Prospect for Seal Performance Test of the Localized APR1400's RCP

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1. Introduction

KAERI completed a development of technologies for performance verification test of APR1400's RCP. Test facility for the localized APR1400's RCP was constructed in KAERI site at the end of 2012. The thermal hydraulic and electric capability of the RCP test facility covers up to 18.5 MPa, 343 °C, 11.7 m^3/s, and 14.0 MW in the design pressure, temperature, flow rate, and the maximum electric power, respectively. In 2013, after finishing the commissioning and modification of the RCPTF, type test (500 hr test) was performed successfully. In 2014 and 2015, 8 production tests for the localized RCPs, which will be installed in Shin-Hanul 1 and 2 nuclear power plant in Korea, were completed successfully. As a final stage of the localization program of the RCP, KAERI will perform a seal LOCA test to verify leakage characteristics and to produce experimental data of the localized seal assembly for the safety analysis during the station black out (SBO) condition.

In this paper, several technical issues developed in a series of research process for the performance verification test for the localized RCP will be described briefly with a main focus on the seal LOCA test.

2. Technical Issues Resolved during the Developing Stage

2.1 Flow Disturbance in the Main Piping

In the RCPTF, to control the RCP flow rate during a test sequence, two subsidiary pipes with 4 control valves are attached to the main piping. The flow disturbance in the main pipe is mainly due to the subsidiary flow from the sub-pipes. Moreover, main measuring parameters including flow rate and shaft vibration of RCP were affected severely by the flow disturbance, especially, in the upstream of the venturi flow meter.

As a counter measure for this flow disturbance, KAERI devised the VRO and etoile-type flow straightener and installed them in the lower part of the main pipe. Flow stabilization was verified by comparing the characteristic data measured at before and after the installation of the VRO and the flow straightener. The current VRO can control the RCP flow rate from 6.5 m^3/s to 9.8 m^3/s. For a higher RCP flow rate up to runout condition, corresponding globe and butterfly valves installed in the subsidiary pipes can be used.

2.2 Measurement and Evaluation of RCP Flow Rate

The venturi flow meter installed in the lower main pipe, upsteam of the RCP casing, is a standard type of venture tube designed according to the ISO 5167-4 and ASME MFC-3M-2004 [1, 2]. Generally, a discharge coefficient (C_D) of venturi flow meter is a function of Reynolds number and it can be acquired by a calibration test which should be performed with a wider Reynolds number condition than an actual working condition of the venturi. The calibration of the venturi flow meter of the RCPTF, however, was performed at Colorado Engineering Experiment Station Inc. (CEESI) in Idaho, USA. CEESI uses a natural gas as a working fluid in a relatively lower Reynolds number range than the rated condition [3].

To compensate the discrepancy due to the working fluids, KAERI introduces the concept of static hole error. It means an effect that pressure tap of finite size may not measure the pressure which can be measured an infinitely small pressure tap. Harris quantify the static hole error in the gas and water respectively, and suggested the correlation to calculate the difference between the discharge coefficient measured in gas and water [4].

The discharge coefficient was reduced by 0.003 ~ 0.016. This reduction in the discharge coefficient resulted in the decrease of the flow rate by 1.33 % at the maximum Reynolds number.

2.3 Measurement of Vibration of RCP and Test Loop

Vibration characteristics of the test loop due to fluid flow can affect the vibration behavior of the RCP such as the frame and the rotating shaft. In order to improve an evaluation accuracy of the RCP vibration data, KAERI performed a frequency analysis of the RCPTF under several kinds of load combinations. Three kinds of experiments were performed as follows:

(1) Frequency measurement & analysis under operating condition
(2) Natural frequency analysis under wet condition
(3) Natural frequency analysis under dry condition

From the analysis, three characteristic frequencies were found such as 20 Hz, 120 Hz, and 200 Hz. The 20 Hz and 120 Hz are originated from the RCP vibration and the 200 Hz was from the main pipe [5].

3. Seal LOCA Test Simulating SBO Condition of APR1400

As a final stage of the localization program, KAERI finished construction of test facility for the seal LOCA test, as depicted in Figure 1, to investigate a sealing performance of the localized seal assembly installed in the APR1400's RCP during the SBO condition. Modification for the RCP test facility to the seal LOCA test facility was completed with an additional installation of centrifugal pump, for a subsidiary coolant circulation through the loop during the SBO period, and heating system of 1.5 MW at the bypass piping system for the temperature and pressure control.

After Fukushima Daiichi nuclear accident in 2011, Safety authorities recommend that utilities increase the safety margins of their nuclear power plant, especially with regard to reactor cooling functions, by improving their ability to cope with beyond-design-basis events - notably, extended SBO, or complete loss of all sources of power. The US NRC's post-Fukushima taskforce recommend, for instance, extending the coping time from 8 h to at least 72 h. In pressurized water reactors (PWRs), the reactor coolant pump (RCP), and more particularly the seal system located between the motor and the impeller, are directly impacted by these recommendations [6].

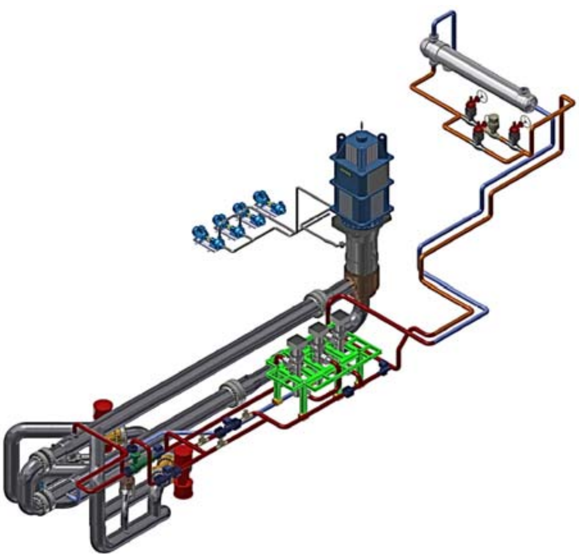

Fig.1 Graphic configuration of the RCP test facility

Test conditions of the localized seal assembly during the SBO were composed as three sub-categories, such as high-pressure and high-temperature condition, low-pressure and low-temperature condition, and zero-subcooling condition as presented in Figure 2, to include all conservative conditions for the seal assembly, main failure mechanisms of which are binding failure of the seal ring, elastomer extrusion, and hydraulic instability. The test conditions were derived with conservatism from several sensitivity analysis results including the FLEX strategy of APR1400.

The seal LOCA test will be performed in October 2017. The test results will be contributed not only a valuable benchmark data to the safety analysis of APR1400, but also to the performance verification of the localized seal assembly of APR1400's RCP.

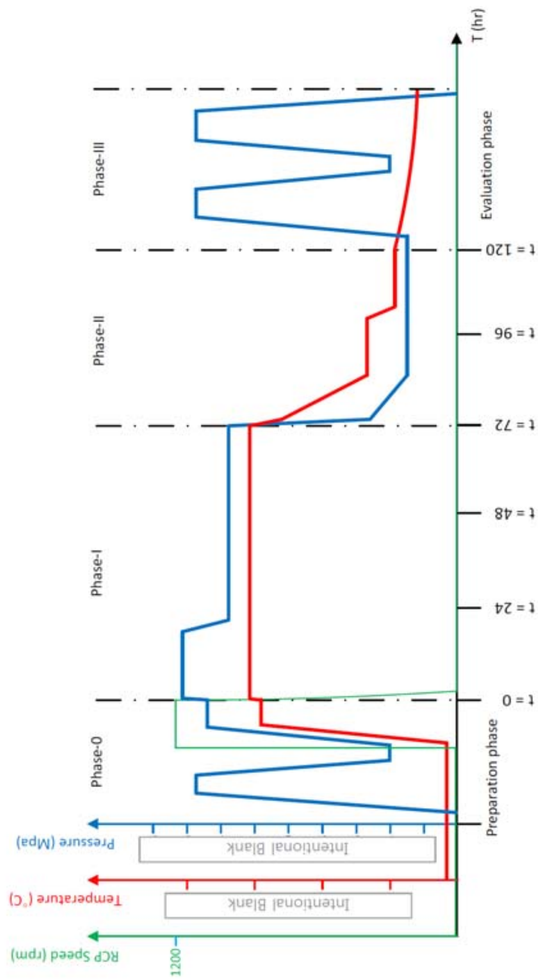

Fig.2 Test condition and procedure of SBO Seal LOCA test

4. Conclusions

In the present paper, the brief descriptions on the technical activities for the development of the verification technologies for APR1400's RCP with an emphasis on the SBO seal LOCA test which will be performed in Oct. 2017 were presented.

KAERI has completed the full set of technology development, prerequisite for the RCP verification test.

The developed technologies were applied successfully to the production-type test for the localized RCP. Moreover, as a final stage of the localization program of the RCP verification and evaluation technology, seal test for the verification of a sealing performance of the localized seal assembly, especially during the station block out (SBO) condition of APR1400, will be carried out in October 2017.

Acknowledgements

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REFERENCES

[1] International Organization for Standardization, “Measurement of fluid flow by means of orifice plates, nozzles and venturi tubes inserted in circulate cross-section conduits running full,” ISO-5167-4, 1991.
[2] The American Society of Mechanical Engineering, “Measurement of fluid flow in pipes using orifice, nozzle, and venture,” ASME MFC-3M-2004, 2004.
[3] Y.-J. CHO, Y.-S. KIM, S. CHO, S. KIM, B.-H. BAE et al., “Advancement of reactor coolant pump (RCP) performance verification test in KAERI,” ICONE22-31075, 2014.
[4] M. J. Reader-Harris, et al., “Discharge coefficients of venturi tubes with standard and non-standard convergent angles,” Flow Measurement and Instrumentation, **12,** 2001.
[5] “Analysis of natural frequency and stability of RCPTF,” Project internal research document, NuRCP-RC-TO010-002, Rev.0, 2014.
[6] “SBO-qualified RCP Seal,” Nuclear Engineering International, www.neimagazine.com, Jun., 2012.