Coupling Multibody and Granular Dynamics: Experimental Validation

Olivier Lantsoght[1], Paul Fisette[1], Frédéric Dubois[2], Olivier Brüls[3] and Nicolas Docquier[1]

[1] *Institute of Mechanics, Materials, and Civil Engineering (iMMC), Université catholique de Louvain (UCL),*
{Olivier.Lantsoght,Nicolas.Docquier,Paul.Fisette}@uclouvain.be
[2] *Laboratoire de Mécanique et Génie Civil (LMGC), CNRS, Université de Montpellier, frederic.dubois@umontpellier.fr*
[3] *Department of Aerospace and Mechanical Engineering, University of Liège (ULg), o.bruls@ulg.ac.be*

Many engineering applications involve mechanical articulated systems interacting with granular media such as the transportation of granular material or the segregation of powder. Our research project is motivated by the specific process of tamping railway ballast. During this maintenance operation, the geometry of the track is restored by squeezing the ballast grains located under the sleeper. The squeezing of the grains is eased by the ability of the granular media to behave like a fluid when excited at a specific frequency range. This state, called fluidification state, reduces the loads applied on the grains during the squeezing phase of the tamping process. Our goal is to develop and validate computer models to simulate and analyze such a process. To this purpose, we couple multibody formalism and the discrete element method (DEM) which have been developed for the last decades. The DEM enables to consider the dynamics of the granular material by accounting for each grain of the media.

The interactions between the multibody system (MBS) and the granular media occur through contacts. The latter can be modelled either by a regularized law or a non-smooth law. The regularized model, or molecular dynamics, was used by Fleissner and Eberhard [1] in a co-simulation framework to deal with the granular media. The Non-Smooth Contact Dynamics approach introduced by Moreau and Panagiotopoulos [2] was extended to the multibody equations of motion by Flores et al. [3]. To solve the unwanted drift-off effect observed in this method, Brüls et al. [4] proposed the non-smooth generalized-α scheme which enables to enforce the unilateral constraints both at position and velocity levels in case of frictionless contact.

In this work, we are focusing on problems involving a large number of grains of various shapes interacting with any kind of three-dimensions MBS. This requires to solve bilateral constraints arising from the MBS with a minimal impact on the computation time required to solve the contact problem. For this purpose, we extended the coordinate partitioning method, which reduces the DAE to an ODE, to the non-smooth dynamics formalism. As a consequence, the contact solving procedure converges towards a solution for the unilateral constraints that automatically satisfies the bilateral constraints. As the granular dynamics and the MBS dynamics are solved together, we avoid numerical instabilities that one can encounter in classical co-simulation approaches. To achieve this goal, we import the symbolic multibody equations generated by Robotran [5] in LMGC90 [6] where the contact resolution and time integration are performed.

Several benchmarks exist for MBS with non-smooth contact models, such as the slider-crank mechanism or the woodpecker toy. Here, we propose a benchmark dedicated to applications involving a MBS that strongly

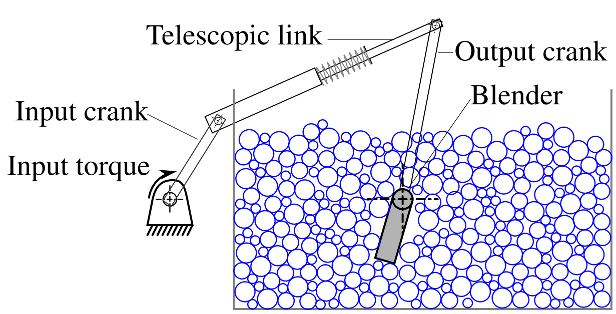
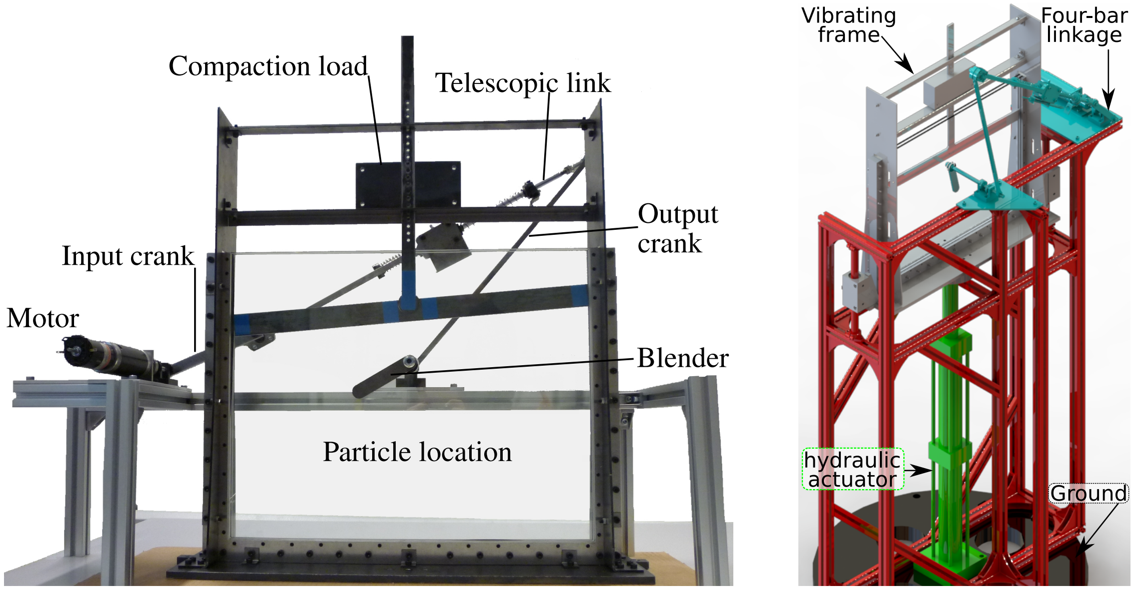


Fig. 1: Principle of the benchmark



(a) Front view of the benchmark being built

(b) Final set-up rendering

Fig. 2: Experimental set-up: the four-bar linkage is fixed on the ground, the frame is shacked by an vertical hydraulic actuator.

interacts with a granular media (Fig. 1). The system is composed of an actuated closed-loop MBS, i.e. a four-bar mechanism, that blends a vibrated granular media composed of cylindrical particles. Some compliance has been deliberately introduced in the MBS by replacing the intermediate link by a telescopic one with a parallel linear spring. The mechanism is actuated by DC motor mounted on the input crank. The simulations of the system highlighted that the elongation of the telescopic link during the motion is reduced when the granular media is excited at higher frequency. This clearly underlines how the fluidification state of the granular media affects the dynamics of the mechanism. The fluidification frequency has been found to be around 8 Hz.

The benchmark is now being built (Fig. 2) to experimentally validate our results. The frame containing the particles will be shaken by an hydraulic actuator at different frequencies. The particles are placed between two glass walls, and photoelasticity is used to observe the force network when some jamming occurs and to link it with the dynamics of the mechanism. The latter is measured by an LVDT sensor placed on the telescopic link. During the oral presentation, we will discuss the experimental validation and present a parametric analysis related to the measured fluidification frequency of the granular media and on the length variation of the floating link.

This work is supported by a FRIA grant from the Fonds de la Recherche Scientifique-FNRS and by the Wallonia.

References

[1] F. Fleissner and P. Eberhard, "A co-simulation approach for the 3d dynamic simulation of vehicles considering sloshing in cargo and fuel tanks," *Proc. Appl. Math. Mech.*, vol. 9, no. 1, pp. 133–134, 2009.

[2] J.-J. Moreau and P. D. Panagiotopoulos, *Nonsmooth Mechanics and Applications*, vol. 302 of *CISM Courses and Lectures*, ch. Unilateral Contact and Dry Friction in Finite Freedom Dynamics, pp. 1–82. Vienna: Springer, 1988.

[3] P. Flores, R. Leine, and C. Glocker, "Modeling and analysis of planar rigid multibody systems with translational clearance joints based on the non-smooth dynamics approach," *Multibody System Dynamics*, vol. 23, no. 2, pp. 165–190, 2010.

[4] O. Brüls, V. Acary, and A. Cardona, "Simultaneous enforcement of constraints at position and velocity levels in the nonsmooth generalized-α scheme," *Computer Methods in Applied Mechanics and Engineering*, vol. 281, pp. 131–161, 2014.

[5] N. Docquier, A. Poncelet, and P. Fisette, "Robotran: a powerful symbolic gnerator of multibody models," *Mechanical Sciences*, vol. 4, no. 1, pp. 199–219, 2013.

[6] F. Dubois and R. Mozul, "LMGC90," in *CSMA2013, 11e colloque national en calcul des structures*, May 13 – May 17, Giens, France 2013.