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Numerical Simulation and Experiment of Pressure Pulsation in Kaplan Turbine

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Abstract

Three-dimensional unsteady simulation using RNG k-ε turbulence model is used in full flow passage of model Kaplan turbine. Then the pressure pulsation is obtained. Monitoring data of pressure pulsation in the turbine is obtained through experiment and is compared with the numerical simulation. And a good coherence is shown between the simulation and the experiment. Then the regularity of the pressure pulsation's distribution and transmission in the turbine is discussed in detail.

Introduction

Recently according to the increase of runner diameter and unit capacity of turbines, the hydraulic vibration of big-scale turbines is more and more serious. Vibration, swing and pressure pulsation are three main parameters to describe the stability of the turbines. Pressure pulsation resulting from the unsteady flow field in the turbines is the main source to generate vibration and instability of the turbine units.

There are two methods of studying pressure pulsation in turbines which are experimental research and numerical research. There is much limitation in experimental research such as high cost and strict conditions. According to the computer technology numerical research has taken more and more important role on turbines. Jaeger etc.[1] get the pulsation information between runner and draft and vortex rope in the draft through unsteady numerical simulation of the turbine's whole passage. Ruprecht A and Heitele E etc.[2] get more details of the pulsation information by ways of the whole passage numerical simulation. Yang Jianming etc.[3] use large eddy simulation to simulate runner and draft and get a close result to experiment. Wang Zhengwei etc.[4] simulate the whole passage of Francis turbine using 3D unsteady RANS method and get the characteristic of pressure pulsation and vortex rope of the draft tube under part load condition.

3D unsteady numerical simulation is applied to Kaplan turbine in this paper and getting the pressure pulsation with a good agreement with the experimental data.

Pressure pulsation experiment of model turbine

In order to study the pressure pulsation of the Kaplan turbine experiment is carried out on professional experiment bench in Haerbin.

During the experiment several pressure sensors are placed in four different positions. They are $0.3D_1$ under the runner (position 1), (-X) (position 2) and (-Y) (position 3) on the inlet of the draft tube and outside of the elbow pipe (position 4), figure 1.

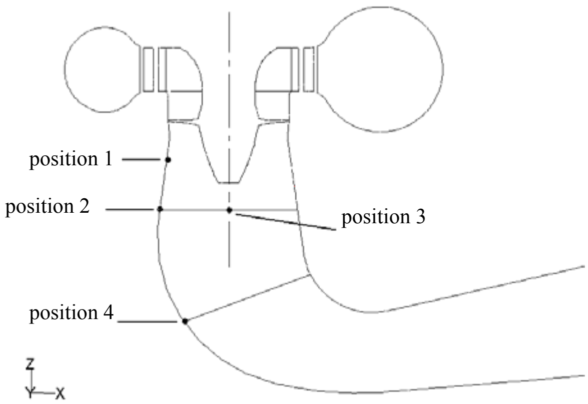


Figure1 sketch map of the four different positions

The experiment system is made of dynamic pressure sensors, high-speed data collection system, computer and windows operation system. Sampling frequency is 320Hz and the data points of every work condition are 2048. One work condition is shown in table 1.

Table 1 parameters of one work condition

Ψ	A_0	H_p	n_{11}	Q_{11}	n	H
15	20	52.2	118.6	805	1267.9	14

Unsteady turbulence simulation of model turbine

3D unsteady turbulence simulation is applied to the whole passage of the model turbine. The characteristic of unsteady performance of guide, runner and draft tube is gained. RNG k- ε turbulence model with standard wall function is selected.

During the simulation there are two grid interfaces. One is between outlet of the guide and inlet of the runner. The other is between outlet of the runner and inlet of the draft tube. The time step is 0.001s and convergence is assured during every time step. By this way the pressure pulsation of different parts of the turbine is gained.

Results and discussions

Analyze of the experiment data

The pressure pulsations of position 1 and position 2 are displayed in figure 2 to figure 5.

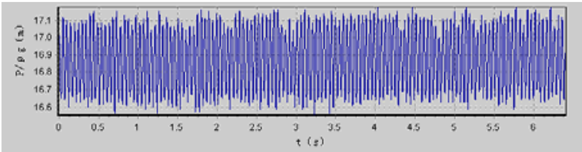


Figure 2 time domain of the pressure pulsation of position 1

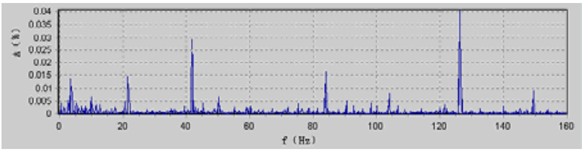


Figure 3 frequency domain of the pressure pulsation of position 1

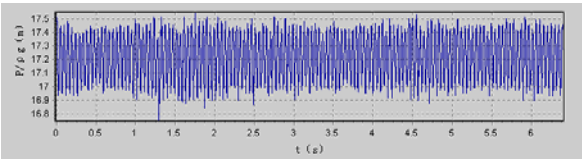


Figure 4 time domain of the pressure pulsation of position 2

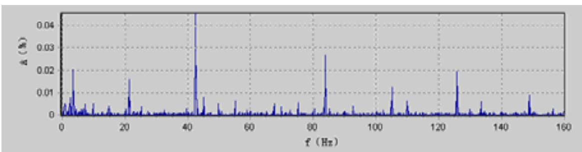


Figure 5 frequency domain of the pressure pulsation of position 2

From the experiment data frequency and corresponding amplitude of the four positions are shown in table 2. The unit of the amplitude is %. The characteristic and translating rule of the pressure pulsation is as follows:

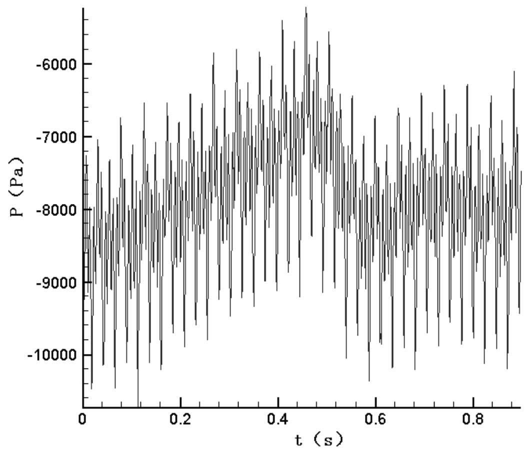
Table 2 frequency and corresponding amplitude of the four positions

f(Hz)	3.2	21.3	42.3	84.2	125.8
P1	0.014	0.015	0.03	0.015	0.041
P2	0.02	0.016	0.044	0.036	0.02
P3	0.016	0.016	0.045	0.035	0.02
P4	0.03	0.005	0.013	0.005	0.002

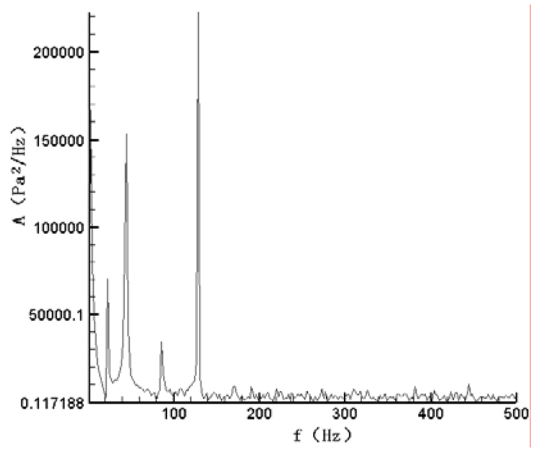
The selected work condition's rotating frequency of the runner is 21.13Hz. It is shown in table 2 that there is a low frequency which is 0.15 time of the rotating frequency. Its maximum amplitude appears outside the elbow pipe and decreases towards upstream gradually. There is also a frequency of 21.3Hz which is equal to the rotating frequency. Its maximum amplitude appears on inlet of the draft tube and decreases towards upstream and downstream obviously. There is a frequency of 42.3Hz which is two time of the rotating frequency. Its maximum amplitude also appears on inlet of the draft tube and decreases towards upstream and downstream obviously. There is a frequency of 84.2Hz which is four time of the rotating frequency. Its maximum amplitude appears on inlet of the draft tube and decreases towards upstream and downstream obviously. There is a frequency of 125.8Hz which is six time of the rotating frequency. Its maximum amplitude appears on the position 1 and decreases towards downstream obviously. There are also some frequencies such as 10.2Hz, 104.1Hz and 148.3Hz. Their amplitudes are relatively smaller.

Analyze of the unsteady simulation's results

Numerical simulation is carried out on the four positions to get the pressure pulsation. Pressure pulsations of position 1 and position 2 are displayed in figure 6 to figure 7.

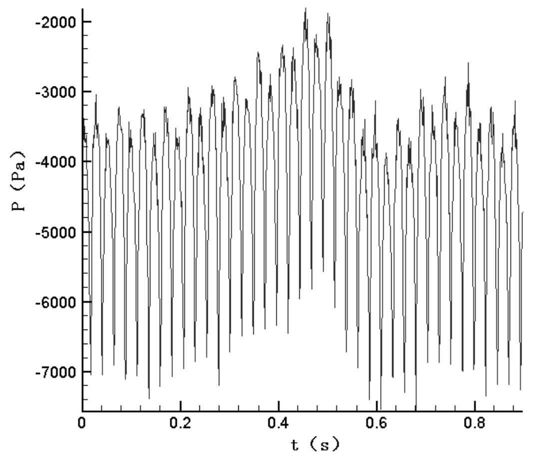


(a)Time domain of the pressure pulsation of position 1

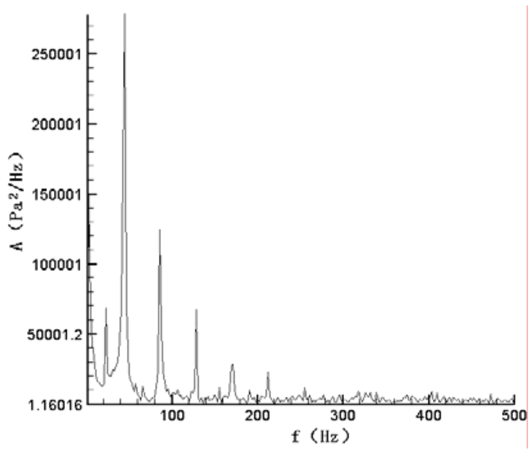


(b) Frequency domain of the pressure pulsation of position 1

Figure 6 numerical pressure pulsation of position 1



(a)Time domain of the pressure pulsation of position 2



(b) Frequency domain of the pressure pulsation of position 2

Figure 7 numerical pressure pulsation of position 2

From the numerical results frequency and corresponding amplitude of the four positions are shown in table 3. The unit of the amplitude is 10 Pa^2/Hz. The characteristic and translating rules of the pressure pulsation are as follows:

Table 3 frequency and corresponding amplitude of the four positions

f(Hz)	3.48	23.4	45.3	86.0	128.8
P1	12600	7030	15300	34300	22230
P2	15000	6850	27790	12450	6730
P3	13380	7760	26960	11670	6760
P4	17430	1700	3800	750	170

From the numerical results it is shown that the characteristic and translating rules of the pressure pulsation are similar with the experiment.

Conclusion

3D unsteady turbulence simulation of the model Kaplan turbine is carried out to get the pressure pulsation which agrees with the experiment very well. Frequency of 0.16 time, 1 time, 2 time, 4 time, 6 time and so on of the ratio frequency appear both in numerical results and experiment. And the characteristic and translating rules of the pressure pulsation are similar between the numerical results and experimental data. However there is some difference between the numerical results and the experimental data which is shown in table 4. EX is the experimental results and NU is the numerical results.

Table 4 the compare between experiment and numerical results

	lf	1f	2f	4f	6f	*ΔH/H*
EX	3.2	21.3	42.3	84.2	125.8	4.80
NU	3.48	23.4	45.3	86.0	128.8	4.01

The difference between the experiment and numerical results may result from the more complex flow field in experiment such as swing of axis, vibration of unit, and fluid-solid couple of each flow passage and electromagnetism of electric machine and so on. These factors may cause the increase of the pressure pulsation's amplitude.

References

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Nomenclature

D_1: diameter of runner
Ψ: runner blade opening
A_0: guide vane opening
H_p: head of original turbine
n_{11}: unit speed of turbine
Q_{11}: specific discharge of turbine
n: real speed of runner
H: experimental head of model turbine
P1~P4: position 1 to position 4