A Nonsmooth Approach to Frictionless Beam-to-Beam Contact

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EXTENDED ABSTRACT

Thin and flexible structures such as cables and beams and their contact interactions play an important role in many engineering systems [1]. Even if beam models and general contact mechanics have been extensively studied in the literature, publications on beam-to-beam contact are scarce. Systems involving the contact of beams have many specificities which are generally linked to the slenderness of their constituents. These influence modeling and numerical methodology choices and include the following aspects. First, the multitude of possible contact configurations ie. contact being distributed along portions of finite length (line-to-line) or over regions short enough to be viewed as pointwise interactions (point-to-point). Some authors apply one single contact model to handle both situations in a unified manner [2, 3]. Contacts are treated as simple discrete forces, but their number and location need to be tuned carefully as soon as the contact location cannot be assimilated to a unique point. A sufficient number of contact points should be chosen to obtain accurate results without over-constraining the system. Other authors argue for a separate treatment [4], where distributed contact forces are assumed in a certain range of configurations and discrete forces otherwise. Second, due to the kinematic assumptions of beam models, distributed contact forces are discontinuous in space [5]. Third, the presence of buckling which limits the applicability of quasi-static solvers and thus, in the general case, calls for the need of dynamic simulation. For contact among beams that have some radial rigidity this means handling contact transitions with discontinuos velocities in time.

In the quest for robust simulation of complex beam assemblies including contact, each issue must be dealt with one by one. A non-smooth approach within the Finite Element Method is taken. Non-penetration is enforced via Lagrange multipliers. It differs from penalty methods in that constraints are verified exactly and the solution is independent of any arbitrary parameter. However, great care has to be taken in the choice of numerical method, which needs to be able to deal with the potential discontinuity of velocities in time or distributed contact forces in space. First efforts by the authors concentrated on a quasi-static mortar formulation for frictionless line-to-line beam contact [6]. It proves to be a convenient strategy for the modeling of beam-to-beam contact along portions of sufficient length. Indeed, over-constraining and the need for a C^1 continuous representation of the beam centerline could be avoided. The method was found to be impractical when the length of the contact region becomes too small. Thus it was complemented by a point-to-point contact model and extended to the dynamic case. The time-integrator of choice is the non-smooth generalized-α (NSGA) scheme tailored to flexible multibody systems with vibrations and impacts. First introduced in [7], it is based on a smooth prediction that excludes impact contributions and two subsequent projection steps that impose non-penetration constraints first at position and then at velocity level. In this methodology a certain freedom remains in the definition of the smooth problem, which has an influence on convergence. A fully decoupled version with an improved behaviour for flexibile systems and non-linear constraints was studied in [8]. Contact information may be included at the prediction stage by additionally imposing constraints at acceleration level, as done in [9]. In the case of contact among slender structures such as beams this is necessary to cope with typical tunneling effects.

Finally, all developments are made taking the $SE(3)$ local frame approach [10]. The equations of motion are written on a Lie group and consistent time and spatial Lie group discretization schemes are a applied. A formulation free of global parametrizations is obtained and locking effects are automatically avoided. Moreover, the contact elements conserve the interesting invariance properties present in the contact free case. At the symposium, progress made on modeling contact interactions among beams will be presented and it will be shown that the combination of all the previously mentioned concepts forms an appropriate framework for handling geometric non-linearities, discontinuities and complex contact configurations exhibited by cable assemblies. Two indicative examples are shown in figures 1 and 2.

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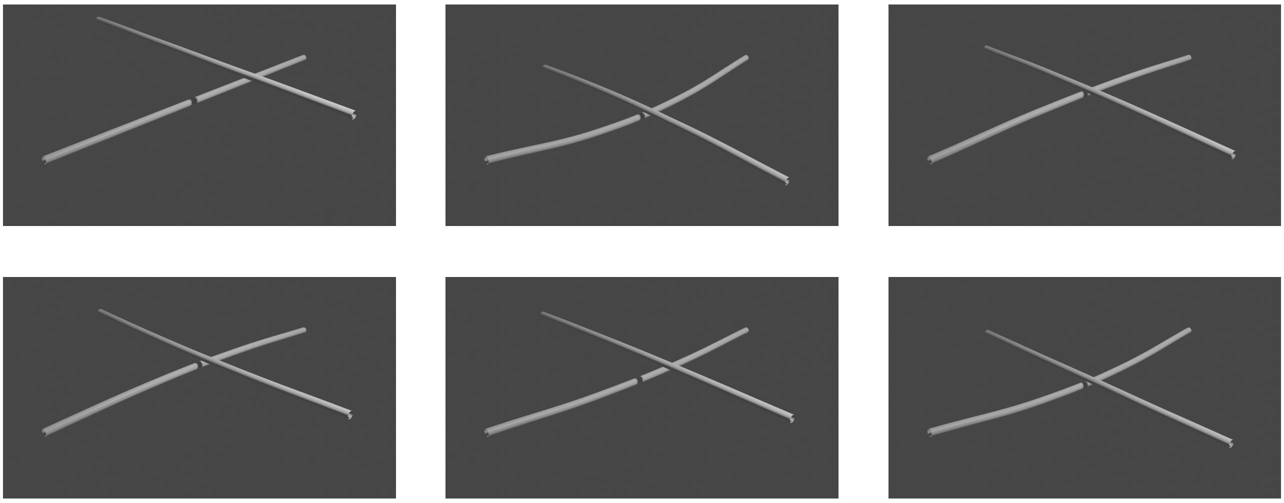

Figure 1: From top left to righ bottom: The top beam is dropped onto the lower beam, which is clamped on both ends. A detachment effect may be observed.

Figure 2: Example of three fiber twisting with line-to-line contact.