Optimization on Blowdown Flow Regulation Characteristics of Steam Generator in a Nuclear Power Plant

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Abstract. During the operation of a nuclear power plant, the blowdown flow measurement signal of the steam generator fluctuates frequently, which interferes with the automatic adjustment function of the flow control valve. When the signal fluctuation reaches the alarm value, the flow control valve will be closed automatically, isolating the steam generator blowdown system, and affect the water quality regulation of the secondary circuit. Through the analysis of the system design, operating conditions and equipment structure, it is shown that due to the blocked flow of the flow regulating valve, the flowmeter is affected by the two-phase flow. In view of the problems, this paper proposes improvement measures from the rationality of flowmeter selection, the optimization of system control logic parameters, and the system multistage depressurization.

Keywords: Steam Generator Blowdown System; Flow Control Valve; Cavitation; Multistage Depressurization.

1. Introduction

During the operation of the power plant, the impurities on the secondary side of the steam generator(abbreviated as SG) accumulate on the surface of the tube plate and heat transfer pipe by gravity and evaporation, resulting in a reduced heat transfer efficiency and equipment corrosion[1], which seriously affects the reliability of the SG. The steam generator blowdown system (referred to as BDS system) can automatically maintain the blowdown flow through intermittent or continuous blowdown, to eliminate non-volatile, soluble impurities and particulate matter, so that the water quality is maintained within the normal operation range of the power station [2].

The accurate measurement of blowdown flow is the key factor that restricts the automatic flow adjustment of BDS system. This paper analyzes the poor automatic regulation characteristics of the steam generator blowdown flow and proposes corresponding improvement measures on the basis of analyzing the design characteristics of steam generator blowdown system .

2. Research Background

The BDS system mainly is equipped with heat exchanger, flow control valve, flow transmitter and electric desalination module and other equipment. During the normal operation of the power plant, the operating temperature and pressure on the SG secondary side are about 292 °C and 7.5MPa, the blowdown flow needs to be cooled and pressured through the heat exchanger and the flow control valve to meet the requirements of the electric desalination device, and the system process flow is shown in Figure 1.

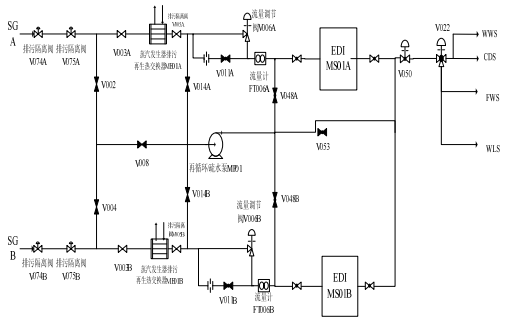


Figure 1. The process flow chart of the BDS system

The Steam generator blowdown flow can be adjusted in the range of 2.1m^3/h ~ 21.1m^3/h. If the concentration of impurities in the blowdown flow is low, the set value can be reduced accordingly, if impurity levels rise due to condenser heat transfer pipe leakage or steam generator heat transfer pipe leakage, the set value will also be increased accordingly. The blowdown flow is automatically controlled by the flow control valve and the flowmeter, which is used to measure the blowdown flow, and its measurement signal is used to control the opening of the regulating valve to maintain the set value by the flow control valve controller. The interlocking control function of the flow signal is as follows:

(1) Adjust the flow control valve V006A/B opening to maintain the set blowdown flow;
(2) When the blowdown flow reaches the alarm value, closes the the flow control valve;
(3) The flow signal is used to calculate the cooling water flow of the heat exchanger.

3. Issues Summary

During the normal operation of a nuclear power plant, when the opening of the flow regulating valve is stable, the blowdown flow meter frequently has the following signal fluctuations of varying degrees:

(1) The flow signal suddenly drops to zero.

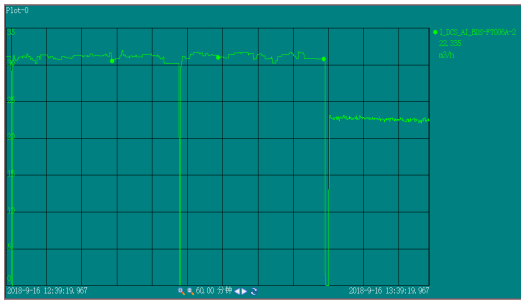


Figure 2. Flow signal sudden drop trend chart

(2) The blowdown flow suddenly increases.

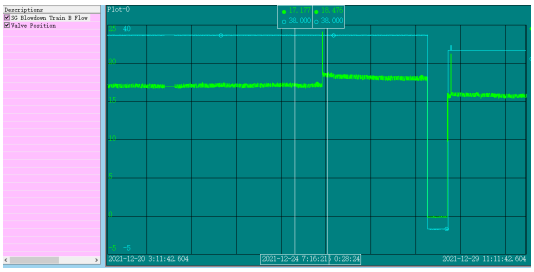


Figure 3. Flow signal upward trend chart

(3) The flow signal fluctuates continuously for a short time.

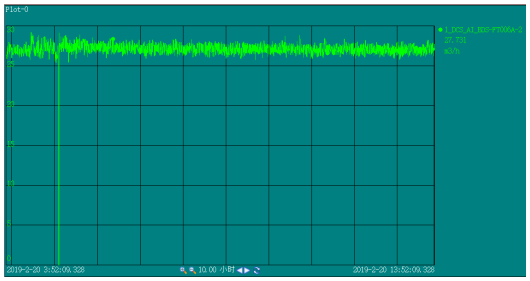


Figure 4. Flow small amplitude disturbance trend chart

The blowdown flowmeter fluctuations result in frequent changes in the opening of the flow control valve, and the irregular operation of the flow control valve further affects the flow measurement, which has the following effects on the operation of the unit:

(1) Affect the automatic adjustment effect of the flow control valve and the heat exchanger cooling water flow control valve, causing the blowdown flow and temperature fluctuations, and causing indirect impact on EDI and other related equipment;

(2) When the signal fluctuation reaches the high or low alarm value of the flow rate, it will cause the blowdown isolation valve and the flow control valve to be closed, resulting in the isolation of the BDS system, and affecting the water quality index of the secondary side of SG. There is a risk of shutdown.

4. Cause Analysis

The flowmeter is an ultrasonic flowmeter, and the measurement principle is the propagation velocity difference method [3]. According to the measurement characteristics of ultrasonic flowmeters, the following factors affecting the time difference measurements may cause signal fluctuations:

(1) Probe and coupler coupling problems;

(2) Vibration and other factors at the probe;

(3) particles, bubbles, or eddies.

For the above disturbance factors, the root cause analysis and verification are carried out from the following aspects.

4.1 Flowmeter Quality and Installation

By replacing the probe, checking the couplant coupling channel continuity and grounding, ensure that the flowmeter signal is sent, received and transmitted normally.

4.2 Two-Phase Flow and Pipe Vibration

The operating conditions of the BDS system are changeable, and the control valve has severe operating conditions such as large temperature difference and large pressure difference, which is prone to flash evaporation and cavitation. Due to the length of the pipeline, the flowmeter is located in the downstream pipeline of the flow control valve, and is close to the flow control valve, which is easily disturbed by two-phase flow. The obvious throttling noise can be felt on site under high load conditions. By the design conditions of the BDS system and the characteristics of the flow control valve, the operating status of the flow control valve is calculated and analyzed.

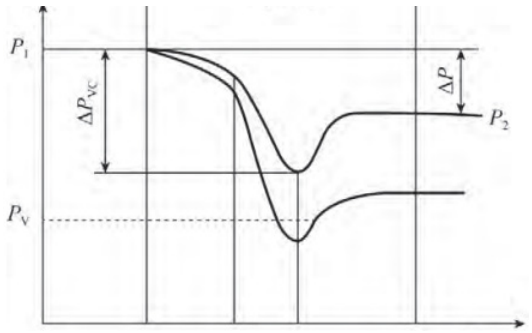


Figure 5. Schematic diagram of cavitation mechanism

The operating status of the flow control valve is usually judged based on the principle of blocked flow. When the high-pressure fluid flows through the control valve, the pressure at the minimum throttling portion of the valve drops to or below the vaporization pressure of the fluid at the inlet temperature (ie the saturated vapor pressure), the liquid vaporizes to generate bubbles, which limit

the flow capacity of the valve, and form a blocked flow. When the pressure rises to equal to or higher than the saturated vapor pressure, the bubble collapse, this process is called cavitation. When the bubble ruptures, huge energy is released, strong vibration and noise occur, and the throttling elements such as valve core and valve seat are damaged, which is the phenomenon of cavitation, and the cavitation mechanism is shown in the following figure.

The structure of the flow control valve is single-stage throttling, and the throttling at the valve core is obvious after the necking. In addition, according to the form of vibration, the sound similar to the impact of sand inside the valve is very similar to the cavitation, so it is judged that the valve has a high possibility of cavitation. The further calculation and analysis are carried out through the following calculation formula [4], and the operating conditions of the flow control valve are calculated as shown in Table 1.

$$\Delta P = P_{\text{inlet}} - P_{outlet} \geq \Delta P_s \quad (1) \qquad \Delta P_s = F_L^2 (P_1 - F_F P_V) \quad (2)$$

ΔP – Actual pressure drop F_L – Pressure recovery coefficient

ΔP_s - Critical pressure drop F_F - Critical pressure ratio coefficient

Table 1. Operating parameters of the flow control valve

Condition	Flow(m^3/h)	△P	Inlet pressure(MPa)	Temperature℃	F_L	$\triangle P_S$
Condition 1	5	7.065	7.531	51.6	0.9	6.09
Condition 2	10	6.501	7.146	51.6	0.9	5.78
Condition 3	15	5.633	6.503	51.6	0.9	5.26
Condition 4	21.12	4.92	5.87	51.6	0.9	4.75

According to the blocked flow principle, when the actual pressure difference of the valve is greater than the critical pressure difference, and the outlet pressure is equal to or higher than the saturated vapor pressure, cavitation will occur. According to the calculation results, cavitation occurs in the flow control valve under the above four conditions, that is, most of the bubbles behind the valve will burst. Because the flowmeter is located closer downstream of the control valve, so it will cause disturbance to the flowmeter.

5. Solution

Aiming at the problem that the ultrasonic flowmeter signal fluctuates due to the cavitation phenomenon, the following treatment scheme is proposed and the feasibility analysis is carried out.

5.1 Flowmeter Change

Table 2. Characteristics of different types of flowmeters

Type	Measurement principle	Applicable fluid
Differential pressure flowmeter	Measure the flow according to the static pressure difference generated when the measured fluid flows through the throttling device.	Not suitable for fluids with sediment and impurities to prevent clogging of the impulse
Rotameter	The flow rate is estimated by measuring the position of the rotating parts installed in the pipeline.	Avoid measuring fluids that are magnetic or contain solid impurities
Electromagnetic Flowmeter	Using the principle of electromagnetic induction to measure the volume flow of conductive fluids.	Not suitable for low conductivity liquids, vapors, and liquids containing air bubbles
Thermal Diffusion Mass Flowmeter	Measure the flow according to the heat exchange relationship between the fluid and the heat source.	Suitable for measuring gas flow

At present, other types of flowmeters mainly include: differential pressure flowmeter, rotor flowmeter, electromagnetic flowmeter and thermal diffusion mass flowmeter, etc. The characteristics of different types of flowmeters are shown in Table 2.

Since the fluid is demineralized water, and has a two-phase flow, the conductivity is unstable, and the medium has solid particles with a diameter of about 0.5mm. Considering the characteristics of the different types of flowmeters above, it is not recommended to change the ultrasonic flowmeter.

5.2 Instrumentparameter Optimization

(1) Control logic optimization

When the BDS system is in normal operation, the flow signal intermittently shows the high alarm value and triggers the system isolation, and returns to the normal value in a short time. By increasing the delay logic of closing the blowdown isolation valve and the flow control valve with a high blowdown flow signal, it can avoid the blowdown isolation caused by the instantaneous fluctuations of the flow rate.

(2) Flowmeter parameter optimization

By adjusting the alarm threshold of the flowmeter signal rejection rate, the fault tolerance of the flowmeter can be improved and the possibility of long-term fluctuations in the flow signal can be reduced. At the same time, by adjusting the fluctuating flow signal and adjusting the sampling average time of the flowmeter, the influence of the high-frequency disturbance of the signal on the control system is effectively reduced.

(3) Adjust the tolerance band of the flow control valve positioner to reduce the impact of the positioner action on the flow measurement when the positioner valve position feedback abruptly changes. At the same time, adjust the PID adjustment dead zone setting to optimize the performance of the control system.

By optimizing the control logic and instrument parameter configuration, the flow fluctuation problem of the BDS system is alleviated.

5.3 Optimization of Flow Control Valve

According to the valve design data, the flow control valve of the BDS system is a pneumatic sleeve type angle valve. According to the structural characteristics of the valve, it can eliminate the blocked flow with the multi-stage decompression sleeve, the outlet pressure of each stage is higher than the critical pressure of the liquid to avoid cavitation phenomenon [5]. Since the flow capacity of the multi-stage throttling valve is lower than that of the single-stage throttling valve, the C_v value of the valve decreases, so the flow diameter of the valve must be increased to meet flow requirements. The optimized valve structure is shown in the figure below.

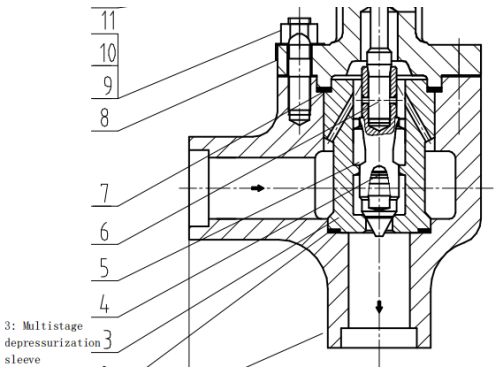


Figure 6. Structure diagram after valve optimization

6. Conclusion

In the nuclear power plants, the accurate measurement of the blowdown flow is always a difficult problem. This paper firstly analyzes the characteristics of flow signal fluctuations to determine the preliminary causes, and further calculates the operating conditions of the valve according to the principle of blocked flow, and clarifies the cavitation phenomenon of the control valve. Finally, this paper formulates a short-term strategy from the perspective of flowmeter transformation and system control logic parameter optimization, which alleviates the problem of frequent fluctuations of flowmeter. In order to solve the influence of the blocked flow, the solution of adopting multi-stage throttling and pressure-reducing valve is proposed. In this paper, the cause analysis and optimization strategy on the blowdown flow measurement fluctuation of the BDS system are of good reference significance for solving similar problems in other power plants.

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