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In comparing the two heat transfer rolls, the Tri-Pass roll proved to be the superior design. In the 14-inch dia size, the Tri-Pass roll was capable of transferring 73% more heat for a fixed temperature differential between the surface and fluid passages. For a fixed heat transfer rate, corresponding to a 6°F drop in heating fluid temperature, the 30-inch dia Tri-Pass roll will operate at a 33°F lower temperature due to a more efficient overall heat transfer coefficient.

Load carrying capacity, or maximum nip load, was not significantly different for the two 14-inch dia rolls; however in the 30-inch dia size the Tri-Pass roll was capable of supporting an additional 400 pli. The greater load carrying capacity of the Tri-Pass roll is a result of its greater moment of inertia. This fact also makes the Tri-Pass roll stiffer, which means it will deflect less under load. If this roll were operating against a VCR, the VCR would require less pressure to obtain the necessary overcrown to match deflections. This reduces the size and operating pressure of the variable crown roll, and increases the life of the internal shell bearings.

The two rolls were also analyzed for dynamic stability. The smaller diameter rolls showed the most significant difference, with the baffle type roll having a critical speed of the baffle close to typical operating speeds. Critical speeds of the larger rolls, in both designs, were well above operating speeds. The Farrel Tri-Pass roll showed greater stability when analyzed for dynamic unbalance. The 30-inch dia Tri-Pass roll had a permissible unbalance 50% greater than the baffle type roll. It is readily apparent that as the roll diameter is increased, the advantages of the drill type roll over the baffle type roll increases significantly.

Conclusions. The use of the TCR is gaining wider acceptance throughout the paper industry. In terms of its importance to calendering, it is as indispensable as the VCR. Given the conditions of: (1) inherent mechanical problems of non-uniform nip load and (2) thermal distortions created by the non-uniform properties of the sheet entering the stack, one must conclude that the key to successful calendering requires a solution to both problems. VCRs provide one solution; temperature controlled rolls, the other. —**PTJ**

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The temperature profiles shown in **Fig. 8** are taken from a four-roll calender stack, which had replaced an eight-roll stack. Here, both VCRs and drilled rolls were used to control the stack temperature. Note the temperature distribution. This stack arrangement resulted in a significant increase in both paper quality and production, as well as a significant increase in roll life between regrinds.

Structural considerations. An additional study was made comparing the Farrel Tri-Pass (drilled) roll with a shell and baffle type roll (**Fig. 3**). The shell and baffle design is basically a shell with an internal baffle to which longitudinal spacer bars may be welded to direct the flow. The study included a heat transfer analysis, strength analysis, and dynamic analysis, of the two rolls. The results are summarized in **Tables I** and **II**, for 14-in.-dia rolls and for 30-in.-dia rolls.

(Continued on next page)

TABLE I
SUMMATION OF RESULTS
14″ ϕ Baffle Type (BT) vs. 14″ ϕ Tri-Pass Roll (TP)

HEAT TRANSFER CAPACITY

$T_{FLUID}-T_{SURFACE} = \Delta T = 40°F$				$q_{bt} = q_{TP} = q = 135{,}000 \frac{BTU}{HR}$	
q_{TP} BTU/HR	q_{BT} BTU/HR	$q_{TP}-q_{BT}$ BTU/HR	%	ΔT_{TP}	ΔT_{BT}
222,471	128,042	93,829	73	25°F	42°F

DESIGN LIMITS

Maximum Load		Deflection/PLI	
P_{TP}	P_{BT}	δ_{TP}	δ_{BT}
152 PLI	147 PLI	0.0004469	.0004612

DYNAMIC STABILITY

Critical Speed			Permissible Unbalance	
V_{TP}	V_{BT} Shell	V_{BT} Baffle	U_{TP} oz-in.	U_{BT} oz-in.
5294 FPM	6008 FPM	2771 FPM	161.02	156.20

TABLE II
SUMMATION OF RESULTS
30″ ϕ Baffle Type (BT) vs. 30″ ϕ Tri-Pass Roll (TP)

HEAT TRANSFER CAPACITY

$T_{FLUID}-T_{SURFACE} = \Delta T = 70°F$				$q_{TP} = q_{bt} = 800{,}000 \frac{BTU}{HR}$	
q_{TP} BTU/HR	q_{BT} BTU/HR	$q_{TP}-q_{BT}$ BTU/HR	%	ΔT_{TP}	ΔT_{BT}
985,180	625,996	359,184	57.4	57°F	90°F

DESIGN LIMITS

Maximum Load		Deflection/PLI	
P_{TP}	P_{BT}	δ_{TP}	δ_{BT}
1105 PLI	722 PLI	.00004074	.00006234

DYNAMIC STABILITY

Critical Speed			Permissible Unbalance	
V_{TP}	V_{BT} Shell	V_{BT} Baffle	U_{TP} oz-in.	U_{BT} oz-in.
17,883 FPM	22,788 FPM	18,308 FPM	9358	6115

BT = Baffle Type Roll
TP = Farrel Tri-Pass Roll

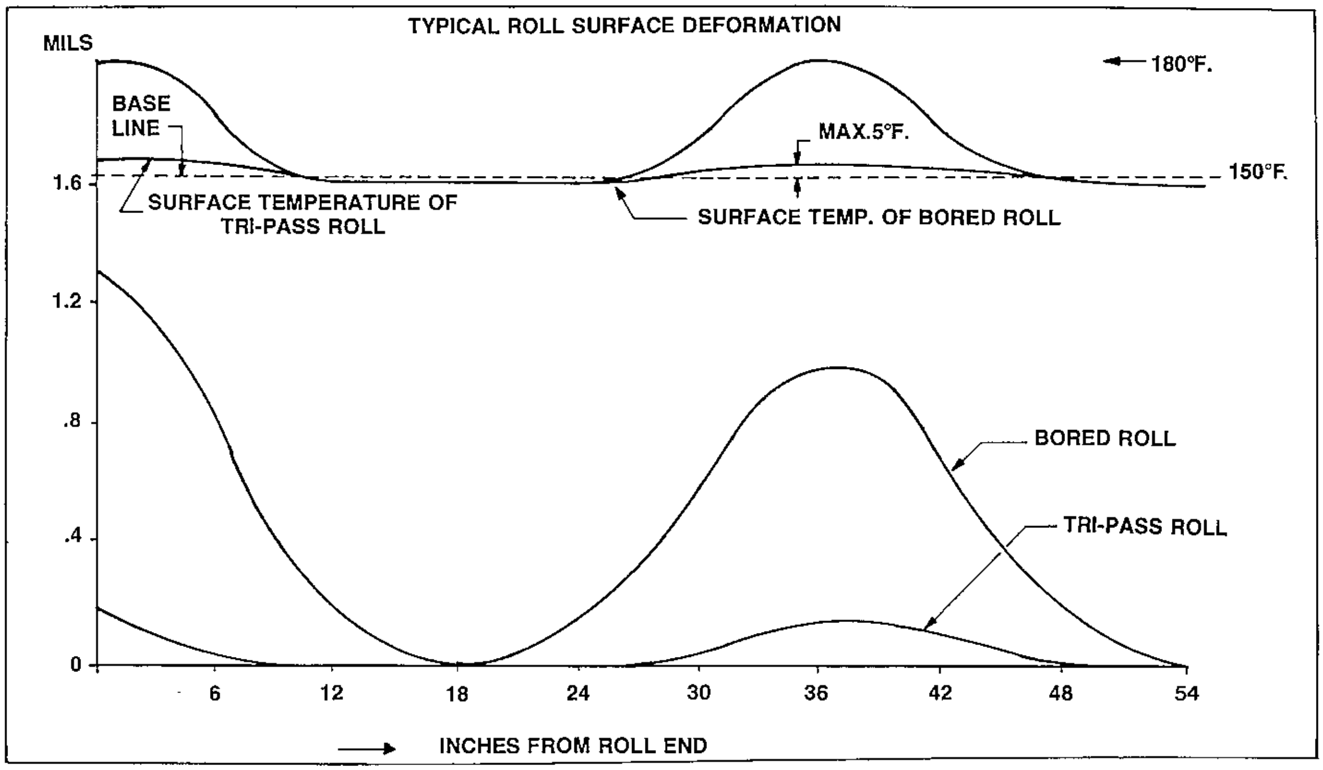

Fig. 7. Typical roll surface deformation.

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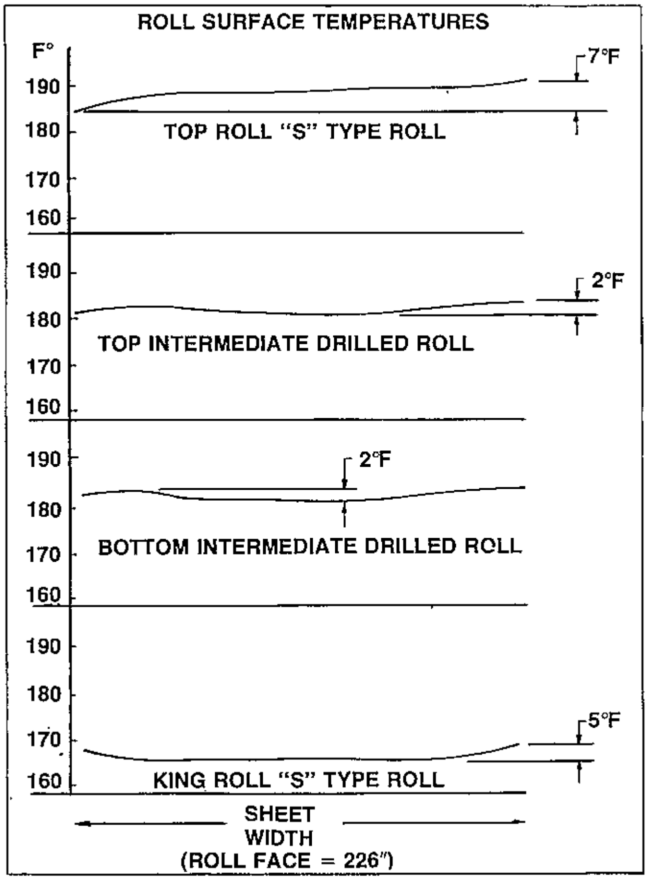
small bore in the roll. The result is a thermal distortion known as the "oxbow" effect, and is the shape a roll will take when the inside and outside roll temperatures are significantly different.

At the face center, up to a distance of one diameter from the roll edges, the axial expansion across the roll diameter is restricted and uniform, no matter what the *radial* temperature differences are. However, toward the free edges of the roll, these thermal expansions cannot be contained and the result is a "bowing" of the roll much as occurs with a bimetallic strip subject to temperature changes. The degree of thermal distortion which can occur is made evident by the fact that in most mills where bore heating is used, friction pads or heat lamps are also used to control the sheet edges.

To determine the magnitude of thermal distortion caused by the "oxbow" effect, a finite element, heat transfer, computer study was conducted on two 22-in.-dia rolls. In this study, a comparison was made between a simple bored roll and a Tri-Pass (drilled) roll of equal diameters. The first important, but not surprising, fact revealed was the significant fluid temperature difference between the two type rolls, for the given heat transfer requirement of 920 Btu/hr/in., shown in **Fig. 5.** Note that the fluid temperature for the bored roll is 100°F higher. The deformation caused by the temperature differences is shown in **Fig. 6,** plotted along the roll face. Note the "oxbow" effect. The graph in **Fig. 7** also shows thermal distortion along the face of the roll, for typical temperatures recorded in operation, for equivalent heat transferred. As indicated by these graphs, only effective heat transfer can be used to minimize thermal distortion.

Fig. 8. Roll surface temperatures.



tions is limited.

Advantages to be gained from the use of temperature control in machine calenders is readily apparent. With supercalenders, however, the use of heated rolls may seem paradoxical when, seemingly, high temperatures are a problem with filled rolls. The fact of the matter is that filled rolls are damaged principally either by high loads or by non-uniform loads. As temperature-controlled rolls reduce the need for high loads, sub-surface heat generation is reduced and blowouts are avoided. In addition, this uniform roll temperature can considerably reduce the occurence of "banding," normally the result of localized loading.

Types of temperature controlled rolls. The above relationships assume uniform nip pressures. With a suitable VCR, such uniformity can be achieved, particularly with the recent introduction of variable-crown, zone-controlled rolls. However, the best VCR will not compensate for thermal distortions produced either by improper roll-heating practices, or by wet or high-density streaks. Such problems are best handled by TCRs designed not only to be structurally sound, but encompassing all the principles of good heat exchanger design.

To accomplish the latter, TCRs are equipped with suitable circulating fluid systems and controlling devices. They are designed to locate the fluid transfer media as close to the roll surface as possible, thus reducing temperature differences and establishing temperature equilibrium rapidly.

One such design is the Tri-Pass (drilled) roll shown in **Fig. 2.** In this design, a heating or cooling medium is fed through one end of the roll into a center hole which feeds radial passages leading to axially drilled holes near the surface of the roll. The fluid makes three passes before it exits, again radially, into the outlet passage. The essential features of this roll design are the location of the fluid passages and the counterflow, both highly practical considerations where temperature uniformity and temperature control are required.

A simple shell-roll design or bored roll are alternatives to the drilled-roll design, but mathematical analysis and practical experience has shown that drilled rolls expand far less for a *given amount of heat transferred than shell or bored rolls*, with consequently less surface distortion. These more common types of heat transfer rolls are shown in **Fig. 3.**

Thermal distortion. Simple uniform radial growth of calender rolls is not in itself a problem, because with uniform temperature rise, the roll does not lose its shape. It is only when a temperature difference exists, either axially (along the roll surface) or radially that the surface profile is altered significantly.

Some of the more common problems in paper calendering are shown in **Fig. 4.** The effects shown in 4A and 4B are self explanatory. The thermal distortion shown in 4C arises when the backtender attempts to gain some form of temperature control by putting a heating or cooling fluid through a

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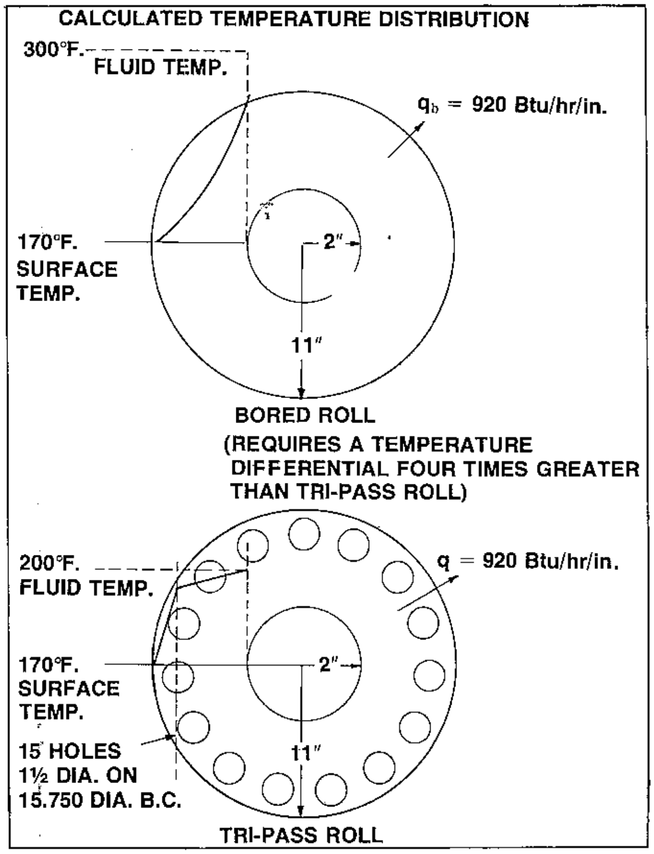
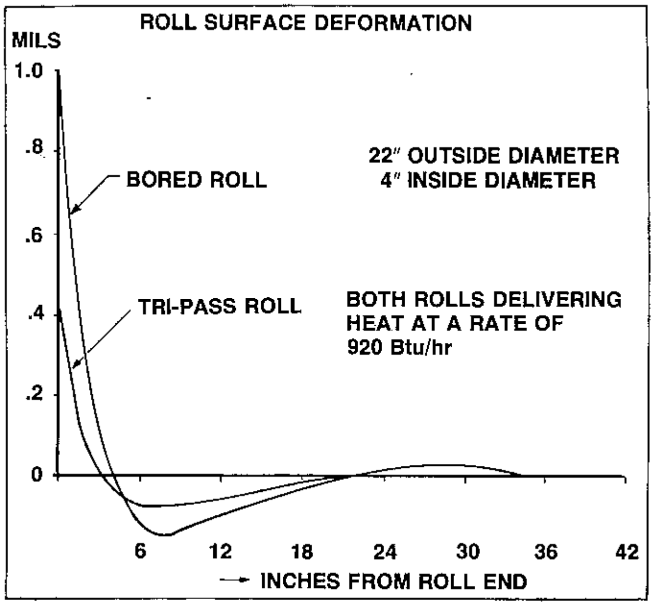


Fig. 5. Calculated temperature distribution.

Fig. 6. Roll surface deformation.



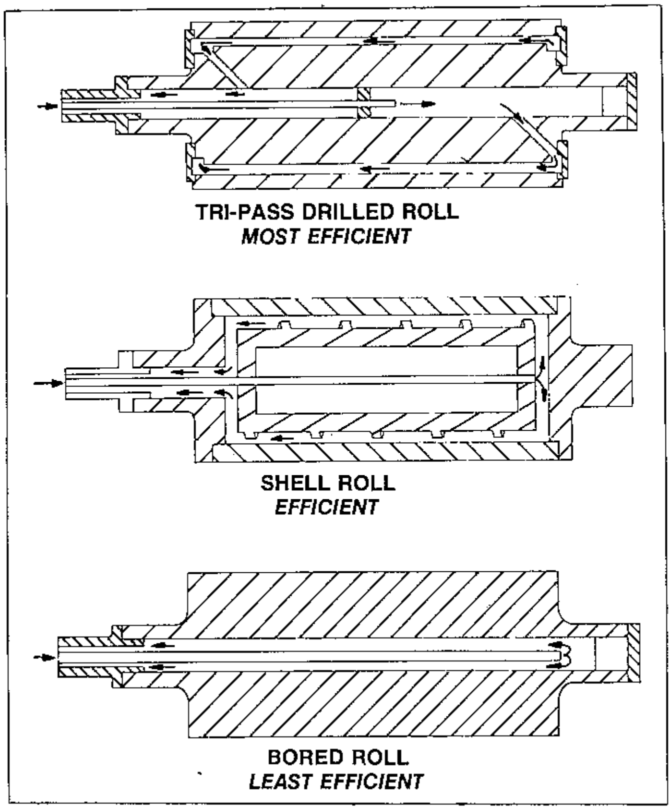
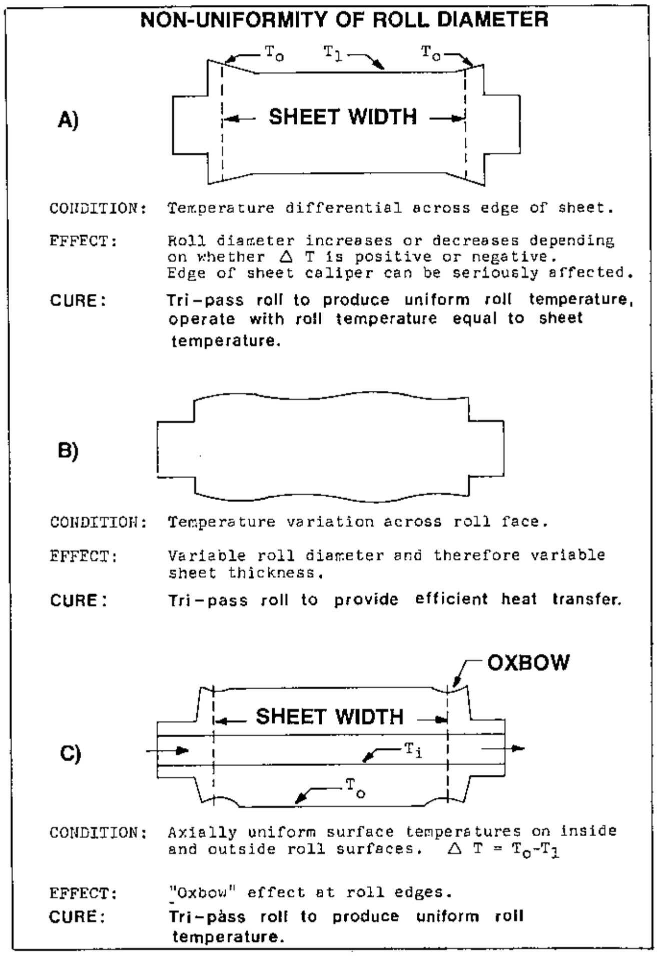


Fig. 3. Types of rolls used for temperature control.

Fig. 4. Non-uniformity of roll diameter.



A)

CONDITION: Temperature differential across edge of sheet.

EFFECT: Roll diameter increases or decreases depending on whether ΔT is positive or negative. Edge of sheet caliper can be seriously affected.

CURE: Tri-pass roll to produce uniform roll temperature, operate with roll temperature equal to sheet temperature.

B)

CONDITION: Temperature variation across roll face.

EFFECT: Variable roll diameter and therefore variable sheet thickness.

CURE: Tri-pass roll to provide efficient heat transfer.

C)

CONDITION: Axially uniform surface temperatures on inside and outside roll surfaces. $\Delta T = T_o - T_1$

EFFECT: "Oxbow" effect at roll edges.

CURE: Tri-pass roll to produce uniform roll temperature.

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stack temperature was one more control variable that helped to meet the ever increasing demand for higher quality paper.

Today, slow but steady gains are being made in the use of TCRs, and it is interesting to note that in Europe, the trend is in supercalenders. (Possibly due to the fact that filled rolls, in Europe, are soft compared to those in the U.S., and more susceptible to blowouts or hot spots.) In the U.S., the majority of TCRs have been installed in machine calenders. Notwithstanding the direction of these developments at this time, it is apparent that the TCR is proving an indispensable tool for modern calender operation.

Why temperature controlled rolls? The idea of using some form of temperature control in calendering is, in itself, not new. For years, air showers, friction pads, and steam directly applied to bored rolls have been used on machine calenders. Such devices may be compared with fixed crown rolls and roll bending, those initial attempts to achieve some form of crown control. Similarly, they have their limitations, because very often, application of such devices solve one problem while creating another.

It is important to recognize that a properly designed TCR serves *two* important functions:

(1) *As an operating parameter,* the TCR allows the stack temperature to be set at an optimum level to produce the best sheet properties. Equally important, it allows the stack temperature to reach equilibrium rapidly, before or shortly after start-up.

(2) *As a control parameter,* the TCR maintains uniform roll temperatures, thus minimizing thermal distortion and insuring *web uniformity.*

During the past decade a number of papers have been written showing definitive relationships between caliper reduction and smoothness, and other paper qualities. The general belief is that if caliper reduction is achieved, smoothness and other qualities follow. However, what has not been firmly established is the optimum path of this caliper reduction; i.e., what combination of temperature, nip load, number of nips, etc., produce the most positive results?

More than likely, this will depend on the paper being manufactured and may require the optimum combination to be determined during actual processing. However, to accomplish this, tools must be made available to the machine operator. Paper-machine builders recognize this fact to the extent that most modern calenders are equipped with *both* variable crown rolls and TCRs.

To appreciate the advantage of a calender having both types of controlled rolls, consider the chart in **Fig. 1.** From this, one can readily see the effect of wider and faster machine roll diameter and speed. To compensate for increases in B & E, parameters A, C, or D must be adjusted. Because parameter A is not readily controllable, C and D remain the most significant operating parameters. With only one of these, paper can still be produced, but the ability to operate the stack at optimum calendering condi-

FINISHING:

Temperature controlled rolls—one key to a successful calendering operation

BY D. A. D'AMATO

> 'Use of temperature controlled rolls is gaining wider acceptance throughout the paper industry, and in terms of its importance to calendering, it is as indispensible as the variable crown roll.'

Without question, the variable crown roll (VCR) has become an indispensable tool for the papermaker; no modern paper machine or supercalender should be designed today without the use of some type of VCR. What appears to be a less significant development (yet equally important to many papermakers) is the temperature controlled roll (TCR).

In 1964, Farrel Tri-Pass (drilled) rolls were installed in a machine calender, marking the first time that temperature controlled rolls were used both to regulate stack temperature and to achieve roll surface temperature uniformity on a production machine. About that time, investigators reported on the effects of higher calendering temperatures on paper caliper and smoothness, as well as other paper qualities. As a result of such studies, some very definite relationships were established between load, calendering temperature, and number of nips, pointing to the fact that

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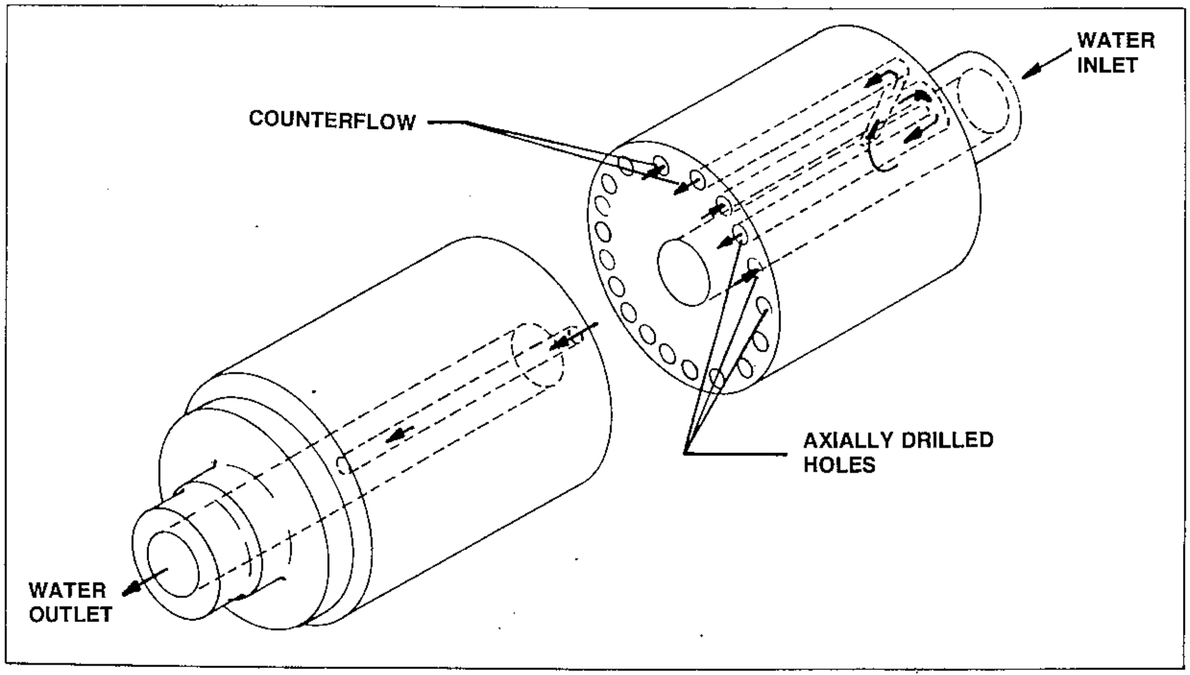
INCREASE IN:	CALIPER	SMOOTHNESS
A. NUMBER OF NIPS	➘	➚
B. SPEED	➚	➘
C. NIP LOAD	➘	➚
D. TEMPERATURE	➘	➚
E. ROLL DIAMETER	➚	➘

Fig. 1.

Fig. 2. Typical Tri-Pass roll configuration.



About the author: D'Amato is associated with the Farrel Company, Emhart Machinery Group.