Sliver Thickness Monitoring by Ultrasonic Method

A K DATTA
Department of Applied Physics, Calcutta University, 92 Acharya Prafulla Chandra Road, Calcutta 700009, India
and
P SENGUPTA
Jute Technological Research Laboratories, 12 Regent Park, Calcutta 700040, India

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An on-line system for measuring the thickness variations in jute sliver coming out of a carding machine has been described. The system uses an ultrasonic transmitter-receiver matched pair for sensing the vertical displacement of delivery roller through which the jute sliver is passing. This, when calibrated, gives a measure of the thickness variation in sliver. Since the sensing is of non-contact type, the transducer maintenance is minimum. The details of electronic circuitry and test results are given.

Keywords: Displacement transducer, Sliver thickness monitoring, Ultrasonic technique

1 Introduction

In the breaker card the softened raw jute in the form of reeds is manually fed at a predetermined rate. The irregular feeding of jute due to human factors introduces variations in the thickness of the output sliver. To control the feed and hence the mass per unit length or thickness of sliver, on-line detection of sliver thickness is necessary. There are several methods for the detection of thickness variations in sliver. Much used capacitive gauging gives direct electrical signal; however, the method gives erroneous result when the moisture content of the sliver varies randomly. Optical and nuclear gauging and ultrasonic absorption techniques are susceptible to contamination and therefore the accuracy depends mainly on the surface cleanliness of the sensing head. Mechanical tongue and groove arrangement of thickness gauging, though popular, can only be used for sensing at low speed.

The displacement of delivery roller when measured by a linearly variable differential transformer (LVDT) gives a measure of thickness; however, it is susceptible to high wear and tear. This paper describes an on-line system for measuring the thickness variations in jute sliver coming out of a carding machine. The method utilizes the interference of ultrasonic waves reflected from the dancing delivery roller to record the displacement of the top roller due to the variations in sliver thickness. Hence the limitations of the earlier absorption methods, either by ultrasonic, optical or nuclear, are avoided with the resultant increase in the speed of sensing.

2 Principle of Operation

The top delivery roller of jute breaker dances vertically due to the variations in the thickness of the jute sliver passing through. The vertical displacement is sensed by the change in the amplitude of the stationary wave formed by the interference of direct and reflected ultrasonic waves. The ultrasonic transmitter, generating an ultrasonic wave of velocity \(c\) and wavelength \(\lambda\), is placed at a suitable height \(h\) above the dancing delivery roller (Fig. 1). As the ultrasonic field is symmetric with respect to the roller surface, there is a reflection from the surface of the delivery roller which interferes with the direct beam. We may replace the effect of boundary plane by an image source symmetrically placed with respect to boundary plane at \(T'\), with both source and the image radiating in-

![Fig. 1—Schematic diagram of ultrasonic reflection](image-url)
to the unbounded space. The ultrasonic receiver placed at height \( h_r \) receives both the direct and reflected wave and gives the corresponding resultant voltage output.

The resultant ultrasonic field \((U)\) received by the receiver is given by

\[
U = \frac{U_d \cos [2 \pi (l_1 - ct) / \lambda]}{l_1} + \frac{U_r \cos [\pi + 2 \pi (l_2 - ct) / \lambda]}{l_2}
\]

where \( U \) is the resultant ultrasonic field intensity; \( U_d \), the free space ultrasonic field intensity at a unit distance in the direction of direct beam path; \( U_r \), the free space ultrasonic field intensity at a unit distance in the reflected beam path; and \( l_1 \) and \( l_2 \), the total lengths of direct and reflected paths respectively. The phase term \( \pi \) in the reflected beam path allows the phase reversal on reflection at the roller surface. \( U \) may now be simplified as

\[
U = \frac{U_d}{l_1} \left[ \cos \left( 2 \pi \left( \frac{l_1 + l_2}{2} - \frac{l_2 - l_1}{2} - ct \right) / \lambda \right) \right]
\]

\[
- \frac{U_r}{U_d l_2} \cos \left( 2 \pi \left( \frac{l_1 + l_2}{2} + \frac{l_2 - l_1}{2} - ct \right) / \lambda \right)
\]

\[
\ldots (1)
\]

If \( r \), the separation between the transmitter and receiver across the roller surface, is large compared to the displacement, we may write \( l_1 = l_2 \) and the path difference \( l_2 - l_1 = 2h_1 \sin \theta \). Under this condition, the amplitude of direct and reflected ultrasonic beam is nearly equal, \( U_d = U_r \).

Therefore, Eq. (2) is written as:

\[
U = \frac{U_d}{l_1} \sin \left( 2 \pi \left( \frac{l_1 + l_2}{2} - ct \right) / \lambda \right)
\]

\[
\times 2 \sin \frac{2 \pi h_1 \sin \theta}{\lambda}
\]

\[
\ldots (2)
\]

The expected ultrasonic field intensity \((U_e)\) in the absence of the reflecting surface, i.e. the top of delivery roller, would be given by the magnitude of the first term of Eq. (2). Thus, the ratio \( R(\theta) \) of the field intensity to be expected at the receiver in presence of reflecting surface, i.e. the dancing roller, to the expected free space ultrasonic field intensity may be written as:

\[
R(\theta) = \frac{|U|}{|U_e|} = 2 \sin \left[ \frac{2 \pi h_1 \sin \theta}{\lambda} \right]
\]

\[
\ldots (4)
\]

\( R(\theta) \) oscillates between 0 and 2 as the \( \theta \) is increased. Since \( \sin \theta = (h_r / r) \), the actual height is increased at a fixed distance. Therefore,

\[
\frac{2 \pi h_1}{\lambda} \sin \theta = \frac{n \pi}{2}
\]

\[
\text{If } \frac{2 \pi h_1}{\lambda} \sin \theta = \frac{n \pi}{2}
\]

\[
R(\theta) = 0 \text{ for } n \text{ even}
\]

\[
= 2 \text{ for } n \text{ odd}
\]

\[
\ldots (5)
\]

The first null, i.e. \( R(\theta) = 0 \), corresponds at \( \theta = 0 \) (i.e. on the roller surface itself). To get an increase in the generated voltage at the ultrasonic receiver with the increase in thickness, some initial conditions have to be met. It is observed that an increase in sliver thickness will reduce \( h_r \), the effective height of the transmitter from the roller surface. That is, if the jute sliver of thickness \( x \) is passed through the delivery roller, then \( h_r \) may be replaced by \((h_r - x)\) in Eq. (4) To get zero voltage reading, when no sliver is delivered out, i.e. \( x = 0 \), \( n \) must be even. We may now write

\[
R(\theta) = 2 \sin \left[ \frac{2 \pi (h_r - x) \sin \theta}{\lambda} \right]
\]

\[
\ldots (6)
\]

Putting \( \frac{2 \pi h_1}{\lambda} \sin \theta / \lambda = \pi \), which occurs when \( n \) is equal to 2, Eq. (6) becomes

\[
R(\theta) = 2 \sin \left( \frac{2 \pi x}{h_r} \right)
\]

\[
\text{since } x \leq h_r \]

\[
\ldots (7)
\]

It may be noted that the voltage is proportionally generated at the ultrasonic receiver due to the variation in ultrasonic field intensity. The constant of proportionality depends on the piezoelectric deformation constant of the material used in the transducer. Since the ultrasonic pressure varies to the square of field intensity, we may write

\[
V(\theta) = (K[R(\theta)]^2)^{1/2}
\]

where \( K \) is the constant and \( V(\theta) \) is the ratio of the expected voltage generated at the ultrasonic receiver, when the roller surface is present, to the expected free space receiver voltage. Therefore,

\[
V(\theta) = 4K \left( \frac{\pi}{h_r} \right)^{1/2} x^{1/2} = K' x
\]

\[
\ldots (9)
\]

The constant \( K' \) includes the transmitter height \( h_r \) above the roller when no jute is passing. Therefore, if the receiver voltage is normalized by the
expected free space voltage, we get a measure of thickness variation of sliver directly given in voltage.

3 The Developed System

The block diagram of the ultrasonic sensing system consisting of ultrasonic transmitter, receiver and its associated electronics for exciting transmitter and decoding receiver signal is shown in Fig. 2. The pulse generator (Fig. 3a) produces rectangular pulse of a repetition rate of about 35 kHz, which is fed to the ultrasonic transmitter having a resonance frequency of $34 \pm 2$ kHz and antiresonance frequency of $37 \pm 2$ kHz. The receiver converts the received ultrasonic field intensity to a voltage at its terminals, which is amplified by a two-stage ac amplifier. The output of the amplifier is rectified, filtered and is again dc amplified for either recording in a dc voltmeter or in a strip chart recorder. The receiver circuit is shown in Fig. 3b.

4 Results and Discussion

The ultrasonic sensor for monitoring the thickness of the jute sliver has been tested by displacing the top delivering roller by the calibrated thickness gauges. The curve of displacement versus dc voltage is given in Fig. 4. The curve is almost linear up to a displacement of 2 mm with a resolution of 0.1 mm. A better resolution can be achieved if the gain of the dc amplifier is increased. Fig. 5 shows a representative strip chart recorder output under dynamic condition on running sliver coming out of the breakeer card.

It is observed that when jute sliver is compressed between a pair of rollers, the cross-section is likely to become oblong with ill-defined free edges. Under this condition the vertical movement of the top roller is unlikely to be strictly proportional to the gravimetric fineness of the sliver per unit length. However, the error introduced is small compared with the total likely displacement particularly during dynamic (running) condition. Therefore, the suitability of the proposed system is claimed particularly when the system performs the function of sensing the mass per unit length under dynamic condition as a part of autoleveller.

During the experiment it was observed that no
shielding is necessary unless one obstructs the direct or reflected beam path. However, the unevenness of the roller surface may affect the accuracy since a portion of the reflected beam may scatter and may not enter the receiver sensing head. The main attractive feature of the proposed system lies in its ready application for on-line sensing, in non-contact way and the system is not disturbed much due to vibration, dust and moisture in a real mill environment.

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