PFI's WEB TENSILE MACHINE
A USEFUL TOOL FOR EXAMINING STRENGTH PROPERTIES OF PAPER WEB SAMPLES

Åge Hansen, The Norwegian Pulp and Paper Research Institute (PFI)

ABSTRACT

A web tensile machine developed at PFI has proved to be a useful tool for characterizing strength properties of paper web samples. Strength-reducing inhomogenities in the sheet structure are revealed and the resistance of the web to flaws from defects is measured on notched web samples. The web, 1m wide and 1.8 m length at a time, is taken from a small diameter roll sample where the web edges are cut perfectly in a specially made slitter machine. The whole web span is illuminated from behind and the paper structure is well visible. This article describes the machine design, the different stretching modes and the equipment for measuring stretching force, web elongation and width contraction. Examples of such measurements are shown. Results of relevance to the web break tension in printing presses will be presented in separate articles.

Application: Testing large paper web samples to obtain more relevant information on runnability than what is obtained in testing small paper strip samples.

INTRODUCTION

The purpose of making a tensile machine for testing paper webs was to obtain more knowledge about web strength of relevance to runnability in printing presses than can be obtained from conventional tests on narrow paper strips. We had found from earlier tests, when gradually increasing the tension on running webs, both in a rewinder and in a printing press, that it was impossible to reach the web tension corresponding to the tensile strength measured on paper strip samples from the same rolls. The running webs broke at much lower tensions [1]. We wished to make more detailed studies of web samples under high tension, to look at structural inhomogeneities and to measure how they influence the web strength.

That shives are weak points in running newsprint webs was demonstrated already in 1965 by Sears et al.[2] using a roll feed test machine where the 38 cm (15-in.) web was progressively stretched through a series of cylinder nips. Potentially harmful shives in newsprint were also observed by MacMillan et al., also in 1965, using a simple static web strainer where the ends of the 38 cm wide sheet were clamped in two slotted cylinders 76 cm (30 in.) apart [3]. This device was useful to detect shives in the 0.3 m^2 newsprint sheet, but it was not designed for simultaneous stress-strain measurements. Another stretching device, specially designed for measuring the fracture resistance of the paper material, expressed as the energy necessary to propagate a crack, was used by Seth [4] This apparatus had pneumatic clamps capable of holding 18 cm wide specimens.

We wished to combine observations of the sheet structure with stress and strain measurements and to study web breaks under different dynamic conditions. We also wished to quantify the flaw resistance of the web by measuring notched web samples and to fit formulae for the drop in break tension against notch size. Such measurements would be done on webs from roll samples with known and different production parameters, in cooperation with Norwegian paper mills. For this purpose, we designed and built a new web tensile machine capable of stretching 1.8 m^2 web samples.

MACHINE DESIGN

A photograph of the web tensile machine is shown in **Figure 1**. The vertical web span is 1.8 m and the web width is 1.0 m.

Framework and pivoting bars

The machine body (**Figure 2**) is made of rectangular steel tubes, welded together to a rigid and heavy framework. Upper and lower horizontal pivoting bars are made of aluminium profiles to reduce weight and thus to minimize the inertia against rapid angular accelerations. The ratio of the arm lengths on the two sides of the pivot is 2:1.

Paper grip by friction - no clamps

The paper web is stretched between the two cylinders at the ends of the pivoting arms (**Figure 3**). The paper web is wrapped 270^o around each of these fixed aluminium (friction) cylinders and is thereafter rolled up on two smaller cylinders which are locked. When the web is stretched by tilting one of the pivot arms, the web is tightened around the aluminium cylinders, and the stretching force is mainly the distributed friction force between the cylinder surfaces and the paper.

The tension in the paper web drops continuously around the ”friction cylinders” from T_o at the tight side to a lower value $T(\theta) = T_o \exp(-\mu\theta)$ after a wrap-around angle θ , where μ is the coefficient of friction between the paper and the cylinder surface. We found $\mu \approx 0.25$ (for newsprint) which means that the web tension drops to about 1/3 after the 270^o wrap around the ”friction cylinders”.

When a paper web is stretched to rupture, it is most probable that the break will occur only in the 1.8 m web span between the friction cylinders. This has also proved to be the case.

With this method of gripping the ”ends” of the web we avoid clamps with line pressure.
The problems with clamps over a 1m wide web would be:
- The risk of non-parallel grip and a stress maximum at one side.
- Stress concentrations at both sides of the clamp line because it prevents width contraction (about 0.2 %).
- Local slip and pressure variations along the clamp line because of local variations in paper thickness.

At high web tensions this could be the starting-point for breaks and this would give a false (too low) reading for the tensile strength of the web.

These problems are here avoided because the stretching force is mainly the frictional force which is evenly distributed over the large contact area between the paper web and the friction cylinders, with no local stress concentrations. The coefficent of friction is high enough to ensure a web break in the 1.8 m long web span and low enough to allow the paper to slide on the cylinder surface during tightening, both around the cylinders and in the cross direction.

Figure 1. The web tensile machine.

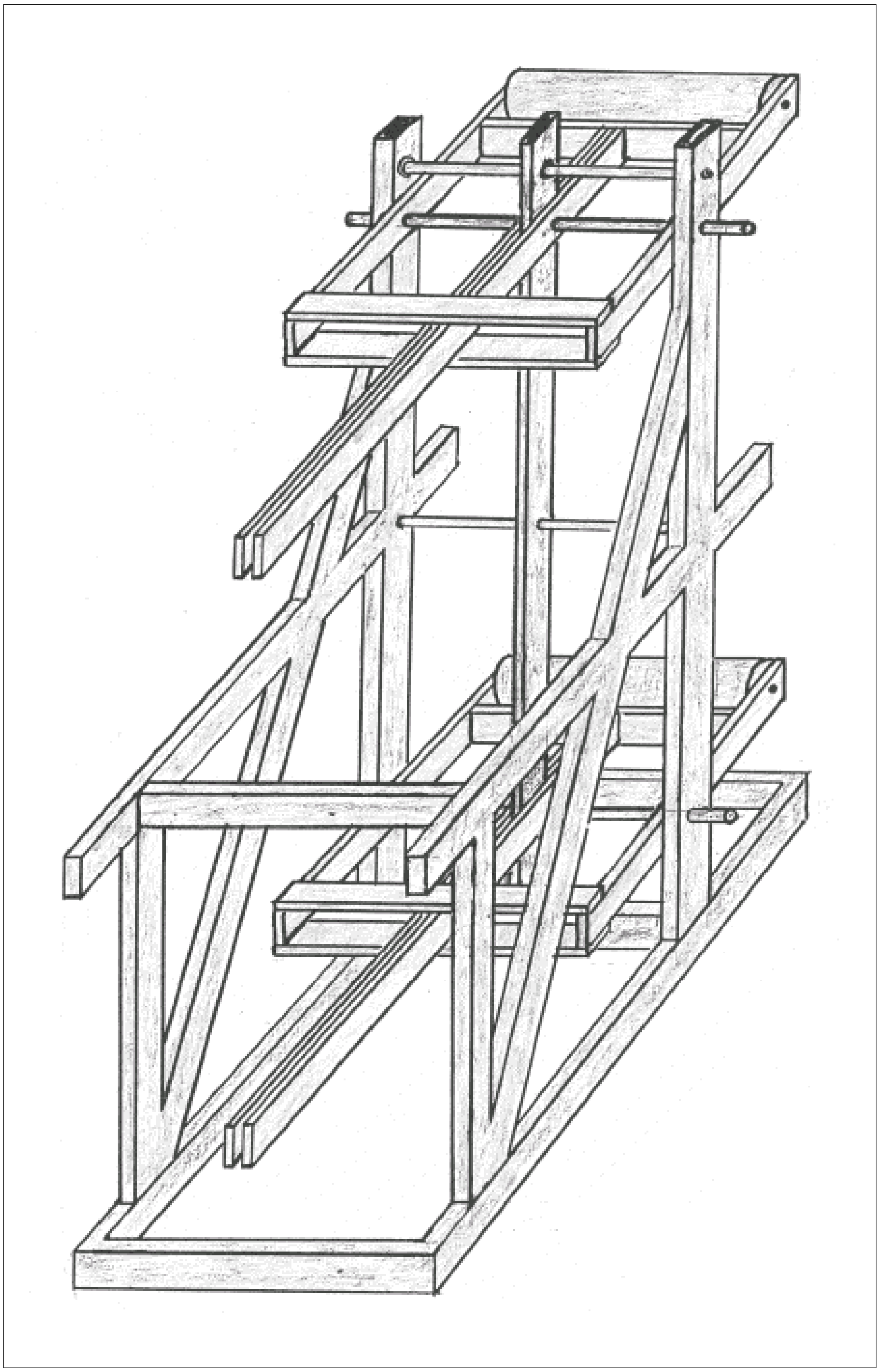

Figure 2. Outline of the machine framework – seen from the rear side.

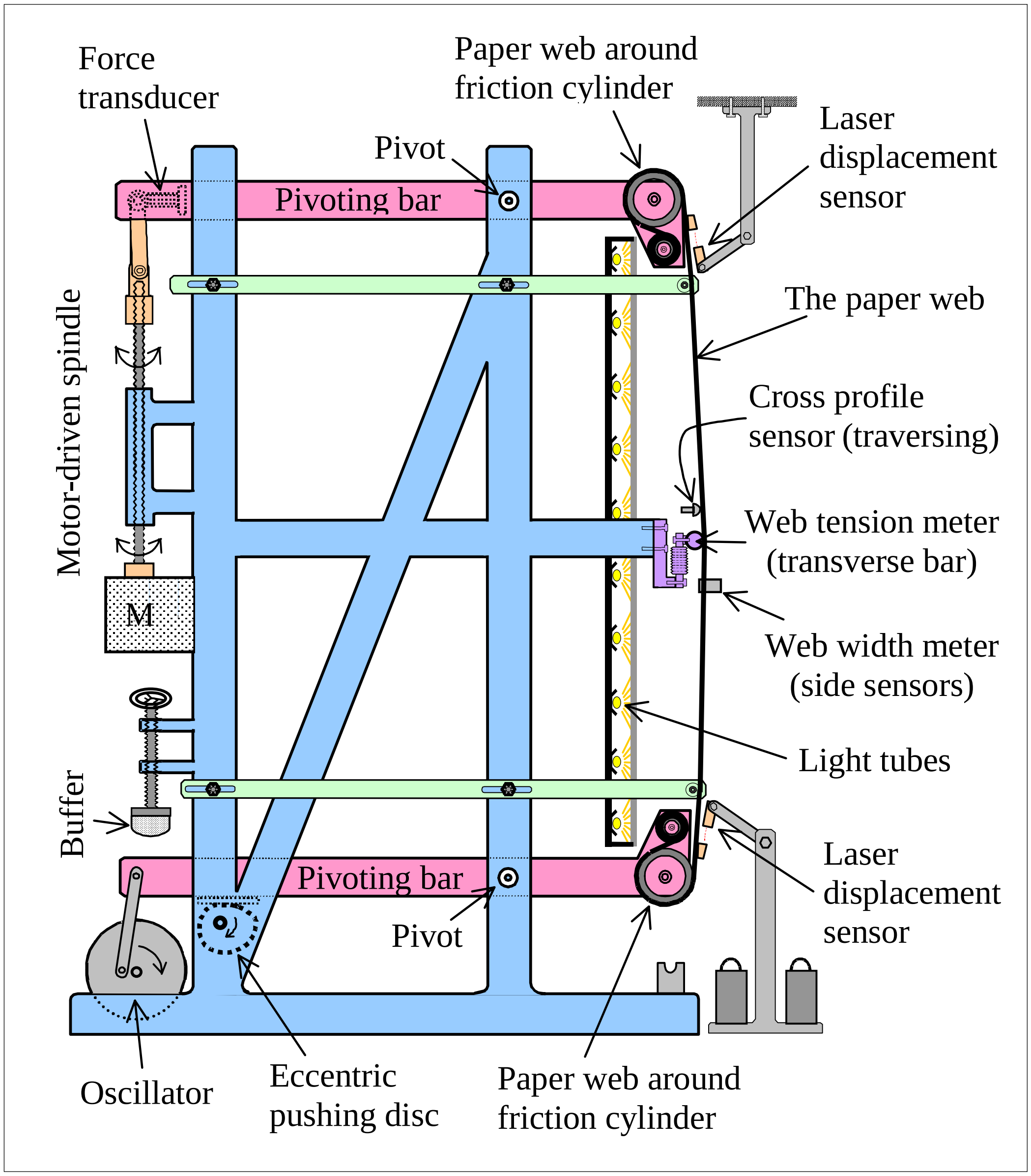

Figure 3. Outline of the web tensile machine, - side view.

Three different stretching mechanisms

Three separate mechanisms, each with its own motor and speed control, provide for three different modes of stretching:

- <u>"Normal" linear stretching</u> with a constant speed adjustable from near zero up to 0,22 % paper elongation per second. A motor-driven screw-spindle (Figure 3) then pulls down the left-hand (back) side of the upper pivoting arm and thus lifts the upper (right) friction cylinder with a speed of up to about 0.4 cm per second.

- <u>High speed stretching or snapping to rupture</u>. A motor-driven eccentric disk pushes up the left-hand side of the lower pivoting bar and forces the friction cylinder to move downwards at high speed. We have used up to 20 cm per second, which means a paper elongation speed of about 11 % per second. This movement starts when an electromagnetic coupling between a motor-driven flywheel and the eccentric disk is engaged with a push-button. The stretching or snapping speed is controlled by the motor/flywheel speed.

- Oscillating stretching, by moving the left-hand side of the lower pivot bar up and down with a rod connected to an eccentric bearing on a motor-driven flywheel (Figure 3). The frequency and the amplitude are controlled by the motor speed and the adjustable eccentricity. The corresponding up-down movement of the lower friction cylinder causes a sinusoidal variation with time in the web stretch which is superimposed on a preset (linearly variable) stretch.

Large paper area – illuminated from behind

Ten horizontal light tubes behind a ground glass plate (Figure 3) illuminate the whole 1.8 m^2 paper area from behind, making the paper structure well visible from the front side. The light intensity is adjustable and the light tubes are high frequency versions, 30 kHz, which do not interfere with high speed video recordings of the rupture events. This background illumination in combination with special front-spotlights is very suitable for visual inspection of the paper structure and searching for local inhomogeneities/weak spots. Magnifying glass and hand microscope are helpful aids.

SAMPLE PREPARATION

The starting-point is a roll sample of small diameter, 20–25 cm, and width of about 108 cm. It is not always easy to produce such small diameter rolls in the paper mills, and we have found it convenient to obtain roll samples in the following way:

Roll samples collected from printing rooms

The main interest has been in paper rolls for rotary printing presses, especially newsprint. To obtain suitable small diameter paper roll samples from different paper mills and different papermachines, we found it easiest to collect such samples from the customers, in the printing rooms.

In co-operation with the printers, the rest roll diameter from the offwinding paper roll was set to a suitable small value. The residual amount of paper on the core should be at least 1 cm (radial thickness), but for more comprehensive investigations up to 7-8 cm (roll diameter about 25 cm) is desirable. Larger rolls are too heavy for convenient handling. The roll samples were plastic-wrapped to keep moisture and brought to a climate room in our institute for further preparation.

During the visits to the printing room information about the runnability of the paper rolls is collected and the roll identification numbers are noted.

Conditioning

The paper rolls are produced with a moisture content which is in equilibrium with an atmosphere of 23 ^{o}C and 50 % relative humidity (RH), which is also aimed at in the printing rooms. All the subsequent preparations of the roll samples are carried out in this standard atmosphere.

The room atmosphere around the tensile machine is in addition controlled by a special air conditioning system by which the air humidity (and the temperature if desired) is widely variable. The effect of paper moisture on paper strength and stretchability can thus be studied. We have used relative air humidities of 25, 50 and 75 % and have calculated the moisture content of the paper from gravimetric measurements on separate sheet samples. Several electrical fans provide for effective air circulation and minimize the time necessary for the paper to reach the new moisture equilibrium.

Web width slitting

To avoid any web edge defects that might have been introduced through roll transport or handling and because the web width in the tensile test machine is limited to 100 cm, we have to reduce the width of the roll samples. For this purpose we have built a small hand-driven rewinder/slitter machine, as shown in **Figure 4**.

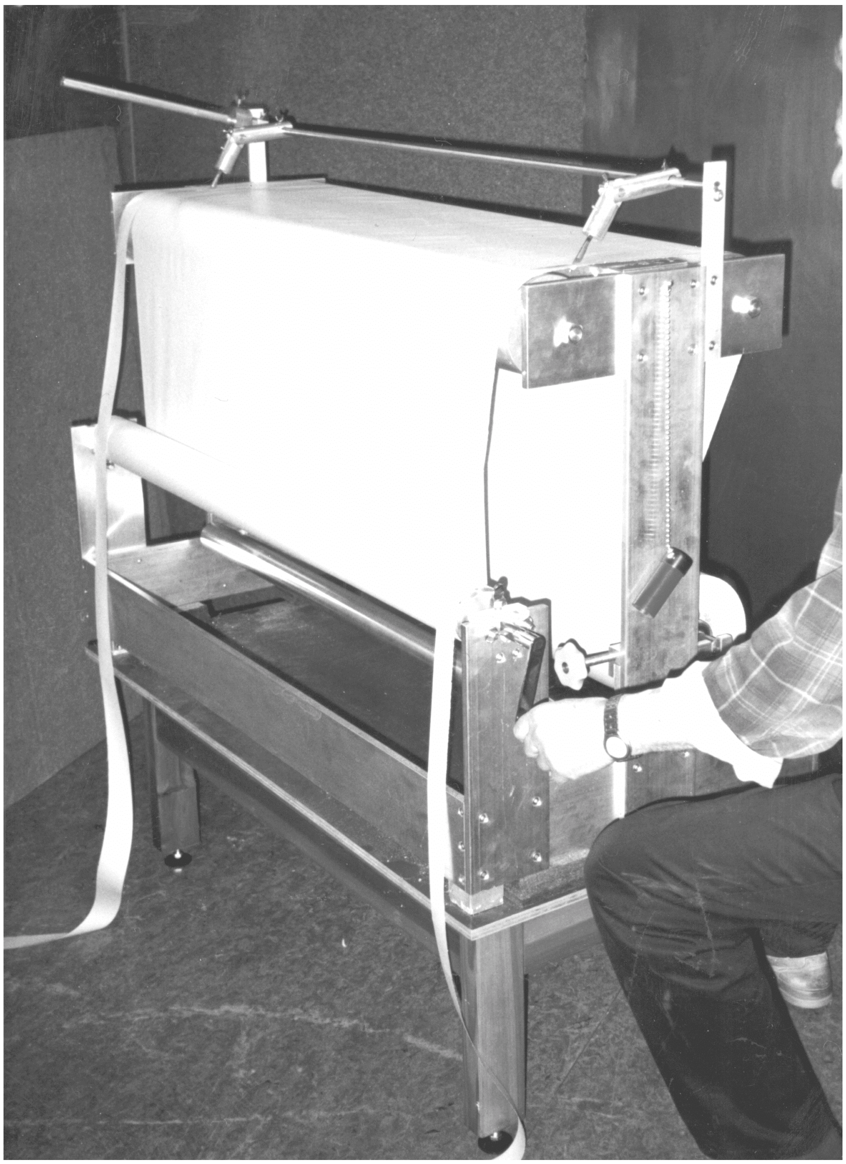

Figure 4. The web slitting machine.

The roll width, which for newsprint is about 160 cm, is first reduced roughly to about 108 cm in a saw before the roll is rewound in the slitter machine. Two sharp scalpel blades slit the web to a width of exactly 100 cm (or less if desired). A web length of 25–50 m is rolled up and transferred to the web tensile machine, to a stand below the lower friction cylinder.

Mounting the web

The end of the rolled up web sample is pulled up to the upper friction cylinder, wrapped around it and fixed by tape to the smaller cylinder where the 25-50 m web is rolled up. The trailing end of the web is pulled down, around the lower friction cylinder and locked after some wraps around the next cylinder. The upper roll-up cylinder is then locked, and the web is ready for a tensile test. A side view of the web is shown in Figure 3. After each tensile test, a new sample length is pulled down and locked.

For special measurements at low or high air humidity, each new web length has to be conditioned for at least 30 minutes before measurements are made. The web should be kept slack during this reconditioning to allow web width changes before the paper is “clamped” around the friction cylinders.

MEASUREMENT EQUIPMENT

The web tensile machine is equipped with measuring devices for recording the tensile force, the web elongation and the web width contraction.

The web tensile force

This force is recorded by two separate measuring devices (Figure 3):

A. A force transducer on the back (left) end of the upper pivoting arm, connecting this and the screw-spindle which pulls on it. Because of the 2:1 ratio of the pivot arms, half the web tensile force acts on this load cell.

B. Two load cells measuring the tensile force component acting on a transverse rod at the middle of the web span. The web has a small wrap-around angle of 3.5 ^{o} around the transverse rod, and the force component acting on it is 6.1 % of the web tensile force. This force component is measured by two parallel-connected load cells, left and right, on which the transverse rod is mounted. The transverse rod is a polished thin-walled steel tube of low weight and with low friction against the paper.

The two measurement systems are calibrated to measure the correct web tensile force by a special arrangement where the paper web is replaced by a stronger nylon web. To the trailing end of the nylon web is fitted a cross bar with a hook which is loaded with known weights. During this calibration, the web path is the same as that during meaurements. The weight hangs beneath the lower friction cylinder while the web is kept in contact with the cylinder.

For both measuring systems, the web tensile force is displayed on a digital display (for static and slow stretching) and on a digital storage oscilloscope.

In the case of very fast stretching, with high frequency oscillations or a sudden snap to rupture using the eccentric pushing mechanism, the measurement system A is not usable because of the mass inertia in the large pivoting bar. The force transducer has an elastic deflection of a few tenths of a millimeter, and this lead to a very small angular movement and acceleration of the pivoting bar. The force reaching the transducer is the web tensile force minus the force which accelerates the pivoting bar.

The measurement system B is, however, suitable for very fast stretching. The load cells backing the cross-rod also have a small elastic deflection (about 0.15 mm) but the mass under acceleration is small. Calculations show that the whole rupture process can be completed within 0.03 seconds, with a true registration of the web tensile force curve.

The ”slow” tensile force meter A is very robust and is used as an extra security, to check the meter B during static or slow stretching.

The friction between the paper and the central transverse bar is very low and the resulting difference in web tension above and belowe it is calculated to be 1.3 % at the most.

The cross variations in web tension

To secure an even tension distribution across the web, or to make a defined skew tension profile for special tests, a traversing ”fingertip”-sensor was made. It gently touches the paper web from behind and can be moved across the web. The ”fingertip”-sensor is a small polished metal hemisphere backed by a miniature load cell, and the whole unit is mounted on a small ”wagon” which can be moved transversely on guide rods. The cross position is measured by the unwound string length from a string extraction/retraction sensor.

This arrangement is placed a little above the middle of the web, just above the transverse bar for web tension measurements (Figure 3). This cross-profile meter can record only relative tension varations across the web. Absolute tension values can be obtained by calibration and setting the mean value equal to the known (measured) web tension. When the cross-profile meter is not in use, it is ”parked” outside the web.

The web elongation

Because the paper slides a little around the friction cylinders during straining, the web elongation must be measured directly on the web. This is done by pasting two small and very light styrofoam cubes onto the web near the two friction cylinders. The cubes are attached to the paper by double-sided adhesive tape. During web straining, the vertical movements of the two cubes are measured by two laser displacement sensors (Figure 3). The cubes have special reflector faces towards the laser sensors, and the outputs from the two laser sensors are added to give a single signal which represents the change in distance between the two cubes. The relative web elongation is obtained by dividing this change by the starting distance between the cubes (about 170 cm). This is a very accurate web elongation meter with no speed limitations for what is mechanically possible.

The web width contraction

When the paper web is stretched, the web width decreases. The width contraction is measured in almost the same way as the web elongation. Laser displacement sensors, one on each side, measure the lateral movements of small styrofoam cubes which are pasted on the web rims. Since the styrofoam cubes also moves a few millimetres upwards during web stretching, care must be taken to ensure that the cube faces are exactly parallel to the web edges.

EXAMPLES OF MEASUREMENTS

Some examples with oscilloscope recordings are shown in the following. All cases are with standard 45 g/m^2 newsprint.

Stretching to rupture

Figure 5 shows the stretching force versus web elongation during a linear stretch from a low initial load to rupture. The stretching force at rupture is about 2.0 kN/m and the elongation at break is about 28 mm. With a distance of 168 cm between the measuring points (the reflector faces on the cubes) this means a relative elongation at break of 1.7 %. In this case, the stretching speed was standard (slow), 0.2 % elongation per second, and the paper moisture was about 11.5 % by weight after conditioning to 75 % relative air humidity.

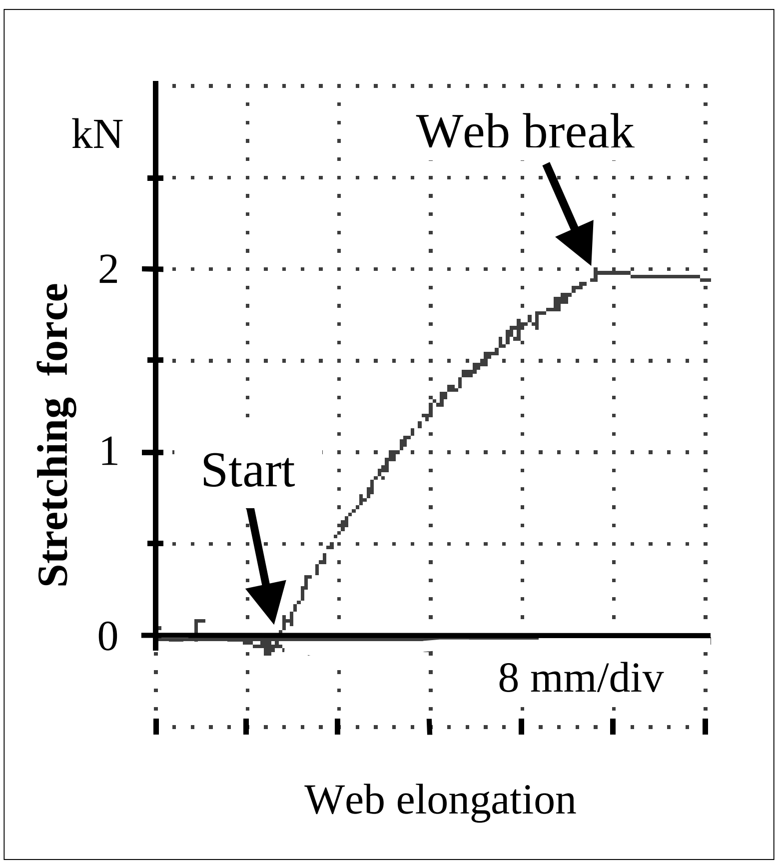

Figure 5. Oscilloscope curve from a web stretch to rupture.

Oscillating stretch

Figure 6 shows the web tension and web elongation during a 6 Hz oscillating stretch. There is a small phase displacement between the two sinusoidal curves. The tension cycles (the lower curve) lie 9° before the elongation cycles. This feature also appears from the ellipse, the tension/elongation-cycles which are simultaneously displayed on the oscilloscope screen. The elliptical area represents the viscoelastic energy loss per cycle.

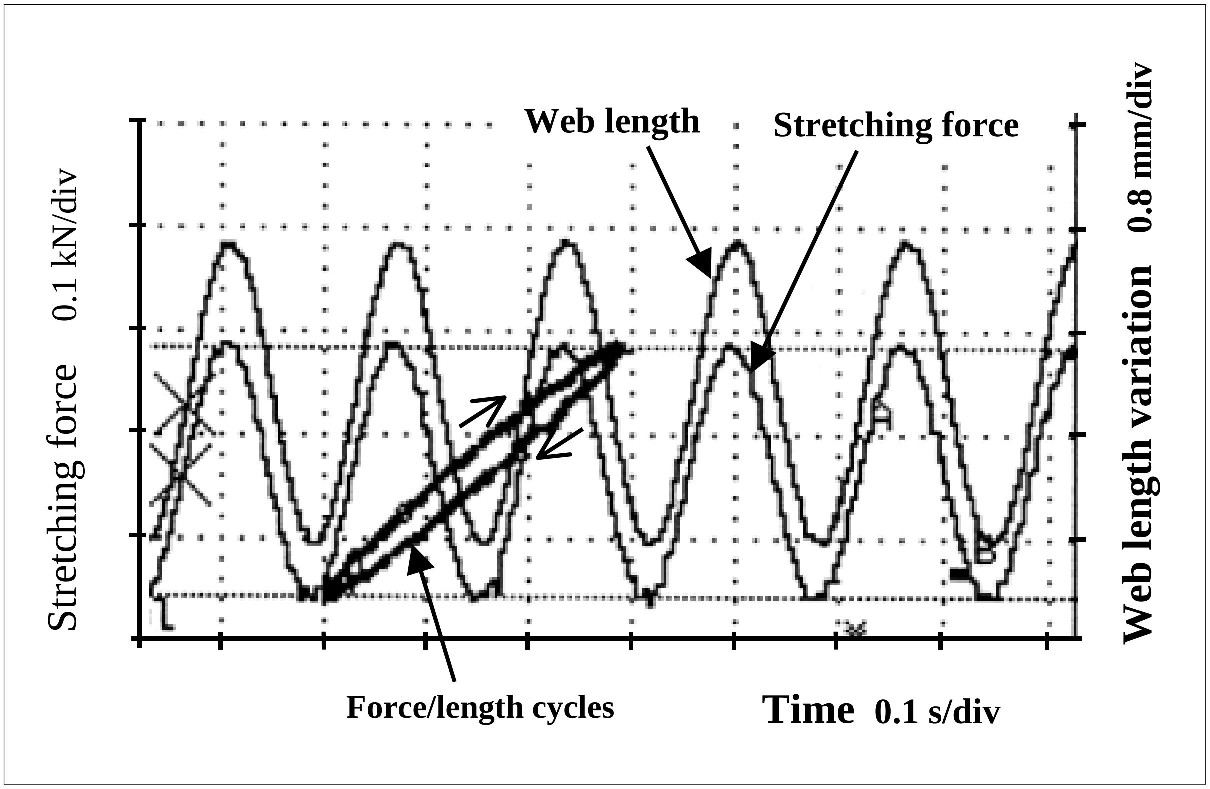

Figure 6. Oscilloscope curves from a 6 Hz oscillating stretch, - variations in stretching force and web length.

Width contraction

Figure 7 shows the curves for the web tension and the width contraction during a 0.7 Hz oscillating stretch. The width contraction curve (the lower curve) lags 10º after the elongation curve. The ellipse shows the tension versus elongation cycles. In this case, the amplitude is small, with relative length variations less than 20 % of the elongation at break. Variations in web width because of tension variations can influence the four-colour register in a printing press.

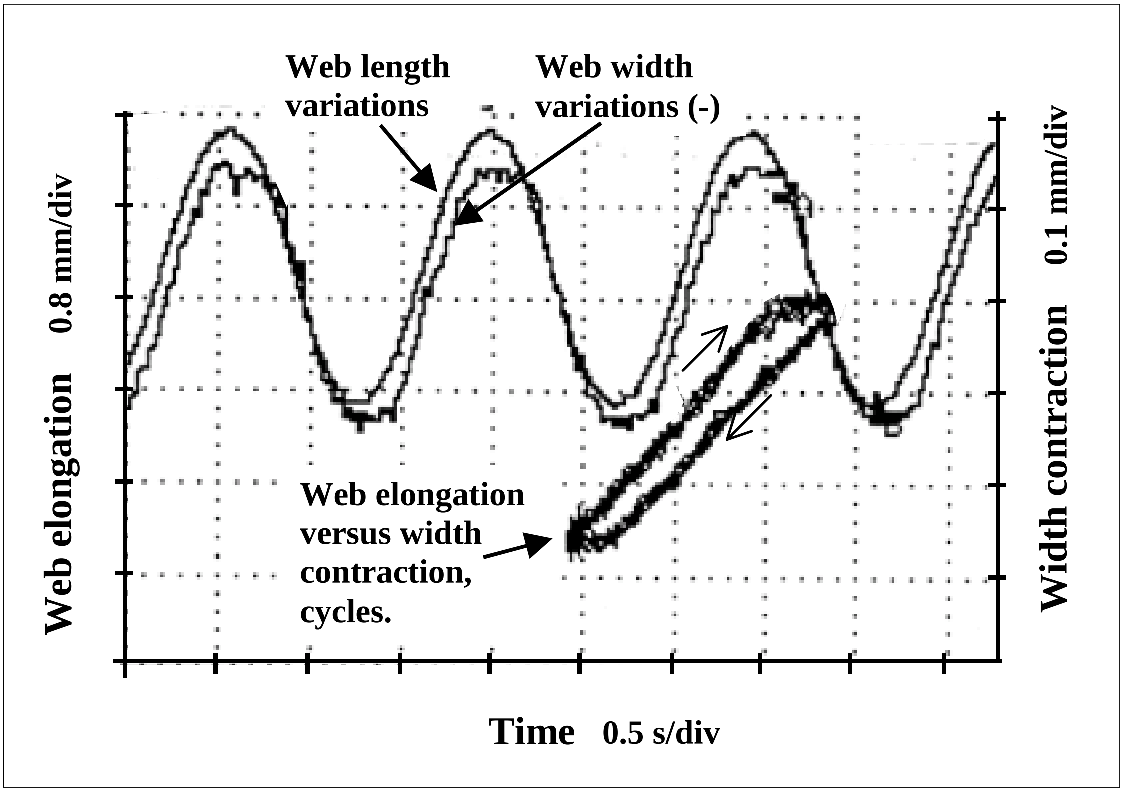

***Figure 7.** Oscilloscope curves from a 0.7 Hz oscillating stretch, - the webs elongation and width contraction.*

FURTHER WORK

A lot of work has already been done on roll samples from different productions of newsprint and magazine paper, and results will be published in subsequent articles [5,6,7].

CONCLUSIONS

A web tensile test machine of a new design has been constructed, and it has proved to be a useful tool for research and quality control of web strength. Important features are its ability to stretch large paper samples, to make visible the paper structure and inhomogeneities, and to measure the web's tensile strength and stretchability under different dynamic and climatic conditions.

Åge Hansen is a senior research scientist at the Norwegian Pulp and Paper Research Institute, N-7491 Trondheim, Norway

ACKNOWLEDGMENT

The author gratefully acknowledges financial support provided by Norske Skogindustrier ASA and the Research Council of Norway

REFERENCES

1. Hansen Å.: (In Norwegian only:) ”Papirbaners bruddstyrke og tøyning – Målinger i trykkpresse og omrullermaskin”.
   (The breaking strength and stretchability of paper webs. Measurements in a printing press and in a rewinder)
   Scan Forsk Rapport nr 515, 1988 and PFI Teknisk Informasjon nr 4/88
2. Sears G. R., Russell F. T. and Carlton W. D., ”Shives in Newsprint: The Role of Shives in Paper web Breaks”, Pulp and Paper Magazine of Canada, July 1965, T351–T360.
3. MacMillan F. A., Farrell W. R., and Booth K. G., ”Shives in newsprint: Their Detection, Measurement and Effects on Paper Quality”, Pulp and Paper Magazine of Canada, Technical Section, July 1965, T361-T369.
4. Seth R. S. “Measurement of fracture resistance of paper”.Tappi J. Vol. 62, No 7, July 1979
5. Hansen Å.: ”Revealing weak points in paper web samples. Identification and estimation of their strength reducing effect.” (To be published)
6. Hansen Å.: “The flaw resistance of large notched paper web samples. Formula description based on measurements in PFI’s web tensile machine.”
   (To be published)
7. Hansen Å.: “The strength-reducing effect of shives in newsprint. Measurements on web samples and extrapolation to running webs.”
   (To be published)

Received: June 13, 2000
Revised: September 6, 2000
Accepted: September 7, 2000

This paper was accepted for abstracting and publication in the January 2001 issue of *TAPPI JOURNAL.*

TAPPI Website: www.tappi.org