Development of Fast running DNBR Calculation Code

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1. Introduction

SMART core adopted a core protection(SCOPS) and a supervising system(SCOMS) to satisfy the SAFDL for AOO and normal operation. Generally, the criteria is limited to the DNBR limit so that the DNBR calculation module is required in the protection and the supervising system of core.

There are CPU time limit and calculation robustness as some requirements of the DNBR calculation module in SCOPS and SCOMS caused by hardware limitations. The non-iterative few channel methods are needed to satisfy the requirements. Non-iterative numerical method is similar to the CETOP algorithm originated from ref. 1. The method is known as the non-iterative prediction and correction method. An optimum number of channels for core lumping model is selected as 4-channel which is same channel number of CETOP model. A compensation model of lumped channel [2] is needed to ensure that the 4-channel thermal hydraulic field is nearly equivalent to that field of 1/8-core model that is calculated by MATRA-S.

The code called FAST that is fast running DNBR calculation is developed to satisfy the requirements of CPU time and calculation robustness. Present paper is described of characteristics and calculation results of developed FAST code.

2. Methods and Results

2.1 Governing equations and enthalpy transport coefficient

Governing equation forms of FAST are similar to the general subchannel code except neglecting transient term and transport coefficient model. Continuity equations is as follows

$$\frac{\partial m_i}{\partial x} = -w_{ij} \tag{1}$$

, where m_i is axial mass flow rate at i subchannel, w_{ij} is lateral flow from i-channel to j-channel.

Axial momentum equation between two adjacent i-channel and j-channel is as follows:

$$A_i \frac{\partial p_i}{\partial x} = -F_i - gA_i\rho_i + w_{ij}^{'}\left(\frac{u_i - u_j}{N_U}\right) + w_{ij}\left(2u_i - \left(\frac{u_i + u_j}{2} + \frac{(u_i - u_j)n_{ij}}{2N_U}\right)\right) \tag{2}$$

, where A_i is channel area, p_i is radially averaged pressure, ρ is coolant density, F_i is momentum force term, u is channel radially averaged velocity. N_U is defined by transport coefficient for axial velocity.

Lateral momentum equation is described as follows:

$$\frac{p_i - p_j}{N_P} = K_{ij}\left(\frac{w_{ij}|w_{ij}|}{2s^2\rho^*}\right) + \frac{1}{s/l}\frac{\partial}{\partial x}\left(u^* w_{ij}\right) \tag{3}$$

, where p_i is channel averaged pressure, K_{ij} is cross-flow resistance coefficient, s is gap width between fuel rods, l is effective length of transverse momentum interchange, u^* is axial velocity carried by the diversion cross flow w_{ij} . N_P is defined by transport coefficient for lateral pressure.

Enthalpy equation is as follows:

$$m_i \frac{\partial h_i}{\partial x} = q_i^{'} - \left(\frac{h_i - h_j}{N_H}\right)w_{ij}^{'} + \left(h_i - \left(\frac{h_i + h_j}{2} + \frac{(h_i - h_j)n_{ij}}{2N_H}\right)\right)w_{ij} \tag{4}$$

, where q' is energy added to i-ch from fuel rods per unit time per unit length, $w_{ij}^{'}$ is turbulent intergchange between i-ch and j-ch. h_i is enthalpy at i-ch. N_H is defined by transport coefficient for enthalpy.

Transport coefficients in eq. (2) to (4) to compensate the different field characteristics between lumped channel and subchannel model are defined as the ratio of the difference of lumped variables over difference of subchannels. All primitive variables in governing equations are unified as the lumped variables using the transport coefficients.

These equations defined by lumped variables with transport coefficient are calculated by non-iterative prediction correction method.

2.2 Non-iterative prediction correction Method

Non iterative method applied to FAST code is a family of single pass marching method. The method excluded the outer-iteration which is necessary to apply boundary condition to the iteration process. The main idea of non-iterative method is that the boundary condition is always applied to the solution at J+1 step whenever the solution is marching along axial node[2].

The scheme begins with the estimation of lateral flow at axial elevation of J. Then enthalpy at axial location of J+1 is predicted using energy equation and axial and lateral flow at J. Using the enthalpy at J+1, properties at J+1 are updated. At prediction step, lateral pressure at J+1 is assumed at zero value to estimate the lateral flow at J+1 in Eq. (3). The estimated pressure, axial velocity and lateral flow at J+1 and J are used to

correct the lateral pressure difference at axial node J. After calculating the correction, the lateral flow at node J is newly calculated based on the correction of pressure difference. Axial flow at node J is updated using the continuity equation and updated lateral flow at J. After all values are updated, the solution is advanced next to axial location until core exit.

In the method, lateral pressures and the axial flows are corrected at each node before the next is calculated.

Therefore the accumulated errors are greatly reduced.

2.3 SMART 4-channel model

MDNBR of hot channel in SMART core is calculated using 4-channel model as shown in Fig. 1. In the model, core is modeled as one fuel assembly and hot assembly included hot channel is used of 1/8 assembly model. Hot channel and surrounded channel is depicted as channel 3 and 4 respectively. Other channels are adopted channels to calculate the enthalpy transport coefficient to compensate enthalpy distribution between lumped channel and subchannel.

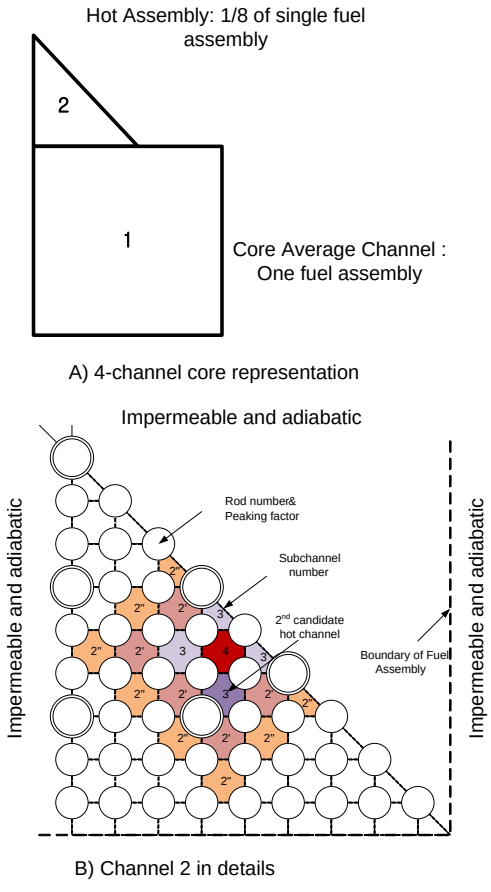

Fig. 1. 4-Channel lumping model of FAST code to calculate the DNBR in hot channel.

2.4 Results of FAST calculation

MDNBR validation is performed on the 1080 calculation cases determined by the LCO. The accuracy is estimated with comparison of MATRA-S[3]. The FAST calculation is always larger than the results of MATRA-S because of excessive mixing of 4-channel model.

Conservatism of MDNBR compared of MATRA-S is satisfied adapting flow correction factor which forces the hot channel flow rate to be reduced as shown lower figure in Fig. 2. The DNBR margin compared of MATRA-S is reduced at the maximum 10 % which appeared at the safety analysis condition with A.O. ±0.6.

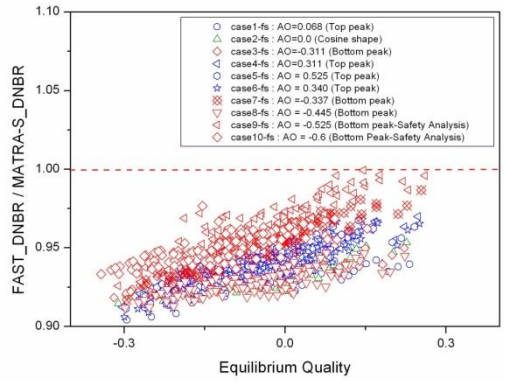

Fig. 2. Comparisons of MDNBR of FAST and MATRA-S for 10 axial power shapes.

3. Conclusions

DNBR calculation module is developed to be implemented into the SCOP and SCOMS. The module is possible to perform online DNBR calculation robustly. For this calculation, the non-iterative prediction-correction method and enthalpy transport coefficient are adopted in FAST. MDNBR calculation of FAST is performed over 1080 validation cases based on LCO of SMART. In the validation results, DNBR margin is closed to it of MATRA-S in the Max. 10 % discrepancy.

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