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Simulation of a sheet-handling machine

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Abstract

The many types of public sheet-handling machines must handle sheets (e.g. tickets, sheet of paper) under various conditions at high speed. It is therefore necessary to understand the sheet's behavior in order to avoid problems associated with handling it. This paper develops a nonlinear simulation that determines the behavior of a sheet handled in a machine. The simulation is based on a discretized model of the sheet using lumped masses and springs. The simulation results are validated with experimental data from a sheet-handling machine fed with various types of sheets. The experimental results agree well with simulation, showing that this method is useful and practical to predict the behavior of flexible sheets handling in a feeding machine.

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Keywords: Sheet-handling; Nonlinear dynamics; Simulation; Validation

1. Introduction

Paper sheet-handling systems must be able to process thousands of tickets, paper and copies with stable operation, i.e. no jams. There are also many kinds of automatic public machines, which feature sheet feeding, such as a mail sorting machine, an automatic ticket gate. These machines require higher reliability than commercial or personal equipment because the public expects to use them without jamming and, if jamming occurs, service personnel may not be readily available to fix the problem. These machines handle a variety of media in different conditions at high speed. A good understanding of the behavior of sheets being fed through a machine can lead to improved design and performance of sheet-handling machines.

Previous researchers have studied this problem. Love [1] developed general models of flexible beams. Adams and Benson [2] treated the postbuckling of an elastic plate quasi-statically. Soong [3] solved a nonlinear problem with a thin beam in a holder. Wang [4] considered buckling of a flat-lying heavy sheet. Benson [5] studied the quasi-static motion of an elastic ring in a frictional channel using nonlinear theory. Mansfield and

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Simmonds [6] considered the nonlinear equation of an elastica emerging horizontally from a channel at constant velocity. Stolte and Benson [7] generalized this problem to variable transport velocity and emerging at arbitrary angle. They also developed this approach to account for the constraint of a guide [8]. Nishigaito et al. [9] analyzed statically the deflection of a sheet by using finite-element method. Yoshida et al. [10] obtained a static method of a predicting paper sticking and jamming using curling deformation of a sheet moving in the paper path based on a spring–beam–mass model. Cho et al. [11] presented multi-rigid body dynamic method for media transport system. Yoshida [12] derived dynamic method based on discretized spring–mass–beams and predicted behavior of sheet-stacking. Wu and Kaneko [13] introduced an analytical method for the analysis of sheet flutter as an expansion of the Yoshida's method. Uraoka and Rahn [14,15] developed an experimentally validated simulation that predicted the response of a uniform sheet.

In this paper, we develop a simulation of distorted sheets handled in a feeding machine. In particular, we focus on the behavior of sheets after they emerge from between two rollers and enter a converging guide. This paper describes sheet phenomenon such as jam and stall through simulation and experimentation. The sheet is discretized using a lumped mass and spring approximation. A nonlinear simulation with guide contact predicts jam and stall. The analytical results are tested on an experimental sheet feeding machine to validate the method. In our simulations and experiments, rectangular sheets are fed into the machine without skew and pass straight through the machine. The motion or vibration of the sheet in the depth (y) direction is assumed to be much smaller than the behavior in other (x or z) directions. We assume that there is no change in the sheet dimensions in y direction. Then, in order to simplify the problem, we consider that the sheet moves only in the x–z plane.

2. Equations of motion

2.1. Derivation

In this section, we derive the equations of motion for sheet-handling. Fig. 1 shows the sheet model. Fig. 1a is the sheet geometry and b is the discretized model. As shown in Fig. 1b, the modeled sheet is discretized using n beams, $n + 1$ masses and $n - 1$ springs. For simplicity, we neglect the viscoelasticity of the sheet and do not include dampers in the model. Viscoelastic effects are assumed to be small relative to air drag. The model parameters l_0, w and d are the overall length, width and thickness of the sheet, respectively. The modeled sheet consists of $n + 1$ masses and $n - 1$ springs. The sheet is assumed to move in a x–z plane with gravity acting in the $-z$ direction, and x_{n+1} and z_{n+1} are the coordinates of the endmost mass. In addition, the sheet is assumed to have initial curvature in the unstressed state.

Fig. 2 shows a close-up image of some elements of the sheet. Fig. 2a shows the initial curvature angles ϕ_{0i} before loading. These angles describe the original shape or curvature of the sheet. Fig. 2b describes the elements after loading.

The parameters l_i and ϕ_i indicate the length and the bending angle to the x-axis of the ith element. Here, m_i, and k_i are the mass and the spring constant, respectively, expressed as follows:

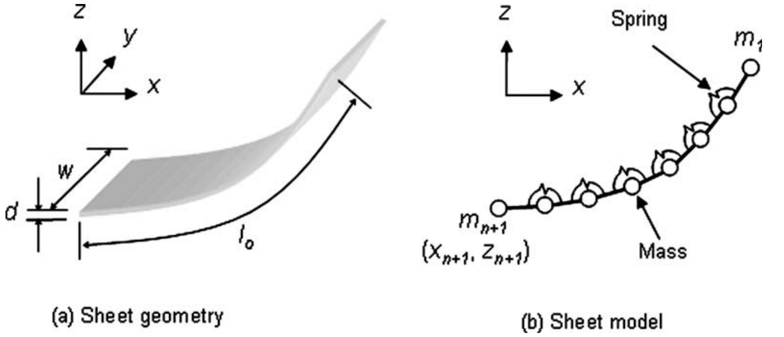

Fig. 1. Sheet modeling.