Energy-balance model of axial fuel relocaiton under LOCA

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1. Introduction

The fuel fragmentation, relocation and dispersal(FFRD) have attracted considerable attention since then the FFRD was observed in Halden LOCA test for high burnup fuel [1]. During LOCA conditions, The fuel pellets are pulverized into very small-sized fragments at a high burnup (> 71 GWd/kgU) [2], and these fine fragments may move to an empty region which is caused by high temperature ballooning. This fuel relocation phenomenon can concentrate the heat load to the fuel relocated region, which leads to oxidation increase of cladding and cladding failure. For this reason, in terms of fuel safety, it is important to analyze the high burnup fuel behavior under LOCA conditions.

To analyze these phenomena, a computational model for fuel relocation under LOCA has been proposed by Jernkvist and Massih[3], which is implemented as an integral part of FRAPTRAN 2.0P1[4]. This relocation model solves the mass conservation quation, but it does not consider the energy conservation equation with regard to the axial direction. This approach could affect the calculated fuel temperature when there is a large axial gradient of the power profile. So in this case, it is not properly reproduced by the relocation model.

In the FRAPTRAN 2.0P1, the relocation model which does not reflect the energy conservation may be different between true and predicted power due to fuel relocation. This is scaled by Gscale parameter which is scale factor for rod average power.

In this paper, we have developed Energy-balance model considering energy conservation to accurately predict the axial rod power due to fuel relocation. The energy conservation is reflected using the fuel mass history by fuel relocation and axial power profile.

2. Modeling approach and methodology

2.1 Modeling approach

In the FRAPTRAN2.0P1 code, the relocated fuel relative mass(Frmass(m)) at each node is calculated by the relocation model which is proposed by Jernkvist and Massih[3]. Then, the axial power(Q) is calculated by multiplying the fuel mass by the axial power profile(q) at each node.

For example, in Fig. 1, the power factor of nodes 3 and 4 are expressed as 1.3(m3) x q3 and 0.7(m4) x q4. However, this approach does not reflect the energy of Fuel mass before fuel relocation. To accurately predict the axial power change at each node after fuel relocation, it is necessary to know the relocated fuel mass history as shown in Figure 1.

The fuel mass history can be expressed in the form of a square matrix. In figure 1, Time 1 represents the fuel relative mass (Frmass) before fuel relocation, and Time 2 represents the Frmass history after fuel relocation. The output factors considering the fuel mass history in nodes 3 and 4 are expressed as q3 x m3 + 0.3 x (q4 x m3) and 0.7(m4) x q4.

As such, in order to reflect the output history before relocation, it is necessary to define the fuel mass history relocated caused by fuel relocation.

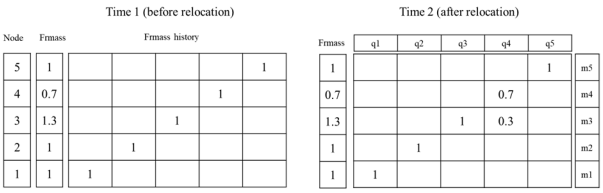

Figure 1. Calculation of axial power considering fuel mass history(m) and axial power profile(q).

2.2 Fuel mass history by fuel relocation

The relocated fuel mass history is defined based on the following assumptions.

1. Calculation start at the bottom (1,1)
2. The value of the bottom (1,1) is always 1 (the bottom can no longer be relocated to the bottom)
3. Fuel relative mass at each node is always 1 (initial fuel pellet)
4. Fill the space of each node based on fuel relative mass(Frmass)
5. The minimum Frmass is 0.01 (due to small fuel fragments that are bonded to the cladding inner surface)
6. The maximum Frmass that can fall from the top is 0.99

Node(n)	Frmass(m)	Frmass history				
1	m1	**(1,1)**	(2,1)	(3,1)	(4,1)	(5,1)
2	m2	(1,2)	**(2,2)**	(3,2)	(4,2)	(5,2)
3	m3	(1,3)	(2,3)	**(3,3)**	(4,3)	(5,3)
4	m4	(1,4)	(2,4)	(3,4)	**(4,4)**	(5,4)
5	m5	(1,5)	(2,5)	(3,5)	(4,5)	**(5,5)**

Figure 2. Square matrix for fuel relative mass(Frmass) history.

Figure 2 shows a 5 x 5 matrix representing the Frmass history of 5 axial nodes. The Frmass history is calculated by filling in the empty space from the bottom to the top. The sum of the axial directions is always 1, which means the amount of the initial fuel pellet. The sum of the radial directions is the Frmass at each node. After the Frmass history was calculated, the axial power factor is obtained by multiplying the axial power profile by the Frmass history. And then, the axial power changed by the fuel relocation is the radial sum of the relocated axial power factors.

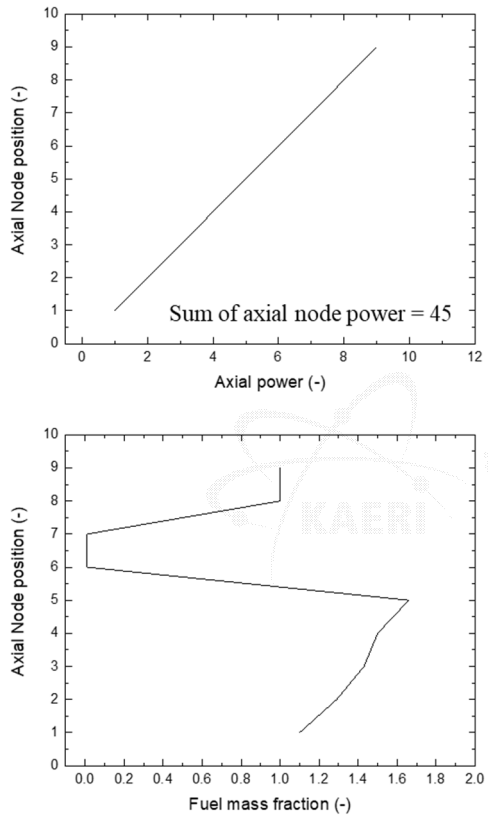

Figure 3. Arbitrary input value of axial power profile and fuel relative mass.

2.3 Calculation of axial node power in relocated fuel

For the verification of the energy balance model implemented as a stand-alone code, an arbitrary input value was used, and these values are shown in Figure 3. It was assumed that the fuel rod consists of 9 nodes in the axial direction. The axial power profile was constructed to have a steep axial distribution. In addition, Frmass assumed that the largest amount of fuel mass was accumulated at node 5 due to fuel relocation caused by ballooning.

Figure 4 shows the comparison of the axial power at each node, which is changed by the fuel relocation, calculated by the existing approach and the energy-balance model. In the region of node 5 to node 2, it was found that the axial power value calculated by the existing approach and the energy balance model was different. In the case of the energy balance model, the axial power was larger than that of the existing approach. The reason is that this model takes into account that the fuel fragments that had high power at the top move to the bottom.

In the case of the conventional approach, the sum of the axial output values of each node was 39.4, whereas in the case of the energy balance model, it was 45.

Considering that the sum of the axial power profiles before fuel relocation was 45, it was revealed that the energy-balance model preserves the rod average power during fuel relocation.

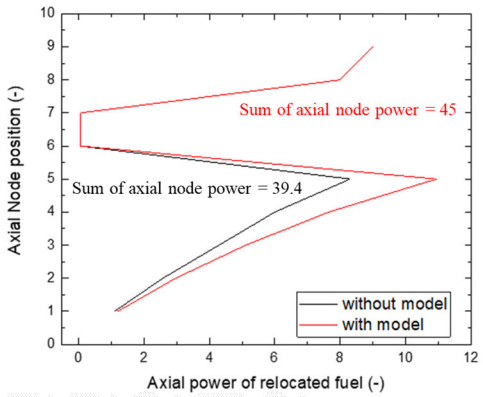

Figure 4. comparison of the axial power calculated by the existing approach and the energy-balance model.

4. Summary

The energy-balance model has been developed to accurately predict the axial power change due to fuel relocation during LOCA. This model was shown that the energy before and after fuel relocation was conserved even in the case with a steep axial power gradient along the fuel rod. In the future, we plan to apply this model to the FRAPTRAN2.0P1 code and evaluate axial power using experimental data.

Acknowledgement

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