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Preliminary Design Concept for a Reactor-internal CRDM

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1. Introduction

Small Modular Reactors (SMR) including SMART (*S*ystem-integrated *M*odular *A*dvanced *R*eac*T*or) are considered to be alternatives which can provide flexible, cost-effective and safe nuclear energy. Several SMRs are being developed with advanced safety-related features including the concepts of passive shutdown after accidents and/or reactor-internal major components. A rod ejection accident may cause severer result in SMRs because SMRs have relatively high control rod reactivity worth compared with commercial nuclear reactors. Because this accident would be perfectly excluded by adopting a reactor-internal CRDM (*C*ontrol *R*od *D*rive *M*echanism), many SMRs accept this concept.

The first concept was provided by JAERI with the MRX reactor which uses an electric motor with a ball screw driveline [1]. Babcock & Wilcox introduced the concept in an mPower reactor that adopts an electric motor with a roller screw driveline and hydraulic system [2], and Westinghouse Electric Co. proposes an internal Control Rod Drive in its SMR with an electric motor with a latch mechanism [3]. In addition, several other applications have been reported thus far.

The reactor-internal CRDM concept is now widely adopted in many SMR designs, and this concept may also be applied in an evolutionary reactor development. So the preliminary study is conducted based on the SMART CRDM design.

2. Methods and Results

In this section, a preliminary design concept for a reactor-internal CRDM is proposed. The validity of the design concept is reviewed by an electromagnetic analysis.

2.1 Preliminary CRDM design

Figure 1 shows a schematic diagram of the CRDM for SMART by KAERI [4] consisting of three coils to manipulate latches in the latch assembly from the outside of the motor housing assembly. The coil assembly and the position indication system are designed to be operated in the reactor building environment, and the latch assembly designed to be operated in the reactor coolant. The motor housing assembly configures the pressure boundary for the reactor coolant. This mechanism has a 15.875 mm step pitch per operational cycle, and this configuration may be applicable to an evolutionary reactor development. The step pitch may be redesigned to 10 mm if necessary.

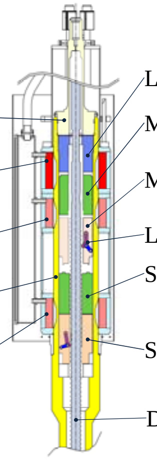

Fig. 1. SMART CRDM configuration

Here, a revised motor housing design is proposed. To be operating in a reactor coolant environment, every component of the CRDM shall be redesigned to be fit for operational condition in a reactor coolant environment at high temperature (350℃) and high pressure (15MPa). The motor housing does not play a role as a pressure boundary in the reactor-internal CRDM anymore because every component is submerged in the reactor coolant with the same coolant pressure. Thus it does not need a thick wall and can be designed just as a support structure for the motor assembly as shown in Figure 2.

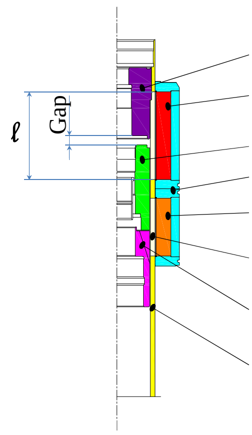

Fig. 2. Simplified analysis model of the proposed design

The motor housing assembly has a uniform thickness with magnetic and non-magnetic material by turns. Magnetic material forms the return path of the magnetic field. If the motor housing has improper magnetic material arrangement, the magnetic field leaks inefficiently. There should therefore be an optimum design to maximize the magnetic force by placing proper magnetic and non-magnetic material in the motor housing assembly. The latch assembly is already designed to be operating in the reactor coolant, modification would be unnecessary.

2.2 Electromagnetic analysis

The analysis model to investigate optimum design arrangement is shown in Figure 2. MagNet v7 by Infolytica Co. is used as an electromagnetic field simulation tool, which uses a finite element technique of Maxwell's equations. The gap in Figure 2 is 15.875 mm, and the current built through the lift coil is 12,750 Ampere-turns. The lift pole, the movable latch pole, the movable latch plunger, and the coil housings are magnetic. The coolant area is filled with water actually, and it is considered as air in the analysis.

The movable latch coil shall be actuated to lift the control rods in practice; however, only the lift coil considered to be actuated in this analysis is used to estimate the material arrangement effect by the lift coil. The thermal effect is not considered in this analysis.

2.3 Analysis results

Because the non-magnetic material portion of the motor housing may affect the efficiency of the magnetic field, the lifting force variation with respect to non-magnetic material part length (ℓ) is estimated. The analysis results are summarized in Figure 3. The horizontal axis represents non-magnetic material length compared to lifting coil length, and the vertical axis represents the lifting force compared to the maximum. The maximum lifting force is estimated to be 2,600N.

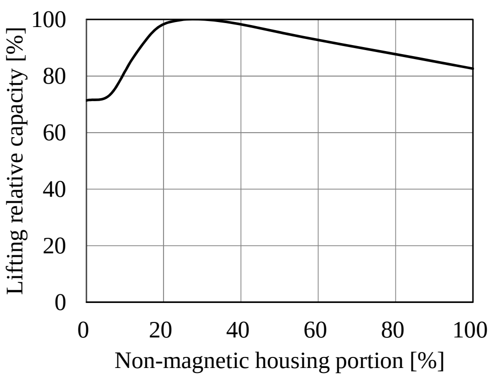

Fig. 3. Lifting force variation

The results show that there is an optimum arrangement of magnetic and non-magnetic materials, which makes the optimized electromagnetic efficiency. In this result, 30% length of non-magnetic material produces maximum lifting force. Because the coil produces enough lifting force required in any case, downsizing may be possible. The lifting force decreases gradually along with increasing non-magnetic portion over the lifting coil length. The minimum force is expected when the whole motor housing is built with non-magnetic material, and it is down to 40% compared to the maximum lifting force.

Figure 4 shows the magnetic flux density profile for the case producing the maximum lifting force.

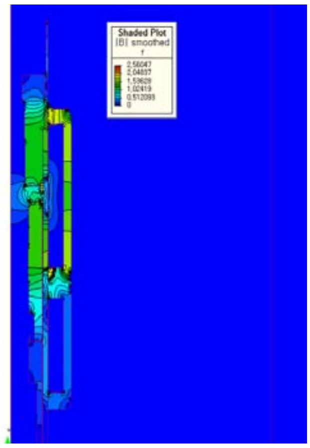

Fig. 4. Magnetic flux density profile

3. Conclusions

A preliminary design concept for a reactor-internal CRDM was proposed and evaluated through an electromagnetic analysis. It was found that there is an optimum design for the motor housing, and the results may contribute to the realization a reactor-internal CRDM for an evolutionary reactor development. More detailed analysis results will be reported later.

Acknowledgement

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