

On-line curl measurement and control

Eric T. Langevin and William Giguere

ABSTRACT: Papermakers and converters must wait until the end of a reel before testing to see if the product contains unacceptable curl. A recently developed device enables the manufacturer to monitor edge curl continuously without stopping and taking samples. The device combines a laser, a line generator, and a digital camera to constantly measure edge curl and display a graphical representation on a control screen. This information can be used to manually adjust the process to correct the curl, or it can be transmitted to a process controller that automatically adjusts a decurling device (e.g., a Steam-Foil® or reverse roll coater).

KEYWORDS: Control systems, curl, monitoring, on-line measurement.

The goal of converters and paper manufacturers is to operate at increasing machine speeds. This makes conventional methods of curl measurement (i.e., cutting samples and measuring them in a humidity chamber) extremely costly. In today's market, the time it takes to cut and properly condition the sample can translate into thousands of dollars in lost production.

A new device has been developed to monitor and control curl, on line, with the aid of a decurling device, thereby eliminating the need to constantly stop and take samples. Curl control is arguably the most important quality criterion in today's high-speed machines. Curl is responsible for most sheet-feed and transport

problems (1). Traditional methods of monitoring curl are inconsistent and time-consuming, costing the manufacturer lost production and wasted product.

What is curl?

TAPPI defines curl as "the tendency of unrestrained flat paper sheets to distort and form curved surfaces of essentially cylindrical shapes" (2). Our experience takes this definition one step further in recognizing that even restrained webs exhibit some degree of curl or distortion. The curl detector, using its extremely precise laser/camera package, can measure even the smallest amount of distortion.

The characterization of curl as an "out-of-plane" shape has been discussed in many papers. An effective way of visualizing curl in three dimensions is to break the web into three components: K_x , K_y , and K_{xy} , where x = MD (machine direction) curl, y = CD (cross-machine direction) curl, and xy = twist (3). This is illustrated in Fig. 1.

However, the easiest and best method of describing curl is to treat the web as a two-sided structure, with each side having separate sheet properties. As the sheet conditions to a specific humidity level, the sheet fibers will expand or contract transversely with a subsequent exchange of moisture. This expansion-contraction behavior, the result of variations in moisture, is referred to as hygroexpansive behavior. Any difference in the hygroexpansive property between each side of the two-sided structure will likely result in curl (4).

Measuring curl

Many methods of measuring curl are used today, and several devices have been designed to standardize the way curl is interpreted. All of these methods, however, share a common weakness: they require the operator/technician to complete the test off-line. Our goal was to design a practical, easy-to-use device that measures curl on-line and eliminates the need to stop production to take samples.

To do this, we reviewed many of the curl-evaluation methods currently used to determine the best

Langevin is a group manager and Giguere is a controls manager at Thermo Electron Web Systems, Inc., P.O. Box 269, Auburn, MA 01501.

Curl Measurement

way of automating a task that had only been done manually in the past. The following is a description of several of the most popular methods currently used to evaluate the amount of curl in a web.

TAPPI Method T 466 cm-82

This method was originally devised in 1944 and requires wetting one side of the paper to determine the maximum curvature developed or the time required to reach maximum curvature. The maximum curvature is an indication of the relative tendency of certain papers to curl under normal usage conditions.

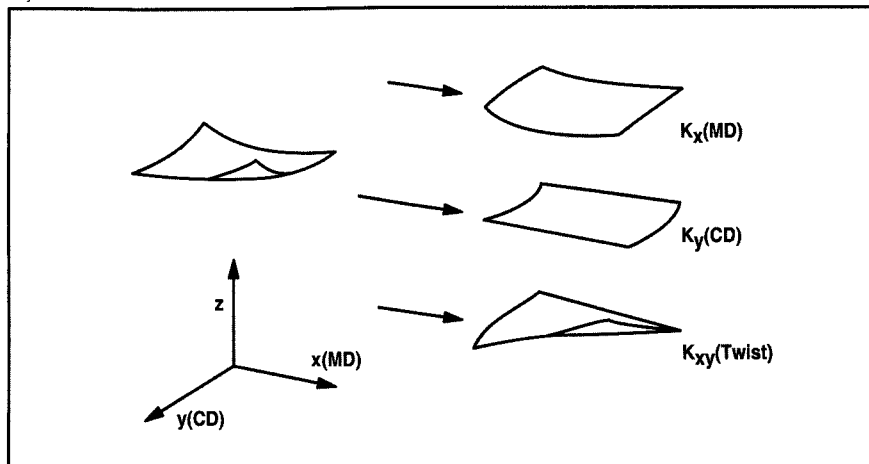
The apparatus consists of a float having near its center a rectangular wetting aperture about 51 mm (2 in.) long (perpendicular to the plane of the figure) and a width, L , which is adjustable from zero to about 25 mm (1 in.). A stop, H , is provided to hold one end of the curling specimen at a fixed angle, F , with respect to the horizontal. A scale, graduated in degrees, is fastened to the float to indicate the movement of the pointed end of the curling specimen (5). This method is difficult to perform and is not always repeatable. It has been replaced more recently with custom "in-house" curl measurement methods.

Manufacturer's Method 1

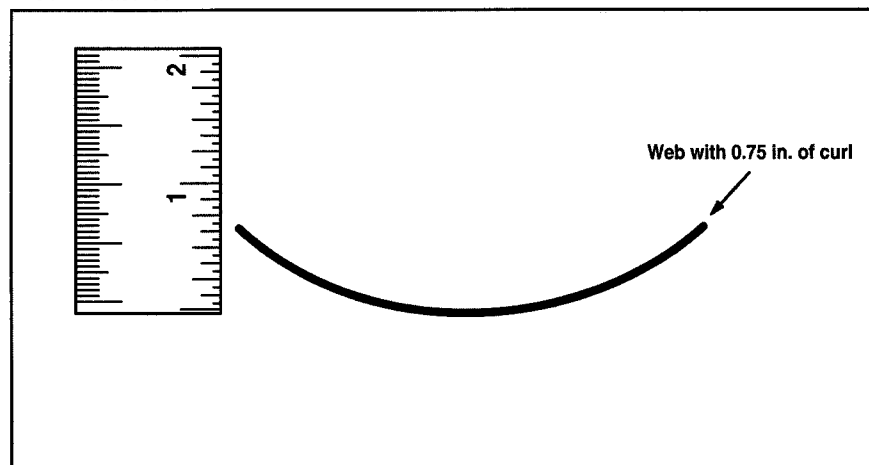
One of the methods most commonly used today uses web samples cut into a specific size (e.g., 150 mm x 150 mm, 200 mm x 250 mm, etc.) and places them into chambers set at 20% RH, 50%RH, and 70%RH. The samples are allowed to condition for approximately 30 min before they are removed from the chamber. A scale is placed next to each sample, and the corresponding "inches of curl" are recorded, as seen in Fig. 2. Any curl reading above a predetermined level (e.g., 20 mm) is considered unacceptable.

This version of Method 1 uses an "inch" scale. However, many converters/papermakers use "degree" scales or protractors in the same manner, as seen in Fig. 3.

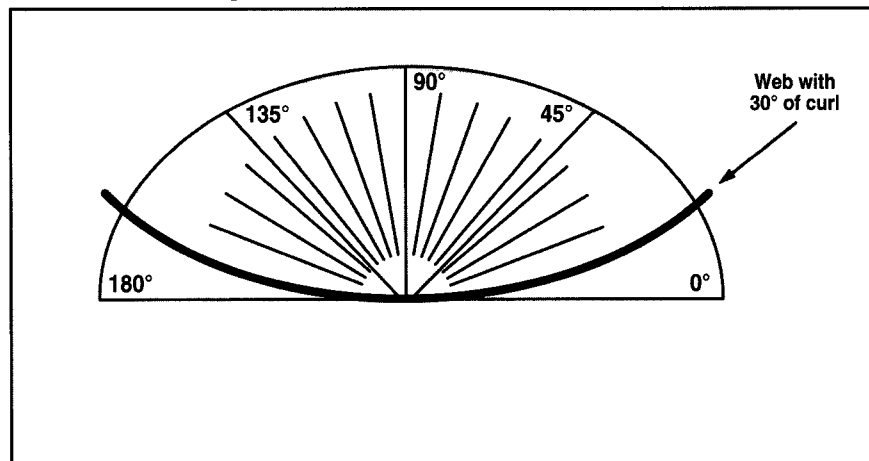
1. General curved shape, characterized by three components: K_x = curl in MD; K_y = curl in CD, K_{xy} = twist



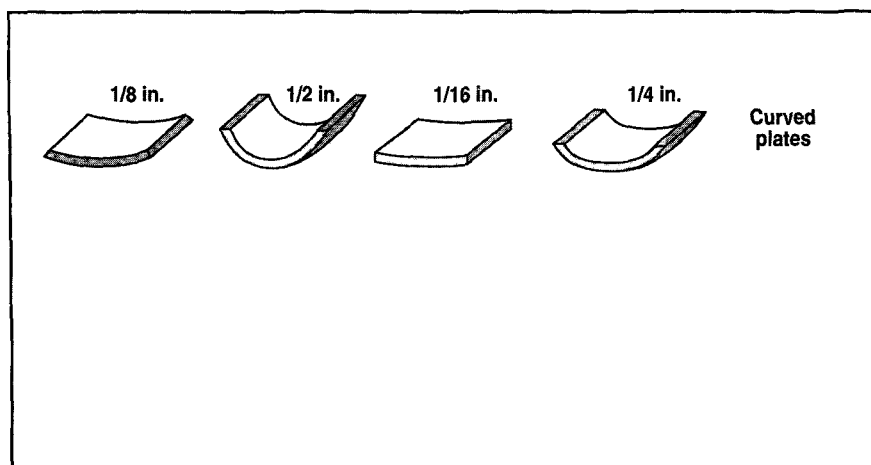
2. Curl measured in inches



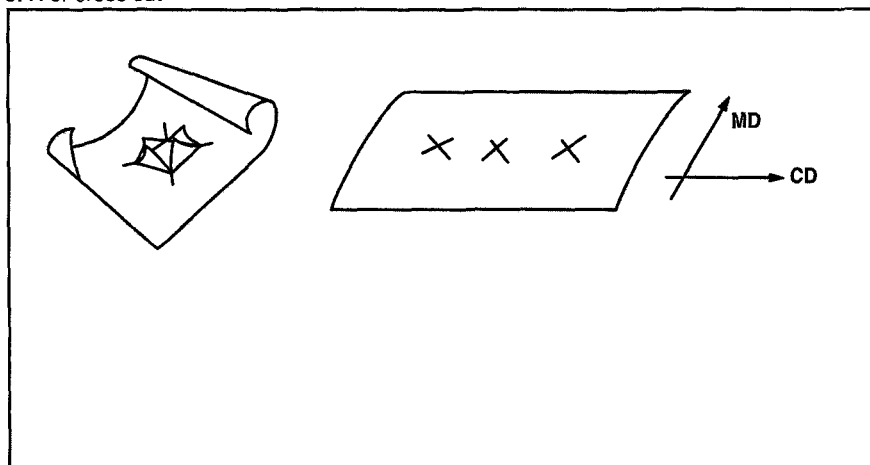
3. Curl measured in degrees



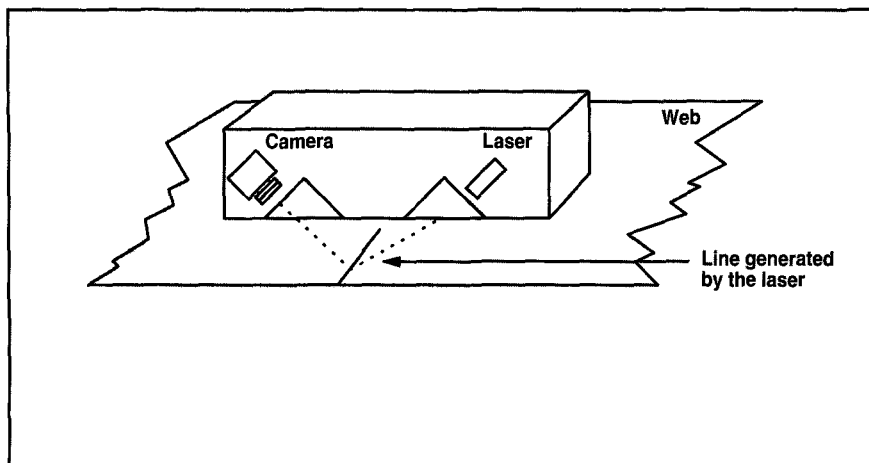
4. Plate scales



5. X or cross cut



6. Curl detector overview



Manufacturer's Method 2

Another method currently used employs a set of steel plates shaped to represent a variety of common web curl shapes (e.g., 3 mm, 6 mm, 12 mm, etc.). Typical plate scales are illustrated in Fig. 4. A technician uses these plates by cutting samples of the produced web and placing the sample next to the plate that most closely approximates the shape the web has taken. Certain plates represent acceptable curl behavior, while others represent unacceptable behavior.

Manufacturer's Method 3

A method less exact than those previously discussed, however equally as popular, is the "cross-cut" or "X-Test." In this method, a sample is cut from the manufactured product (e.g., 250 mm x 250 mm or 300 mm x 600 mm). An X is then cut in various locations across the sample (normally in three locations), and the sheet is inspected for both MD and CD curl. The method is illustrated in Fig. 5. If the X lies flat, curl is acceptable; if the edges curl upward or downward, the curl and the product may be unacceptable.

Manufacturer's Method 4

All converters and papermakers use operators who know their machines and can identify variations in the manufacturing process. These operators monitor curl by viewing the moving web from the side and determine if the web is curling in the positive or negative direction. After the operator identifies positive or negative curl, the on-line decurling device (i.e., the Steam-Foil®, curl bar, etc.) is adjusted to "flatten" the sheet.

This method, with a skilled operator constantly monitoring the beginning of each new roll, is considered by many to be the most effective and least expensive curl-control method. However, problems, such as operator-to-operator variation and the limited availability of skilled operators to constantly monitor curl, are two of the more significant factors pre-

Curl Measurement

venting the widespread use of this method.

Test method summary

With the exception of Method 4, the common thread among the traditional methods is that they are all performed off-line at a significant cost. More importantly, because the tests are performed only at the end of each run, there is no means of detecting machine-direction curl variation. The lack of a consistent standard for measuring curl leads to problems with many end users.

On-line measurement of curl

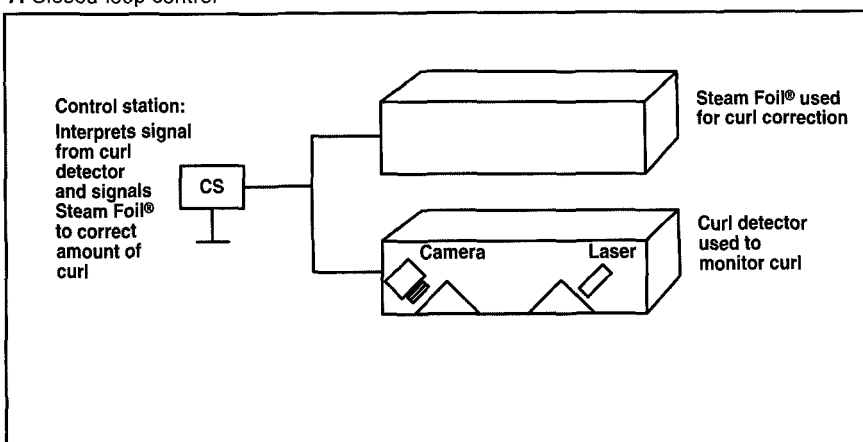
Technique

Recognizing the superiority of on-line curl measurement as opposed to end-of-run sampling, we identified Method 4 as the procedure most likely to be effectively automated and focused on developing a device capable of handling the task currently performed by the operator.

Experience tells us that if any curl exists in the web, the stresses and tension applied by idlers, chill rolls, etc., will force the curl to appear at the edges of the web. We developed a curl detector that combines a laser, a line generator, and a digital camera to constantly monitor the web's edge and display the information graphically for the operator. The primary difference between the curl detector and an operator is that the detector can measure curl down to 0.25 mm, while the human eye can only detect curl down to approximately 2.5 mm. This device, in short, more effectively replaces the eyes of the operator.

The curl detector is illustrated in Fig. 6. The method of curl detection is quite simple. The laser projects a line in the cross-machine direction atop the moving web. This line conforms to the web's surface contours. A flat web reflects a perfectly straight, undistorted line. Any web curl causes line curvature in proportion to the amount of curl. The cam-

7. Closed-loop control



I. Typical correlation table

Grade	Measured curl	Thermo curl points	Corr. factor
42 lb carbonless	12.5 mm (+)	80	160 pt/25 mm
42 lb carbonless	25 mm (+)	160	160 pt/25 mm
42 lb carbonless	6.25 mm (-)	-40	160 pt/25 mm
50 lb thermal	31.25 mm (+)	200	160 pt/25 mm
50 lb thermal	8 mm (+)	50	160 pt/25 mm
50 lb thermal	0	0	160 pt/25 mm

era captures the line as a digitized image. With this image, together with knowledge of the laser-to-sheet-to-camera geometry, the web curl is accurately reconstructed for display on a video monitor. Curl height can be accurately calculated, limited only by the camera's resolution. This system can detect edge curl as small as 0.25 mm. On-line curl measurement leads directly to on-line closed-loop curl control.

Candidate paper grades

Although only recently introduced, the curl detector has been successfully tested on a variety of grades, including telefax paper, carbonless paper, printed paper, and release liner. These tests included not only

stand-alone curl measurement, but also the first successful implementation of closed-loop curl control.

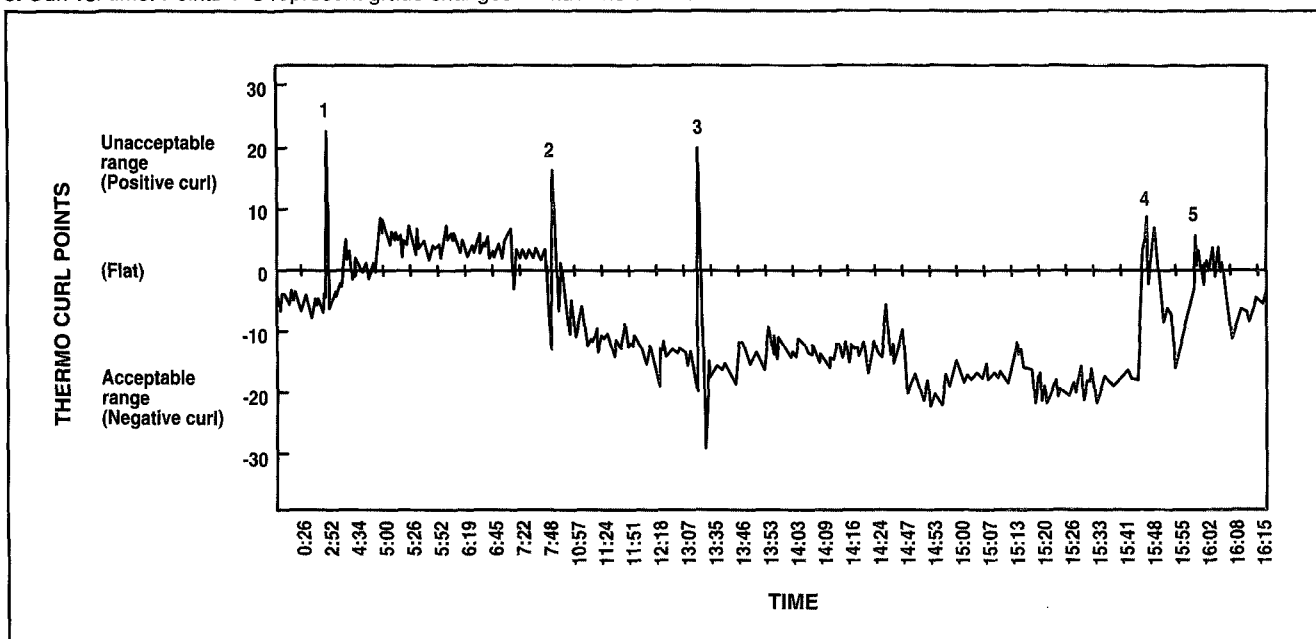
Stand-alone curl measurement

The curl detector is designed to operate in a stand-alone configuration, where it constantly monitors edge curl and displays this curl in real time (or as an average) to the operator. In this mode, the operator is able to identify changes in curl that require adjustments in the paper-making/converting process.

Closed-loop curl control

The curl detector is also designed to operate as part of a closed-loop curl control system connected to a decurling device (e.g., reverse roll

8. Curl vs. time. Points 1–5 represent grade changes or machine shutdown.



coater, Steam-Foil®, etc.) by means of either a 4–20 mA signal or RS-232 communications link, and automatically signal that device to correct the out-of-specification curl. In a closed-loop configuration, the detector monitors the amount of curl exiting the decurling device and determines whether additional decurling is necessary. For example, if necessary, it will signal the control device to increase steam flow in the case of the Steam-Foil® or increase roll speed in the case of the reverse roll coater. This curl strategy virtually eliminates the need for operator involvement and significantly reduces wasted product by constantly correcting out-of-specification web curl. The closed-loop configuration is illustrated in Fig. 7.

Typical configuration

Typically the curl detector would be located at or near the reel after the curl-correction device (i.e., after the reverse roll coater or Steam-Foil®) to measure the result of control actions. The unit itself is mounted approximately 12 in. above the web in an area where the web travels without support.

Because the curl detector is monitoring edge curl, it must be mounted parallel to the web's edge. The unit's small size and weight allows the flexibility of using mounting brackets that provide adjustment in the cross-machine direction to accommodate various deckle widths. This enables the system to be used on virtually all grades without restriction.

Operating parameters

The system can effectively monitor curl through a 4-in. range (i.e., it can measure from –50 mm of curl to +50 mm of curl). It is accurate to within $\pm 0.25\%$ and repeatable to $\pm 0.1\%$. The system can withstand 25 mm of both web flutter and edge wander (i.e., the web can be fluttering as much as ± 25 mm from flat). The detector can filter out the flutter and focus only on the curl. The same applies to web wander (± 25 mm), and the system can filter out the wander and only focus on curl. This flexibility allows the detector to measure curl in the most difficult applications.

Data logging

In either the stand-alone or closed-loop configuration, the system has data-logging capabilities whereby

the measured curl values are stored for review purposes and curl mapping. This enables the operator to review roll curl throughout the manufacturing process and to ensure that all of the product actually met the appropriate curl specifications. These data can then be archived along with other product information, so if problems occur after the product has been delivered to the customer, there is history available on the product in question.

System correlation

Due primarily to web tension, the amount of curl measured by the curl detector during production is significantly less than the actual curl in the unrestricted web. Therefore, the curl detector must be capable of measuring levels significantly below those of traditional techniques. As previously discussed, the curl detector is capable of measuring in 0.25-mm increments. This information is displayed on the operator's station as "curl points."

During initial system startup, measurements are taken with the curl detector for various grades and conditions. Samples are also taken and measured for curl using conven-

Curl Measurement

tional techniques. These measured data are then correlated with the data collected by the curl detector. This correlation allows the operator to relate the amount of edge curl measured by the curl detector with actual web curl. Table I is a typical correlation table.

Applications

Target curl

Figure 8 depicts measured curl under various conditions using the curl detector. Note that the detector is capable of monitoring even slight degrees of change. In this case, the customer requested a significant degree of negative curl (downcurl), and the curl detector was able to indicate when the target was achieved. In this application, the customer was using a Steam-Foil® as a correction device.

The results were very important for this customer, because the curl detector enabled them to recognize that increased steam flow does not always translate into an increase in negative curl. For instance, if the Steam-Foil® is applying steam at a rate of 100 lb/h and product is being manufactured with negative curl, simply increasing the steam output to 125 lb/h will not necessarily produce additional negative curl. By ac-

cumulating data, a maximum point of curl correction can be found that corresponds with a specific level of steam for a particular grade of paper.

Troubleshooting

Currently, no on-line method of curl detection exists, and therefore determining the causes of intermittent curl problems can be difficult. Using the curl detector enables accurate measurements, and problems can be more easily traced to their sources.

Summary

Many consider curl to be the most important quality criterion facing today's papermakers and converters (6). The costs associated with controlling curl and limiting wasted product are significant. Presently, the only methods of measuring curl involve stopping production, taking samples, and measuring them off-line in controlled settings. This process can prove costly both in the time it takes to run the tests and, more importantly, the fact that the sample being tested is from a roll that has already been produced. Manual measurement methods preclude the initiation of immediate process changes that would reduce lost product.

The ability to monitor and correct curl on-line has been demonstrated to be superior to conventional test/measurement methods. Cost savings in the form of reduced scrap can be significant (7-11). ■

Literature cited

1. Lyne, M. B., *TAPPI 1988 International Printing and Graphic Arts Conference Proceedings*, TAPPI PRESS, Atlanta, p. 89.
2. TAPPI TIS 0108-01, "Definitions of Graphic Arts Terms."
3. Erikson, L. E., *Nordic Pulp Paper Res. J.* (2)2: 66(1987).
4. Mann, K. C., *Tappi J.* 75(5): 133(1992).
5. TAPPI T 466 cm-82, "Degree of Curl and Sizing of Paper."
6. Viavattine, J. M., *TAPPI Quality Assurance—Management and Techniques Review of 1989*, TAPPI PRESS, Atlanta, p.155.
7. Colley, J., *APPITA* 41(1): 12(1988).
8. Gray, D. G., *J. Pulp Paper Sci.* 15(3): J105(1989).
9. Hartman, R. R., *TAPPI 1989 Polymers, Laminations and Coatings Conference Proceedings*, TAPPI PRESS, Atlanta, p. 339.
10. Votava, R. J., *TAPPI 1983 Papermakers Conference Proceedings*, TAPPI PRESS, Atlanta, p. 45.
11. Anderson, J. G., *Tappi J.* 74(6): 131(1991).

Received June 1, 1993.

Accepted July 19, 1993.

Presented at the 1993 TAPPI Polymers, Laminations and Coatings Conference.