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Effect of blade geometric parameters on the operating stability of the hydraulic turbine

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Abstract: -From the point of view of the hydraulic design of hydraulic turbine, the effect of the variation of the runner blade geometric parameters on the stability of the hydraulic turbine was analyzed extensively. Meanwhile, a comparative test with runner outlet vortex strip, blade stall and blade stress distribution based on blade geometric parameter variation is carried out. At different operating conditions of hydraulic turbine, the pressure distribution and velocity vector variation on the blade profile are influenced by the variation of the blade geometric parameters respectively, and the stability of the hydraulic turbine is influenced by the blade leading inflow attack and stall, and influenced by the variation of the blade outlet circulation.

Key-Words: - Hydraulic turbine, Operating stability, Vortex strip, blade stall, Outlet circulation

1 Introduction

The vibration and blade cracks of turbine obsess designer always. Because of the distinctiveness of turbine, when operating under small guide vane angle conditions, the runner blade inlet attack angle is big, thus the streamline distribution is not good, and it also causes inlet blade stall and blade-to-blade channel vortex. Besides, because the outlet positive circulation is very large, rotational vortex rope with great energy happening at runner outlet impinges directly on draft tube wall, generating great impingement and noises. These are the instability factors of hydraulic turbine operation. Thus, reducing the range of these instability factors to ensure hydraulic turbines to operate in 40%□100% output operation stable region are the objectives of turbine designers and researchers. At present, the large size hydropower generators, fabricated by domestic or foreign factories, have certain extend of vibration problem or blade crack problem, for example Wuqiangxi hydropower plant, Yantan hydropower plant, Ertan hydropower plant, Tianshengqiao hydropower plant, Geheyan hydropower plant, Lijiaxia hydropower plant, Dachaoshan hydropower plant and Xiaolangdi hydropower plant etc. The vibration and blade crack not only influence economic benefits of power plant but also severely influence the working ambient and the workers' health during operation. Thus operation stability problems are always the important and difficult problems for power plants. There are many factors which can cause runner vibration. This paper was based on hydraulic design, by changing the geometric parameters of the blade. We conducted CFD analysis of blade pressure distributions, velocity vector variation, streamline distribution and circulation variation under different operating conditions. This paper studied the influences of blade leading inflow attack, blade stall and outlet vortex variation on the stability of operation. By using the combination of CFD analysis and experiment, the effects of blade geometric parameters on turbine's operation stability were presented, in order to enlarge the turbine's stable operation region.

2 Influence of blade inlet attack angle to operating stability

The blade attack angle not only affects the runner's performance but also determines the inception of blade channel vortex and blade stall, it is the direct reason of hydraulic turbine unit vibration. During conducting experiments, when blade stall incepted, the whole test rig's vibration sound increased immediately, even floor began to vibrate. Blade stall is one of the main reasons of hydraulic vibration. Because of turbine's operation characteristics, the blade channel vortex can not be avoided in every operation conditions, how to reduce the vibration region and ensuring runner operating stably in 40%□100% output region, are the objectives of turbine designers. After large quantity of CFD analyses, the results show that under low load conditions, the velocity near the pressure side of the blade is small,

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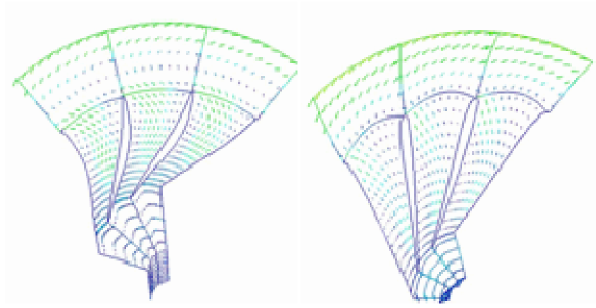
secondary flow incepts at blade tip near the crown, and blade stall and vortex tend to appear. The calculation in reference [3] also has the same results that negative rake angle blade can delay such phenomena.

Take Yantan hydropower plant rehabilitation project for example to compare the CFD analysis result and experimental result. The blade after rehabilitation is negative rake angle blade. The model runner diameter is 350mm. The calculation and experimental head is 30m, and unit speed is 75rpm. Fig. 1(a) is velocity vector of CFD analysis result at 12mm guide vane opening before rehabilitation; Fig. 1(b) is velocity vector CFD analysis result at 12mm guide vane opening after rehabilitation; Fig. 2(a) is the inlet flow pattern experiment result at 12mm guide vane opening before rehabilitation; Fig 2(b) is the inlet flow pattern experiment result at 12mm guide vane opening after rehabilitation; Fig 3(a) is velocity vector CFD analysis result at 16mm guide vane opening before rehabilitation; Fig 3(b) is velocity vector CFD analysis result at 16mm guide vane opening after rehabilitation; Fig 4(a) is the inlet flow pattern experiment result at 16mm guide vane opening before rehabilitation; Fig 4(b) is the inlet flow pattern experiment result at 16mm guide vane opening after rehabilitation.

In order to keep the similarity of the results, the calculations were conducted under the same guide vane opening, the same head and unit speed. The results show that negative rake angle blade delays blade stall. It is favourable to the stability of runner operation. Fig. 2(a) and Fig. 2(b) are the experimental results of original blade and negative rake angle blade operating under part load condition.

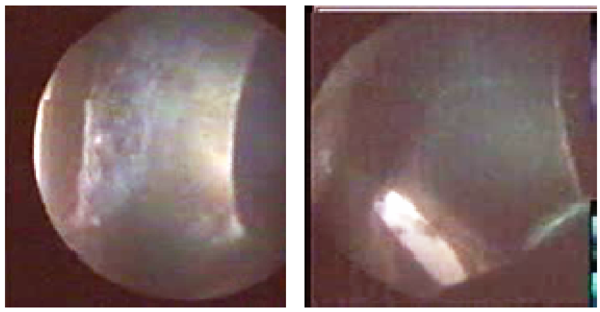
The runner with negative rake angle blades delays the stall at blade suction side, accelerating blade pressure side stall. Because the pressure side blade stall unit speed is very high, under negative rake angle condition, blade pressure side stall region is not in the runner's operation region, and suction side blade stall region is not in runner operation region either. Thus negative rake angle delays the blade stall in runner operation region. The comparison of CFD analysis results and experimental results show that the CFD analysis results agree perfectly with the experimental results.

The CFD analysis results show that secondary flow appears in both Fig.1 (a) and Fig.3 (a), the corresponding experimental results show that different extent of blade stall appears under both conditions. Fig.2 (a) and Fig.4 (a) show that there are blade stalls happen at blade leading under both conditions. But there is no secondary flow in Fig. 1(b) or Fig. 3(b); the corresponding experimental results show that there is no blade stall happen at blade inlet in both Fig. 2(b) and Fig. 4(b).



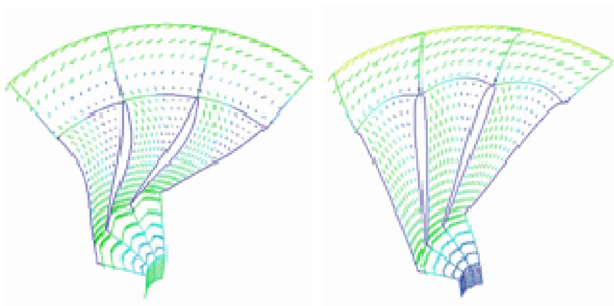
(a) Before redesign (b) After redesign

Fig.1 Velocity vectors distribution at 12mm guide vane opening



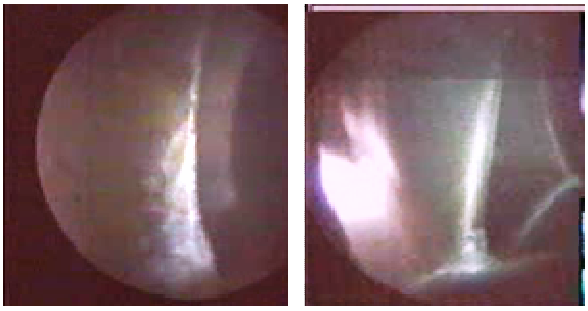
(a) Before redesign (b) After redesign

Fig.2 Inlet flow pattern at 12 mm guide vane opening



(a) Before redesign (b) After redesign

Fig.3 Velocity vectors distribution at 16 mm guide vane opening



(a) Before redesign (b) After redesign

Fig.4 Inlet flow pattern at 16 mm guide vane opening

In addition, negative rake angle blade has one more special character compared with original blade, the ratio of 95% restrict discharge and optimal discharge is relatively larger, the ratio is about 1.4, but the ratio of original blade 95% restrict discharge and optimal discharge is about 1.2. Thus negative rake angle blade has 10% larger stable operation region than the original.

3 Influence of blade outlet circulation to operating stability

The blade outlet circulation variation affects outlet vortex strip variation. Generally, when operating under optimal condition points the outflow of the runner is normal and the outlet circulation is very small or near zero. If properly control the outlet circulation, we can properly control the outlet vortex strip, i.e. the bigger the ratio of the output restrict discharge to optimal discharge, the larger the stable operation region. According to reference [4], when the runner outflow is normal, the runner blade outlet circulation is zero, and no vortex strip happens at this time; when operating at the right side of hill curve, the blade outlet circulation is negative; the vortex strip is column shaped and stable; when operating at the left side of hill curve, the blade outlet circulation is positive and the vortex strip is rotational and unstable. The bigger the ratio of the output restrict discharge to optimal discharge, the larger the stable operation region. Thus properly change the blade outlet circulation can enlarge the turbine stable operation region.

The comparison of CFD analysis results and experimental results are as follows, Fig.5 is the comparison of blade outlet circulation distribution before and after runner rehabilitation under condition of guide vane opening at 12mm. Fig. 6(a) and (b) are outlet vortex strips at 12mm guide vane opening before and after runner rehabilitation. Fig. 7 is blade outlet circulation distribution before and after runner rehabilitation under condition of guide vane opening at 16mm. Fig. 8 is outlet vortex strip at 16mm guide vane opening before and after runner rehabilitation.

From the comparison of CFD analysis result and experimental results, it can be seen that the outlet circulation, especially the circulation near the crown (hub) has great effects on vortex strip, and the effects of circulation near the band (shroud) are very small.

4 Blade stress distribution

Compare to the original blade, the negative rake angle blade has not only good stability but also favourable stress distribution character. The stress analysis shows that when the thicknesses are same, the negative rake angle blade has better stress distribution character than original blade. Fig.9 is the results of original blade and negative rake angle blade, showing that negative rake angle blade has obvious advantages, especially to obtain an even distribution of blade stress, thus negative rake angle blade has better anti-crack ability.

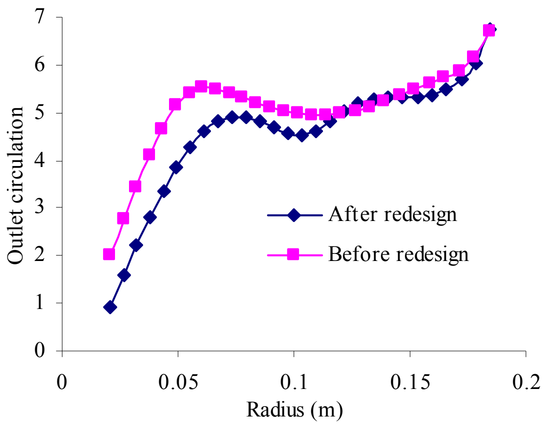


Fig.5 Difference of outlet circulation at 12mm guide vane opening

(a) Before redesign (b) After redesign

Fig.6 Runner outlet vortex strip at 12mm guide vane opening

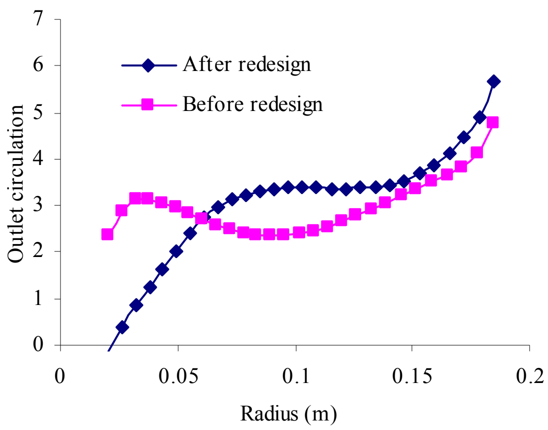
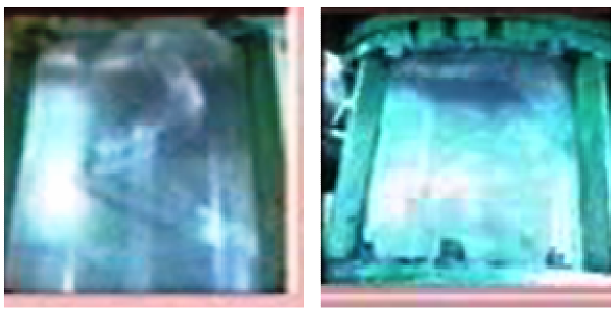


Fig.7 difference of outlet circulation at 16 mm guide vane opening



(a) before redesign (b) after redesign

Fig.8 Runner outlet vortex strip at 16 mm guide vane opening

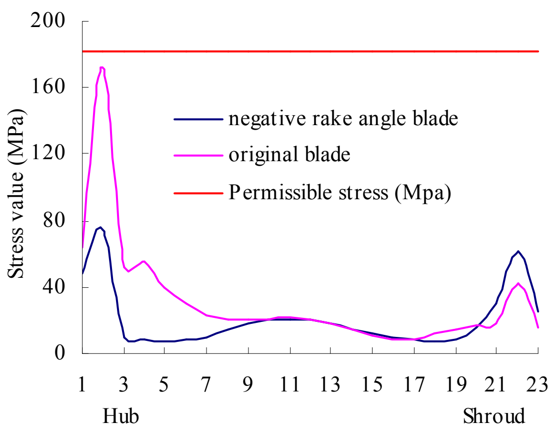


Fig. 9 Numerical stress at outflow edge of runner blade from hub to shroud

5 Conclusion

The CFD analysis results show that the velocity at the blade leading of the original runner near the crown and the pressure side of the blade is slow. And vortex strip tends to appear when operating under small load conditions. The blade inflow attack angle has great effects on blade stall, and the negative rake angle blade delays the inception of blade stall. The blade outlet circulation variation affects outlet vortex strip variation; the bigger of the ratio of output restrict discharge to optimal discharge, the bigger the turbine's stable operation region. Properly adjusting outlet circulation can enlarge the stable operation region. Outlet circulation especially the circulation near the crown primarily affects the vortex strip. Increasing the ratio of restrict discharge to optimal discharge can enlarge the stable operation region of the runner with negative rake angle blades. The negative rake angle blade stress distribution is relatively even, increasing the anti crack ability. In addition, the turbine vibration depends on all kinds of frequency, so it is advisable to separate natural frequency, rotation frequency and pressure fluctuation frequency etc. If there is a conflict, properly the change of blade geometric parameters, blade number and channel shape could achieve the same result. Thus blade geometric parameters have great importance to turbine's stable operation.

6 Acknowledgements

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