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Hypotheses Formulation in Multibody Modeling: Application to Bicycle Transmission Dynamics

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Abstract

Being very active at the Université catholique de Louvain (UCL, Belgium) in the field of multibody dynamics, we are now focusing on an important aspect of this modeling activity: the statement and formulation of "reasonable and relevant modeling hypotheses". Of course, this problematic concerns all fields of engineering but in the particular case of modeling, we think that the focus must be reinforced at both research and educational levels.

In the field of mechanical design, the starting point is a client request to build a new machine (or process) or to enhance the performances of an existing one. The "translation" of this request into the well-known *project specification* represents the first step of the design process. In the field of modeling – multibody applications in the present case – we want to adopt a similar methodology for our own research and industrial collaborations: the "translation" of the client request (being in this case the modeling of a new system or the improvement, by simulation, of an existing one) into a so-called *modeling specification*. Among other things, the latter will contain an unambiguous formulation of the modeling hypotheses, which are needed to simplify the original system for obvious reasons: a reasonable number of parameters to be identified, reasonable time for model establishment and of course reasonable computational time.

Our motivation comes from the following observation: facing a modeling R&D project, engineers working with commercial software have a tendency to build models (often including impressive 3D virtual representation) which are sometimes "a bit monstrous" with respect to the real original client problem. As an example, the understanding of the dynamic behavior of pneumatic suspension systems of railway vehicles does not necessarily require the introduction of complex wheel/rail contact models "just because it is a railway vehicle". On these observations, we have thus decided to focus on this important step — hypotheses formulation — for both students in mechanical engineering and researchers in multibody dynamics.

Let us briefly illustrate this problematic via the modeling of a mountain bike equipped with modern suspension systems (see Fig. 1). The precise question is: what is the influence of the pedaling forces on the bike bounce motion and suspension power dissipation? Let us restrict the bike

Figure 1. Mountain bike with closed-loop suspension mechanisms

(+driver) to a planar motion, by focusing on vertical and pitch motions of the various bodies. Fig. 2 gives an illustrative result which shows the power dissipated in dampers for different values of damping and stiffness coefficients, when the drivers is pedaling at constant velocity.

As regards *a posteriori* hypotheses, an interesting validation concerns the kinematics and dynamics of the roller chain transmission. With respect to bicycle bounce performances (which is the

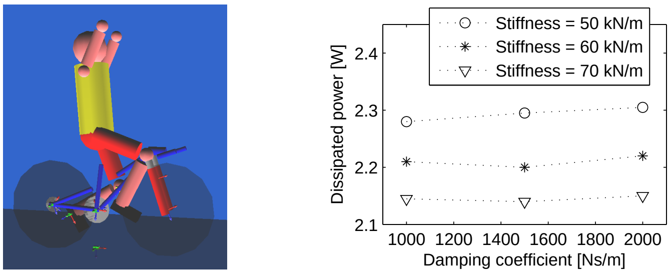

Figure 2. Bike bounce motion (left: Robotran MBS model, right: power dissipated in dampers)

project modeling objective), we can propose three different modeling approaches for the transmission, each of them being associated with a given "hypothesis level". From the most to the less restrictive one, these models are:

- Model 1: Constant transmission ratio via kinematic constraint
- Model 2: Torque-equilibrated chainring
- Model 3 - Motion transmission via a "rolling without slipping" kinematic constraint

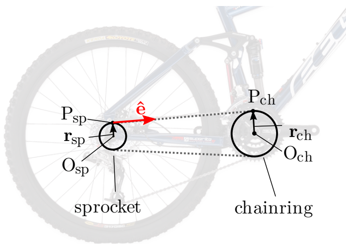

Figure 3. Motion transmission via a "rolling without slipping" kinematic constraint

Fig. 3 briefly illustrates this third model (in which the chain is still unnecessary). Instead of blindly imposing a constant transmission ratio between the front and rear angular velocities (Model 1), it is more subtle to notice that, assuming that the upper chain is permanently tight, it can be considered as a rigid body along $P_{ch} - P_{sp}$. A "rolling without slipping" constraint at the chain/chainring and chain/sprocket connection can then be formulated as follows:

The projection on the unit vector $\hat{\mathbf{e}}$ of the absolute velocities of the chain material points P_{ch} and P_{sp} must be equal at any time, that is:

$$h(q, \dot{q}) \triangleq (\mathbf{v}_{P_{ch}} - \mathbf{v}_{P_{sp}}) \,.\, \hat{\mathbf{e}} = 0, \ \forall t \tag{1}$$

which represents a velocity-level kinematic constraint.

The presentation will detail the three proposed models and will especially focus on their — non negligible — influence on the results, in particular the dissipated power in the rear and front suspensions.

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