PROPOSITION DE SUJET DE THESE

Intitulé : Formulation and evaluation of a FEM-DEM optimized Lagrange multipliers edge-to-edge structural coupling to mitigate interface spurious wave generation

Référence : **SNA-DMAS-2025-17**
(à rappeler dans toute correspondance)

Début de la thèse : October 2025	**Date limite de candidature :** April 2025

Mots clés

Structural coupling, Time integration, Lagrange multipliers, Spatial discretizations, Finite Elements, Discrete Elements, Non-uniform mesh / grid.

Profil et compétences recherchées

Master of Science (M. Sc.), Engineering School. Specialty: Computational mechanics and / or Mathematics. Knowledge on time and space discretizations, and of programming languages (Matlab, Python and / or C++). Some use of commercial FE softwares (such as Abaqus, LS-DYNA, Ansys, etc.) would be appreciated.

Présentation du projet doctoral, contexte et objectif

In solid mechanics, there is a number of situations in which it is desirable to couple in the computational domain several descriptions for the problem considered. Indeed, varying spatial discretization steps or even discretization types can be required, depending on if high or low accuracy is required in the region considered. This is for example the case of FEM-DEM coupling, where the quite accurate and costly Discrete Element Method (DEM) can be employed to track failure propagation, while the quite cost-efficient Finite Element Method (FEM) can be employed where a high level of accuracy is not required (see Fig. 1).

The domain decomposition methods enable the connection of several sub-domains for which the models, approximations or solving techniques applied are different. There are two distinct categories: the overlapping (such as Arlequin [1]) and non-overlapping (or edge-to-edge) methods. The advantages and drawbacks of overlapping techniques are as follows. They should generally be more accurate for the coupling of different types of degrees of freedom (DOFs) in the coupling region, and are generally said to allow the cancellation of spurious waves that are likely to occur when coupling the subdomains. In fact, the spurious waves are only partly mitigated [2, 3]. Moreover, this approach is employed to the detriment of computational efficiency, since the overlapping region, where the costly discretization is employed, can represent several times the region of interest.

An edge-to-edge FEM-DEM coupling was thus proposed to favor computation cost-effectiveness [4]. However, both the coupling of FEM translationnal DOFs to the translationnal and rotationnal DEM ones and the treatment of spurious wave generation at the coupling interface need to be investigated.

Spurious reflections are waves of purely numerical nature, i.e., that do not correspond to physical reflections caused by geometry or material impedance changes at the coupling interface. Spurious waves are an undesired numerical pollution in the results obtained, that may lead to prediction errors in the simulation of phenomena sensitive to waves superposition, such as spalling in fast dynamics. Two possible origins can be attributed to these spurious waves: the coupling technique itself and also the change of discretization step (non-uniform grid / mesh). Some preliminary results tend to show that spurious waves are mainly caused by the discretization step, at least when considering a Lagrange multiplier coupling and a central difference time-integration scheme [5]. To mitigate the discretization step induced spurious waves (see Fig. 2), an optimized Runge Kutta Nystrom (RKN) scheme was thus formulated and found satisfactory in 1D and 2D for purely FEM non-uniform grids [6].

A first possibility would be to formulate a Lagrange multipliers edge-to-edge structural coupling based on the optimized RKN scheme, analogously to the Central Difference (explicit) time integration scheme [4]. More generally, the origin of, and the mitigation techniques for spurious waves in coupled problems need to be evaluated (literature survey) so as to propose a cost-efficient and energy preserving edge-to-edge coupling that mitigates spurious waves. Note that the stability, wave dispersion and dissipation will be (as usual) also evaluated. The benefits of the new structural coupling on spurious wave generation at the coupling interface will first be evaluated on coupled FEM - FEM computations and then on coupled FEM - DEM computations. The plate impact and spalling test cases appear to be suitable benchmarks, since they are quite sensitive to wave propagation, and thus to spurious waves.

Another aspect will concern the appropriate coupling of FEM and DEM DOFs along the coupling interface. A proper coupling between translational and rotational DOFs in the FEM - DEM case could for example be formulated analogously to that of hexaedra continuum FE linking to shell FE. Other possibilities will be collected by means of a literature survey on this topic.

To summarize, the proposed research work will consist of:

- performing a literature survey (spurious wave origin and mitigation, structural coupling) and acquiring past developments [4, 6],
- enabling an appropriate handling of FEM and DEM DOF types along the coupling interface,
- evaluating and formulating existing or new time integration schemes with respect to stability, wave dispersion and dissipation, energy conservation and spurious wave mitigation criteria,
- formulating a Lagrange multipliers edge-to-edge structural coupling based on the selected time integration scheme,
- evaluating the formulated coupling both on coupled FE-FE and FE-DE plate impact and spalling test cases.

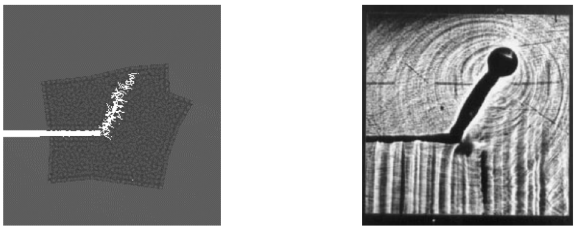

Figure 1. Coupled FEM-DEM modeling of Kalthoff fast dynamics failure propagation experiment.

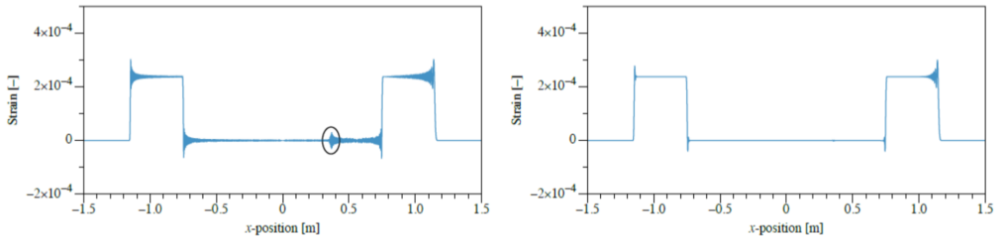

Figure 2. Discretization step induced spurious waves. Central Difference (left) and optimized RKN3 (right).

References

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Collaborations envisagées

The thesis will be part of a collaboration between ONERA, CERAMATHS and LAMIH (Polytechnic University Hauts-de-France / UPHF).

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