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Transverse Vibration of Papermaking Felt

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Abstract
The papermaking felt of high-speed papermaking machine vibrates seriously in a transverse direction. In this study, the transverse vibration of papermaking felt was analysed mechanically with respect to flexural rigidity, and a model was developed. The analytical resolution is obtained by the separation variable method. The result shows that it is a sinusoidal steady-state response. The natural frequency is calculated by the principle of free vibration. The flexural rigidity and density of papermaking felt are the main factors influencing its natural frequency. The validity of the model is verified theoretically and experimentally. The amplitude of the transverse vibration was tested by an optical non-contact measuring system. The amplitude-frequency characteristic curve shows that the natural frequency measured agrees well with the theoretical one.

Key words: *papermaking felt, flexural rigidity, transverse vibration, natural frequency, PSD.*

Introduction

Papermaking felt is used for the conveyor belt and filtration belt in the press section of a papermaking machine. The transverse vibration of papermaking felt increases steeply during high-speed operation, which will interrupt production and even damage the machinery. Nowadays, growing attention is focused on the operational stability of papermaking felt.

The transverse vibration of papermaking felt is closely related to its characteristics and mechanical devices. Moreover, it is similar to the vibration of general textiles. Gligorijevic [1] studied yarn oscillation in warp knitting. The free oscillatory frequencies of yarns are related to the length of yarn sections and the tensioning force. Aubry et al [2] investigated the vibrating characteristics of textile surfaces under uniaxial tension. However, they did not consider the properties of yarn or fabric in their analysis. Matsudaira [3] discussed the bending vibration characteristics of fabrics and new mechanical parameters which represent this character. The study evaluated the wearing characteristics of fabrics, not operational stability. Papermaking felt is a special kind of fabric, different from yarn and general fabric. As regards paper machines and paper technology, more attention should be paid to the design of papermaking felt [4]. Papermaking felt is actually a mass-spring system [5]. Resonance can be avoided by designing the structure of papermaking felt [5 - 7]. It is also a damp material that reduces the amplitude of vibration and even attenuates the vibration to zero. However, the natural frequency of papermaking felt changes during its service life. The flexural rigidity of the papermaking felt used decreases due to severe wear [8], as a result of which the natural frequency of the papermaking felt decreases and gradually becomes closer to the natural frequency of the papermaking machine. The natural frequency of papermaking felt is considered in the designing of Tamfelt [9]. However, the designing and manufacturing of papermaking felt mainly depend on experience.

The transverse vibration of papermaking felt is studied mechanically in this paper. An identified model is used to simulate the transverse vibration of papermaking felt, in which the flexural rigidity is considered. The experiment designed verifies that the model is reliable.

Theoretical analysis of the papermaking felt system

Modelling of papermaking felt

The structure of the press section of a papermaking machine is shown in ***Figure 1***. In order to analyse the transverse vibration of papermaking felt, the section

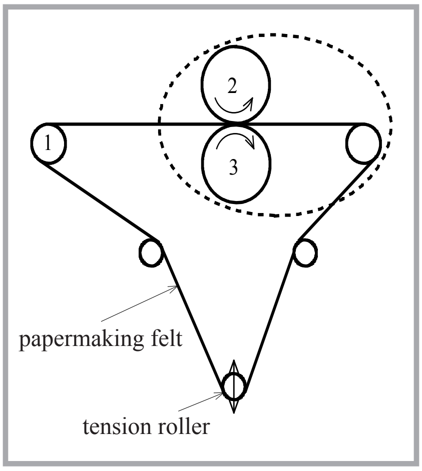

Figure 1. *Diagram of press section.*

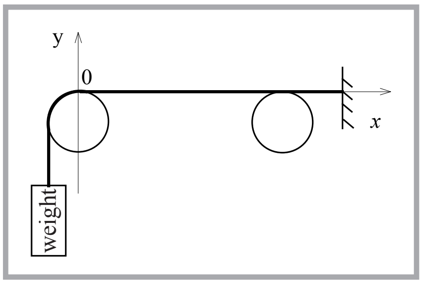

Figure 2. *Sketch map of system.*

designated as a broken circle is simplified as a sketch map in ***Figure 2***.

Under uniaxial tension, the transverse vibration of papermaking felt is something like that of string. Papermaking felt has a unique base cloth, which makes its flexural rigidity greater than general fabrics. Therefore, the transverse vibration of papermaking felt is similar to that of a Euler beam.

Equation of motion

The governing differential equation of motion is given using Newton's second law, which is a combination of the string [10] and beam models [11].

$$T\frac{\partial^2 y}{\partial x^2} - EI\frac{\partial^4 y}{\partial x^4} - m\frac{d^2 y}{dt^2} = 0 \qquad (1)$$

where:

m – linear density of the sample in kg/m,
T – tensioning force in N,
EI – flexural rigidity of the felt sample in N·m^2.

The boundary conditions are as follows:

$$y(0,t) = 0,\ y''(0,t) = 0, \qquad (2)$$
$$y(l,t) = Ae^{j\omega t},\ y''(l,t) = 0$$

The separation variable method is used to solve Equation 1. Supposing $y = e^{j\mu x} e^{j\omega t}$, where μ is the wave number, and ω the angular frequency, the equation of motion can be obtained as follows:

$$y\ y = \Big(a\cosh\left(\sqrt{|p_2|}x\right) + b\sinh\left(\sqrt{|p_2|}x\right) + c\cos\left(\sqrt{p_1}x\right) + d\sin\left(\sqrt{p_1}x\right)\Big)e^{j\omega t} \qquad (3)$$

where

$$p_1 = \frac{-T + \sqrt{T^2 + 4m\omega^2 EI}}{2EI},$$

$$p_2 = \frac{-T - \sqrt{T^2 + 4m\omega^2 EI}}{2EI}$$

Substituting the boundary condition in Equation 2 into the equation of motion in Equation 3 to obtain the integration constant, the equation of motion becomes

$$y = \frac{A}{\left(p_1 + |p_2|\right)}\left(\frac{p_1\sinh\left(\sqrt{|p_2|}x\right)}{\sinh\left(\sqrt{|p_2|}l\right)} + \frac{|p_2|\sin\left(\sqrt{p_1}x\right)}{\sin\left(\sqrt{p_1}l\right)}\right)e^{j\omega t} \qquad (4)$$

The equation of motion in Equation 4 is of a standard wave form, which means that the behaviour of every point on the papermaking felt is simple harmonic vibration.

Natural frequency

Substituting the free boundary condition into Equation 3, we get Equation 5.

In order to obtain a non-zero solution of Equation 5, the determinant of the equation system should be zero. That is $\sin\left(\sqrt{p_1}l\right) = 0$.

The natural frequency of the papermaking felt is

$$f = \frac{n}{2l}\sqrt{\frac{EI}{m}\left(\frac{n\pi}{l}\right)^2 + \frac{T}{m}} \qquad (6)$$

where l - the length of the sample in m.

From Equation 6 we can see that the natural frequency of papermaking felt is related to the tension T, flexural rigidity EI, linear density m and the length l. For the papermaking machine, the tension T and length l are invariable. Therefore, the flexural rigidity EI and linear density m of papermaking felt are the main factors influencing its natural frequency. The structure of papermaking felt is a key parameter determining the flexural rigid-

$$\begin{cases} a + c = 0 \\ a|p_2| - cp_1 = 0 \\ a\cosh\left(\sqrt{|p_2|}l\right) + b\sinh\left(\sqrt{|p_2|}l\right) + c\cos\left(\sqrt{p_1}l\right) + d\sin\left(\sqrt{p_1}l\right) = 0 \\ a|p_2|\cosh\left(\sqrt{|p_2|}l\right) + b|p_2|\sqrt{|p_2|}\cosh\left(\sqrt{|p_2|}l\right) - cp_1\cos\left(\sqrt{p_1}l\right) - dp_1\cos\left(\sqrt{p_1}l\right) = 0 \end{cases} \qquad (5)$$

Equation 5.

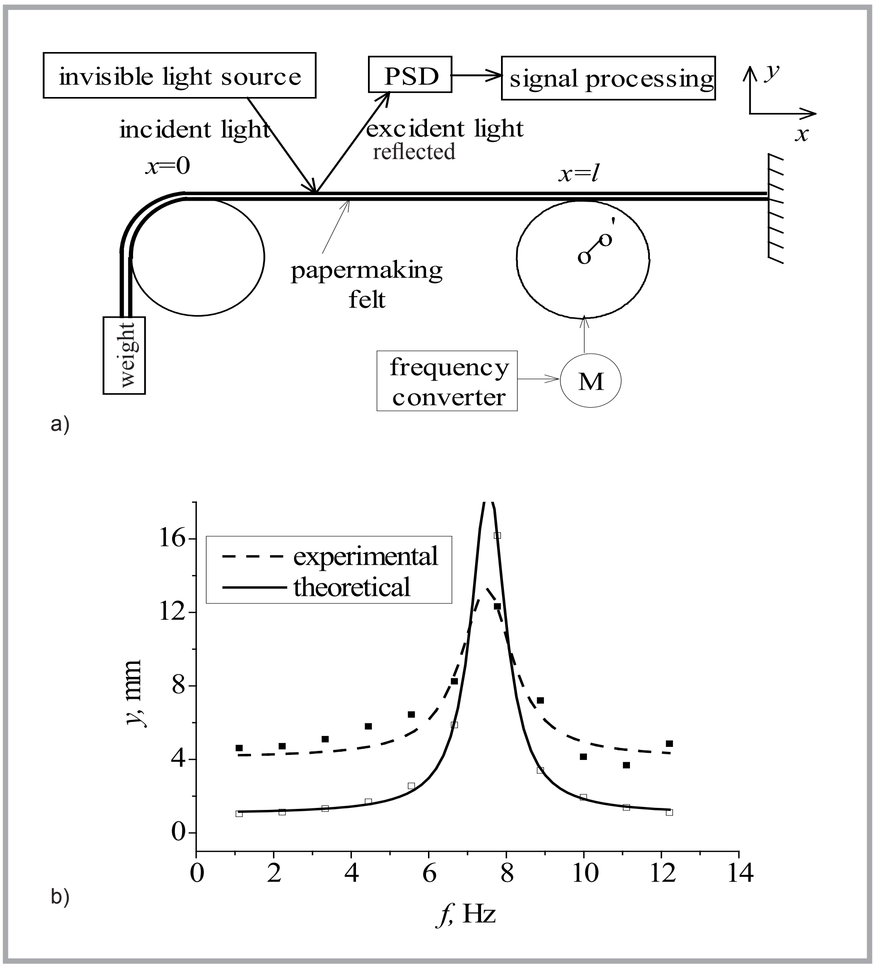

Figure 3. *Diagram of experiment (a).and frequency domain curve (b).*

Table 1. Parameters of the sample.

Area density, kg/m2	Sample breadth, m	Test point, m	Flexural rigidity, N·m2	Tensioning force, N
1.5	0.04	0.95	1.8×10-3	19.8

ity *EI*. Structure type and density design are the main aspects of papermaking felt. As long as the natural frequency of the papermaking felt is far from the running frequency of the contacting rollers, serious transverse vibration can be avoided.

Natural frequency (*EI* << *T*)

$$p_{1,2} = -\frac{T}{2EI} \pm \sqrt{\left(\frac{T}{2EI}\right)^2 + \frac{m\omega^2}{EI}} = \frac{T}{2EI}\left(\pm\sqrt{1+\frac{4m\omega^2 EI}{T^2}} - 1\right) \quad (7)$$

If $m\omega^2 << (T/2EI)^2$, that is $EI << T^2/4m\omega^2$, using the progression expansion, we can obtain

$$\sqrt{1+\frac{4m\omega^2 EI}{T^2}} - 1 \approx 1 + \frac{2m\omega^2 EI}{T^2} + -\frac{1}{2\cdot 4}\left(\frac{4m\omega^2 EI}{T^2}\right)^2$$

Hence

$$p_1 = \frac{m\omega^2}{T}, \ |p_2| = \frac{T}{EI} + \frac{m\omega^2}{T} \quad (8)$$

Substituting Equation 8 and free boundary conditions into Equation 3, $f_0 = \frac{n}{2l}\sqrt{\frac{T}{m}}$ is obtained, which is the same as the natural frequency of classical string [10].

Experiment

Experiment setup

The amplitude of transverse vibration was tested by an optical non-contact measuring system [12, 13]. A schematic of the system is shown in ***Figure 3.a*** (see page 107). The distance between the two rolls is 1.18 m. The driven roll on the right in ***Figure 3.a*** has a 2 mm eccentricity.

An invisible light emitted by a XIP-113 laser diode power supply is the incident light shining on the sample. A PSD (Positioned Sensitive Detector) [14] collects the reflected light and transforms the light signals into electrical ones, which are processed by a LabVIEW program, and the amplitude is obtained. The excitation frequency is varied by tuning the frequency converter. The behaviour of the stationary amplitude of vibration in correspondence with the measurement point versus the excitation frequency, in the neighborhood of the first natural frequency, is shown.

Material

The sample was conventional laminated papermaking felt. The weave of the upper and lower base cloths was 1/3 twill. The warp yarn was of four plies and the weft six. The warp density was 200/10 cm. Other parameters of the sample are listed in ***Table 1***.

Experiment results

Frequency domain curves are obtained by Lorentz fitting to the experimental and corresponding theoretical data shown in ***Figure 3.b*** (see page 107). According to the fitting curves, one can estimate the value of the natural frequency of papermaking felt.

From ***Figure 3.b*** (see page 107) we can see the experimental natural frequency is close to the theoretical one, which means that the equation of motion can correctly describe the transverse vibration of papermaking felt.

Conclusions

Papermaking felt plays an important role in paper machines. The transverse vibration of papermaking felt running at high speed is complex, which is affected by its own properties and the mechanical device.

In this study, the transverse vibration of papermaking felt was analysed mechanically. Under uniaxial tension and with its unique base cloth structure, the mixture model of string and beam can correctly characterise the transverse vibration of papermaking felt.

The transverse vibration of papermaking felt was tested by an optic non-contact measurement system, the result of which shows that the experimental natural frequency is close to the theoretical natural frequency.

The natural frequency of papermaking felt can be designed by adjusting its structure and density. If its natural frequency is far from the running frequency of the contacting rollers, serious transverse vibration can be avoided.

References

1. *Gligorijevic V., Djordjevic M., Cirkovic N., et al. Yarn Tension and Oscillation in the Process of Warp Knitting. Fibres & Textiles in Eastern Europe. 2003, 11(1), pp. 25-27.*
2. *Aubry E., Postle R., Renner M.. Vibration Properties of Textile Surfaces. Textiles Research Journal. 1999, 69(5), pp. 335-338.*
3. *Matsudaira M., Zhang R. Damping Property of Fabric Bending Vibration. Journal of the Textile Machinery Society of Japan (English edition). 1996, 49, T324-332.*
4. *Zhou R. M. Real-time Spectrum Analysis of Press Section. Light Industry Machinery. 1992, (1), pp. 59-67.*
5. *Parker J. R. Aspects of Wet-press Vibration and Its Control. Paper Technology and Industry. 1980, 21(5), pp. 162-166.*
6. *Floyd R. S. Suppressing Press Vibration. Pulp and Paper Canada. 1986, 87(6), pp. 132-136.*
7. *Marcel D. Papermakers Wet Felts, United States Patent 4,883,097, 1989*
8. *Shorp B. A. Paper Machine Operations. Atlanta (third edition): TAPPI Press, 1991, p. 601.*
9. *Lehto J. Press felts for the Optimum Press Section Performance. Paper Technology. 2003, 44(3), 40-48.*
10. *Sack R. A. Transverse Oscillations in Traveling Strings. British Journal of Applied Physics. 1954, 5, pp. 224–226.*
11. *Mead D. J. Waves and Modes in Finite Beams: Application of the Phase-Closure Principle. Journal of Sound and Vibration. 1994, 171(5), pp. 695-702.*
12. *Noon J., Wichert J. A. Non-linear Vibration of Power Transmission Belts. Journal of Sound and Vibration. 1997, 200(4), pp. 419-431.*
13. *Pellicano F., Fregolent A., Bertuzzi A., et al. Primary and Parametric Non-linear Resonances of a Power Transmission Belt: Experimental and Theoretical Analysis. Journal of Sound and Vibration. 2001, 244(4), pp. 669-684.*
14. *Makynen A. J., Kostamovaara J. T., Myllyla R. A. A High-Resolution Lateral Displacement Sensing Method Using Active Illumination of a Cooperative Target and a Focused Four-Quadrant Position-Sensitive Detector. IEEE Transactions on Instrumentation and Measurement. 1995, 44(1), pp. 46-52.*

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