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Development of a 3-D simulation analysis system for PWR control rod drive mechanism

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ABSTRACT

A 3-D virtual analysis system to analyze the motion of control rod drive mechanism (CRDM) was developed. The analysis system consists of a 3-D model established as per the actual dimensions and interfaces of CRDM parts and a routine to calculate the forces acting on the mechanism, and was verified by mock-up test using the same equipment as the actual product. The analysis system is useful for functional evaluation in maintenance or to factor out root causes in the case of malfunction of CRDM.

1. Introduction

Control rod drive mechanism (CRDM) (Fig. 1) is an important equipment to drive control rods vertically to control the negative reactivity of a reactor. CRDM is mounted on a reactor vessel closure head. CRDM mechanical subassembly called latch assembly is submerged in a primary coolant inside the pressure boundary and is activated by magnetic force sequentially generated by CRDM drive coils outside the pressure boundary.

Direct access is not allowed for the latch assembly without a cutoff operation of the pressure boundary. It is important for plant management to establish method to factors out root causes in case of malfunction of CRDM which have been reported in several plants a year or to monitor aging trend of CRDM.

The motion of CRDM can be evaluated from coil current of drive coils and sound traces from operational test data in outage duration of plant that show aspects of the motion of CRDM (Fig. 2). But this existing evaluation method to confirm the completion and timings of each sequential motions of CRDM cannot provide enough information for quantitative evaluation of motion of CRDM and for future maintenance plan.

To establish the quantitative evaluation method for the motion of CRDM, 3-D virtual dynamic analysis simulator to simulate the motion of CRDM was developed.

2. Development of CRDM simulator

At first, the 3-D virtual analysis simulator to simulate the motion of CRDM was developed based on the actual design and configuration of CRDM. To simulate the interfaces of CRDM parts during the motion of CRDM, the details of parts including contact surfaces were modeled. The forces acting on CRDM are calculated by time steps in the simulator based on physical theory or experimental data. The simulator uses parameters as adjustable inputs to perform the evaluation of delayed motion or malfunction of CRDM as per the given operational conditions.

Then, to confirm the adequacy of the 3-D virtual simulator, the mock-up test using the product of CRDM was performed. The mock-up test included displacement measurement device to measure the motion of CRDM parts. Also, the devices to obtain

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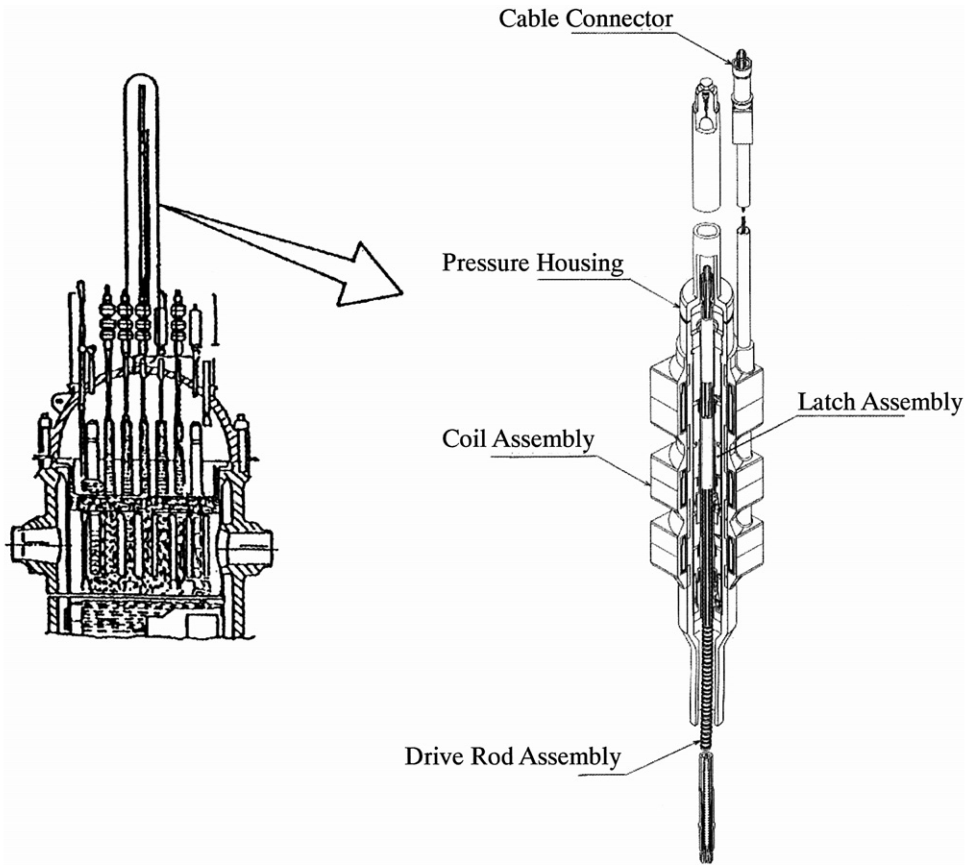

Fig. 1. CRDM for PWR.

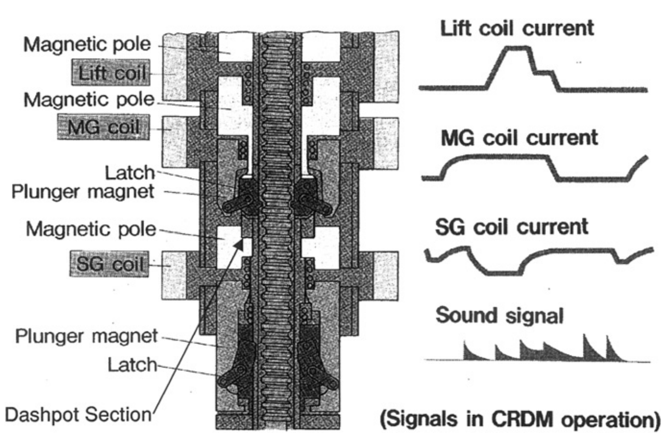

Fig. 2. CRDM mechanism and stepping current trace.

variable parameters for verification of the sensitivity of CRDM motion against parameters were used.

3. Analysis model for CRDM

The 3-D virtual analysis simulator consists of two main programs as shown in Fig. 3. The first one is the main analysis program to calculate the variable parameters by time step. The second one is a 3-D virtual model to perform dynamics analysis. The 3-D model was established as per the actual dimensions and interfaces of CRDM parts based on nominal dimensions at the ambient temperature using dynamic analysis software. The dimensional variations due to temperature and manufacturing tolerances are able to be considered in the subroutine program described in Section 3.1.

3.1. Acting forces of CRDM

The following forces acting on CRDM are calculated by the subroutines in the main analysis program.

(1) Magnetic Force: CRDM drive coils consist of three coils: lift coil, movable gripper coil, and stationary gripper coil. When these coils are energized, magnetic excitation occurs to generate the magnetic force for CRDM parts. This magnetic force varies depending on the gap between the magnetic surfaces in the CRDM and the current of drive coils.
During this development, it was found that the time delay of magnetic force is significant compared to the magnetic force logically calculated based on the gap between the magnetic surfaces and the coil current only. Therefore, the data of time delay magnetic force were acquired by a mock-up test as described later in Section 4.3 to use for magnetic force in the subroutine.
(2) Mechanical spring force: In the CRDM, mechanical springs are set to obtain spring back force when the drive coils are de-energized. This spring force varies depending on the stroke of the compressed spring. The spring force is calculated depending on the displacement of the CRDM parts, considering the property of springs in the subroutine.
(3) Fluid force: The CRDM latch assembly is submerged in a coolant inside the pressure housing. The fluid force on the CRDM parts occurs by the coolant exchange during the motion of CRDM parts. The fluid force depends on the velocities of the