Investigation of falling control rods in deformed guiding tubes in nuclear reactors using multibody approaches

Radek Bulín[1], Michal Hajžman[1] and Pavel Polach[1,2]

[1]*New Technologies for the Information Society, University of West Bohemia, {rbulin,mhajzman,ppolach}@ntis.zcu.cz*
[2]*Research and Testing Institute Plzeň, polach@vzuplzen.cz*

Multibody approaches can be successfully employed for the modelling of nonlinear motion and dynamical analysis in nuclear engineering. One of the interesting applications is the analysis of control assemblies or control rods used for the nuclear reaction control and emergency stops. Generally, control assemblies can be simplified to the typical problem of a long thin rod moving through guide tubes and driven by a motor. Two different approaches to the modelling of control assemblies for nuclear reactors are introduced in this paper. Both models are used for the numerical simulation of falling control rods in deformed guiding tubes during the emergency reactor shut-down.

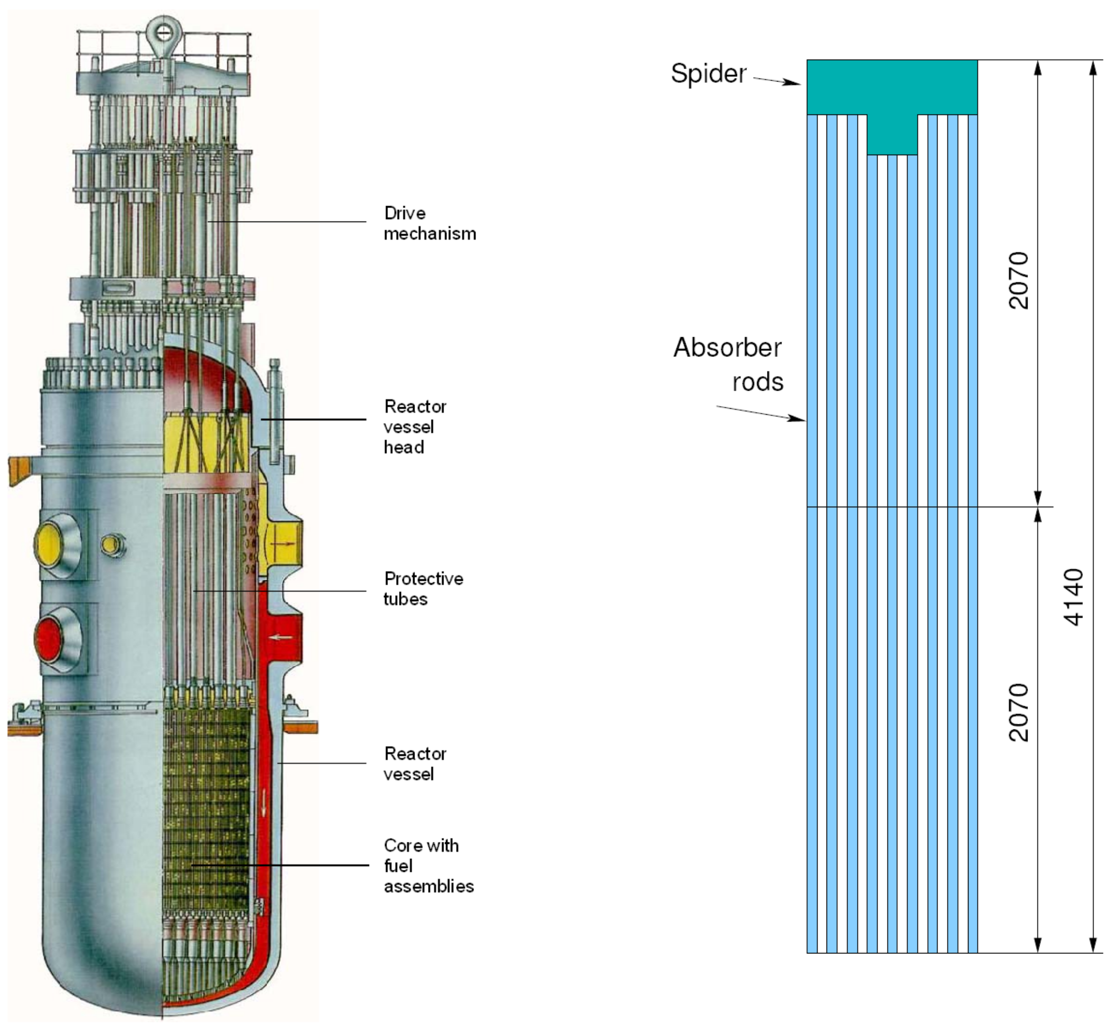

Fig. 1: Scheme of the VVER 1000 nuclear reactor (left) and its cluster of control rods (right)

The first model is a complex multibody model of the LKP-M/3 control assembly of the VVER 1000 nuclear reactor, see Fig. 1, created in the alaska simulation tool [1]. It is composed of 22 rigid bodies coupled by 22 kinematic joints. The number of its degrees of freedom is 45. The influences of the pressurized water have to be introduced in the multibody model because the rod control cluster assemblies are falling in a limited space and water resistance is not negligible. Possible contacts of the falling rod control cluster assembly with adjacent structural parts inside the reactor are supposed.

The second presented approach is based on the absolute nodal coordinate formulation (ANCF). The model of a long thin control rod is composed of three-dimensional ANCF beam elements. Various ANCF beam elements such as those mentioned in [2, 3] are implemented and tested using the implemented in-house computational tool. Possible contacts and a friction between the thin rod and the guiding tube are also included in the model. Since nuclear reactors are exhibited to various operational conditions, such as high temperatures and coolant pressure pulsations, the guiding tubes can be deformed. The influence of the deformation of the guiding tubes on the successful drop of the control rod is further studied.

Both presented modelling approaches can be considered complementary. The first approach is used to obtain a global response of the control assembly of the VVER 1000 nuclear reactor e.g. to the seismic loads, while the second approach is utilized for a detailed analysis of the interaction between the control rods and the deformed guiding tubes.

As an example, a simple deformable rod drop in a straight guiding tube with nonzero initial horizontal velocity is shown. Snapshots of the rod axis motion in selected times are shown in Fig. 2.

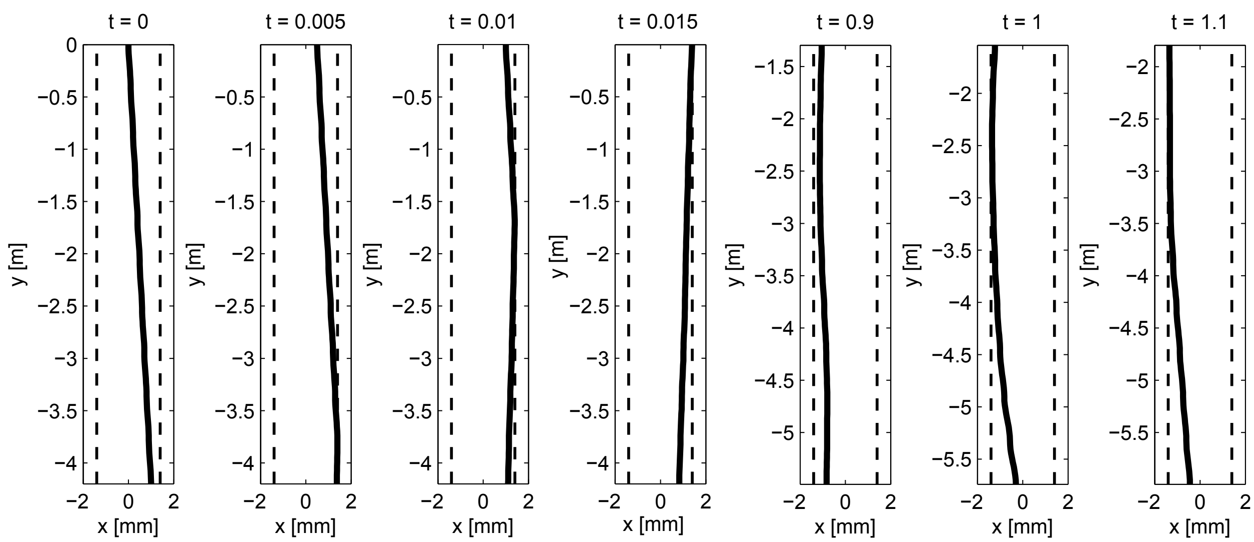

Fig. 2: Snapshots of the rod axis motion in selected times (time).

References

[1] P. Polach and M. Hajžman, "Multibody model of the VVER 1000 nuclear reactor control assembly and simulation of its moving parts drop," *Mechanisms and Machine Science*, vol. 54, pp. 254–263, 2018.

[2] A. L. Schwab and J. P. Meijaard, "Comparison of three-dimensional flexible beam elements for dynamic analysis: Finite element method and absolute nodal coordinate formulation," in *Proceedings of IDETC/CIE 2005*, pp. 1–9, September 24 – 28, Long Beach, California USA 2005.

[3] J. Gerstmayr and A. A. Shabana, "Analysis of thin beams and cables using the absolute nodal co-ordinate formulation," *Nonlinear Dynamics*, vol. 45, pp. 109–130, 2006.