5 - 19 CAD Modeling Study for Accelerator Driven System Simulation

Li Jinyang, Yu Rui and Gu Long

The accelerator-driven subcritical system has promising future in transmutation of nuclear spent fuels[1]. In this study, the Monte Carlo codes of FLUKA and OpenMC are selected to deal with the ADS problem since these two codes are free-source codes and also the coupling codes that have the potential to deal with ADS problems. In order to satisfy the demands of interactive modeling with FLUKA and OpenMC codes, solve the complicated modeling problems and make the modeling process more easier, a compatible interactive modeling program for these two codes, which is called CAD-PSFO based on an open source software FreeCAD, has been developed for ADS facility, and also a CiADS benchmark has been tested with this program in this paper.

Boundary representation (B-Rep) is often used to define the geometry information in almost all of CAD modeling softwares, such as commercial softwares ProE, CATIA, solidworks, UG and open source code FreeCAD. However, the Monte Carlo codes including the FLUKA and OpenMC codes can only use constructive solid geometry (CSG) to describe geometry feature. Furthermore, FLUKA and OpenMC have different types of CSG approaches to create a solid geometry according to their own modeling rules. The theory of this code is converting the CAD model to the Monte Carlo code input card based on the transformation from the B-Rep to CSG model.

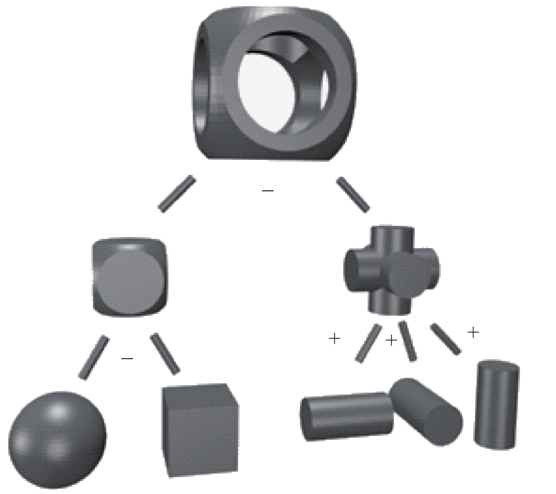

Fig. 1 (color online) Boolean operation for basic geometries.

Basic code structure of CAD-PSFO demonstrates that a CAD model without redundant and auxiliary surfaces will be decomposed into different convex units and the corresponding boolean logical relationship will be judged. Then, CAD-PSFO will set up a geometry database to store these information and loop through all units. After the former procedure CAD-PSFO will get the topology information of each geometry, which includes the points, lines, surfaces, grids and their normals. When these items of information have been acquired, the surfaces logic relationships will be judged. The combination of complex geometries are fulfilled by boolean operations classes, which includes union (“+”), subtraction (“−”) and intersection (“*”). Using this boolean operation classes, simple geometries can be used to generate the complex ones. For example, the basic geometries in the bottom layer of Fig.1 can be combined into two kinds of geometries in the second layer using “−” and “+”, respectively. And finally, the complicated CSG model in the top layer will be constructed.

The ADS facilities including main vessel and reactor core structures as shown in Fig. 2(a), which consist of complicated models and have many complicated structures, have been selected to verify the CAD transformation capability of the CAD-PSFO code, that means all material and boundary conditions for these facilities during the transformation process are neglected in this work. Although only CAD transformation verification is considered in this work, it is also a big challenge to transfer these geometries to CSG model since there are many weird structures and repeated pin-cell structures in these facilities. Moreover, there are also many indescribable quadric surfaces in some of these facilities.

In order to verify the validity of CAD-PSFO modeling transformation ability, the parameter of relative volume deviations has been selected. The reference ADS main vessel and auxiliary mechanical structures are modeled by CATIA as shown in Fig. 2(a), and the parsed modeling results generated by CAD-PSFO are shown as Fig. 2(b). According to the comparison result of relative volume deviations between the two models shown in Fig. 3, 19 916 units have been selected and the maximum deviation is less than $\pm1.5\times10^{-6}$. Alhough the average approaching volumes in CAD-PSFO slightly less than the real ones, CAD-PSFO has good parsed resolution to the ADS facilities model.

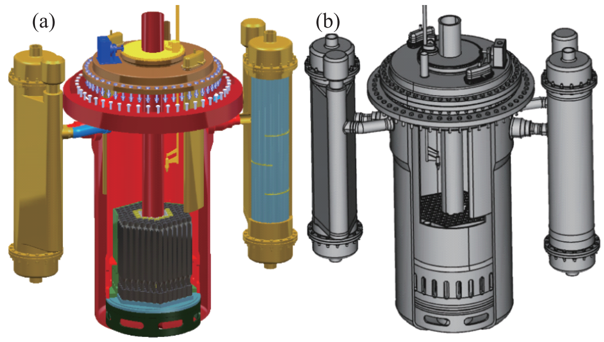

Fig. 2 (color online) The comparison between CAD-PSFO result and CATIA model (a-CATIA referential model; b-CAD-PSFO transfer result).

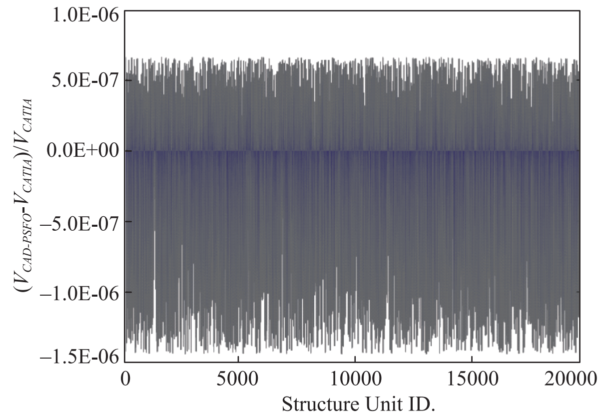

Fig. 3 Volume deviation analysis between CAD-PSFO code and CATIA.

Reference

[1] Wenlon Zhang, Hushan Xu, Bulletin of Chinese Academy of Sciences, 27(3)(2012)375. (in Chinese)

5 - 20 Seismic Analysis of ADS Zero-power Facilities with Finite Element Model

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It is acknowledged that Accelerator Driven System (ADS) offers interesting transmutation possibilities. The accelerator and reactor combination can be used for spent fuel transmutation utilizing high energy neutrons in reactor core. Zero-power facilities are constructed for ADS design and operational verification. During earthquake, the localized stress of mechanical structures will increase due to vibration, which is a risk for structural integrity. The detailed seismic analysis is needed for stress assessment in earthquake conditions. Three-dimensional finite element model of the ADS zero-power facilities is constructed to perform dynamic evaluation using ABAQUS/standard code. The Square Root of Square Sum (SRSS) calculation method is chosen to combine modals in response spectrum analysis. The first principal stress of vessels and bolt strength are evaluated. Both water zero-power reactor core and lead reactor core vessels meet ASME-III-ND specification. The support leg stress assessment meets the requirements of ASME-III-NF. The ADS zero-power facilities maintain structural integrity during the hypothetical earthquake.

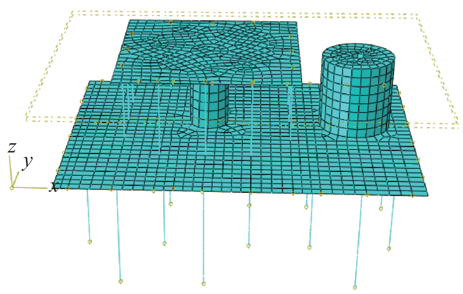

Fig. 1 (color online) Shell element mesh.

The three-dimensional frame model is constructed while the mass of non-bearing structures are added on the related load-bearing structures. In the analysis, shell and beam elements are used to simulate. Vessels and support platform are applied with S4R shell elements, which are 4-node general-purpose shells in reduced integration with hourglass control. The support legs and ribs are applied with 265 B31 linear beam elements (18). The employed shell mesh, shown in Fig.1, consists of 1935 S4R and 40 S3 elements in the following analysis.

The first natural frequency is 17.634 Hz, which means the whole model is flexible. The spectrum analysis is used for the seismic analysis instead of equivalent static method. The two former modes of vibration are translation modes of the lead facility.

The Square Root of Square Sum (SRSS) calculation method is chosen to combine modes in response spectrum analysis. The floor response spectrum is chosen input (20). According to nuclear services as ASME code Section III Subsection ND (21), container permissible stress is taken as:

$$\sigma_{\mathrm{m}} \leqslant 1.0\mathrm{S}=152\ \mathrm{MPa},$$