

The technical challenges of making better paper: preparing for the 21st century

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ABSTRACT: *Our first steps toward making better paper must be directed at the development of better detection and control methods than those available today. We also must appreciate that the really difficult paper quality problems are a result of complex interactions between the various parts of the paper machine and are not strictly attributable to any single operation. To achieve timely success in a competitive environment, we must conduct both empirical and fundamental research, with each synergistically feeding into the other.*

KEYWORDS: *Forecasts, paper industry, paper machines, productivity, quality control, sheet forming, theories.*

A paper machine is more than an organized collection of high-cost nuts and bolts. One of the most important contributions a machine builder can make is to understand what paper properties are important to its customers and then try to build equipment that maximizes those properties while minimizing their variation. Reduced variation represents a resource that paper manufacturers and vendors need to further exploit.

We think that in the future every machine configuration, down to the individual components, will be carefully scrutinized for its impact on paper properties at dimensions far smaller than we now consider (in the paper plane and in its thickness). When the paper machinery and process produce less variation in all important size classes, the technically oriented papermaker can operate much closer to paper property specifications with-

out fear of producing off-standard product. By not having to compensate for excessive variations, the papermaker can turn his or her attention to more productive endeavors, such as optimizing raw materials while producing a competitive product.

However, we can't attack these issues until methods and equipment are devised to accurately detect, measure, and then control the various sizes we think are important. But, first, we must figure out what is important. Even this will not ensure that the work will be undertaken. There must be a driving force to produce change—something (usually market forces) must convince us that smaller-scale variation is a paper quality issue worth pursuing. As always, nothing comes for free; it will be a slow process and will require commitment and investment in the future.

Fortunately for the technicians and scientists of this world, there are always plenty of problems to solve. This paper poses questions about some of the technical challenges we think our industry faces in producing the uniform paper of the future, suggests where our knowledge could be improved, and mentions several pieces of machinery designed to address these issues as we move into the 21st century.

Improvement in fundamental papermaking knowledge

Paper nonuniformity occurs over a wide range of sizes. **Table I** lists just a few of the many nonuniformities which papermakers either fight or learn to live with every day. Cutshall (1) provides excellent insight into the nature of paper variation.

Today we are able to detect and control large-scale variations like "smiles," "frowns," or "streaks" in the cross-direction (CD) profiles and to some extent even fairly small sizes like paper flocs. At the other extreme we can detect individual molecules if we want to (using an atomic force microscope). However, the paper industry's biggest challenge is to detect and control sizes from several microns to about 10 cm—a large region critical to papermaking.

Many important paper properties are determined at dimensions we don't routinely measure. For example, most commercial formation instruments utilize light transmission (which is great for eyes but not necessarily for printing presses) instead of directly measuring the mass variation, and none

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can adequately detect individual flocs much smaller than about 0.5 mm. Yet, sizes smaller than this are still important, and particles hundreds of times smaller than this are routinely present in the paper. These small particles (fines and fillers) have a large influence on liquid penetration, optical properties and paper strength, yet we really do not have satisfactory means to measure their distribution in the paper.

Some now feel that property gradients are important (how "hard" are the flocs?). Gradient measurements require much higher resolution than is available on our conventional instruments. For example, fiber orientation might be an important paper property, but these instruments measure over distances that are several orders greater than the fibers themselves. This resolution may be sufficient for studying diagonal curl but is too coarse for measuring cockle dimensions.

We don't understand all the reasons for cockle in paper; we can't measure cockled paper and then walk up to the paper machine, turn a knob, and make them go away. We don't really know the mechanisms that cause machine-direction (MD) microstriations (2), although many have tried to reduce or eliminate these nonuniformities and failed. We are not certain if more intense wet pressing produces dimensionally unstable paper just because of higher density or, more likely, because of the increased gradients in density and moisture (3). We can only speculate why a blade former sometimes improves the small-particle distribution without significantly improving the fiber distribution, and we don't fully understand the mechanisms that make formation improve as the headbox consistency is increased toward some optimum condition—experience quite contrary to normal fourdrinier operation.

We cannot detect stable CD basis weight streaks any narrower than about 10 mm. Even if we could obtain better resolution, we couldn't utilize it for control purposes because the narrowest slice actuator spacing is about

I. Dimensions important in papermaking

Some defects	Some tools
Meter region (cm to m) "Smiles", "frowns", "tilts" in CD profiles, streaks, spikes, pulsations	Slice actuators, attenuators, piping support, traversing Beta-gauges, jet velocity gauge, zone control, variable crown rolls
Millimeter region (mm to cm) Formation, grainy edges, felt uniformity, cockle, curl, coater streaks, print and gloss mottle	Soft X-ray, Beta radiographs, image analysis, glossmeter, NMR, stereo microscopy, spectroscopy, ESCA, sonic velocity
Submillimeter region (micron to mm) MD microstriations, print smoothness, surface density and porosity, coating "graininess", "orange peel" gloss patterns, print "speckle", ink dot gain, optical dot gain	Scanning electron microscope, ordinary light microscope, image analyzer, confocal scanning laser microscope, microglossmeter, acoustic microscopy, SIMS, UV microscopy, laser

75 mm. The on-machine MD basis-weight-detection resolution is several orders worse than the CD. Except for extremely long-term variations, active control over time-related events like pulsations or mechanical vibrations coming to the headbox is not yet a reality in the paper industry, although it is used successfully elsewhere (for example, in noise cancellation and automobile suspensions). Today, we can only minimize MD variations with proper design of the approach flow system and structural support—we don't really control it.

Because life can't wait for paper scientists and technicians to come up with all the answers, many decisions on equipment worth millions of (unsubsidized) dollars must be made every day with insufficient information. So, we think there is much in all sectors of our industry that we can do

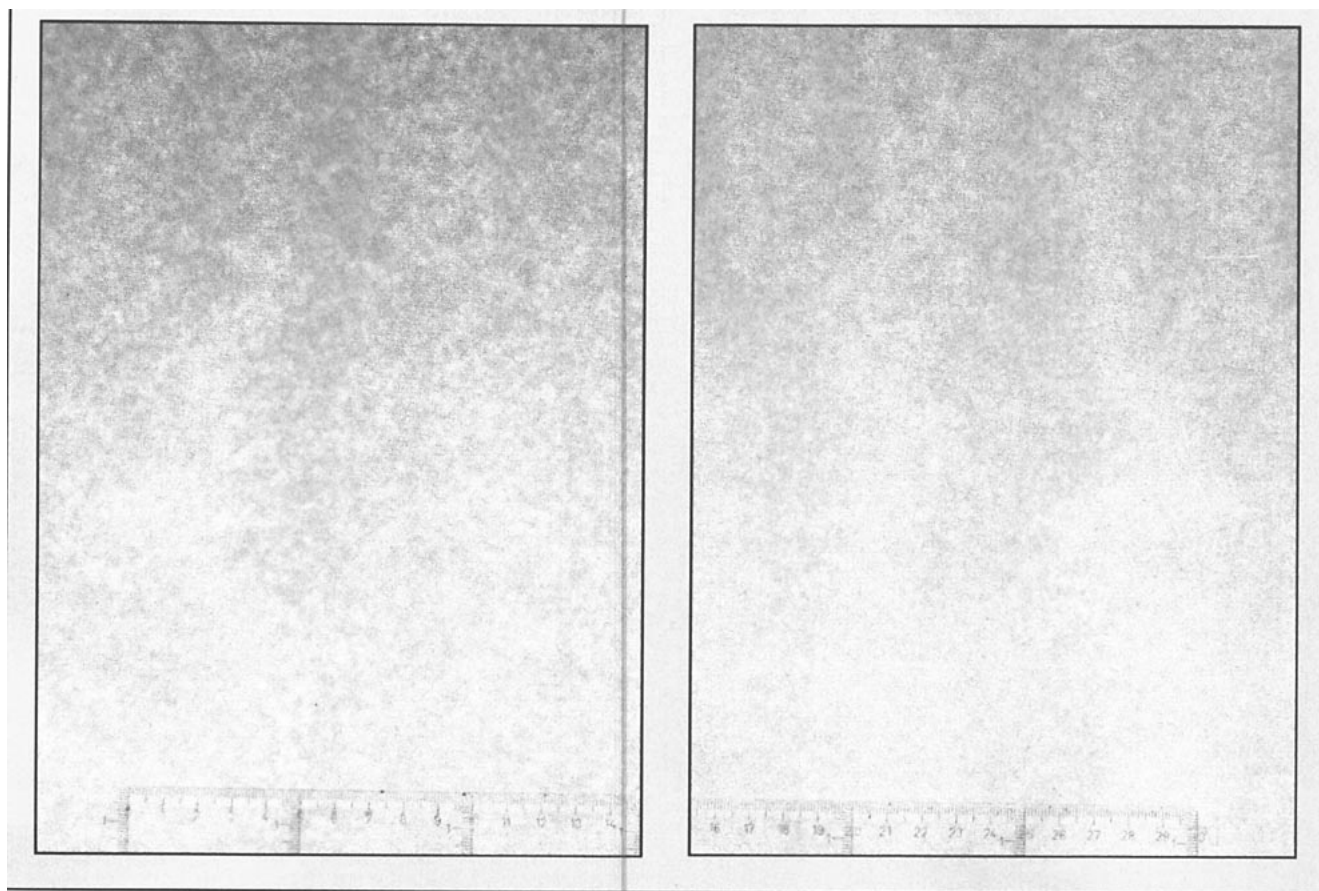
better, from the making of the paper, to the machinery itself, to the science behind all of it.

Formation and small-particle distribution

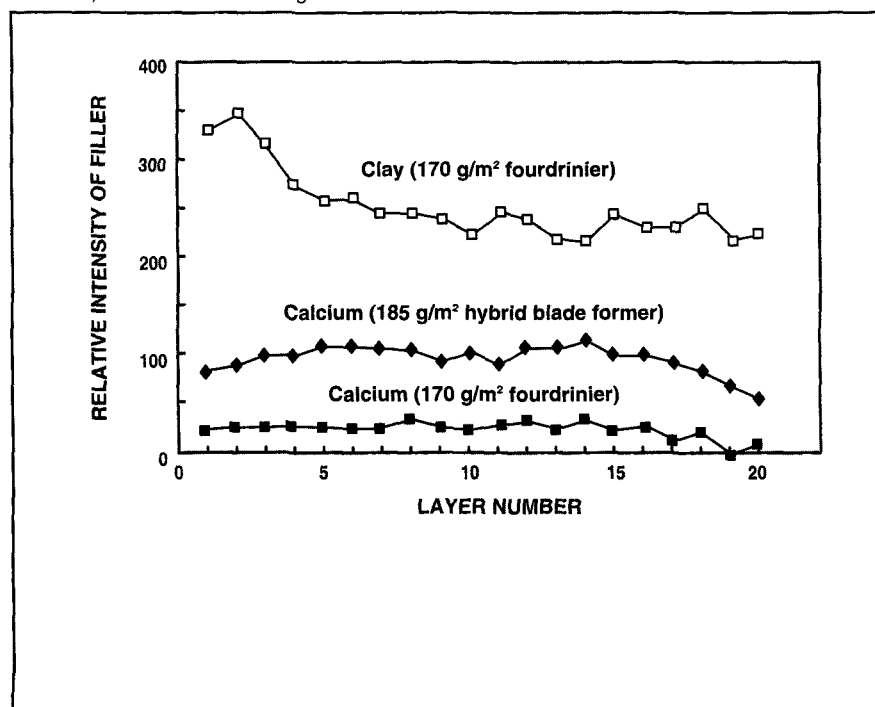
No formation instrument will ever replace a papermaker looking through the sheet to assess its quality. Still, some situations force us to be more objective about paper formation (e.g., wet end guarantees). Unfortunately, there are almost as many ways to measure "formation" as there are to define this elusive term, and it seems every papermaker has his or her own method.

In our company, we try to think of formation as being comprised of the fiber mass distribution and the small-particle distribution—both essential attributes of the paper. The literature contains much on the measurement of

1. The impressive improvement in lookthrough achieved after a hybrid roll former (left) was replaced by a hybrid blade former. Large divisions on scale are centimeters.



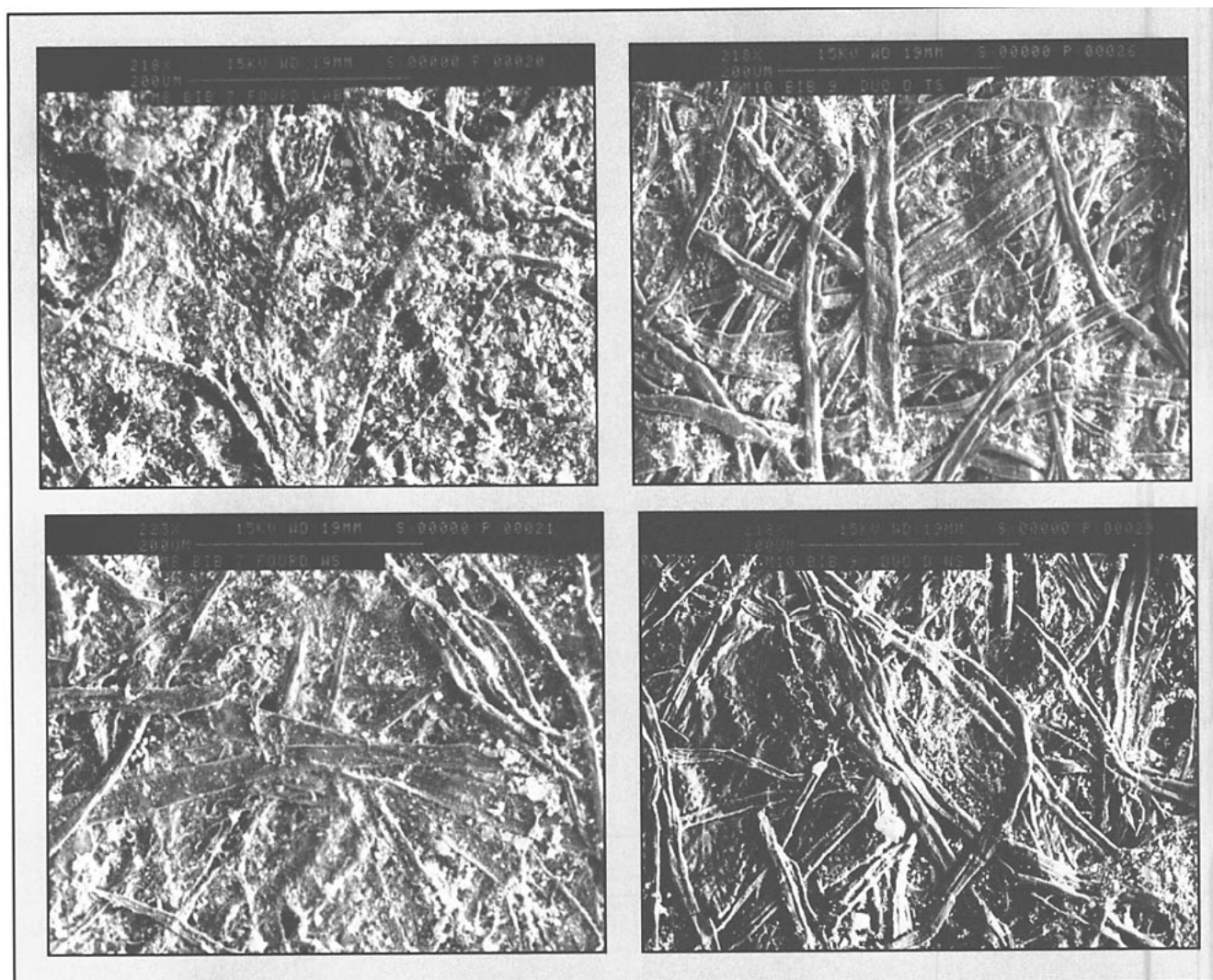
2. High-resolution measurements of filler distribution in the sheet thickness direction (z-direction) of a woodfree coating basestock



both the optical density and the mass density distribution of paper fiber. [Norman (4), Cresson (5), and Tomimasu (6) all give excellent recent critical reviews of paper formation and its measurement by literally dozens of workers.] However, the literature contains little on the high-resolution measurement of the small-particle distribution (fines and fillers) on or inside the sheet. Small particles in the paper fiber network play an essential role in the uniformity of penetration by liquids such as water from coatings or the vehicle from printing inks. They also have dramatic effect on the "lookthrough" of the paper, masking or even hiding the true fiber mass distribution from view because of the strong internal light-scattering effect.

Figure 1 shows the impressive improvements in lookthrough that were achieved after a hybrid roll former was replaced with a hybrid blade former.

3. SEM (220X) in backscatter mode showing the surface filler distribution for the papers presented in Fig. 2. Fourdrinier paper is shown at left, paper produced using a hybrid blade former is on the right.



Both papers were a 75-g/m² woodfree coating basestock made at 945 m/min. The M/K formation doubled to 30 after the blade former was installed. The formation of some grades even quadrupled. Although the lookthrough does not reveal the small-particle distribution, the reduced print mottle for the paper produced with the hybrid blade former implies that this distribution improved along with the formation.

The type of forming equipment and its operation determine the small-particle distribution, both at the surfaces and in the various layers through the sheet thickness. Some papers that have excellent lookthrough don't necessar-

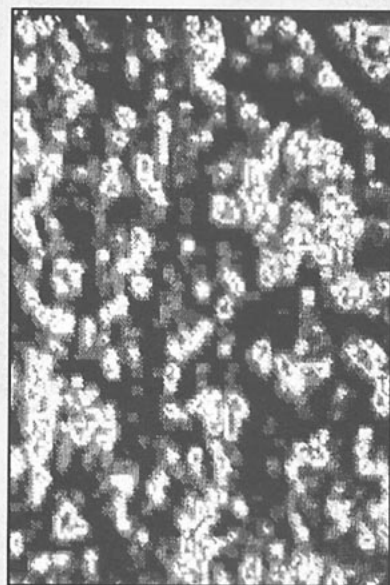
ily have the best coating or printing characteristics. Although vastly improved lookthrough helps sell paper and paper machinery, this aesthetic appeal may not always translate into the expected functional improvements in the final product. We think an important part of the explanation might be found in the small-particle distribution. However, there are problems in detecting and measuring this distribution.

With an X-ray detector and an image analyzer coupled to the scanning electron microscope (SEM), we now can obtain higher-resolution measurements (compared to sheet splitting) of the *z*-direction filler distribution (Fig.

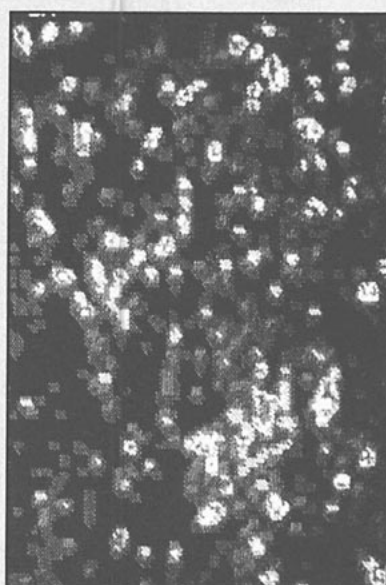
2). Impressive as this is, we still cannot obtain the in-plane distribution inside the sheet, which is important in determining the continuity of the filler distribution for some papers where the filler is needed to block liquid penetration.

While the SEM in its backscatter mode allows us to make subjective assessments of the surface filler distribution (Fig. 3), this distribution cannot be measured in a meaningful way. Energy dispersive spectrometry (EDS) with computerized mapping also is useful for subjective determinations of surface filler distribution (Fig. 4), but it lacks good resolution. Neither the SEM backscatter mode nor EDS can

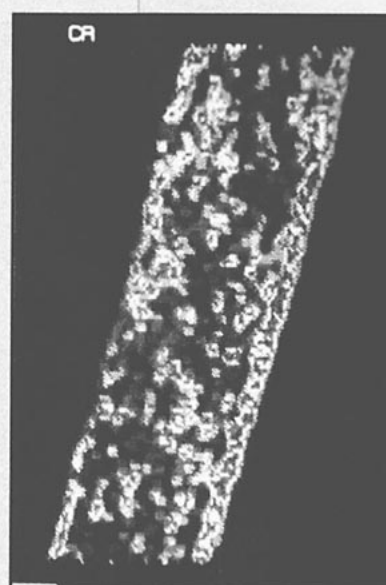
4. EDS maps of calcium for a woodfree basesheet (the two images at left) and after coating (far right)



Felt side



Wire side



Cross section wire side

The original EDS maps are color coded to indicate the calcium signal intensity at each pixel, but this cannot be reproduced here. The basepaper contained calcium carbonate from the coated broke. The surface views show a difference between the two sides in both the amount of calcium carbonate and its spatial distribution. However, the EDS maps reveal almost nothing about the fiber density at the paper surface. Even though the wire side had large regions where filler was absent (as expected for a fourdriner sheet), the coated sheet exhibited a better coating holdout on this side (right-hand side of the cross section on the right). The surface densification from wet pressing produced the much better holdout for this coating. However a uniform and high coating holdout can still have a print mottling tendency due to the effect that an uneven basesheet filler distribution has on water leaving the coating (and thus its structure).

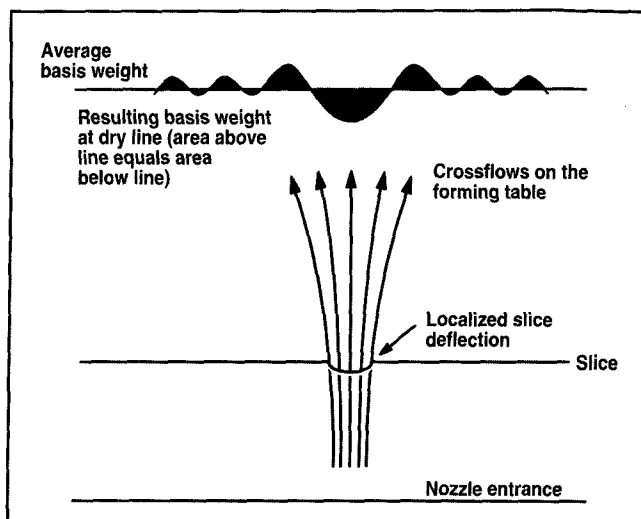
reveal the x - y distribution inside the sheet. The new confocal scanning laser microscope (CSLM) may eventually prove useful for detecting small-particle distributions both at the surface and inside the paper, but today's equipment still needs further development. Electron beam and soft X-ray imaging (6) both give resolution down to or near the fiber dimension level, but this is still more than one order of magnitude larger than individual particles. Electron beam imaging can't discriminate filler from fiber, but differential soft X-ray absorption has the potential to do so and is now possible on a research basis (7).

Another problem with many methods is their inability to utilize large-enough field sizes at the resolutions we need. This is necessary for adequately characterizing a given paper sample; the field of view and resolution must be compatible with the defect size being measured.

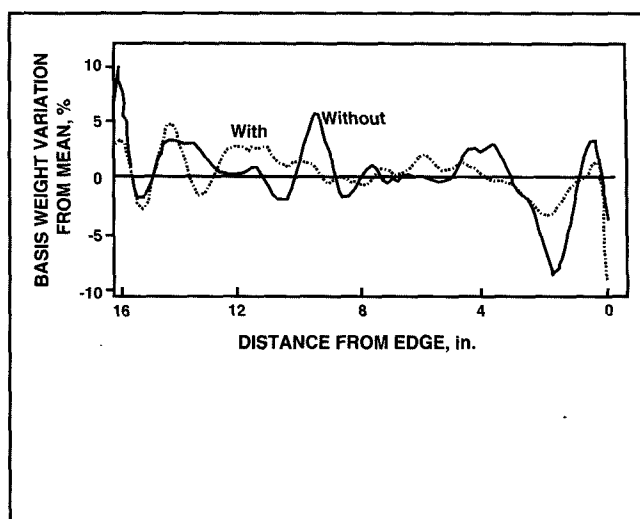
None of the techniques just mentioned can begin to deal with small organic particles: fines. We don't have instruments to discriminate these particles from the paper fibers without first separating and tagging them prior to the papermaking process. This has been done in a research context but, of course, is not practical in a commercial environment. Eventually we must find a way to do this.

It is questionable to assume that the fines distribute in the same way as the fillers during the forming process; in fact, it is questionable to assume that even all fillers act alike (e.g., Fig. 2). In the coming decade we need to further refine existing techniques and develop new ones to study the small-particle distribution of commercially-formed sheets, trying to relate this to the end-use performance (look-through, coating uniformity, print mottle, missing dots, picking, linting, etc.). Only then can we try to develop paper machinery that will control this distribution.

5. CD basis weight control by flow redirection



6. Effect of dilution control on basis weight profile



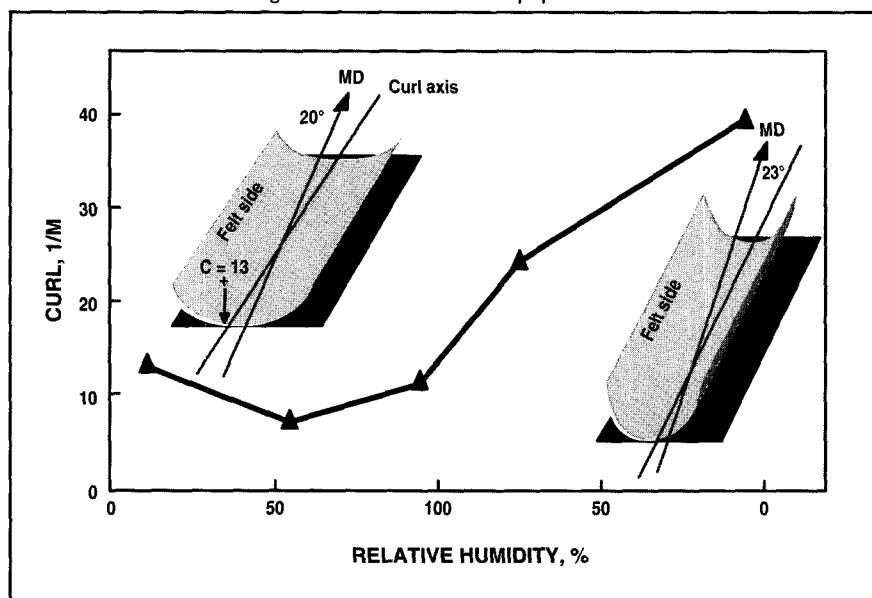
High-resolution basis weight control

Ever since the paper machine was invented, CD basis weight control has been performed by a "flow redirection process"—mass is redirected by the headbox slice geometry to a different place on the table from where it started.

In recent years, the flow redirection process (Fig. 5) has been fine tuned using fairly sophisticated computer-controlled slice actuators. This equipment has produced some excellent basis weight profiles (less than 0.5% variation is not uncommon). However, we still experience serious asymmetric (off-MD-axis) fiber orientation problems because this process inherently creates crossflows during the forming process. This process is additionally limited by the size and amplitude (the resolution) of the basis weight streak, which can be corrected by mechanically deflecting the slice (no better than about 10 cm in practice).

Work is currently underway to achieve CD basis weight control by a method which does not utilize the slice to redirect mass. In the first phase of this work, the control is accomplished by locally diluting the stock consistency inside the headbox. In one commercial installation, heavy basis weight "spikes" as narrow as 4 cm were sub-

7. Schematic of felt side diagonal curl for a fourdrinier paper



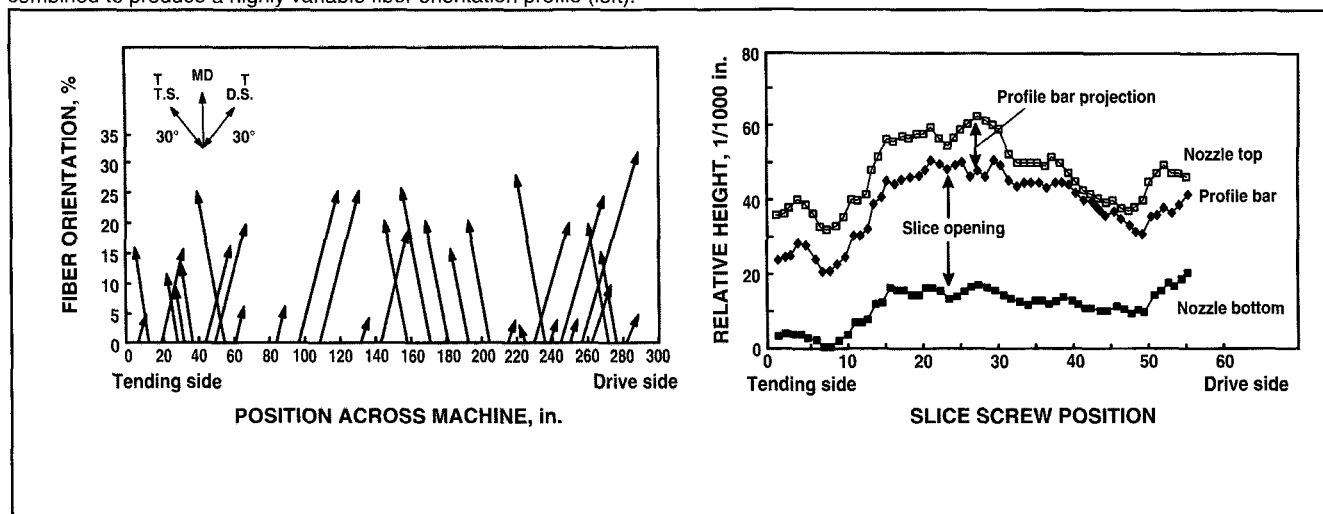
stantially reduced with this method (Fig. 6). However, several drawbacks still remain: basis weight cannot be locally "added" with the dilution method, there is a limit to the correction amplitude and zone width, and the extra dilution flow creates crossflows which can adversely affect the fiber orientation profile.

Having demonstrated that the dilution method is effective in a commercial setting, the next step is to test a system which raises or lowers the local consistency such that the basis

weight can be profiled at high resolution and that the flow rate everywhere out of the slice is equal and in the machine direction (even at the edges). We envision that present-day slice screws, actuators, and their associated control system will be replaced, although there still would be some mechanical preadjustment capability to ensure parallelism in the nozzle and slice area.

A system like this will give unprecedented profile resolution, and it will finally be possible to uncouple the CD

8. Fiber orientation profile using the tensile method. The very nonuniform slice screw profile (right) and an almost "square" jet-to-wire ratio combined to produce a highly variable fiber orientation profile (left).



basis weight profile from the fiber orientation profile—something never before achieved.

Asymmetric fiber orientation

Asymmetric fiber orientation is an important issue, especially for copy papers because, above all, these papers must not curl at angles to the running direction after being exposed to high temperatures in today's fast copy machines.

Because, during evaporative drying, paper fiber shrinks much more in its radial than longitudinal direction, its orientation in various layers creates residual drying stresses which lead to curl and may also contribute to cockle problems. It is well known that asymmetric fiber orientation can lead to diagonal curl (Fig. 7), and some feel that sharp changes in fiber orientation (Fig. 8) can affect runnability on the paper machine and in converting operations. We emphasize that fiber orientation and its measurement is *not* the same as tensile orientation, although this distinction is often lost in the literature and in discussions. The latter depends strongly on wet strain and the restraint conditions during drying in addition to geometric fiber orientation.

Although dependent on the fiber flexibility, suspension consistency, and

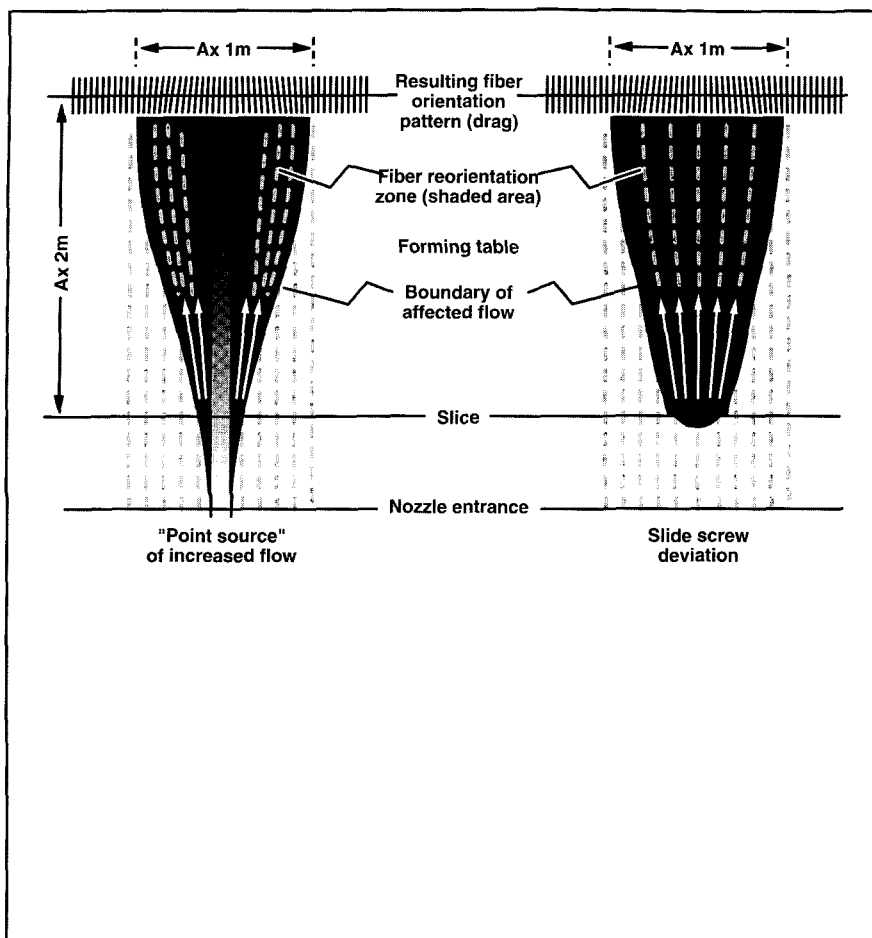
headbox flow condition, the final fiber orientation is highly influenced by the forming process (8). The current simplified explanation (neglects z -direction velocity distribution in the jet) is that the fibers in the layers near the forming fabric are reoriented in a fluid shear field from whatever position they have assumed in leaving the slice to a new position as the suspension drains. It can be speculated that much of the asymmetric reorientation occurs within a relatively short distance after jet impingement and is found mainly in the lower layers (Fig. 9).

These are points that should be given further study since recent optical velocity measurements have shown surface excess speed persisting up to the dry line (9, 10). From past operation experience, it is well known that very small velocity differences can change the MD/CD property ratios significantly (the absolute velocity difference is the fundamental parameter, not the still-sometimes-used jet-to-wire ratio). On a 1000-m/min paper machine, it takes an imperceptible jet angle of only 0.5° from the MD to produce a crossflow velocity component of almost 10 m/min—more than enough to give the sheet an asymmetric orientation. In other words, very small flow disturbances can have very large effects on the paper.

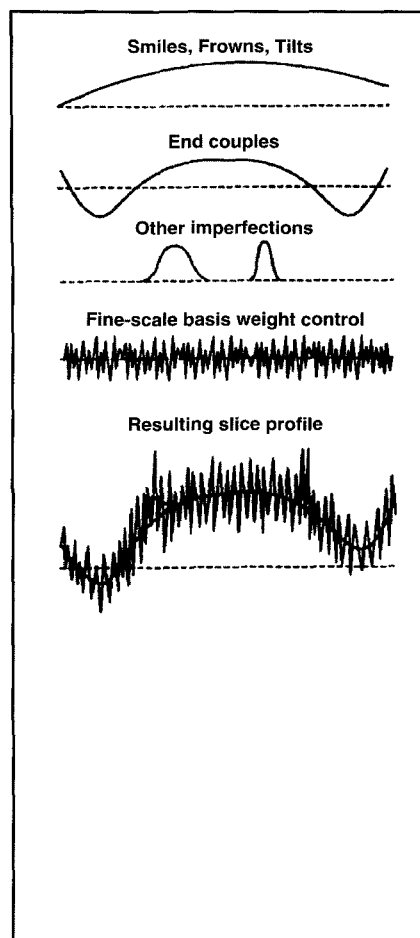
The velocity difference associated with fiber reorientation is actually a vector sum of the MD and CD velocity components *at any instant*. The MD component originates with the jet velocity setting (with any local MD variations superimposed). The CD component is initiated by localized headbox crossflows, edge waves, table shake, a serrated slice, or a forming shower if any are present. Localized crossflows are a result of slice screw settings or mechanical and hydraulic deficiencies upstream of the slice. Surprisingly, crossflow originating from even a point source (e.g., a single tube in the headbox) can affect the fiber orientation over a relatively large area because it takes some distance for the pressure disturbance to equalize inside the jet (Fig. 9).

Recent headbox designs have recognized the importance of fiber orientation and provided unique methods of obtaining parallel top and bottom nozzle surfaces to relieve the slice screw array of unnecessary correction tasks (Fig. 10). Almost all slice screw patterns today are a result of trying to obtain the most uniform CD basis weight profile possible and do not take fiber orientation into account. This is because the papermaker is trying to build a good reel—and good reel building does not include making good fiber orientation today. Besides

9. Schematic of the process leading to asymmetric fiber orientation



10. Recent methods to minimize crossflows from the slice



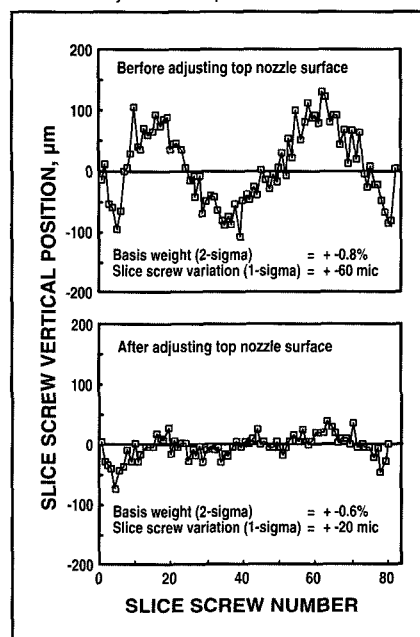
being headbox and approach-flow related, the slice screw pattern is affected by paper shrinkage in the dryer, forming fabric and table conditions, the paper machine operator (or the slice screw control algorithm design), and other real-life machine conditions. Interestingly, the very nonuniform slice geometry shown in Fig. 8 (right) was still producing a very good basis weight profile even though the sheet was wrinkling in the press section! We need a better approach in the future.

Interestingly, there are an infinite number of patterns which can satisfy a particular basis weight profile requirement, with some (e.g., Fig. 8) creating worse fiber orientation problems than others. Any time a slice screw is activated, a new crossflow is introduced which affects the fiber orientation. Therefore, the strategy for

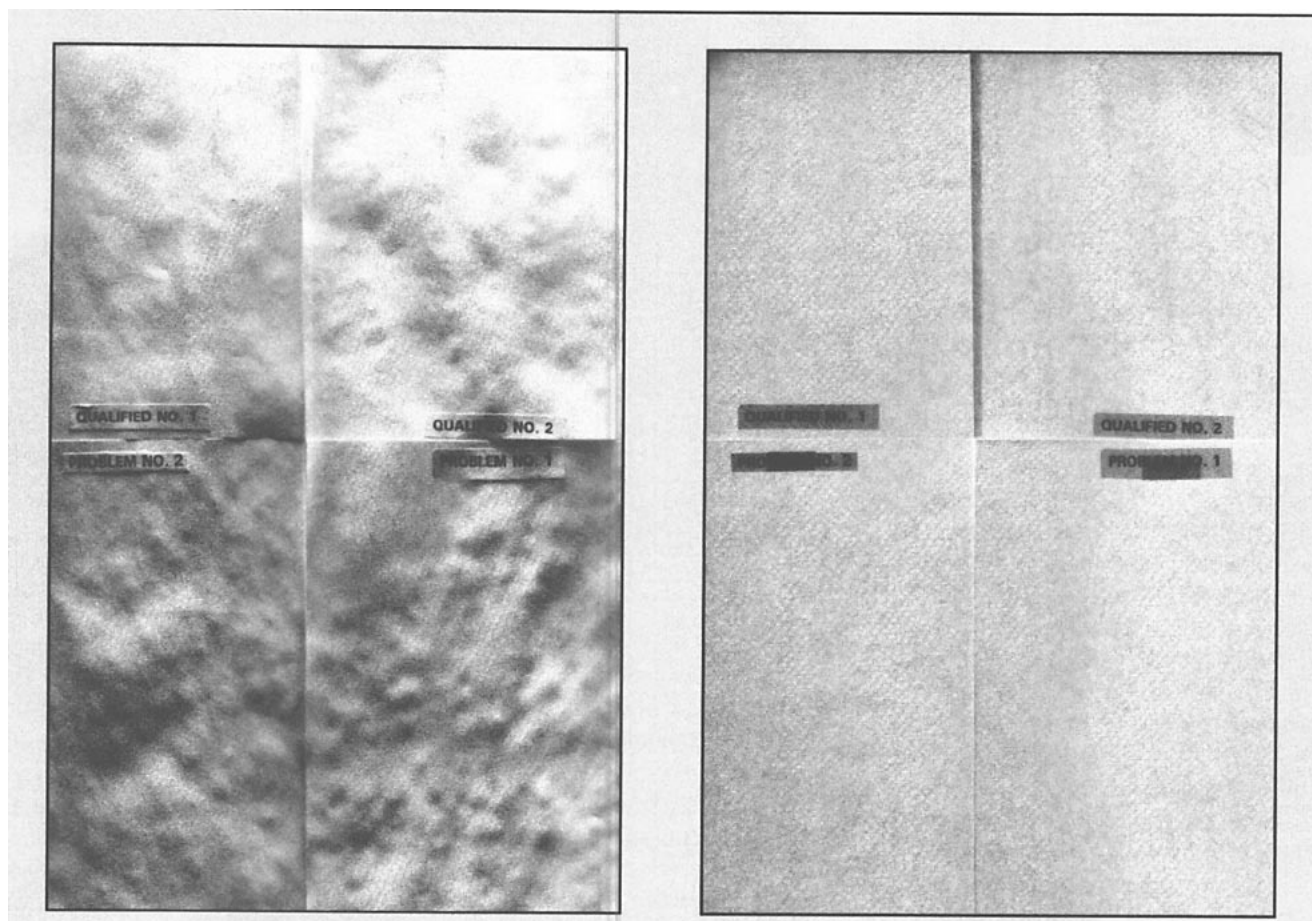
fiber-orientation-sensitive grades should be to first seriously question how good the basis weight profile really needs to be and then to make the fewest adjustments possible to the slice screw array to attain that profile.

Figure 11 shows how much room for improvement there is in this regard. Although it is possible to do, current slice screw control algorithms do not incorporate the above strategy into a "fiber orientation optimizer." Off-line fiber orientation instrumentation can be used to manually optimize the fiber orientation profile (a few paper manufacturers are doing this) but, of course, this is a fairly tedious process. Since no on-line equipment is yet available, feedback control is not possible. These are areas which we predict will receive more attention.

11. Improved slice screw profile resulting from an adjustable top nozzle surface



12. Cockles in "good" and "bad" copy paper after going through the copy machine. The two papers on top are "Xerox qualified". The transmitted light images (right) do not show a good correspondence with the cockles. The bottom paper is a very flat and stable bond paper used as a reference.



The space-related velocity variations just discussed are difficult enough to deal with, but when time-related variations are superimposed, an impossibly complex picture of fiber orientation can be imagined (e.g., a high-speed, pulsating jet being operated close to the wire speed). In fact, one often wonders how uniform paper can ever be made.

The greatest improvement in fiber orientation variation occurs if both the MD (mostly time related) and the CD (mostly space related) variations are reduced together. The CD basis weight control system mentioned earlier is expected to eliminate the occurrence of CD crossflows. Stock approach systems with more rigorous pulsation and vibration requirements should reduce the time-related variations.

Cockles

Cockles have historically plagued many papermakers, and all the causes for this vexing problem are still not well understood. As with fiber orientation, the requirement for the paper to remain flat after heating in a high-speed copy machine has fueled a renewed interest in the causes of cockles (Fig. 12). The kind of furnish being used strongly determines the paper's propensity for cockling, but there are many machine conditions that also are important.

It is interesting that cockles have sizes of dimes, nickels, and quarters but that many of the instruments we use to measure cockled paper have the size of dollar bills. It is tempting to believe that a direct correspondence exists between formation and cockle.

This is sometimes true, but there are too many cases of copy paper with good lookthrough giving bad cockle (and vice-versa) to make this generalization. An instrument just developed at the Finnish Paper Research Institute (11) to measure the size, shape, and orientation of cockles may improve our understanding.

Already these workers have noticed that most cockled copy paper does not show a direct correspondence between the local mass distribution and the cockle dimensions, but paper with bad cockles very often has a worse measured formation. This implies there are other factors that cockles and formation have in common, but we still await an explanation. We have not yet attempted to correlate cockle with local fiber orientation but may try using the laser method, which has better

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resolution than a sonic velocity instrument. Also, methods are needed to measure the local hygroexpansivity and residual drying strains since this is the fundamental reason for the paper to be drawn out-of-plane in the first place.

We know that stock system pulsations certainly can lead to cockled paper (12), but, other than the usual explanations about basis weight and moisture barring, we don't know the exact mechanism pulling the sheet out-of-plane. For example, could local fiber orientation be involved?

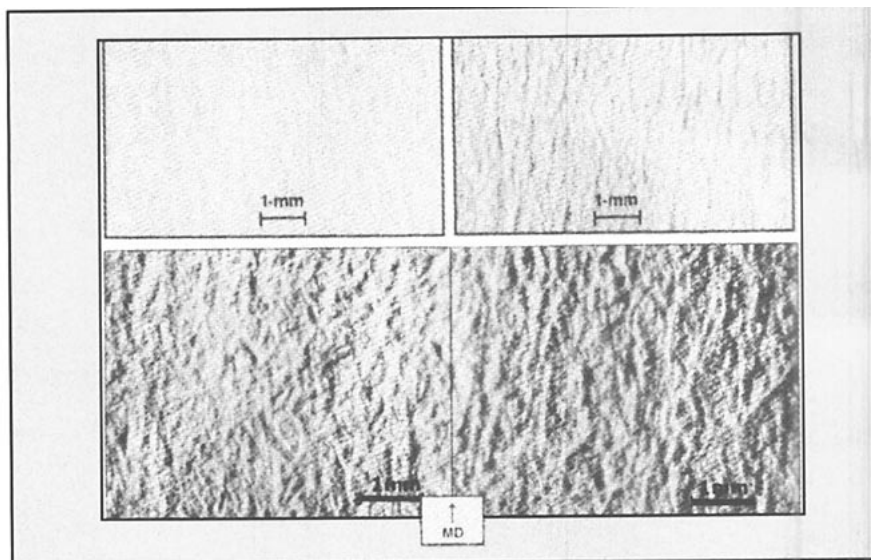
Since stresses developed during drying are affected by the local drying restraint, it would be interesting to investigate if local heat transfer and restraint variations in the dryer fabric contribute to cockle severity. Recently, we have noticed that more intense wet pressing generally leads to greater dimensional instability (3) and wonder if this might play a role in cockle severity. We haven't proven yet whether the decreased stability is due simply to the higher sheet density or (more likely) to the increased gradients in density and moisture from wet pressing.

Sheet marking

The demand for better paper and board finish keeps rising, even though excellent finish is inherently incompatible with faster machine speeds. We need to seek ways that will allow us to produce paper faster, but without increasing the intensity of the papermaking operations, because we think this is what gives the various gradients that lead to the finish problems being experienced.

For example, the wet pressing operation can introduce sharp density and moisture gradients into the paper which we think then interact with the drying process and then later with the hygroexpansion mechanism (2). Performed with too much intensity, wet pressing can create an interconnected fiber network where some fibers have a much different "history" than others

13. Machine-direction microstriations in paper as a result of wet pressing. They always are more prominent on the side through which most of the water was removed (the press felt side shown in the upper right photo) compared to the smooth roll side (upper left). They also are more prominent when the pressing is more intense (lower photos).



(e.g., some fibers have more of their water removed by mechanical densification than by evaporative drying). Fibers with such different histories lying so close together and reacting differently to the subsequent introduction and removal of liquid or vapor can pull the sheet out-of-plane at various dimensions down to the microscale. This is an area that is not well understood in terms of paper finish and merits future research.

Of course, an important source of sheet marking can certainly be mechanical pressure nonuniformities from the pressing surface (felts and press rolls). However, we wonder if many so-called press marking problems are actually induced by strong density gradients from pressing too much water out too quickly ("hydraulic marking"). We also suspect that the sheet is mechanically unstable exactly at those places where density gradients exist and that subsequent shrinkage or expansion pulls the sheet out-of-plane at these sites.

Why, for example, in a groove-marked sheet do we find the groove indentations on the smooth roll side after the sheet is dried—not on the side facing the grooves? Similarly, why

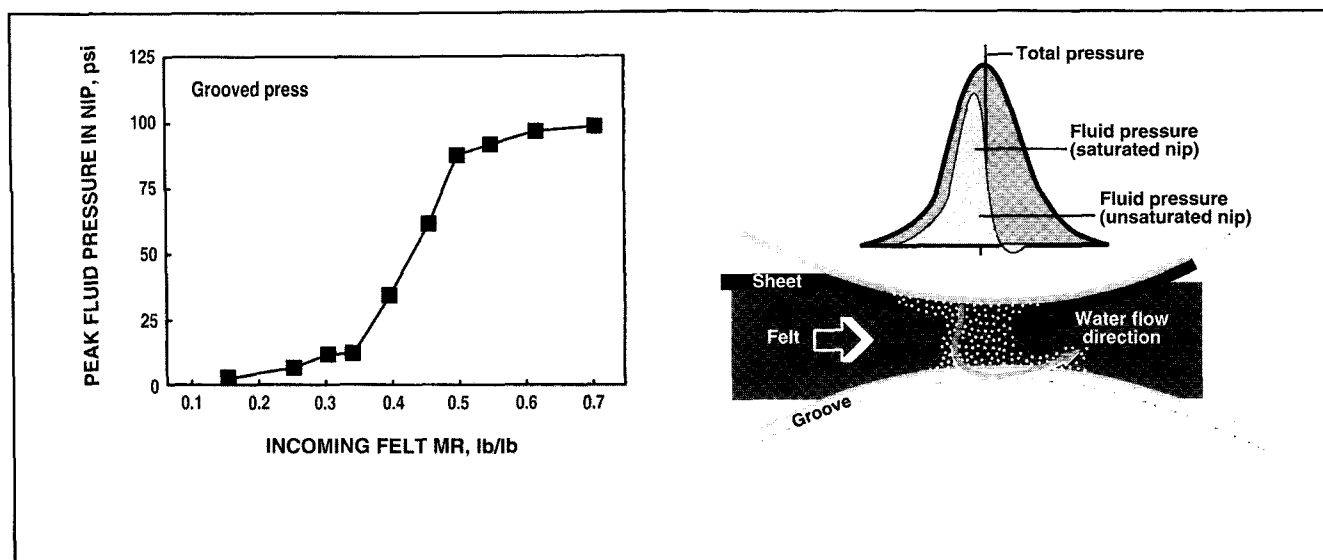
in a shadow-marked sheet are the raised suction hole areas found on the smooth roll side and not the side toward the suction roll? Lastly, why are the MD microstriations (Fig. 13) always found on the side of the sheet where the water was rapidly pressed out, regardless of how the sheet was formed or dried? And they are stronger as the pressing intensity increases. These tiny striations bear no resemblance to any pattern seen in the press felt, so it isn't surprising that different felt designs have not made a big difference. We think all these observations relate to a complex interaction between density and moisture gradients, fiber network conformation and springback, mechanical instability, and shrinkage during drying.

Obviously, more systematic investigations are necessary in the coming decade before we can understand the fundamentals and then design equipment to eliminate (or at least minimize) these problems.

Saturated nips and paper quality

Although a cause-effect relationship has not yet been proven, there is mounting evidence that paper quality

14. Rapid rise in fluid pressure during nip saturation [from Beck (14)]. Any increase in press load, incoming water content, felt filling, or compaction causes water to be forced horizontally some distance through the nip (right).



can be subtly but adversely affected by pressing in a saturated press nip—even when it is vented.

Nip saturation occurs when all the available void volume in the press felt and press roll vents becomes filled with water. Nip saturation first appears near mid-nip, and full saturation occurs when the saturation zone grows large enough to essentially fill the nip. At this time any further increase in incoming water amount produces no further increase in fluid pressure (Fig. 14). This process takes some time to develop on a commercial paper machine, and can't be observed from the outside unless nip rejection occurs (water ejects out the nip entrance). It is believed that more modern press nips operate with some degree of nip saturation than is realized (13).

As a nip goes into saturation, the fluid pressure in both the felt and the sheet rises drastically (Fig. 14), becoming a very large proportion of the total applied pressure. Under certain conditions, the fluid pressure might even change the shape of the total pressure profile (e.g., separating the press rolls slightly and making a sharper nip). When the sheet passes through the saturation zone, we speculate that it experiences a “water ham-

mer”—like fluid shear stress concentrated at the fiber layers next to the press felt, intensifying (or even creating) the thin dense “skin” that might already be present from earlier nips. Because we still have an incomplete view of exactly what happens to the paper inside the press nip (15), we can't explain precisely how and where the thin skin (only a few fiber layers thick) is created—we only know that it is. We are also quite certain this skin is implicated in smoothness, porosity, and other problems (2). Hopefully, someone can find the answers in the coming decade.

Almost all modern vented press nips run in a partially or fully saturated condition at some point in the felt life. It normally is not possible to tell when this is happening because catastrophic crushing rarely is present, nor does the saturation zone usually build to the point of nip rejection. (Interestingly, higher machine speeds make nip rejection less likely.) Venting of the press-roll surface is important in helping to delay the onset of fully developed nip saturation and thus minimize the “water hammer” effect inside the nip. However, when even the press-roll vents become filled with water (or compressed air and water), the fluid

pressure can rise rapidly (depending on the felt design and its condition) due to the high back pressure from water being forced to flow in the MD through the nip (Fig. 14). This in-plane flow occurs in the felt (and in the grooves or blind-drilled holes if they are interconnected), but there is abundant evidence of in-plane flow in the sheet also.

We think that shoe presses are especially vulnerable to the insidious effects of nip saturation because:

- This press type depends so much on the felts transporting water away from the nip instead of some being thrown out at the nip like with a roll press.
- High press impulse gives more sheet water removal and also leads to greater loss of felt void volume and vacuum box dewatering capacity.
- One side of the majority of today's shoe presses is not vented (there are no vents in most blankets or sleeves), and this places extremely difficult demands on both felts.
- The occurrence of nip saturation cannot be directly observed and thus goes unnoticed by the operator.

For roll presses the answer to nip saturation is already available with current technology: felt designs with enough void capacity for the press impulses being used, careful attention to water management around the press nip, proper purging of press-roll vents, and sufficient felt conditioning in the form of chemical cleaning and vacuum box dewatering.

These same things are even more important for shoe presses. However, there is another area which must be addressed for future shoe presses: venting of the blanket or sleeve. Until recently, a vented blanket could not be made to last under high-impulse conditions. There now is available a special blind-drilled shoe-press sleeve that has the mechanical integrity to withstand the shoe-press environment (13). This sleeve (**Fig. 15**) is expected to reduce or eliminate the negative effects of nip saturation on sheet finish. It also is expected to significantly improve the life of both the felts and the opposing roll cover.

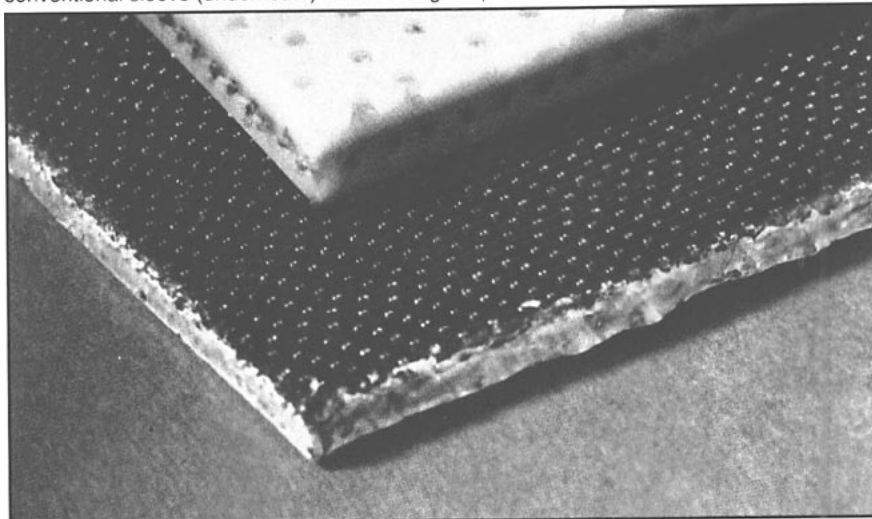
Conclusions

We have come far in our understanding of making paper, but the future still contains a myriad of technical challenges, most of which we can't predict today. I have tried to present our ideas about a few areas that must be attacked if better paper is to be made more productively.

Variation in paper properties remains an important issue facing us today because it affects both quality and productivity. Although we have so far managed to address variation at relatively large sizes, all sectors of the industry must now concentrate on being able to measure and control variation at much smaller sizes than previously thought important or attainable.

Because we cannot do everything at once, we must somehow decide which things to attack first and at what level—not an easy task. Since no one person or company has all the answers, is it too unrealistic to suggest that

15. A recently-developed blind-drilled sleeve for the shoe press (top) compared to the conventional sleeve (underneath) whose design exposes the base fabric to the wet felt side



TAPPI sponsor a workshop of qualified and interested parties to develop specific recommendations? Each of us could then try to design and build the equipment that best addresses these important issues. □

Literature cited

1. Cutshall, K. A., Tappi J. 73(6): 81(1990).
2. MacGregor, M. A. and Conners, T. E., Tappi J. 72(4): 177(1989).
3. MacGregor, M. A., Tappi J. 74(11): 195(1991).
4. Norman, B., BPBIF Transactions of the 9th Fundamental Research Symposium (Vol. 3), Mechanical Engineering Publications, London, 1989, p. 73.
5. Cresson, T., The sensing, analysis, and simulation of paper formation, Ph.D. thesis, State University of New York, Syracuse, May 1988.
6. Tomimasu, T., Kim, D., Suk, M., *et al.*, Tappi J. 74(7): 165(1991).
7. Tomimasu, H., Japanese patent application Heisei 3-218438 and Japan Tappi J. 45(12): 106(1991).
8. Niskanen, K. J., BPBIF Transactions of the 9th Fundamental Research Symposium (Vol. 1), Mechanical Engineering Publications, London, 1989, p. 275.
9. Norman, B., personal communication re STIF FEX machine results.
10. Loewen, S.R. and Butler, A., Pulp Paper Can. 93(12): (1992).
11. Kajanto, I. M., Proceedings of the 1992 Paper Physics Seminar, PSC Communications 32, Oy Keskuslaborio, Otaniemi, Finland, p. 24.
12. Dittman, R. L., TAPPI 1992 Practical Aspects of Pressing and Drying Short Course Notes, TAPPI PRESS, Atlanta, p. 237.
13. Schiel, C. S. and MacGregor, M. A., TAPPI 1992 Engineering Conference Proceedings, TAPPI PRESS, Atlanta, p. 39.

14. Beck, D., TAPPI 1986 Engineering Conference Proceedings, TAPPI PRESS, Atlanta, p. 105.
15. MacGregor, M. A., BPBIF Transactions of the 9th Fundamental Research Symposium (Vol. 2), Mechanical Engineering Publications, London, 1989, p. 511.

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