Development of Growth and Bow Analysis Models for the PLUS7^{TM} Fuel Assembly

S. Y. Jeon, H. K. Kim, B. J. Cho
KEPCO Nuclear Fuel Co., Ltd, Reactor Core Technology Dept.
1047 Daedeokdaero, Youseong-gu, Daejeon, 305-353, Korea, syjeon@knfc.co.kr

1. Introduction

The fuel assembly bow has been observed to some extent in virtually all commercial PWR(Pressurized Water Reactor). The extreme level of fuel assembly bow can be the main cause of IRI(Incomplete Rod Insertion), adverse effects on the nuclear design due to excessive water gaps between fuel assemblies, or handling difficulties impacting nuclear plant performance. In this study, fuel assembly growth and bow analysis models have been developed for the PLUS7^{TM} fuel design to evaluate the growth and bow characteristics. The growth and bow analysis has been performed to investigate the applicability of the analysis models for the design evaluation.

2. PLUS7^{TM} Analysis Models

2.1 Skeleton and Assembly Models

The PLUS7^{TM} skeleton and fuel assembly models have been developed based on the methodology described in the Reference 1 for the skeleton and fuel assembly lateral stiffness analysis and in-core analysis. Fig. 1 and 2 show the PLUS7^{TM} skeleton and fuel assembly models, respectively. The PLUS7^{TM} skeleton model consists of the guide tubes, spacer grids, guide tube-to-spacer grid joints and top nozzle holddown springs connected to each other using the appropriate joints, connections and interfaces. The PLUS7^{TM} fuel assembly model consists of the skeleton model and fuel rod model. The skeleton model was developed with 143 nodes and 174 elements. The fuel assembly model was developed with 257 nodes and 356 elements.

The guide tubes were simulated using two beams with growth and creep capabilities. A pair of guide tubes was used to represent the total number of guide tubes that exists in the real fuel assembly design as shown in Fig. 2. The grids were modelled using representative beam elements rigidly attached to the guide tubes with growth capabilities. The guide tube-to-spacer grid joints were also simulated by beam elements as shown in Fig. 3. The fuel rods were represented by two beam elements with growth capabilities. The contact elements with friction were used to represent the interface between fuel rods and grid springs and dimples of skeleton model as shown in Fig. 3. A pair of fuel rods was used to represent the entire fuel rods in the fuel assembly same as the guide tubes in the skeleton model. The holddown springs were simulated by two linear springs in the upper part of the fuel assembly to simulate the holddown forces applied to the fuel assembly. The gap elements were used at the end of the fuel rods to simulate the fuel rods to nozzle gaps.

The skeleton and fuel assembly finite element model were constrained at the ends of top and bottom nozzles to simulate in-reactor support conditions. The skeleton and fuel assembly models were used to tune the parameters of the models to match the analysis results with the test results. These parameters are the factors affecting the grid strap height, the stiffness of the guide tube to grid connection beams and fuel rod drag force.

2.2 Core Model

The PLUS7^{TM} core model has been developed based on the skeleton and fuel assembly models. There are two kinds of core models, one for a single fuel assembly and the other for all the fuel assemblies in each row and/or column of the full core configuration. Fig. 4 shows a typical configuration of the fuel assembly core model. The typical core model consists of fuel assembly models and gap elements between fuel assemblies and between the outermost fuel assemblies and the core barrel. The number of fuel assemblies in a row or column is dependent on the type of reactor core. The core model for a single fuel assembly was used for the growth and bow analysis of PLUS7^{TM} fuel assembly design. The single fuel assembly core model consists of a PLUS7^{TM} fuel assembly model and gap elements between PLUS7^{TM} fuel assembly and core barrel. The core model was developed with 279 nodes and 378 elements.

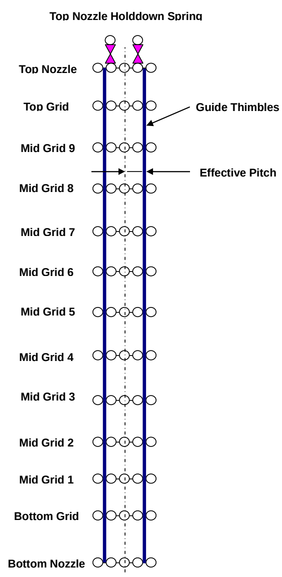

Fig. 1. Skeleton Model

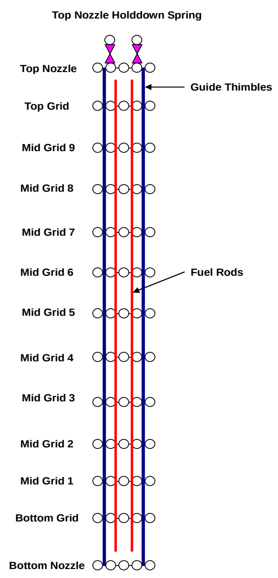

Fig. 2. Fuel Assembly Model

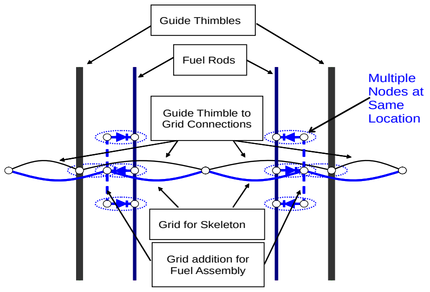

Fig. 3. Interfaces for Guide Tubes, Spacer Grids, and Fuel Rods

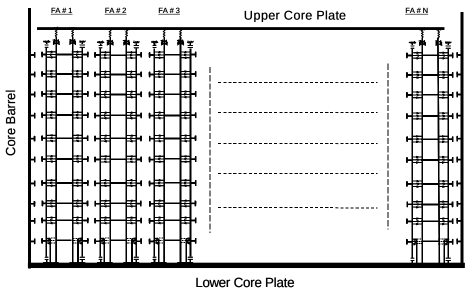

Fig 4. Typical Configuration of the Fuel Assembly Core Model

3. Growth and Bow Analysis

The PLUS7™ fuel assembly growth and bow were analyzed for the assumed in-core conditions to investigate the in-core structural behaviour of PLUS7™ fuel assembly using the SAVAN2D. The core model with a single fuel assembly was used. The core analysis was performed from 0 to 32,000 hours with 10 hours time step. Fig. 5 shows the comparison of growth for PLUS7™ fuel assembly between measured and analyzed results at in-core conditions. The fuel assembly growth and creep models for SRA(Stress Relief Anneal) ZIRLO™ material have been used to analyze the PLUS7™ fuel assembly growth. As shown in the figure, the analysis results are well coincident with the available PLUS7™ fuel assembly growth data.

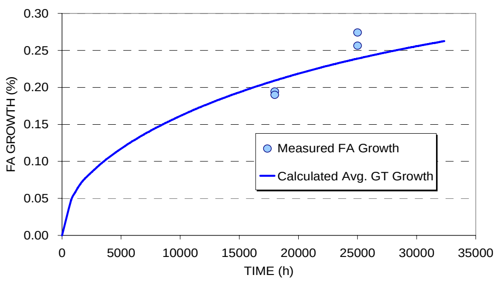

Fig. 5 Growth Analysis Results

Fig. 6 shows the fuel assembly bow evolution results during the cycle. The fuel assembly bow was increased up to 25,000 hours and decreased after 25,000 hours due to the gap close. Fig. 7 shows the gap analysis results for each grid location. The gaps were decreased according to time increase and the gaps for grids 7, 8 and 9 were closed at 23,000 hours.

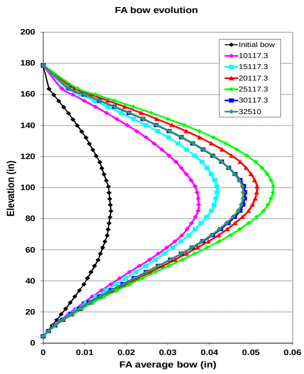

Fig. 6 Bow Evolution Results

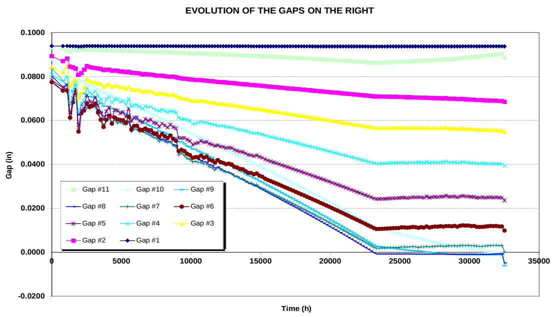

Fig. 7 Gap Analysis Results

4. Conclusion

(1) The PLUS7™ skeleton and fuel assembly models for SAVAN2D analysis have been developed based on the test results and the PLUS7™ core model has been developed using fuel assembly model as a basic model.

(2) The in-core analysis results were compared with the measured data to estimate the growth and bow characteristics of the PLUS7™ fuel assembly. The analysis result shows a good agreement with the test result and measured data.

(3) It was concluded that the PLUS7™ fuel assembly and core models can be utilized for the PLUS7™ out-core and in-core structural performance analysis.

Acknowledgement

This work was supported by the Nuclear Research & Development of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy.

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[1] Sang-Youn Jeon, Hyeong-Koo Kim, Alberto Cerracin, Miguel Aulló, Yuriy Aleshin, and Michael L. Boone, “An Investigation on the Fuel Assembly Growth and Bow Prediction”, 2008 Water Reactor Fuel Performance Meeting, Seoul, Korea, 2008.