Fluid-structure interaction simulations of the vibrations of a bundle of 7 rods induced by a gap vortex street

Henri Dolfen*, Fulvio Bertocchi†, Martin Rohde† and Joris Degroote††

*†† Ghent University
Department of Flow, Heat and Combustion Mechanics
Sint-Pietersnieuwstraat 41, 9000 Ghent, Belgium
e-mail: henri.dolfen@ugent.be, web page: http://www.ugent.be/ea/floheacom

† Department of Radiation Science and Technology
Delft University of Technology
Mekelweg 15, Delft 2629 JB, The Netherlands

†† Flanders Make, Belgium

ABSTRACT

The existence of quasi-periodic fluctuations in densely packed rod arrays has been known and researched for several decades now. The differences in hydraulic diameter that exist in the gaps between rods cause large velocity differences. This gives rise to an instability that is comparable with the Kelvin–Helmholtz instability. The result is a sequence of coherent structures, that are convected downstream [1]. This phenomenon is often called 'gap vortex street'. The interest in this kind of geometries mainly comes from the nuclear society, as this array of tubes resembles the configuration of fuel rods in the core of many reactor types, as well as the heat exchangers that are extensively used in power plants. Fluid-structure interaction (FSI) simulations could be a useful tool for predicting possible damage associated with vibrations, like fretting and fatigue, facilitating the design and safe operation of power plants.

In this research an experimental benchmark is mimicked. It is attempted to select the most relevant features and to make appropriate simplifications. The experimental setup contains 7 steel rods, positioned triangularly and enclosed in a hexagonal duct. The central rod is hollow and contains a short silicone section. The water-filled cavity inside is closed at the bottom, but is at the top connected to the outer flow in such a way only the static pressure is transmitted (no stagnation zones).

A partitioned approach is applied to solve the fluid-structure interaction. A quasi-Newton method is applied at the fluid-structure interface, namely the IQN-ILS algorithm. In this way, a computational fluid dynamics model is coupled with a structural finite elements model, without intervening in the code of the solvers itself. The simulation was performed for some different flow rates.

It was found that the main pulsation frequency was slightly overpredicted by the CFD model. When looking at the vibrations, it can be seen that the deformation resembles the mode shapes of vibrating cylindrical shells. As the experiments only provide the displacement of a small patch of the wall, displacement data was extracted for a single position on the wall. Unlike what was found in the experiments, the frequency was equal to the flow pulsation frequency. Here the predicted frequency was a factor of 2 higher than values provided by the experiments.

The simulations are not able to capture the quantities of interest completely accurately. The flow pulsation frequency is approximated reasonably well. There is however a mismatch of the structural response, of which the cause is hard to determine. It is concluded that the numerical model is able to capture the physical phenomena appearing in the experiment well in a qualitative way, and to a limited extent also quantitatively.

REFERENCES

[1] L. Meyer, "From discovery to recognition of periodic large scale vortices in rod bundles as source of natural mixing between subchannels—A review", *Nuclear Engineering and Design*, Vol. **240**, pp. 1575–1588, (2010).