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Fluid-structure interaction simulation of a wire-wrapped tube array using overset grids

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Axial flows in tube bundle geometries are omnipresent in nuclear power plants, including fuel assemblies and heat exchangers. The tubes are often long and slender which makes them susceptible to fluid-structure interaction (FSI) phenomena, among which in particular flow-induced vibrations (FIV) are of concern. Typically spacer grids are employed for vibration control in fuel assemblies, but current reactor research also investigates the use of wire spacers, involving a wire helicoidally wound around each rod, to preserve the distance between adjacent rods. This poses new challenges for high fidelity numerical simulations using Computational Fluid Dynamics (CFD) and FSI. The wire-wrapped geometry is complex, among other things due to small gaps, making the meshing process complicated and cumbersome.

This research explores the use of overset grids for such wire-wrapped tube bundles. In this meshing method grids are allowed to overlap, allowing much more freedom for meshing. In the overlapping regions the flow solution is interpolated between the different grids, such that each part of the domain has correct boundary conditions. In this case the approach consists of making one grid for a single tube with a wire, the so-called component mesh, and placing this grid in a so-called background mesh that takes into account other geometrical features (e.g. the bundle duct). In the case of bundles, the same tube mesh can be repeated several times without additional meshing effort, regardless of the bundle size. The build-up of the grid is thus entirely modular. Another advantage is that the meshes typically can handle much more deformation, for example in the case of an FSI simulation, compared to single grid approaches.

The approach is verified using 4 cases found in literature, using the same component mesh either one or multiple times for each case, thus reducing the meshing effort to a minimum thanks to the freedom and re-usability overset offers. The first two cases involve the wire-wrapped tube in a cylindrical domain, the first one simulating a steady deformation using FSI, the second one a free vibration of the tube. Good agreement with results in literature was found. The latter two cases are CFD simulations of a 7-pin and 19-pin bundle in a hexagonal duct, and excellent agreement with literature results was obtained. The overset approach was proven beneficial for simulating wire-wrapped bundle geometries: with largely reduced effort the same predictive capabilities can be obtained and potentially even be extended, e.g. for cases with larger deformation or even contact.