A MECHANICALLY CONSISTENT FORMULATION FOR FLUID-POROUS-STRUCTURE-CONTACT INTERACTION

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Abstract. Fluid-structure interaction (FSI) is pivotal in various domains, including biomechanics, aeroelasticity, and physiological flows. The intricate field of fluid-structure-contact interaction poses profound mathematical and numerical challenges, particularly when considering realistic contact scenarios and the influence of surface roughness. This work delves into the mathematical underpinnings and numerical methodologies essential for addressing these challenges. This work focuses on heart valve hemodynamics as a case study, emphasizing the mathematical and numerical intricacies of contact modeling. Obtaining a method that is mechanically consistent, even in real contact scenarios, remains complicated to achieve, primarily due to the complexities introduced by topological changes and surface roughness effects. From a computational perspective, contact introduces challenges in altering the fluid domain topology and preserving stress balance. Two approaches, realistic and relaxed contact, have emerged, each with its own set of challenges. Previous contributions have proposed innovative approaches to overcome these challenges, such as incorporating fluid stress modeling within the contact zone [1] and introducing poroelastic layers to account for surface roughness [2].

This work introduces a new mathematical framework for fluid-porous-structure-contact interaction, leveraging the Navier-Stokes-Brinkman (NSB) equations to incorporate porous effects within the contact region. This approach maintains mechanical consistency during contact, circumventing issues associated with real contact models and complex interface coupling conditions, allowing for the modeling of tangential creeping flows due to surface roughness. The NSB-based porous layer description seamlessly integrates into existing fluid-structure interaction codes, offering practical solutions for diverse applications where contact occurs. Including this unified fluid-porous representation in a pre-existing FSI code within the Ansys LS-DYNA multiphysics solver, we show how the introduction of this model in a small region of the domain can impact the dynamic of the system. We compare this approach with a simple FSI with relaxed contact and strong closure with a gap on an idealized valve numerical example. This research has broad implications for fields reliant on accurate fluid-structure interactions, and promising advancements in modeling and numerical simulation techniques.

Keywords: Fluid-structure interaction, penalty-based contact, Navier-Stokes-Brinkman

References

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