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Effect of the Seal Gap on Reactor Coolant Pump Seal Leakage Rate

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1. Introduction

Reactor coolant pump (RCP) seals limit the leakage of the high pressure reactor coolant system water along the RCP shafts to the containment atmosphere. RCP seal failure refers to the loss of integrity of the reactor coolant system (RCS) pressure boundary. Larger leak rates by the loss of RCP seal integrity than the capacity of the reactor coolant makeup system may lead probability of core-melt. Since loss of seal cooling by the station blackout (SBO) may lead to seal failure and loss of RCS water, RCP seal leakage rate is the critical value for the coping analysis of SBO conditions. The seal failure and shaft movement will change the seal gap. In this paper, RCP seal leakage rate is calculated and an effect of the seal gap on RCP seal leakage rate is studied using RELAP5 code.

2. RCP and RCP seal

The Klein, Schanzlin & Becker AG (KSB) RCP seals are used in OPR100 nuclear power plant (NPP) and Shin-Kori unit 3 and 4 NPP.[1] During normal plant operation, there are two redundant means of cooling via seal injection flow and the CCW system. Seal injection cooling water is directly injected into the RCP seal where a small portion flows to the seal package and the remainder is combined with a recirculation flow in the upper portion of the pump. Cooling water from the ultimate heat sink by the CCW system is directed to the RCP heat exchanger.

Fig. 1 shows the schematic diagram of KSB RCP seal. Seal injection water enters the high pressure seal cooler (HPSC) and is divided into two flow paths. One flow is circulated through the journal bearing, jet pump/ cyclone filter, HPSC and back to the seal area. The remaining flow enters the high pressure side of the first seal assembly and passes through a throttle coil before entering the second seal assembly. Flow from the second seal continues through another throttle coil to high pressure side of the third seal assembly and then to the volume control tank (VCT). The controlled bypass leakage around the seals is required for seal pressure distribution. Two throttle coils are arranged to provide a pressure breakdown distribution in the three seal stage cavities of 0.42:0.42:0.16. The pressure in the uppermost stage is set by the staging flow resistance and the pressure in the down steam VCT.

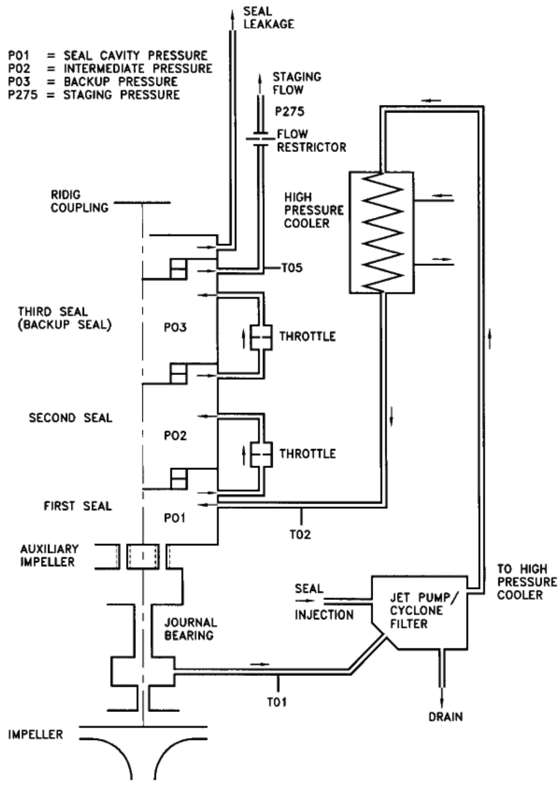

Fig. 1. the schematic diagram of KSB RCP seal

3. Analysis Methodology

In this paper, the detailed simulations of RCP seal leakage are conducted using RELAP5 Mod3.3 code.[2] RELAP5 code has been developed for transient simulation of light water reactor coolant systems. The RELAP5-Mod3.3 model of the RCP and RCP flow paths is used for the analysis as shown in Fig. 2.[3] In this model VCT is not modeled. The CBO flow exiting the seals is piped into the VCT and then return to the environment in a short time. Heat transfer is not modeled between fluid and RCP structures for conservatism, because fluid cooling by heat transfer causes a higher resistance in the flow path. The model includes the RCP cavity through the RCP internals, the seal packages and exit flow to the reactor drain tank (RDT) and reactor containment (RC) building. The recirculation loop with the components of Jet pump/cyclone filter and HPSC is also included in the model.

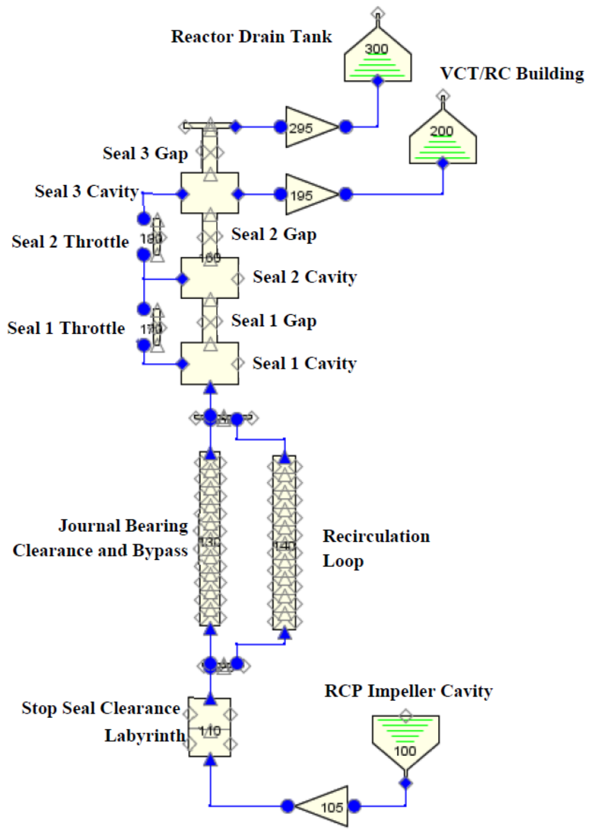

Fig. 2. RCP seal leakage RELAP5 nodal diagram

The boundary conditions are set as the RCS normal operating condition at the RCP impeller, containment conditions at the VCT and normal operation condition at the RDT as shown in Table 1.

Table 1. Boundary conditions

	RCP Cavity	VCT	RDT
Pressure (kPa)	15306.	101.35	122.04
Temperature (K)	563.7	294.3	322.0

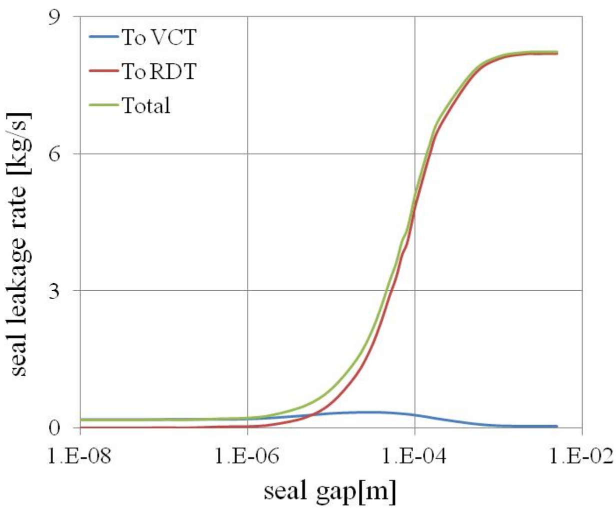

Fig. 3. Seal leakage rate with seal gap

4. Analysis Results

4.1 No seal failure

Fig. 3 shows the RCP seal leakage rate with the seal gap. The gaps of every three seal stage are assumed as the same value. As the seal gap approaches zero, which means no seal failure, the seal leakages to the VCT and RDT approach $1.8X10^{-2}$ and 0 kg/sec, respectively.

4.2 Failure of all seal stages

When the seal gap is larger than 0.1 mm, the seal leakage to VCT starts to decrease. When the seal gap is larger than 1 mm, the leakage to VCT approaches to zero because the seal leakage flow through the third stage seal to RDT. The maximum seal leakage to VCT is 3.3 kg/sec. The seal leakage increases with the seal gap. The seal leakage is 8.23 kg/sec when the seal gap is 5 mm. Table 2 Shows the seal leakages with the seal gap.

Table 2. Seal leakage with seal gap

Seal gap [mm]	0.5	1	2	3
Seal leakage [kg/sec]	7.80	8.13	8.22	8.23

4.3 Failure of first two seal stages

When the first two seal stages fail, reactor coolant water flows through seal throttle and seal gap to the VCT because the third seal stage stick the flow to RDT. The seal gap of first two seal stages doesn't affect the seal leakage rate which is 4.34 kg/sec.

5. Conclusions

RCP seal leakage rate is calculated by RELAP code. For no seal failure, RCP seal leakage rate is 1.8 kg/sec. Failure of all seal stages leads the large seal leakage rate which is 8.23 kg/sec. Failure of first two seal stages affects the total seal leakage rate but the increase of seal leakage rate is small.

REFERENCES

[1] Reactor Coolant Pump Type R01 Technical Manual ShinKori 3&4 Nuclear Power Plant, Westinghouse, August 2011.
[2] RELAP/MOD3.3 Code Manual Volume II: Appendix A Input Requirements, Information Systems Laboratories, Inc., October 2010.
[3] Mie Azuma, Naugab E. Lee, Raymond E. Schneider, Mathew C. Jacob, "RELAP5 Simulation of Reactor Coolant Pump Seal Leakage under Loss of Seal Cooling Conditions," Proceedings of ICONE-23, May 2015.