A study on auxiliary steam reducing device in marine nuclear power plants

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Abstract: The pressure reducing device is one of the important parts of the auxiliary steam system in marine nuclear power plants. The pressure of auxiliary steam is reduced to meet the requirements of users with low pressure steam of second-loop system. This paper proposes a new auxiliary steam pressure reducing device, which can reduce the pressure of auxiliary steam in a concentrated region, and then provide low pressure steam to users. The new auxiliary steam pressure reducing device decreases the size, simplifies the adjusting mode, and improves the stability and reliability of auxiliary steam system. At last, the unsteady-state simulation based on Jtop is carried out on the auxiliary steam pressure reducing system. The results show that, when the pressure of high-pressure steam at upstream is changed, the steam pressure is stable, which is provided to users with low pressure steam.

1. Introduction

In marine nuclear power plants, the auxiliary steam system is used to transport the high-pressure steam in the header pipe to the turbogenerator, turbo-auxiliary machinery, low-pressure steam generator[1-2]. At the same time, the pressure reducing valves in the auxiliary steam system reduce the pressure of auxiliary steam, and transport the low-pressure steam to the users with low pressure steam, such as the main air ejector, auxiliary air ejector, gland air ejector, and so on. The reducing valve is one of the important parts of the auxiliary steam system, it is used to reduce the pressure of auxiliary steam to meet the requirements of users with low pressure steam[3]. Therefore, the study on pressure reducing valves in the auxiliary steam system is of great significance to the stable operating of the users with low pressure steam.

In the traditional auxiliary steam system, the pressure reducing valve and the safety valve are set on every branch connecting the steam header pipe and the main air ejector, auxiliary air ejector or gland air ejector, and so on. Although the design scheme can meet the requirements of users with low pressure steam, the auxiliary steam system has a complex piping layout, the adjusting mode is perplexity, and the size of the system is larger. As there is only one pressure reducing valve and one safety valve on every branch, the reliability of the system is low without the spare parts[4]. In the traditional auxiliary steam system, the pressure of high-pressure steam at the upstream of the pressure reducing valve is stable. However, in marine nuclear power plants, the pressure of high-pressure steam at the upstream is unstable, because of the Anti-slip characteristics. So a higher adjusting capability of pressure reducing valves is required in marine nuclear power plants.

This paper proposes a new auxiliary steam pressure reducing device in the marine nuclear power plant. The pressure reducing device reduces the pressure of high-pressure steam in a concentrated region, and then provide low pressure steam to users, for example the main air ejector, auxiliary air...
ejector or gland air ejector, and so on. On one hand, the design decreases the size, simplifies the adjusting mode, and improves the stability of auxiliary steam system. On the other hand, as there are two branches in the pressure reducing device: one is for use, the other is for stock, the reliability of auxiliary steam system is improved. At last, the unsteady-state simulation based on JTop is carried out on the auxiliary steam pressure reducing system to verify the characteristics of the new auxiliary steam pressure reducing device.

2. Concept design
As shown in figure 1, in the traditional auxiliary steam pressure reducing device, a pressure reducing valve and a safety valve are set on every branch connecting the steam header pipe and the users with low pressure steam, including the main air ejector, auxiliary air ejector or gland air ejector, and so on. As shown in figure 2, in the new auxiliary steam pressure reducing device, the users with low pressure steam share the pressure reducing device, and the advantages of the new auxiliary steam pressure reducing device are as follows:

(1) The new auxiliary steam pressure reducing device needs less equipments, decreases the size of the system, improves the system integration, simplifies the adjusting mode, and increases the stability of the system.

(2) The new auxiliary steam pressure reducing device includes two reducing branches, and one is for use, the other is for stock. So the reliability of auxiliary steam system is improved.

(3) The adjusting capability of pressure reducing device is better. The steam pressure at the inlets of users with low pressure steam is kept stable under the condition that the pressure of high pressure steam is changed because of the Anti-slip characteristics of the marine nuclear power plant.

3. Simulation

3.1 Model
To study the unsteady characteristics of the new auxiliary steam pressure reducing device, this paper uses the JTopmeret software to build a graphical simulation model of the auxiliary steam pressure reducing device.
reducing system. Simulation model based on JTopmeret software is of highly consistent with the real system structure. As shown in figure 3, the auxiliary steam pressure reducing system consists of a auxiliary steam pressure reducing device and six users with low pressure steam, including two main air ejectors, an auxiliary air ejector, a gland air ejector, a sea water desalting plant and an exhaust steam system.

In order to facilitate simulate and analysis, some simplifications and premises are made as follows:

(1) There are two branches in the real pressure reducing device: one is for use, the other is for stock. In the model, only one branch is considered.

(2) The globe valves and safety valve is not considered, which will not influence the study results.

(3) The resistance characteristic curve of the pressure regulating valve is assumed to be linear[5].

(4) The heat transfer on the pipe wall is neglected.

The simplifications and premises above are all reasonable.

![Figure 3. The model of auxiliary steam pressure reducing system.](image)

### 3.2. boundary conditions

As shown in table 1, at the inlet of the auxiliary steam pressure reducing system, the upstream pressure of high pressure steam is assumed. For every user, the downstream boundary condition is the mass flowrate.

| Item                                                   | Number |
|--------------------------------------------------------|--------|
| Pressure in the steam header pipe(high pressure steam)(MPa(a)) | 4.2    |
| Pressure at inlet of the main air ejectors 1(MPa(a))     | 2.8    |
| Mass flow rate required by the main air ejectors 1(Kg/s) | 0.24   |
| Pressure at inlet of the main air ejectors 2(MPa(a))     | 2.8    |
| Mass flow rate required by the main air ejectors 2(Kg/s) | 0.24   |
| Pressure at inlet of the auxiliary air ejectors (MPa(a)) | 2.8    |
| Mass flow rate required by the auxiliary air ejectors (Kg/s) | 0.24   |
| Pressure at inlet of the gland air ejector (MPa(a))      | 2.8    |
| Mass flow rate required by the gland air ejector (Kg/s)   | 0.1    |
| Pressure at inlet of the sea water desalting plant (MPa(a)) | 2.8    |
| Mass flow rate required by the sea water desalting plant (Kg/s) | 0.5    |
| Pressure at inlet of the exhaust steam system (MPa(a))   | 2.8    |
| Mass flow rate required by the exhaust steam system(Kg/s)  | 2.1    |
3.3. The pressure control system
A control scheme of PID control is presented in this paper[6-7]. The PID control scheme logic is shown in figure 4. The control target is set as the required pressure at the inlets of users with low pressure steam. Real-time pressure of the branch is monitored and regulating valve opening is adjusted by PID operation. When the pressure in the steam header pipe is changed, the pressure at the inlets of users with low pressure steam will change, becoming higher or lower than the required pressure. Then the signal is feedback to the PID control, and the PID operation adjusts the regulating valve opening.

![PID control scheme logic](image)

Figure 4. PID control scheme logic.

4. Results and analysis

4.1. The pressure in steam header pipe is changed
To test the characteristics of the new auxiliary steam pressure reducing device, different working conditions of the system are simulated as the pressure in steam header pipe is changed. As shown in Table 1, the pressure in the steam header pipe at design condition is 4.2MPa. The regulating valve is operating to adjust the pressure at the inlets of the users with low pressure, and the target pressure is 2.8MPa. The simulation result is present in figure 5. When the pressure in the steam header pipe is 4.2MPa, the pressure at the inlets of all users with low pressure is stable, and the target pressure (2.8MPa) is achieved. The opening of regulating valve is 0.58 ("0" represents the valve is closed, and "1" represents the valve is fully open), which is in the best opening range.

![Simulation result](image)

Figure 5. The simulation result (the steam header pipe is 4.2MPa).

When the loading of second-loop system is decreased, the pressure in steam header pipe will rise. As shown in figure 6, if the pressure in the steam header pipe rises from 4.2MPa to 4.8MPa, the opening of regulating valve and the pressure at the inlets of all users will be unstable, but reach to a stable state in a short time. The opening of regulating valve is 0.45 at the stable state (the pressure at the inlets of all users is still 2.8MPa).
If the pressure in the steam header pipe continues to rise from 4.8MPa to 5.1MPa, the same phenomena are present as that in figure 6. The opening of regulating valve is 0.40 at the stable state. When the pressure in the steam header pipe is 5.3MPa, the opening of regulating valve is 0.38. When the pressure in the steam header pipe is 5.5MPa, which is the highest pressure that the system can reach to, the opening of regulating valve is 0.36. Therefore, we can draw the conclusions that the opening of regulating valve varies ranging from 0.36 to 0.58 under all the working conditions, and it is in the best opening range. When the pressure in the steam header pipe varies, the opening of regulating valve and the pressure at the inlets of all users with low pressure can reach to a stable state in a short time. The new auxiliary steam pressure reducing device is able to meet the requirements of all users with low pressure.

4.2. The mass flowrate of steam required by users with low pressure is changed

In the auxiliary steam pressure reducing system, the mass flowrate of steam required by the exhaust steam system usually varies with the loading of second-loop system. As shown in figure 7, when the pressure in the steam header pipe is 5.3MPa, if the mass flowrate of steam required by the exhaust steam system decreases from 2.1kg/s to 1.1kg/s, the opening of regulating valve and the pressure at the inlets of all users can reach to a stable state in a short time. The pressure at the inlets of the two main air ejectors, an auxiliary air ejector, a gland air ejector and a sea water desalting plant is still 2.8MPa, but the pressure at the inlets of the exhaust steam system is 2.85 MPa, the opening of regulating valve is 0.277. The reason is the resistance in the pipe connecting the exhaust steam system and the steam header pipe declines as the mass flowrate of steam decreased. The opening of regulating valve is 0.277. When the mass flowrate of steam required by the exhaust steam system is 0.2kg/s, the opening of regulating valve is 0.173, which is out of the best opening range.

When the pressure in the steam header pipe is 5.2MPa, and the mass flowrate of steam required by the exhaust steam system is 0.2kg/s, the opening of regulating valve is 0.34. If the mass flowrate of steam required by the exhaust steam system is 0kg/s, the opening of regulating valve is 0.3. The results show that the regulating valve is able to meet the requirements of all users, except for the working condition that the pressure in the steam header pipe is 5.5MPa.

5. Conclusions

The new auxiliary steam pressure reducing device decreases the size, simplifies the adjusting mode, and improves the stability and reliability of auxiliary steam system.

When the pressure in steam header pipe is changed, the new auxiliary steam pressure reducing device is able to meet the requirements of all users with low pressure.

When the mass flowrate of steam required by users with low pressure is changed, the pressure at the inlets of users with low pressure steam can't be the target value(2.8MPa). At the working condition that the pressure in the steam header pipe is 5.5MPa, the regulating valve isn't able to meet the requirements of all users.
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