Transactions of the Korean Nuclear Society Virtual Spring Meeting
July 9-10, 2020

Fluid-Structure Interaction Modeling Issues of the Fuel Assembly

K.H. Lee [a*], H.S. Kang [a], D.S. Oh [a], H.G. Kim [a]
[a] *KAERI, 111, 989 bungil, Deaduk-dero, Yusung-gu, Daejeon, Korea*
[*] Corresponding author: leekh@kaeri.re.kr

1. Introduction

Engineering prediction of the design problem with fluid-structure interaction issues occurring in the commercial reactor core and the steam generator are known to be challenging for both researchers and industries involved in nuclear production of electricity. Sharing the knowledge and experience on how to model these phenomena with optimal accuracy and engineering usability is therefore of great interest for contributors worldwide. The seminar on this issue was held at Aix-en Provence, France, organized by Dr. G. Ricciardi (CEA), in last February, 2020. The seminar particularly focused on three specific issues for the fuel assembly: 1) accidental situations (Earthquake and LOCA): how does the fluid modify the behavior of several fuel assemblies in a core or a storage rack in case of external event as a seismic excitation or a loss of coolant accident? 2) Fretting wear: what is the response of a fuel rod induced by a turbulent axial flow and correlate to fretting wear? 3) Fuel assembly bowing: how does the main axial and secondary transverse flows contribute to the establishment and/or aggravation of fuel assembly bowing deformations in a nuclear core? Some issues are not common in Korean NPP, but some can also be an important issue on the safety aspect and stable operation.

I was invited and presented some spent fuel safety research things at this topical seminar and want to share the key issues discussed in the seminar.

2. Fuel assembly FSI modeling issues.

2.1 Turbulent induced vibration and fretting wear

Grid to rod fretting (GTRF) coupled with the fuel vibration induced by the flow has been years long R&D issues in worldwide [1-5], but now, I think, is not an popular issue in Korean nuclear industry because of various efforts to reduce the problem and to develop high quality fuel design by Korean fuel vendor[6-8]. GTRF, however, is still important R&D and interesting fluid-structure interaction issues in France, anyway.

Fundamental research question of the problem is “what the response of a fuel rod induced by a turbulent axial flow is”, “how can fluid force be obtain by the flow simulation and how it correlates to fretting wear?” The last question is the most challenging, but many researches are still undergoing to find out the way using CFD, experiment and analytical works in CEA, France. [9-12]. The type of FIV in GRTF is turbulent buffeting, very small random vibrations related to the fluctuating pressure field associated with the turbulent flow. Most experimental study for this problem can be easily affected by the far-field noise depending on the specific test loop. Good news is that many research works related to the CFD with better algorithm has been still performed as the evolution of the computing power, but one interesting R&D activities on directly solving FSI simulation is undergoing with computationally affordable way and by capturing all relevant physics [13] to correlate fuel vibration to the resultant wear.

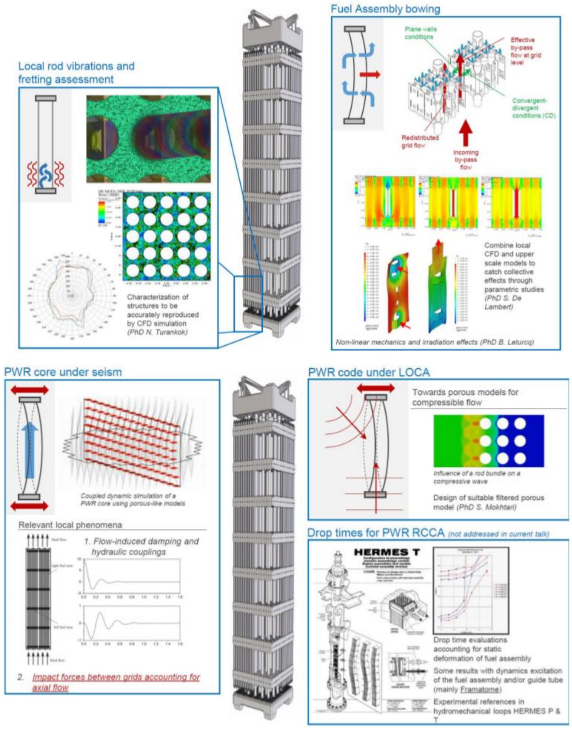

Fig. 1. Overview of fuel assembly fluid structure interaction modelling issues, raised in France.

2.2 Fuel assembly bowing and its consequence to core flow distribution and hydrodynamic force.

As shown in Fig. 1, fuel assembly has been bowed in the reactor core due to the irradiation creep with hold-down force, hydrodynamic force, and neutron physics[14, 15]. Severe bow can cause handling problem of the fuel loading during the outage and bad influence to core performances and RCCA drop time. So, FA bow should be accurately predicted by the verified model, but this is an also multi-physically coupled problem. One interesting thing is that FA bow can make flow distribution irregular in the core, thus it can affect core power distribution and fuel loading while the operation.

Fundamental question on the fuel assembly bowing is how the main axial and secondary transverse flows contribute to the establishment and/or aggravation of fuel assembly bowing deformations in a nuclear core? [16, 17]

2.3 Seismic and LOCA accident simulation for the integrity of fuel assembly

Accidental situations can modify the behavior of several fuel assemblies and flow structure with distribution in a core or a storage rack in case of external event as a seismic excitation or a loss of coolant accident. During an earthquake, the fuel assemblies in the PWR core are moved and can collide with certain in-line phase. In the case of high excitation, these shocks can break the spacer grids affecting the reactor functioning [18-21]. Simulation and experimental works are needed in order to validate models and to have a better understanding of involved phenomena within the assembly coupling and vibrations.

3. Conclusions

Fluid-structure interaction phenomina in fuel assembly are frequently encountered and also quite interesting R&D issues for researchers, power supplier and regulators. Thus, sharing the knowledge on how to model these phenomena and validate through experiment is worthwhile. Here in this paper introduces some related issues on that, mostly raised in France. Making common ground to free discussion on this issue is highly desirable for improving nuclear safety and better public acceptance in Korean nuclear power industry.

Acknowledgments

This work was funded by the Industrial Technology Innovation Program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), granted financial resource from the Ministry of Trade, Industry & Energy(MOTIE), Republic of Korea. (No. 20171510101920).

REFERENCES

1.Blau, P.J., *A microstructure-based wear model for grid-to-rod fretting of clad nuclear fuel rods.* Wear, 2019. **426-427**: p. 750-759.

2.Rubiolo, P.R., *Probabilistic prediction of fretting-wear damage of nuclear fuel rods.* Nuclear Engineering and Design, 2006. **236**(14): p. 1628-1640.

3.Kim, K.-T., *A study on the grid-to-rod fretting wear-induced fuel failure observed in the 16×16KOFA fuel.* Nuclear Engineering and Design, 2010. **240**(4): p. 756-762.

4.Kim, H.-K., Y.-H. Lee, and K.-H. Lee, *On the geometry of the fuel rod supports concerning a fretting wear failure.* Nuclear Engineering and Design, 2008. **238**(12): p. 3321-3330.

5.Hu, Z., *Developments of analyses on grid-to-rod fretting problems in pressurized water reactors.* Progress in Nuclear Energy, 2018. **106**: p. 293-299.

6.Park, N.-G., et al., *Indirect estimation method of the turbulence induced fluid force spectrum acting on a fuel rod.* Nuclear Engineering and Design, 2009. **239**(7): p. 1237-1245.

7.Kim, K.-T. and J.-M. Suh, *Development of an advanced PWR fuel for OPR1000s in Korea.* Nuclear Engineering and Design, 2008. **238**(10): p. 2606-2613.

8.Kim, K.-T., *Evolutionary developments of advanced PWR nuclear fuels and cladding materials.* Nuclear Engineering and Design, 2013. **263**: p. 59-69.

9.S. Benhamadouche, P.M., C. Le-Maître, *CFD estimation of the flow-induced vibrations of a fuel rod downstream a mixing grid*, in *Proceedings of PVP 2009 ASME Pressure Vessels and Piping 2009 / Creep 8 Conference*. 2009.

10.P. Moussou, S.B., C. Bodel., *CFD estimation of the unsteady fluid force along a fuel rod downstream a mixing grid*, in *Proceedings of PVP 2011 ASME Pressure Vessels and Piping 2011*. 2011: Baltimore, Maryland.

11.Delafontaine, S. and G. Ricciardi, *Fluctuating pressure calculation induced by axial flow trough mixing grid.* Nuclear Engineering and Design, 2012. **242**: p. 233-246.

12.Bakosi, J., et al., *Large-eddy simulations of turbulent flow for grid-to-rod fretting in nuclear reactors.* Nuclear Engineering and Design, 2013. **262**: p. 544-561.

13.De Ridder, J., et al., *Simulating the fluid forces and fluid-elastic instabilities of a clamped–clamped cylinder in turbulent axial flow.* Journal of Fluids and Structures, 2015. **55**: p. 139-154.

14.Horváth, Á. and B. Dressel, *On numerical simulation of fuel assembly bow in pressurized water reactors.* Nuclear Engineering and Design, 2013. **265**: p. 814-825.

15.de Lambert, S., et al., *Modeling the consequences of fuel assembly bowing on PWR core neutronics using a Monte-Carlo code.* Annals of Nuclear Energy, 2019. **134**: p. 330-341.

16.Wanninger, A., M. Seidl, and R. Macián-Juan, *Mechanical analysis of the bow deformation of a row of fuel assemblies in a PWR core.* Nuclear Engineering and Technology, 2018. **50**(2): p. 297-305.

17. Tayal, M., *Modelling the bending/bowing of composite beams such as nuclear fuel: The bow code.* Nuclear Engineering and Design, 1989. **116**(2): p. 149-159.

18. P. Moussou, 2020, State-of-the-art for fluid/rod bundle excitation knowledge, *1st International Seminar on Fluid-Structure Interaction Modelling for Nuclear Fuel Assemblies*, Feb. 2-3, Aix-en Provence, France.

19. B. Dressel, 2020, Structural and FSI modeling approach in accident analysis for a Framatome BWR fuel design, *1st International Seminar on Fluid-Structure Interaction Modelling for Nuclear Fuel Assemblies*, Feb. 2-3, Aix-en Provence, France.

20. B. Chazot, 2020, Modeling of the hydraulic effects applied on a fuel assembly under earthquake excitation - Dynamic CFD porous model, *1st International Seminar on Fluid-Structure Interaction Modelling for Nuclear Fuel Assemblies*, Feb. 2-3, Aix-en Provence, France.

21. V. Faucher, 2020, FA Simulation : modelling and computational challenges, *1st International Seminar on Fluid-Structure Interaction Modelling for Nuclear Fuel Assemblies*, Feb. 2-3, Aix-en Provence, France.