ECCOMAS Thematic Conference on Multibody Dynamics
July 24 - 28, 2023, Lisbon, Portugal

Friction modeling from a practical point of view

Matthias Schuderer, Thomas Schaeffer, Georg Rill, Carsten Schulz

Faculty of Mechanical Engineering
Regensburg University of Applied Sciences
Galgenbergstr. 30, 93053 Regensburg, Germany
[matthias.schuderer, thomas.schaeffer, georg.rill, carsten.schulz]@oth-regensburg.de

EXTENDED ABSTRACT

1 Introduction

A large number of different friction models are presented in the current literature. Today, commercial multibody simulation (mbs) packages such as Adams, RecurDyn or Simpack offer a limited choice of specific friction models, in particular specific stick-slip approaches. For instance, Adams users can choose between a regularized static friction model, the dynamic LuGre model and an Adams-specific friction model to describe stick-slip [1]. This paper applies a practical example to test these friction models with respect to their runtime performance, their reproducibility of friction phenomena, and their user-friendliness.

2 Friction models in commercial multibody simulation packages

A typical user of these mbs packages is usually limited to the provided friction models for modeling stiction and sliding phenomena. The simplest model provided by Adams and Simpack is a piecewise defined static regularization between friction regimes. RecurDyn has removed the static regularization for joint friction in version 2023 [2]. In general, a static regularization approximates the stiction behavior by a slow joint creep. To achieve real stiction, mbs package-specific friction models are provided. These models switch between stick and slip. Each algorithm uses the relative velocity to distinguish between different states to maintain long-term stick [1, 2, 3]. Adams also offers the LuGre model as a dynamic friction model.

A regularized friction model $\mu = \mu(|v|)$ is usually defined by three characteristic points: $(\mu(|v|=0)=0)$, $(\mu(|v|=v_s)=\mu_s)$, and $(\mu(|v|=v_d)=\mu_d)$, where μ_s and μ_d specify the static and dynamic friction values and the velocities v_s and v_d model the regularization and the attenuation pattern. The LuGre model uses the fictitious velocity $v_A > 0$ and the exponent $\alpha = 2$ as a standard to describe the transition from the static friction value μ_s to the dynamic friction value μ_d.

In static friction regularization, the friction coefficient μ is calculated by a piecewise defined function, depending on the relative velocity v. In the first section for $|v| \leq v_\mathrm{s}$ the friction coefficient $\mu(|v|)$ increases from $\mu(0) = 0$ to the stiction coefficient $\mu(v_\mathrm{s}) = \mu_\mathrm{s}$. In the second section for $v_\mathrm{s} < |v| \leq v_\mathrm{d}$, $\mu(|v|)$ decreases from $\mu(v_\mathrm{s}) = \mu_\mathrm{s}$ to the the dynamic coefficient $\mu(v_\mathrm{d}) = \mu_\mathrm{d}$ and in the third section for $v_\mathrm{d} < |v|$ the friction coefficient applies to $\mu(|v|) = \mu_\mathrm{d} = \mathrm{const.}$ The transitions can be modeled in several ways, e.g. using 3rd-order-polynomials (Adams, [1]) or trigonometric functions (Simpack, [3]). Subsequently, the friction force is given by $F_\mathrm{fric} = -\frac{v}{|v|}\mu(|v|)F_\mathrm{N}$.

The steady-state friction characteristics of the LuGre model is typically computed by the equation

$$\mu_\mathrm{LG}(|v|) = \mu_\mathrm{d} + (\mu_\mathrm{s} - \mu_\mathrm{d})e^{-(|v|/v_\mathrm{A})^\alpha} \tag{1}$$

Due to the definition in (1), $\mu_\mathrm{LG}(0) = \mu_\mathrm{s}$ and not $\mu_\mathrm{LG}(0) = 0$, the LuGre approach as regularization can only be approximated. Therefore, the approach is slightly modified in section $0 < |v| \leq v_\mathrm{s}$ to represent as a static regularization. Figure 1a shows a

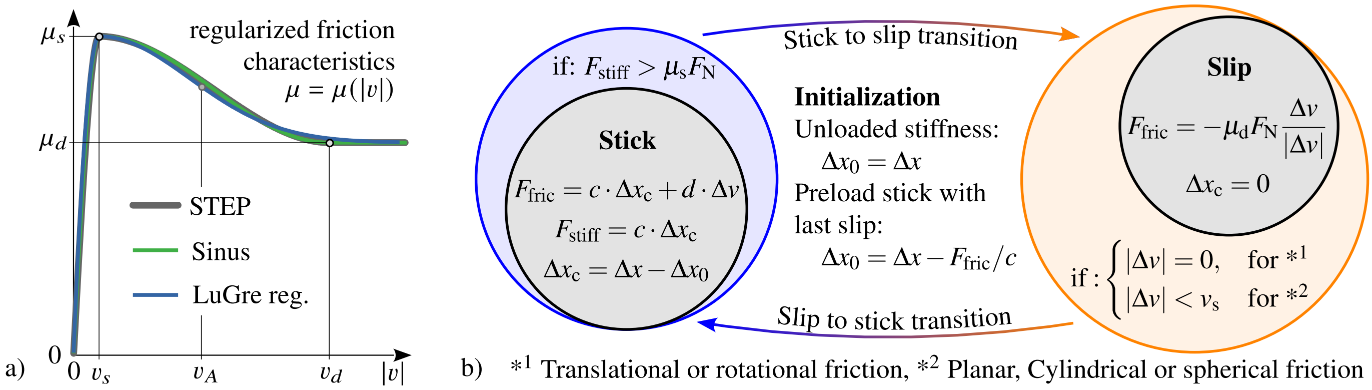

Figure 1: a) Comparison of regularized friction characteristics, b) Simpack specific stick-slip model (refers to [3])

general plot comparing the regularizations. The difference between the 3rd-order-polynomial (STEP-function) and the Sinus-function is less than 1 %. In addition, Figure 1a shows the regularized characteristics of (1) and the meaning of the fictitious parameter $v_{\mathrm{A}} = \frac{1}{2} v_{\mathrm{d}}$.

Specific friction models which include real stiction can generally also be described by a piecewise defined function. For instance, the second and third section can be formulated similarly as described above. In contrast, the joint displacement x is additionally considered in the first section. In Adams and RecurDyn the friction coefficient $\mu(|x|, |v|)$ is computed in section $0 < |v| \leq v_{\mathrm{s}}$ as a function of the relative velocity v and the relative displacement x. The specific stick-slip model in Simpack differs in description from the others. Simpack distinguishes between the states as shown in Figure 1b and uses a spring-damper element to describe the stiction behavior.

The LuGre model is a well-known dynamic friction model often described in the literature. It bases on a bristle model that describes the friction behavior by the dynamics of a bristle [4]. The Adams implementation also takes a normal force dependency into account [1]. The advantages and disadvantages of this description are well known and can be found in Marques et al. [5], Åström et al. [6] and Rill et al. [7], among others.

Adams, RecurDyn and Simpack allow users to define and apply own static or even dynamic friction models. Therefore, a static friction model with a regularization adjusted to the definition of the steady-state LuGre friction characteristics was implemented in mbs packages.

3 The crane festoon system as a practical friction test bench

The festoon model used by Rill et al. [7] has proved to be a useful practical application, as it combines a variety of friction phenomena into a general multibody system. This model allows to investigate the breakaway behavior at different pulse loads as well as the stick-slip effect. Additionally, when the cable trolleys are moved in positive and negative directions, the friction model must dynamically change the sign of the friction force as a result.

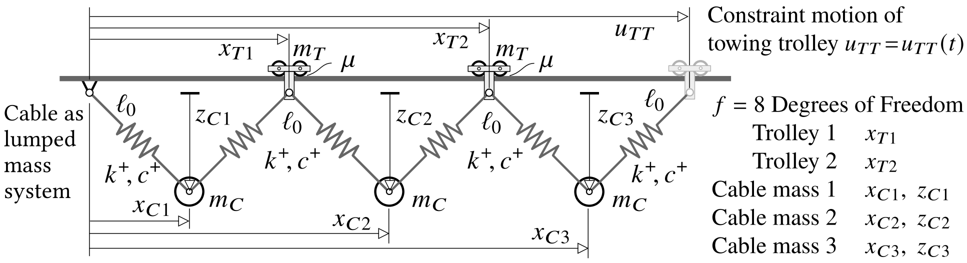

Figure 2: The festoon model used by Rill et al. [7]

4 Conclusion

In this paper, the crane festoon system is proposed as a practical and more suitable friction test bench. The runtime performance of these models are evaluated using the specific mbs packages as well as in the independent software environment Matlab. Moreover, all these models are studied with respect to the reproducibility of friction phenomena using the crane festoon model. The paper will provide an overview of which models can be applied to which issue, as well as how they can be parameterized.

References

[1] Adams 2022.4 - Adams View User's Guide, Hexagon AB, 2022

[2] 6.2.2.6.2.1. Joint Friction. URL: http://dev.functionbay.com/RecurDynOnlineHelp/2023/Professional/Professional_ch02_s02_06.html#properties (last access on 23.01.2023), FunctionBay Inc., 2022

[3] About Coulomb Friction. SIMULIA User Assistance 2023x, Dassault Systèmes Simulia Corp., 2022

[4] C. C. de Wit, H. Olsson, K. J. Åström, P. Lischinsky, A New Model for Control of Systems with Friction, IEEE Transactions on Automatic Control 40(3) (1995), 419-425.

[5] F. Marques, P. Flores, J.C. Pimenta Claro, H. M. Lankarani. Nonlinear Dynamics: A survey and comparison of several friction force models for dynamic analysis of multibody mechanical systems. Nonlinear Dynamics 86, 1407–1443, 2016.

[6] K. J. Åström, C. C. de Wit, Revisiting the LuGre friction model, IEEE Control Systems Magazine 28(6) (2008) 101-114.

[7] G. Rill, Th. Schaeffer, M. Schuderer. LuGre or not LuGre. Multibody Syst Dyn Preprint (2023) https://doi.org/10.21203/rs.3.rs-2266522/v1