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THE ORIGIN AND ALLEVIATION OF THE CD VARIATIONS IN THE PHYSICAL PROPERTIES OF PAPER

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ABSTRACT

It is shown that many physical properties of paper vary significantly in the CD, as much as 10% or more. These variations are believed to be due to the great dependence of sheet properties on the jet minus wire speed differential, and on the large random variations in the headbox discharge velocity, especially from older, air-padded headboxes run at speeds greatly exceeding their design capacity. These jet velocity variations arise both from partially plugged tube bundles feeding the headbox, and from eddy currents created by the slice rectifier roll.

Instead of replacing such headboxes to overcome these problems, it is proposed that two elements of slow (100 m/min), early 20th century Foundriniers missing from modern high speed machines be re-introduced. One is a "stilling" zone on the first part of the wire, once supplied by an apron; this can now be provided by a wide non-dewatering forming board. The second element is a unique Formation Shower which generates CD shear-inducing (like that due to a shake) repetitive ridges, and keeps the stock dispersed throughout the forming zone. The excellent results obtained in the first commercial installation employing these concepts at 650 m/min on light weight papers are presented.

INTRODUCTION

It is long been known that the properties of machine-made papers vary both in the machine- (MD) and cross-directions (CD). The major recognized sources of the MD variations are furnish changes and drifts, and changes in the refining conditions and the headbox consistency, etc.; while those of the CD variations are the condition of the dewatering elements, basis weight and moisture non-uniformities, and the pressing and drying conditions. What has not been widely recognized and is only now coming to light is that in the case of many paper machines, especially older ones, the CD variations of many properties greatly exceed those in the MD, at least over the short term, i.e., during a given production run. The source of these variations and the mechanisms responsible for them were only recently postulated for the first time, as far as we are aware (1).

In this paper, some randomly-selected CD variation data of several sheet properties from (1) are presented, followed by a theory of their origin, and finally, a suggested means of eliminating or at least alleviating them.

THE CD VARIATIONS OF SOME SHEET PROPERTIES

We first became aware of the large size of the variations of many sheet properties in the CD while taking profiles of the formation quality of reel strips with an M/K Systems, Inc. Microformation Tester (2). This instrument and the nature of the Formation Index which it provides are described elsewhere (3). It suffices for our proposes here to state that the Formation Index rises with improved sheet uniformity as judged by eye, and that a 20-25% increase represents a significant improvement in the appearance of a sheet.

We reported large random CD variation in formation quality in reference (2), and Figure 1 is reproduced from that article. We speculated that these variations were caused by the excess dewatering and sheet formation occurring on the forming board of most paper machines, particularly on those producing lighter weight papers. However, we did not theorize on the mechanisms responsible for these variations.

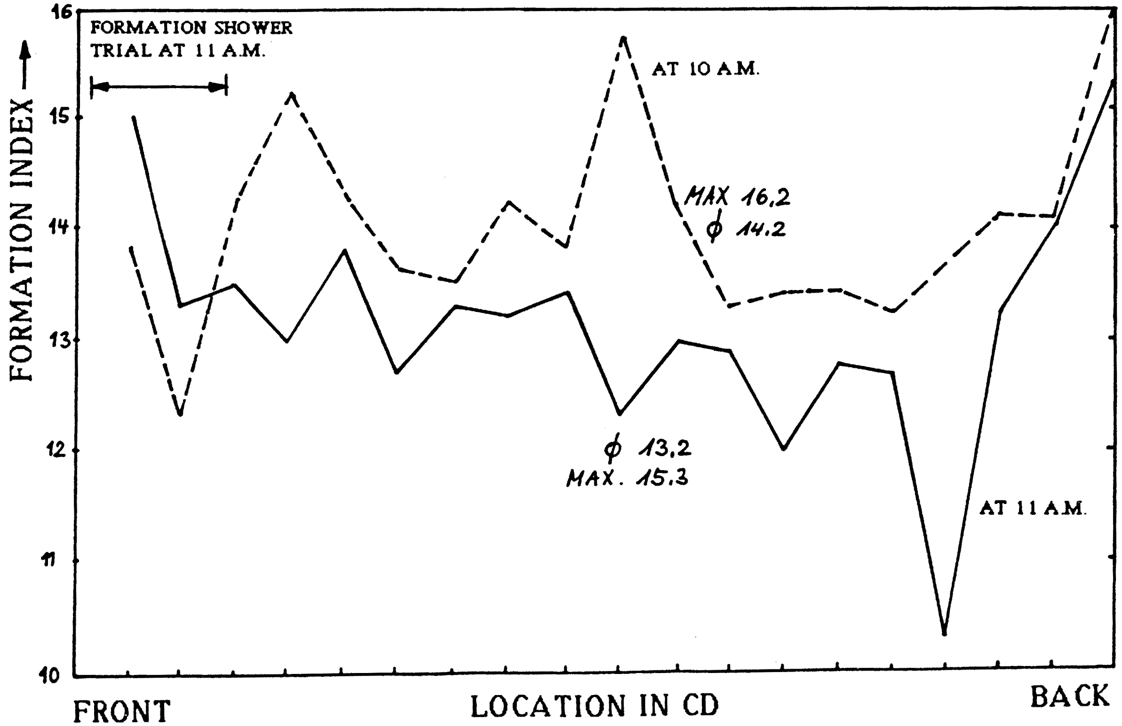


Fig 1—CD Formation profile across a Fine Paper machine (from (1))

During the development of the QNSM Formation Tester in the early 1960's, Burkhart, Wrist, and Mounce (4) also reported excessive CD variations in formation quality. However, they did not speculate upon their origins either.

Formation quality is not the only sheet property showing excessive CD variations. R. Jones (1, 5) provided the CD profiles of the MD:CD tensile strength and tear ratios of newsprint reel strips shown in Figures 2 and 3. A mill wishing to remain anonymous provided the CD profiles shown in Figures 4 and 5 of the MD and CD tensile strengths of 205g/m^2 linerboard from reels produced 40 minutes apart on a 600m/min machine equipped with a hydraulic headbox. On the basis of these and many other comparable data, we have concluded that one can go to the test station at the end on many paper machines, especially older ones, and observe similar variations whenever physical tests are run across a reel strip, i.e., in the CD.

The economic consequences to the paper industry of such CD variations in sheet properties are incalcuable. How many times has a shipment been returned to a mill after it had made specifications on the basis of an average only to fail at the customer's plant on the basis of more scrutinous tests. Most likely, papers with large localized CD variations probably have equally large localized MD variations, a matter we have often observed but have not examined in any depth. But if this is the case, -as it most likely is-, then when one CD reel strip makes specifications on an average basis, another one only a few meters downstream in the MD may well fail.

It is well-known that the tension applied to a sheet during drying has a pronounced effect on many of its mechanical properties. It is also well known that the tension applied on a sheet in the CD is a minimum at the edges of a paper machine, and a maximum at its center. As the effect of the tensions applied in one direction have a negligible effect on the mechanical properties in the perpendicular direction (6), drying tension may well play a role in some regular CD variations in the mechanical properties of a sheet. However, it is highly unlikely that CD drying tensions play much of a role either in irregular

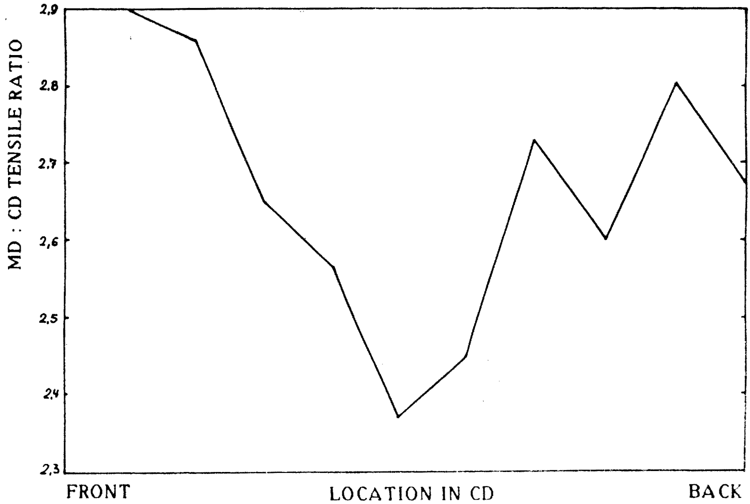


Fig 2—MD : CD Tensile ratio across a Newsprint machine

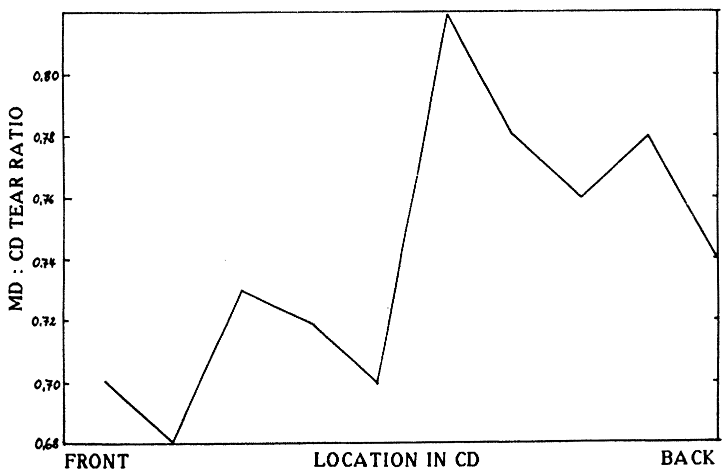


Fig 3—MD : CD Tear ratio across a Newsprint machine

CD variations in the mechanical properties of paper or in non-mechanical properties such as formation quality.

A THEORY OF THE ORIGIN OF THE CD VARIATIONS IN SHEET PROPERTIES

In a classical set of papers by Schroder, Svensson, and Ostenberg, et al (7, 8) in the early 1960's, it was shown that in the 120-240 m/min speed range, many sheet properties are highly dependent on the jet-to-wire speed ratio in the 0.9-1.1 range. Among the properties examined in considerable detail were the MD:CD ratios of the three primary characteristics of the load-elongation curve of paper (its elastic modulus, failure strength and stretch), its tear ratio, its bursting strength, and its formation quality. It was found that the difference between the MD an CD strength properties were a minimum when the jet-to-wire speed ration was equal to about 1.0, and that the burst and formation quality were optimum at this ratio as well.

It is unfortunate that the curves of references (7) and (8) were plotted as a function of the jet-to-wire speed ratio as shown in Figure 6 reproduced from reference (7). The data points of these two curves are replotted in Figure 7 as a function of the jet-minus-wire speed differential, and independent of the sign, i.e., independent of whether the paper machine was run in a rush or drag mode. Clearly, all of the data points fall more or less on a given curve.

When the formation curves from (7) (as shown in Figure 8) are replotted in the same manner as in Figure 9, the data fall on two curves. This result can be interpreted to mean that the formation quality of a sheet is a function of both the absolute machine speed (via an overall difference in the fiber dispersive forces generated), and the size of the jet-minus-wire speed differential.

The important conclusion to be drawn from all of this is that the sheet properties discussed above are highly sensitive to shear generated in the MD when headbox stock travelling at one speed lands on the bare wire of the

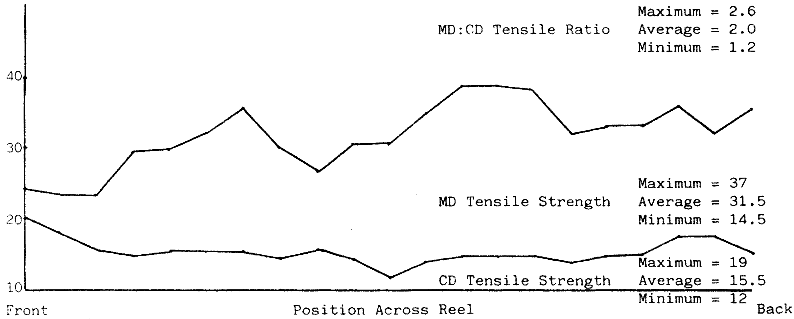


Fig 4—Tensile properties of Reel Strip of Linerboard at 8.30 am

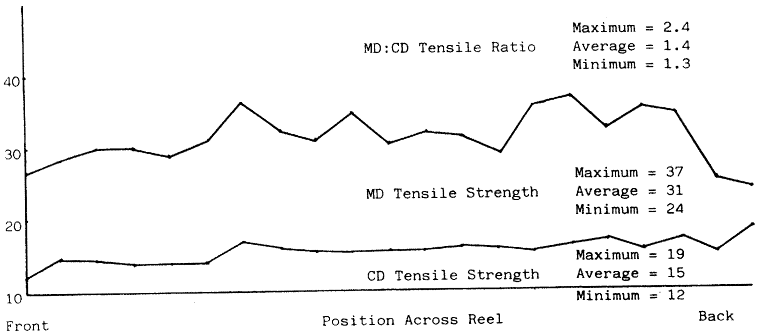


Fig 5—Tensile properties of Reel Strip of Linerboard at 9.10 am

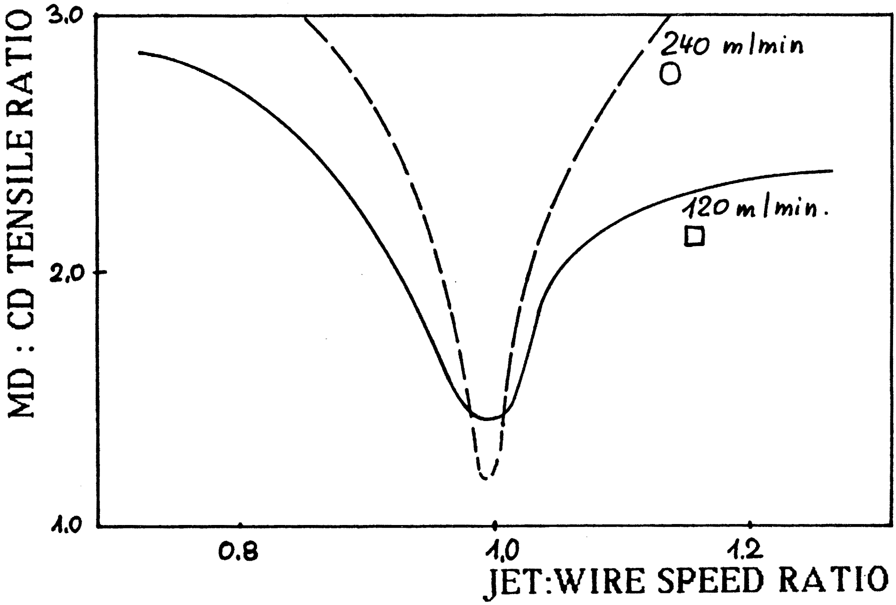


Fig 6—MD : CD Tensile ratio as a function of Jet : Wire speed ratio

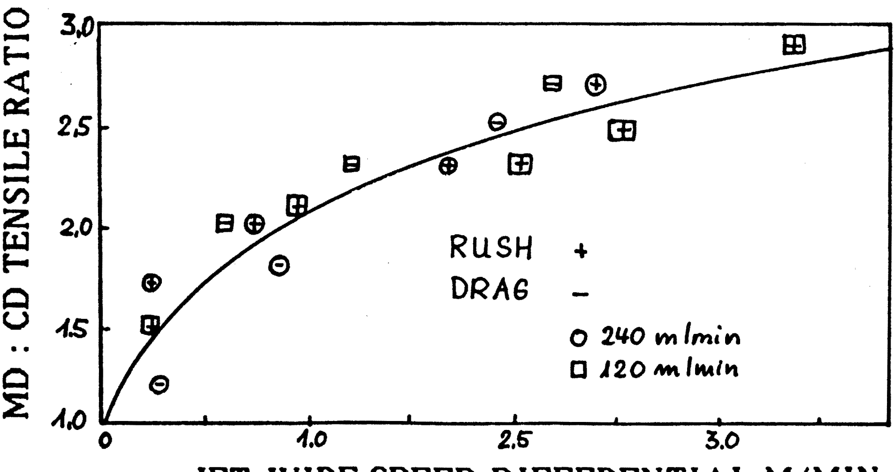


Fig 7—MD : CD Tensile ratio as a function of Jet : Wire speed differential

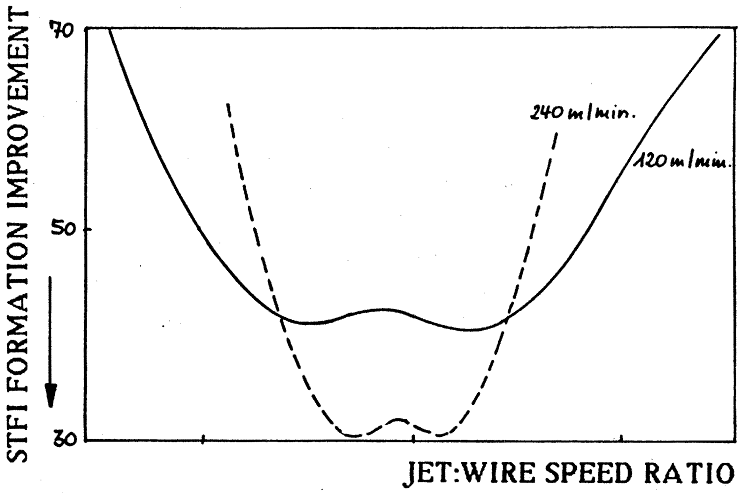


Fig 8—Formation as a function of Jet : Wire speed ratio

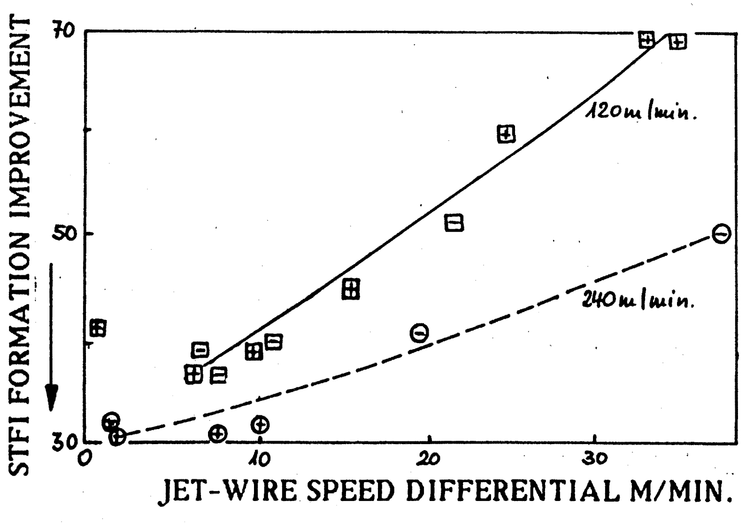


Fig 9—Formation as a function of Jet — Wire speed differential

Fourdrinier travelling at a slightly different speed. However, the effect of this MD shear on these sheet properties appears to be independent of which parameter is larger, the jet or the wire speed.

Forgacs reported in (9) that there is a considerably larger degree of MD bias in the fiber orientation on the wire side of newsprint than on its top surface, illustrating the effect of MD shear on fiber orientation. Newsprint is typically formed under drag-conditions for runability reasons. The top side of the sheet, formed after the MD shear has been dissipated by frictional drag forces during the run of the stock down the table, exhibits a far more random fiber orientation distribution than the wire side.

It was discussed in reference (2), and has long been known from observation, that the largest proportion of dewatering and sheet formation per unit drainage element occur on the bare wire over the forming board, and that these phenomena decrease step-wise down the table as sheet formation progresses. Typically, 1/4-1/2 of water is removed, and roughly the same proportion of light weight grades is formed over the forming board of Foundriniers when "velocity" forming is employed, i.e., when the jet is landed on the wire as horizontally as possible. On the other hand, with "pressure"-forming, i.e., when a relatively larger jet impingement angle is employed, as much as 1/2-3/4 of lighter weight sheets is formed on the forming board.

All of the above factors are hardly new, and do not of themselves explain the large random CD variability in sheet properties. However, there is a newly-discovered element in the picture which seems to us to obviate the origin of the irregular CD variations in sheet properties. This is the large and often high frequency CD variability in the velocity of the jet being discharged from many headboxes, particularly older ones.

R. Jones (5) and we have measured the velocity of these discharges across the width of a number of headboxes with "projection slices" employing a Doppler Shift Flow Meter. Such instruments are generally employed to measure the velocity of flows in pipes by holding their probe against their outside surface; it is a totally non-interfering test. As this instrument is a widely-used tool in the paper industry, its principles of operation are well-known and will not be discussed here.

The flat probe of a Doppler Shift Flow Meter can be held reproducibly against the slice lip in front of the "formation bar" (or "spoiler" or "parrot beak") of any headbox with a projection slice; see insert of Figure 10. By moving the probe from point-to-point across the slice, the relative CD velocity profile on the jet can be readily measured.

The curve of Figure 10 shows a typical CD jet velocity profile of a 20-year old headbox being run at about double its original design capacity. The jet velocity is seen to vary in excess of 10%. Introducing this new finding into the two parameters discussed above, namely (1) that many sheet properties are highly dependent on the jet-minus-wire speed differential, and (2) that an inordinate amount of web formation occurs on the forming board where this differential is a maximum, a major source of the origin of the irregular CD variations in sheet properties becomes obvious. In other words, if the jet-to-wire speed differential varies as much as indicated by Figure 10, then a glance at Figures 7 and 9 tells us that many sheet properties must vary accordingly.

In addition to these CD variations, we have also observed similar large scale, high frequency MD variations when holding the probe of the Doppler Shift Flow Meter at a fixed location of the slice. These variations were conformed by the comparable variations in the jet-to-wire speed ratio recorded by the on-machine computer. These oscillations undoubtedly are a major source of localized MD variations in sheet properties.

We believe these velocity variation stem from at least two sources. Firstly, it has been found (5) that very often (again particularly in the case of older headboxes) the stock velocity varies markedly from tube-to-tube of the tube bundle feeding a headbox; see Figure 11. It appears that the tube bundles of many older headboxes suffer from a form of "arteriosclerosis" (10).

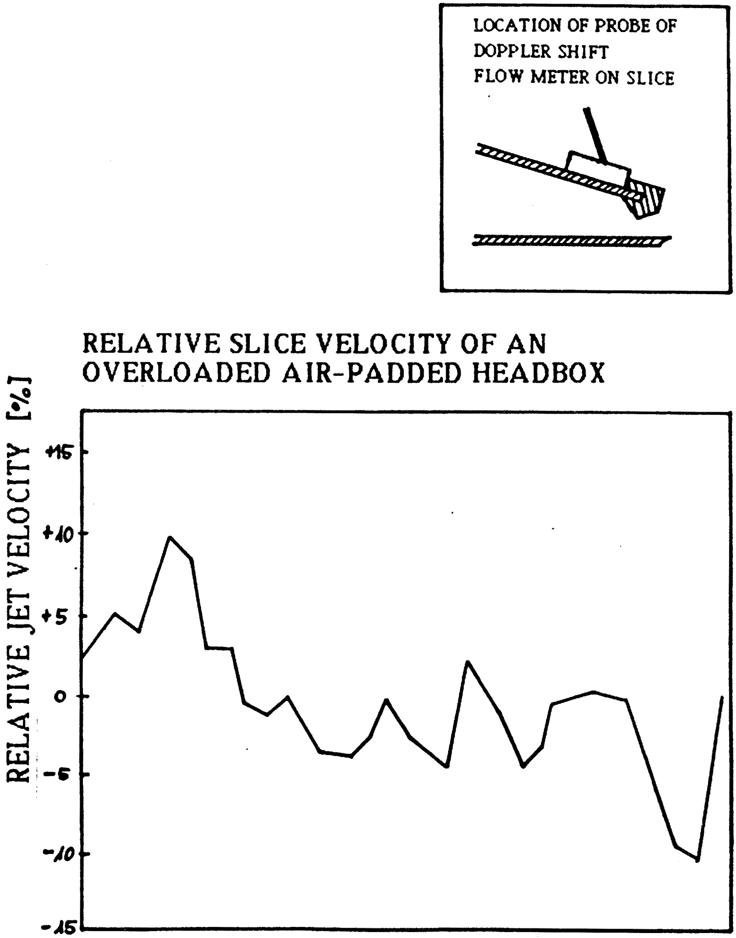


Fig 10—Relative slice velocity profile of an overloaded Air-padded headbox (from 14)

As the only resistance to the stock flow between the tube bundle and the slice of air-padded headboxes are two or three rectifier rolls with a pressure drop of a few centimeters of water, the flow variations from the tube bundle readily pass through the slice.

In hindsight, the partially plugged state of tube bundles is not a surprising finding. The fact is that there are very few air-padded headboxes in which the tube bundle is readily accessible to inspection or to mechanical cleaning with brushes. The majority of mills rely on the high velocity of the stock flow through their tube bundles, and to periodic boiling out to keep the pipes clean. Clearly, this is not adequate in the long run in many cases.

A second probable cause of the CD jet velocity variations is the slice rectifier roll itself, especially in the case of headboxes being operated at flows far in excess of their original design capacity. In fact, the suitability per se of slice rectifier or "holey" rolls in headboxes is brought into question (10)

The primary objective of the headbox is to deliver the exact same quantity of fluid to the forming wire at a single velocity from point to point across the width of the machine. This concept has always been fundamental to papermaking, and central to headbox design (11).

If, in addition, the fibers in the delivered stock are in a well-dispersed state, so much the better. But this latter characteristic is not nearly as critical as the uniformity of the velocity in the CD. This is because irrespective of the degree of fiber dispersion at the slice, the stock will reflocculate in a matter of centimeters of its travel down the table unless it is treated properly there (10). Good sheet formation is achieved on the wire, not in the headbox; see (10), for example.

Given these requirements, it seems rather incongruous that the last structural element through which the stock flows just ahead of the slice is a roll which divides its

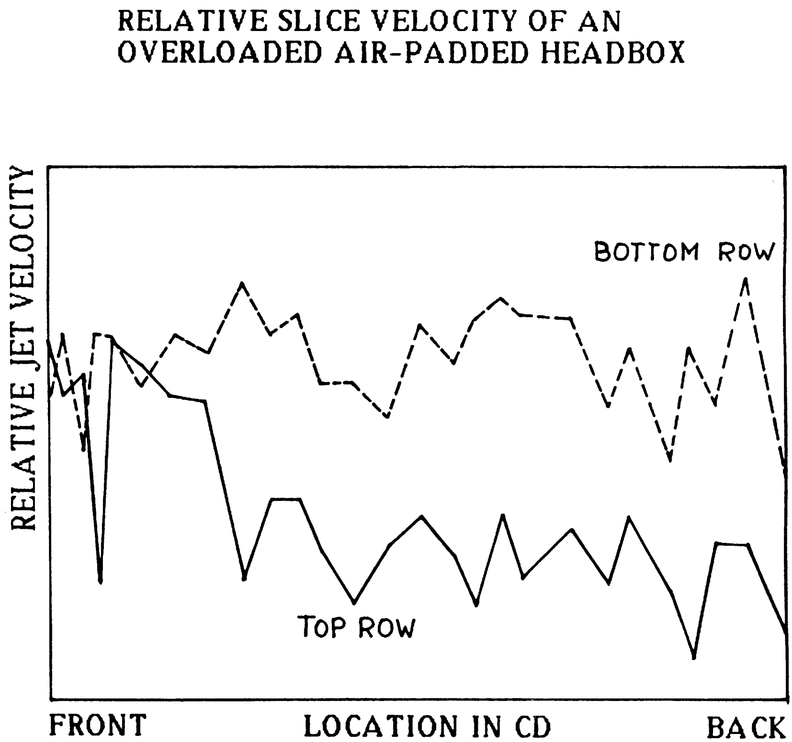


Fig 11—Stock velocities in Inlet tube bundle of an overloaded Air-padded headbox (from (14))

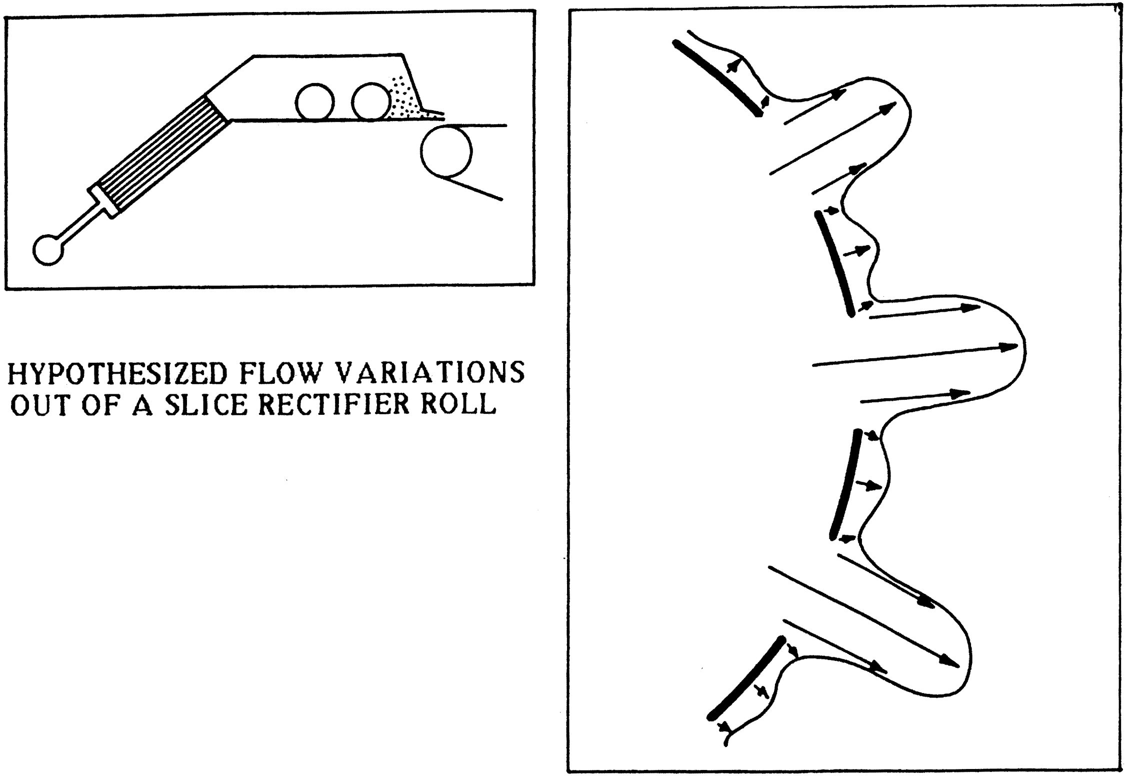


Fig 12—Hypothesized flow variations out of a Slice Rectifier Roll

velocity more or less equally into zones with a large velocity, V, and a velocity of essentially zero; see the sketch in Figure 12. Clearly, if the discharge of a slice rectifier roll were deposited directly and undampened onto the forming wire, it would be impossible to form a sheet of paper.

So the design of air-padded headboxes calls for a "stilling" zone between the slice rectifier roll and the slice lip in which the severe flow variations and eddy currents produced by this roll die out. When a properly-designed air-padded headbox is run well within its original flow specifications, this does in face occur (12).

The problems arise when a headbox is run at flows which significantly exceed its design capacity, i.e., after the paper machine has been speeded up (as almost invariably happens with time). Then the "stilling" zone is too short, and the headbox discharge contains large flow variations, i.e., streaks and eddy currents. Most likely, these rectifier roll eddy currents are in addition to the flow variations induced by the now partially plugged tubes on the inlet which most likely have not been brushed out since the machine start-up either.

Finally, it is curious indeed (or is it?) that the new generation of headboxes, the "hydraulic" ones, do not have slice rectifier rolls. In fact, when one suggests installing such a roll in a hydraulic headbox, one is met with incredulous stares. But isn't "what's good for the goose, good for the gander"?

ALLEVIATING THE VARIATIONS IN CD PROPERTIES

Short of replacing an old air-padded headbox, how can its CD flow variations be eliminated or at least be reduced? One obvious approach is to replace its old tube bundle with one that can be properly cleaned out, and increase the size of its "stilling" zone. These steps require a major rebuild, in which case it might be just as well to start over with a new hydraulic headbox (which have their own set of problems! (10)).

A second approach is to re-examine (i.e., "research") the manner in which paper was manufactured before the advent of high speed papermachines. These early Fourdriniers in general produced papers of much higher quality than are made today without headboxes per se, and without turbulence. This latter point is a most important concept to bear in mind in the following discussion.

Early Foundriniers employed two practices which are missing from modern high-speed machines. As shown in Figure 13, the "headboxes" of these early machines - usually a pond with a pair of knife slices, and in some cases, with a rectifier roll inbetween - delivered the stock onto a flexible rubber apron. This apron completely prevented dewatering and sheet formation for the first 20-50cm of stock travel down the Fourdrinier. During the travel of this thin layer of stock (with a thickness or "scale" equal to that of the slice opening) on the apron, there must have been considerable dampening out of the flow non-uniformities coming from the headbox; why else the apron? (see below).

In addition to an apron, slow speed Fourdriniers had (and still have) a shake which provides CD shear throughout sheet formation. In reference (13), we showed that a 5 Hz shake on a 60m/min machine introduces a new CD shear-generating pulse into the stock every 10cm of its MD travel down the Fourdrinier. This type of pulse is probably the most effective fiber dispersing force available of the Fourdrinier because :-

1. It acts virtually continuously through the forming zone on the stock which, as a rule, would otherwise reflocculate within 5-100 milliseconds after the decay of shear or fine-scale turbulence (10), and

2. It acts on all of the stock in a uniform manner. This is in marked contrast to stock jump type turbulence, which throws stock upwards in a more or less random manner in the hope of producing a uniform fiber distribution. Clearly this is a contradiction in concepts. It is effective only because randomly-induced fiber dispersive forces are more effective than none

whatsoever because of the reflocculation characteristics of stock.

As paper machines have been speeded up, the distances between the points of application of CD shear by means of the shake have been increased proportionately, resulting in a great decline in their effectiveness. In general, their contribution to sheet uniformity dies out at machine speeds of 300-400 m/min.

During the past five years, we have been working on a number of techniques for introducing the same type of CD shear on high speed Fourdriniers as is produced by shakes on low speed machines. The most promising means we have found to date are the serrated slice (14) of which there are about 200 in operation around the world today, and more recently, a unique Formation Shower discussed below in detail.

The most severe problem which we have encountered in working with serrated slices are the flow non-uniformities of headbox discharges. When a serrated slice is installed on a headbox with an unstable discharge, its non-uniformities are greatly amplified. Depending on the magnitude of these flow disturbances and the machine speed, the stock flow on the first part of the wire may either "jump", "spout", "rooster-tail", or in the most severe cases, literally fly in the form of a giant spray down the table. When this occurs, it is impossible to form a decent sheet of paper, and the serrated slice must be replaced once again by a straight one.

It was while viewing the unstable discharge of a headbox with a straight slice on a papermachine producing a new grade of unacceptable quality at about 500 m/min that we first conceived of the approach described below. This approach provides the two key elements to formation of old Fourdriniers missing on modern high speed machines, (1) a "stilling zone" on the wire, and (2) a means for initiating and maintaining CD shear throughout the forming zone. We call this approach "Modified Shear Forming" (Patents applied for) to distinguish it from Shear Forming with a serrated slice and a non-dewatering forming board for Formation Board as described in (15).

In this modified approach, the narrow dewatering blades of the forming board are replaced by contiguous, non-dewatering flat blades; see Figure 14. Depending on the severity of the flow disturbances in the headbox discharge, the non-dewatering zone on the Fourdrinier may be extended partially down the first foil beam by equipping it with non-dewatering blades as well, and abutting the leading edge of its first blade to the trailing edge of the last non-dewatering blade of the forming board.

When a slow moving, thick fluid body (circa 30cm deep) like the pond inside of an air-padded headbox is stretched out into a fast moving, thin layer (typically 2 cm) with a free surface like stock on the wire, the velocity variations within it, i.e., its streaks and eddy currents are diminished rapidly. This is because the size of "scale" of the flow variations are greatly reduced (from a maximum of 30 cm down to 2 cm in this example), and the rate of decay of such currents in inversely proportional to their scale.

This solution, or at least alleviation of the CD headbox discharge flow variations, like so many other "solutions", has its own problems. Firstly, it reduces the dewatering capacity of the Fourdrinier table somewhat and more seriously, it provides significant time for severe stock reflocculation on the wire.

The loss of dewatering capacity by closing up the forming board and perhaps part of the first foil beam is readily compensated for in a number of conventional ways. Unused foil slots might be filled with blades; larger angled blades employed; an additional foil beam installed if there is room (as is generally the case); or top wire dewatering supplied as is becoming increasingly common.

There are two approaches to keeping the stock dispersed on the Fourdrinier. The most widely-used one today is to introduce random stock-jump type turbulence by means of foil blades. This method is optimized by careful regulation of the spacing of the blades and their angles; see (17) for example.

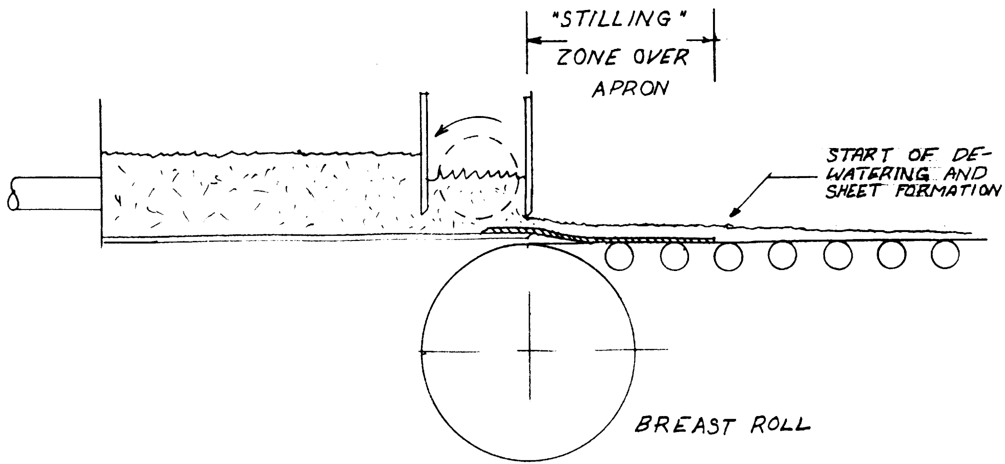


Fig 13—"Headbox" and initial forming Zone of an early Foundrinier

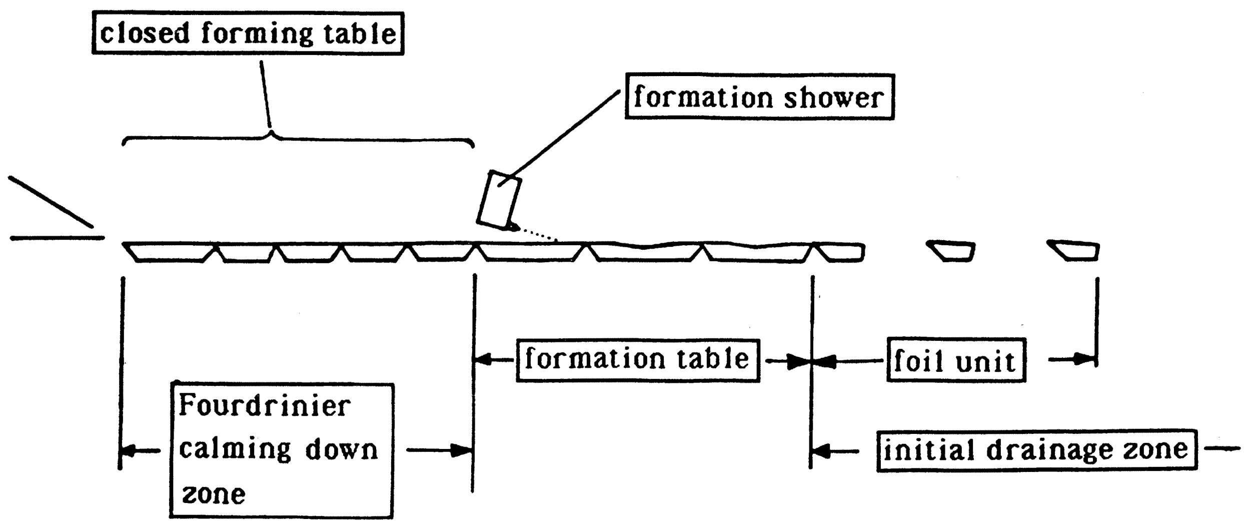


Fig 14—Table layout for "Shear Forming" on machine with an unstable headbox discharge.

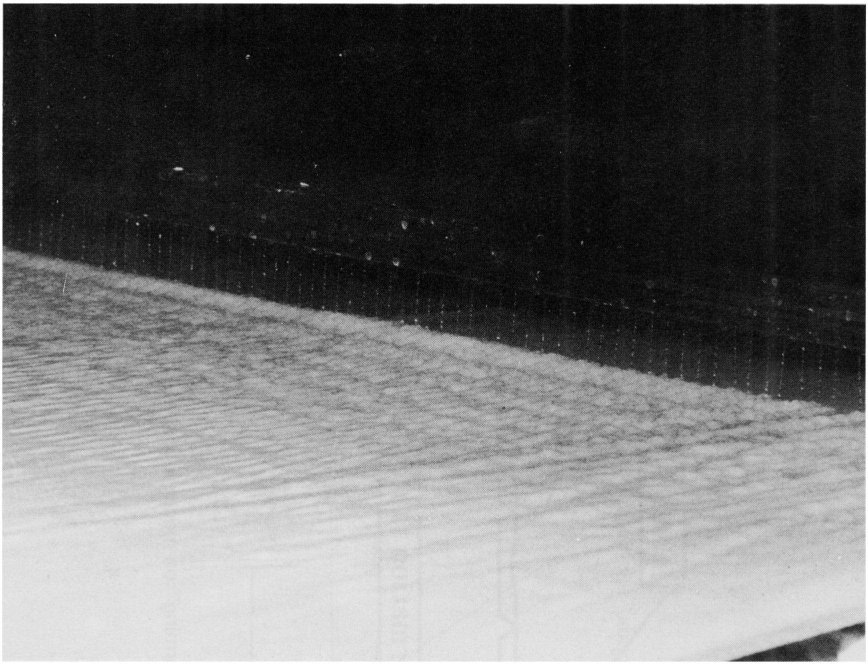


Fig 15—Home-made shower causing severe and essentially useless stock-jump

The second approach is to introduce CD shear. In the case of a slow machine, i.e., below 100 m/min., a high speed shake of 3-5 Hz is highly effective, far more so than stock jump type turbulence. On higher speed machines, where the effect of the shake is lost, we have found that multiple phase-changing ridges generated by a serrated slice or a properly-designed formation shower appear to be able to produce results comparable to that of the shake at low speeds (14).

The serrated slice (14) is now in fairly wide use in North America with over 100 installations on machines producing all types of paper including tissue, newsprint, fine papers, sack papers and even heavy boards. In addition, there are a comparable number operating in Europe, and a handful in other parts of the world.

While it has long been known that the collapse and regeneration of regularly spaced ridges is perhaps the most effective means available for redispersing stock on the wire of a paper machine (14, 16), the physical mechanisms involved have not been elucidated to date. A quantative description of what we believe them to be is presented in the Appendix.

As already discussed, the serrated slice is only effective in producing phase-changing ridges on paper machines with a stable uniform headbox discharge. In the case of paper machines with unstable discharges, we believe the best means for redispersing the stock is to employ a properly-designed Formation Shower on the end of a non-dewatering Forming board after the flow variations have been largely dissipated; see Figure 14. We emphasize the term "properly-designed", as virtually all of the many formation showers in use today (primarily on board machines) are crude, home-made affairs consisting of a pipe with un-deburred, drilled holes operated at a fairly high pressure; see Figure 15. The jets of water produced by such showers generally break up before they impinge the stock surface, and generate only severe stock jump. Such action does little to enhance sheet uniformity.

Fig 16—Properly designed Formation Shower

A properly-designed Formation Shower employs closely-spaced nozzles producing needle jets which strike the stock surface as continuous streams at an acute angle from a small height; see Figure 16. It is operated at the pressure which gives the needle jets a velocity about equal to that of the wire speed. At this pressure, the landing of the needle jets on the stock does not cause any stock jump, at least up to 650 m/min. (this is the maximum speed at which we have employed it to date).

A Formation Shower of the type described above produces the same type of ridged flow as a serrated slice. When it is mounted at the end of about a 1-1 1/2 meter long non-dewatering forming board instead of at the slice proper, it acts on a much calmer flow than that at the slice. In other words, a long, non-dewatering Forming Board on a high speed machine as shown in Figure 14 replaces the apron on the slow-speed Fourdrinier. The properly-designed Formation Shower replaces the shake, and redisperses the stock prior to the initiation of sheet formation on the wire. When these ridges are allowed to collapse and reform several times during the travel of the stock down the wire (by the methods described in (15)), CD shear is generated throughout the forming zone, and the sheet formation quality is greatly enhanced.

THE INITIAL MODIFIED SHEAR FORMING SYSTEM

The initial modified Shear Forming System was installed in October of 1984 on a high speed Fourdrinier (500-600 m/min) employing a rectifier roll headbox with a vertical slice producing a highly unstable discharge; see Figure 16. In the past. this machine has been producing acceptable lightweight papers (in the $20g/m^2$ range) only from highly refined, slow furnishes. When it was used experimentally to produce free sheets of comparable weight from fast-draining furnishes, the grades were of unacceptable quality. The sheet was characterized by pronounced streaks at a regular spacing of about 2.5cm, a distance equal to the center-to-center spacing of the holes of the slice rectifier roll. In addition, the sheet was extremely "floccy" in appearance, and had a low Formation Index; see Figures 18 and 19.

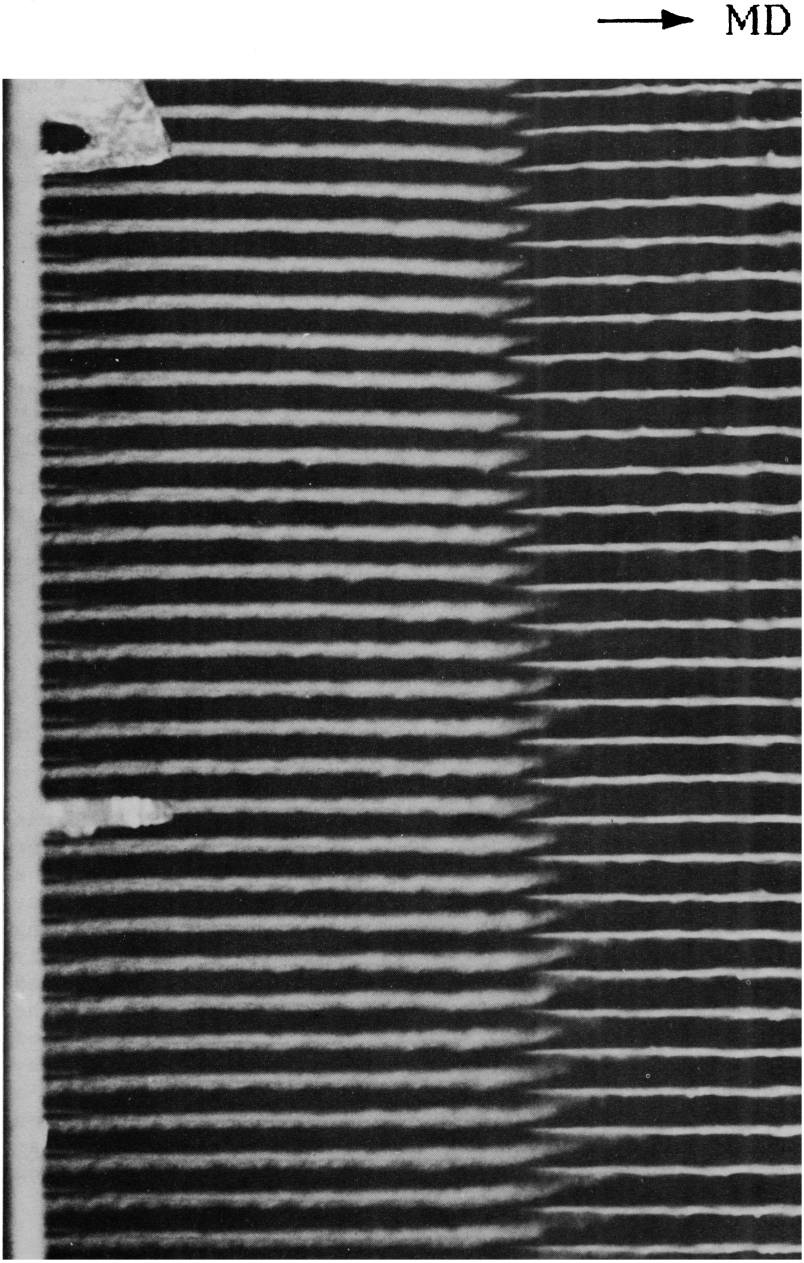
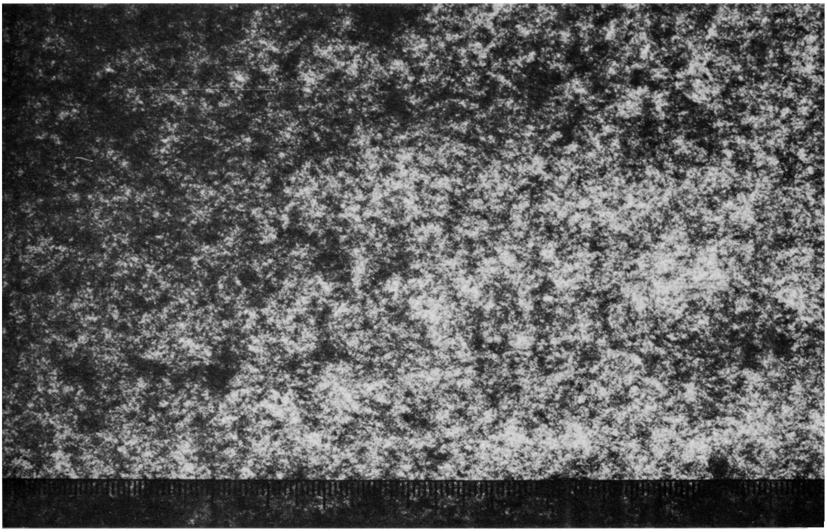


Fig 17—"Rigid flow" of stock produced by a properly designed formation Shower



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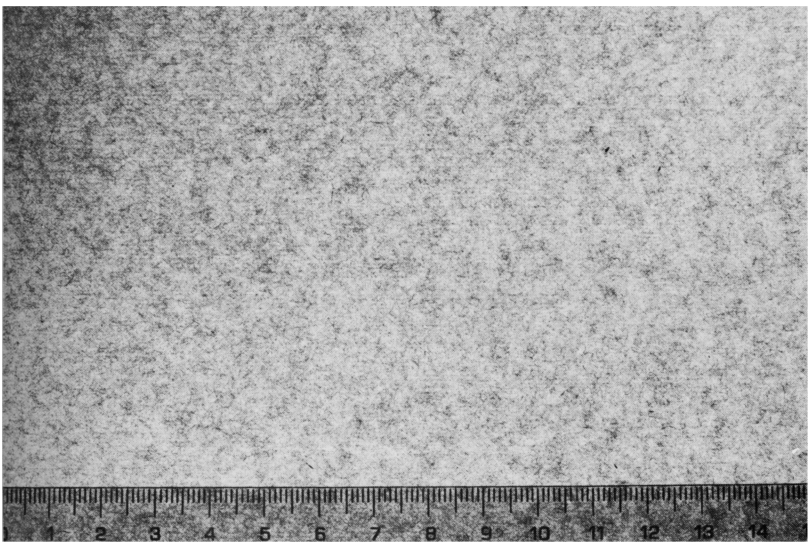

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Fig 18—Transparencies of sheets 1 - before and 2 - after installation of Modified Shear Forming System

After the installation of the non-dewatering forming board, a pair of non-dewatering blades in the first two positions of the first foil beam, as well as the properly-designed Formation Shower over this last blade, the sheet was markedly improved. The Formation Index of the free sheet was increased, on the average, over 50% (for example, 6.2 vs 3.8 for some typical, randomly-selected samples as shown in Figure 18). The flocs were greatly muted, and the streaks from the slice rectifier roll were as faint as those of the slow, former grades. In the words of the mill superintendent, "I don't think we'll ever turn that shower off".

The characteristics of the lightweight sheet produced from slow-draining stocks were greatly enhanced as well. The most useful gain to the mill was an increase in Sheffield Smoothness from the 30-50 range to 50-75.

The measured CD formation profiles of the free draining sheet after the installation of the modified Shear Forming System showed about the same magnitude of variations as the original sheets. In fact, if anything, it was slightly greater (see typical profiles in Figure 19). This result is often obtained on extremely poorly-formed papers which are quite uniformly bad. Phenomena that effect a well formed sheet locally, like a dirty foil blade, etc., do not hurt a badly-formed one. On the other hand, once the formation is improved, these disturbances come into play once more.

The best general evidence of a reduction in CD variations, obtained in this initial installation was the stabilization of the dry line on the wire. Prior to the installation of the shower it was jagged and unstable; afterward, it was a stable, straight line.

The most-feared problem of the installation did not materialize, large-scale plugging of the nozzles. At start-up after a thorough cleaning, only 3 of the 288 nozzles, all near the discharge end of the shower, were partially plugged. After two months of operation, only six were partially plugged. It should be noted that the shower runs with fresh water and has a filter ahead of it.

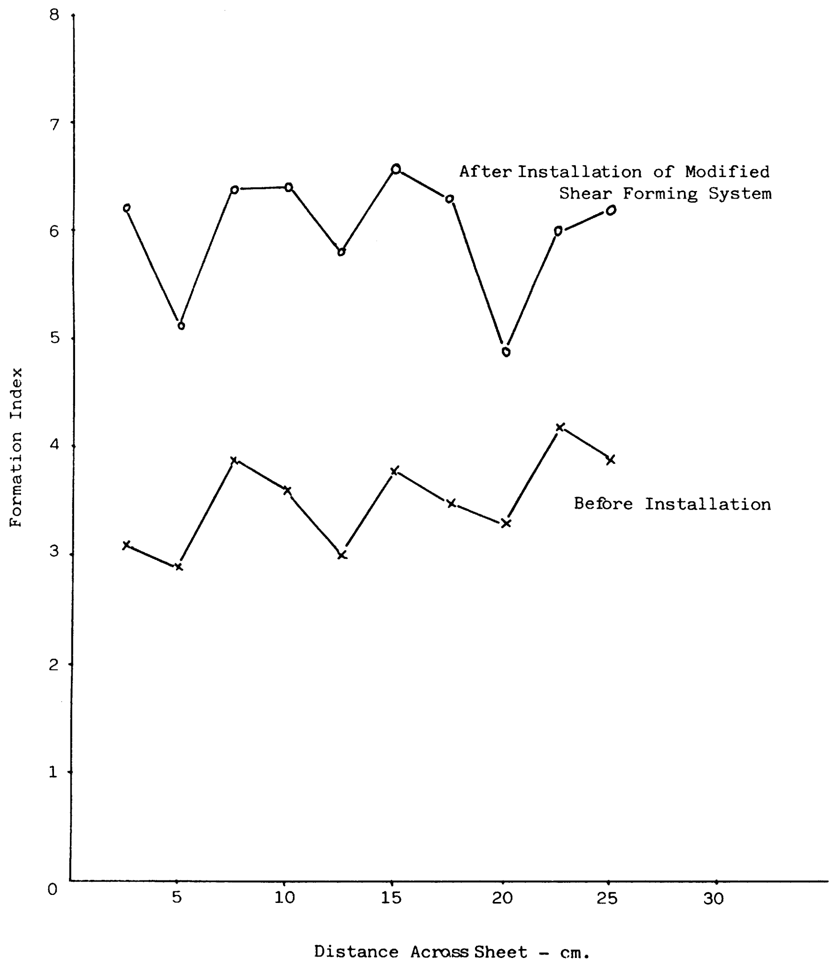

Fig 19—CD Variation of Formation of Free Sheet

In addition, a novel, self-cleaning system has now been installed.

Relative to the magnitude of the rebuild, the improvement in sheet quality obtained in this initial installation is the largest we have ever observed. In terms of the improvement in the average Formation Index, it is about equal to that which we have generally observed with the installation of a top wire former. These devices represent a couple-of-orders magnitude larger capital investment.

FUTURE WORK

Even with over two hundred serrated slices, a dozen or so non-dewatering forming boards, and now a highly successful Modified Shear Forming installation in operation (with two more on order at the time of publication), we consider the concept of Shear Forming to be still in its infancy; much remains to be done.

It is clear that the amount of improvement in formation which can be obtained in any given installation will depend at least upon the following two factors:

1. The better the initial quality of the sheet, the less is the improvement attainable (as by all other formation aids),

2. The distance down the table over which the phase changing ridges are maintained is critical. In some installations, they seem to carry "magically" down to the end of the forming zone, while in others they are destroyed after only one or two phase changes. The following guidelines are useful in extending ridges down the table.

a. Table rolls should not be employed as they invariable destroy the ridges at speeds in excess of about 150m/min.

b The length of the first full set of ridges on the table (i.e., after the first phase change of the headbox discharge on the wire or after the impingement of the shower's jets) is equal to about .08 cm/(m/min) of machine speed. Thus, at a speed of 300m/min, the first set of ridges is about 24 cm in length. Successive sets of ridges are incrementally shorter as the stock dewaters.

Ideally, foil blades should be located at the positions where the phase changes occur, or close to these points. On the other hand, blades should not be located at the midpoint or peak of the ridges as decaying vacuum pulses here cause the ridges to jump, and in some cases, be destroyed.

Sheet formation improvements obtained by Shear Forming should not be considered a substitute for those attainable by the new generation of Top Wire Formers. In fact, we believe the two methods to be complementary. The serrated slices and formation shower operate primarily on the first-formed half of the sheet or so whereas the top wire formers act primarily on the last formed portion. So ideally, a Fourdrinier should be equipped with both.

In the first installation to employ both a serrated slice and a top wire former, a machine producing lightweight fine papers in the 300-400 m/min range, this was found to be the case. Shortly after the start-up of the top wire former, many of its "bugs" were blamed by the supplier on the serrated slice. So the mill finally removed it, with the result that things rapidly went from bad to worse, The serrated slice was reinstalled within 24 hours.

APPENDIX

The Mechanism of Stock Redispersion on the Wire by Means of the Phase Changing Ridges Generated by a Serrated Slice or a Properly-Designed Formation Shower

The best starting point for presenting the mechanism causing the phase-changing of ridges is by means of a description of the following classical fluid dynamics experiment.

Consider what occurs when a small glass sphere, i.e., say a marble, is dropped down onto a large quiescent fluid surface. When the marble strikes the fluid and begins its penetration, it forces the fluid directly beneath it to flow laterally away from the impact zone and build up a circular ridge around it; see Sketch A.

When the marble has fully penetrated the surface and is completely submerged, the fluid surface directly above the marble is concave, and surrounded by the ridge at a greater height; see Sketch B. The head of the fluid ring around the zone of marble penetration initiates a flow to fill in the "hole" left by the marble; see Sketch C. Finally, the surface tension of the fluid acts to minimize its surface area, and also "fill the hole".

Thus, fluid now converges radially to the center point from the raised ring all around the cavity. As the flow streams converge upon each other in the center of the cavity, their colliding kinetic energy causes a column of flow upward at the center.

If the initial energy of the fall of the marble was sufficiently high, then the energy of the fluid returning to the center of the cavity is sufficiently great for drops of water to be sent flying vertically upward into the air; see Sketch D. When these return to the surface, they in turn act as falling marbles, thereby restarting the process on a reduced scale.

SKETCHES OF DROPPING MARBLE EXPERIMENT

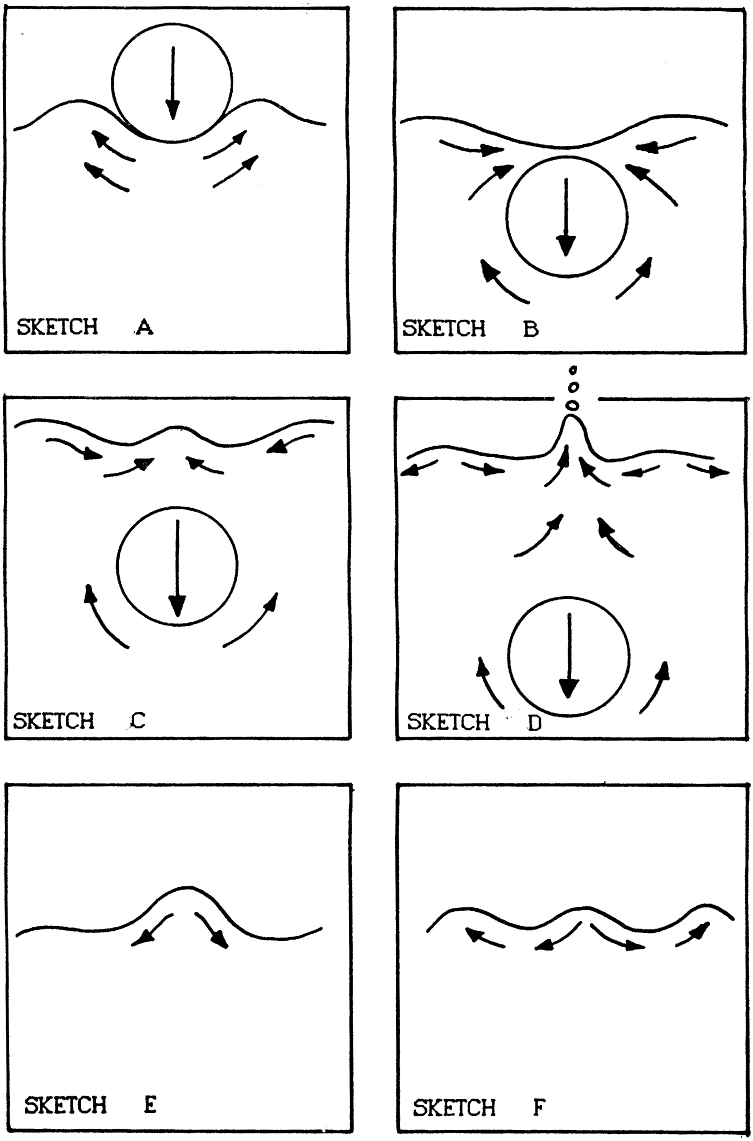

Fig 20—Sketches of dropping marble experiment

Instead of a cavity, the downward projecting corners of the serrated slice (or the fluid needle jets of a formation shower) convert the thin wedge of fluid issuing from the slice (or travelling down the wire) into parallel ridges of fluid. From observation, it appears that for a given geometry of the serrated slice, the wavelength (or life) of the initially regenerated ridges (i.e., after the first phase change on the lead blade of the forming board) is dependent only on the speed of the fluid in the machine direction, i.e., they are 0.08m. in length per m/min. of machine speed. Thus, the ridges of a machine operative at 300 m/min. are roughly 24 cm in length while those of a 600 m/min. machine, 48 cm.

In other words, the initially regenerated ridges take a certain fixed period of time to collapse. This is because their height or the head of fluid causing their collapse is fixed.

When the ridges travel down the wire adjacent to one another, the fluid travelling in the CD during their collapse meet along a line half way between them, just like the fluid rushing toward the center of the cavity in the marble dropping experiment described above. As the two flows from the adjacent ridges are travelling toward one another in the CD, a new fluid ridge is formed midway between them as the initial pair undergo collapse; see Sketch E. In Figure 21 showing the ridges of a serrated slice travelling at about 700 m/min. the formation of the second set of ridges is clearly seen to take place well before the initial ridges have fully collapsed.

We believe there are at least three phenomena occurring during the phase change of the ridges which will promote fiber dispersion. Firstly, there is a lateral mass transfer of fluid as portions of adjacent ridges combine to form new ones. Secondly, there is CD shear created as the ridges collapse and new ones are formed. Thirdly, there must be considerable acceleration and deceleration of the fluid during the phase change, especially at higher machine speeds, as is evidenced by the thinness of the fluid zones between the collapsing and forming ridges; see Figure 21. These velocity changes must also cause fiber-dispersive shear.

Fig 21—Ridges of a serrated slice travelling at 700 m/min

If the phase change takes place over a foil blade, then sheet formation occurs while fiber redispersion is taking place. This is probably the thought that occurred to the late J. Parker in about 1970 when he wrote in his classic book. "The Sheet Forming Process" (16), "Perhaps the most important source of dispersion is the shear generated by the free surface instabilities caused by the wire passing over table rolls (at low speeds) and foils, and by jet impingement on the wire. This shear is so effective because it occurs in the immediate zone of drainage and is not dissipated before it can be used. These instabilities are manifested as MD ridges and eruptions on the free surface in a streaky pattern....

A phase shift of the free surface ridges occurs as they pass over a table roll, the hills becoming valleys and vice versa."

REFERENCES

1 Kufferath, W., & Kallmes. O., Das Papier 38, V164-73, No 10A (1984).

2 Kallmes, O., Paper Trade Journal 168, No.10, 32-5 (May 30, 1984).

3 Miller, C., & Kallmes, O., Pulp & Paper Mag. Canada 79, 2, T61-4 (February 1978).

4 Burkhart, G., Wrist, P.E., and Mounce, Pulp & Paper Mag. Canada 61:No.6, T319-T334 (June 1960).

5 Jones, R., Hyuck Corp., Personal Communications, 1984.

6 Van den Akker, J.A., et al in F. Bolam, Consolidation of the Paper Web, Tech. Sect. B.P. and BMA, Plough Place, Fetter Lane, EC4, 1966, P.477-506.

7 Schroder, S., & Svensson, O., Svensk Papperstidn V.68:1, 25-33 (Jan 1965).

8 Svensson, O., & Ostenberg, L., Svensk Papperstidn V.68:11, 403 (Nov 1965).

9 Forgacs, O., & Strehs, I., Pulp & Paper Mag Canada. 64(1):T-3 (1963).

10 Kallmes, O., & Thorp, B., Presented at 1984 TAPPI Papermaker's Conference, Orlando, Fl. To Be Published in PIMA Magazine, February, 1985.

11 Van der Mear, W., TAPPI 37(11):502 (1954).

12 Wrist, P., in F. Bolam, The Formation & Structure of Paper, Tech. Sect. of BP & BMA, Plough Place, Fetter Lane, London EC4, 1962, p.839-899.

13 Kufferath, W., and Kallmes, O., Das Papier 35, 10A October, 1981.

14 Kallmes, O., & Perez, M., TAPPI 65(11):67-70 (Nov., 1982).

15 Kallmes, O., & Thorp, B., TAPPI 66(12):54-8 (Dec., 1983).

16 Parker, J., The Sheet Forming Process, S.T.A.P. 9 TAPPI 1972.

17 Schmid, W., & Brabetz, H., Wochenblatt fur Papierfabrikation 11/12, 1981

Transcription of Discussion

SESSION 3 WATER

Chairman B.W. Attwood

The Origin and Alleviation of the CD Variations in the Physical Properties of Paper

by O.J. Kallmes, W. Kufferath and B.A. Thorp

D.G.N. Stirling Wiggins Teape R & D, Beaconsfield, England

You showed a graph of the jet/wire speed ratio which illustrated poorer formation at unity. There is no scale on the graph. Could you put some values to the deviation from unity required to produce the optimum formation?

Dr. O. Kallmes It is about 1% or 2% variation from unity, either drag or rush, which is required. It again illustrates the point that a small amount of shear is helpful in improving formation.

Above ± 2% or so deviation, turbulence is induced and this is not condusive to generating improved formation.

Stirling Does that mean that the CD velocity variation across a typical headbox which you have been talking about is greater than this variation?

Kallmes Far greater. There are very few headboxes on the market which exhibit CD velocity variations of less than 1%.

Stirling The second point is that you referred to a machine making one-time carbonising tissue at 2000 ft/min with very good formation. How can you explain that very good formation?

Kallmes The stock was a very slow draining one, and the machine was equipped with a long wire with a large number of foils. Therefore, the effect of the headbox was only imprinted on the first formed portion of the sheet.

If you drain a free beaten stock very quickly, then the headbox defficiencies are imprinted on a large proportion of the formed sheet.

Stirling Why did the slow drainage not allow flocs to form?

Kallmes Because it was such a short fibred furnish.

Dr. H. Paulapuro FPPRI, Helsinki, Finland

Mr. Thorp showed a slide illustrating the differences in velocity caused by the rectifier roll in the headbox. These unstable streaks also occur in hydraulic headboxes. Have you examined the effect of formation showers or serrated slices on the unstable streaks with this type of headbox?

Kallmes The serrated slice works very well on a high turbulence headbox provided the machine is not running at too high a speed.

Paulapuro Have you tried to measure, quantitatively, the unstable streakiness?

Kallmes No, we have not.

Prof G.A. Baum IPC, Appleton, USA

Have you documented any improvement in cross web uniformity with these devices?

Kallmes Yes, we have seen, for example, an improvement in reel hardness profile. Figure 18 on page 471 shows an example of the formation improvement that can be achieved.

Baum Have you taken CD strips and measured tensile ratios?

Kallmes No, we have not looked at tensile strength but we have seen improvement in CD formation uniformity. As a rule of thumb, however, machines with very poor formation often show good CD uniformity on a gross scale. Improvements to formation then can initially lead to a deterioration in CD uniformity. So you have to optimise from there.

Baum We have often observed that the maximum value, of say tensile strength, does not occur along the machine direction but at some angle to the machine direction, due to cross flows. Would you like to comment on that?

Kallmes There are a great many cross-flows in headboxes and these come out on the forming table. I recently saw a new high-turbulence headbox running at 600 m/min with an initial stock height of 3 cm, with no deckle straps, and with no cross-flows visible at all. So it would appear that at least the manufacturer of this box has solved the problem.

Baum Would you expect your showers or serrated slice to minimise the effect of cross-flows?

Kallmes No. Those flows are usually large in scale in comparison with the flows we create.

Baum Those of us who have measured CD profiles in mechanical properties find that you see a bell-shaped distribution from one side of the machine to the other, presumably due to non-uniform drying. Can you comment on that?

Kallmes We are concerned more with variation due to non-uniform fibre distribution rather than those due to drying.

It is remarkable how few really good headboxes there are.

Dr. J. Mardon Omni Continental, New Westminster, Canada

I must disagree with about 25% of what you have said.

I will put in a written contribution in due course.

(An agreed written contribution from Dr. Mardon was not available in time for inclusion - Ed.)

There is a very considerable literature on what is called the wake effect from rolls to which you have not referred. The wake effect is a major problem with modern headboxes with various static turbulence inducing systems.

As you said there is no evidence to suggest that modern, high turbulence headboxes are any better than correctly designed roll boxes.

A large part of your presentation is indicative of the technological slippage which has taken place, especially in North America over recent years. The solution would have been to renew the headbox in many of the cases you cite.

As regards the flocs in the jet in Diane Murdock's picture, as I pointed out in Denver, these probably came from scooping at perforated roll rather than reflocculation. You did not mention the effect of short fibres on flocculation. There is a critical percentage of short fibres mixed with long fibres which will drastically improve formation. Above that critical level the addition of more short fibres has little beneficial effect on formation. This critical percentage is dependent on consistency and speed of flow and can be investigated as we did in 1961-4 in a recirculating water tunnel.

Kallmes I did not hear anything in what you have said with which I would disagree. Ours is not an attempt to review the literature.

What we are doing is to try and do something to improve the formation as we find it. Not everyone can afford the luxury of a new headbox every time the machine speed is increased.

Regarding your comments on Diane Murdock's picture, the flocs appear but where the ridges change phase they disappear and then reform again. So I do think we are seeing the break up and reformation of flocs. Furthermore, the headbox shown did not have a perforated roll.

B.A. Thorp I think Dr. Mardon is correct. Headbox technology has not kept up with the speed at which modern machines are operating. This problem is getting worse not better. When you adjust the profile on hydraulic boxes at high speeds you create a velocity profile. You can see those as a wet streak on the table.

Dr. W. Kufferath A good headbox is not sufficient to guarantee good formation. You also need turbulence on the wire for this.

Prof. K. Ebeling Helsinki University, Finland

I would like to draw your attention to an excellent piece of work by Heikki Sara, "Measurement of paper formation by power spectrum and standard deviation", D. Sc. thesis at Helsinki University of Technology, Dept. of Forest Products, 1978, presented at 1979 EUCEPA Conference, London. In the appendices of this work, the inter-relation between CD properties and formation on high speed papermachines is reported.

A.A. Ibrahim Papyrus Inc., Westerville, USA.

In my experience in the paper industry there is something missing. The jet/wire speed ratio is not precisely known on most machines. Take the whole slice geometry and the forming board distance. Most of the time, it is done incorrectly. There is plenty of information which is available. If one can use the trajectory equation properly the whole system can be set in one unit and have remarkable results.

Kallmes You can set the trajectory right at a point. If the jet velocity is extremely variable across the machine then you cannot set it right all the way across the machine width.

B. Radvan Wiggins Teape R & D, Beaconsfield, England

Could I ask Dr. Kallmes about the terrible looking profiles he illustrated in his talk. How were these measured, and were they real? Laser doppler anemometry can be subject to all sorts of errors which means that it does not measure true velocity.

Kallmes It was actually a sonic device we were using and therefore was looking at the whole flow. In one case the mill did not believe they were experiencing this degree of variation but we were able to correlate the variation seen by the instrument with that measured from the jet/wire ratio by the computer which was a pressure variation.

Radvan Dr. Kallmes's paper has been criticised on the grounds that it reviews well known knowledge. Perhaps that is a little unfair since, after all, these Symposia only occur every four years and we, the audience, cannot reasonably expect to hear brand new knowledge which has emerged over the last three or four months since there is not enough of it to fill five full days. So what I would suggest is that we look for a new slant on old information or a new way of looking at it, preferably based on knowledge which has been acquired during the last four years. It seems to me that this paper fulfills this requirement admirably. It examines the effect of the application of regular shear as against turbulence.

My second comment is very brief. I really don't know what this is all about; if you really want to reduce reflocculation all you have to do is make paper in foam.