On the Frictional Contacts in Multibody System Dynamics

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Abstract

The dynamic behavior of multibody systems has been extensively studied due to the need of understanding the interaction between bodies and to predict their performance on duty. Contact analysis includes two main phases, the contact detection and the evaluation of contact forces. Typically, the contact forces are divided into two different components, the normal force and the tangential force, this work only regards to the last. There are different phenomena associated with friction, such as the dry friction and the lubricated friction. Friction is a highly complex phenomenon, which occurs in all mechanical systems. In some case the presence of friction is doubtless desirable, e.g. while walking or braking a car. One of the first works appeared in the 16th century resulting from Leonardo da Vinci's work, who stated that the friction force is proportional to normal load, opposes to the motion, and is independent of the contact area. Coulomb stated that friction was independent of velocity magnitude, and developed the first friction model [1]

$$\mathbf{F}_\mathrm{T} = \mu \left\| \mathbf{F}_\mathrm{N} \right\| \mathrm{sgn}(\mathbf{v}) \tag{1}$$

where μ is the coefficient of friction, $\mathbf{F}_\mathrm{N}$ denotes the normal contact force, $\mathbf{v}$ is the relative velocity of the bodies on the contact surfaces, and sgn($\mathbf{v}$) returns a unit vector with velocity direction.

Coulomb friction law was the basis for the developing of more complex models capable of capturing several phenomena, such as viscous friction, stick-slip motion, friction lag, among others. The number of friction models proposed in the literature is enormous, and it is common to divide between static and dynamic models. The static models describe the steady-state behavior of the system, and it must be stated that most of these models present a discontinuity of friction force when the relative velocity is zero, which can cause difficulties in describing friction realistically. In general, the static friction approaches have limitations in capture some friction phenomena, such as pre-sliding displacement or frictional lag. Thus, better alternatives have been developed, namely the dynamic friction models, which use an extra state variable to calculate the friction force.

Thus, the main purpose of this work is to present and compare several friction force models that can be utilized in the context of multibody systems formulations. In the sequel of this process, some of the most relevant static (Coulomb, Coulomb with stiction, Stribeck curve, Karnopp, Bengisu and Akay, and Awrejcewicz) and dynamic (Dahl, Reset Integrator, LuGre, Elasto-Plastic, Gonthier et al. and Liang et al.) friction models are briefly described. [1-11]. To perform a comparative analysis between the presented friction models, it was used the 1-DOF spring-mass model (Figure 1). This is a standard example for validation of friction models which is widely used for 1D formulation simulation.

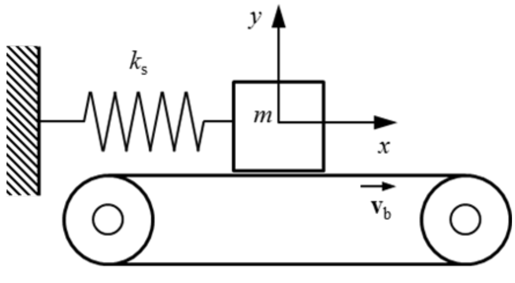

Figure 1. Representation of the 1 DOF spring-mass model.

The results were gathered into three different sets of models: static models without stiction, static models with stiction, and dynamic models. For each model, position, relative velocity and friction force were plotted, as it is represented in Figure 2 for the static models with stiction and the dynamic models. From the analysis, it is possible to see that some models present a similar macroscopic behavior. However, with the analysis of the displacement and velocity dependence by the friction force, the differences between the friction models become clearer.

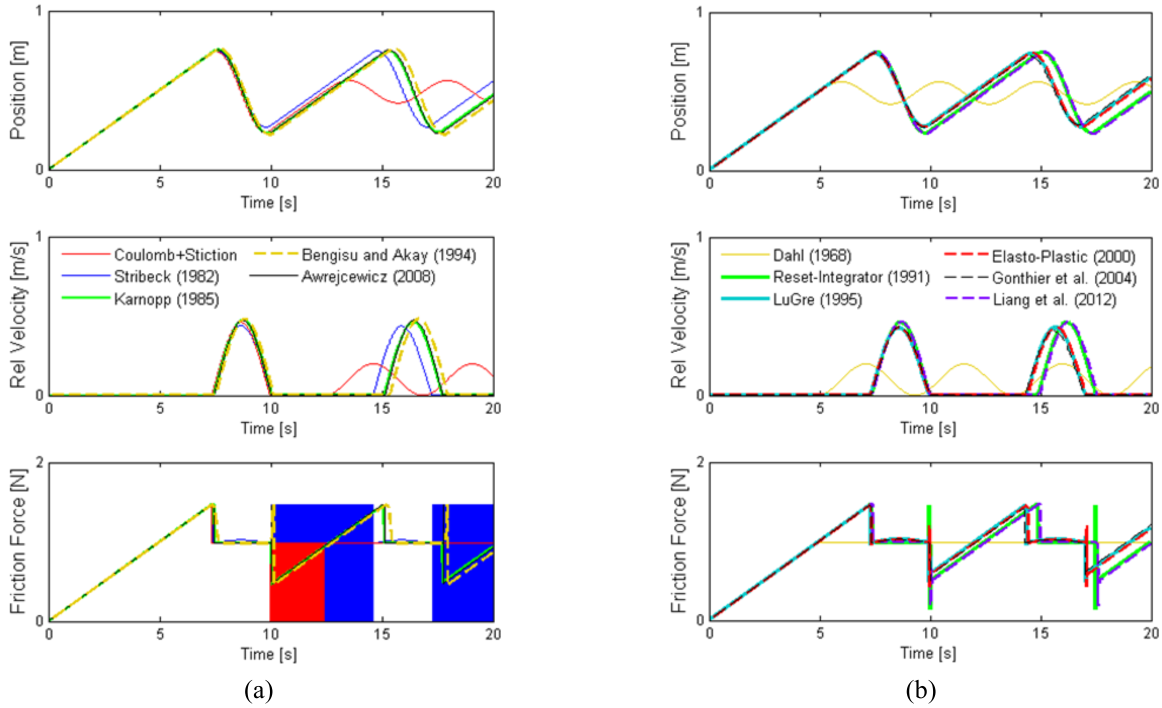

Figure 2. Simulation results: (a) static models with stiction; (b) dynamic friction models.

From the simulation results, it can be stated that the modelling of friction phenomena has a direct influence on the dynamic response of the system. Thus, to correctly model, analyze and simulate multibody systems, appropriate friction models must be adopted. Nevertheless, in order to have more complex friction models, it is, in general, necessary to introduce a large number of parameters.

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