

Analysis of Unplanned Shutdown in HANARO: Thermal Analysis of Thermal Overload Relay for Shutoff Rod Pump Motor

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1. Introduction

During the 116th cycle of HANARO (High-flux Advanced Neutron Application Reactor) operation, an unplanned reactor shutdown occurred due to the drop of shutoff rod (SOR) #2. An evaluation of the rod's drop time indicated a gradual loss of hydraulic pressure. Subsequent system inspections were conducted to identify the cause of the pressure loss and the thermal overload relay (TOR) of SOR pump motor was identified as the most probable cause of the failure. This study performed CFD analysis to evaluate the thermal behavior of the bimetal within TOR, considering both the trip conditions and various scenarios for future stable operation.

2. Methods and Results

This section first details the operating environment of the pump motor during the reactor shutdown incident. A numerical model is then introduced to simulate the TOR. The simulation results and the requirements for stable operation are discussed.

2.1 Operating Environment

The SORs in the HANARO research reactor is a critical safety component to control reactivity by dropping into the core during emergencies. The HANARO is equipped with four independent SORs. These SORs are managed by a hydraulic driving system, where each individual rod is driven by its own dedicated hydraulic pump. The pumps pressurize pool water into a cylinder to lift and maintain the rods in an extracted position. A loss of hydraulic pressure, such as from a pump failure, results in the rod drop into the core by gravity.

During 116th cycle of HANARO, SOR #2 dropped unexpectedly, triggering a reactor alarm and leading to a reactor shutdown. An evaluation of the rod's drop time confirmed that the incident was caused by a loss of hydraulic pump function.

To identify the root cause, a detailed inspection of the hydraulic pump system was conducted. While no mechanical or electrical defects were found in the pump system, the investigation identified the triggering of the TOR within the pump motor as the cause of the power

interruption. The TOR is a protective device designed to disconnect the power supply by utilizing the differential thermal expansion of a bimetal when the motor overheats.

The environmental conditions of the pump motor at the time of the incident were as follows. First, the pit containing the SOR hydraulic pumps was covered with an acrylic cover, which led to heat accumulation. As a result, the internal air temperature of the pit rose more than 20°C above the ambient temperature of the reactor hall. Second, the operating current of SOR pump motor #2 was measured at 9.4A, which was notably higher than the operating currents of the other SOR pump motors that ranged from 8.6A to 8.9A. To evaluate whether the TOR could be triggered under these conditions, a numerical simulation was conducted.

2.2 Numerical Model

To evaluate the thermal behaviors of the TOR within pump motor, a three-dimensional numerical model was simulated using ANSYS Fluent v16. The model encompassed the major components of the motor, including the external case, internal windings, shaft, and the TOR assembly consisting of the bimetal, resistance heater, and its protective case. The components of the model are shown in Fig. 1.

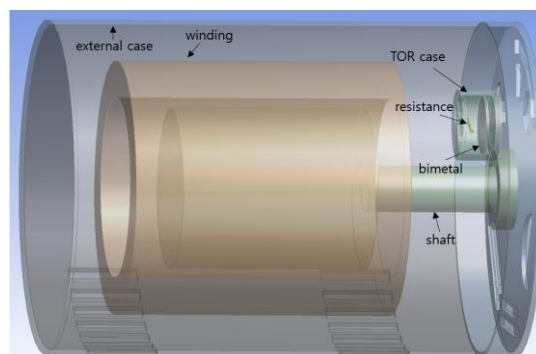


Fig. 1. The components of the pump motor in the model.

To validate the numerical model, the measured surface temperature of the pump motor and the winding temperature inferred from them were used [1]. The analysis results were confirmed to be in good agreement with these experimental values.

2.3 Results

Figure 2 shows the numerical results of the TOR for SOR pump motor #2 under incident conditions. Since the triggering temperature range of the bimetal within the TOR is estimated from 105°C to 110°C, it can be confirmed that SOR #2 dropped due to the triggering of the TOR caused by motor overheating. Table 1 presents the operating currents and the corresponding bimetal temperature ranges for the other SOR pump motors under the same conditions. The results indicate that while the bimetal temperature of SOR pump motor #2 was the highest, the bimetal temperatures of the remaining pump motors were also within the trigger range, suggesting a high potential for recurrence.

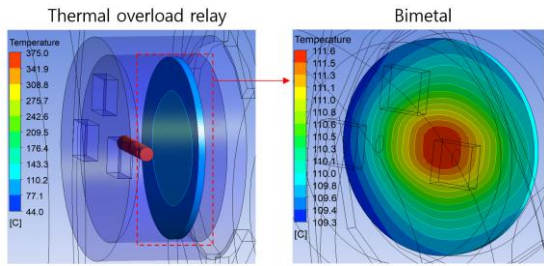


Fig. 2. Numerical results of the TOR for SOR pump motor #2 under incident conditions.

Table 1: Operating currents and calculated bimetal temperatures for SOR pump motors

	motor #1	motor #2	motor #3	motor #4
motor current	8.8 A	9.4 A	8.9 A	8.6 A
bimetal T_{high}	107.8°C	111.6°C	108.4°C	106.6°C
bimetal T_{low}	105.6°C	109.3°C	106.2°C	104.5°C

Several actions were carried out to improve the operating environment. The acrylic cover was removed to increase the cooling efficiency of the pump motors, and the pit's temperature would be monitored. Additionally, SOR pumps #1 and #2 were replaced. The operating currents of the replaced pumps were 8.5A to 8.6A. Since SOR pump motor #3 now has the highest operating current, the bimetal temperature variations for this motor were calculated while changing the pit temperature. The results confirmed that maintaining the pit temperature below 35°C is necessary for the stable operation of the SOR pumps. Although removing the acrylic cover should significantly reduce the pit temperature because the reactor hall is maintained at approximately 25°C, the installation of cooling fans may be required if the pit temperature rises due to poor air circulation.

3. Conclusions

In this study, a thermal analysis of the TOR for the SOR pump motor was performed to investigate the cause of the unplanned reactor shutdown of HANARO. The CFD analysis confirmed that the SOR #2 could be dropped by the overheating of the motor. The simulation results for the other SOR pump motors indicated that the same accident could recur under the same environmental conditions, as their bimetals were also within or near the trigger temperature range. To improve the operating environment of the SOR pumps, the acrylic cover was removed, and SOR pumps #1 and #2 were replaced. The analysis concludes that maintaining the pit temperature below 35°C is necessary for the stable operation of SOR pumps.

REFERENCES

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