Research on Nuclear Post-accident Liquid Level Detection Signal Deviation in Nuclear Power Plant Reactor Building

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Abstract: The level meter in the containment of nuclear power plant adopts the principle of static pressure measurement, and the pressure guiding medium is silicon oil, which is used to continuously measure the level of circulating coolant in the containment under the nuclear accident status and post-accident, aimed at the problem of serious deviations in measurement results caused by large changes in the density and volume of silicone oil affected by temperature changes, a detailed analysis of the root cause of the problem occurred, and the serious consequences that may arise will be described, proposed three solutions, analysed and demonstrated the feasibility of the three options and whether they meet the requirements of operating personnel to monitor the circulating cooling liquid level under the nuclear accident status and post-accident, after comprehensive analysis and comparison, the solution was finally determined. The results show that, according to the requirements of the measurement environment temperature range, selecting 85 degrees as the environment temperature for instrument calibration can minimize the measurement error, which is beneficial for the operators to monitor the circulating coolant level in the containment under the nuclear accident status and post-accident, meet the application requirements.

1. Introduction

As the largest nuclear power plant construction country in the world, China also has many operating nuclear power plants. Nuclear power plant EAS is an important system related to quality and safety, EAS stands for nuclear power plant reactor building sprinkler water system. Among them, the level sensor EAS003/004MN (MN-liquid level measurement analog meter) are all 1E (1E-nuclear safety) level PAMS (PAMS-post-accident monitoring) meters, which are used for level continuous measurement in the accident state and post-accident. After the measurement signal is redistributed through protection groups III and IV, after the measurement signal is redistributed through protection groups III and IV, the other is sent to BUP/P-VDU (P-VDU-backup monitoring screen) through the network for display and to KIC (KIC-power station computer information system) for display [1].

After the accident, EAS started, FSAR (FSAR-Final Safety Analysis Report) requires the operator to continuously monitor the liquid level of the containment pit. When the EAS003/004MN level sensor reaches a low value, the operator should look for possible leaks on the RIS (RIS safety injection system) or EAS loop outside the containment in time, isolate faulty equipment in time and restart non-faulty equipment. Due to the temperature, the existing static pressure instrument of EAS003/004MN has a large measurement deviation, the operator’s failure to respond in time has led to a further reduction in the amount of water used for recycling in the containment pit, the results in a greater risk of cavitation for the safety jet pump and low-pressure safety injection pump, and ultimately leads to the failure of the...
cooling measures, resulting in more serious consequences.

At present, the measurement method adopted by the field instrument is static pressure measurement, and the pressure guiding medium is silicone oil, the measurement method has serious problems. The density and volume of the pressure-conducting medium change greatly after the temperature is affected, which leads to a large deviation in the measurement result.

Aiming at the serious problem of the pressure-guiding medium of the static pressure liquid level measuring instrument is affected by the temperature change and the density and volume change greatly, which leads to serious deviations in the measurement results. This article focuses on analyzing the root cause of the problem, proposing three solutions, after a comprehensive comparison, the optimal solution is finally determined.

2. Explanation of measurement deviation of static pressure instrument

The EAS003/004MN meter is designed to work in a temperature range of 25~150℃[2], and a measuring range of -3.4m~1m, the manufacturer clarified the problem of large deviations after being affected by temperature, the manufacturer stipulates that the calibration temperature of the meter is 25℃, when the ambient temperature is 25℃, the instrument range is \((-23.798, 0.192\) KPa, the calculation formula for the influence of temperature on the measuring range:

\[
\Delta P = 0.311 \times (T-25) \times (25.4 \times 9.807)
\]

\[= 0.775 \times (T-25)\]

(1)

Among them, \(\Delta P\) is the influence factor of temperature on the range, and \(T\) is the temperature after the accident. It can be seen that:

- When temperature \(T=110\)℃, \(\Delta P = 6.58\), the physical range after correction is \((-17.22, 6.77)\) KPa;
- When temperature \(T=120\)℃, \(\Delta P = 7.35\), the physical range after correction is \((-16.45, 7.54)\) KPa;
- When temperature \(T=130\)℃, \(\Delta P = 8.13\), the physical range after correction is \((-15.65, 8.32)\) KPa.

Fig1 can be obtained (the horizontal axis is the measured liquid level (unit: m), and the vertical axis is the instrument pressure difference (unit: KPa).

As shown in Fig1, when the vertical axis instrument pressure difference is the same, the horizontal axis liquid level measurement result becomes smaller with the increase of the ambient temperature, and the deviation is about 0.1m per 10℃. Therefore, when the on-site ambient temperature deviates from the instrument calibration temperature (25℃), the measurement deviation of the instrument also increases accordingly, and the maximum deviation is about 1m. This will not meet the requirements of instrument measurement accuracy, and will affect the operator's monitoring of the liquid level of the reactor building after the accident, which needs to be improved.

![Fig1. Schematic diagram of EAS003/004MN measured value changing curve with temperature](image-url)
3. FASR technical requirements

Nuclear power plant FSAR (FASR stands for Final Safety Analysis Report) requires the cycle cooling stage of nuclear power plant reactor building after the accident, the operator can decide to stop half of the EAS system equipment. But the following information must be monitored:

(1) The correct operation of the pump, with the help of a flow meter and temperature measurement of the pump and motor;
(2) Equipment cooling water temperature and pollution degree;
(3) EAS003/004MN level value;
(4) Isolation of unused pipelines (PTR001BA suction pipeline, sodium hydroxide injection pipeline, test pipeline, isolation of an EAS series if necessary. PTR-reactor and spent fuel pool cooling and processing system, BA-storage tank);
(5) Check the leakage from the EAS system by measuring the liquid level in the pit of the room with the measuring equipment (pumps, valves, heat exchangers).

From the requirements of FSAR, it can be seen that accurate monitoring of the liquid level of the reactor building during the operation of nuclear power plants and the accident stage is essential.

4. Solutions for deviations in measured values

4.1 Solution one

Not replacing measuring instruments: The static pressure liquid level measuring instrument currently in use is calibrated under the condition of an ambient temperature of 25°C in accordance with the manufacturer’s recommendation, however, the temperature of the instrument installation environment will rise rapidly to 120°C under post-accident conditions, as the temperature continues to rise, the influence of temperature on the pressure guiding medium will become greater and greater, the error increases by 0.1m for every 10°C rise, and the maximum error can reach 1m. Therefore, combined with the preconditions that the temperature of the cooling water entering the reactor building after the accident under the design conditions rapidly rises to 120°C, and the recirculation cooling stage drops to 50°C, take the middle value of 50°C to 120°C to be 85°C for instrument calibration. The manufacturer’s test verifies that the liquid level measurement deviation can be reduced to within ±20% within the temperature range of 50°C to 120°C, it can meet the requirements of the GB13627-Nuclear Power Plant Accident Monitoring Instrument Guidelines for the deviation of the liquid level instrument in the containment pit.

4.2 Solution two

Replace the measuring instrument: because this static pressure liquid level measuring instrument is currently the only post-accident monitoring liquid level measuring instrument on the market that meets the requirements of the K1 appraisal test, uniqueness in procurement, however, because the static pressure type liquid level meter has the defect that the pressure guiding medium is easily affected by the ambient temperature to produce measurement deviation, the liquid level meter with another measurement principle is selected to replace it. Compared with the K3 level quality appraisal, the K1 level quality appraisal adds important LOCA (LOCA-loss of primary circuit coolant) test and irradiation test.

This program chooses a split liquid level measuring instrument with independent intellectual property rights of guided wave radar measurement principle, the split guided wave radar level gauge meets the requirements of K3 quality appraisal, the structure is divided into a sensing part and a transmitter part. The transmitter part is installed outside the containment and has already met the requirements of the K3 qualification test. There is no need to supplement the K1 qualification test.
The sensor part is a probe and a protection tube, made of 316L stainless steel, which can withstand a cumulative irradiation measurement of $2 \times 10^4$ KGy, this part is installed in the reactor building. The sensor part and the transmitter part are connected by a K1 coaxial cable and a connector, as shown in Fig. 2.

The split guided wave radar level gauge has the following advantages:

1. Mature measuring principle;
2. High measurement accuracy, not affected by temperature;
3. K3 level appraisal products have been installed and applied in Qinshan Nuclear Power Plant;
4. The manufacturer is willing to bear all the costs of the preliminary qualification test in advance. If the test fails, the nuclear power plant will not bear the cost risk;
5. Adopting the group purchase mode of group factories can greatly reduce costs and completely solve the problem of large deviations in liquid level measurement after the accident.

The split guided wave radar level gauge has the following shortcomings:

6. The application of the split guided wave radar level gauge that meets the K1 level appraisal requirements to the continuous measurement of the liquid level of the containment pit in the accident state and after the accident is the first domestic and international case, and it needs to pass the K1 level appraisal test before it can be applied.

4.3 Solution three

Replace the measuring instrument: using the float level gauge produced by French AREVA-ELTA, replace the existing static pressure level gauge after supplementing the K1 quality appraisal test, compared with K3 quality appraisal, K1 quality appraisal adds important LOCA test and irradiation test [5].

The level gauge is divided into a sensor part and a transmitter part, the sensor is installed in the containment pit, measuring liquid level output voltage signal, the transmitter is installed outside the containment, and receive voltage signal and convert it into $4 \sim 20$ mA current signal. The sensor part and the transmitter part are connected through the K1 instrument cable and connector to realize the measurement signal channel. The float level gauge is shown in Fig. 3.

The float level gauge has the following advantages:

1. The measuring principle is mature, independent of temperature;
2. K3 certified products have been applied in EPR reactor type (Taishan Nuclear Power Plant).

The float level gauge has the following disadvantages:

1. If the K1 level appraisal test is completed first, the appraisal test fee of ELTA company needs to be paid in advance of more than 2 million yuan. At the same time, ELTA company does not promise to pass the appraisal test, and there is a cost risk;
2. The equipment cost is expensive, estimated to be more than 1.3 million/unit;
3. The circulating cooling water of the reactor building contains debris in post-accident stage, which may cause the float level gauge to jam and fail, and there is a risk of losing the level monitoring function;
5. Comparative analysis of solution
The comparative analysis of the three schemes in the third section is shown in Table 1.

| Solution   | Advantage                                      | Disadvantage                                                      |
|------------|------------------------------------------------|-------------------------------------------------------------------|
| Solution one | Only need to modify the relevant procedures and documents | There is still measurement deviation                              |
| Solution two | Eliminate measurement deviation, not affected by temperature | First application, on-site construction is required, which is difficult and risky |
| Solution three | Eliminate measurement deviation, not affected by temperature | Not guarantee to pass the K1 quality appraisal test, high costs, the risk that the level gauge cannot measure, on-site construction difficult and risky |

After the comparative analysis and risk identification of the above schemes, confirm the selection solution one as the final solution implementation, by modifying the instrument calibration procedures and the management guidelines for serious accidents, and selecting 85°C as the ambient temperature for instrument calibration, the measurement error can be minimized, compared with solution two and three, it can also meet the needs of operators to monitor the post-accident liquid level in the containment. After implementation, it can find a solution for the measurement error of the liquid level, and it can also save costs and avoid site high-risk operation.

The risk of choosing solution one for improvement is that there is still an error in the measured value of the instrument, however, the measured value after the accident is higher than the actual value, which is equivalent to amplifying the safety margin. It is helpful for operators to respond in advance and take measures. In fact, it is a safer consideration and also meets the requirements of nuclear safety.
6. Test verification
The engineers of the maintenance department of the nuclear power plant have followed the requirements of solution one. Re-calibrate the on-site liquid level meter by selecting an ambient temperature of 85℃, perform simulation verification after calibration, and the verification result is qualified, the measurement error did not exceed the verification report provided by the manufacturer, and all the documents were upgraded to meet the requirements.

7. Conclusion
Three solutions are proposed for the serious problem that the pressure-guiding medium of the static pressure liquid level measuring instrument is affected by the temperature change and the density and volume change greatly cause the serious deviation of the measurement, explain the three solutions in detail, compare the advantages and disadvantages of different solutions, analyze the risks of different solutions, after comparison and research, finally, 85℃ is selected as the ambient temperature for instrument calibration, re-calibrate the level meter, compared with solution two and three, it is more suitable for the status quo and requirements of nuclear power plant operation, greatly save costs and avoid potential risks, and it has also been recognized by nuclear power plant operators, equipment managers and maintenance personnel.

The research results presented in this article provide a clear reference and basis for solving the above problems, at the same time, it solves the same problems mentioned above in most CPR (CPR-Pressurized Water Reactor) reactor-type nuclear power plants. In addition, it also provides a new method and a new way for the technical improvement of the same type of liquid level monitoring instrument used in the nuclear island plant of the nuclear power plant.

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