10th OpenFOAM Conference

An Upwind Vertex Centred Finite Volume Algorithm for Large Strain Contact Dynamics in OpenFOAM

Callum J. Runcie[1], Chun Hean Lee[1], Antonio J. Gil[2], Javier Bonet[3]

[1] Glasgow Computational Engineering Centre (GCEC), University of Glasgow
[2] Zienkiewicz Centre for Computational Engineering, Swansea University
[3] Centre Internacional de Mètodes Numèrics en Enginyeria (CIMNE)

Numerous problems in the simulation of prototype tests and manufacturing processes involve contact-impact phenomena, typically characterised by a non-smooth response associated with transitions between contact and separation modes and between stick-slip modes. Such problems are posed mathematically by demanding the satisfaction of linear momentum balance equation, initial and boundary conditions for each body separately, while imposing additional set of kinematic and kinetic conditions that govern the interaction of these bodies with each other. When considering frictionless model of contact, these conditions act to avert interpenetration of the bodies (kinematic condition) and to insure compressive interaction normal to the interface (kinetic condition). One challenging aspect is that impenetrability cannot be expressed as an evolution (or algebraic) equation and so requires special numerical treatment [1]. The most common techniques addressing this include penalty method, Lagrange multiplier method, or a combination of both. In the penalty method, the impenetrability constraint is enforced as a penalty normal traction along the contact surface. This allows unpredictable amount of interpenetration and, potentially, can generate ill-conditioned systems that may require extremely small time steps for stability. For Lagrange multiplier method, impenetrability is weakly enforced and, in general, requires computationally demanding iterative solvers [1].

In the current work, a second order finite volume algorithm [2] established upon a set of conservation laws will be explored and implemented in the open-source platform OpenFOAM. The methodology exploits the use of a system of first order Total Lagrangian conservation laws formulated in terms of the linear momentum and a triplet of deformation measures comprised of the deformation gradient tensor, its co-factor and its Jacobian. Taking advantage of this formalism, the continuity of the normal components of the velocity and traction at contact interface will be explicitly enforced at the boundary fluxes by means of the Rankine-Hugoniot jump conditions [2, 3]. For instance, the normal traction will be enforced in the usual linear momentum equation, whereas the normal velocity will be enforced in the conservation equations for the triplet deformation measures. Additionally, a shock capturing technique can be easily incorporated in order to improve dramatically the performance of the algorithm at the vicinity of contact. No ad-hoc algorithmic regularisation procedures are needed. Finally, and to demonstrate the robustness and accuracy of the methodology, a wide spectrum of benchmark problems will be presented and compared. The overall methodology will be shown to be capable of handling contact-impact problems, even in the case of nearly incompressible scenarios.

[1] M. W. Heinstein, F. J. Melo, S. W. Attaway, T. A. Laursen. Contact-impact modelling in explicit transient dynamics, CMAME 187 (2000) 621–640.

[2] O. I. Hassan, A. Ghavamian, C. H. Lee, A. J. Gil, J. Bonet, F. Auricchio. An upwind vertex centred finite volume algorithm for explicit fast solid dynamic, JCPX 3 (2019) 100025.

[3] R. Abedi, R. B. Haber. Riemann solutions and spacetime Discontinuous Galerkin method for linear elastodynamic contact, CMAME 270 (2014) 150–177.