Web Flutter Measurement Sensor

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***Abstract*—A novel sensor to measure web flutter is proposed in this letter. The sensing principle is based on scattering of light and directionally sensitive coupling properties of optical fibers. A linear array of optical fibers, oriented appropriately, is used to collect light scattered from a web. The flutter amplitude is determined by observing the amount of light transmitted by the fibers in the fiber array. Experiments were conducted to demonstrate the ability of the proposed sensing strategy in measuring web flutter with different kinds of web material.**

***Index Terms*—Fiber-optic sensor, material processing, web flutter, web handling.**

I. INTRODUCTION

THE TERM web is used to describe materials that are manufactured in a continuous, flexible strip form. The continuous web material is transported on rollers to different sections of the processing machinery where the required operations are carried out. Since continuous roll-to-roll manufacture of products is more efficient than batch processing, many materials such as plastic, paper, textiles, metals, films, etc., are generally manufactured in rolled form.

During transport on rollers, the web may move in three different directions—longitudinal, lateral, and transverse (see Fig. 1). This letter describes a sensor to measure the transverse motion of the web, which is also called web flutter. The mechanism of web flutter in process lines is complex and is believed to be caused by a combination of various operating conditions such as web transport velocity, web tension, air flow around the web, and material properties [1], [2]. It is known that web flutter can cause web breaks and/or wrinkles. Therefore, it is necessary to monitor web flutter and minimize it through some corrective control mechanisms.

A few sensors for monitoring web flutter have been reported in the literature. In [2], instruments such as a stroboscope, laser vibrometer, etc., were used for flutter measurement; due to their use in many broad applications, they often have expensive signal processing equipment. A vision-based system was proposed in [3]; the method is computationally complicated and may be limited by the ability of the camera to acquire quality images. One can also find several sensors in the patent literature to measure web flutter [4]–[7]. In [4], flutter amplitude is measured based on angle of reflection of light from the web surface. Web flutter is determined by measuring the time required for the incident light beam to strike the web and return to the receiver in [5]. In [6], the change in air pressure around the web is used to determine the amount of web flutter. Infrared proximity sensors to measure flutter are reported in [7]. All the existing sensors and sensing methods exhibit some common limitations such as: 1) ambient light issues; 2) problems with change in opacity of web material; 3) presence of dust and harsh environmental conditions may affect their performance; and 4) change in air pressure created by blowing air around the drying section. Further, these sensors need frequent calibration as none of them provide direct measurement of web flutter. A new sensor that provides direct flutter measurement and overcomes many of the limitations of the existing sensors is proposed in this letter.

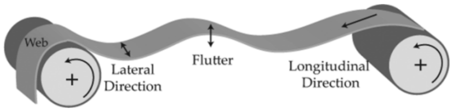

Fig. 1. Machine direction flutter during web transport.

II. WORKING PRINCIPLE

The basic working principle of the sensor is the same as the one presented in [8]. For the sake of brevity, the specific details necessary to understand the working principle of the sensor to measure flutter is described in this section; the readers are encouraged to refer to [8] for a detailed description of the basic working principle. A collimated laser source is incident on the web edge, as shown in Fig. 2. A fiber array is positioned such that the light scattered from the web edge is incident on the array. The orientation of the fiber array is such that its length is parallel to the direction of flutter. Based on the numerical aperture of the fibers, only one or a few fibers in the array transmit the scattered light incident on the fiber array. Specifically, those fibers in the array which are directly in line (see Fig. 2) with the web edge will transmit light, while the rest of the fibers do not. As the web flutters, the point of scattering changes and thereby a different fiber in the array transmits the scattered light. Therefore, web flutter is measured by tracking the fiber that transmits scattered light. Light transmitted by the fiber array is processed in real-time using a linear pixel array, where each fiber is terminated onto a pixel.

The working principle of the sensor has several advantages. The measurement is direct, linear, and is unaffected by the properties of the web material. The sensing technique is simple and does not require complex signal processing algorithms. Once the sensor is installed it does not require recalibration. Since optical fibers are used, signal processing can be performed away from the measurement area. Therefore, the sensor can be used in high temperature and high humidity conditions.

III. EXPERIMENTAL RESULTS

The fiber-optic sensor was installed on an experimental web platform (see Fig. 3) to evaluate the sensor performance. The linear fiber array consists of 64 multimode fibers having a pitch

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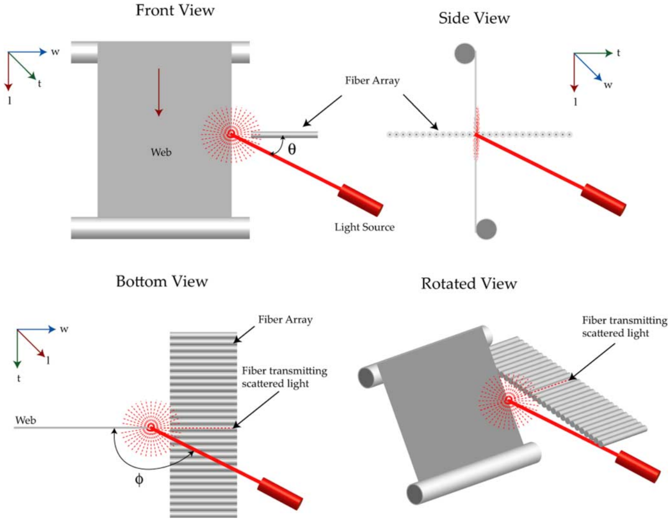

Fig. 2. Illustration showing the position, orientation of the fiber array and the light source in order to measure web flutter. Axes notation: l—longitudinal; w—lateral; t—transverse.

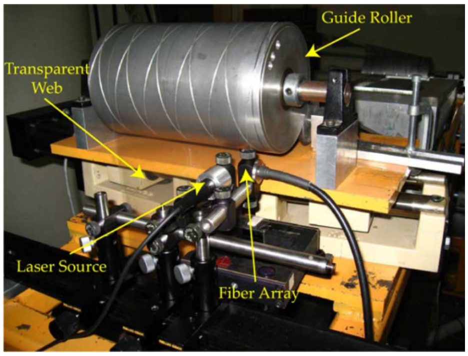

Fig. 3. Fiber-optic sensor installed downstream of a guide mechanism; incident source orientation, as shown in Fig. 2, is $\theta = 0$ and $\phi = 90^\circ$.

of 125 μm. Hence, the resolution of the sensor is 125 μm and the sensing range is 8 mm. The specifications for the light source are as follows: 40 mW laser diode, 830 nm wavelength, and 10×5 mm collimated rectangular beam. The scattered light is directly coupled into the fiber array without using any lens; the intensity at the fiber depends on the physical and geometric properties of the web; adequate amount of scattered light was coupled into the fibers using this light source for various tested web materials. Experiments were conducted with different web materials and transport velocities. The web was excited by attaching a small insert on one side of the guide roller; as the web goes over the insert on the guide roller, the insert excites transverse vibrations.

A representative sample of the experimental data from the fiber-optic sensor is shown in Fig. 4. The vertical axis shows the amplitude of flutter (the complete sensing range of the sensor is shown) and the horizontal shows time in seconds. The top plot in Fig. 4 shows the output of the fiber-optic sensor when the web is not excited; the bottom three plots show the output with excitation. The middle two plots shows the output with an opaque web transported at 0.305 m/s (60 fpm), whereas the bottom plot shows the output when a transparent web is transported at 0.508 m/s (100 fpm). Experiments reveal that the sensor is capable of measuring web flutter of different amplitudes, frequencies and with materials having different optical and mechanical properties.

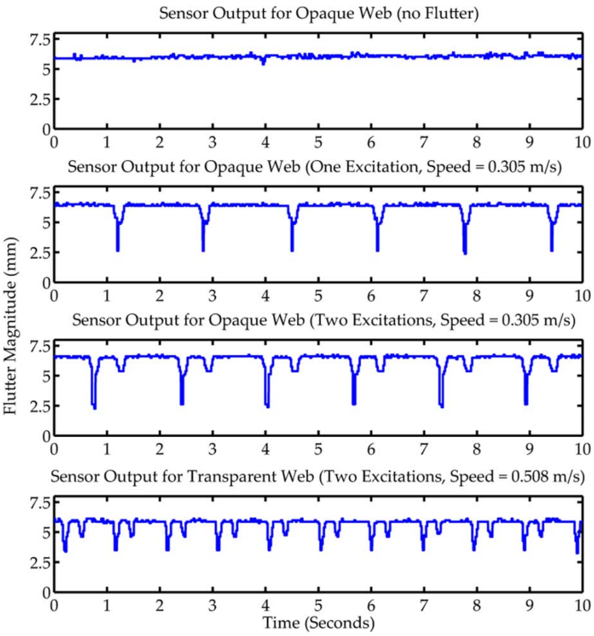

Fig. 4. Experimental results.

IV. Conclusion

The fiber-optic sensor proposed in this letter to measure web flutter utilizes a novel sensing strategy that overcomes some of the common limitations of the existing sensors. The working principle of the sensor is simple and requires uncomplicated signal processing to measure the amplitude of web flutter.

The proposed flutter sensor and the lateral sensor reported in [8] can be constructed as one unit with a single light source to provide 2-D visualization of web edge position. With dedicated DSP chips the sensor can be readily extended to provide real-time frequency measurement of flutter. Traveling waves are usually observed when web flutters [1], [2]. Although it may not be likely in many situations and has not been reported in the literature, it is possible that a standing wave may result in the lateral direction for a moving web; further research is required to study the measurement of such a standing wave with the proposed sensor.

References

[1] Y. Watanabe, S. Suzuki, M. Sugihara, and Y. Sueoka, "An experimental study of paper flutter," *J. Fluids Structures*, vol. 16, no. 4, pp. 529–542, May 2002.

[2] Y. B. Chang and P. M. Moretti, "Flow-induced vibration of free edges of thin films," *J. Fluids Structures*, vol. 16, no. 7, pp. 989–1008, Oct. 2002.

[3] C. Doignon and D. Knittel, "A structured light vision system for out-of-plane vibration frequencies location of a moving web," *Mach. Vision Appl.*, vol. 16, no. 5, pp. 289–297, Dec. 2005.

[4] H. A. Wells, "Method of paper tension control to maintain flutter within a predetermined range," U.S. Patent 4,501,642, 1985.

[5] R. Ahola and R. Myllyla, "Procedure for analyzing reciprocating motion," U.S. Patent 4,637,727, 1987.

[6] D. D. Nguyen, "Apparatus for determining amplitude and frequency of web flutter," U.S. Patent 4,968,386, 1990.

[7] D. D. Nguyen, "Method and apparatus for detecting amplitude and frequency of web flutter using infrared optical sensor," U.S. Patent 5,073,714, 1991.

[8] A. Seshadri and P. R. Pagilla, "Design and development of a new edge sensor for web guiding," *IEEE Sensors J.*, vol. 7, pp. 698–706, May 2007.

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