Study and Resolution of Pressurizer Pressure Great Fluctuation Problem in CRP1000 RGL04 Test

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Abstract. RGL04 Test is the highest risky test during CPR1000 power operation,which is difficult to control the state and easily results in house load, turbine trip and reactor trip. Pressurizer pressure great fluctuation problem has occurred in some of CPR1000 units, and the pressure exceeds the allowed operation range during test transient. The paper discusses the reason of the problem and the resolution is given: according to the different overheating degree of core, groups of on-off heater are actuated, or the proper power reduction rate is chosen to satisfy the operation requirement.

Keywords: RGL04 · Pressure control · Overheating · CPR1000 · Power reduction

1 Introduction

Power control bank-turbine load test (RGL04 test) [1] is to be performed to verify the accuracy of calibration G9 curve by quickly reducing the power before nuclear power plant connecting to power grid. G9 curve represents the corresponding relationship between power control rod position and steam turbine load. For the reactor with load following operation mode, it is necessary to calibrate the G9 curve periodically in order to accurately control the reactor power, and Rod Position Indication and Rod Control System (RGL) can precisely regulating the power according to the turbine load demand.

According to RGL04 test feedback of CPR1000 nuclear power plants, Pressurizer pressure of some units fluctuated greatly, and the lowest value exceeded the operating limit of ±0.1 MPa. This paper analyzes the causes of this problem and gives solutions through simulation: according to different core overheating degree, groups of on-off heater are started to increase pressure during the test, or appropriate power reduction rate is adopted to meet the requirements of operating limits. This method is reasonable and verified by current plants, and can be applied to solve the same problems.

2 Description of RGL04 Test

The initial state of RGL04 test for CPR1000 unit is as follows:

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- The reactor power is maintained at 100% FP for at least 48 h, and xenon density is balanced;
- Turbine control is in automatic mode;
- Power control rod groups are all draw at 225 steps;
- Temperature control rod R is placed in automatic mode;
- The axial power deviation change rate is less than 1% FP/hour;
- The average reactor temperature is maintained within ±0.5 °C of the reference value;
- Pressurizer pressure control is in automatic mode, and on-off heater is in operation;
- Chemistry and Volume Control System is in automatic mode.

During the test, the unit power firstly reduces 100 MWe from full power (from 100% FP to around 90% FP) at 30 MWe/min; Then the power was reduced to 550 MWe (from 90% FP to 50% FP) at 50 MWe/min. In the process, R rod is manually operated and maintained at its original position, and the power control rod follows the load change automatically. Before power reduction, the dead zone of power control rod movement will be set to one step and the rod movement speed will be 72 steps/minute. During the test, the relationship between the turbine load and rod position was recorded, and a new G9 curve was determined.

3 The Problem of Pressurizer Pressure Greatly Fluctuation

When CPR1000 turbine load decreases normally, the power decrease speed is 0.5% FP/min (5 MWe/min), and the fluctuation range of system pressure does not exceed the operating limit. In RGL04 test, because the load drops rapidly, the shrinkage of primary coolant volume is obvious, and the pressure easily goes out of the operating limit.

Based on CAITA2 code simulation, when the power is linearly reduced from 100% FP to 50FP% at 5% FP/min (50 MWe/min), the changes of nuclear power and Pressurizer pressure (Figs. 1 and 2) show that the minimum pressure is 15.3 MPa, which exceeds the operating limit. Therefore, it is difficult to avoid the pressure from exceeding the limit at 50 MWe/min.

In the situation, if the pressure is required to meet the steady-state fluctuation limit, it can only be achieved by increasing the system pressure or changing the speed of power reduction.

4 Solution

4.1 Increasing System Pressure in Test

The problem of large pressure fluctuation in RGL04 test can be alleviated by manually opening two or four groups of on-off heater in advance. Pressurizer on-off heater, as a booster actuator with power non-adjustable, has four groups and it is closed at rated full power operation [2].

The influence of different on-off heater groups on Pressurizer pressure in test was analyzed by CAITA2 code at 0 °C overheating degree at 30 MWe/min (Fig. 3). At 3000s, the power was reduced from 100% FP to 50% FP at a rate of 30 MWe/min (3% FP/min).

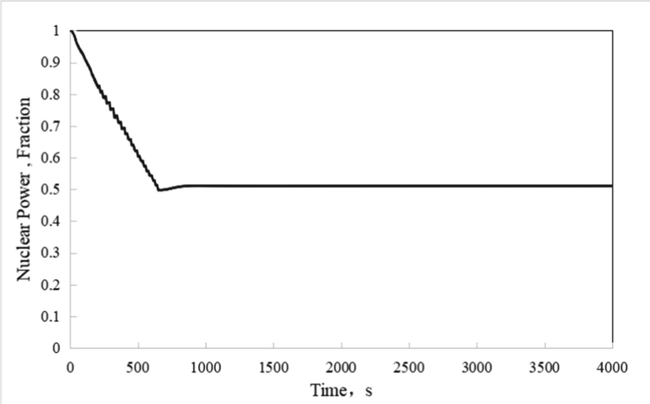

Fig. 1. Nuclear power variation in load ramp from 100%FP to 50%FP with gradient of 5%FP/min

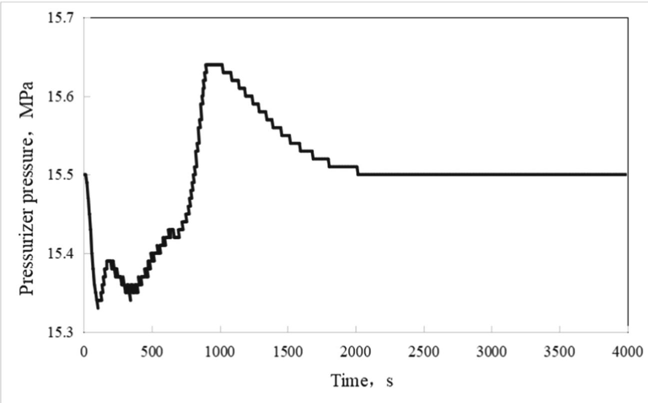

Fig. 2. Pressurizer pressure variation in load ramp from 100%FP to 50%FP with gradient of 5%FP/min

Shown from the Fig. 3, the Pressurizer pressure can be controlled within ± 0.1 MPa by actuating four groups of heater. Due to the insufficient heat provided, opening two groups of on-off heater is not enough to alleviate the pressure drop caused by power reduction. So heaters will continue to open until all the groups are started.

When no heaters work, the initial value of pressure controller PID output is 0. The on-off heater opening threshold is triggered quickly in transient, and the system pressure begins to rise until the power reduction process ends (Fig. 4). When two groups of on-off heater working, the initial value of PID output is greater than 0 and the opening threshold of all heaters is not triggered until 4000s. The pressure fluctuation is the largest on the contrary. When four groups of Heater are turned on, the PID output fluctuation is minimal, and the pressure is relatively stable.

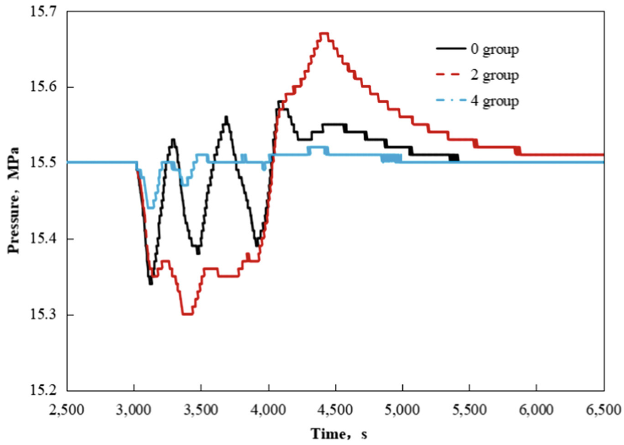

Fig. 3. Pressurizer pressure variation at different groups of on-off heater started during load ramp with gradient of 30 MWe/min

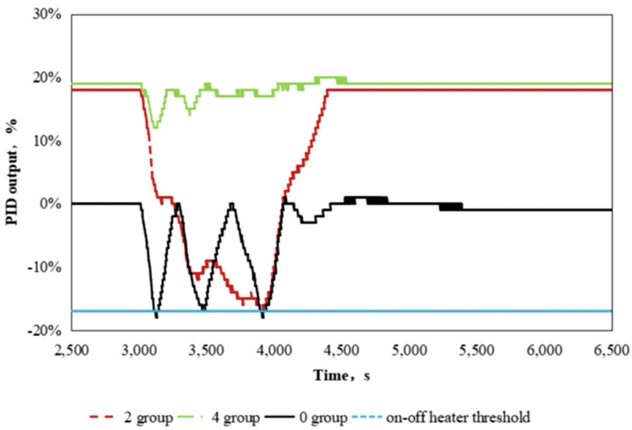

Fig. 4. Pressurizer controller PID output at different groups of on-off heater started during load ramp with gradient of 30 MWe/min

4.2 Decreasing Power Reduction Rate in Test

Under different power reduction rates, the fluctuation of Pressurizer pressure in test is different. Under 0 °C overheating and without heaters opening, the test is simulated at different reduction rates (Fig. 5). The greater the power reduction rate is, the more drastic the pressure changes. The pressure fluctuation of 50 MWe/min and 30 MWe/min are more than ± 0.1 MPa. Therefore, the appropriate power reduction rate can reduce the fluctuation degree of pressure.

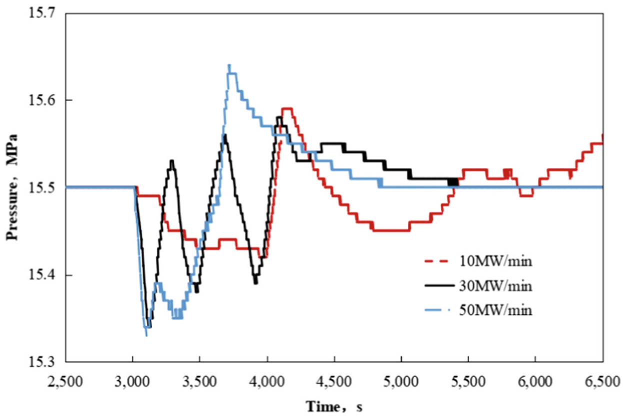

Fig. 5. Pressurizer pressure variation with different power reduction rate during load ramp

4.3 The Influence of Core Overheating

Accurate G9 curve enables the power control rod to exactly compensate power changes and ensure that the average coolant temperature is consistent with the reference value. However, due to the change rate of turbine load faster than that of core power, the power effect cannot be completely compensated by the power control rod. So the core will overheat (the average core temperature is higher than the reference temperature) in the test [3]. In the process of rapid power reduction, due to R rod manually operated, the change of average core temperature lags behind the change of power, which leads to the temperature deviation. The temperature overheating degree is accumulating. At present, core overheating phenomenon in RGL04 test is commonly existed in CPR1000 unit, and the average temperature overheating is about 3–5 °C (the test will be terminated if the overheating exceeds 6 °C) (Fig. 6). This core overheating problem is related to the operation mode of the CPR1000 unit and is the inherent characteristic.

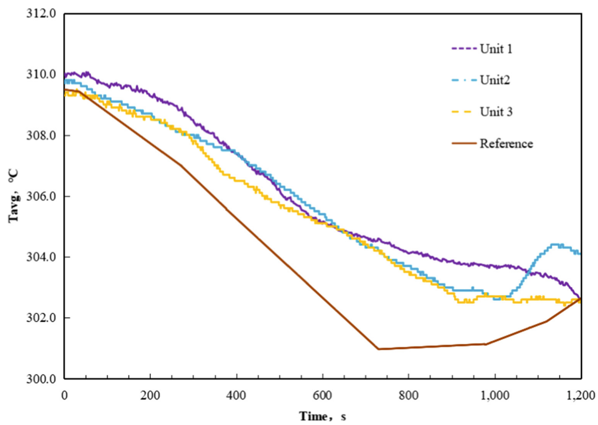

Fig. 6. Overheating degree of core average temperature in RGL04 test of different CPR1000 unit

In the process of load reduction, the existence of core overheating alleviates the problem of large pressure fluctuation in test to a certain extent, but it is still impossible to avoid the pressure from exceeding the operation limit. Without heaters opening and at a rate of 30 MWe/min, the test is simulated and Pressurizer pressure under different overheating shows that the greater the core overheating is, the smaller the pressure fluctuates (Fig. 7). Therefore, the overheating of the core is helpful to alleviate the fluctuation problem.

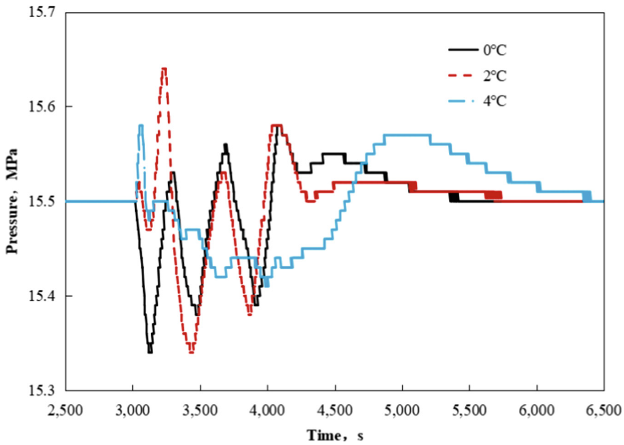

Fig. 7. Pressurizer pressure without heaters started during load ramp with gradient of 30 MWe/min

4.4 Strategy

According to the different core overheating degree, the combination of the groups of on-off heater actuated in advance and different power reduction rates is designed as shown in Table 1. The operator can choose the appropriate power reduction rate and groups of heater started based on the actual unit state. In the table, the condition of two groups of heater opened is not considered because the heat generated by the two groups of heater is insufficient to compensate for the system pressure reduction. Because the initial value of PID output is greater than 0, it spend much more time to start all the on-off heaters, which will induce large pressure fluctuation reversely.

It should be noted that when the power reduction rate is 50 MWe/min and the overheating degree is less than 2 °C, the Pressurizer pressure cannot be maintained within ± 0.1 MPa even if opening four groups of heaters. So it should be avoided.

Table 1. The groups of on-off heater opened in advance in RGL04 test at different conditions

Overheating degree (°C)	Power reduction rate (MWe/min)				
	10	20	30	40	50
0	0	4	4	4	NA①
1	0	0	4	4	NA①
2	0	0	4	4	4
3	0	0	4	4	4
4	0	0	0	4	4
5	0	0	0	0	4

Note: ①the Pressurizer pressure cannot be maintained within ±0.1 MPa even if opening four groups。

5 Conclusion

The problem of Pressurizer pressure greatly fluctuation in RGL04 test of CPR1000 unit is discussed and the solution is given that: the operator can choose the appropriate power reduction rate and start the corresponding on-off heater groups in advance based on the different core overheating conditions to maintain the pressure within operation limit, and reduce the risk of occurrence of load rejection and reactor tripping in the test.

References

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