

Curl control with a Coanda actuator system

Kimberly C. Mann and Lee A. Huff

The controlled delivery of steam through a Coanda nozzle offers a new approach to decurling.

One of the most important quality parameters of finished paper is curl. Of the many mechanisms which induce curl, the three most prevalent are attributed to drying conditions, variations in fiber orientation, and single sided coatings. Current methods employed to address and correct for curl provide limited—and in some instances, complex—solutions. Recent applications representing varying ranges of operating conditions demonstrate the controlled delivery of steam utilizing a Coanda nozzle as a superior decurling medium.

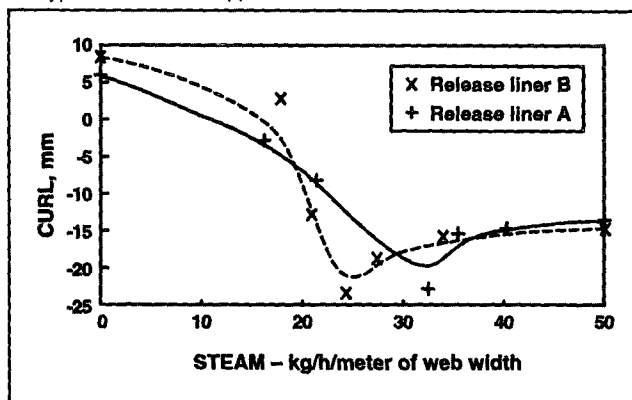
(The paper industry has long utilized the Coanda nozzle in air flotation dryers. The discovery of the Coanda effect is attributed to Henri-Marie Coanda, whom some people credit with the first jet aircraft—in 1910 (1)!)

With the expanding use of automated and sophisticated high-speed printers in the converting industry, the quality issues attributed to the various paper products being run are becoming more critical. In today's competitive market, the converting area is expected to maintain higher quality levels of finished products and is oftentimes required to upgrade substandard rolls of paper (2).

The control of curl is among the most important quality criteria which must be addressed (3). Curl is responsible for most sheet feed and transport problems (4). Present methods of curl control work both to prevent the formation of curl during the papermaking process and to remove curl (decurl) from an existing web. Some of these require the use of water application, drying restraint, or mechanical deformation.

Traditional methods where the application of steam is used as a means of curl control have limited success in isolated situations. Typically used on thin sheets, steam is applied most often by homemade pipe showers. They have very little control, exhibit problems with spitting, allow condensate to collect on external surfaces, and in most cases are limited to beneath-the-sheet locations. Later approaches attempt to incorporate cross-direction curl profilability by regulating the flow through spray or impingement nozzles with limited success. A recent advance in the *controlled* use of steam utilizing the Coanda

1. Typical curl control application



nozzle proves it to be an effective decurling method.

Figure 1 illustrates the results of an application where steam was used on silicone release labels. The shape of the curves is typical of most curl control applications. As is clearly shown on the graph, the new method of applying steam provides a wide range of control.

Curl-inducing mechanisms

A TAPPI Technical Information Sheet defines curl as "The tendency of unrestrained flat paper sheets to distort and form curved surfaces of essentially cylindrical shape" (5). Though simply expressed, this definition hides the fact that there are many mechanisms which can cause curl. Some of them are complicated and difficult to formulate. Gray (6) states more simply, "... a flat paper sheet is an unstable structure ..."

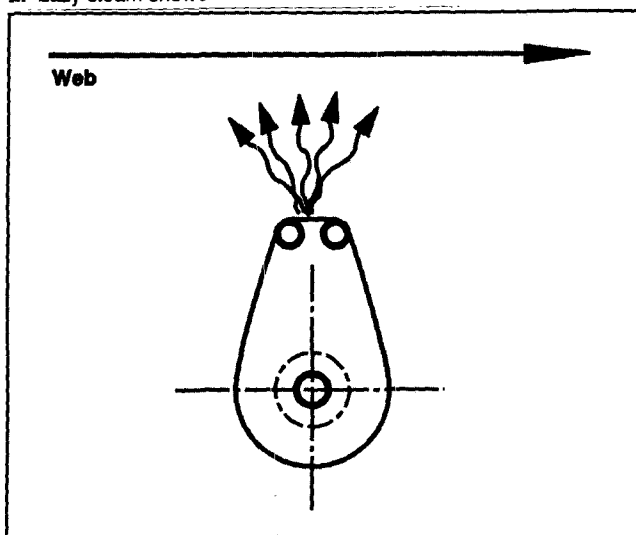
A convenient way to explain curl is to treat the paper web as a two-ply laminated structure with each layer having separate sheet properties. Three processes which influence the formation of this structure are differential drying, different degrees of fiber orientation on each side of the sheet, and the application of another material to one side of the sheet.

Differential drying

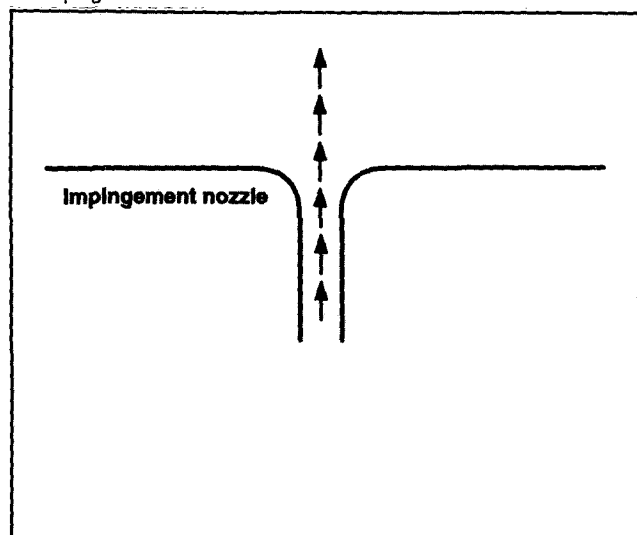
The conventional method used to dry the web on a typical paper machine feeds the sheet over steam-heated steel or

Mann is engineering manager and Huff is sales manager with Thermo Electron Profiling Systems, 35 Sword St., Auburn, MA 01501.

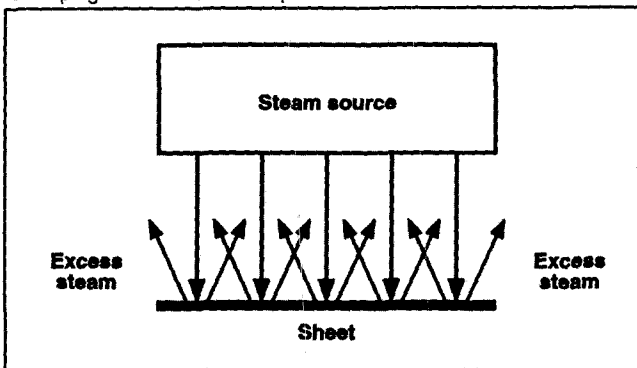
2. Lazy steam shower



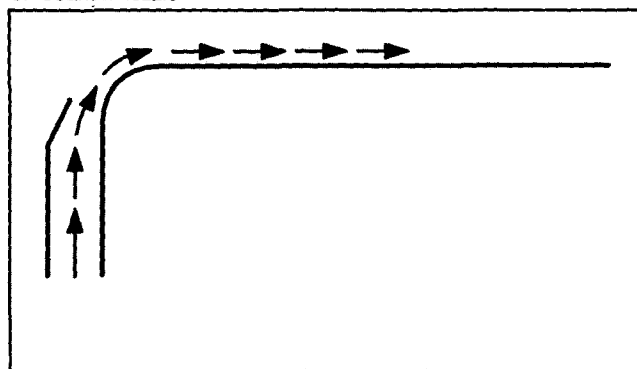
3. Impingement shower



4. Impingement surface disruption



5. Coanda nozzle



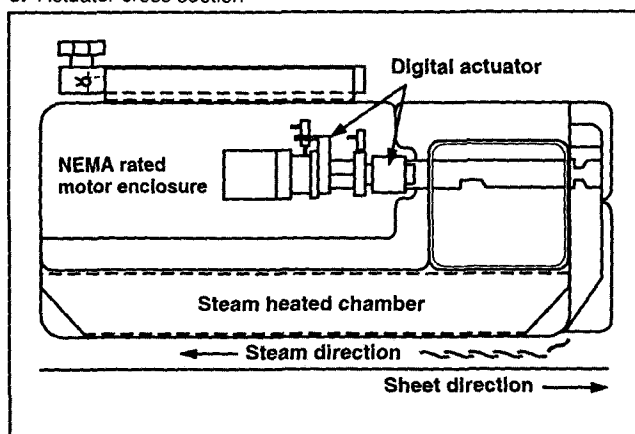
cast-iron cylinders, which induces a systematic drying cycle as the sheet passes from one cylinder to the next. Any difference in dryer section temperatures can cause differential drying throughout the thickness of the sheet. This differential drying will result in varying stress patterns becoming frozen into the dry sheet. The release of these drying stresses (and their corresponding induced strains) will cause the sheet to curl as it conditions to different environmental moisture levels (3, 7).

The expansion and contraction of paper fibers resulting from moisture variations is referred to as hygroexpansive behavior (8). Drying conditions have a significant influence on this property. Keeping in mind the two-ply structure of the sheet, differences in hygroexpansivity between the two layers (due to differential drying) is a basic cause of sheet curl. (A good analogy is to think of the sheet as a bimetallic element with temperature as the driving force.)

During conventional drying, nonuniform cross-machine shrinkage induces nonuniform cross-machine sheet properties which contribute to sheet curl. This is caused by not restraining the web as it passes from one cylinder to the next. Consequently, this lack of shrinkage restraint results in increased hygroexpansivity (9).

Curling tendency is defined as the change in sheet curvature per unit change in equilibrium moisture content (8). Cross-machine variations in curling tendency result

6. Actuator cross section



in a nonuniform curl profile at the reel. This makes it extremely difficult to maintain consistent sheet properties in the final product. Variations in the shrinkage restraint contribute to this problem by varying the hygroexpansivity of the two-ply sheet (8). Another cause of cross-machine variation stems from the removal of moist air in the dryer section. If not done in a controlled fashion, dryer edges are more likely to result (7).

Different fiber orientation

Different fiber orientations on each side of the sheet influence the sheet hygroexpansivity and subsequent curl. Examinations of paper made on fourdrinier machines show that the fibers on the wire side tend to be more oriented in the machine direction than those on the top side. Exposed to higher ambient humidity conditions, the moisture reabsorbed by the finished sheet causes the fibers to swell transversely, with the sheet expanding more on the wire side than on the top. This creates the formation of curl in the cross-direction towards the top side (6). In addition, as moisture is being removed through the wire, a density gradient forms through the web which further contributes to the structural two-sidedness of the sheet (8).

Fiber density variations in the cross-direction can induce variations in curling tendency across the sheet. Deviations in the mean fiber orientation, with the fibers angled slightly toward the nearest sheet edge, can also cause a nonuniform curl profile (6).

Single sided coating

The application of material to only one side of the sheet, such as sizing or coating, can create a two-sided condition. Any inherent differences in the hygroexpansive properties of both sides may result in curl. A nonuniform coating application in the cross-direction also contributes to cross-machine variations in the curl tendency.

Present methods of curl control

Traditional curl control methods employ devices either to prevent curl during the papermaking process or perform a decurling function during the calendering or converting processes. Advantages and disadvantages of some of these are listed below.

Drying restraint

Much of the cross-machine shrinkage occurs during the drying process on a paper machine due to the unrestrained draws between dryer cans. This shrinkage can be reduced by employing intermediate vacuum rolls in the dryer section to increase the web restraint. The restraint can be increased to 84% in a single tier dryer section compared to 38% restraint in a single-felt dryer (10).

This method can be quite expensive and require a significant amount of machine downtime to install, unless it is part of the original design or incorporated into a dryer section rebuild. In addition, there is no cross-machine profilability to address any variation in curling tendency.

Dryer can temperature adjustments

Used traditionally as an inexpensive tool for curl control, papermakers adjust the steam pressures between the top and bottom cylinders in the last dryer section (8). The resulting temperature differences create differential drying of the web, which induces intentional two-sidedness to the sheet. Because the thermal mass of each cylinder is significant, the temperatures cannot be adjusted quickly. And, as discussed before, this method provides no cross-machine control.

Flotation dryers

Because of the precise and uniform drying offered by

flotation dryers, differential drying can be reduced or even eliminated. However, there is no drying restraint to prevent shrinkage in the cross-direction. As with drying restraint equipment, there is considerable expense associated with this approach during a retrofit.

Liquid application

This method employs the direct application of water to the surface of the web to wet-curl (decurl) the sheet. This is done either by moisture boxes or by reverse roll coating. The web is then often run over a steam-heated roll to vaporize the moisture and force it into the sheet. The required equipment is easily retrofitted onto both paper or converting machines.

On reverse roll coaters, the web is in direct contact with the transfer roll, making it susceptible to pickoff of delicate coatings. The equipment must be mounted beneath the web, which further limits its application. Rough profilability is achieved by varying the orientation between the metering and transfer rolls. However, the moisture application profile cannot match alternating high and low curling tendencies in the cross-direction. Finally, because it contacts the sheet, the transfer roll finish must be critically maintained.

Compared with other curl control devices, reverse roll coaters are difficult to set up and maintain. Many converting operations employing reverse roll coaters for curl control are now looking to replace their equipment with less complicated and more reliable devices.

Second side coating

This method can effectively remove the two-sidedness of the web. In addition, it provides improved profilability over other traditional methods. However, the expense of the additional coating is normally unacceptable. In some situations, a second coater is not available, and the web must be run through the equipment a second time in order to coat the reverse side.

Curl bars

A mechanical-curl (decurl) method, curl bars deform the sheet by forcing it to assume a new shape (similar to folding). It is a simple approach and fairly easy to position onto a machine. But like other approaches, there is no cross-machine decurl control with this method and its employment is oftentimes associated with frequent web breaks. Undesirable sheet surface effects, such as static buildup and sheet markings, may result as the curl bar continuously rubs against it.

Steam showers

The use of steam as a decurling medium is not new. Steam introduces heat and moisture into the web to loosen the interfiber bonds which began to form between the sheet fibers before water in the swollen fibers was removed (6), and which were set during the drying process. In other words, steam helps to loosen and flatten the web by removing the fiber restraints which were set during the papermaking process.

Traditional steam showers are typically pipes with holes or slots machined along one side. They use a "lazy steam" flow to deliver steam to the web, as shown in Fig. 2. They perform best on thin sheets which limit their application.

They are not complicated to use and are fairly easy to install. In order to avoid problems with spitting, the showers are usually mounted beneath the web. There is very little control, other than manually opening and closing the feed valve, and any excess steam condenses onto external frame surfaces.

Steam showers which attempt to provide additional operating control replace the drilled holes in a pipe shower with digitally actuated solenoid or pneumatic valves which are capable of changing the flow openings by 7% steps. A steam delivery profile can be established by engaging each valve differently. However, because the device still depends on a "lazy steam" mist, the effectiveness is limited. As with traditional pipe showers, the tendency to drip and condense excess steam onto cooler machine frame sections still exists.

Impingement type showers operate by directing jets of steam directly onto the web through a series of nozzles, as shown in Fig. 3. These nozzles are arranged in a pattern and are located in close proximity to the sheet. Digitally driven pneumatic or solenoid control valves typically provide 7% step adjustments to the steam flow from each nozzle. The design is better suited to preventing dripping and spitting by utilizing superheated steam.

Because of the point source application of steam, impingement showers can disrupt the surface of the sheet and affect the overall quality of the final product. Figure 4 illustrates the effect of impingement showers on the sheet. This aspect is more pronounced on the more delicate webs. Although this equipment offers better profilability than "lazy steam" showers due to its closer position to the sheet, it is at best crude due to the large step increment associated with the control valves.

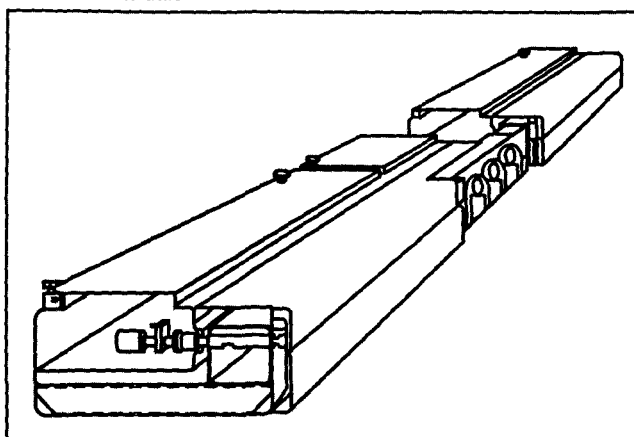
A superior method: the Coanda nozzle

The controlled application of heat and moisture to the sheet is an effective method to control curl. Recent advances in the controlled use of steam prove it to be successful in curl control while eliminating the problems once associated with it. As we discussed earlier, steam helps to soften the fiber bonds which were set during the drying process and also during the application of sizing and coating to one side of the sheet. Subsequent conditioning results in a flatter sheet.

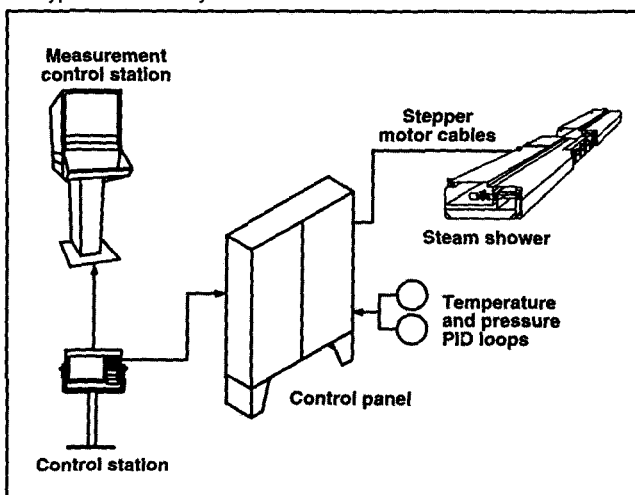
The actuator used to achieve effective decurl is a patented profiling steam shower utilizing a Coanda nozzle to apply steam counter-flow to the moving web, as shown in Fig. 5. The beauty of this approach is that it offers an efficient means to apply steam to the sheet in a controlled fashion never before possible.

The heart of the actuator is a Coanda nozzle which performs by ejecting a stream of steam over a curved surface such that the steam adheres to it. The nozzle consists of individual control zones situated along the entire width of the sheet which act independently to regulate the amount of steam delivered to the moving web. Each zone is controlled by a stepper motor which opens and closes a steam throttling valve in step increments as low as 0.1%. The desired curl profile in the cross-machine direction is maintained through adjusting each control zone from a remote operator station, as shown in Figs. 6 and 7.

7. Coanda actuator



8. Typical actuator system



Because steam is applied counter-flow to the moving web, this process is inherently more efficient than other steam processes. In other words, less steam is required to achieve the desired curl control. Any vagrant steam is collected by an attached vacuum system so it cannot condense onto other machine surfaces.

The outer surfaces of the actuator are heated to prevent moisture from collecting and dripping onto the web. This allows the actuator to be mounted in any orientation, including above the web.

The proper application of heat and moisture to the web to control curl is extremely critical; both parameters must be delicately balanced. Optimal performance of the Coanda actuator is achieved by integrating a systems approach into the paper manufacturing process to better handle several variables which affect its operation. Different web materials usually require different combinations of applied heat and moisture for curl control. The Coanda actuator system provides continuous monitoring and control of steam temperatures and pressures and also allows the machine operator the flexibility to change process parameters quickly to match changing web requirements. Figure 8 illustrates a typical actuator system.

Applications and results

Recent applications have utilized new steam actuators with 152-mm-wide control zones. Analyses of various webs have shown typical sheet temperature increases of 10°C to 30°C and moisture increases of as much as 3.7%. Because energy is transferred to the web by the condensing steam, cooler incoming web temperatures (20°C to 40°C) provide better results. Five applications demonstrating superior control and performance attributes are illustrated below.

Release label

Pressure labels utilizing silicone release liners have been decurled from a 10-mm positive face-stock curl to a negative liner curl of over 20 mm, as demonstrated in Fig. 1. Steam was applied to the sheet through the silicone liner. It is important to note that a flat sheet condition was desired. Having the ability to reverse the curl to such an extent demonstrates the considerable control capabilities the system provides.

As Fig. 1 shows, increasing the steam delivery to the web results in an increase in the curl reversal—up to a point. Beyond a certain steam flow rate, inefficiencies begin to enter into the process from the inability of the web to absorb any additional steam. At higher flow rates, this excess steam bounces off the web to be absorbed by the vacuum system. In addition, unlike impingement-type steam showers, the higher flow rates delivered by a Coanda actuator will not significantly disrupt the web surface. Finally, because this inflection point occurs well beyond most levels of curl reversal, the system will always operate at higher efficiencies than traditional steam showers.

Fax paper

Thermally sensitive webs, such as fax paper, require a delicate application of steam in order to achieve effective curl control without imaging (darkening) the sheet by the steam. A 25-mm curl reversal has been achieved on an application where the process line speed exceeds 350 meters/min.

Adhesive coating

Paper manufactured with adhesive applied in strips, rather than across the entire width of the web, has also benefited greatly from this approach. Because the nonuniform coating induces varying curl tendencies across the web, the profilability of the Coanda actuator was able to provide flat sheet conditions on the final product.

Plotter paper

Paper coated with a temperature-sensitive imaging material was turned to a flat condition from a tightly scrolled curl without raising the sheet temperature above 65°C. (This was achieved on a single pass. Originally, a reverse roll coater was employed during a two-pass operation.) As with fax paper, it is important to maintain web temperatures below the coating transition temperature.

Printed forms and labels

The curl on printed forms and product labels has been effectively managed to provide better downstream process control. A reverse curl has been consistently induced into printed checks during the printing operation. This allows for continuous form feeding on automatic check writing

equipment without jamming. Inducing a negative curl on printed product labels aids in continuous sheet feeding during later converting operations.

Additional benefits

Depending on the location of the Coanda actuator, additional benefits can be derived from the controlled application of steam. The moisture added to the web can help to reduce the static buildup associated with various processes. In addition, improvements in reel building can be achieved. If the Coanda actuator is located before a machine calender or supercalender, improvements in gloss and smoothness can be realized.

Direct curl monitoring on the machine has not yet been developed. However, as more knowledge is gained about the correlation between curl and the addition of heat and moisture into the web, the Coanda actuator system is capable of communicating with existing measurement equipment to provide automatic curl control.

Summary

The paper and converting industries have long been associated with producing high-quality paper products while dealing with many different obstacles determined to impede their efforts. In today's increasingly demanding marketplace, discovering a method to effectively address and overcome even one of these obstacles can vault an organization to the head of a highly competitive pack.

The control of curl is considered by many to be among the most important quality criteria which must be addressed (3). Present methods employed to tackle this issue provide limited success in specific applications due to the fact that there are many complicated mechanisms which can cause curl. Managing one of them is not a guarantee that others will also become harnessed. The precise engagement of heat and moisture to the web through the use of steam delivered by a profiling Coanda nozzle has been demonstrated to be a superior method of curl control in a variety of applications. □

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