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# Modelling a braiding process as a constrained multibody system with frictional contacts

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## 1. Introduction

Automated braiding machines are used to fabricate near-net-shaped preforms for composite manufacturing. Typically, slender textile yarns are driven by bobbin carriers with synchronized horn gear motions and deposited on the surface of a rigid body (the mandrel). The combined framework of nonlinear finite elements with multibody dynamics is used for the transient modelling of such mechanical systems with rigid and flexible bodies undergoing contact-friction interactions. For representing systems with finite transformations, a differential geometric framework is helpful. Therefore, the equations of motion are defined on a Lie group together with bilateral and unilateral constraints. In nonsmooth mechanics, the non-penetration condition is expressed as a unilateral constraint in the form of a Signorini condition with a Coulomb friction law. The bilateral and unilateral constraints can be simultaneously imposed at position and velocity levels to avoid constraint drift, and to capture instantaneous jumps at velocity level. Standard time integration schemes fail to model the nonsmooth contributions, which demands the need of a specialized time integrator capable of handling discontinuities. In this work, the carrier kinematics is formulated as switching bilateral constraints, which represent nonsmooth boundary conditions for the yarns. The yarn-to-mandrel frictional interactions are further introduced.

## 2. Method

The yarns are modelled as geometrically exact beams [5] on the Lie group $SE(3)$ and driven by the imposed carrier motion. The yarn-to-mandrel frictional interactions are introduced as contacts between beams and rigid bodies and solved using a collocation approach by representing the neutral axis of the beam with proxy collision geometries [6]. The time discrete equations are solved using the decoupled version of the nonsmooth generalized-$\alpha$ time integration scheme [3] with the Gauß-Seidel solver So-bogus [4]. Three decoupled subproblems are solved using the splitting strategy as $\Delta\mathbf{q}_{n+1} = \Delta\tilde{\mathbf{q}}_{n+1} + \mathbf{U}_{n+1}$ and $\mathbf{v}_{n+1} = \tilde{\mathbf{v}}_{n+1} + \mathbf{W}_{n+1}$, where, $\Delta\tilde{\mathbf{q}}_{n+1}$ and $\tilde{\mathbf{v}}_{n+1}$ are smooth displacements and velocities, and $\mathbf{U}_{n+1}$ and $\mathbf{W}_{n+1}$ are position corrections and velocity jumps. For instance, the velocity jump $\mathbf{W}_{n+1}$ is computed at time step $t_{n+1}$ as in [2]:

$$\mathbf{M}(q_{n+1})\mathbf{W}_{n+1} - h\mathbf{f}^*_{n+1} - \mathbf{g}^T_{q,n+1}\boldsymbol{\Lambda}_{n+1} = 0 \tag{1a}$$

$$-\mathbf{g}^{\overline{\mathcal{U}}}_{q,n+1}\mathbf{v}_{n+1} = 0 \tag{1b}$$

$$-(g^j_{Nq,n+1}\mathbf{v}^j_{n+1} + e^j_N g^j_{Nq,n+1}\mathbf{v}^j_n) \in \partial\psi_{\mathbb{R}^+}(\Lambda^j_{N,n+1}) \quad \text{if } \; g^j_N(q) \leq 0, \tag{1c}$$

$$-(\mathbf{g}^j_{Tq,n+1}\mathbf{v}^j_{n+1} + e^j_T \mathbf{g}^j_{Tq,n}\mathbf{v}^j_n) \in \partial\psi_{C(\Lambda^j_{N,n+1})} \quad \text{if } \; g^j_N(q) \leq 0, \tag{1d}$$

where, $\mathbf{f}^*_{n+1} = \mathbf{f}(q_{n+1}, \mathbf{v}_{n+1}, t_{n+1}) - \mathbf{f}(\tilde{q}_{n+1}, \tilde{\mathbf{v}}_{n+1}, t_{n+1}) + (\mathbf{g}^T_{q,n+1} - \mathbf{g}^T_{\tilde{q},n+1})\tilde{\lambda}_{n+1} - (\mathbf{M}(q_{n+1}) - \mathbf{M}(\tilde{q}_{n+1}))\dot{\tilde{\mathbf{v}}}_{n+1}$. $q$ is the configuration variable, $\mathbf{v}$ is the velocity, $\mathbf{M}$ is the mass matrix, $h$ is the time step size, $\boldsymbol{\Lambda}$ is the Lagrange multiplier representing the impulse with $\Lambda^j_N$ and $\boldsymbol{\Lambda}^j_T$ as the normal and tangential components respectively, $\overline{\mathcal{U}}$ is the set of indices for bilateral constraints and $j$ is the contact point with the gap (relative position) split into normal component $g^j_N$ and tangential component $\mathbf{g}^j_T$. A Newton impact law is defined with $e^j_N$ and $e^j_T$ as the normal and tangential restitution coefficients ($e^j_T = 0$ for contact involving flexible bodies). $\psi_{\mathbb{R}^+}$ is the indicator function of the real half line $\mathbb{R}^+$ and $\psi_C$ for the section of the Coulomb's friction cone.

## 3. Preliminary results

The simulation of biaxial braiding process involving 30 yarns subjected to carrier motion and deposited on the surface of a cylindrical shaped mandrel has been performed using Odin [1]. The radius of beam is $r = 0.001$ m with $l = 3$ m and the material properties are $E = 89$ GPa, $\nu = 0.21$ and $\rho = 2750$ kg/m$^3$. Each yarn is discretized using 50 beam finite elements with spherical collision elements (radius = $r$) attached to the nodes. The simulation time is 30 seconds with time step size $h = 0.001$ seconds. The coefficient of friction $\mu = 0.1$.

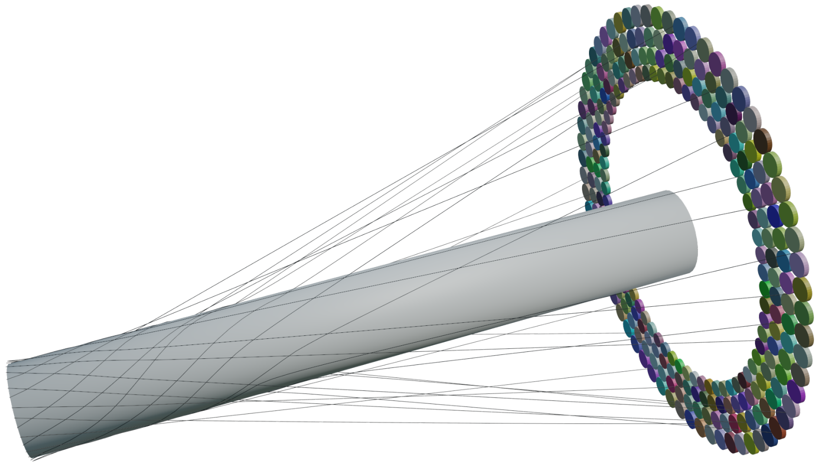

Figure 1: Transient simulation of 30 beams driven by the carrier motions and interacting by frictional contact with a cylindrical mandrel

## 4. Conclusions

The carrier kinematics is formulated as switching constraints and applied as nonsmooth boundary conditions to beams. The yarn-mandrel frictional interactions are further modelled based on a collocation approach. In the future, a beam-to-beam contact formulation shall be further introduced for the modelling of yarn-yarn contact.


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## References


[1] A. Cosimo and O. Brüls. Odin. DOI: https://doi.org/10.5281/zenodo.7468114, 2022.

[2] A. Cosimo, F. J. Cavalieri, J. Galvez, A. Cardona, and O. Brüls. A general purpose formulation for non-smooth dynamics with finite rotations: Application to the woodpecker toy. *Journal of Computational and Nonlinear Dynamics*, 16(3), 2021.

[3] A. Cosimo, J. Galvez, F. Cavalieri, A. Cardona, and O. Brüls. A robust nonsmooth generalized-$\alpha$ scheme for flexible systems with impacts. *Multibody System Dynamics*, 48(2):127–149, 2020.

[4] G. Daviet, F. Bertails-Descoubes, and L. Boissieux. A hybrid iterative solver for robustly capturing Coulomb friction in hair dynamics. In *Proceedings of the 2011 SIGGRAPH Asia Conference*, pages 1–12, 2011.

[5] V. Sonneville, A. Cardona, and O. Brüls. Geometrically exact beam finite element formulated on the special Euclidean group SE(3). *Computer Methods in Applied Mechanics and Engineering*, 268:451–474, 2014.

[6] A. Tasora, S. Benatti, D. Mangoni, and R. Garziera. A geometrically exact isogeometric beam for large displacements and contacts. *Computer Methods in Applied Mechanics and Engineering*, 358:112635, 2020.