TENSCAN, AN ACOUSTIC NDE DEVICE TO MEASURE TENSION IN A MOVING PAPER WEB

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INTRODUCTION

In paper mills, the speed of paper web has been increasing all the time and the speeds may be in excess of 120 km/h (60-70 miles/h). High speeds are also needed in slitter-winders to manage the continuous production of paper from the machine despite the roll changes. It is clear that at such speeds the tension of the moving paper has to be known; in particular, the tension profile across the machine direction since the profile may contain tension peaks that break the web even though the average tension may be acceptable.

The tension is usually measured by strain gauges mounted under the bearings of the reels but, first of all, they suffer from big inertia due to the large masses of the reels and secondly, they do not yield the tension profile across the machine direction. The web breakage at full speed is a "major bang" producing considerable economic losses. Evidently, a non-contacting, on-line and non-destructive tension evaluation unit is needed to submit real-time tension information for control. Figure 1 shows the mess created by a web break.

In this paper we describe an acoustic, non-contacting tension evaluation device which measures the tension profile of the moving paper web using membrane waves with an inherent speed compensation feature. The device consists of a measuring head plus a separate, advanced electronic unit which calculates and displays the tension profile on a video monitor by cross-correlation technique. The commercial version of the device is being marketed and installed on paper machines and slitter-winders. The device was first created as an academic exercise which then developed into a series of prototypes which finally led to a high-quality industrial instrument outperforming rivals which use either mechanical force or pressure [1].
MEMBRANE WAVES AND THE MEASUREMENT PRINCIPLE

The Tenscan is based on membrane waves, which are mechanical waves which propagate along a stretched membrane. In acoustic waves the restoring forces are the elastic constants, in membrane waves the restoring forces are the tension forces that stretch the membrane. A foil may be termed a membrane if the thickness of it is much less than the wavelength. A membrane usually does not support itself (as does a plate) unless under tension.

In ideal conditions the phase velocity $c$ of membrane waves in a uniformly and unidirectionally stretched membrane obeys the following simple formula

$$c = \sqrt{\frac{T}{g}}$$

Here $T$ is the applied tension and $g$ the basis weight. Ideally, the elastic properties or bending stiffness do not affect the measurement.

In real measurement conditions the ideal conditions are not met and even air loading has to be taken into account [2]. However, as the phase velocity of the membrane wave is slower than the velocity of sound in air with the tensions occurring in practice, the membrane wave is a trapped wave in the paper and does not actually radiate into surroundings.

Figure 2 displays the measurement method. A loudspeaker with a narrow slit in front of it is placed adjacent to the paper providing a spatially confined sound burst which excites the membrane mechanically at the desired frequency.
range which is about 200-400 Hz. The wave begins to propagate in both directions parallel to the applied tension. To monitor the velocity of the membrane waves two measurement stations "upstream and downstream" are placed sequentially along the path of propagation. In the previous version we used two microphones near the paper to pick up the evanescent acoustic radiation but in the later, improved version we shine a light spot on the web with a small HeNe laser and pick up the displacement of the spot with a position sensitive light detector. In such a way the system is made immune to the surrounding noise of the paper machine.

As the detectors are placed at different, known distances from the source, there is a certain delay between the signals. This delay is easily measured with electronic circuitry using cross-correlation techniques. The speed of the paper itself is not negligible compared with the speed of the membrane wave, so the movement of the paper has to be compensated. It is performed by the two measurement stations at both sides of the generating point. If \( t_1 \) is the propagation time upstream, \( t_2 \) downstream and \( S \) the distance from the slit source, then the tension will simply be

\[
T = gS^2 \left( \frac{t_1 + t_2}{2t_1 t_2} \right)^2
\]

as the velocity of the paper cancels out.

Meriläinen [2] has analyzed the effect of the air loading on the membrane wave. The air load appears as an increase of the mass of the paper per unit area (basis weight). The agreement between the theory and experiments has not been entirely satisfactory and therefore in practice the effect of air loading on each paper quality or membrane material has simply been determined experimentally and the calibration values have been stored as a lookup-table in the

Fig. 2. The measurement principle (pat.).
memory of the accompanying microprocessor based computer. The present instrument has the useful property that it can be tested and calibrated on a special frame where the paper can be hung under suitable weights to simulate various tension values in laboratory as the longitudinal paper velocity can be eliminated.

As is well known, longitudinal wrinkles will appear on paper when it is under tension. This represents another source of error which is somewhat hard to interpret. However, these wrinkles appear also on the laboratory test frame and their effect may be studied. It has turned out that the effect of the wrinkles is much less than expected. In the paper qualities mostly needed in paper making the velocity-to-tension conversion shows only small fluctuations. In actual running conditions these wrinkles appear and disappear seemingly randomly without much effect. Only when the wrinkles move sideways through the measurement stations their motion creates inaccuracies. The tension measurement accuracy has turned out to be better than 2% in laboratory conditions. In actual running conditions the accuracy is about +4%.

THE ACTUAL INSTRUMENT

Tenscan is being manufactured commercially [3]. Several units have been made and installed with a lateral mechanical scanning system so that the across-the-machine tension profile may be measured. Figure 3 shows the unit. Tenscan may be regarded as an on-line, non-destructive evaluation unit which prevents the appearance of wrinkles,

Fig. 3. The Tenscan unit.
Fig. 4. The measured tension profile before and after correction.

calendar cuts, run together in winders, web breaks, poor customer rolls and improves the productivity of printing machines. Figure 4 shows an undesired tension profile which has been adjusted with the help of Tenscan, as shown in the lower picture.

The measurement range of the instrument has turned out to be 20 - 5000 N/m, absolute accuracy ±4%, repeatability ±2%, resolution ±1%, basis weight range 6 - 250 g/m² and the measurement distance from the surface of paper 0.1 - 9 mm.

REFERENCES

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