1)$$

$$\dot{x} = A\omega\cos(\omega t + \phi), \quad (2)$$

$$\ddot{x} = -A\omega^2 \sin(\omega t + \phi). \quad (3)$$

3.2 SHAFT CENTRELINE ORBIT ANALYSIS

Shaft centreline orbit is refers to the axis of rotation in the rotating machinery and the axis is relative to the trajectory of the bearing. In the actual operation process, the abnormal vibration of hydroelectric generating unit will respond on the locus of journal bearing. The Shaft centreline orbit diagram shows the operation situation, which is a simple visual image method, and one can see the change situation from the diagram, and is easier to determine the vibration sources, which influence the stability of unit [8, 9].

3.3 AUTO SPECTRUM ANALYSIS

Auto-spectrum analysis transforms signals from time domain to frequency domain, and each periodic harmonic component corresponding to the spectrum of the signals is obtained. With the change of factor generated by the frequency of the vibration signals, the vibration will be changed., the frequency domain analysis is carried out on the collected signal to better grasp the dynamic law of vibration. The meaning of auto-spectrum analysis is a more complex signal of waveform in a specific period, which is, transformed various harmonic amplitudes the frequency and phase information and they are divided into multiple independent harmonic components [10, 11].

The signals are transformed by fast Fourier, which is defined as follows:

$$x(\omega) = \int_{-\infty}^{\infty} x(t)e^{-j\omega t}dt, \quad (4)$$

where: $\omega = 2\pi f$, f(t) is time domain data sequence and $x(\omega)$ is the frequency spectrum function of the sequence. Its inverse transformation form is:

$$x(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} x(\omega)e^{j\omega t}dt, \quad (5)$$

$x(\omega)$ is a complex function:

$$x(\omega) = |x(\omega)|e^{j(\omega)}, \quad (6)$$

$|x(\omega)|$ is the amplitude function of $x(\omega)$. In practice, the amplitude-frequency drawing cannot be coming out, the frequency density of $x(\omega)$ usually can be used to make an approximate description:

$$x(\omega) = 2\pi x(f). \quad (7)$$

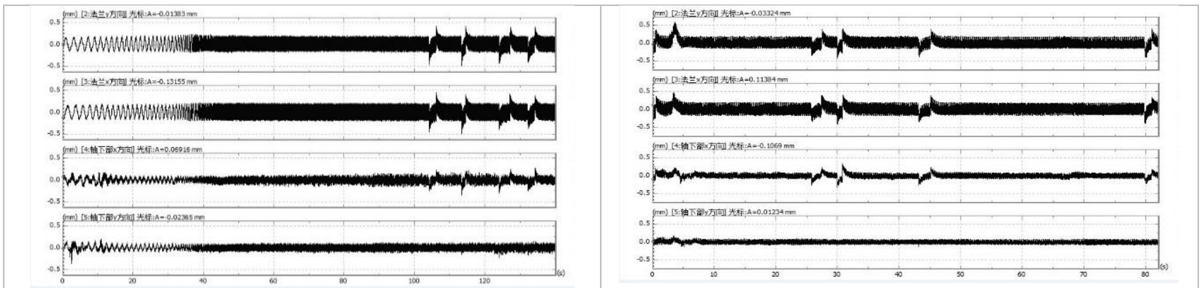
In this test, the spectrum analysis is used to judge the vibration of hydro-generator units. In analysis, FFT is used to make a frequency domain analysis for the vibration signals.

4 The analysis results

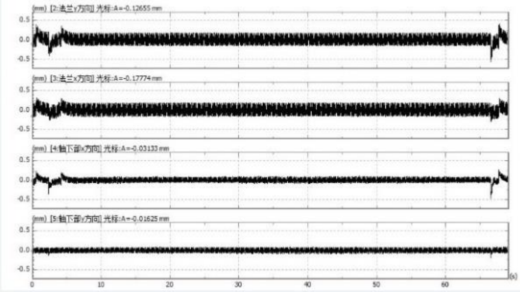
4.1 TIME DOMAIN ANALYSIS RESULTS OF SHAFT SWING

Under the working condition of the above 12, the data are analysed respectively for time domain analysis; the results are shown in Figure 2.

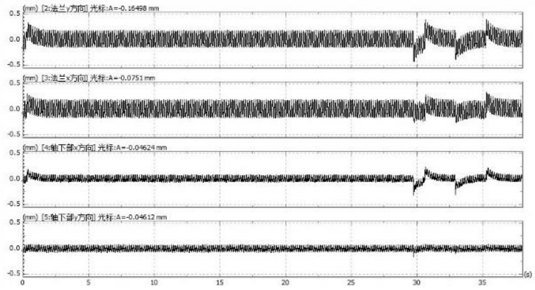
It can be seen that, from Figure 2, when the conditions are in a state of stable work, shaft swing is beyond status, the maximum superscalar is 0.465mm and 0.447mm in X and Y directions, (the allowed values is 0.250mm); under most of the working conditions, the shaft swing at water guide bearing in X and Y direction is in the acceptable range, only in the part of the time period, it is in excessive state, X direction is 0.353mm and 0.263mm, Y direction is 0.575mm and 0.362mm, (the allowed values is 0.250mm). When the working conditions are changing, the shaft swing is also in excessive state, the maximum superscalar is 1.808 mm and 0.974mm in X and Y directions under the reduction excitation condition, (the allowed values is 0.250mm); the shaft swing at water guide bearing in X direction is in excessive state, the biggest superscalar is 0.766mm under the reduction excitation condition, (the allowed values is 0.250mm), the shaft swing in Y direction is in the acceptable range only under the processes of synchronization, load increasing and keep 600kw. Under other conditions, the swing is overweight; the largest superscalar also occurs under reduction excitation condition, the value is 1.206mm, (the allowed values is 0.250mm). Based on the above analysis, we can draw a conclusion that the shaft swing is the biggest in the reduction excitation condition.



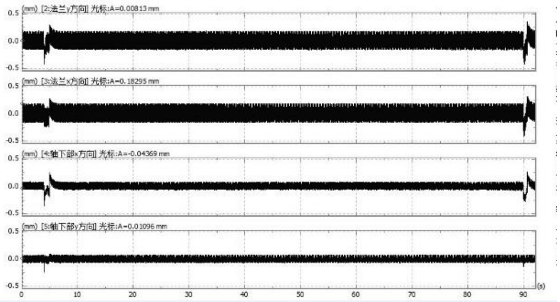
(a) The boot condition (b) The plus exciting condition



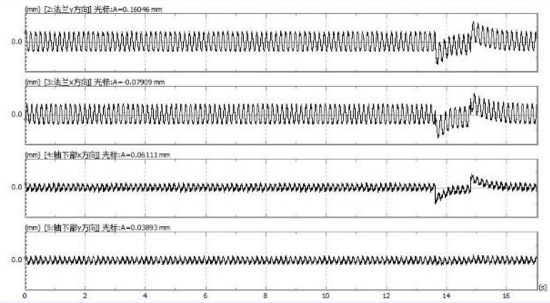
(c) The synchronization condition



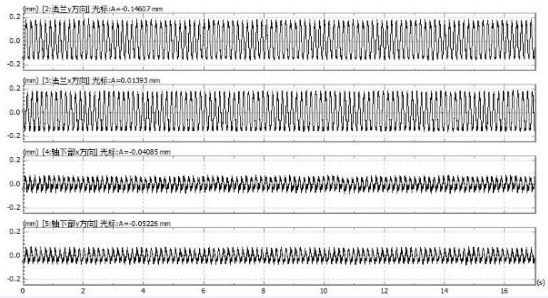
(d) The load increasing to 250kw condition



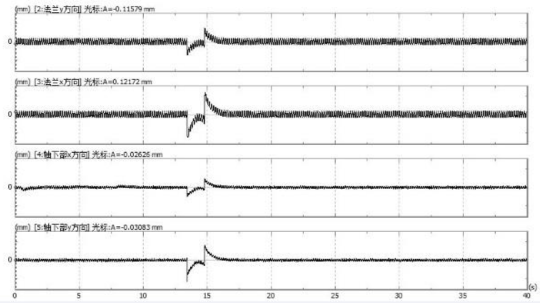
(e) The load increasing to 500kw condition



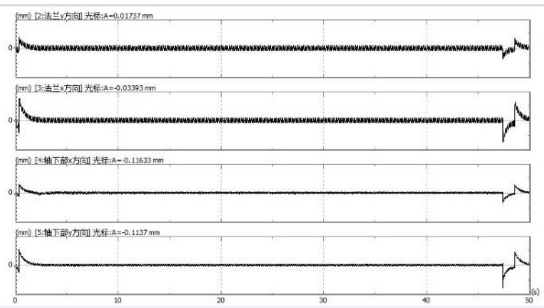
(f) The load increasing to 600kw condition



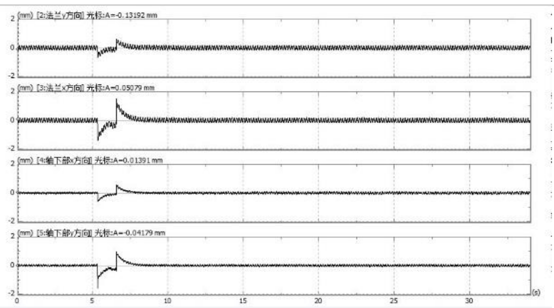
(g) The keeping 600kw condition



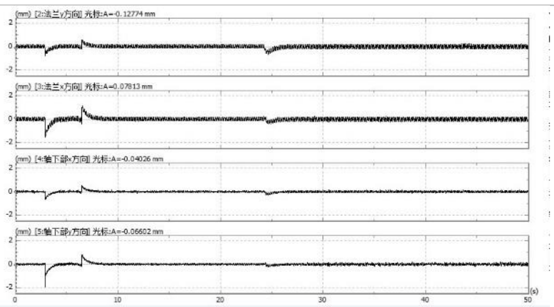
(h) The load reducing to 500kw condition



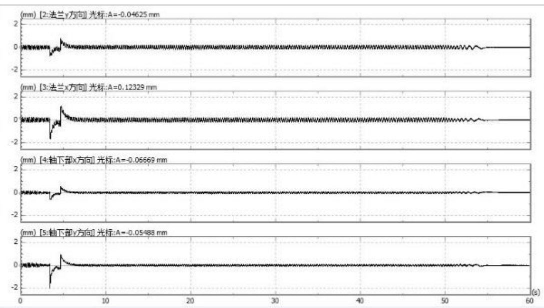
(i) The load reducing to 250kw condition



(j) The splitting condition



(k) The reducing excitation condition

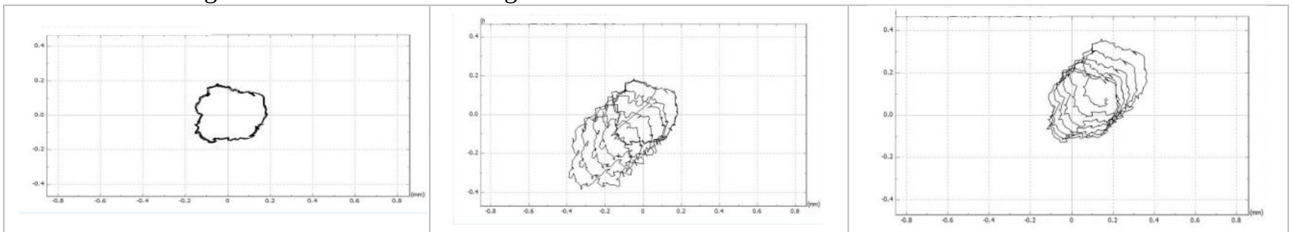


(l) The shutdown condition

FIGURE 2 The time domain of shaft swing at flange and water guide bearing under various conditions

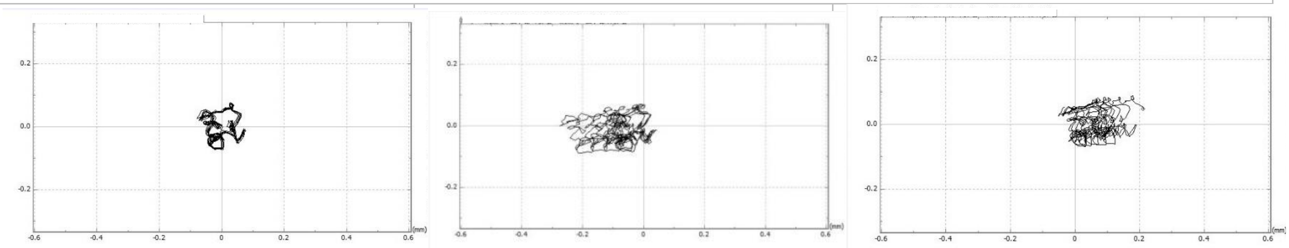
4.2 SHAFT CETRELINE ORBIT ANALYSIS RESULTS OF SHAFT CSCILLATION

The x-y graph analysis is proceeded at flange and water guide bearing under all conditions, due to space problem, we take the working condition of load increasing to 600kw as an example; the axis trajectory deviation is shown in Figure 3 and Figure 4, From the graph, we can see that when conditions change or the load is adjusted, the axis trajectory is unstable and produces deviation, the offset direction is roughly same, and the offset amplitudes are different.



(a) Under stable operation condition (b) Under load increasing to 600kw condition (c) Under load increasing to 600kw condition

FIGURE 3 The axis trajectory for shaft flange



(a) Under stable operation condition (b) Under load increasing to 600kw condition (c) Under load increasing to 600kw condition

FIGURE 4 The axis trajectory for water guide bearing

4.2 AUTO SPECTRUM ANALYSIS RESULTS OF SHAFT OSCILLATION

The auto-spectrum analysis is used in shaft oscillation; the analytical results under each condition are shown in Table 1. From the Table 1, we can find that the vibration frequencies mainly concentrate in 1HZ, 2HZ, 6HZ, 19HZ, 25HZ, and 50HZ, the turbines rotation frequency is 6.25HZ, the vibration frequency 6HZ is close to rotation frequency 6.25HZ, the frequencies 25HZ and 50HZ respectively are 4 times and 8 times of rotation frequencies, mainly from the different number of guide vanes and runner blades, the frequencies 1HZ and 2HZ are from 0.15 to 0.3 times of rotating frequencies.

TABLE 1 Auto-spectrum analysis (HZ)

Direction	**X of flange**	**Y of flange**	**X of water guide bearing**	**Y of water guide bearing**
the boot	7,1	7,1	7,1,25,20	7,1
plus exciting	6,1	6,1	6,1,25,19	6,19
synchronization	6,1	6,1	6,1,25,19	6,19
load increasing to 250kw	6	6,1	6,1,25,19	6
load increasing to 500kw	6,1	6,1	6,1,25,19	6
load increasing to 600kw	6,1	6,1	6,1,25,19	6
keeping 600 kw	6	6	6,25,19	6
load reducing to 500kw	6,1	6,1	6,1,25,19	1,6
load reducing to 250kw	6,1	6,1	1,6,19	1,6,19
splitting	1,6	6,1	1,6,19	1,6,19
reducing excitation	6,1	6,1	1,6,25	1,6
shutdown	4,1	4,1	1,4,25	1,4

4.3 THE REASON OF SHAFT SWING

Based on the above analysis, we can discover that the shaft swing is biggest change in the reduction excitation condition, it is because that the generator unbalanced magnetic pull and the bearing clearance are not uniform, moreover, the hydraulic turbine thrust bearing is positioned in the upper guide bearing and the swing of flange is always greater than that of water guide bearing, the shaft swing exists in the inflection point. In runtime, the shaft swing degrees of the main frequency is close to 6.25HZ, the rotation frequency of the turbine indicates that the axis of turbine is not straight or has some mechanical l problems such as bad entering and so on.

When the working condition changes, the shaft centreline orbit has a large range of migration, which is concerned on the electromagnetic factor and hydroelectric factor. The flange shaft orbit is elliptical and the water guide bearing shaft orbit is distorted and has more spikes, the reason is that the runner blades are impacted by water, and the different number of guide vanes and runner blades lead to the hydraulic factors such as frequency difference of water conservancy.

5 Conclusions

In all working conditions, the shaft degrees are beyond the scope of the standard state, when the conditions change, the shaft centreline orbit will appear larger range of deviation. The cause of this abnormal situation is more complex, on the one hand, the main shaft axis is not straight has an undesirable phenomena, on the other hand, the hydro-generator exists unbalanced magnetic pull and uneven bearing clearance and so on.

In addition, there exists overweight phenomena in upper bracket, lower guide bearing, water guide bearing and head cover; when the load is 500kw, the vibration is the most serious. From the vibration frequency analysis, it also can be reflected that the causes of turbine vibration is more complex, not only the mechanical and electromagnetic aspects, but hydraulic factors are all should be considered.

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Authors

Liying Wang, born on January 6, 1978, in Shijiazhuang, Hebei Province, China

University studies: M.S. degree in Institute of Mechanism, Shijiazhuang Tiedao University, in 2003; she received the Ph.D. degree in vehicle engineering from Beijng Jiaotong University, China in 2014.
Scientific interests: intelligent computing, intelligent control theory, and control systems engineering.

Lisha You, born on October 14, 1989, China

Current position, grades: a graduate student at Hebei University of Engineering, China
University studies: Bachelor degee in thermal energy and power engineering from Hebei University of Engineering, China in 2012.
Scientific interests: hydraulic turbine and mechanical vibration.