Optimal Design of Three-way Joint Structure for Steam Pipeline of Offshore Floating Nuclear Power Plant

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Abstract—Offshore nuclear power plants have many advantages, but their small space determines that operators cannot work far away from the steam power generation system. In order to improve work comfort and reduce noise damage, this article has carried out optimization design work for the three-way joint of the steam pipeline. On the basis of the female model, a smooth numerical simulation of the three-way joint is carried out to show its internal flow field. On this basis, with the uniform optimization design method, the best branch rounding radius of the confluence tee joint and the branch tee joint were obtained respectively.

1. Introduction

Offshore nuclear power plant (ONPP) is an organic combination of reactor technology and modern ship engineering. It turns nuclear power equipment from land to sea without occupying additional land space. It can not only provide energy and fresh water guarantee for marine resource development and offshore islands, but also avoid The negative feedback from the public on nuclear facilities has high economic application value and prospects, and is a direction for the future development of nuclear power plants. In recent years, Russia[1], the United States[2], France[3], South Korea[4] have successively initiated the development and application of offshore nuclear power plants, forming various types of offshore nuclear power plant programs.

![Schematic diagram of marine nuclear power plant](image)

Fig. 1 Schematic diagram of marine nuclear power plant

Different from land-based power stations, due to the narrow space of ONPP, it is difficult for operators to stay away from the power generation system when working. In this way, the convergence and diversion not only cause noise damage to the operators. Therefore, the design and operation of ONPP must consider reducing noise to prevent personnel from being harmed by noise.

The steam pipeline is an important part of the offshore nuclear power plant, and its structure is shown in Figure 2. The high-temperature and high-pressure steam generated from the two steam generators (SG) is first merged into a steam pipeline through the three-way confluence, and then split...
to the two generators to generate electricity. During the working process of the confluence and diversion tee, due to the confluence and diversion of steam, fluid pressure pulsation and fluid vortex will occur, which not only affects the safety of the piping system due to vibration transmission, but also generates greater noise. Therefore, the three-head joint must be optimized to reduce its vibration and noise[5].

2. Structural optimization method of three-way joint

2.1. Performance factors

Using Ansys Typical confluence tee and shunt tee joints are shown in Figure 3 and Figure 4. The steam flow conditions are: the steam inlet velocity of the three-way confluence is 61m/s, and the inlet velocity of the split three-way is 81m/s. Calculating internal flow field with ansys19.0, the flow field is shown in Figure 5. It can be seen from the figure that there is a local large flow velocity phenomenon at the rounding of the two branches of the tee, so changing the rounding radius of the branch can change the speed unevenness of the middle surface.

Since the path diameter of the branch is determined by the steam generator and the generator set, there is only one uniformity design factor in the model, that is, the rounding radius of the branch. This article is to carry out the structural optimization design of the confluence tee and the shunt tee according to the rounding radius of the branch.
2.2. Uniform optimization design method

In the process of engineering optimization design, in order to find the optimal form that conforms to the actual application of the engineering or to reduce the manufacturing cost to create more commercial benefits, it is necessary to do a lot of experiments to find the optimal solution. With the rapid development of computer technology and CFD commercialization, CFD simulation is often used to verify research and design results. Therefore, in a sense, numerical simulation is also a test method. However, whether it is experimental verification or numerical simulation, there are problems in how to design the scheme. If the design of the scheme is correct and reasonable, it will be possible to shorten the test cycle, reduce the test cost, and quickly obtain better results with less test times.

The uniform design method is based on the above ideas. The uniform design method is based on probability theory, mathematical statistics and linear algebra, etc. It is a mathematical method for scientifically arranging test schemes, analyzing test results correctly, and obtaining optimized schemes as soon as possible. The purpose of experiment design is to gain an understanding of the regularity between experimental conditions and experimental results. Through the uniform test method, select representative points within the scope of the test, and use the representative points to represent all points, which can greatly reduce the number of tests.

In the process of experimental design, the uniformity principle is one of the important principles of experimental design, that is, the selected program points are evenly distributed in space, and the uniformity can be ensured to make the obtained program representative. Its characteristic is that each level of each factor is tested once and only once. According to the principle of uniformity, a series of uniform design tables are generated. The user determines the appropriate number of experimental levels according to the number of factors of the applied problem, and finds the uniform design table to obtain the desired scheme.

2.3. Optimize the design process

![Fig. 6 Schematic diagram of component optimization design process](image)

The fluid pressure pulsation and fluid vortex in the three-way joint are the noise source, and the turbulence pulsation is the excitation source of structural vibration. Therefore, the low-noise structure optimization of the splitter is usually based on the flow field optimization results. The flow field optimization design process is shown in Figure 6. First determine the optimization goals and optimization variables, select the calculation samples according to the uniform design method, and then perform solid modeling, meshing and numerical simulation on the selected samples, and then apply the regression model to approximate, Use four-variable second-order response model or three-
variable second-order response model to find the relationship between optimization variables and optimization goals, apply genetic algorithm to obtain the optimal combination of optimized variables, and finally pass CFD verification, if the result is not much different from the numerical test result, the optimized result obtained is reliable, and the optimized result and the optimized design fitting formula are given.

3. Optimization results

3.1. Confluence tee joint
The diameter of the female confluence tee joint is 250/250/350, and the rounding radius of the branch is R360. In the optimization design, 6 are selected near the mother model, namely: R350; R360; R370; R380; R390; R400.

Take the speed of each node on the midplane as a sample, take the average speed as the expected E, and describe its uniformity by variance X. The uniformity coefficient is set to \((X/E)^2\). The smaller the uniformity coefficient, the better the structure. The uniformity coefficient of the confluence tee at several levels is shown in Figure 7. It can be seen from the figure that the relationship between the velocity uniformity coefficient of the mid-surface of the confluence tee and the rounding radius of the branch is not clear, and polynomial fitting cannot be used. Only a few optional values close to the existing rounding radius can be obtained. For enumeration and comparison, since the uniformity coefficient corresponding to R370 is the smallest, R370 is the optimal structure.

![Fig. 7 The relationship between uniformity coefficient and branch road rounding radius](image)

3.2. Shunt three-way joint
The diameter of the female confluence tee joint is 200/150/150, and the rounding radius of the branch is R178. As with the confluence tee, 8 were selected near the mother model during the experimental design, namely: R150; R160; R170; R178; R190; R200; R210; R220.

Similar to the law of the confluence tee, the relationship between the velocity uniformity coefficient and the branch rounding radius of the branch tee is not clear, nor can it be fitted with polynomials. It can only be selected for the existing rounding radii that are close to each other. The values are listed and compared, and it can be seen that the uniformity coefficient corresponding to R200 is the smallest, which is the optimal structure.
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Fig. 8 The relationship between uniformity coefficient and branch road rounding radius

4. Conclusions
In this paper, by analyzing the structure of the confluence and distribution tee of the steam pipeline in the offshore nuclear power platform and its noise influence factors, the key optimization variable of the rounding radius is determined, and the rounding radius is used to optimize the speed unevenness in the three-way joint. Numerical simulations were carried out for different rounding radii. The calculation results show that the best branch rounding radius of the confluence tee 250/250/350 is 370, while the best branch rounding radius of the split tee 200/150/150 is rounded. The radius is 200.

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