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Computation of static stresses of the head cover bolts in a pump turbine

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Abstract. The static stress of bolts connecting head cover and stay ring in a pump turbine has been analyzed through ANSYS. The 3D flow of the pump turbine was simulated to get the pressure on head cover and stay ring. The stresses of bolts under 2 loading conditions were calculated: preload only as well as both preload and hydraulic pressure. Results showed that the stress of bolts was greater than head cover and stay ring. Stress concentration of bolts appeared at the position where diameter changed. Due to the influence of hydraulic pressure, the stress of bolts became larger. Head cover and stay ring deformed at the position where stiffness was poor.

Keywords: pump turbine, head cover, bolt, stress.

1. Introduction

The pump turbine plays an important role in the safe and stable operation of the power grid. It's a huge assembly including many components, such as head cover and stay ring. The two components are bolted together. In order to reduce the leakage, an enough preload should be applied on the bolt to make head cover closely contact stay ring. The failure of bolts may cause severe damage [1], thus it's necessary to study the stress characteristics of the bolts. Many factors can cause failure of the bolts [2-4], including stress concentration, fatigue accelerated by high alternative loads and smaller preload. Finite element method can be used to analysis the stress and strain of bolts. Both detailed models and simplified models were used to simulate the response of bolts after loading [5-8]. Research on bolt preload showed that preload can enhance the joint stiffness on flange joint [9-10]. Research comparing different methods for simulating the preload [11] indicated that pretension element can be used to reduce the computational time.

Many researches focus on the simple bolted connections. However, few studies have been done on the bolts used in practice engineering application. In this paper, the stress characteristics of bolts



connecting head cover and stay ring in a pump turbine unit have been studied, and the structure was shown in Fig. 1. The finite element model including head cover, stay ring and all the bolts has been established. A fluid-structure interaction method is used to get the stress and strain of the bolts under working condition.

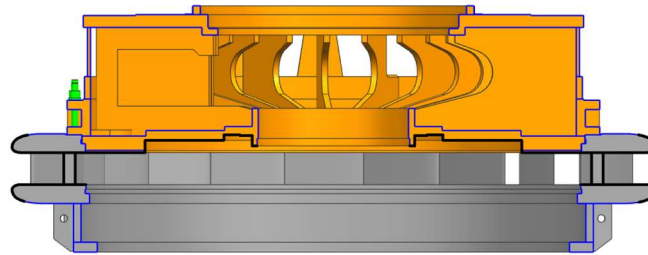


Fig. 1 3D model of head cover, stay ring and bolts (cutaway view)

2. Finite element models and boundary conditions

The prototype studied here was a pump turbine with a runner inlet diameter of 4.94 m, rated output of 383 MW, rated head of 447 m and rated speed of 375 rpm, the unit has 9 blades and 20 guide vanes. In order to obtain the hydraulic pressure on the surface of head cover and stay ring, the clearance was included in the flow path, as shown in Fig. 2. The flow path was shown in Fig. 3. The mesh of clearance was shown in Fig. 4. SST $k-\omega$ turbulence model was used to solve the problem.

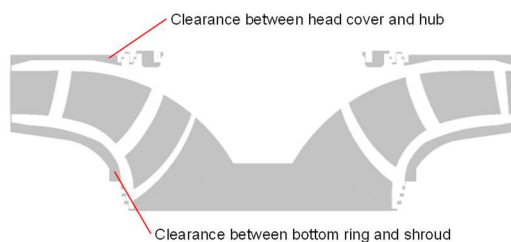


Fig. 2 Clearance between runner and stationary parts



Fig. 3 Flow path of the pump turbine



Fig. 4 Mesh of clearance between hub and head cover

The mesh of head cover, stay ring and bolts was shown in Fig. 5 and Fig. 6. Thread on bolts was simplified. The loads were hydraulic pressure on head cover and stay ring surface (obtained from CFD) and gravity. The surface of stay ring connecting with concrete was assumed as fixed support. Contact element was used to simulate the contact between head cover and stay ring and between nut and head cover. Pretension element was used to simulate the preload applied on the bolts.

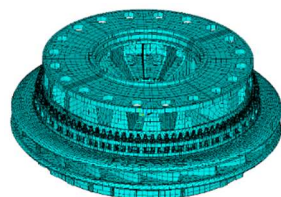


Fig. 5 Finite element model of the assembly



Fig. 6 Mesh of bolt and nut

3. Calculation result

The flow field of the pump turbine under rated operation condition in turbine mode has been calculated. The relative pressure distribution of the clearance between hub and head cover was shown in Fig. 7. The relative pressure is defined as follow:

$$p_{ref} = \frac{p - p_{out}}{\rho g H}$$

Where p_{out} is the average pressure at the outlet of draft tube, ρ is density of water, g is gravity, H is the head. The high pressure zone at the verge of clearance indicated the influence of the leading edge of runner blade. The pressure decreased as water flowed into the seal ring.

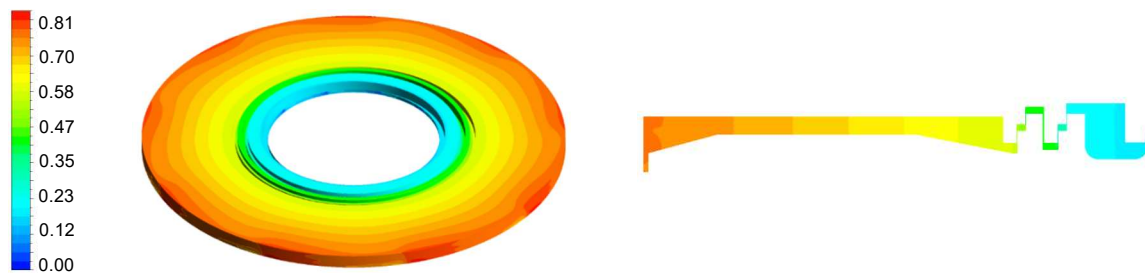


Fig. 7 Relative pressure distribution of the clearance (left: up view; right: cutaway view)

During the assembly process, only preload was applied to bolts, and there was no hydraulic pressure. The von Mises stress distribution under assembly process was shown in Fig. 8. The stress of bolts was greater than other parts. Stress concentration appeared at the position where diameter changed. There was downward deformation at the verge of head cover flange. The deformation was smaller where ribbed plate provided support, which caused the bending of bolts. Except the part connected with bolts, there was little deformation at other parts of head cover and stay ring, and the stress was quite low.

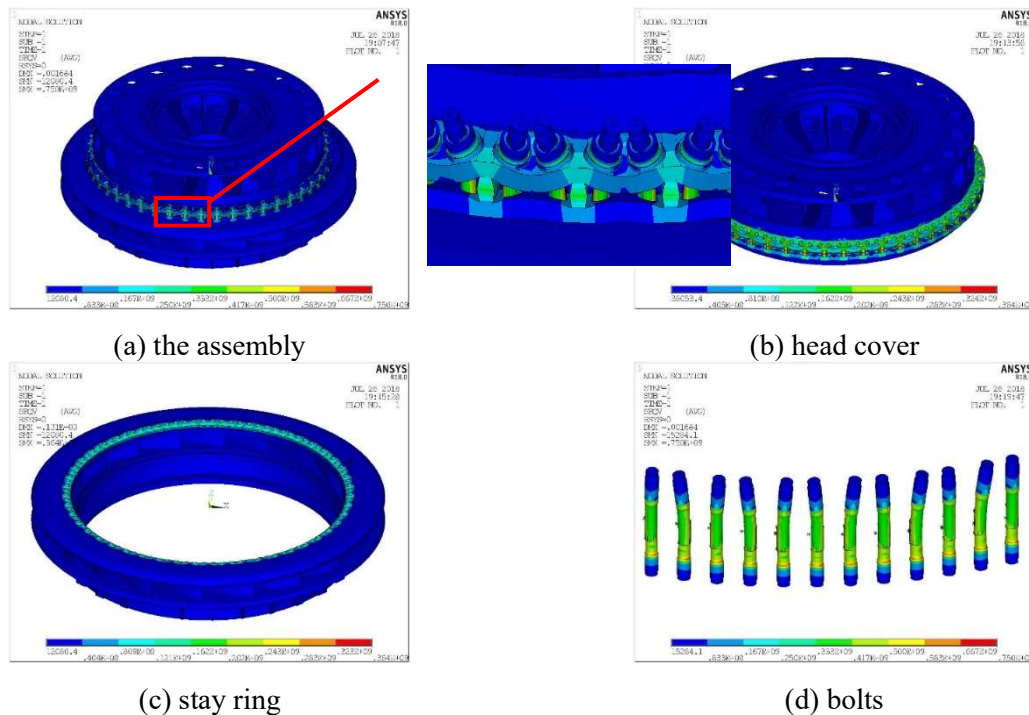


Fig. 8 Von Mises stress distribution (preload only)

Fig. 9 showed the von Mises stress distribution of head cover, stay ring and bolts during working process. The stress of bolts became greater due to the hydraulic pressure. Water pushed the head cover, and the central section of head cover was lifted up, causing the stress concentration at the corner of the ribbed plate. The entrance door on one of the ribbed plates weakened the stiffness of the head cover, thus a larger deformation can be found at the upper of the head cover. In addition, the hydraulic pressure was passed on the stay ring via bolts, thus the stay vanes were stretched.

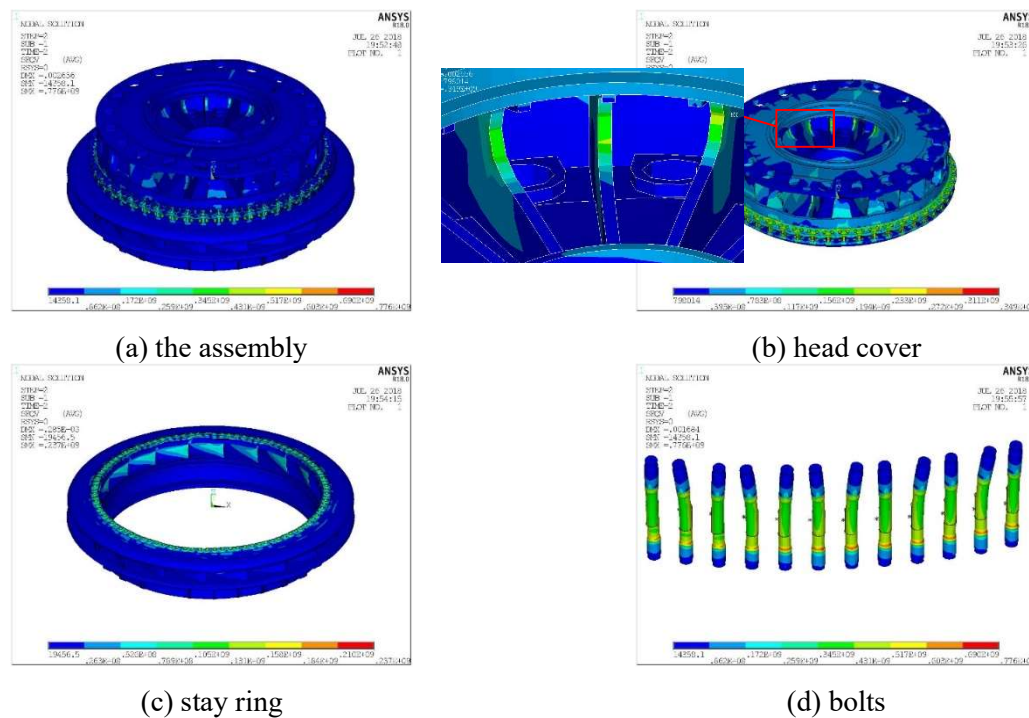


Fig. 9 Von Mises stress distribution (preload and hydraulic pressure)

4. Conclusion

The stress of bolts connecting head cover and stay ring of a pump turbine was analysed. In assembly process, only preload was applied on the bolts. There was no hydraulic pressure. The bolt bended due to the structure of head cover flange. The stress concentration of bolts appeared at the location where diameter changed. In working process, the stress of bolts became greater. The head cover was lifted up by hydraulic pressure, causing the stress concentration in the corner of ribbed plate. Some parts of stay ring near bolts were stretched due to the hydraulic pressure.

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