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Numerical analysis of rotor-stator interaction in a high-head pump-turbine

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ABSTRACT

Due to the unsteady characteristics of rotor-stator interference are bound up with the conversion between mechanical energy and work, increasingly number of people are focus on the research on the Rotor-Stator Interference (RSI) of turbomachinery. Because the radial distance between the guide vane and runner is small, mutual interference effect is very obvious, pressure fluctuation appears in the vaneless space. Especially in the pump operating conditions, the diffusion flow and high Reynolds number lead to the RSI become the main cause for unstable flow in hydraulic system of high head pump-turbine. In order to study this problem, three dimensional steady and unsteady numerical simulations of a high head Francis pump-turbine were carried out based on commercial software CFX, the mechanism of RSI and the influence factors were analyzed.

Firstly, five turbine operating points with different guide vane opening and five pump operating points with different discharge were selected for three dimensional calculation of steady flow. The influence of the RSI between guide vane and runner on the flow regime in different guide vane opening conditions were analyzed, and the transformation law of RSI between guide vane and runner when discharge decreased at pump mode were summarized. It can be seen from the results of steady calculations that the influence of the RSI on the flow regime of guide vane and runner was small in the big guide vane opening condition at turbine mode, but in the small guide vane opening condition, the water flow appeared disturbance back and forth between the guide vane and runner, and local vortex formed. In the same guide vane opening condition at pump mode, the RSI had greater influence on the flow regime of guide vane and runner when the discharge decrease, especially the high-speed water retaining ring appeared at a low discharge because of RSI. Time domain and frequency domain analysis were applied to the pressure fluctuation of monitoring points about unsteady simulations, it was found that the RSI caused pressure pulsation of complex frequency characteristics in guide vane and high frequency pressure pulsation in stay vane and spiral case.

Integrated the flow analysis results, It is found that RSI affects the inflow condition of runner at turbine mode , outflow condition of runner and the flow regime in guide vane at pump mode. In order to reduce the negative influence of RSI, the runner blade angles of high pressure side had been adjusted. So, based on design procedure of low specific speed of Francis

runner, ensured the same conditions of other design parameters, three blades with different blade angles of high pressure edge were designed. Numerical simulations and comparison of the three runners have been carried out at five turbine operation points and five pump operation points. The obtained results show that the larger blade angle of high pressure edge, the bigger of attack angle, the more serious of collision, leading to the efficiency decrease, but has little disturbance of the internal flow in turbine operating conditions. At pump mode, the bigger blade angle of high pressure edge, the smaller matching angle of the guide vane angle. When the blade angle of high pressure edge, guide vane and stay vane match well each other, the disturbance of RSI to flow regime decreased significantly, and the hydraulic efficiency is the highest. But the other two kinds of blade angle of high pressure edge due to mismatch the guide vane and stay vane, the internal flow field appeared instable phenomenon such as collision, flow separation and reflux, and the hydraulic efficiency at pump mode declined seriously.

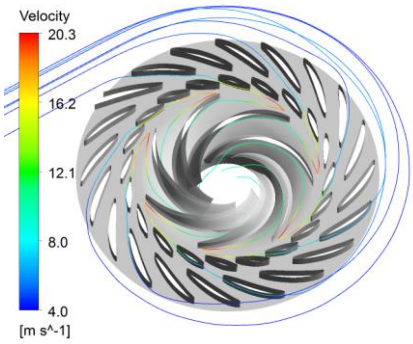

Figure.1 Streamline distribution in turbine at large guide vane opening

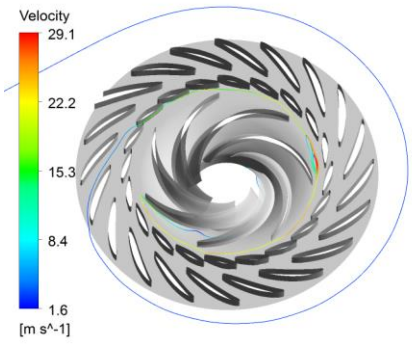

Figure.2 Streamline distribution in turbine at small guide vane opening

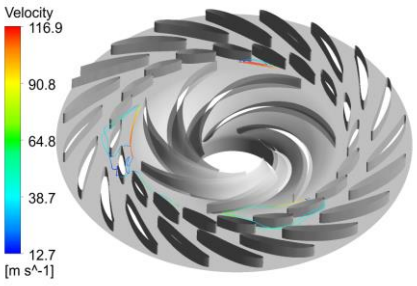

Figure.3 High speed retaining ring formed in guide vane at small discharge operating condition at pump mode

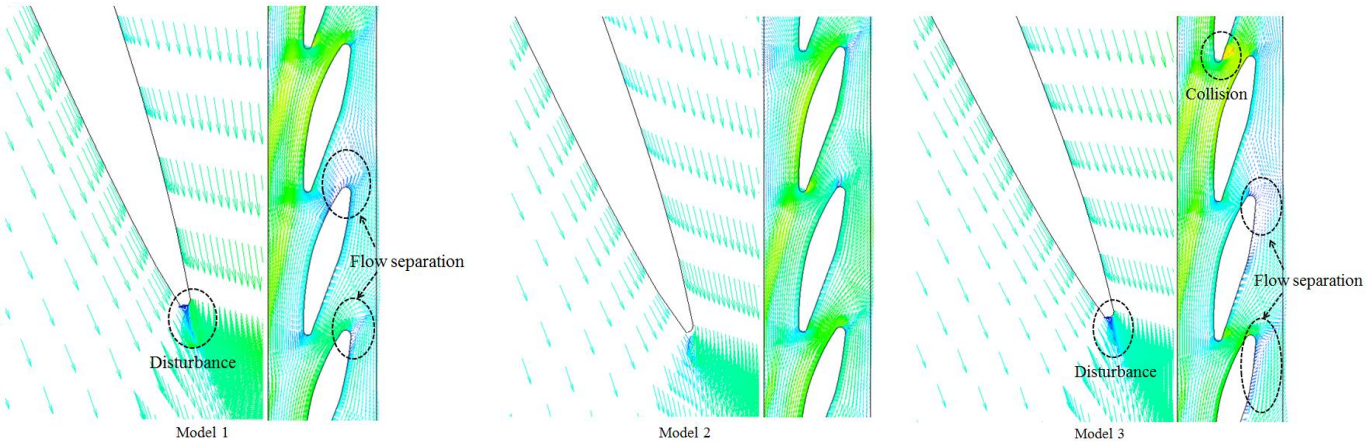

Figure.4 Velocity vector diagram of dynamic and static cascade in pump operation