Modeling friction for yarn/fabric simulation Application to bending hysteresis

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ABSTRACT

This paper describes studies done at Gemtex Laboratory on the modeling and simulation of woven fabric. The main difficulty in this area is to take into account the hysteresis phenomena that occurs in fabric's traction, shearing and bending behavior. Part I of this paper presents a friction based approach to obtain a time-free model for this nonlinear phenomena. Part II presents the application to yarn and fabric bending comparing simulated results and lab measured data with the Kawabata Evaluation System. Using this new approach it will possible to improve our futur fabric model based on [Ngo-Ngoc et al., 2002] and identify the hysteresis parameters for the simulation.

INTRODUCTION

The possibility of determining the yarn and weave parameters to obtain the desired fabric properties is a very attractive challenge. That is why fabric modeling research started in the 1930's when the textile research community was founded and since that time this area is still a today topic

This work on fabric modeling has been done in two fields, computer graphics and textile engineering. But the goals are different, computer graphics works are more interested in good visual appearance whereas textile engineering work focuses on "exact" physical modeling.

The Kawabata evaluation system [Kawabata, 1980] shows that yarn and fabric behavior is highly nonlinear and most of fabric models do not take into account this phenomena or approximate with linear function. This nonlinear behavior had made the traditional fabric models such mass spring network inadequate. Several frictional models are examined here to identify a model that will best describe hysteresis phenomena and in particular bending behavior. This nonlinear characterization should pave the way for fabric simulation and the bending parameter's identification.

CONSIDERATIONS

Hysteresis corresponds to the apparition of a "delay" caused generally in a mechanical system by dry friction which produces an energy loss. In mechanical systems friction is often only one of many forces (torques) present which might induce undesirable phenomena such as hysteresis.

Friction occurs in all mechanical system especially where there is a physical interface between two surfaces in contact. There is a wide range of physical phenomena that cause friction, this includes elastic and plastic deformations, wave phenomena, ... It is the tangential reaction force between two surfaces in contact. Physically these reaction forces are the results of many different mechanisms, which depend on contact geometry and topology, properties of the surface materials, displacement and relative velocity and presence of lubrification.

Considering a yarn, this structure is a fibrous assembly. So when it is submitted to deformation, friction occurs at fibers contact. That's why we consider that hysteresis appears in fabric an yarn deformation. Therefore dynamic friction models can be adapted to suitably describe the yarn or fabric deformation. A potential advantage of such model is their ability to describe closely some of the physical phenomena found in textile modeling and to depend on parameters directly related with the phenomena to be observed like the change on yarn or fabric characteristics (torsion, count, weaving data, ...)

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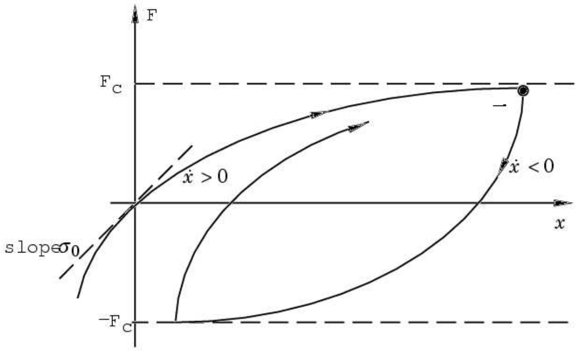

Figure 1: Stress-strain curve

MODELING FRICTION

Friction has been investigated for a long time. The most basic laws date back to the work of Leonardo da Vinci. The physicist Amonton made the same studies and defined two laws: first that friction is directly proportional to applied load, second that friction is independent of the apparent area of contact [Amontons, 1699]. Then Coulomb published the most comprehensive study of friction at that time [Coulomb, 1785]. Lately Karnopp [Karnopp, 1985] and Stribeck [Stribeck, 1902] improved coulomb model in order to take into account stiction and stricbeck effect. Although these models bring a better understanding the friction they are considered as “static” model because that friction force is a function of the velocity. This observation shows drawbacks of these models, so they can be avoided for modeling dynamical system. The publication of a new class of friction models resulting from the need of control friction system brought a new way to deal with friction.

Dhal’s Model

Dhal’s model [Dahl, 1976] was developed for the purpose of simulating control system with friction especially in servo system with ball bearings. The starting point is the stress-strain curve in classical solid mechanics 1. He modeled the stress-strain curve by a differential equation. Let x be the displacement, F the friction force and F_c the coulomb friction force then:

$$\frac{dF(x)}{dt} = \sigma_0\,(1 - \frac{F}{F_c} sign(v))^{\alpha} \tag{1}$$

with σ_0 the stiffness coefficient, α a parameter that determines the shape of the stress-strain (generally $\alpha = 1$)

This formulation implies that friction force is only position dependent (rate independent).

The time domain model is obtained from:

$$\frac{dF}{dt} = \frac{dF}{dx}\frac{dx}{dt}$$

then

$$\frac{dF}{dt} = \frac{dF}{dx} v = \sigma_0\,(1 - \frac{F}{F_c} sign(v))^{\alpha} v \tag{2}$$

for $\alpha = 1$the Dahl model 1 reduces to:

$$\frac{dF}{dt} = \sigma_0 v - \frac{F}{F_c} \mid v \mid$$

with $F = \sigma_0 z$ the model is then:

$$\begin{array}{rcl} \frac{dz}{dt} & = & v - \frac{\sigma_O |v|}{F_c} z \\ F & = & \sigma_0 z \end{array} \tag{3}$$

This model is a generalization of ordinary coulomb friction but it does not have stribeck effect and stiction. These phenomena are the main area of research for the extension of the model

The Bliman-Sorine Model

Based on the experimental studies made by Rabinowicz [Rabinowicz, 1951] and Dahl work this model assumed that friction only depends on the sign of the velocity and the variable $s = \int_0^t \mid v(\tau) d\tau \mid$. Thus the model is defined by:

$$\begin{array}{rcl} \frac{dx_s}{dt} & = & Ax_s + Bv_s \\ F & = & Cx_s \end{array} \tag{4}$$

Thanks to to the rate independence property of the model it is possible to use the theory of hysteresis operators developed in [Krasnosel’ski and Pokrovski, 1989].

The complexity of the model is given by the dimension of the state space. First order model is identical to Dahl’s model and the second order model can be viewed as a parallel connection of a fast and a slow Dahl model. Thus it is possible to obtain stiction.

MODEL SELECTION FOR BENDING DEFORMATION

Several classical friction models presented above were considered. Investigations showed that Dahl Model is best described as a position dependent friction model. The driving factors behind the choice of this model are its simplicity and the easiness to have a first parameters approximation from a KES bending curve. Despite its simplicity the model accurately describes the resistive force presents for the fabric or the yarn. Furthermore, Dahl’s model was chosen for its flexibility because viscous damping stiction stricbeck effect and stick-slip could be included with some modifications.

IDENTIFICATION AND RESULTS

To achieve this work an identification procedure is perfomed. Unlike a spring stiffness which can easily measured statically, friction identification involve dynamic measurements.The KES Bending tester is one a few measurement apparatus which evaluates “pure” bending behavior of a yarn and a fabric. That’s why we choose it.

The parameters of the Dahl model cannot be expressed as linear coefficient of the independent variables meaning that numerical scheme such as nonlinear least squares or other method are required to estimate the parameter value. We choose the nonlinear least squares algorithm.

We identify bending for a twill weave fabric. Concerning the yarn bending behavior we use the yarn which composes the tested fabric. The parameters are:

	σ gf/cm^2	F_c gf cm/cm^2	α
yarn	0.061	0.014	1
fabric weft	0.55	0.16	1
fabric warp	0.60	0.23	1

Figures 2 and 3 show the identification results

From the preliminaries studies, we see that parameters reflects change in yarn/fabric characteristics.

CONCLUSION

Knowledge of an environment’s friction is essential to understanding and modeling textile structure. Nevertheless, because it is highly nonlinear, friction is rarely fully included in yarn or fabric modeling. It is often simplified leading to incomplete model. We have presented a method to include friction phenomena ion fabric and yarn simulation. To achieve this goal we use a dynamic friction model that provide a good representation of hysteresis behavior. Furthermore we have identify model parameters and show that they depend from yarn and/or fabric characteristics. More studies should be done in this way especially for fabric traction and shear. Using this approach can improve fabric our futur fabric model in order to simulate KES system from the only known yarn mechanical properties and weaving data.

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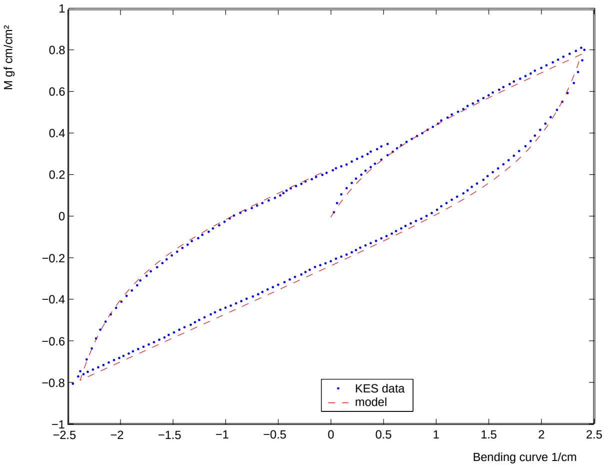
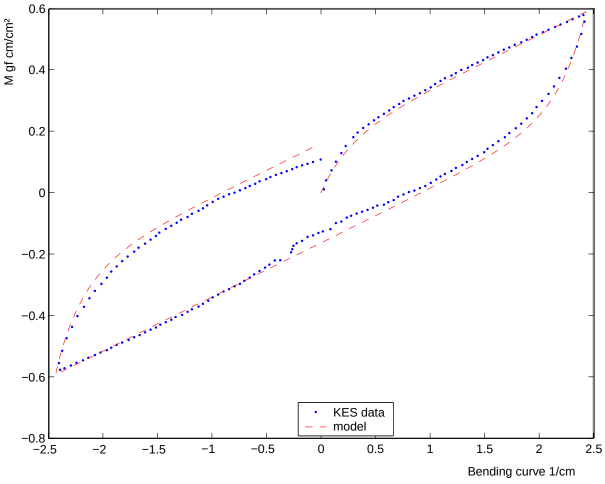


(a) warp



(b) weft

Figure 2: Fabric identification

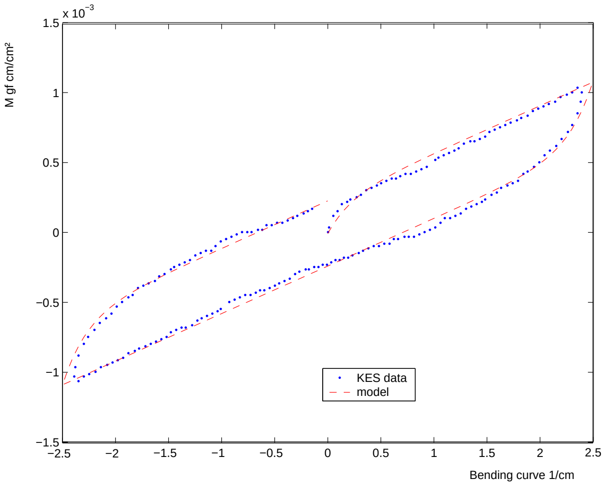


Figure 3: Yarn identification

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