ALE beam formulation using reference dynamics for pushbelt CVTs

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Abstract
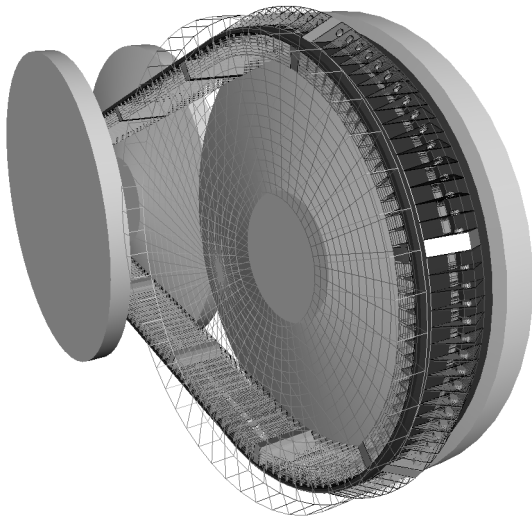
(a) A pushbelt CVT with elements, loop-sets and pulley sheaves.
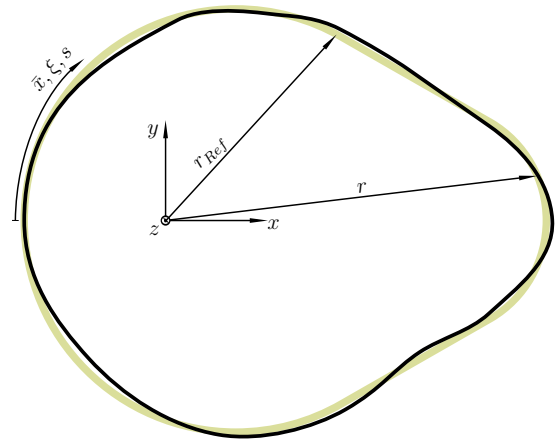
(b) General overview of the loop-set kinematics using a reference curve (yellow) with local deformations.

For the efficient simulation of continuously variable transmissions (CVTs) using a pushbelt (see Figure 1a), an efficient model for the loop sets is required. Due to the stiff material (steel) and the thin structure, models known from literature (e.g. [2] or [4]) tend to have numerical problems concerning the robust dynamical integration.

In this work, a specific model for the loop sets is presented. The general idea is to separate the overall dynamics from local deformations as sketched in Figure 1b. Thereby, the number of degrees of freedom (DOFs) can be reduced.

For modeling the turnaround motion, the DOF s is introduced following the idea of [3] but being a time dependent free parameter to enable transient boundary conditions, e.g. a runup case. The transformation from the Lagrangian coordinate $\bar{x}$, which follows the mass particle in space, into the Eulerian coordinate ξ, which is fixed in space, satisfies

$$\bar{x} = \xi + s(t), \qquad \frac{d\bar{x}}{d\xi} = \frac{\partial \bar{x}}{\partial s} = 1, \qquad \frac{d\bar{x}}{dt} = \frac{ds}{dt} \qquad (1)$$

Furthermore, a ratio parameter Θ is introduced as DOF to describe the geometric transmission of the planar reference curve. The kinematics of it depends explicitly on the primary radius $r_P(\Theta)$ which is interpolated with local splines for different ratios Θ constrained by the length of the loop set and the distance of the CVT shafts.

Additional local deformations about the reference curve enable the analysis of crucial effects in the CVT like spiral running, a *cats back*-shape of the push-strand or misalignement. The position given in the inertial frame x, y, z of the neutral phase of the beam is then given by

$$r = r_{Ref} + r_f = r_{Ref} + \mathbb{B}q_f \tag{2}$$

where r_{Ref} is the position of the reference curve and $\mathbb{B}$ the interpolation of the local nodal deformations q_f. Local ansatz functions with respect to the Eulerian coordiante ξ are used for the finite element discretization.

The derivation of the equations of motion is based on the Lagrange equations. Due to the coordinate transformation (1) the integrals for the kinetic energy T and the potential energy V have time dependent limits. As the loop sets are closed structures, many of the additional boundary integrals vanish and compact equations of motion result.

The simulation results are compared to the corresponding ones using a general beam model with a co-rotated Lagrangian description as described in [1]. Due to the specific modelling, the necessary number of degrees of freedom can be reduced for comparable results, which yields less computational costs. Yet, not all possibilites concerning code optimization have been implemented within the new formulation. Besides, a good correlation to measurements can be achived. Furthermore, the effect of the local deformations can be analyzed more precisely due to the separation of the global and the local deformations.

References

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