Progress in Nuclear Energy 107 (2018) 100–109

Contents lists available at ScienceDirect

Progress in Nuclear Energy

journal homepage: www.elsevier.com/locate/pnucene

FreeCAD based modeling study on MCNPX for accelerator driven system

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ARTICLE INFO

Keywords:
FreeCAD
MCNPX
ADS
Hierarchical tree
Ray-casting technology
Markov chain

ABSTRACT

MCNPX is a general purpose Monte Carlo radiation transport code designed to track many particle types over broad ranges of energies and it has the potential to deal with Accelerator Driven System (ADS) problems. The neutronics design and analysis of ADS using MCNPX code is significantly complex mainly on constructing the three dimensional geometry model, especially when there is an additional spallation target coupled with the subcritical reactor constructed by abundant nested repeated structures in several levels. This modeling process has long been recognized as a time consuming, tedious and error-prone task, which is hard to master for novice users. Therefore, it is imperative to build a code system that can translate CAD models of ADS to the native language of MCNPX code. In this context of demand, a code system named CAD-PSMC (FreeCAD based parsing script for MCNPX code) has been developed to solve the ADS modeling conversion problems. In the framework of this code, hierarchical tree-based basic geometry classes and Boolean&Affine operations have been established with a mapping relationship to MCNPX code. Additionally, ray-casting technology and Markov chain based iteration method have been proposed to solve the problem of spline surfaces in complex geometries. Finally, the applicability and accuracy of CAD-PSMC code have been demonstrated by comparing with various reference models and numerical calculation results.

1. Introduction

Monte Carlo N-Particle eXtend (MCNPX) is a general-purpose, continuous-energy, time-independent and generalized-geometry radiation transport code developed by Los Alamos National Laboratory (Waters et al., 2007), which has the potential to manipulate MeV to GeV proton beam with high intensity impinging directly upon heavy metal spallation target, and simulate the copious neutrons transport process in subcritical reactor (Gulevich et al., 2008). However, compared with ordinary nuclear energy system, the neutronic design and analysis of ADS is significantly complex mainly due to the complicated and large scale geometry with a complex spallation target and corresponding auxiliary systems in the center of the system.

The MCNPX codes typically provide a native scripting language and syntax for specifying the spatial domain model in terms of various Boolean combinations of geometric surface and volume primitives. However, the native language provided by MCNPX is highly abstract and not intuitive. Especially when the research object is large and complex, the modeling process will become time-consuming, tedious and error-prone. In order to solve this kind of problems, two approaches always been taken into consideration, including using CAD model directly for Monte Carlo analysis, and translating CAD export files into the native input language of Monte Carlo code (Wu et al., 2015; Li et al., 2007). In this study, the second approach has been employed, since it is a flexible way to establish an interface of MCNPX code in modeling process.

In recent years, the use of neutral files for CAD modeling data exchange has become a consensus in research community (Wu, 2009), and there are a number of widely used MCNPX assisted modeling software packages, for example Visual Editor (Carter and Schwarz, 1995), Moritz (Van Riper, 2007), SimpleGEO (Theis et al., 2006, 2011), DesignModeler (Hermanns et al., 2003), and MCAM (Wang et al., 2014). The Visual Editor has become one part of MCNPX distribution package, which can read MCNPX input files and draw the section view of reference model colored by different materials. The second software Moritz is developed by White Rock Science, which can generate two and three dimensional models, and provide a lot of useful functions to assist in writing MCNPX input cards. The third software SimpleGEO is

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https://doi.org/10.1016/j.pnucene.2018.04.015
Received 12 July 2017; Received in revised form 14 April 2018; Accepted 21 April 2018

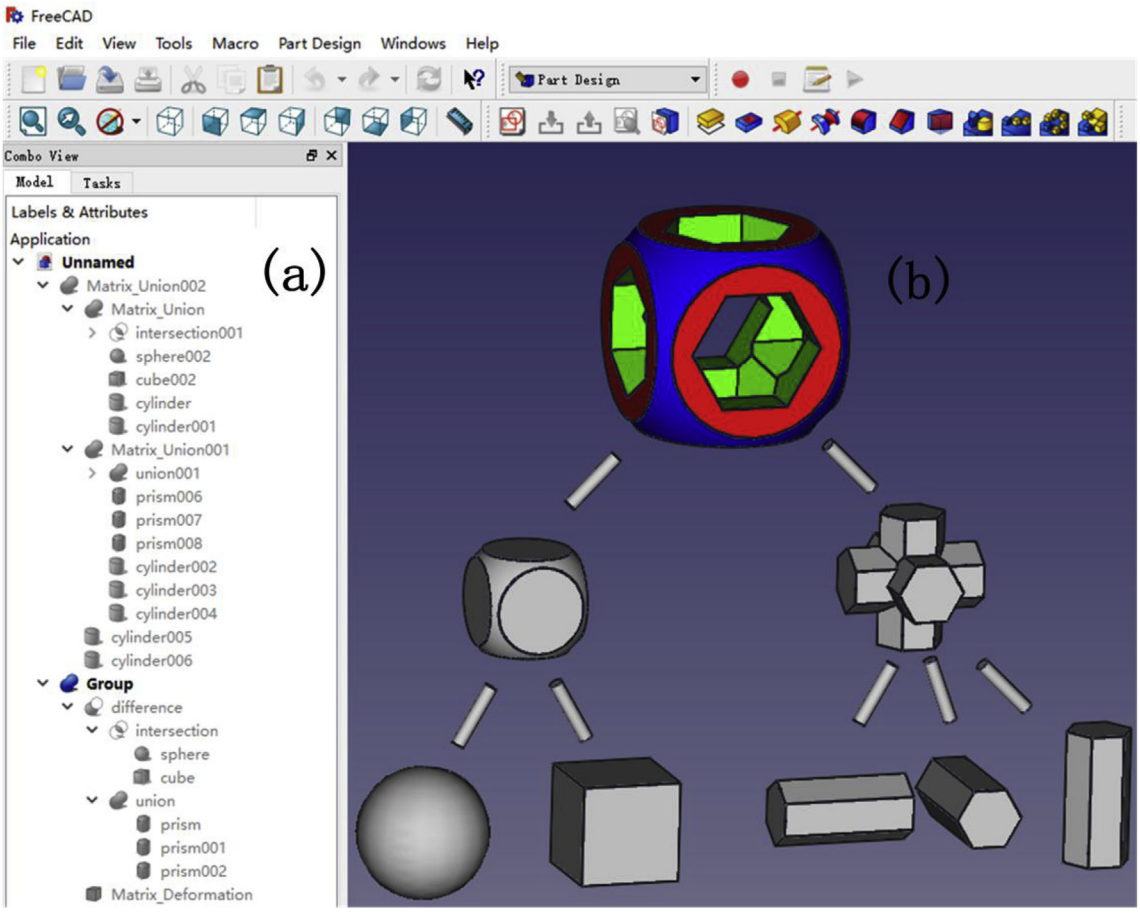

Fig. 1. User interface of FreeCAD ((a)-left column is hierarchical tree; (b)-right column is the corresponding tree graph models).

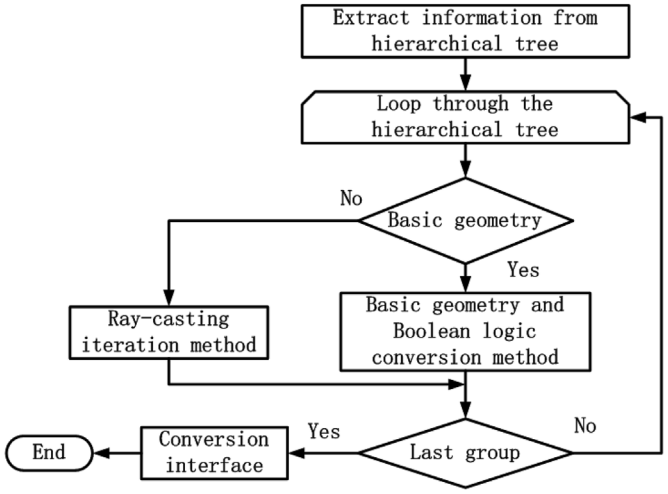

Fig. 2. Code structure of CAD-PSMC.

developed based on CAD technology, which can easily create models via the operations of dragging&dropping, and directly export CAD models to the MCNPX input files. The fourth software DesignModeler is a modular in ANSYS Workbench, which can import and export models in MCNPX file format. And the last software MCAM is developed by FDS team in Chinese Academy of Science, which has bi-directional automatic conversion ability to transfer boundary representation (BREP) models to the constructive solid geometry (CSG) ones (Requicha and Voelcker, 1983), and user can assign or modify the physics properties associated with the model on graphic user interface.

Although these software can convert CAD model to MCNPX native scripting language, it remain a challenge for these codes to express the spline surfaces, which cannot easily be described in mathematics using specific or high order functions (Yu et al., 2015). In the context of modeling demand, a compatible interactive modeling program called CAD-PSMC (FreeCAD based parsing script for MCNPX code) has been developed. The details of the methods are described in Section 2, including building the hierarchical tree-based basic geometry classes and Boolean&Affine operations, setting up the corresponding mapping relationship to MCNPX code, and employing ray-casting technology and Markov chain based iteration method to solve the problem of complex models with spline surfaces. The verification and application of CAD-PSMC are introduced in Section 3. Finally, conclusions are drawn in Section 4.

2. Methodology and algorithms

CAD packages are widely spread among the engineering community (Duret et al., 1988). The development of CAD-PSMC code is based on the open source modeling code FreeCAD (Gayer et al., 2016), which is a general purpose parametric 3D CAD modeler aiming directly at mechanical engineering, product design and wider range of uses around engineering including nuclear engineering. In the user interface of FreeCAD (Fig. 1), the left column is hierarchical tree including all the topology information, which can be extracted by means of the application program interface provided by FreeCAD, and the right column is the corresponding tree graph models, whose leaves contain geometric primitives and nodes representing Boolean&Affine operations associate with the hierarchical tree.

The methodology and algorithms of CAD-PSMC are based on the