Correlation Dimension for Pressure Fluctuation in Hydraulic Turbine Draft Tube

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***Abstract*—Based on the actual experiment signals of draft tube, the correlation dimension analysis has been carried on using the time domain signals. Through correlation dimension analysis of pressure fluctuating under different load, the results indicate that the pressure fluctuation conditions in draft tube are not same under different load, the corresponding fractal correlation dimensions are also different. So the correlation dimension can well identificate the situation of pressure fluctuation and instruct the steady operation of hydroelectric power station.**

***Index Terms*—Correlation Dimension, Embedding dimension; Pressure Fluctuation, Draft Tube**

I. INTRODUCTION

Pressure fluctuation in draft tube [1] is a main factor which effects the stable operation of turbine, in the operation process, all sorts of dynamic testing instruments are used to loot, record and analyze the pressure fluctuation signals, which can control the stable operation of turbine. In recent years, scientific and technological personals have discussed the pressure fluctuation in draft tube; reference [2] investigated the model turbine and analyzed the change rule of draft tube under different positions and different working conditions, which provides reference for improving the design of draft tube. Pressure fluctuation signals are random, many of which are nonlinear, many characteristics can not get only from the instrument and the personal experience, so it is not easy to accurately grasp operation situation of the turbine. In order to accurately master the change rule, it is very necessary for us to choose an advanced diagnosis technology and method.

Fractal dimension is important parameter to describe chaos phenomena of complex system, in which, fractal correlation dimension has a good characteristic through establishing the relationship between the space reconstruction and nonlinear problem. It is very meaningful to realize the automatic identification by fractal correlation dimension to analyze the pressure fluctuation in draft tube, in this paper, fractal correlation dimension [3] is used to analyze the pressure fluctuation in draft tube, the simulation experiments demonstrate that correlation dimension for pressure fluctuation in hydraulic turbine draft tube is practicable

II. THE PRINCIPLE OF CORRELATION DIMENSION

Correlation dimension [4] calculation involves reconstruction of the phase space which plays an important impact on the reliability of the correlation dimension calculation in which time delay and embedded dimension are two main parameters.

Correlation dimension calculation method was first put forward by Grassberger and Procaccia, known as the GP algorithm. The algorithm experienced a lot of improvements. Specific calculation process is as follows:

A. Build m dimension model space

Considering a measured data sequence $X=\{x_1,x_2,x_3,\cdots,x_i,\cdots,x_n\}$ from experiment, in which T_s is sample interval, x_i is short for the measured value x_{iT_s} at time i. For we do not know the dimension of phase space, we firstly set up a m dimension space using those team number, the first few points of which constitute a m dimension space vector y_1:

$$y_1=(x_1,x_2,x_3\cdots,x_i,\cdots,x_m)$$

Shift the start point to right for a time interval $\tau=kT_s$ (k is an integer) and constitute another m dimension space vector y_2:

$$y_2=\{x_{1+k},x_{2+k},x_{3+k},\cdots,x_{i+k},\cdots x_{m+k}\}$$

In this way, we set up a m dimensional phase space including a set of m dimension vector:

$$\{y_1\}\quad (i=1,2,3,\cdots,N_m)$$

Where k is time delay; m is embedded dimension; $N_m=n-(m-1)$ is the number of vectors in the reconstructed phase space.

B CalculateTthe Distances Between Different Vectors

Take a random vector y_1 from N_m as a reference point. Calculate the distances between the reference point and remaining points:

$$r_{ij}=d(y_i,y_j)=\left[\sum_{l=0}^{m-1}(x_{i+1}-x_{j+1})^2\right]^{\frac{1}{2}} \tag{1}$$

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For all points $\{y_1\}$, repeat the calculation and get a $N_M \times N_m$ matrix R

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1N_m} \\ r_{21} & r_{22} & \cdots & r_{2N_m} \\ & & \cdots & \\ r_{N_m1} & r_{N_m2} & \cdots & r_{N_mN_m} \end{bmatrix} \quad (2)$$

(3)Calculate the correlation function

For a given number $r(r>0)$, the definition of correlation function is:

$$C(r) = \lim_{N_m \to \infty} \frac{1}{N_m^2} \sum_{i=1}^{N_m} \sum_{j=1}^{N_m} \left[H(r - r_{ij}) \right] \quad (i \neq j) \quad (3)$$

In which H is Heaviside function, defined as:

$$H(u) = \begin{cases} 1 & (u \geq 0) \\ 0 & (u < 0) \end{cases} \quad (4)$$

Correlation function reflects the proportion of distance between two points less than r in the reconstructed m dimension phase space. Correlation function is a function of the given r. If r is too large, distances between points will not exceed r and correlation function $C(r)=1$, which can not reflect the internal nature of the system. If r is too small, all the distances will exceed r and correlation function $C(r)=0$, then r still can not reflect the entities objectively. So the value range of r is limited in size at both ends.

(4)Calculate the correlation dimension

When the r value falls into a certain rang, there is a relationship:

$$\lim_{r \to 0} C(r) = r^d \quad , \quad d = \lim_{r \to 0} \frac{\ln C(r)}{\ln r} \quad (5)$$

Vector d is defined as the correlation dimension of the vector set $\{y_1\}$ $(i = 1, 2, 3, \cdots, N_m)$.

III. The Experiment Processes

A Basic Parameters

The total capacity of this Hydropower station is 880MW(4×220MW), The basic parameters of this hydropower station are as follows:

B Point Position Selection

For point position selection [5, 6], amplitude in the point position should be large than other positions, from the experience and some literatures, the largest value of pressure fluctuation generally appears on the cone tube (0.3 ~ 1.0) D2 department. Therefore, the measuring points should be layout the getting door of the draft tube, the general pressure pulse sensors are leaded by the 500 mm long 4inch water pipe. When the sensors are installed, it should be flushed with port and without jagged, it should not combine with other pipeline and not allow use pipeline between the sensor and measuring point to avoid affect the accuracy. The point layout is shown in Fig. 1.

C Test System

TABLE I.
THE BASIC PARAMETERS

Hmax	124.5 m
Hav	117.3m
Hr	108m
Hmin	92.5m
D2	4.55m
Nr	224.5MW
Nmax	249.4MW
n	166.7rpm
Qr	234.0m3/s

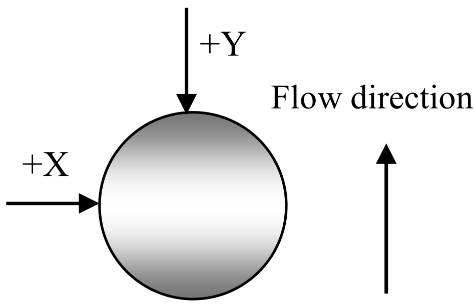


Figure 1. The setting of sensors pressure fluctuation

In this experiment, INV306GM special hydraulic machinery vibration and noise test analysis system is used. AK-3 type proliferation silicon strain type water pressure pulsation, the voltage which is Proportional to the water pressure is outputed, the signal range is -10 ~ 50m water column, dynamical range is 0 ~ 1000HZ,it is mainly used for water pressure and water pressure pulsation measurement.

D Test Results

When situation of sampling is stable, we start to sample, sample time is 20s, and sampling frequency is 1024Hz, 14 conditions are as follows in Table 2.

riental signal processing software is used to analyse the signal, part of time domain waveform figures are shown in Fig. 2

From the graph, we can see when the load is between 90-140MW, the draft tube will appear periodic pressure fluctuation

TABLE II.
THE CORRELATION DIMENSION OF MEASURED SIGNAL

Situation \ m	12	13	14	15	16	17	18	19
a=63%	3.2604	3.2953	3.3083	3.3372	3.4014	3.4276	3.4436	3.4436
a=50%	3.2416	3.2812	3.3047	3.3375	3.3691	3.3801	3.3841	3.3841

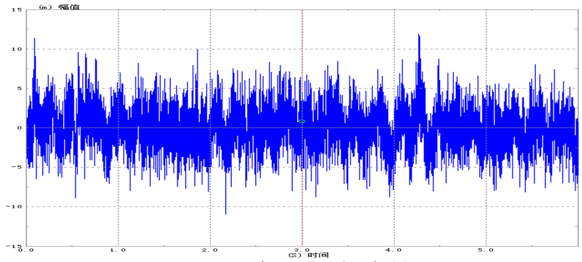


Figure 2.1 load=20MW

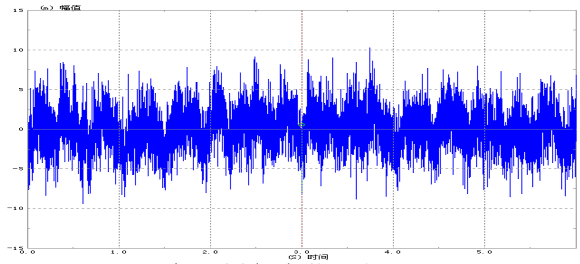


Figure 2.2 load=60MW'

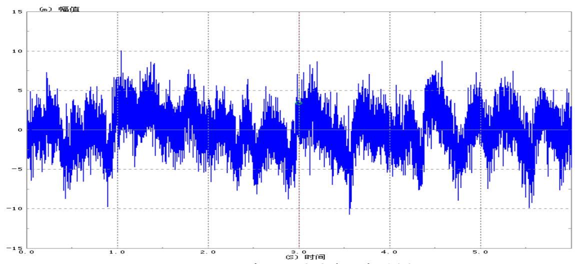


Figure 2.3 load=100MW

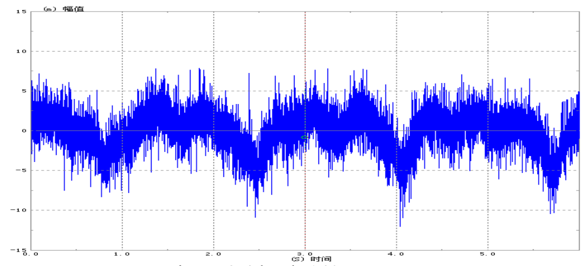


Figure 2.4 load=140MW

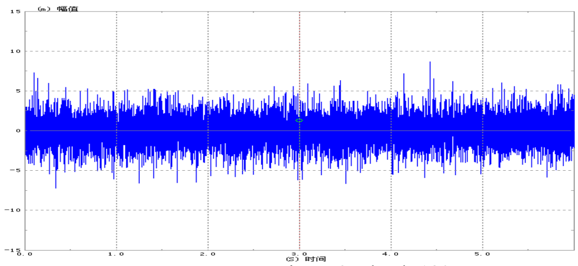


Figure 2.5 load=180MW

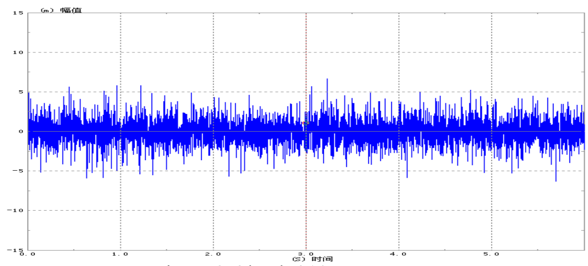


Figure 2.6 load=210M

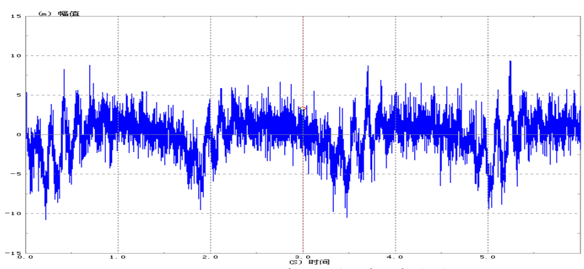


Figure 2.7 load=150MW

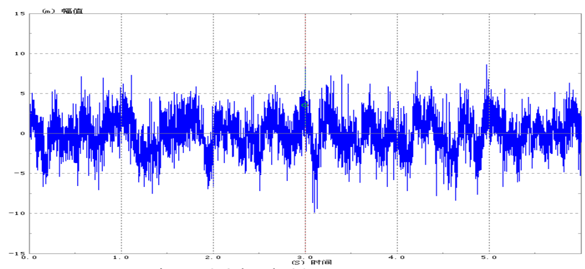


Figure 2.8 load=90MW

Figure 2 The part of time domain waveform figures with different loads

IV. THE APPLICATION OF CORRELATION DIMENSION IN PRESSURE FLUCTUATION OF DRAFT TUBE

According to test, test values of pressure fluctuation under each condition are obtained, working condition is randomly selected in a series of data, in this paper, we chose the situation which is that the opening of blades is 50% and the opening of guide vane is 63%. In the test process, all the test data are filtered by electronic filter, therefore all the data have been denoised

TABLE III.
THE WORKING CONDITION OF SAMPLES

No.	load (MW)	Pressure fluctuation（m）		
		max	mean	min
1	20	12.34	7.15	2.17
2	40	9.83	5.41	1.23
3	60	10.43	5.62	0.81
4	80	10.00	5.01	0.23
5	100	10.01	6.20	2.31
6	120	8.91	6.19	3.27
	140	7.52	4.83	2.14
7	160	7.13	3.76	0.21
8	180	8.32	5.26	2.17
9	200	7.25	4.71	2.41
10	220	8.31	5.50	2.72
11	210	6.21	3.07	0
12	150	8.72	6.91	4.27
13	90	7.23	4.20	2.16

A The selecting of sampling length N

In selecting of the sampling length N, in order to guarantee the stability and reliability of data, we intercept the middle data as the single variables time series $x_i(i=1,2,\cdots,N_m)$ to avoid the influence which the instrument brings to the stability in starting and the termination of test. Different length N can lead to different correlation dimension, with the increase of N, correlation dimension will be stable, so we select 512 vibration test data as the research object, namely, N = 512.

B The selecting of embedding dimension m

Embedding dimension [9] is an important parameter in phase space reconstruction, the value of m is the premise of calculating the correlation dimension, m is gradually increased until the embedding dimension did not change, now the m is the smallest embedding dimension.

C The selecting of delay time τ

According to formula (5) [10], the delay time τ is 14s 。

D The correlation dimension of measured signal

According to the test parameters, after analyzing, the results are shown in Table 3.

From Table 3, the relationship charts between embedding dimension and correlation dimension are shown in Fig. 3 and Fig. 4.when the opening of guide vane is 50% and 63% .

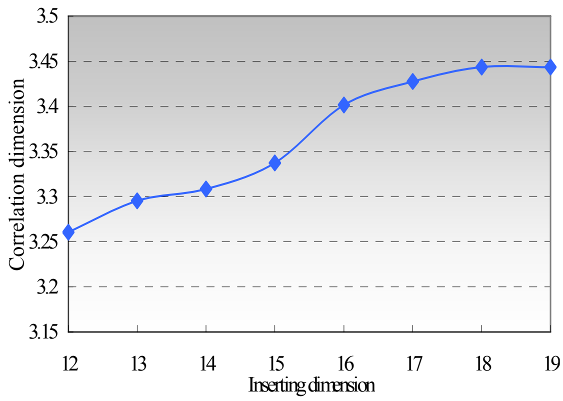
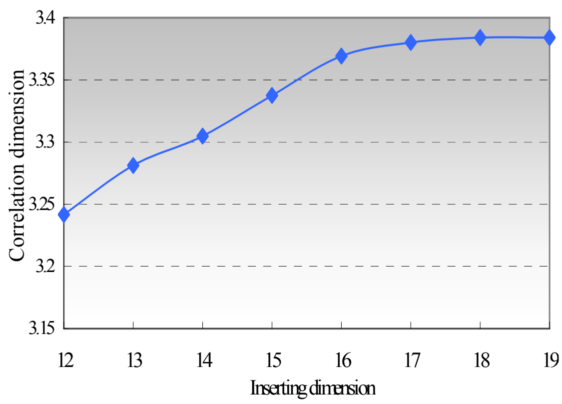


Figure 3. The relation between embedding dimension and dimension when a= 63%



. Figure 4. The relation between embedding dimension and correlation correlation dimension when a= 50 %

E The Results analysis

From Fig. 2, we can see that the amplitude is different under different looad, when the load is between 90-140MW, the draft tube will appear periodic pressure fluctuation. From Fig. 2 and Fig. 3, we can see that when embedding dimension is greater than or equal to 18, correlation dimension is tend to a stable value, so the smallest embedded dimension is 18. From Fig. 5 and Fig. 6, we can see that the fractal correlation dimension is 3.4436 and 3.3841 respectively when the opening is 50% and 63 % respectively; the results are coincided with Table 2. It can be concluded that the fractal correlation dimension is different under different working conditions, so the correlation dimension can be used as a feasible index to judge the pressure fluctuation in draft tube.

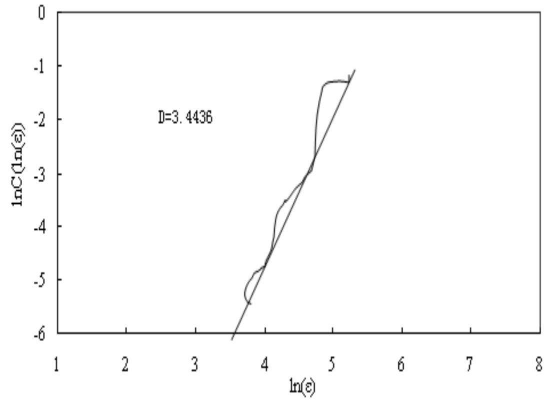


Figure 5. Fractal correlation dimension chart when a =50%

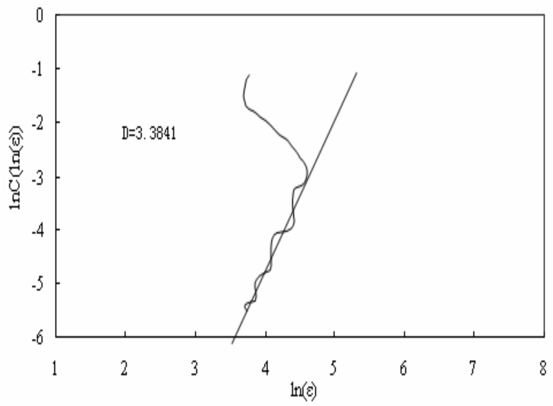


Figure 6. Fractal correlation dimension chart when a=62.85%

V. CONCLUSIONS

Correlation dimension is a method that the local situation can reflect the overall situation, its advantage is that only part of data can analyze the overall condition. In this paper, correlation dimension is used to analyze the test data of pressure fluctuation in draft tube, the calculated results show that pressure fluctuation is different under different conditions, the corresponding correlation dimension is not the same. The results show that correlation dimension can identify the situation of pressure fluctuation in draft tube, and the analysis is feasible.

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