PERMANENT OUT-OF-PLANE-DISTORTIONS OF PAPER PRINTED IN HEAT-SET WEB OFFSET

by

R. Bosse
Consultant
Germany

ABSTRACT

Paper, a flat material, frequently with a coated surface, is made out of fibres. In heat-set offset printing a permanent out-of-plane distortion, the so-called washboard effect, occurs quite frequently, which is clearly visible in a lot of web printed products. In the last few decades manufacturers of heat-set dryers have tried to eliminate this washboard by different constructive measures without any real improvement. Views on this washboard have shown a dependency on various physical properties of the web. In printing practice it can be shown that the washboard is caused by the combination of tension, heating and cooling the paper. The washboard occurs when the paper is not flattened when cooled.

Views of paper

View 1. Paper, seen under a microscope, is a fibrous material with embedded fillers and a coating as a surface layer on both sides.

View 2. Paper as a web of material with mechanical characteristics and numerous inhomogenous variables.

View 3. Paper as a long tensioned web: For example in a 10 meter tensioned length, there is a transversal contraction in the web that causes troughs to be formed. In unprinted webs as well as in non-heatset offset or in gravure printing, these troughs will disappear after the release of tension, but they do not disappear in heatset offset printing. They have been ironed into the paper by the cooling rolls like a crease in a pair of trousers.

View 4. A relationship between these troughs and a partial sticking of the printed paper web to the cooling rollers has clearly been proven. The heated web, coated with printed ink is still adhesive when coming out of the heatset drier. The troughs can clearly be seen. In these areas where the web is printed with 'adhesive ink', the web remains stuck to the first chill roll. Ribs are formed into the web while it winds around the chill roll. Air-cushions are inside these ribs, which in addition prevent the paper from being stretched evenly across the chill rolls. Apart from this, the inhomogenous air cushions also spoil the heat transfer to the chill rolls. The stiffness of the paper web and the radius of the first chill roll do not cause enough tension to press the web flat.

View 5. In addition to the view of the stationary tensioned web we must in reality consider the speed of the web. The moving web carries an adhering air film.

View 6. The adhering film of air and solvents can be pealed off by means of a 'knife' built up by an electrostatic plasma current.

INTRODUCTION

Processes in the dryer of a web offset press cannot be presented clearly without taking the tension/stretching property of the printed substrate into account. In daily routines settings of the printing press are made on an empirical basis. Some engineering views based on the results of innumerable visits to companies, with different problems in web handling, particularly web offset printing will be shown within the framework of this paper. These views have been further refined in seminars about drying of printed ink and remoistening of the dried-out paper.

Basically the following definitions are to be taken for granted. In the end, all known laws of nature, as well as all physical or chemical formulas, are only views which help us to understand the complex processes in nature. Technical science provides us with calculation methods.

Example: There are the two contradicting views of the nature of light. The corpuscular view and the wave view. We have learnt how to use them and – depending on the individual application – we take one of these views without reflecting any further that this contradiction is not based on the nature of light, but exclusively on a simplified reduction into views to help our imagination.

The same applies to the real facts in web offset printing which are presented as views in order to simplify each of the individual processes to be examined.

BASIC VIEWS OF PAPER

View 1. Paper, seen under a microscope, is a fibrous material with embedded fillers and a coating as a surface layer on both sides.

View 2. Paper as a web of material with mechanical characteristics and numerous inhomogenous variables.

Depending on the task to be performed, we either use the microscopic fiber view or the macroscopic web view. But we always have to bear in mind that there are some applications or practical problems in which these simple views will fail, unless we succeed in refining or modifying them.

As we have discovered in numerous studies, every grade of paper has a characteristic tension/stretching property that can be represented in a diagram (Fig. 1). The slope of this curve corresponds with the elastic modulus.

On the other hand, if we look at a long piece of paper, e.g., a paper web which is not on a reel but a band lying flat on a plane surface, this paper web would in reality not lie completely flat on this surface, rather we would see smaller or larger bulges. In these areas where there are bulges, the paper is longer than in the surrounding areas. In order to remove these bulges, the paper web must be stretched until the bulges are also under tension. Represented in a diagram (bulges are the longer areas of the paper web), these tension/stretching curves do not run through the zero point of this diagram. The surrounding areas of the bulges have to be stretched by to a specific tension before the bulge itself is put under tension. For the areas with bulges, we thus get a parallel curve that is displaced to the right below the standard curve (Fig. 2). The extent of this parallel displacement complies with the size of the bulge. In papermaking large bulges are called 'water pockets'.

If we then add other variables, e.g.: changes regarding the thickness or humidity of the paper, the tension/stretching curve changes as well (Fig. 3) [1], [2]. As a consequence we get a parametric field that is dependent on many different parameters, all in one roll of paper. At the paper mill when the paper web is wound, the web must be stretched to such an extent that all areas of the web are tensioned. Slack areas will cause wrinkles. Now it is pretty obvious that paper on one reel has different tensions and thus local differences in stretching. This has been proven in various studies (Fig. 4, 5, 6 and 7) [6],[7]. When the paper roll is unwound in the printing press, torque is applied by means of a brake to such an extent that the paper web neither tears nor gets slack (Fig. 8). This means that a setting of a constant average tension is required when unwinding. This tension compensates local stretching differences where necessary (Fig. 9). Now, the in-feed unit must stretch the paper web to a preset stretching value in order to guarantee close register for the print, and high precision in cut-off and folding. Seen in a diagram (Fig. 10) this is a procedure which, depending on the various properties of the material, generates local web tension differences through constant stretching (a slightly lower speed in the in-feed unit without slippage).

While printing, various things happen to the tensioned paper due to the influence of ink, moisture and heat. Wet stretching causes the so-called fan-out effect. All these influences shall not be discussed here.

PAPER IN THE HEATSET DRYER

In the dryer, several processes must be taken into consideration, which all influence each other in many ways. This can be seen in the following view.

View 3. Paper as a long tensioned web. Up to now the view is of a single-axis state of tension. For example in a 10 meter tensioned length there is a transversal contraction in the web. That causes troughs to be formed. In unprinted webs as well as in non-heatset offset or in gravure printing, these troughs will disappear after the release of tension, but they do not disappear in heatset offset printing. They have been ironed into the paper by the cooling rolls like a crease in a pair of trousers. If, however, thickness (d) is small in comparison to width (b), and if the width is small in comparison to length (l), ($d<b<l$), a modified view must be taken for this substrate under tension. There are several reasons for this consideration:

- When a web is stretched, force is applied at the clamping lines only. In contrast to independant threads running parallel, a web has a 'bond' to the surrounding areas of the web. The tension lines thus run in a constricted manner especially at the edges of the web depending on transversal contraction (Fig. 13).
- This lateral force can cause a bulge in accordance with Euler's critical compression of a bar. (A bar can endure a compressive strain to a specific extent only before it buckles to the side.)

- Likewise the paper web cannot endure an unlimited compressive strain in cross direction without buckling. The result will be fluting. This was clearly shown (Fig. 11, 12) in graphs using the calculation means of finite elements [3].

Consequently the fluting of a paper web primarily has nothing to do with the inhomogeneity of the material (humidity or thickness) or with the printed image area, but is solely the result of the tension of a long, thin web.

Additional inconsistencies will make these bulges grow, or occur at lower tension. By means of our photographs, it can be shown that this transversal contraction is strongly dependent on the properties of the material. In a net of plastic threads, the holes are nearly square over the total area, as long as the net is slack (Fig. 14). Under tension, the holes of a net will deform and get more or less diamond shaped depending on their location. The transversal contraction becomes very obvious. Nevertheless, there is no fluting of the grid (Fig. 15, 16).

If we take another substrate, e.g. a strip of linen, there will be bulges, depending on the force applied. (Fig. 17) The check-pattern lines on the right side show the direction of the threads, the check-pattern lines in the left part form a net turned by 45° to the direction of the threads. Both strips are glued together with one stiff bar, so that they are under identical tension.

The strip in which the force lines are identical with the direction of the threads show little transversal contraction, whereas the strip with force lines diagonal to the threads shows obvious transversal contraction. At the same time fluting develops.

Such fluting is common in tensioned paper webs (Fig. 18). In unprinted webs as well as in non-heatset or in gravure printing, this fluting will disappear after the release of tension, but they do not disappear in heatset offset printing, forming the so-called washboard. This washboard effect can easily be seen, even after more than one year in a perfect bound magazine.

A relationship between fluting and a partial sticking of the printed paper web to the chill rolls could clearly be shown.

After years of extensive examinations and observations in many printing plants, the following view for the formation of the washboard effect was developed. There is fluting as in other printing processes due to web tension. Paper variables of the web such as minor differences in thickness inevitably are an additional cause of the fluting. The permanent washboard effect is not created while drying, but during the cooling process. The following takes place.

View 4. A relationship between these troughs and a partial sticking of the printed paper web to the cooling rollers has clearly been proven. The heated web coated with printed ink is still adhesive, when coming out of the heatset drier. The troughs are clearly to be seen. In these areas where the web is printed with 'adhesive ink', the web remains stuck to the first chill roll. Ribs are formed into the web while it winds around the chill roll. Air cushions are inside these ribs, which in addition prevent the paper from being stretched evenly across the chill roll. Apart from this, the inhomogenous air cushions also spoil the heat transfer to the chill rolls. The stiffness of the paper web and the radius of the first chill roll do not cause enough tension to press the web flat.

The same process is repeated at the following chill rolls. The reduction of web temperature causes the printed ink to be less adhesive. During cooling the flutes are ironed into the paper. The washboard effect is the result.

Direct and indirect evidence indicates the proof for this roughly outlined view. If the washboard is obvious on the printed product, then one can see the ribs winding around the chill rolls.

The permanent washboard effect on a printed sheet can be ironed out in the laboratory the same way as a piece of clothing is flattened by ironing. The surface of matt paper is very rough so it does not stick to the chill roll. The chill rolls flatten the flutes. Thus the washboard is eliminated on matt paper.

View 5. In addition to the view of the stationary tensioned web we in reality must consider the speed of the web. The moving web carries an adhering air film.
The thickness of this air film has been defined in many studies. A computer model on the basis of the oil film theory was presented [4] by deviating a moving web with a smooth roller (Fig. 19). The thickness of the air gap between roller surface and web surface is approximately 100 µm at a speed of 10 m/s. With increasing speed the thickness of this gap increases.
A major problem for the dryer is to overcome this air film.
All heatset dryers fulfill three essential functions:

- to heat the web
- to evaporate and remove solvents
- to convey the web contact-free.

All heatset dryers function with hot air (130°C to 300°C ≈ approx. 260°F to 570°F).
In the dryer flutes may touch the hot air nozzles especially if the nozzle pressure is inconsistent (Fig. 20). A slight sine wave of the web will smooth these flutes. This view indicates that a web without sine waves could touch the nozzles when passing through the dryer more easily.

An absolutely new approach to overcome this air film has been developed by Eltex (Fig. 21). The principle of this new process is both simple and surprising, as the patent specification shows [5].

View 6. The adhering film of air and solvents can be pealed off by means of a 'knife' built up by an electrostatic plasma current. The essential test result is that as soon as a specific electrostatic field is applied to the web a turbulence is created disturbing the adhering laminar film of vapours. Eltex is presently negotiating with dryer manufacturers as to how such electrodes can be incorporated into a dryer, and what effects this would have on the total drying system. Apart from web offset dryers, preparations are being made for applications in gravure and flexo printing.

CONCLUSION

In the engineering views for 'Paper in Web Offset Presses' presented here, much has only been touched upon or not even mentioned. No technical formulas have been presented, as much is still unknown.

The author of this paper would like to gather more information on these subjects as comprehensive as possible in order to access and systematically catalogue this material. There is a lot of professional knowledge available in the individual companies and institutes, but it still had not been systematically published.

After critical appraisal of the available knowledge, potential gaps or inconsistencies could be shown, and the required research activities could be formulated. For example, we still do not know the elastic/plastic properties of paper grades at temperatures between 20°C and 150°C (≈ 70°F and 300°F). A diagram, which I found by chance, shows the stretching of paper, heated up to a temperature of 100°C (Figure 22).

The paper presented here could be a starting signal to analyse, precisely describe and enlarge the views presented and to make them known to the professional public.

REFERENCES

[1]Kunz, Werner, “Druckfarbe und Bedruckstoff - die notwendigen Materialien des Druckers“ (Printing Ink and Substrate - the inevitable Materials of the Printer), VDD Druckfarbe & Bedruckstoff, 1979, (Lit.: DF6), (e.g. material B 60 g/m², E =6050 to 6383; N/mm² {= 6.05 to 6.38 10^9N/m²} in one reel)

[2] Wolfermann, W., “Mathematischer Zusammenhang zwischen Bahnzugkraft und inneren Spannungen beim Wickeln von elastischen Stoffbahnen“, (Mathematical Relations between Web Draw and Inner Tensions winding Elastic Webs), TU Munich, Dissertation, 1976, (Lit.: DF155); $E_{longitudinal}$ 0.4 .... 12.5 10^9N/m²; E_{cross} (0.25 ... 0.5) • $E_{longitudinal}$

[3] H. Gopal and M. D. Kedl, “Using finite element model to define how wrinkles form in a single web span without moment transfer“, Proceedings of the 1. Web Handling Conference, Oklahoma, 1991, (Lit.: 5485)

[4] Kothari/Satheesh/Chambers, “Computations of air films and pressures between webs and rollers for steady and unsteady operating conditions“, Proceedings of the 4. Web Handling Conference, Oklahoma, June 1997, (Lit.: O207, Nr. 16)

[5] Eltex has applied for a patent regarding an innovative system of the permeability of boundary layers. {DE 195 25 453 A1 (16.1.97) laid open to public inspection. (Eltex is a company specializing in electrostatics, market leader in Electrostatic Assist in gravure printing and the manufacturer of the redampening unit LG50, in which the water droplets penetrate the laminar boundary layer in the electric field at an accelerated speed.}

[6] Eriksson, L., “Disturbances during reel change in paper machines”, Proceedings of the 4. Web Handling Conference, Oklahoma, 1997, (Lit.: O207)

[7] Linna, Kaljunen, Moilanen, Mähonen Parola, “VTT Long-term study on the variation of the web tension profile”, TAGA/IAIGAI Conference, 17/20 September 1995

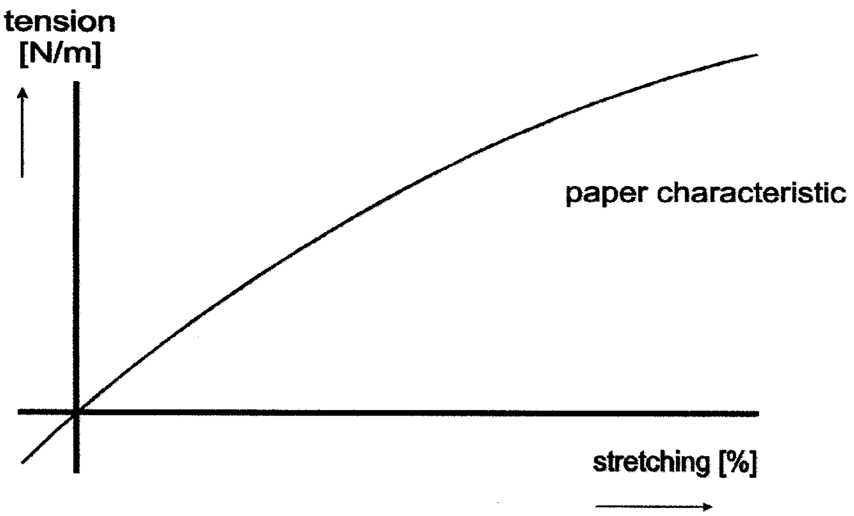


Fig. 1 Tension/stretching behaviour of a paper (in qualitative terms)

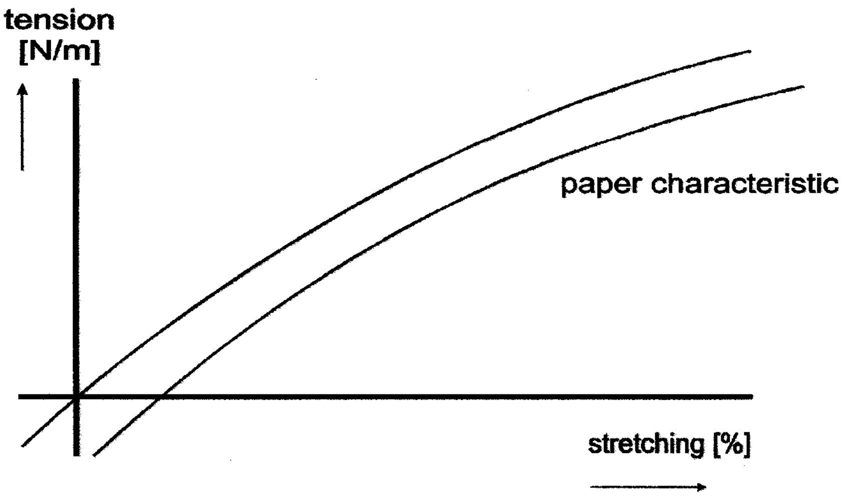


Fig. 2 Tension/stretching behaviour at two positions of a paper not lying absolutely flat (bulge = right curve; surrounding of the bulge = left curve)

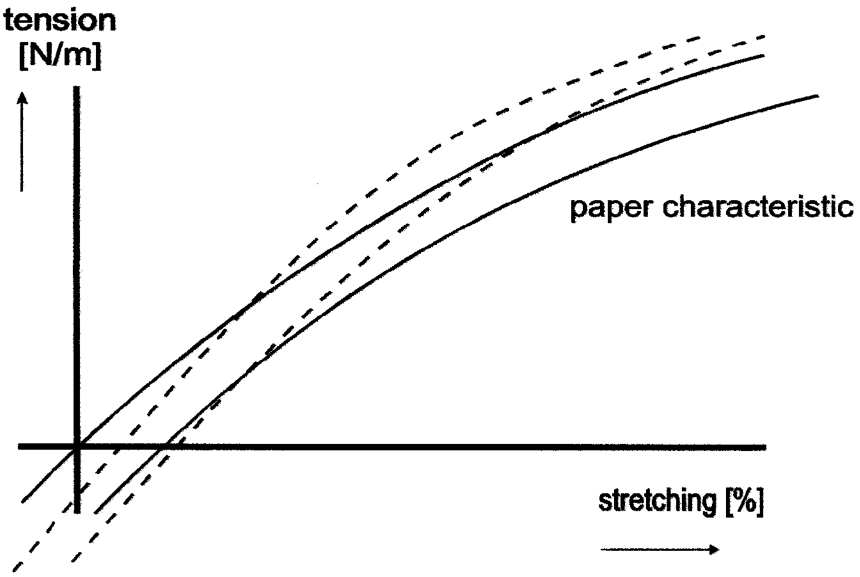


Fig. 3 Tension/stretching behaviour (parametric field) of a paper

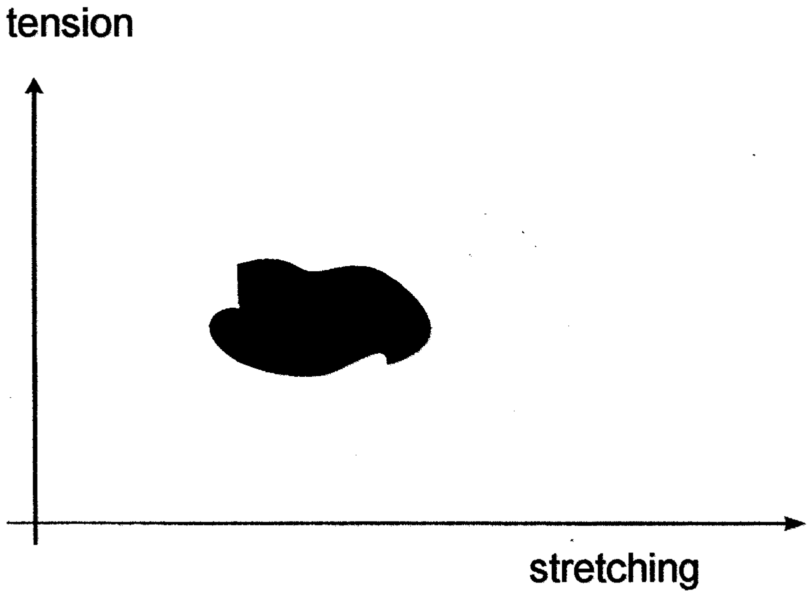


Fig. 4 Range of the tension/stretching in a paper reel

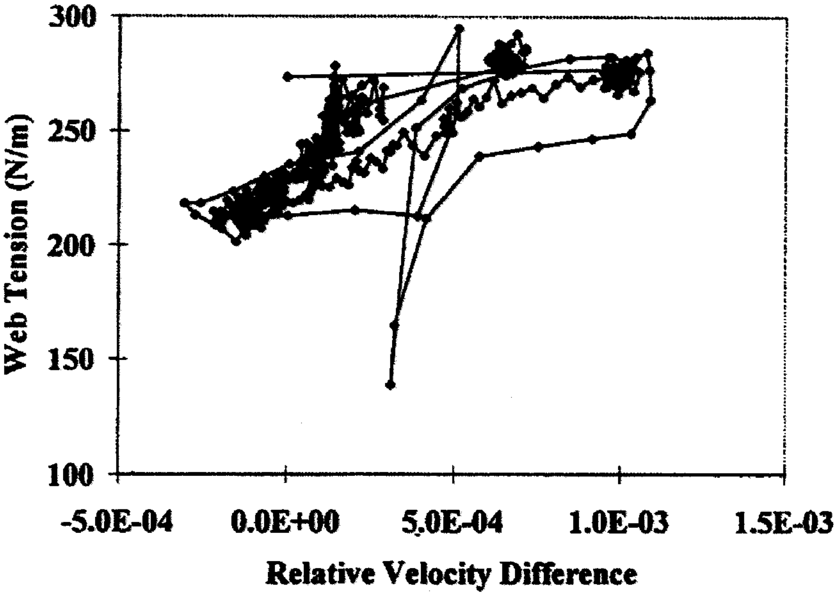


Fig. 5 Web tension and relative velocity during reel change [6]

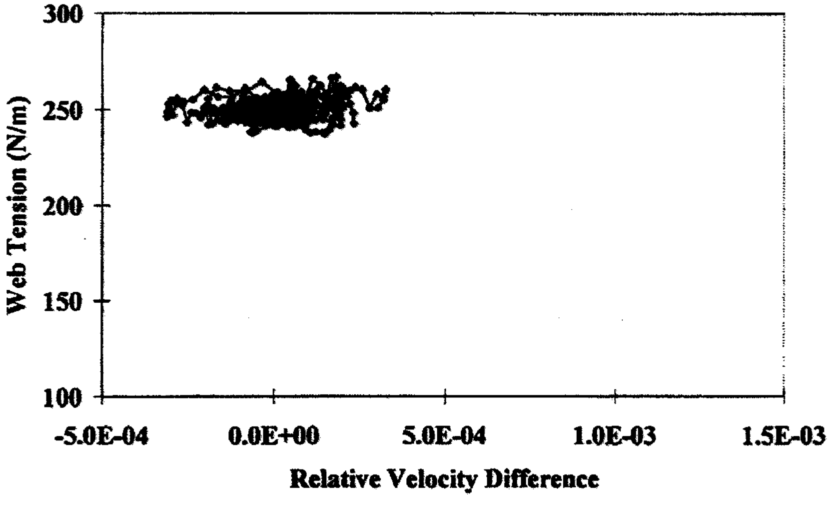


Fig. 6 See figure 5, with an optimized control of the reel change process

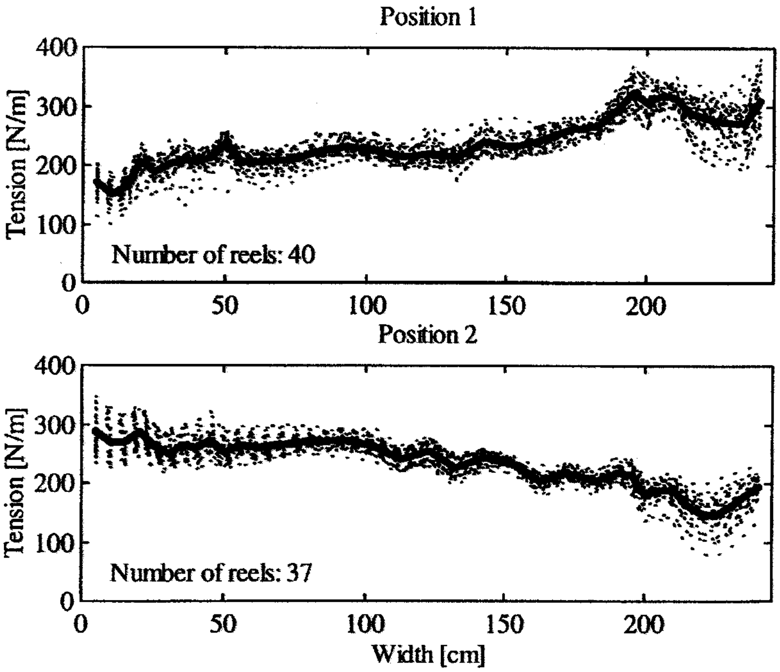


Fig. 7 VTT – Web tension profile in a paper reel

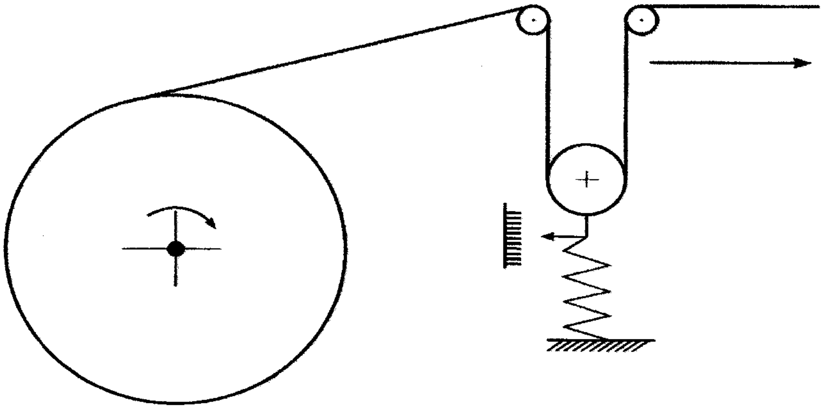


Fig. 8 Control circuit: Unwinding of the reel
with constant tension (= braking moments/radius)

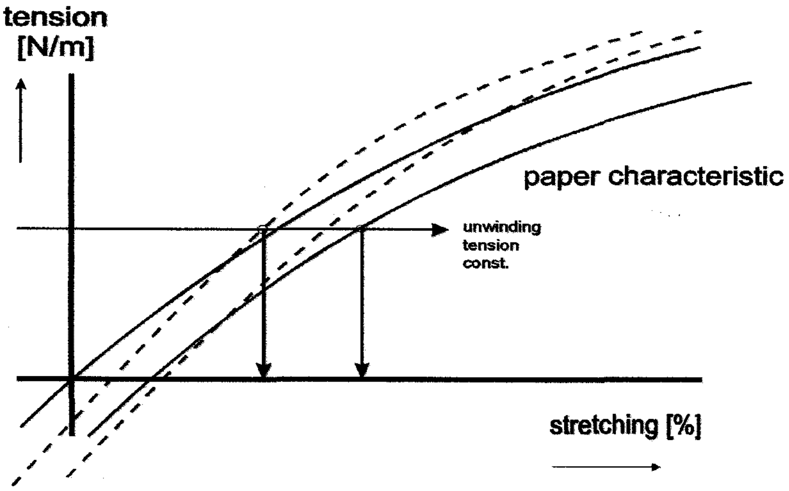


Fig. 9 Constant tension (=braking moments/radius) while unwinding

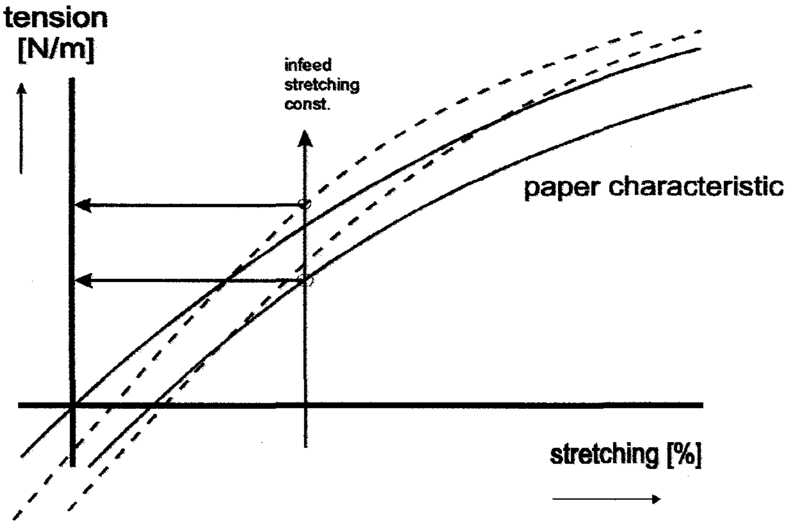
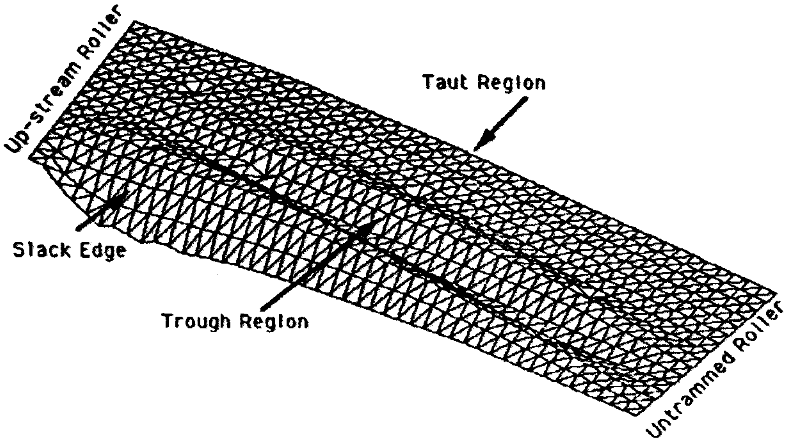
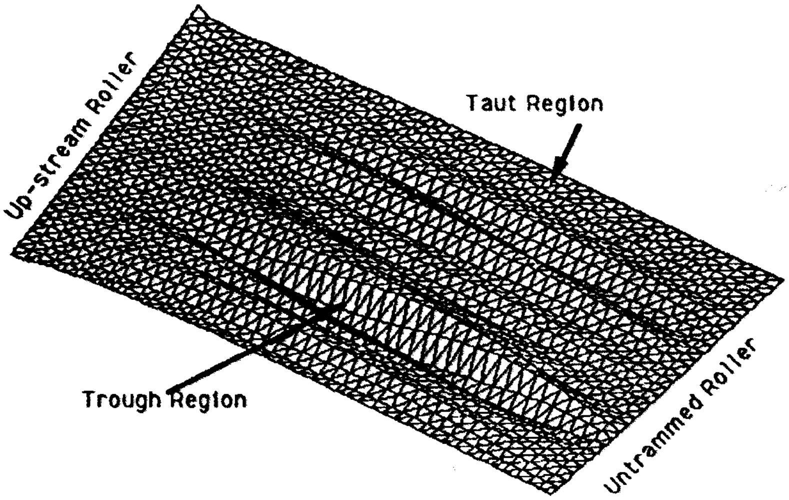


Fig. 10 Constant stretching by lower speed in the infeed unit



Deformed web shape for L/W= 3.0

Fig. 11 The development of troughs calculated by means of the finite element method with a different ratio of length to width



Deformed web shape for L/W = 1.5

Fig. 12 The development of troughs calculated by means of the finite element method with a different ratio of length to width

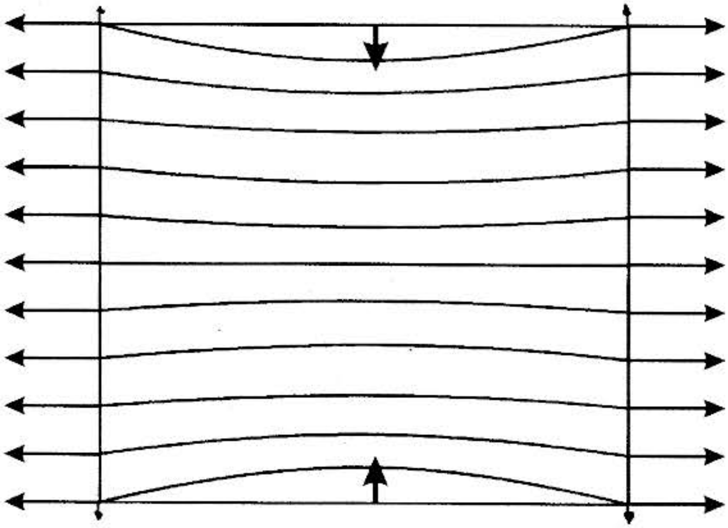


Fig. 13 Transversal contraction as a result of stretching a web

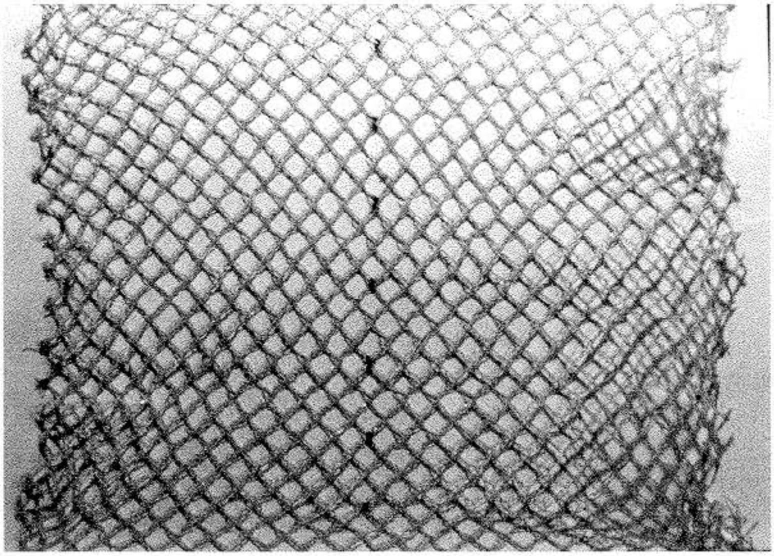


Fig. 14 A net of plastic threads, untaut: The holes of the net are nearly square.

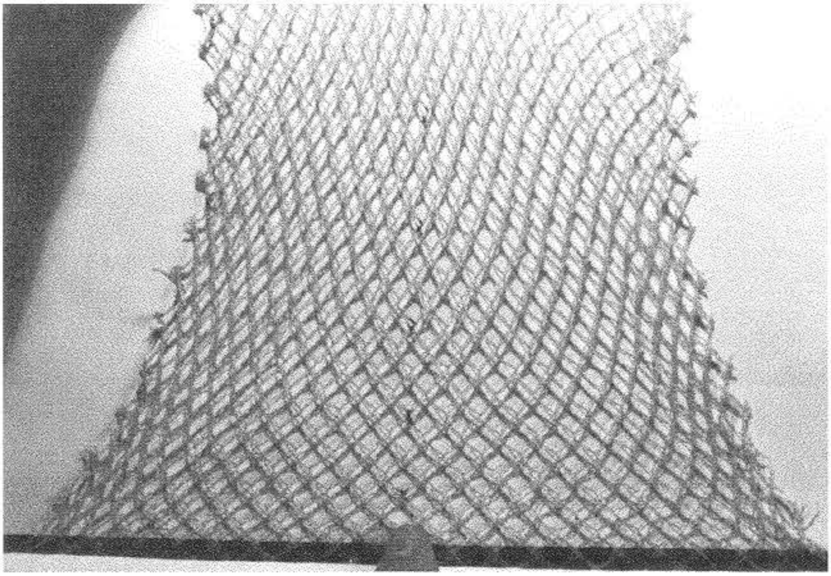


Fig. 15 Net, slightly tensioned: The holes are diamond-shaped depending on their location; transversal contraction in the middle.

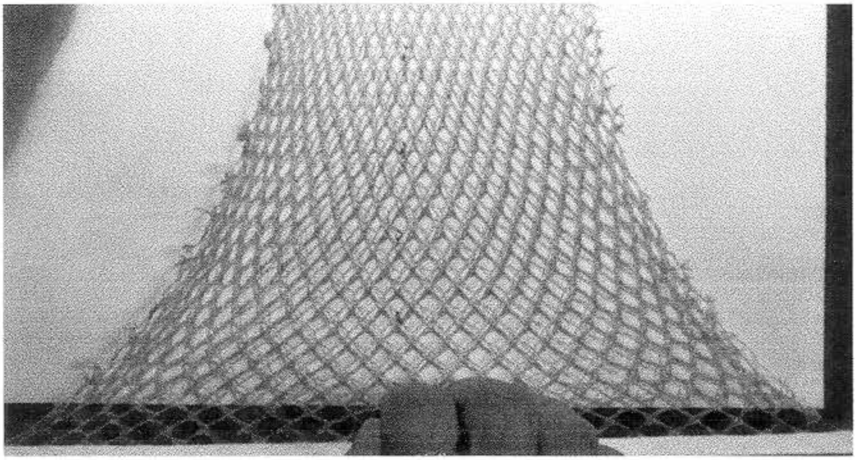


Fig. 16 Net, strongly taut: The holes are deformed even more; the transversal contraction is very strong. Nevertheless there is no fluting.

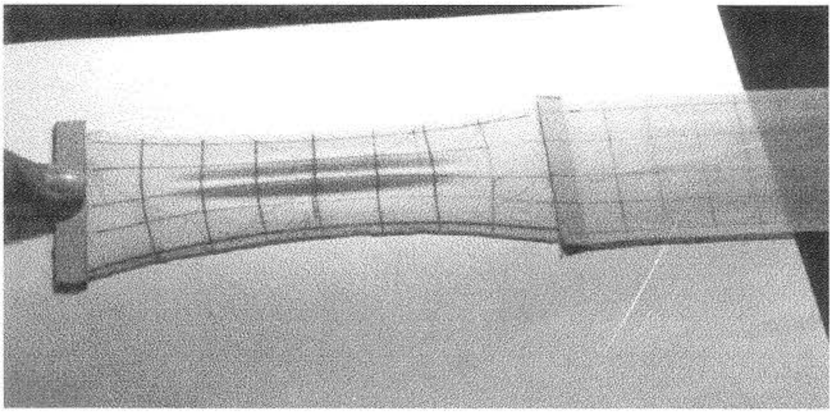


Fig. 17 Two strips of linen glued to each other. The strip, in which the force lines are identical with the direction of the thread (right), shows little transversal contraction.
At the strip with force lines in a 45°angle to the threads (left) transversal contraction and fluting are obvious.

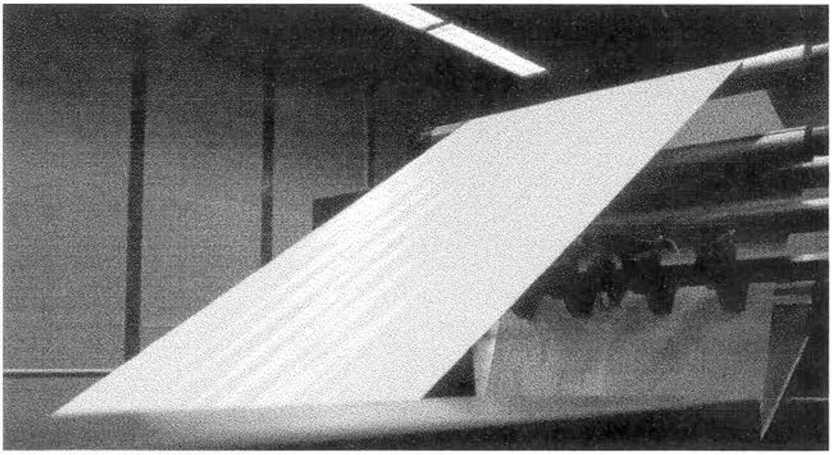


Fig. 18 Fluting of a tensioned paper web

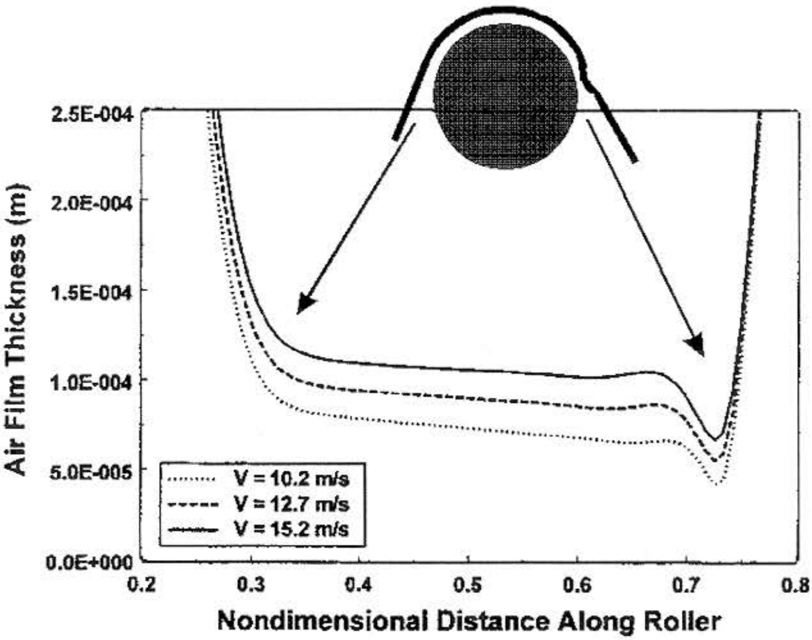


Fig. 19 Air gap between a web of material and an idle roller

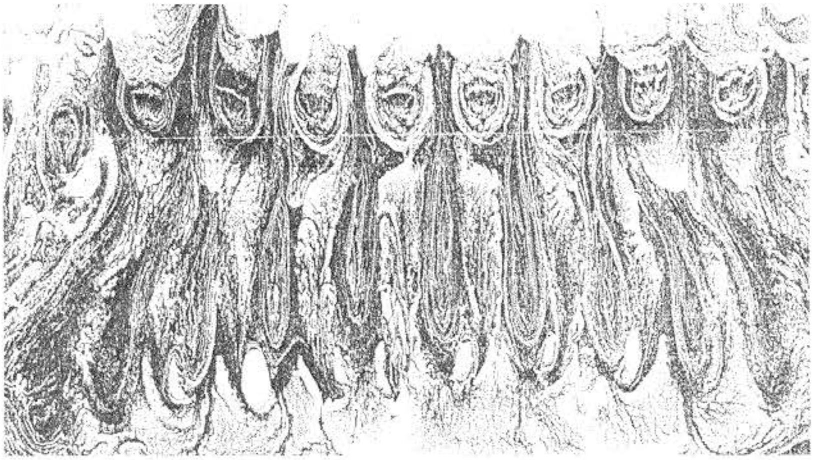


Fig. 20 Flow pattern of air nozzles (VITS-Dryer)

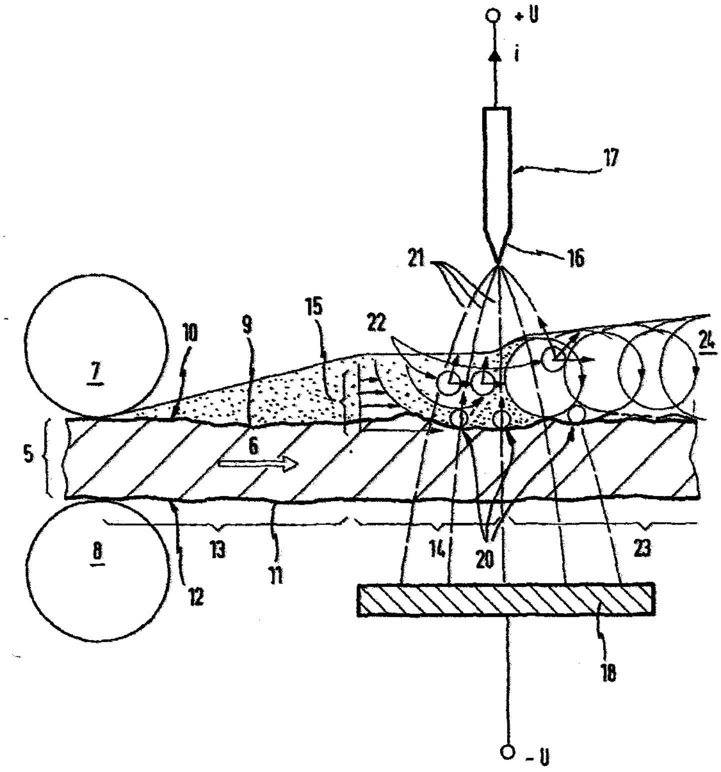


Fig. 21 Breaking up the boundary layer by means of ionic and electronic flows

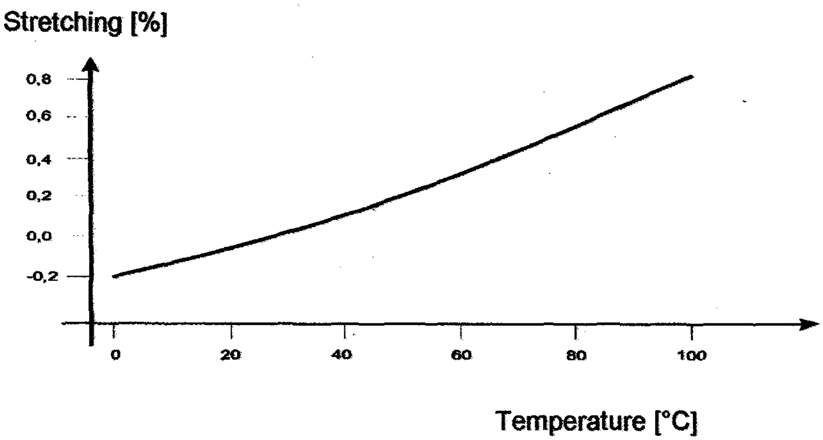


Fig. 22 Stretching of paper while heated

Rolf Bosse

Permanent Out-of-Plane Distortions of Paper printer in Heat-set Web Offset

6/8/99 Session 3 10:45 - 11:10 a.m.

Question – Roger Whitefield, Dupont
Can you please explain why you think paper forms flutes?

Answer – Rolfe Bosse, Munich
Any material forms flutes. I was concerned about paper.

Question:
One of your materials there does not form flutes. And I was wondering why you believed paper forms flutes, based on your two examples?

Answer – Rolfe Bosse, Munich
I think it's the bond of the material in between. Here (using parallel strings) we have a no bonds in between. Here (in the sketched net) we have no ridged bonds. And here (price of linear) we have a more rigid bond, and therefore we get flutes. That's the same material, and one part of the material forms flutes and the other one does not. We have to look for stiffness or compressibility or items like this to determine if the flutes are formed or not. Here the stretching is extremely high, no fluting. Yet, here it is not so high and we get flutes. I don't know which physical parameter is correlated to the fluting.

Question – Pete Towns, Mobil Chemical
I was curious on your example with the linen, when you pulled it and half of it formed flutes and the other half didn't. Were you saying that the fibers were running in a different direction, and by that are you indicating that whatever the material that its formation of flutes or corrugations is greatly impacted by the directional characteristics?

Answer – Rolfe Bosse, Munich
Yes. It is absolutely the same material, the same stiffness, the same grade, because I cut it from a piece of linen directly and at 45 degrees. The people who make clothing know that you make clothes cut on a bias.

Question- Jim Dobbs, 3M
One thing you can never forget with the web is that it's moving and the normal entry roll, as far as I am concerned, Everything we've ever done, that normal entry roll, and the fact that the edges are not going to lock into the roller at an angle, has to be taken into account. And you eluded to this a little bit on smooth web's troughs will slide out as they hit a roller. Sticky webs will not. And your examples, the starting point you have to then run the web. You have to move it onto the roller. And I think there in lies a lot of the answer to where these troughs come form.

Answer - Rolfe Bosse, Munich
I have to admit that that is absolutely true.

Comment – Ron Lynch, Procter and Gamble
With some of the webs that we run, some of the nonwoven webs that we run when we do tensile testing on the web, where you have constrained both edges of the web in the

testing device and then you elongate them you get the neck down you see the troughing but when you run these web through process machinery under perhaps very similar conditions they in fact run very smoothly through the machine. So some of this troughing may be in fact be due to the constraint to the original width at the ends of the webs and then having the neck down in the center of the webs. You have some shear stresses that are built into that. So in running these webs you may in fact see a very different behavior on some of them and some other part of this again. It can give you similar effects of toughing in some sense due to attempts to change width.

Question – Al Forrest, DuPont
In wound rolls we see this buckling type of phenomenon and you can show that the first mode of buckling is a sine wave which is the same type of troughing that you get between rollers with films and paper. I believe it's the same type of thing. As we understand it, it's the necking end of the film between the rollers that causes sort of a compressive loading in the transverse direction. It introduces this buckling. I believe John Shelton did some work on that and found that a closed form solution to the stress in a web between two rollers and you can actually show how it is that you get that little compressive type of feature that can give rise to a buckle and again the first mode of buckling in something that has some type of lateral constraint and certainly the tension effect between the two rollers gives you a lateral constraint that sends a corrected back to the center. The first sign of buckling is a CD-strain and it's fairly easy to show mathematically and you can set up a little experiment to shows this also. So that's basically our understanding of what causes that troughing.

Answer - Rolfe Bosse, Munich
But the sinusoid troughing is only in the middle of the web, the edges are usually free of buckles.

Question – Al Forrest, DuPont
Well if you think of how the compressive load could flow into something like that, at the free edge there can be no compressive loading.

Answer – Rolfe Bosse, Munich
That's it.

Question – Al Forrest, DuPont
Okay, so the compressive loading has to be bigger in the middle and at the free edge it has to be back down to zero.

Answer – Rolfe Bosse, Munich
That's the model.