Nuclear Fuel Assembly Deformation, Reduced Mechanical Model Dedicated to FSI Simulation

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ABSTRACT

In the pressure vessel of a PWR the core is constituted of a number of fuel assemblies. Under operation, they all suffer from various phenomena, among them, initial trapped efforts, thermal expansion, irradiation growth, creeping, tightening relaxation and rod slipping. Each fuel assembly may develop contacts with its neighbors and strongly interacts with the fluid. It then undergoes vertical as well as lateral fluid forces, which are partly coupled with its instantaneous shape. As a consequence the fuel assembly tends to get distorted during and still after operation. The first concern is economic: at the end of a cycle, when changing the assembly position in the core, the contact interactions with its neighbors due to its distorted shape sometimes delay the handling. The second concern is that the shutdown rods have to slide into the deformed shape of the guide tube and might be slowed due to excessive friction forces. In order to precisely assess these situations it is necessary to simulate numerically a complete core, taking into account all of the previously mentioned phenomena. For that purpose, we propose a light but relevant reduced mechanical model of a fuel assembly, partially based on a POD analysis performed on a detailed fuel assembly model. We then show that a rather simple model, still based on classical finite elements can be used and simplifies the integration of the local nonlinear constitutive equations. We then compare both of the detailed and reduced model on typical situations and show excellent agreement. The CPU time ratio between them, for a full nonlinear simulation of a single fuel assembly under operation, is over 1000, which is competitive against separation of variables based reduced order methods such as POD, PGD and even APHR[1]. So, yet still with a simplified FSI approach, the drastic memory and CPU reductions obtained now enable us to complete a 3D core simulation representing at least 4 years under operation (4 cycles), with as much as 241 individual fuel assemblies, in a reasonable time of a few hours. [1] David Ryckelynck, Djamel Missoum-Benziane. Multi-level A Priori Hyper-Reduction of mechanical models involving internal variables. Computer Methods in Applied Mechanics and Engineering, Elsevier, 2010, 199, pp.1134-1142. <10.1016/j.cma.2009.12.003>. <hal-00461492>