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Dahl and LuGre dynamic friction models — The analysis of selected properties

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ABSTRACT

The paper presents a method of determination of parameters for LuGre and Dahl dynamic friction models. The method involves the use of numeric optimisation, in which the objective function is a minimisation of the sum of squares of relative errors between the actual and modelled friction hysteresis courses. It was specified that the limiting value of the cycle time of the signal, forcing the relative motion, above which the simulation of friction hysteresis in the presliding regime is not dependent on the velocity of displacement. The analyses of numerical results indicated that the parameters of dynamic models have limited the scope of application in relation to the normal forces exerted on the kinematic friction pairs, as opposed to the static friction models.

1. Introduction

Friction is a phenomenon that commonly appears in almost all mechanical systems. The desire to explore this phenomenon has inspired researchers for many centuries. The first documented attempts of friction phenomenon modelling are attributed to Leonardo da Vinci. According to his research, the reaction force of friction is directly proportional to the normal force exerted on the body and the constant number of ¼, universal for all bodies. Years later it turned out that this constant (in modern models called the coefficient of friction) is correct for many combinations of materials of friction pairs. Despite a long history of research, the actual nature of the formation of the friction force has not been known yet. Ineffective compensated friction reaction forces lead to a limitation of technical devices functionality to such a degree that they become completely useless. Particular difficulties in friction force identification occur at very low velocities and displacements — typical for processes of precision positioning of the working device elements, such as robots, control systems of aircraft, aiming mechanisms, or machine tools. The author of the paper recognizes the seriousness of the problem of effective friction force defining due to the work experience; modelling, analysis and experimental verification of the sorting and positioning processes of objects stream with the use of nonprehensile manipulators. The issue of automatic, high-efficient positioning and sorting of unit loads occurs in the logistics centres in conveyor transport systems [1,14] or assembly lines. Friction, in these processes, is one of the dominant physical phenomena which determines the reliability and precision of programmed handling activities.

The source of dynamic nonlinearity causing the disturbances in receiving the assumed paths and errors in achieving programmed positions of working mechanisms are such phenomena as: stick–slip, break-away force, frictional lag or hysteresis of friction force in the range of presliding displacements.

Understanding the nature of friction, its modelling, identification and compensation are still current challenges faced by the researchers and designers of device drive control systems.

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The purpose of the present paper is to propose a methodology for determining the parameters of Dahl and LuGre dynamic friction models which, in the available literature, is not presented and discussed in detail. There was also an analyis of an influence of body weight of kinematic friction pair on the efficiency and computing convergence of the models considered.

2. Contemporary friction models

The friction forces models proposed today can be divided into two major groups [6–8]:

- static models (derived from the Coulomb model) [8], e.g. models by Karnopp, Quinn, Kikuuwe, Awrejcewicz [4], and Wojewoda [18],
- dynamic models (derived from the Dahl model), e.g. LuGre model [6,19,13], Leuven model [12,16], and GMS model [3,5,10,11].

This division results from the modelling of friction at rest state.

In the static models, there is an assumption that in the standstill friction conditions the relative motion between the rubbing bodies does not occur and in the dynamic models — that small presliding displacements appear, at which the friction force is a function of displacement. This property has been confirmed by detailed experimental studies.

In the range of kinetic friction (when the bodies' relative velocity is above at about 0.003 m/s [1]), the two groups of models describe friction force similarly — as a function of slip velocity.

Static models, with a simpler structure and fewer parameters than in the dynamic models, are mainly dedicated to the study of friction pairs with significant slip velocities and a small number of transitions between standstill and kinetic friction states, especially when these transitions run in a rapid manner [1].

In case of modelling of precisely positioned mechanical systems with friction, it is necessary to use the dynamic friction models which consider both friction regimes [15,17]. Dynamic friction models, as opposed to the static models, allow for recreating processes occurring in standstill friction conditions and at very small as well as high sliding velocities. The main disadvantage of dynamic models is their complexity that results in being highly computation-wise time-consuming and in generating high calibration costs.

2.1. Dahl model

The Dahl model (1968) belongs to the earliest dynamic friction models; it was designed to simulate a symmetrical hysteresis loops observed in bearings subjected to sinusoidal excitations with small amplitudes. This model was applied e.g., in standard models of simulation in the aerospace industry [9].

The Dahl model is represented by the equation

$$\frac{dF}{dx} = \sigma_0 \,\mathrm{sgn}\left(1 - \mathrm{sgn}(v)\frac{F}{F_C}\right) \left|1 - \mathrm{sgn}(v)\frac{F}{F_C}\right|^{\delta_D} \tag{1}$$

which can be converted into form (2) — easier for the numerical implementation:

$$\begin{cases} F = \sigma_0 z \\ \dot{z} = v\,\mathrm{sgn}\left(1 - \mathrm{sgn}(v)\dfrac{\sigma_0 z}{F_C}\right) \left|1 - \mathrm{sgn}(v)\dfrac{\sigma_0 z}{F_C}\right|^{\delta_D} \end{cases} \tag{2}$$

where:

F friction force [N],
z state variable interpreted as elastic deformation of surface asperities of adjacent bodies [m] (Fig. 1),
$v = dx/dt$ sliding velocity [m/s],
x body displacement [m],
σ_0 asperity stiffness [N/m],

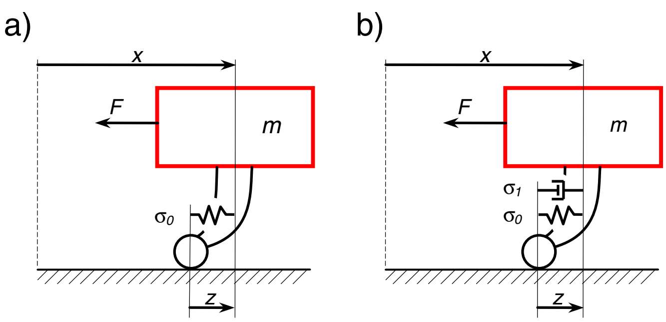

Fig. 1. Graphic representation of variable state z [21]: a) Dahl model, b) LuGre model.