Assessment of FRAPCON-MATRA Coupling for a Multi-rod Geometry

Seong-Jin Kim[*], Hyo-Chan Kim, Hyouk Kwon, Kyong-Won Seo, Dae-Hyun Hwang
Korea Atomic Energy Research Institute, Daejeon, Korea
[*]Corresponding author: sjkim2@kaeri.re.kr

1. Introduction

A various multi-physics coupling has been attempted to obtain the reactor core conditions by the best estimate[1]. MASTER-MATRA coupling has been applicable for a SMART simulator[2,3] and DeCART-MATRA coupling has been conducted for the SMART whole core in steady state[4]. FRAPCON-MATRA coupling was archived for a preliminary problem consisting of a single fuel rod and 4-subchannels. In this study, FRAPCON-MATRA coupling method to calculate multi-rod using the previous coupling algorithm is presented and applied to SMART 5x5 CHF bundle.

2. Methods and Results

2.1 Description of Codes

MATRA

MATRA (Multi-purpose Analyzer for Static and Transient Effects on Reactors) code, which has been developed at KAERI, is a subchannel analysis code to design a nuclear reactor. The code can calculate a thermal-hydraulic in steady-state or transient condition in the core. The MATRA code has been coupled with other physics code to provide thermal-hydraulic parameters. Basically, the MATRA code had a capability to consider continuously variations of flow area and gap size, which are input by user. In this coupling, the area and gap are dynamically changed due to iteration with the FRAPCON code. Thus, the effect of rod diameter variations to be calculated from the FRAPCON code is able to reflect to the MATRA code as a variation of the flow area($=AFACT$) and a variation of gap size($=GFACT$) as followings:

$$AFACT_{K,I}=\left[AREA0_{K,J}-\sum_{L=1}^{4}PHI_{L,I}\left(D_L^2-D0_L^2\right)\frac{\pi}{4}\right]/\,AREA0_{K,I}$$

$$GFACT_{K,N}=\left[GAP0_{K,N}-\sum_{L=1}^{2}\left(D_L-D0_L\right)\frac{1}{2}\right]/\,GAP0_{K,N}$$

where K, I, N mean the axial node, channel and gap number, respectively. “$PHI_{L,I}$” is a fraction of the outer rod(#L) perimeter facing the channel-I. “L” is the number of the rod to be adjacent to channel-I or gap-N. “AREA0” and “GAP0” mean the nominal area and gap size when the diameter is fixed as an initial value.

FRAPCON

FRAPCON-3 code[5] solves a steady state response of fuel rod in a light-water reaction during a long-term burnup. It has a capability to estimate the temperature, pressure, and deformation of a fuel rod according to the variation of the coolant and rod power. The reference [5] describes that this code considers several phenomena which are heat conduction through the fuel and cladding to the coolant, elastic and plastic deformation of cladding, mechanical interaction of fuel-cladding, and fission gas release from the fuel and rod internal pressure, cladding oxidation.

2.2 Single Rod Coupling

In the previous work, coupling method between the FRAPCON and MATRA to solve a single rod problem was described. In summary, the FRAPCON is provided with the heat transfer coefficient considering thermal-hydraulics between subchannels from the MATRA code. Simultaneously, the MATRA code is provided with the rod diameter recalculates the thermal-hydraulic conditions considering the rod diameter variation. The communication was conducted by TCP/IP socket. An independent server program generalized the flow of communication between codes.

2.3 Multi-Rod Coupling

A stand-alone FRAPCON code cannot solve the multi-rod but single fuel rod. Therefore, the previous coupling method needs to be modified to achieve coupling such as calculations for fuel assembly coupling, whole core coupling. The modified method to couple multi-rod can be summarized as followings:

(a) Using Multi-Port Connection
(b) Using Single-Port & MPI Communication
(c) Modifying the FRAPCON code
(d) Writing the FRAPCON into the MATRA

The first is the extension of the previous coupling method. It is an easy way that each fuel rod consisting of fuel bundle or whole core has an independent FRAPCON code according to each fuel rod. At this time, the communication between the FRAPCON codes and server program is reached through the independent port. This means that it is more inconvenient to calculate FRAPCON-MATRA as the rod increases. Thus, the second is designed to modify and improve the first way using MPI communication technique. In this method, communication between the server and FRAPCON code using the socket port is maintained. However, gathering and broadcasting coupled data are achieved through MPI communication. The third is the way that the FRAPCON code is modified to be able to calculate the multi-rod in itself. The last is that the MATRA code includes the FRAPCON such as subroutine form. This way needs no algorithm to communicate between codes including server program. However, the third and the last method are not a scope in this stage even though they are economic and efficient. Thus, the method (a) and (b) are selected to this study.

The coupling procedure using multi-port was presented in Fig. 1. As shown in Fig. 1, if there are N-fuel rods, the number of the independent FRAPCON code have to become N. Each independent FRAPCON code is connected to the server program with different TCP/IP port. The server program gathers diameter variations of each fuel rod from the independent FRAPCON codes and broadcasts the heat transfer coefficient to each FRAPCON code. The communication between the server program and the MATRA code are identical to the previous work[1].

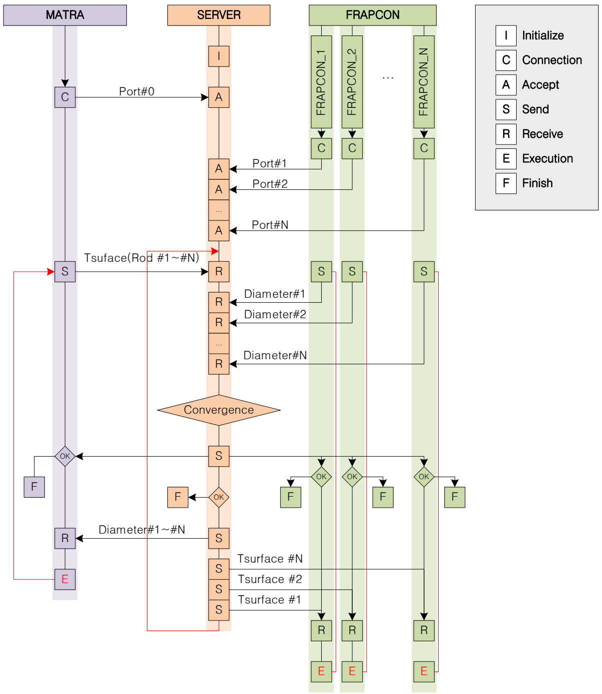

Fig. 1. Flow chart of multi-rod coupling using multi-port between FRAPCON and MASTER

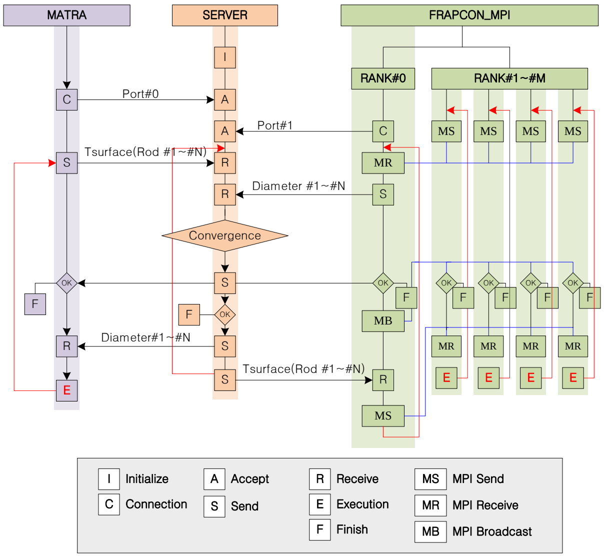

Fig. 2. Flow chart of multi-rod coupling using single-port and MPI between FRAPCON and MASTER

The procedure of the method (b) was presented in Fig.2. The part of communication between the server and the MATRA code are identical with the method (a). In case of communication between the server and FRAPCON codes, the number of port was decreased from the number of rods to one. The FRAPCON codes according to each rod with different port are also merged into one, named by FRAPCON_MPI. As shown in Fig.2, the main node controls the flow of coupled variable between the serve and FRAPCON_MPI code. The main node of the FRAPCON_MPI gathers the deformation results of fuel rod and shares heat transfer information received from the MATRA code. The numbers of port, input and execution file of the FRAPCON to conduct coupled calculation with N-rods are summarized in Table I.

Table I. The number of port and files respect to coupling method when the number of rod is N.

Method	Number of Port	Input File	Execution File
(a)	N	N	N
(b)	1	N	1
(c)	1	1	1
(d)	0	1	0/1

2.4 Calculation Results

FRAPCON-MATRA multi-rod coupling of method (a) and (b) was conducted to a SMART 5x5 CHF bundle. The axial power was assumed as a cosine shape. It was also assumed that the radial peaking of circumferential rods was lower than central rods. One of the experimental conditions for the SMART 5x5 CHF bundle was selected as an operating condition in this study. There was no difference between the method (a) and (b). Therefore the comparison results were omitted in this paper.

The calculation results are depicted in Figs. 3 and 4. Figure 3 shows the rod diameter profile of corner and center rod which have the lowest and highest radial peaking, respectively. In case of the corner rod, an increment of the rod diameter was evaluated as having a range of 8.16 ~ 11.80 ㎛. It was evaluated that the diameter of the center rod increased within 10.28 to 23.60 ㎛. The green line means the difference of MDNBR between coupled and stand-alone calculations in Fig.3. As shown in this figure, it was evaluated that the variation of rod diameter had little effect on MDNBR in this operating conditions. Insides, a comparison of rod temperature between the coupled and stand-alone calculation was shown in Fig.4. In Fig.4, closed and open symbols mean the temperature of the corner and center rod, respectively. It was evaluated that the rod surface and center temperature of the coupled calculation were lower than those of the stand-alone calculation due to an increase of diameter. In case of the center rod, the maximum differences of rod surface and center temperature were 2.38 and 2.54 ℃, respectively.

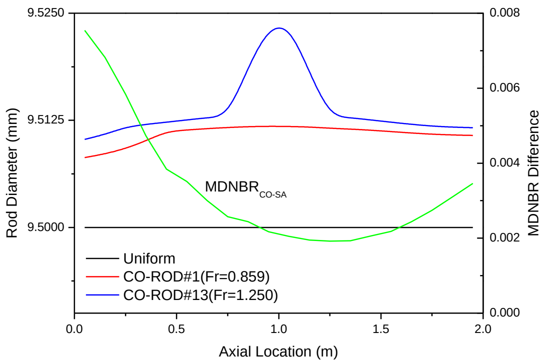

Fig. 3. Rod diameter and MDNBR difference profile between stand-alone and coupled calculation.

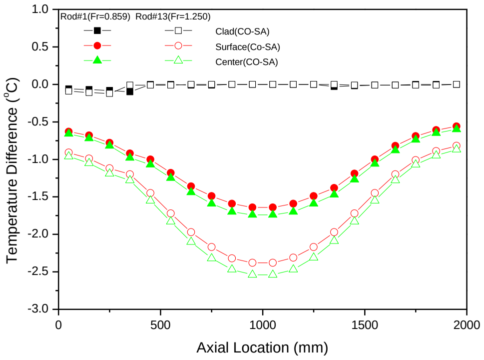

Fig. 4. Temperature difference profile between stand-alone and coupled calculation.

3. Conclusions

The multi-rod coupling method of FRAPCON-MATRA was presented and was applied to the SMART 5x5 CHF bundle. From the results, it was shown that this method was successful even though it had a shortcoming that the FRAPCON's input are needed as equal as the number of rod to be coupled. These methods will be improved to apply to a FA or whole core coupling.

ACKNOWLEGEMENTS

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIP) (No. 2012M2A8A4026261)

REFERENCES

[1] S.J. Kim, et al., Preliminary Coupling of MATRA Code for Multi-Physics Analysis, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 29-30, 2014.

[2] S.J. Kim, at al., Development and Assessment of Core T/H Code's Real Time Model for SMART Simulator, KAERI/TR-4904/2013, Korea, Jan., 2013.

[3] S.J. Kim, et al., MATRA-MASTER Coupling for 3-Dimensinal Transient Analysis of SMART Reactor Core, KAERI/TR-5786/2014, Korea, Jan., 2014.

[4] S.J. Kim, et al., MATRA-DeCART Coupling for Steady-state Pin-by-pin Analysis of SMART Reactor Core, KAERI/TR-5785/2014, Korea, Jan., 2014.

[5] K. J. Greelhood, et al., FRAPCON-3.4: A Computer Code for the Calculation of Steady-State Thermal-Mechanical Behavior of Oxide Fuel Rods for High Burnup, NUREG/CR-7022, Vol.1, U.S.NRC, United State, Mar., 2011.