Simulation of crashworthiness problems with implicit time integration methods for non-linear dynamics

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When studying impact problems, time integration of the equations of evolution occurs in the non-linear range. Usually, explicit algorithms are used in such a context. Nevertheless, due to its lack of stability in the non-linear range, and its limitation in the time step size, an implicit scheme could advantageously be used. The most widely used implicit algorithm is the Newmark algorithm. Nevertheless, with this algorithm used in the non-linear range, the conservation of the energy is no longer satisfied. To avoid divergence due to the numerical instabilities, numerical damping was introduced, leading to the generalized-α methods. But these schemes can exhibit instabilities in the non-linear range too. Therefore a new family of integration algorithms for problems in structural dynamics has appeared that satisfies the mechanical laws of conservation (i.e. conservation of linear momentum, angular momentum and total energy) and that remains stable in the non-linear range.

The first algorithm verifying these properties was described by Simo and Tarnow. They called this algorithm Energy Momentum Conserving Algorithms or EMCA. It consists in a mid-point scheme with an adequate evaluation of the internal forces. This adequate evaluation was given for a Saint Venant-Kirchhoff hyperelastic material. A generalization to other hyperelastic models was given by Laursen, who iteratively solved a new equation for each Gauss point to determine the adequate second Piola-Kirchhoff stress tensor. Another solution that avoids this iterative procedure leads to a general formulation of the second Piola-Kirchhoff stress tensor, was given by Gonzalez. This formulation is valid for general hyperelastic materials. The EMCA was recently extended to dynamic finite deformation plasticity by Meng and Laursen. Armero and Romero also introduced numerical dissipation in these conserving algorithms. This dissipation only affects the total energy but preserves the angular momentum. Moreover, it is proved to be stable in the non-linear range, contrarily to the generalized-α algorithms. It is called Energy Dissipative Momentum Conserving algorithm or EDMC. Besides, Armero and Petöcz proposed a treatment of contact interactions in a consistent way in the non-linear range.

All the conserving methods described above were established for hyperelastic materials. We have recently established a new expression of the internal forces for the hypoelastic materials using the final rotation scheme. When associated with the mid-point scheme, this expression ensures the conservation laws of the mechanics for a hypoelastic constitutive model. Moreover, using the radial return mapping, we prove that this adaptation remains consistent with the Drucker postulate when plastic deformation occurs. In this work we introduce numerical dissipation in a consistent way for such hypoelastic constitutive models. Moreover, we propose a method to enhance the contact simulation proposed by Armero and Petöcz to surfaces with discontinuous normal as is the case when the two bodies in contact are deformable and are thus discretized by finite elements. With such improvements, we are able to simulate complex simulations of impact such as a blade-loss in a turbo engine.