The 6th Joint International Conference on Multibody System Dynamics and
The 10th Asian Conference on Multibody System Dynamics
November 1-5, 2020, New Delhi, India

Movement of a Bowed Subassembly Within a Fast Reactor Core cavity: A Multibody Dynamics Approach

Vandeep Godhani, R. Suresh Kumar, Sanjeev Kumar, Jose Varghese, R. Vijayashree

Reactor Design & Technology Group
Indira Gandhi Centre for Atomic Research
Kalpakkam, Tamilnadu, India
[v_bharat, suresh, sky, varghese]@igcar.gov.in

Abstract

Liquid metal cooled fast breeder reactors (LMFBRs) are being designed and operated worldwide for green energy production. Fast breeder reactor(FBR) core typically consist of fuel elements in clad tubes closely packed within a hexagonal sheath called fuel subassembly (FSA). The closely packed FSA are free-standing on its foot supported inside a rigid structure called the grid plate. FBR core is designed to achieve high burn-up to reduce the fuel cycle cost and improve the economy. However, high burn-up leads to irradiation-induced damages such as bowing and swelling to the free-standing core subassemblies. This situation creates high restraining forces between the FSA and the shift in the FSA axis (bow). Since FSA is designed for a specified period of operation within the reactor, the removal and replacement of spent FSA with the new one is required periodically during refuelling. The handling of FSA within the reactor core under liquid sodium during refuelling becomes more challenging due to bowing and high restraining forces, causing the design of the In-vessel handling machine (IVTM) more complicated [1]. During refuelling, the gripper of IVTM exerts sufficient axial force to remove the spent FSA from the highly restrained core. The resulting vacant hexagonal cavity in the core is filled by inserting a fresh FSA by the same gripper. A clear understanding of the mechanics of the core under irradiation is required for the reliable design of refuelling machines for FBR. Core mechanics study specific to each reactor is carried out theoretically and verified experimentally by various countries. The present work is a detailed Multibody Dynamics (MBD) investigation of the mechanics of movement of the bowed SA within a typical fast reactor core cavity. To understand the effect of the contribution of the array of FSA surrounding the core cavity, an MBD based analysis is carried out by modelling both straight rigid cavity and straight flexible cavity. Recurdyn is the code used for the analysis [2].

The maximum amount of bowing due to target burn up of 100000 Mwd/t of fuel predicted for the Indian fast reactor PFBR being constructed at Kalpakkam is 54 mm. Conservatively a 55 mm bowed FSA is considered for the insertion into a vacant hexagonal cavity formed by six surrounding FSAs. For the rigid cavity case, only six rigid SAs are sufficient, while for the flexible cavity case, the cavity modelling is done with six flexible SAs. Only modelling of six SAs is not enough to simulate the stiffness of the core as the flexibility of the cavity is influenced by the stiffness offered by the adjacent rings of FSAs. However, modelling of the entire core is not practically feasible as it involves more computational difficulties. Because of this reason, only six FSAs surrounding the cavity are 3D modelled, and the effect of the surrounding rings of FSA are taken care of by adopting equivalent spring elements. The core cavity with the connectivity of each member is represented in Fig.1.

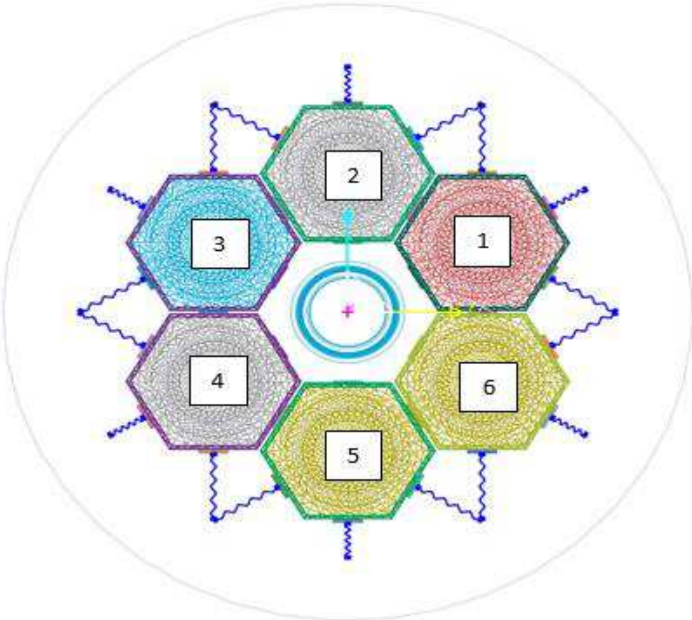

Figure 1: Schematic diagram of adjacent SAs with spacer pads and spring elements

Spring element stiffness is calculated by assuming that FSAs surrounding the cavity come into contact progressively by applying contact forces from the FSA being inserted in the radial direction extending from the cavity towards the core boundary. Since the contact between the FSAs is at the pad location, the bending stiffness of the individual FSA is estimated by considering the FSA as a cantilever beam with force applied at the pad location. The contribution from other rings is considered progressively by accounting for the stiffness of the contacting FSA when the respective gap between the FSA gets closed.

MBD simulation is carried out using the 3D model shown in Fig.1. Bowed FSA is introduced into the cavity with a velocity of 35 mm/s. The contact force between the bowed FSA and the adjacent FSAs during insertion and extraction generates friction force required to be estimated for arriving at the handling capability of IVTM. A critical comparison of the mechanics of movement of the bowed FSA within a rigid and flexible cavity suggests that the force required for insertion or extraction of the bowed FSA within the flexible cavity is significantly low compared to the rigid cavity. The flexibility offered by the neighbouring cavity helps to reduce insertion and extraction forces.

References

[1] Raghupathy, S., Varghese, Jose, Surendran, C.S., Sakthivel Rajan, V.N., Arumugam, S., Kumar, Sanjeev, & Puthiyavinayagam, P."Component Handling System: Prototype Fast Breeder Reactor (PFBR) and Beyond". *International Conference on Fast Reactors and Related Fuel Cycles: Next Generation Nuclear Systems for Sustainable Development (FR17) Programme and Papers, (p. v).* International Atomic Energy Agency (IAEA), 2017.

[2] Recurdyn documentation - Recurdyn User's manual.