The Effects of Fuel Design on the Fuel Assembly Bow Characteristics in PWR

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1. Introduction

The fuel assembly bow has been widely observed in virtually all commercial Pressurized Water Reactors (PWR). The extreme level of fuel assembly bow can bring the Incomplete Rod Insertion (IRI), adverse effects on the nuclear design, or handling difficulties that affect the nuclear plant performance. In this study, the effects of fuel design on the fuel assembly bow have been studied based on the measured fuel assembly bow data for several different fuel assembly designs.

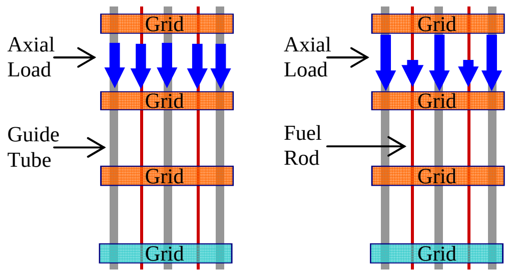
2. Bow Characteristics

The fuel assembly bow measurements have been performed for the PLUS7^{TM}, 17ACE7^{TM}, 16ACE7^{TM} fuel designs in Ulchin-3, Kori-3, and Kori-2 nuclear power plants, respectively. The fuel assembly bow data for the previous fuel designs, such as 17x17 V5H and RFA designs, also have been measured in Yonggwang-2 nuclear power plant. The measured fuel assembly bow data have been analyzed to investigate the characteristics of fuel assembly bow for different fuel assembly designs[1].

The typical shape of PLUS7^{TM} fuel assembly bow was "S" shape and the direction of fuel assembly bow was changed as the number of cycle increase. The typical shapes of 17ACE7^{TM} and 16ACE7^{TM} fuel assembly bow were "C" shape and the direction of fuel assembly bow was not changed as the number of cycle increase. The fuel assembly bow values are increased during cycle 1 and cycle 2 and decreased during cycle 3 or stayed with the same values for the ACE7^{TM} fuel design. The lower fuel assembly bow of the 17ACE7^{TM} fuel design compare to the previous design is mainly due to the improved tube material and high strength guide tube design. And, It seems that the fuel assembly bow does not depend on the fluence, and the fuel assembly bow tends to be limited to a certain maximum value.

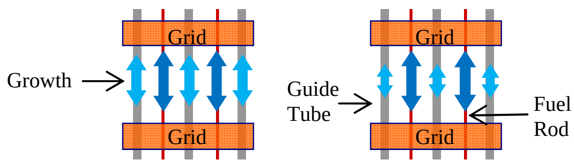
3. Fuel Design Effects on the Fuel Assembly Bow

The fuel assembly bow is the loss of straightness caused by differential temperatures and strains between opposite faces of a fuel assembly. The fuel assembly bow is mainly due to the irradiation growth of guide tube and fuel rods. The fuel assembly and fuel rods grow during operation in reactor as a result of the cumulative effect of oxide formation, stress free irradiation growth, stress induced irradiation creep, and elastic deformation. Due to the fuel assembly growth the compressive load of the holddown spring increases while the fuel rod growth tends to put the fuel assembly structure in tension. The amount of this load change that is applied to the guide tubes and fuel rods depends on whether the rods are slipping through the grids or not[2]. Fig. 1 shows the load sharing between guide tubes and fuel rods. At the beginning of life, the rods slipping forces are high, and then the thimbles and rods share the load change according to their relative stiffness. During operation the grid spring forces relax and the rods slipping forces are low, then the thimbles take the entire load change. The net compressive force on the guide thimbles is one of the primary effects to induce the fuel assembly to bow.



(a) Beginning of Life (b) End of Life
Fig. 1 Load Sharing Change between Guide Tubes and Fuel Rods

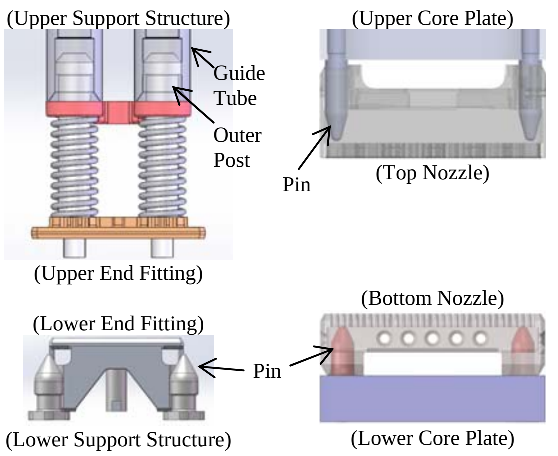
Generally the irradiation growth of the fuel rod is higher than that of the fuel assembly because of the higher neutron fluence and temperature. The higher irradiation growth of the fuel rod will cause tensional stress through a spacer grid spring force on the guide thimble within a span of the fuel assembly until the sliding takes place between the grid spring and fuel rod. The effect of the fuel rod irradiation growth on the fuel assembly growth will be increased for the fuel assembly design with higher grid spring forces. The spacer grid spring forces are decreased as a function of the fluence due to the irradiation induced stress relaxation. The spacer grid spring with Inconel alloy has less stress relaxation than zirconium alloy. The fuel assembly design with all Inconel grids has strong fuel rod growth effect on the fuel assembly growth. Fig. 2 shows the fuel rod growth effect on the guide tube growth.



(a) Beginning of Life (b) End of Life
Fig. 2 Fuel Rod Growth Effect Changes on the Guide Tube Growth

Based on the measured fuel assembly bow, the bow characteristics, such as bow shape, bow direction and bow variation, etc. were totally different for OPR1000 and Westinghouse type fuel design. The interface design and fuel assembly design characteristics are investigated.

The interface designs between fuel assembly and reactor internals are different for OPR1000 type and Westinghouse type reactors. Fig. 3 shows the interface design between fuel assembly and reactor internals. The outer posts of fuel assembly are inserted into the guide tubes of upper support structure and the lower end fitting legs are guided by pins of lower support structure for the OPR1000 type reactor. The alignment pins of upper core plate are inserted into the top nozzle pads of fuel assembly and the lower core plate pin are inserted into the bottom nozzle legs for Westinghouse type reactor.



(a) OPR1000 type (b) Westinghouse type

Fig. 3 Interface Design between Fuel Assembly and Reactor Internals

The height of upper end fitting is relatively high and the connections between upper end fitting and guide tubes are continuous along the axial direction of fuel assembly for the OPR1000 type. And, the fuel assembly is restrained by the upper support structure at the very end of upper end fitting. The upper end fitting rotation at the interface location can be occurred based on the boundary conditions between fuel assembly and reactor internals. On the other hand, the height of top nozzle is relatively low and the connections between top nozzle and guide tubes are not continuous for the Westinghouse type. And, the restrained locations of top nozzle by the upper core plate pins are not the top of top nozzle. It was evaluated that the direction of OPR1000 type fuel assembly bow can be changed as the number of cycle increase and the typical shape of PLUS7^{TM} fuel assembly bow will be “S” shape because of the boundary condition between fuel assembly and reactor internals and continuous stiffness along the axial direction of fuel assembly. It was also evaluated that the direction of Westinghouse type fuel assembly bow can be maintained and the typical shapes of 17ACE7^{TM} and 16ACE7^{TM} fuel assembly bow will be “C” shape because of firm connections between fuel assembly and reactor internals and almost fixed boundary conditions between top nozzle and guide tubes.

The fuel assembly bow values will be increased as a function of the fluence due to the fuel assembly growth increase. However, the increase of fuel assembly bow will be stopped or sometimes it will be decreased due to the relaxation of holddown force and spacer grid spring force. The fuel assembly lateral stiffness increases as the fuel assembly bow increases and the increase of resistance from neighboring fuel assembly can be the main causes of fuel assembly bow decrease at the end of life. Because of these reasons, the fuel assembly bow does not depend on the fluence, and the fuel assembly bow tends to be limited to a certain maximum value.

Three different groups of the fuel assemblies are loaded in the core according to the loading pattern. Most of fuel assemblies can be surrounded by the fuel assemblies with different level of burnup. The non-uniform irradiation growth of fuel rod and guide tube in a fuel assembly can be caused by different burnup distribution among the surrounding fuel assemblies.

4. Conclusion

The effects of fuel design on the fuel assembly bow have been studied based on the measured fuel assembly bow data for several different fuel assembly designs. It was evaluated that the following items are main fuel design parameters to consider for the fuel assembly bow evaluation.

- Fuel assembly lateral stiffness
- Fuel assembly and fuel rod growth
- Relaxation of the holddown spring force and spacer grid spring force
- Burnup distribution of the surrounding fuel assemblies
- Interface design between fuel assembly and reactor internals

Acknowledgement

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