An Investigation on the Bow Characteristics of the PWR Fuel Assembly

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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 characteristics of the fuel assembly bow have been investigated by analyzing the measured fuel assembly bow data for several different fuel assembly designs.

2. Fuel Assembly Bow

The reactor core in PWR is comprised of an array of square fuel assemblies. Each fuel assembly is installed vertically in the reactor vessel and stands upright on the lower core plate. After all fuel assemblies are set in place on the lower core plate, the upper core support structure which contains the upper core plate is installed. The upper core plate press down the fuel assembly hold-down springs to hold the fuel assemblies in place against the upward hydraulic force, putting the fuel assemblies under compressive load.

The fuel assembly length will be increased due to the irradiation growth and oxide formation, and decreased due to the creep down and elastic deformation. The hold-down spring forces will be increased as the irradiation induced growth increase. The amount of the creep down will be increased with the higher downward hold-down spring forces and upward hydraulic force. These irradiation growths and creep downs are main parameters for the evaluation of the fuel assembly axial growth and lateral bow. The irradiation growth is defined as a change in shape without a volume change during irradiation in the absence of applied stress. The main phenomenon which can be caused by irradiation growth is 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 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. At the beginning of life, the rods are not slipping through the grids, and then the thimbles and rods share the load change according to their relative stiffness. During operation the grid spring force relax and the rods slip through the grids, 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. As the distance between assemblies in the core is very small, the fuel assemblies push one another and the bow can be propagated through the core.

3. Bow Characteristics

The fuel assembly bow measurements were 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.

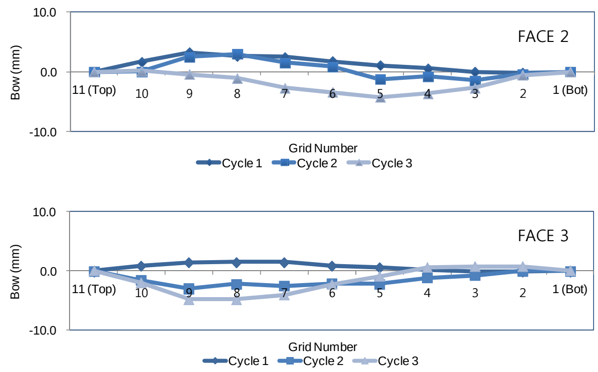

Fig. 1 PLUS7^{TM} Fuel Assembly Bow

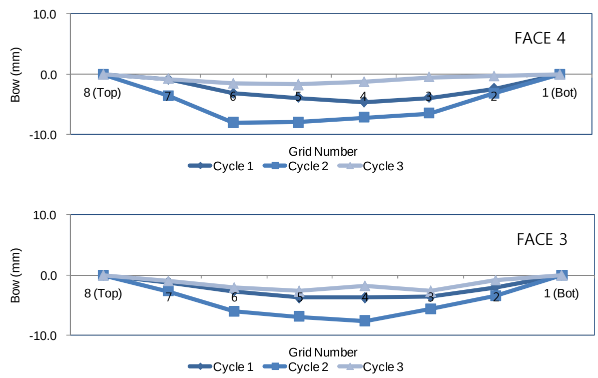

Fig. 2 17ACE7 ^{TM} Fuel Assembly Bow

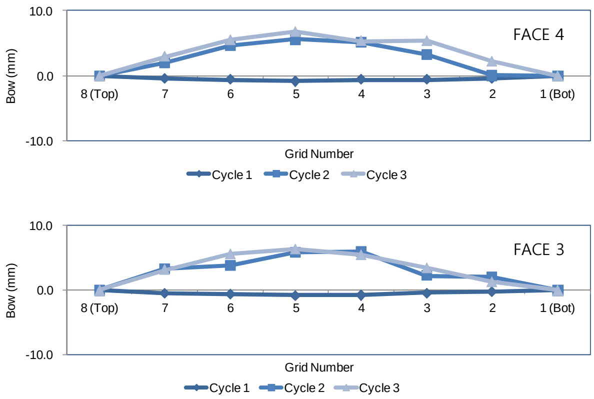

Fig. 3 16ACE7^{TM} Fuel Assembly Bow

Figs. 1, 2 and 3 show fuel assembly bow for each face of the fuel assemblies. Each fuel assembly design has its own bow characteristics. Fig. 1 shows the evolution of fuel assembly bow for the PLUS7^{TM} fuel design from cycle 1 to cycle 3. The typical shape of the PLUS7^{TM} fuel assembly bow is "S" shape and the direction of fuel assembly bow was changed as the number of cycle increase. Figs. 2 and 3 show the evolution of fuel assembly bow for the 17ACE7^{TM} and 16ACE7^{TM} fuel design from cycle 1 to cycle 3. The typical shapes of 17ACE7^{TM} and 16ACE7^{TM} fuel assembly bow are "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.

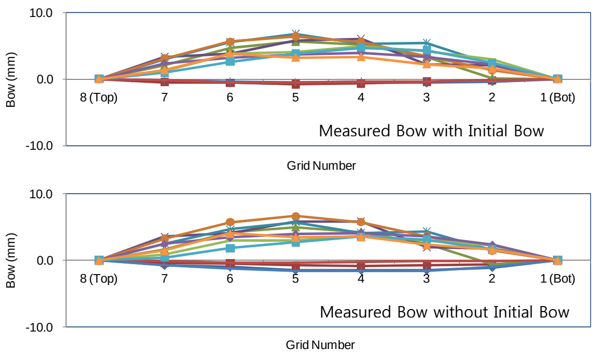

Fig. 4 Measured Bow vs. Initial Bow (16ACE7^{TM})

Fig. 4 shows the measured bow with and without initial bow for the 16ACE7^{TM} fuel assemblies. The measured bow with and without initial bow are almost same because the initial bow is very small. Fig. 5 shows the measured bow of V5H and 17ACE7^{TM} fuel designs. The measured bow of V5H fuel design is higher than that of 17ACE7^{TM} fuel design. The lower fuel assembly bow of the 17ACE7^{TM} fuel design is mainly due to the improved tube material and high strength guide tube design. Fig. 6 shows the fuel assembly maximum bow variations as a function of fluence for PLUS7^{TM}, 17ACE7^{TM} and 16ACE7^{TM} designs. Based on the results, 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.

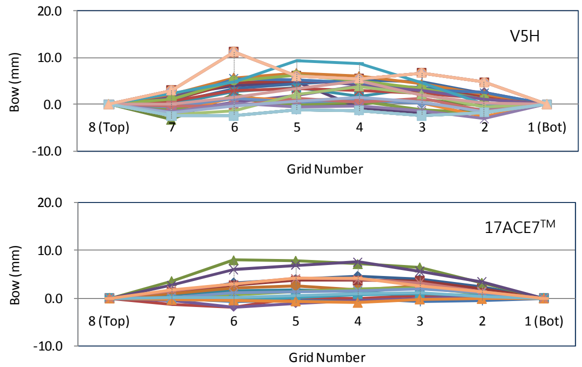

Fig. 5 Fuel Assembly Bow (V5H vs. 17ACE7^{TM})

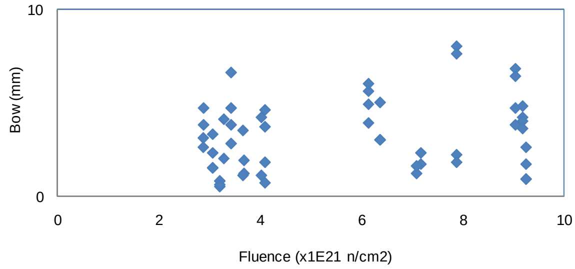

Fig. 6 Fuel Assembly Bow vs. Fluence

4. Conclusion

The measured fuel assembly bow data for different fuel assembly designs have been analyzed to investigate the characteristics of the fuel assembly bow.

(1) The typical shape of PLUS7^{TM} fuel assembly bow is "S" shape and the typical shapes of 17ACE7^{TM} and 16ACE7^{TM} fuel assembly bow are "C" shape.

(2) The bow directions of the fuel assembly can be changed during its life time and the bow values are not always increased.

(3) 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.

The fuel assembly bow analysis results will be utilized for the fuel assembly design evaluation.

Acknowledgement

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REFERENCES

[1] Sang-Youn Jeon et al., "An Investigation on the Structural Behavior of the PWR Fuel Assembly due to Irradiation", Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, 2007.