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Research Status of the Effects of the Pressure Tube Deformation on the Power Derating

E. H. Ryu [a*] and J. Y. Jung [a]
[a]*Korea Atomic Energy Research Institute, 1045 Daedeok-daero, Yuseong-gu, Daejon, 34057, Korea*
[*]*Corresponding author: ryueh@kaeri.re.kr*

1. Introduction

The most important factor affecting the power derating of a (CANDU) CANadian Deuterium Uranium reactor is the pressure tube. It is well known that radial creep and sagging significantly affect pressure tube aging [1, 2]. Therefore, their effects should be investigated rigorously. While radial creep is relatively easy to study, the combined effect of radial creep and sagging is not, because of its dimension and complexity. Moreover, there is an increasing need for such a study of the combined effect of radial creep and sagging.

In light of the Fukushima accident, there is great emphasis on reactor safety. Accordingly, the combined effect of sagging and radial creep on the power derating of a CANDU reactor, center rod temperature, and (CHF) critical heat flux margin needs to be investigated thoroughly — an argument supported by the regulatory bodies of the nuclear industry.

In the correlation of the power deration, among 4 factor of the pressure tube aging phenomena, only the radial creep is incorporated because the effect of sagging is not known clearly [3].

In this paper, status preparation of the (DEFENS) Diffusion Equation targeted and Finite Element based Numerical Simulator code [4] and the (CUPID) Component Unstructured Program for Interfacial Dynamics code coupling which are dealing with neutronics and thermal-hydraulic, respectively will be presented in various aspects-such as parallel performance implementation, 2 group and incremental cross section for iteration calculation, sub-channel division for the PHWR thermal-hydraulic analysis and discussion about a variety of coupling ways.

2. Parallel Performance Implementation

The DEFENS code is based on the finite element method (FEM). To analyze a channel with sufficiently enough precision requires a large number of elements; for example, typical CANDU channel with dimensions such as 6 m length, 0.28575 meter for width and column, requires at least 400,000 unknowns (nodes) or 2,200,000 elements. Thus parallelization of the computer code should be done prior to analysis. Prior to the regular analysis, the preprocessor, the GENI code is parallelized first with Message Passing Interface (MPI). The GENI code provide pre-processed mesh and additional information to the main body. Fig. 1 shows a flow chart of FEM analysis.

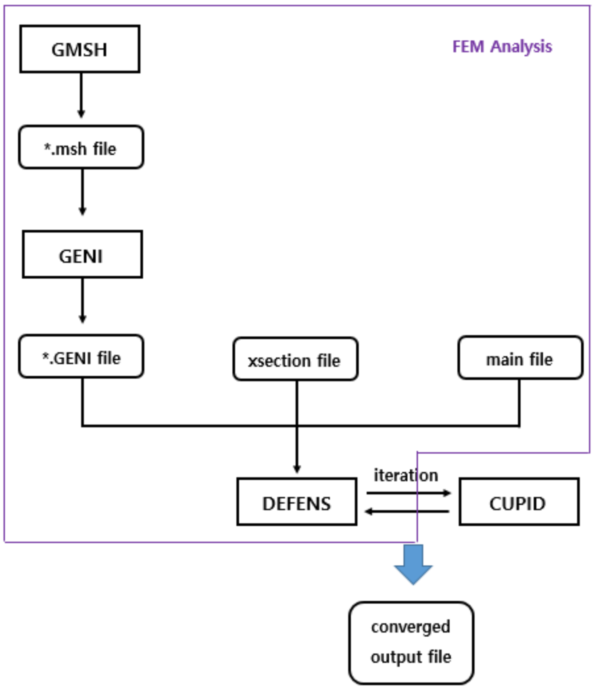

Fig. 1. Expected Flow Chart of Pressure Tube Deformation Analysis

The GENI code, which is located in the analysis flow, can be verified. In addition, there are four codes for analyzing pressure tube deformation. Because the GENI code accounts for a significant amount of the total calculation time, parallelization of the GENI code is necessary in such an analysis and in general FEM analyses. The two main factors affecting such a parallelization are speed-up ratio and parallel efficiency.

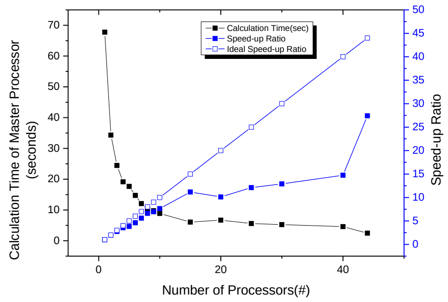

Fig. 2. Speed-up Ratio of the GENI Code in Cluster

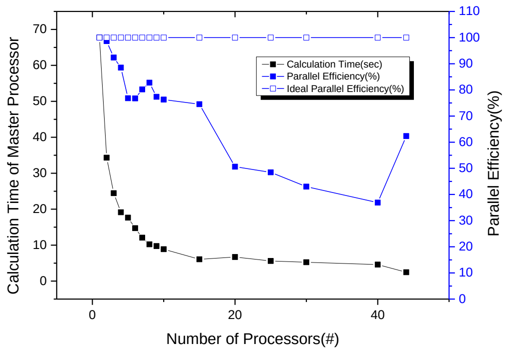

Fig. 3. Parallel Efficiency in Cluster

Results from a PC environment and from a cluster environment were obtained. The results from the former were worse than those from the latter. Therefore, in this paper, only the results from the cluster environment are presented.

In Fig. 2 and 3, because two major parameter-speed-up ratio and parallel efficiency- always get away from the ideal lines in the reality, the results are quite satisfying and promising, although last two peak in each figure at the largest number of processor look like strange, it happens in the parallel result in reality. A parallelization of the main body is under way with the PETSC library, which was developed at the Argonne National Laboratory(ANL).

3. Sub-channel Division

To incorporate the thermal-hydraulic, the CUPID code is selected and the sub-channel region is considered as below figure. In contrast to the PWR sub-channel, structured squares cannot be used in the PHWR channel because of its geometrical characteristic.

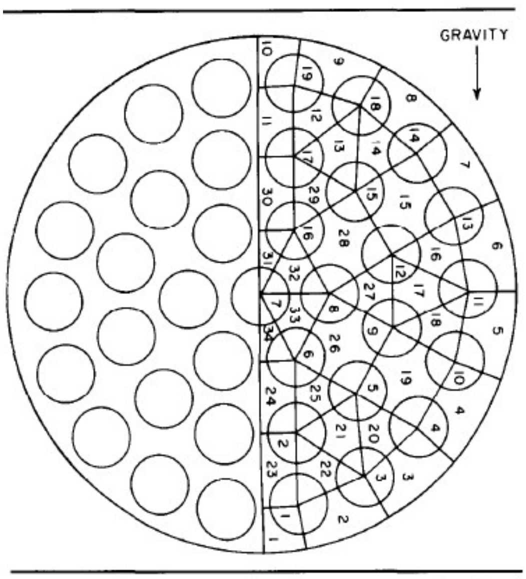

Fig. 4. Sub-channel and Rod Numbering in ASSERT

Although the CUPID code is decided as the base code for the coupling calculation, the ASSERT code is used as the sub-channel analysis code for a long time in the PHWR side. The above figure shows typical sub-channel division of the ASSERT code. In Fig. 4., a total of 34 regions which is larger than the number of rods in a bundle exist in the half of the channel for sub-channel. As Fig. 4, the shapes and areas of the sub-channels are different from one another, whereas the shapes and areas of the sub-channels in PWR assembly are all identical to one another; that is, they are all squares of equal areas. Because the rods are positioned within an irregular structure, the resulting sub-channels cannot be structured geometry.

Currently, it is decided that the sub-channel division of the ASSERT code will be followed for the neutronics and T/H coupled calculation.

4. Two Group and Incremental Cross Section

In Fig. 1, to run the DEFENS code, 3 inputs are required. The the DEFENS code will be provided with the mesh input from the GENI code. The main input file is a kind of global input which will control FEM analysis. The other is cross section file which contain nuclear properties of materials which are used in the CANDU bundle. To generate the base cross sections which has nuclear properites, the McCARD code is used as default because the Monte Carlo CANDU reactor physics system is constructed in the government project, previously. In addition, because of there are a number of sub-channels in a bundle, the McCARD code calculation for two group cross section is done again with new region division.

Consistently, the region division for the incremental cross section generation is done with new sub-channel division. Also, fuel, coolant temperature, and coolant density were considered in the coupled simulation. The number of temperature and density points are minimized as two to reduce computational effort due to a number of sub-channels.

5. Conclusion

The preparations for the neutronics and T/H coupled calculation is explained in this paper. Except for the above mentioned things, the CAD modeling for the CUPID input is under way. The parallel performance of the DEFENS code will be presented in the near future. Because the effect of sagging has yet to be discussed, the value of this research can be found at that point of view. In addition, the normal performance of MPI implementation is verified with the GENI code.

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REFERENCES

[1] J. Y. Jung and et al., A Development of Evaluating Model of Crept Pressure Tube Diameter for CANDU Reactor, KAEIR/RR-3497, 2011.
[2] J. Y. Jung and et al, Development of Core Technology of PHWR Safety Enhancement and Evaluation, KAERI/RR-3777, 2014.
[2] Grant A. Bickel and M. Griffiths, Manufacturing and Microstructure Effects on Irradiation Deformation of Zr-2.5Nb Pressure Tubing, Vienna, Austria, 2011.
[3] E. H. Ryu and H. G. Joo, Finite Element Method Solution of the Simplified P_3 Equations for general Geometry Applications, ANE Vol. 56, page 194-207, 2013.