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Analysis of Dynamic Characteristics of the Main Shaft System in a Hydro-turbine Based on ANSYS

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Abstract

The parts of hydro-turbine and its stability is often damaged and affected by the vibration and this often results in great loss. The reason of vibration is various. Based on a real machine in laboratory, this paper uses ANSYS finite element software to model the main shaft system in the hydro-turbine generating unit. On this basis, it takes the modal analysis and calculates the critical speed of rotation. The results can provide a reference for dynamic analysis and a foundation for the design or improvement.

Keywords: hydro-turbine; speed of rotation; modal analysis; vibration; main shaft system; rotor dynamic; whirl.-

1. Introduction

As large machines which are used in many hydropower stations, the hydro-turbine, whose operating condition is important to the economy of the whole country, is always a high light concerned by the people in all the related fields [1]. Among these people there are a lot of engineers and what they pay most attention to is the dynamic characteristics of the water turbine.

Actually, the whole hydro-turbine generating unit is so complex that we have not figured out many problems yet, even though we kept working for several decades. What makes the dynamic problem so difficult is the complicated environment in which the unit works [2]. With no doubt , this is the key point often discussed by scholars, hoping to achieve a breakthrough so that we can understand the dynamic

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characteristics in detail, even the mechanism of energy exchanging. Some of them try the simulation and the others do the experiments.

The main shaft system, which is one of the key parts in the hydro-turbine generating unit, is in such a complex working condition. Basically, it endures three kinds of forces from the electric field, magnetic field and water respectively. Any one of the three can be a excitation for the vibration in specific location of the main shaft system, not to mention the fact that they often work together to create a unknown but very fierce vibration, even in the whole unit.

Usually vibration is the direct cause for damages, so we need to concentrate on the dynamic characteristics [3][4]. Whether analyzing by simulation or experiments, one kind of basic data to be got is the natural frequency. Correspondingly, another important result is the critical speed of rotation[5][6][7], which is often close to the natural frequency. These characteristic parameters and the results can shows engineers the resonance zone and also can be a standard for monitoring the unit in case it is in danger. They are the goals for this simulation work.

2. Model&Method

The model for the main shaft system in the hydro-turbine generating unit is made up by several parts: the generator rotor and the runner, the main shaft and the related bearing. Frankly speaking, due to the nonlinear characteristics caused by the interaction of machinery, electromagnetic field and the water, it is very hard to establish a model which can contains all the factors, such as the nonlinear oil film force from the bearing. So necessary simplification is inevitable for the model [8].

On the whole, the main shaft system of the hydro-turbine is still a rotor-bearing system, though very complex. In this point of view, using the theory rotor dynamic to do the analysis is appropriate. There are two methods which are often adopted to deal with rotor dynamic problem. One is the transfer matrix method, such as Riccati transfer matrix method. The other is the finite element method (FEM), which has higher numerical stability but will take more storage space of the computer. Both of methods are widely used to solve the rotor dynamic problem. The former method divides the system into several parts after it gets the lumped mass model, such as the disk, the shaft and the bearing. Then it establishes the relation of the state vectors between the both ends of the cross-section and use the continuity conditions to obtain the relation between the state vectors in any cross section and the initial one. The latter method, namely FEM, is not adopted to analyze rotor dynamic problem until 1970s. The key idea of the FEM is to transform the infinite DOFs (degrees of freedom) problem into a finite DOFs one, and then solve it. As the computer technology develops, the FEM become very popular to analyze a mechanics problem, not just the rotor dynamic [9].

This paper uses large commercial finite element software ANSYS to establish the 3D geometry model （Fig.1）. The part where the lower bearing lies in is a hollow shaft. After meshing the 3D geometry model it gets the FEM model (Fig.2).

Fig.1 The 3D geometry model of the main shaft system

Fig.2 The finite element model of the main shaft system

3. Calculation & Results

To do the calculations, there are two important points that should be paid more attention to:
(1) Gyroscopic effect. Due to the angular movement (whirl) of the rotation parts(like disk) , it will generate a moment of inertia, which is called gyroscopic moment. The gyroscopic effect is caused by this moment. Generally speaking, the direction of the gyroscopic moment makes the inclination angle of the rotation shaft axis smaller, which can increase the stiffness of the shaft and then the critical speed of rotation.
(2) Damp. Rotor-dynamic system is made up of many parts. They work together to form damp. Overall, the damp will decrease the critical speed of rotation, though not obviously. However, it also affects the dynamic deformation and the amplitude while the rotary is in the critical speed of rotation, which shows a apparent tendency of decreasing.

In the module of ANSYS/Rotordynamic the two things we talked above are both considered. The first one can be carried out by a APDL (ANSYS Parametric Design Language) sentence, and the second one is applied when putting the element parameters. Two kinds of elements in ANSYS, SOLID45 and COMBIN14, are used to mesh the 3D geometry model. The COMBIN14 element is a simplification for the bearings. There are a total of 2812535 elements and 150555 nodes. Some of the calculation parameters, such as the material properties, the damp and the stiffness, are shown in table.1

Table.1 Parameters for calculation:

Young’s modulus	210GPa
Poisson’s ratio	0.3
Density	$7800kg/m^3$
Bearing stiffness	1.6×10^9N/m
Bearing damp	2.3×10^7N.s/m

The rated speed of the rotation from factory is 600r/min. Apply the speed of rotation from 0.1, 1/3 rated speed, 1/2 rated to rated speed and write every speed as a loadstep file to create the Campell diagram. After it is solved by the computer, the modal map in different orders(in this paper we take the first six orders) and the frequencies are obtained (Table.2, Fig.3-8). The critical speed of rotation can be seen from the Campell diagram.(Fig.9)

Table.2 Frequencies:

orders	Frequency(Hz)
1	315.30
2	321.37
3	326.73
4	430.07
5	436.00
6	474.97

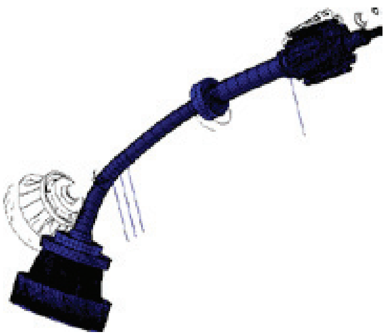

Fig.3 the first order mode

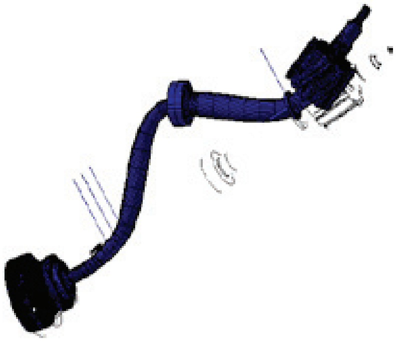

Fig.4 the second order mode

Fig.5 the third order mode

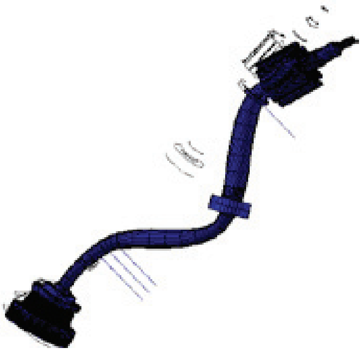

Fig.6 the fourth order mode

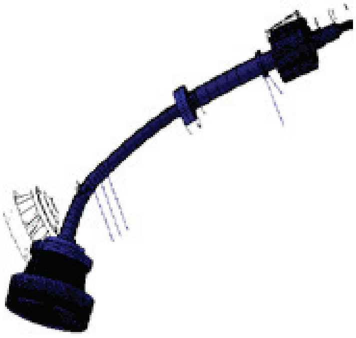

Fig.7 the fifth order mode

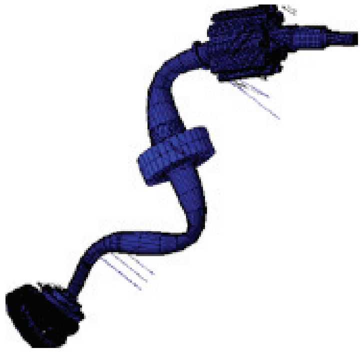

Fig.8 the sixth order mode

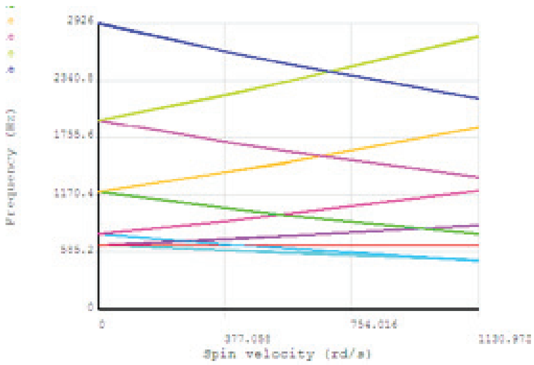

Fig.9 The Cambell diagram

4. Conclusion

1.As the order number increases, the frequency also become larger.

2.From the modal map it can be seen that the sixth order's vibration is very fierce and complex. The first and the fifth order's vibrations appear to be lateral vibrations. The others left shows they includes torsional vibration. Some of the modes don't appear well, maybe it's the reason that thrust bearing is not taking into consideration.

3.As the working speed of rotation increases, due to the gyroscopic effect, the natural frequency of the positive whirl will increase while the negative whirl decrease. When the speed of the rotation equals the angular frequency, it is the critical speed of rotation, which clearly shows on the Campell diagram.

4.From the whole solving process, gyroscopic effect should be considered when you set the options for this analysis, because it does affect the dynamic characteristic a lot. Actually, you can't get a Campell diagram if you don't choose the coriolis option on.

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