Thermal Effect of Crud Deposition and Irradiation Heat on the In-Vessel Control Element Drive Mechanism

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1. Introduction

The In-Vessel Control Element Drive Mechanism (IV-CEDM) is designed to be installed inside the reactor vessel unlike commercial ex-vessel CEDM as it has several advantages including fundamental exclusion of the rod ejection accident [1-2]. This difference requires new considerations of crud deposition and irradiation heat effect. Due to the installation location and magnetic properties of the IV-CEDM, more crud may be deposited on the IV-CEDM and irradiation heat would not be so negligible that they may affect the driving performance and the integrity of the coils. This paper studies on thermal effect of crud deposition and radiation induced heat on the IV-CEDM.

2. Methods and Results

A finite element static thermal analysis method was performed to investigate the thermal effects of crud and irradiation heat on IV-CEDM's performance. The analysis was conducted using commercial software ANSYS ver. R2021 [3].

2.1 Finite Element (FE) Model of the IV-CEDM

The previous work [4] developed the FE model of the IV-CEDM (Fig. 1) for thermal analysis which consists of axisymmetric plane element (PLANE55) and thermal surface effect element (SURF151). The FE model incorporates thermal experiment results of the coil. Crud deposition layer was added to the previous FE model [4] as shown in Fig. 2. Thermal conductivity of crud, 0.78 W/m-K, referred to EPRI Report No. 1022896 [5]. Irradiation heat source to all solid materials and heat generation of the coils due to current input were applied.

2.2 Thermal Analysis

Parametric study was done to investigate the thermal effect on performance of the IV-CEDM. Four parameters were considered in this study which were 1) crud deposition thickness, 2) current input, 3) coolant flow velocity and 4) radiation induced heat generation. Ranges of the parameters were determined based on previous study [4] and commercial PWR design data.

Three temperature criteria for performance of the IV-CEDM established in [4] were checked with analysis results:

1) Temperature of the Mineral Insulated (MI) coil shall be maintained below 400℃ for insulation resistance
2) Temperature of the magnetic parts shall be maintained below 500℃ to prevent reduction of electromagnetic force
3) Temperature of the coil housing shall be maintained below 345℃ to avoid nucleate boiling

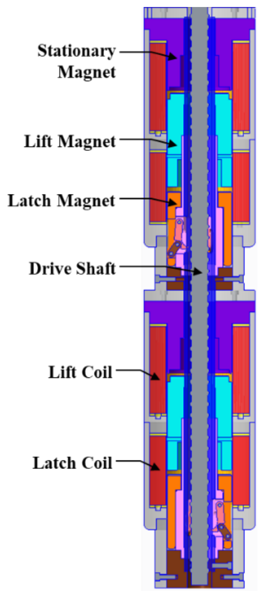

Fig. 1. IV-CEDM Design

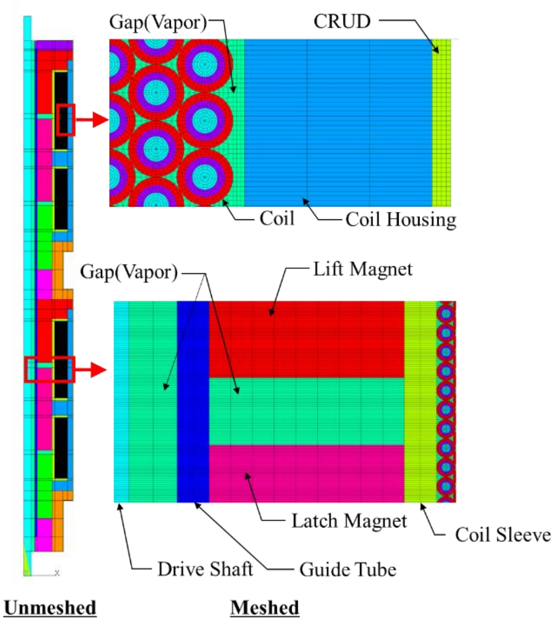

Fig. 2. Analysis model of the IV-CEDM

2.3 Analysis Results

Temperature distribution of the IV-CEDM when crud thickness is 0.1 mm, coil input current is 6 A, coolant flow velocity is 0.2 m/s, irradiation heat generations are 0 and 10^5 W/m^3 is shown in Fig. 3. Fig.3 shows that dominant heat source may change from coil current to irradiation heat as to crud or/and radiation induced heat.

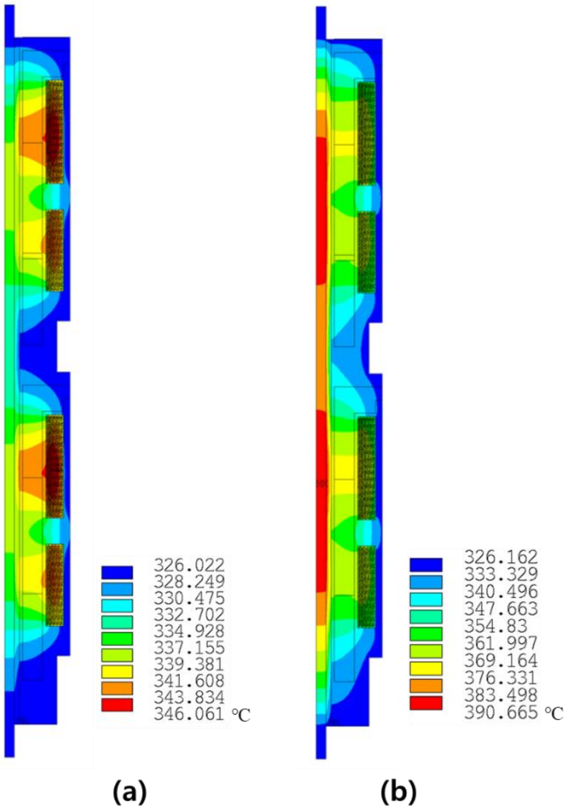

Fig. 3. Temperature distribution of the IV-CEDM (t_{crud}=0.1 mm, I_{coil}=6 A, $v_{coolant}$=0.2 m/s):
(a) $Q_{irradiation}$ = 0 W/m^3, (b) $Q_{irradiation}$=10^5 W/m^3

Fig. 4. represents effect of crud thickness. It was found that there was little change in temperature even with increasing crud thickness and it was maintained even at low flow velocity.

Fig. 5 implies that the IV-CEDM should not be installed right above the core because temperature of the IV-CEDM is highly sensitive to irradiation heat. In case that the flow velocity is 0.003 m/s, the surface temperature first reaches the limit of 345℃ when the irradiation heat is approximately 7×10^4 W/m^3. On the other hand, when the flow velocity is 0.2 m/s and irradiation heat is near 2×10^5 W/m^3, the conductor temperature first reaches the limit of 400℃.

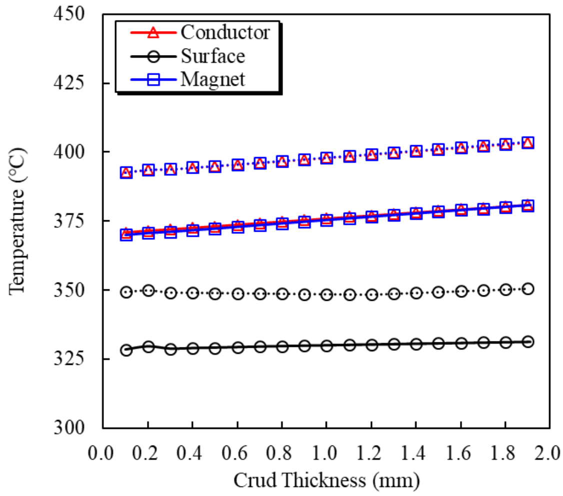

Fig. 4. Maximum temperature vs crud thickness: $v_{coolant}$=0.2 m/s (solid line), 0.003 m/s (dotted line), t_{crud}=0.1mm, I_{coil}=6 A

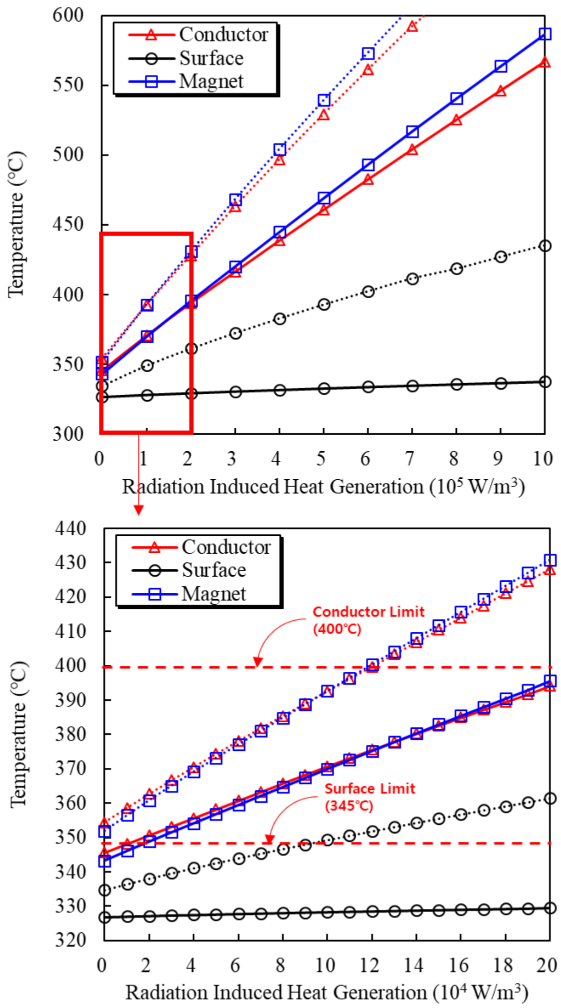

Fig. 5. Maximum temperature vs irradiation heat: $v_{coolant}$=0.2 m/s (solid line), 0.003 m/s (dotted line), t_{crud}=0.1mm, I_{coil}=6 A

3. Conclusions

Finite element thermal analysis was performed to investigate the effects of crud deposition and irradiation heat on the IV-CEDM. It was found that crud deposition has little thermal effect on the IV-CEDM. However, irradiation heat turned out to have significant effect. Through parametric study, allowable irradiation heat values with various coolant flow velocity were found. By using those results, distance between the IV-CEDM and the core should be determined so that irradiation heat does not cause overheating the IV-CEDM.

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