

A new cross-profiling system for hard- and soft-nip calenders

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CROWN COMPENSATION AND CD PROFILE CORRECTION

The development of the swimming roll, about 40 years ago, made it possible to create a uniform distribution of nip force over the width of the roll independent of the level of median nip force. Additionally, such rolls permit general nip force corrections at the edges and in the center of the roll. The zonal deflection-controlled roll of a more recent date, currently used primarily in large and fast hard- and soft-nip calenders, gives us a tool for CD profile corrections in six to eight zones. Neither the swimming roll nor the zone-controlled roll, however, provides the means for localized corrections and their exact positioning at any point along the roll face. That is why separate correction devices are used in addition to the relatively expensive systems of zonal deflection-controlled rolls. These devices are based on the principle of modifying the diameter of the chilled iron rolls by localized heating or cooling of their surfaces. The width of the zones heated or cooled varies from 38 mm (1.5 in.) to 76 mm (3 in.), depending on the system or design used.

Figure 1 shows a CD caliper-profiling system used in several soft-nip calenders. In this case, the broad-wave irregularities are corrected with a zonal deflection-controlled roll, and the narrow waves are corrected with a separate induction heating unit.

When adjusting such systems, it must be taken into account that the components of this system have markedly different setting times. Corrections by hydraulic pressure can

be set in a few seconds, while thermal devices become fully effective only after more than 20 min. The additional external correction devices can improve the CD caliper profile to a great extent (1). In multi-roll calenders, this equipment can help materially to eliminate the drawbacks of the system. A negative aspect, however, of all such correction devices is their fairly high energy consumption and reduced accessibility of the machine. The varying surface temperatures of the chilled iron roll also have a greater effect on the smoothness and gloss of the sheet than if the correction were made by nip load variations alone.

FUNCTIONAL EFFECT OF A ROLL WITH INDIVIDUALLY CONTROLLED ELEMENTS

Zone-controlled rolls have been proven in practical operation to produce zone-wide profile corrections. As previously mentioned, however, zonal divisions, as well as the necessary width of the zones, preclude narrowly localized corrections, which are at times necessary. An effort was made, therefore, to improve the deflection capabilities to allow such nip force distributions. The development of this new roll was based on the well-proven elements of the zone-controlled roll (2). Its design distinguishes itself, however, mainly by its individually controlled elements. The heads of its sleeve chamber are sealed by hydrostatically braced ring seals. The roll is made in two different versions: the BC type and the SL type. On the BC type, the shell bearing is centered on

ABSTRACT

A newly developed controlled crown compensated roll gives the paper-maker a tool for making both broad- and narrow-wave CD profile corrections without external devices. The design of this roll is based on the principle of well-established zone-controlled rolls but allows control of each element. The size of the linear profile deviations is independent of the median nip force, with corrections applied as additions to or subtractions from the nip force at any desired location including the edges.

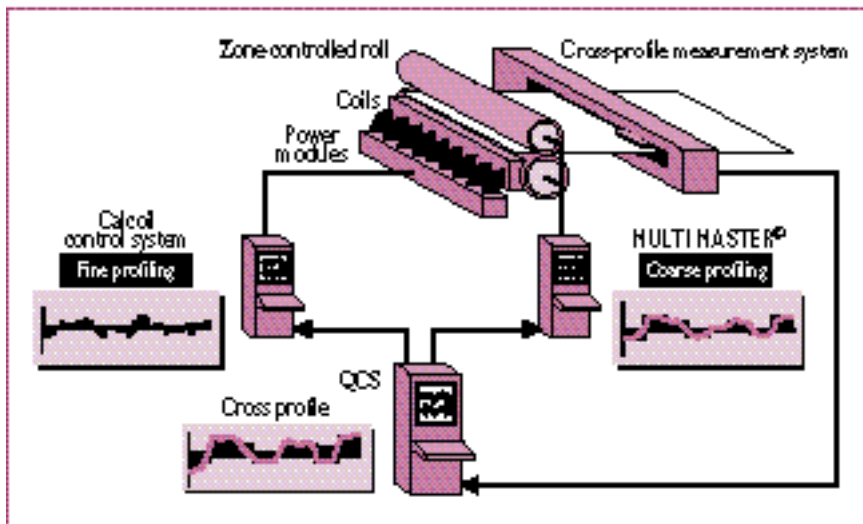
The effect of the linear force settings on caliper corrections depends on the magnitude of the median nip force. At a lower linear force level, a given amplitude of corrective force has a greater effect than the same amplitude at a higher median nip force. With increased sheet density, higher linear force differentials are required for a given caliper reduction.

Application:

This paper explains the mechanism of the single-element-controlled roll. The possibilities of local corrections of the line load as well as their effects on the thickness are also demonstrated. Furthermore, the advantages of the MULTIHV technology in comparison with the standard CD caliper control are shown from a technological and economic point of view.

the shaft. The SL type has a shell that is movable in the direction of the nip. The stroke may be 30–60 mm, as required. **Figure 2** is a photograph of a roll shaft with the HV (HYDRO VARIO) elements in the assembly.

With the design of these elements, on the one hand, and the capability of preloading the shell with hydraulic pressure in the chamber between the shaft and shell, it is possible to create a resultant positive or negative nip pressure, as shown in



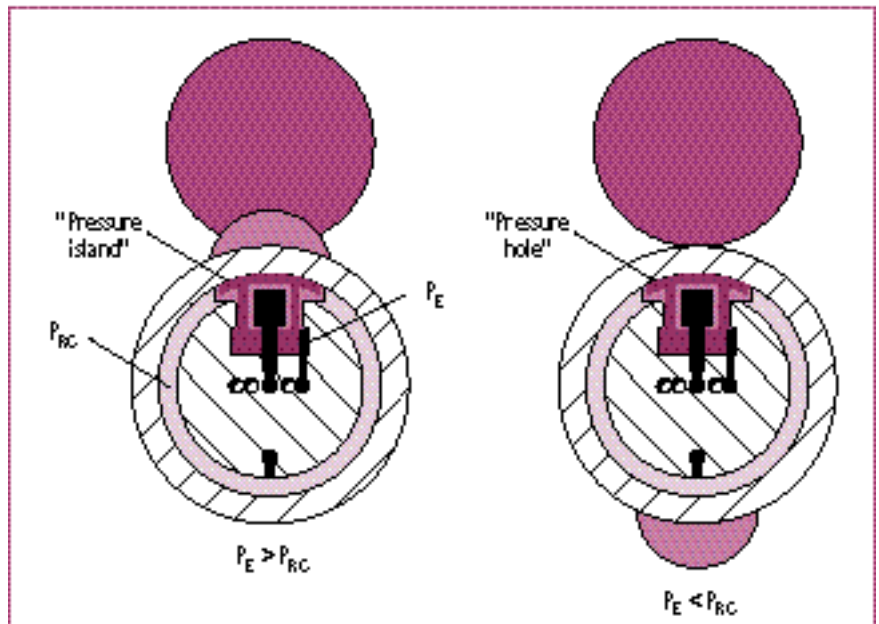
1. Cross-profile control in soft calender with zone-controlled roll and external inductive heating



2. Assembly of a MULTI HV-Roll

Fig. 3. If the pressure within the elements exceeds that of the chamber, the elements are charged with oil that leaks into the sleeve chamber. The pressure within the element constitutes a "pressure island" within the chamber. This creates a resultant linear force within the shell toward the nip (positive nip pressure). If, however, the pressure in the elements is lower than that in the chamber, oil leaks from the chamber into the elements. The lower pressure within the elements creates "pressure holes," resulting in a force away from the nip (negative nip pressure).

Control of the roll with individually controlled elements uses components comparable to those in zone-controlled rolls. Algorithms for their calculation were adjusted to the greater number of elements. The roll is computer controlled and can be linked to a master computer of a paper machine or off-machine coater.

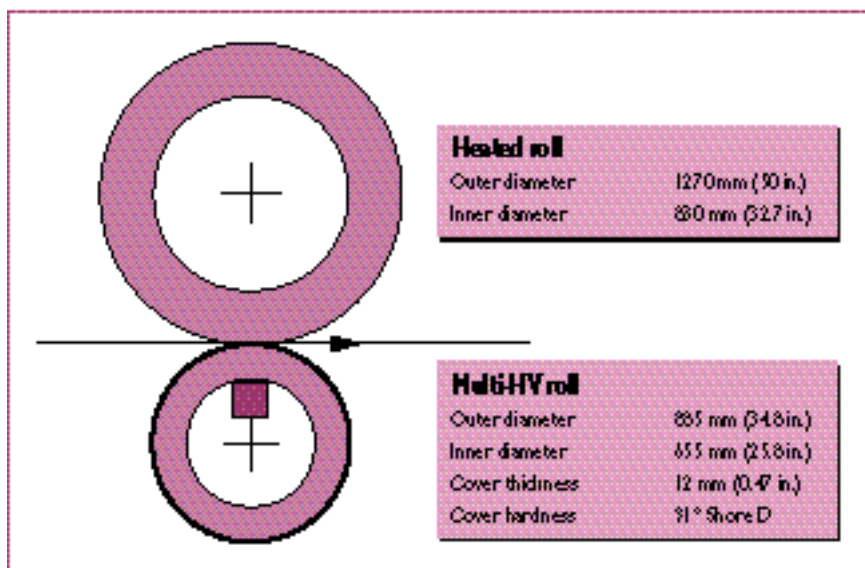


3. Effect of force on roll shell through different pressures in the element and in the sleeve chamber

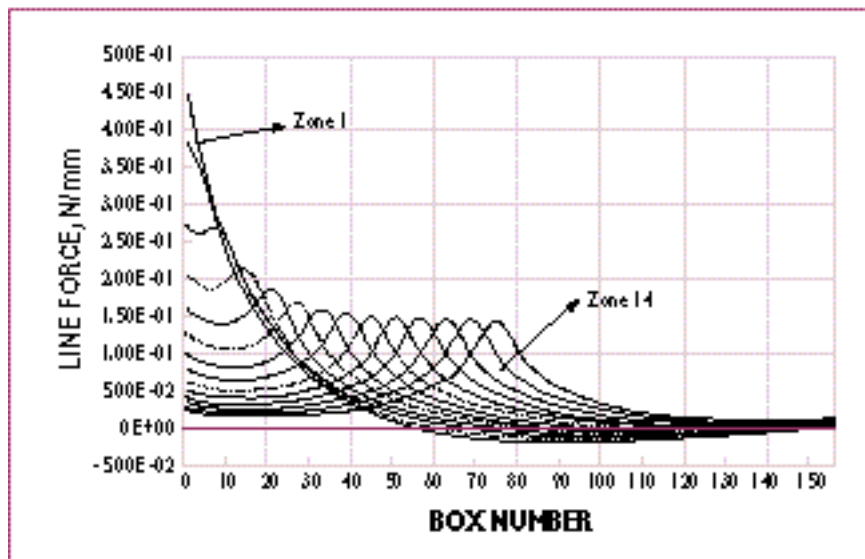
CORRECTION POTENTIAL OF ROLLS WITH INDIVIDUALLY CONTROLLED ELEMENTS

In general, all profiles can be set with this roll, just as with the zone-controlled rolls. Uniform linear force profiles, as well as broad-wave profile corrections, can be set across the

entire roll width. Thanks to the applied system with sleeve chamber pressure, a sheet can be calendered at approximately 5 N/mm. Even at such low linear loads, the full correction potential of the roll is available in both directions. Nip force additions up to 100 N/mm and subtrac-



4. Roll configuration used for FEM calculations



5. Line force shapes created by loading with a single element

tions to zero are feasible. This feature is already applied in practice for calendering newsprint with a high content of deinked fiber as well as for calendering board. Likewise, the full correction potential is available also at high nip loads in the region of ± 100 N/mm.

In the following observations, we shall dispense with nip load settings

that are considered current practice, i.e., uniform nip load over the entire roll face, and broad-wave corrections. We rather present the capabilities of carrying out localized corrections with the use of the new roll.

Finite elemental calculations

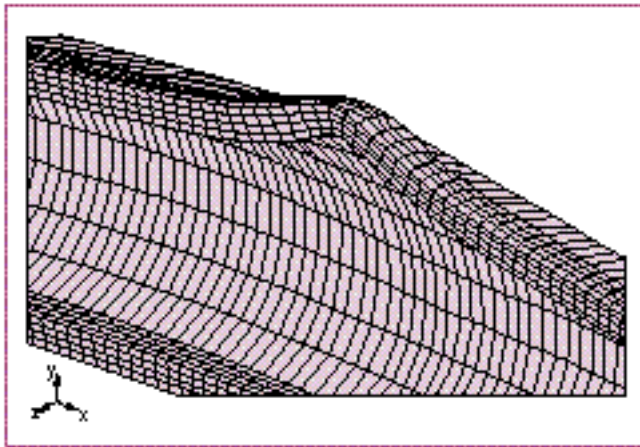
The possible local corrections of nip load with a roll of the SL type are calculated for the soft-nip calender

with an effective width of 6100 mm, as shown schematically in Fig. 4. The elasticity factor used corresponds to a hardness of 91° Shore D for the roll cover and a sheet with a basis weight of 50 g/m². There are 28 individually controlled elements facing that nip. The roll width was divided into 256 data boxes to show the results.

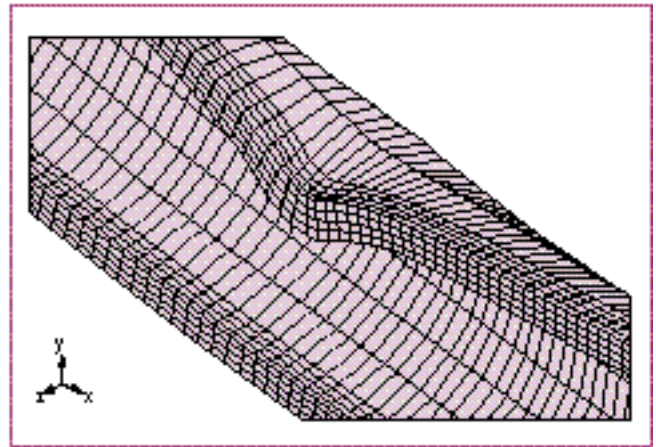
For the purpose of accurately calculating the effect of the local nip load, the rolls are substituted with a finite element model (FEM).

In this connection, it is important to also include the localized effects of the distortion of the shell. To this end, the roll face is divided into element blocks in the directions of circumference, thickness, and length. The components for balancing these elements create an equational system with, for example, 80,000 unknowns. It is also possible to solve the equations individually for each MULTI HV element and thus obtain the linear force distribution as a function of each element. The curves of such linear loads under pressure in one individual element, e.g., through a "pressure island," are shown collectively in Fig. 5 for all elements on the left side of the roll. Zone no. 1 is the edge zone, and zone no. 14 is next to the centerline of the roll. All of these curves clearly show the area effect of the force applied, which diminishes with increasing distance and then converts to deflection of the beam.

Corresponding to the calculations for a "pressure island," the effects of a "pressure hole" have been calculated, namely, when the pressure of the ring chamber exceeds that in the element. Due to the initial loading of the shell, local pressure relief can be obtained to the same extent as local pressure loading; the curves are mirror images of those in Fig. 5.



6. Localized shell deformation with a single element creates a "sealed pressure area"



7. Localized shell deformation with a single element creates a "pressure hole"

The deflections of the shell, which occur during loading or relieving of an individual element, are shown enlarged in **Figs. 6 and 7**. In these illustrations, too, the contributions to the local deflection made by oil pressure in the element and the circular gap are clearly visible. According to this deflection, the MULTI HV roll is capable of considerable local linear force corrections through positive and negative pressure in the elements.

Results of finite elemental calculation

Due to the individual control of each element and the initial pressure in the shell, it is possible to correct the profile at any desired location along the roll in the form of positive or negative nip loading of equal magnitude. The linear force profile results from the previously mentioned zones of effect in individual element loadings for a specific target profile (3). For the purpose of this calculation, single or double triangle-shaped linear force additions and subtractions with a maximum value of ± 50 N/mm were specified and moved in steps across the entire roll width. The linear force curves shown in the

following illustrations show the results of calculations on possible actual profiles and the oil pressures required in the elements and the sleeve chamber of the roll. The calculations clearly show that initial loading of the shell in the sleeve chamber, as well as the means of applying negative forces created thereby for the purpose of local correction, considerably increases the correction potential of the roll.

It is a significant feature of this roll that the location of any peak of loading and relief is not tied to the position of the elements. The peak can be moved practically across the roll width independently of the location of the elements, and the number of possible settings is equal to the number of data boxes. Correction is strictly confined to the specified value and does not affect the shape of the curve in adjacent areas. **Figure 8** demonstrates how a triangular nip force relief of 50 N/mm is moved across one element.

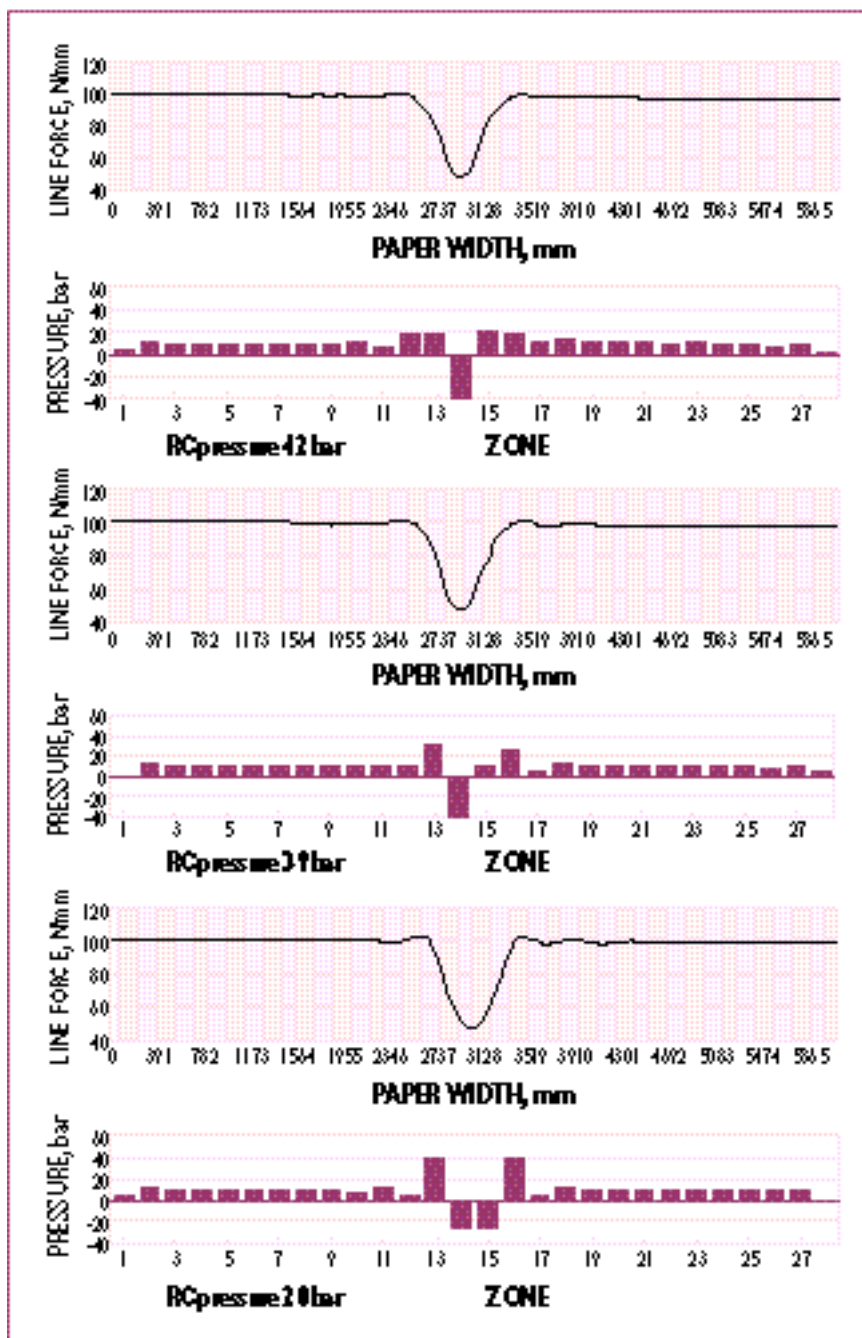
The three vertically positioned graphs differ from each other only by the position of the nip force trough. That trough is in the center of the element on the top graph; in the middle one, it is located between

the center and edge of the element; and in the bottom one, it is exactly between two elements. It can be readily seen that a local nip relief of a specified magnitude can be created at any point along the face of the roll.

A pressure peak can be programmed to move in the same manner as the pressure trough shown across the face of the roll. The curve is then a mirror image of the trough. **Figure 9** shows two such pressure peaks with their attendant oil pressures. The peaks are spaced 680 mm apart in the bottom graph, and the nip load reverts to its original uncorrected value between the peaks.

Figure 10 demonstrates that the correction potential of this roll is effective even at a low median nip force. Up to a nip force of 50 N/mm, the local relief can be set down to zero—negative line forces do not exist—and at higher nip forces, the relief can reach -50 N/mm. According to calculations, local pressure peaks of +50 N/mm can be set at a median nip force of about 5 N/mm and relieves in the amount shown.

In designing a roll with individual element control, emphasis was placed on the need to make correc-



8. Shifting of a localized linear force relief across the roll width

tions in the edge zones, where there is a frequent need to adjust the CD profile, to the same extent as in the center section of the roll. Nip force reliefs, as well as nip force increases,

can be set in the edge zones or moved to another location.

The final illustration in this series of correction settings shows the example of a wave in the nip force

profile. In Fig. 11, a -50 N/mm dip and a $+50\text{ N/mm}$ rise are shown adjacent to each other. The space between peaks is approximately 680 mm, a tremendous potential considering the amount of difference between the pressures.

The results showed that strictly localized corrections can be made only by using negative nip forces within the roll. The FEM calculations also included consideration of shell wall thickness, size of the elements, and material of the shell as well as the option of producing negative nip forces by means of a second row of hydrostatic support elements.

All variants considered unequivocally show that the roll system previously described has benefits in its correction potential compared to piston-supported rolls of single- or dual-row design. The results are submitted in a separate publication (4). Narrower corrections are only possible if composite material is used instead of a gray cast-iron shell. Work in this field has advanced to a great extent, and the results are presented later.

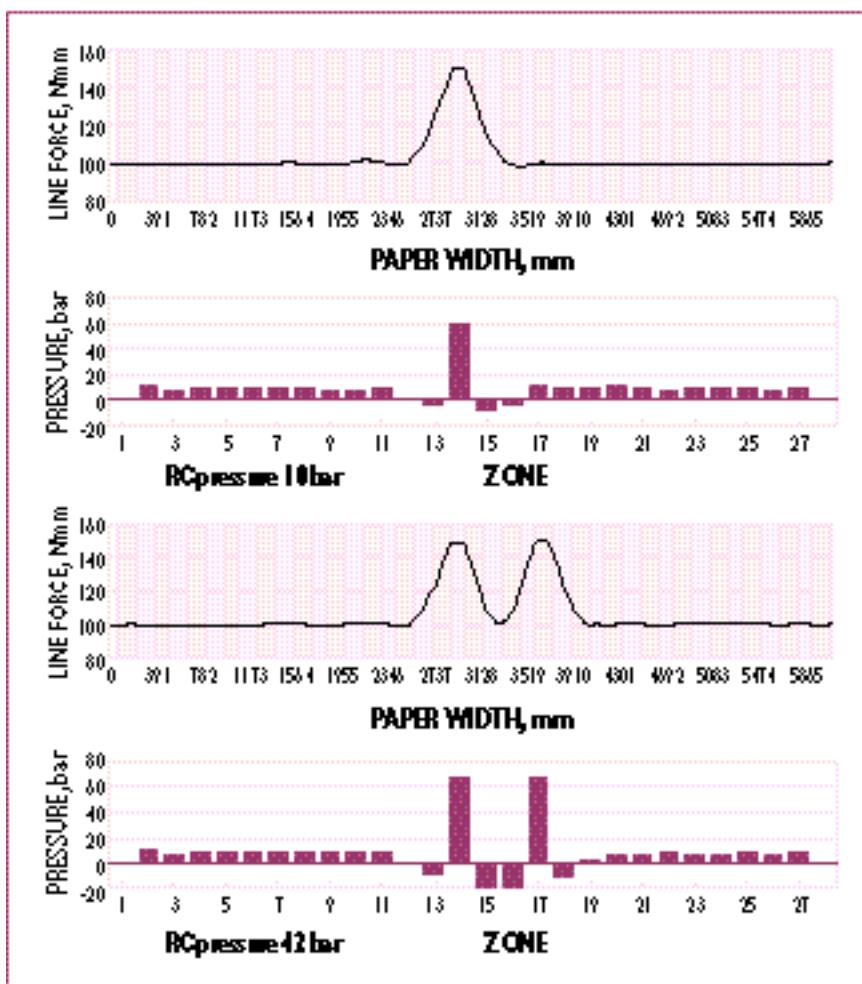
Comparison of the individual element-controlled roll with thermal correction devices

The minimum effective width of a local correction by rolls with individually controlled elements at the basis, i.e., the point at which the nip force reverts to its uncorrected level, is roughly double the spacing of the elements; this means it starts at about 300 mm on small elements and reaches about 600 mm in large rolls. For roll dimensions per Fig. 4, the effective widths used to produce local nip force reductions are shown for a variable number of elements in Fig. 12. If relief is accomplished with three elements, the nip force correction is about 500 mm wide. This also causes a gentle overstep of

the linear force of about 5 N/mm next to the "pressure hole." Such a minimal linear force differential is of negligible effect on the caliper profile. If more elements are used to create local relief (five or seven), the transition to basic linear force is smooth. This increases the width of the correction, of course.

The effective widths of these local corrections may seem large compared to thermal profiling, which generally features zone widths of 60–75 mm. A detailed study of the effective widths of thermal profiling shows, however, that they are substantially greater than the emitter spacings of those profiling systems. The local heating or cooling of the chilled iron roll creates thermal stress, which causes the roll to deform. Because of the properties of the material, these annular deformations abate only gradually and are thus considerably wider at their bases than the original source of heat or cooling. **Figure 13** shows the calculated fading process from localized shell deformations caused by heat sources in the pair of rolls previously analyzed (5). According to this, the localized shell deformation extends to a width of about 1200 mm. When two heat sources are located next to each other, they cause a common annular deformation. No deformation between the two sources of heat occurs only when the two sources are widely separated.

The progression of the paper caliper profile correction in calenders by means of thermal devices has been researched thoroughly (6). It has been shown that two sources of temperature drops or rises, spaced less than 500 mm apart, result in a common increase or decrease of nip force. Only when spaced about 1000 mm apart, the nip force reverts to its uncorrected value between the tem-

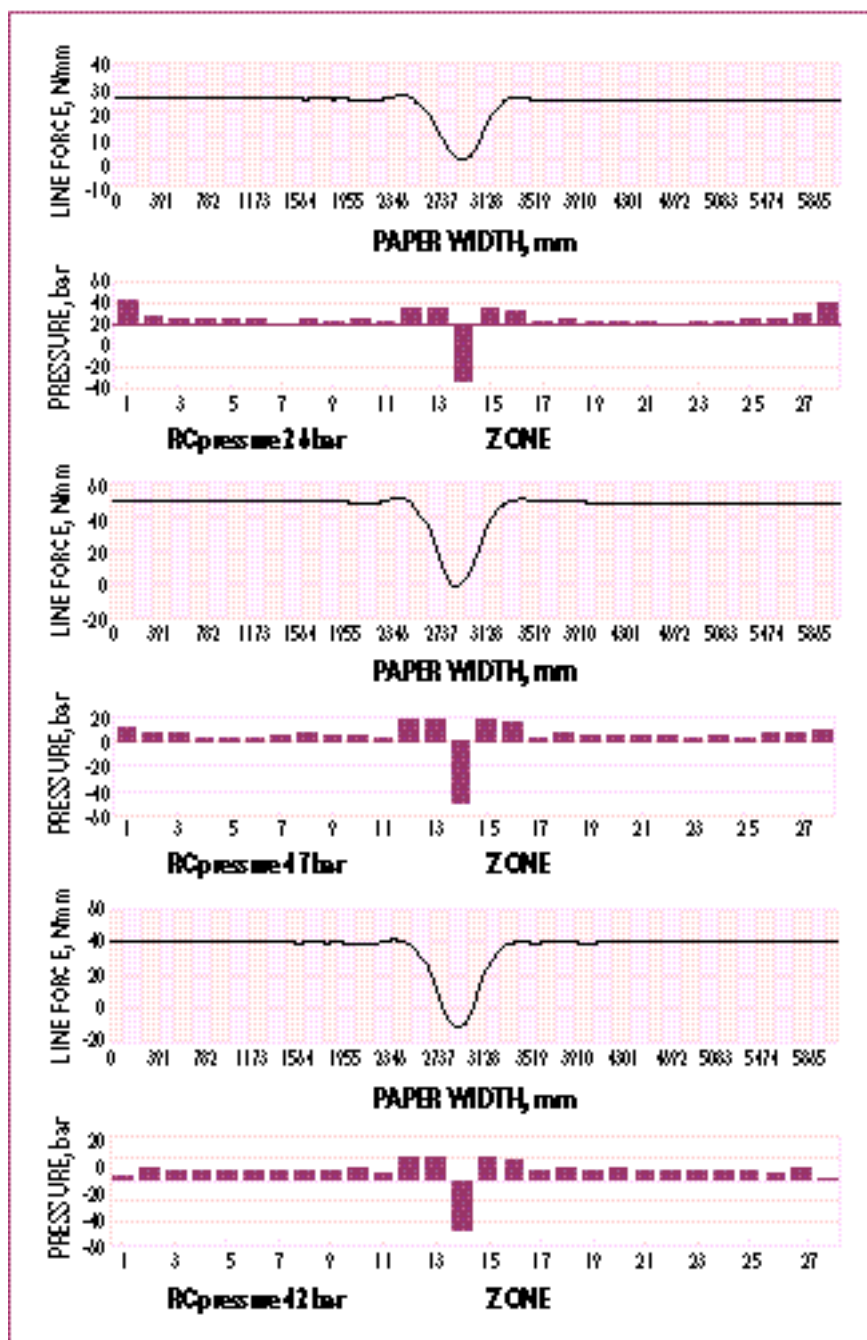


9. Example of increased local linear force

perature valleys or peaks. In consequence of calculations made there, the minimum base width of the correction is approximately 800 mm, depending on the design of the chilled iron roll.

The base width for the MULTI HV roll, i.e., its narrowest effective correction, is thus smaller than the effective width of profiling with thermal devices. Nip force corrections can be made with this roll, extending over a shorter section than those of thermal profiling. This statement is valid, even though the spacings of thermally profiled zones

are only 60–75 mm. The slow abatement of annular shell expansions, as well as the inability to apply intensive heat and cold simultaneously, is the cause of such an expansion of the effective width. Added to this is the comparatively long time required for thermal profiling, 15–30 min, before there is a stable thermal effect. Profile corrections by nip force setting, on the other hand, are effective within seconds.



10. Influence of mean linear force on the correction potential

THE EFFECT OF NIP FORCE ON CALIPER CORRECTION

The densification of the sheet in hard- and soft-nip calenders is a non-linear function of linear load (see Fig. 14).

The graph shows the measured caliper of newsprint [100% recycled furnish, 45 g/m² (27.5 lb/3000 ft²) calendered at 1400 m/min, and 108°C temperature of the chilled iron roll]. The paper was calendered

with a soft nip, the roll cover having a hardness of 91° Shore D. The heated roll had a diameter of 1350 mm; the elastic roll diameter was 985 mm. The rapid initial reduction of caliper levels abates with increasing densification. This curve alone signifies that comparatively low nip force variations at low or moderate median nip force levels produce considerable caliper deviations. At high median nip forces, however, the caliper curve is basically flat; therefore, nip force changes in this range do not cause such extensive caliper deviations. On the other hand, this illustration shows that smaller caliper corrections are produced with a constant nip force deviation at a high nip force level than at a low one.

The following illustrations help to demonstrate the possible caliper corrections by varying the median linear load in steps of ± 50 N/mm. In Fig. 15, we show three curves of caliper over linear load for the same newsprint. The caliper line shown in the previous illustration was complemented by curves at nip forces increased by 50 N/mm and decreased by 50 N/mm.

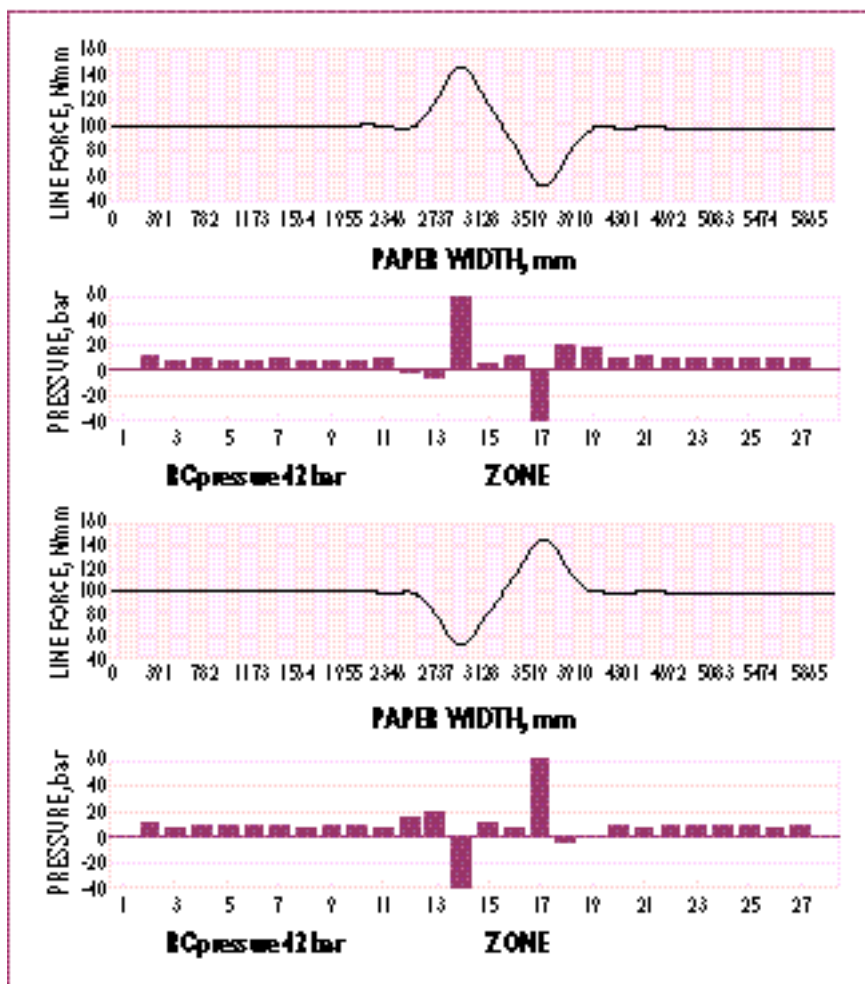
If we compose the difference of caliper $C(L+50)$ at nip force $L+50$ and caliper $C(L)$ at nip force L , and again the difference $C(L-50)-C(L)$, we can directly read the possible caliper modifications (Fig. 16). The upper curve shows the possible caliper increase by local nip force relief of -50 N/mm; the lower one shows the possible caliper reduction by a local nip force increase of $+50$ N/mm at the median linear loads indicated on the abscissa. The nip force can be relieved to zero; negative nip forces are not feasible. Therefore, only a relatively small initial nip force differential is available at a low nip force level. From this

illustration, considerable corrections are available at low nip force levels. The same difference in nip force causes smaller caliper changes at high nip force levels. A difference of ± 50 N/mm produces a correction of just ± 1 μm (0.00004 in.).

A general assessment of possible caliper correction with hard nip can be made with the aid of the logarithmic calender equation (7). The calender equation, with parameters for groundwood content newsprint, was used to calculate the effect of median nip force on the remaining densification of the sheet (machine speed = 1200 m/min, moisture content = 7.5%, sheet temperature = 60°C). The calculated results are entered in Fig. 17 as previously described over the median linear load. The capability of correction is the same for hard and soft nips when the caliper difference is shown as a function of the difference in nip force. To obtain equal deviation of nip force in a soft nip, greater deformation of the roll shell is required. Note that in the connection, the modulus of elasticity of the roll cover, as well as the paper properties, is a factor in the amount of roll shell deformation required to obtain a specified nip force differential.

Temperature differences of 10–25°C are generated in profile corrections through localized heating or cooling of the chilled iron roll. If we neglect, for the time being, the effect on caliper of those differences in temperature, Figs. 16 and 17 also reflect the quality function of such correction devices. According to the literature (1), the corrective effect of a thermal device is materially reduced as the nip force of a soft-nip calender is raised from 100 to 300 N/mm.

To research the possibilities of caliper correction with the aid of

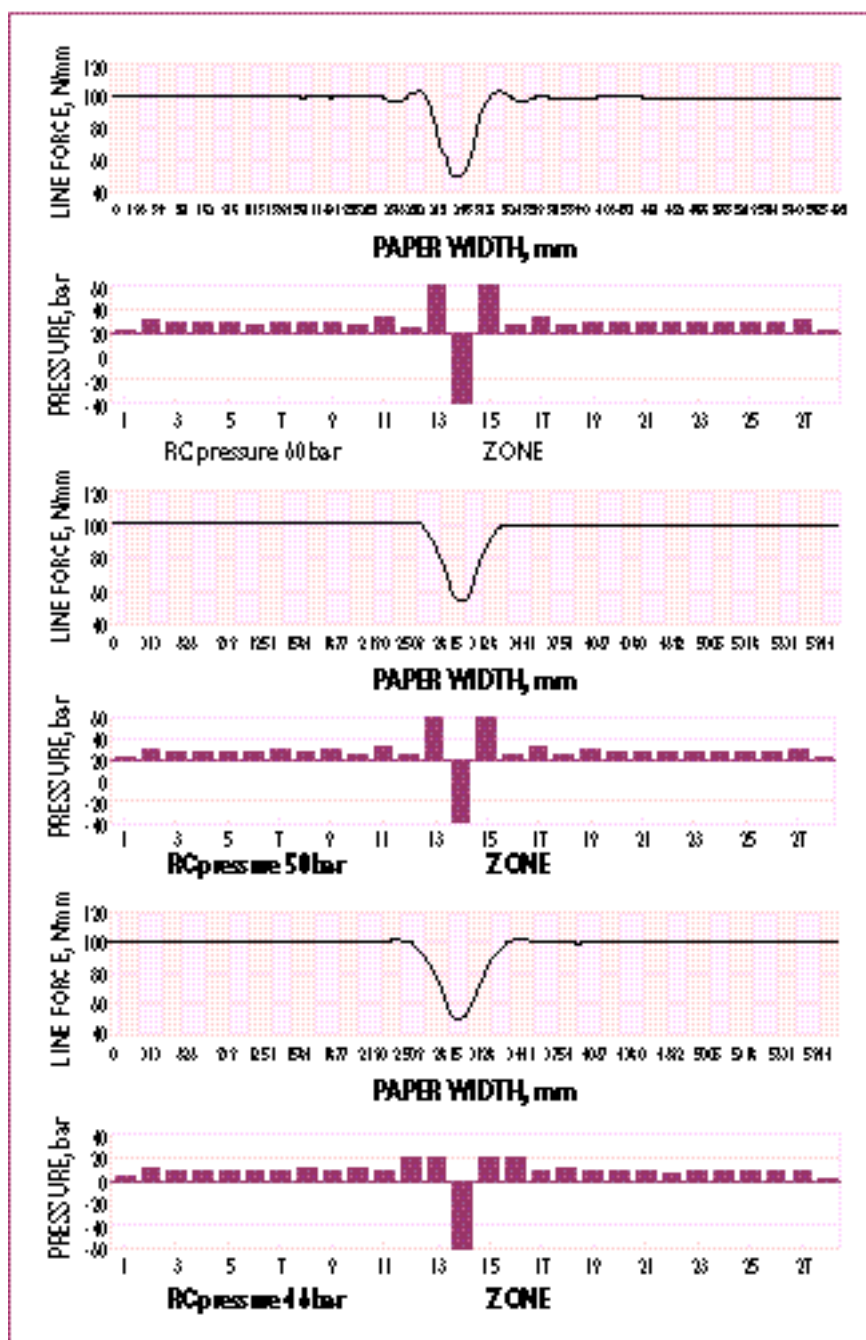


11. Wave-type correction of the nip force

crown-compensated rolls with individually controlled elements, we conducted a series of tests with a hard- and a soft-nip calender in our R&D lab. Figure 18 shows the caliper of an 80 g/m² lightweight coated (LWC) offset paper after calendering with two soft nips at 1000 m/min. High nip forces are required with two nips to obtain the levels of smoothness and gloss required for good printability. In this process, caliper corrections of about ± 1 μm are attainable with ± 50 N/mm. Therefore, individually element-controlled rolls for soft nip calenders, which operate at high nip forces, are

designed for nip force differentials of ± 100 N/mm.

When caliper correction is required, the difference in nip forces by necessity also causes differences in smoothness and gloss in the cross-machine direction. Figure 19 shows the gloss of the same LWC paper. Temperature has a considerable effect on the generation of gloss over the entire range of nip forces. If caliper is corrected only with localized nip force variations, the gloss differentials are smaller than with simultaneous temperature changes across the roll width.



12. Minimal correction width of the roll with individually controlled elements

APPLICATION—CALENDERING NEWSPRINT IN A SOFT-NIP CALENDER

The first rolls with individually controlled elements were installed in an

8.6-m (338-in.)-wide paper machine for newsprint in December 1994. Recycled fiber newsprint is calendered in a MAT-ON-LINE® soft-nip calender. Elastic roll covers of 91°

Shore D are being used. Various nip force corrections were set after startup, and the CD caliper profiles were measured in ten layers at the mill laboratory. Initially, we examined the effect of the nip force corrections in a single nip only. For this purpose, one stack was opened, while triangular nip force corrections were done in the second nip at median nip force levels of 30 and 50 N/mm. The paper in this test had a basis weight of 45 g/m², an average moisture content of 7.5%, and machine speed of 1350 m/min.

Figure 20 shows the effect of one plus/minus peak in Stack 1 at a median nip load of 30 N/mm. The peaks of -20 N/mm and +25 N/mm produced caliper changes of +4 and -6 µm, respectively. The base width is 600 mm.

The effect of the caliper on a waveform nip force adjustment, with an amplitude of 25 N/mm and a median nip force of 50 N/mm in Stack 2, is pictured in Fig. 21. A caliper variation, also in wave form, of about ±4 µm results from that nip force setting.

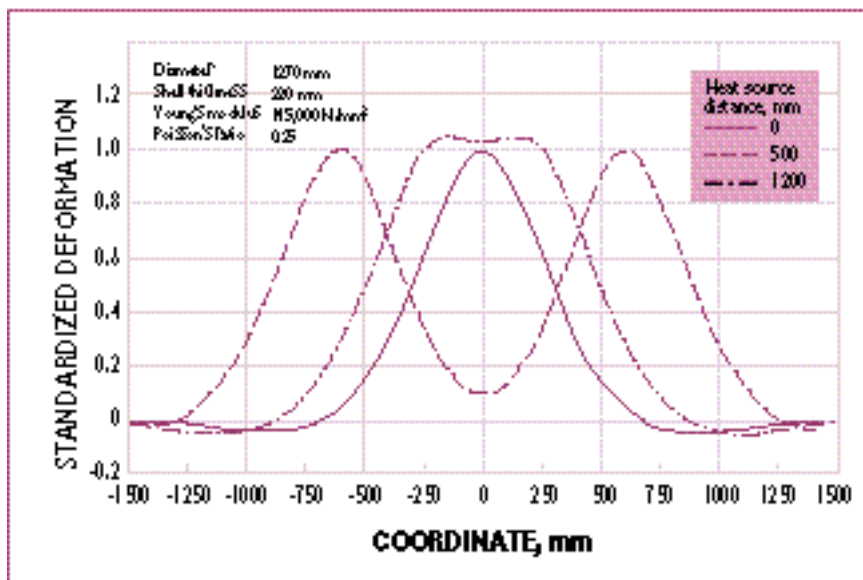
When both nips are set equally to a median nip force of 50 N/mm, the median caliper reading after Nip 1 is about 61.6 µm (0.0024 in.), and after Nip 2, the reading is 59.3 µm (0.0023 in.). The effect on the caliper of the sheet of a triangular nip force increase of 25 N/mm in Nip 1 and, to the left, a relief of 25 N/mm in Nip 2 can be gleaned from Fig. 22. In the two-nip operation, the caliper reduction produced by Nip 1 is modified by about 1 µm in Nip 2. A nip relief in Nip 2 can have as its effect only the caliper difference of the sheet between the first and second nip, as demonstrated by this setting.

Then again, this illustration clearly shows that the corrective forces of each nip are effective as

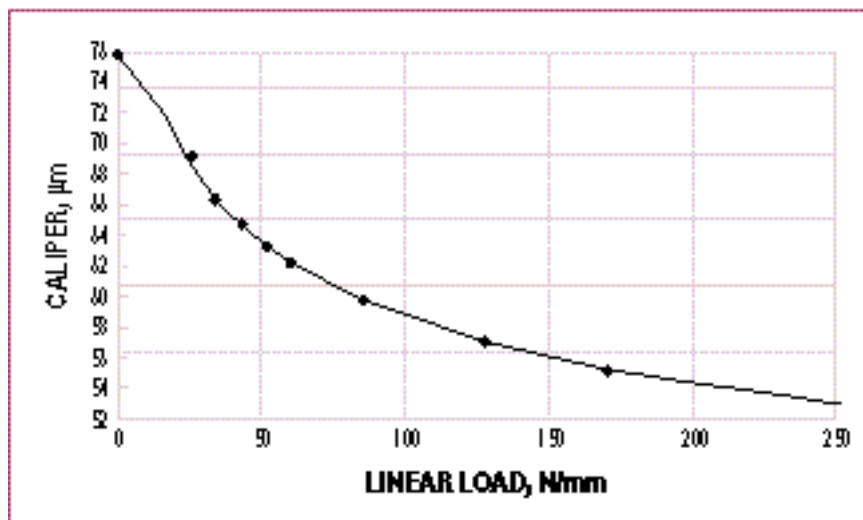
long as there is no material difference between the median nip forces of the two calenders.

This also opens the capability of correcting the CD caliper profile of closely adjacent peaks by having each of them damped by a different roll. The application of individual element-controlled rolls in this soft-nip calender has confirmed that the 2S value in CD caliper profile deviations can be held to less than 1 μm without the use of additional devices. This enabled the papermaker to effect substantial savings in energy and service. No excessive wear of roll covers was identified to date, especially since the paper maintains also a good basis weight profile. Primarily corrected are typical CD profile variations caused by shrinkage of the sheet near the edges. The user is also in a position to correct roll diameter irregularities caused by temperature difference or by roll grinding. At the low nip pressure levels used in newsprint calenders, even minor irregularities in the diameter of the rolls can have substantial consequences. **Figure 23** shows a soft-nip calender in which the CD caliper corrections are done with two rolls with individually controlled elements.

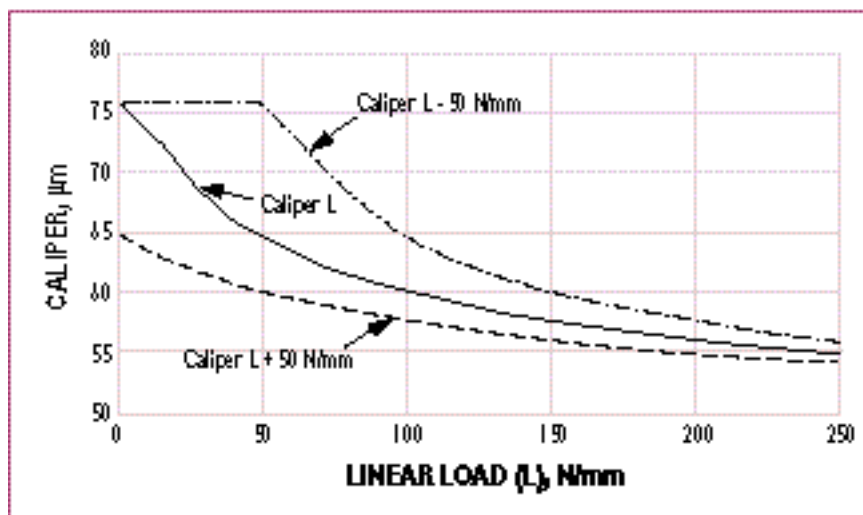
Note that defects should be corrected where they occur if good runnability is to be attained. The crown-compensated roll with individually controlled elements is justified, even when the CD profile is good. It enables the user to set exactly uniform nip force profiles by having the means of compensating for thermal irregularities of the heated roll and for deviations in diameter, which occur invariably when rolls are ground. Moreover, the life of roll covers in soft-nip calen-



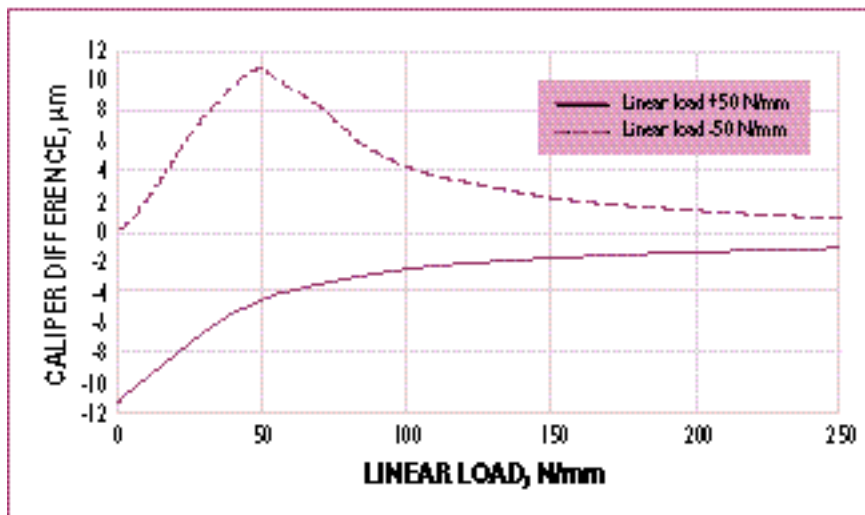
13. Deformation of a chilled iron roll at local outside heating



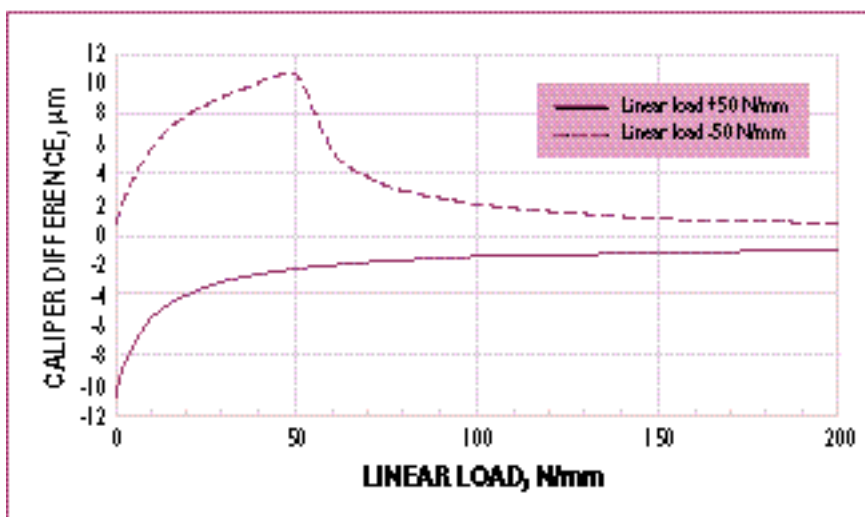
14. Soft nip—measured caliper of 45 g/m² newsprint paper after calendering with one nip



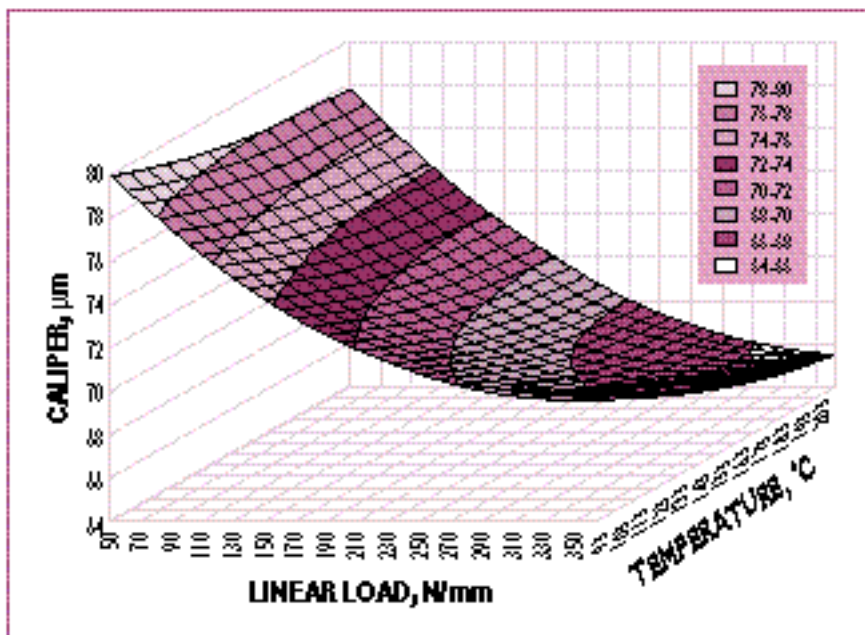
15. Soft nip—caliper of 45 g/m² newsprint paper calendered with one nip. Linear force difference ± 50 N/mm



16. Soft nip—effect of local linear force difference of ± 50 N/mm on newsprint caliper



17. Hard nip—effect of local linear force difference of ± 50 N/mm on newsprint caliper [calculated with calendaring equation (7)]



ders can be increased by compensating for the wear of the cover.

Application in board calender

For the smoothing and calibrating of board (basis weights 152–310 g/m²) ahead of an on-machine coater, a single-nip calender with a sheet width of 5.6 m (220 in.) was started up in January 1995. The crown-compensated roll is equipped with 28 individually controlled elements. The board is being calendered with a thermal roll having a surface temperature of 200°C and with median nip loads of 5–100 N/mm. The calender has completely met the requirements of the product with respect to smoothness and CD caliper profiles. When engineering rolls for board calendering, roll deformations required for caliper correction are greater than those for papers with low basis weights.

CONCLUSIONS

At low nip forces, even minor deviations of form or force produce comparatively major changes in the CD caliper profile. At high nip forces, the same deviations are less critical. Therefore, low nip forces require that linear load profiles be set exactly when making corrections of CD caliper profiles. At high median nip loads, however, major nip load differentials are needed to effect material caliper changes.

Research and testing, confirmed by field experience with rolls in operation, have shown that CD caliper profiles can be controlled with the MULTI HV-Roll in single-nip calenders and soft-nip calenders without additional corrective devices. The corrections obtained by this method match the conventional ones in both size and exactness of

18. Soft-nip calender—caliper of LWC offset paper (80 g/m², moisture 6.3%, speed 1000 m/min, two nips)

KEYWORDS

Calenders, corrections, cross direction, crowning, dimensions, force, machine components, paper making equipment, profiles, roll crown, rolls, soft nip calenders, thickness.

location. This new type of roll makes it possible to effect these corrections without delay. Profiles are adjusted immediately when nips are closed after a web break. No additional energy is required for this correction with rolls having individually controlled elements. **TJ**

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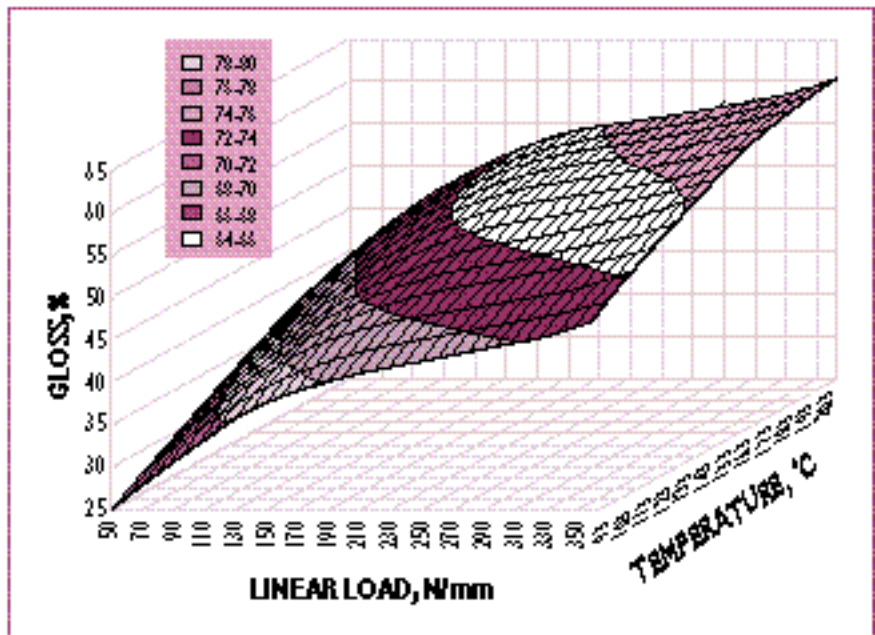
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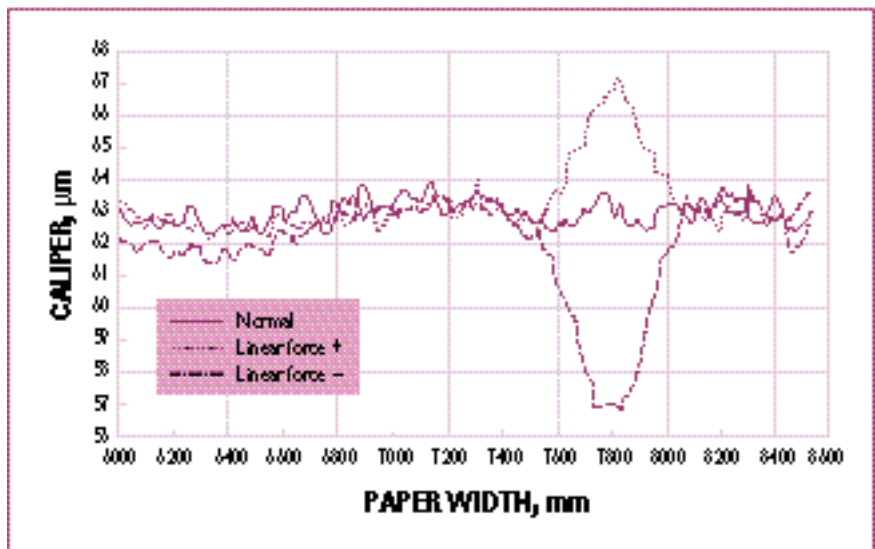
Presented at the TAPPI 1995 Finishing and Converting Conference.

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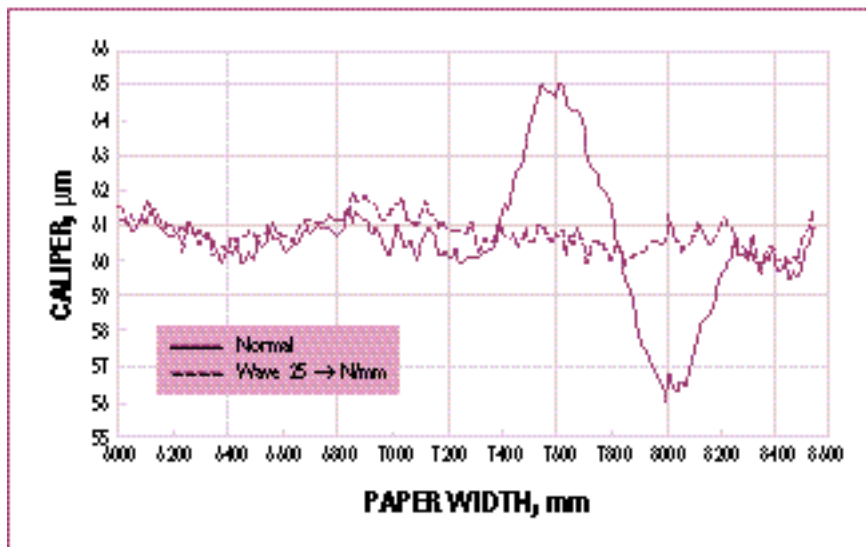
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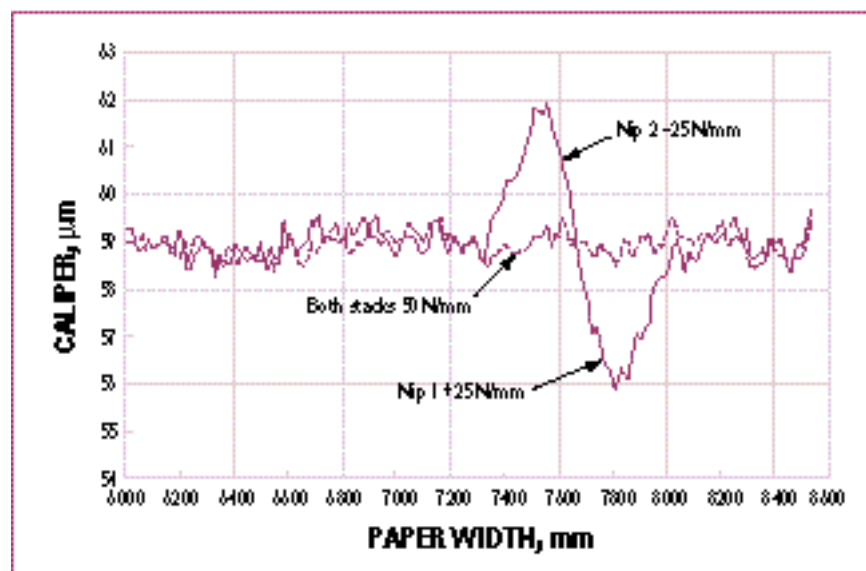
19. Soft-nip calender—gloss of LWC offset paper (80 g/m², moisture 6.3%, speed 1000 m/min, two nips)



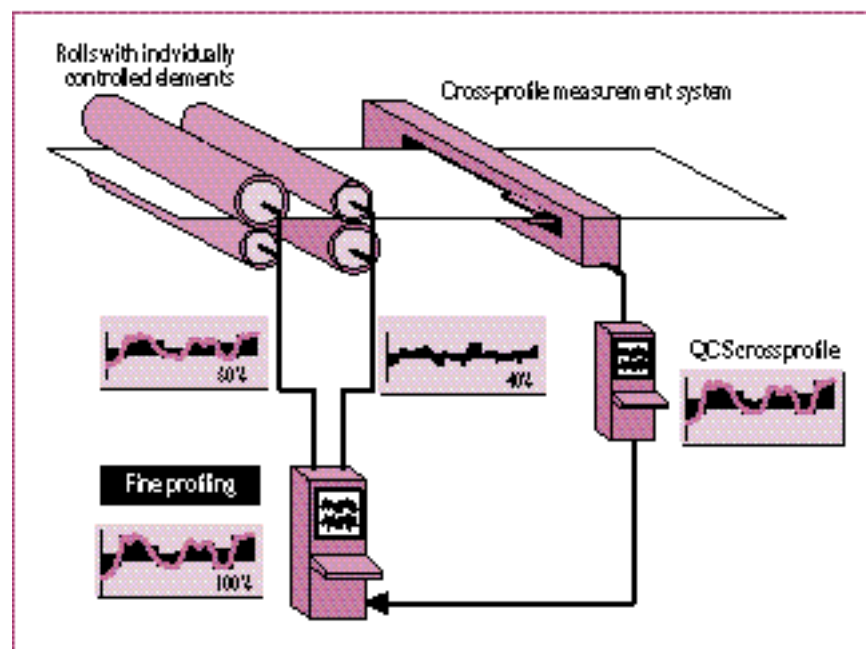
20. Soft-nip calender—effect of local nip force corrections on newsprint caliper (mean linear force in No. 1 stack 30 N/mm, speed 1350 m/min)



21. Soft-nip calender—influence of a waveform nip force adjustment on newsprint caliper (mean linear force in No. 2 stack 50 N/mm, speed 1350 m/min)



22. Soft-nip calender—influence of a line load plus peak in the first nip and a minus peak in the second nip on newsprint caliper (mean linear force in both stacks 50 N/mm, speed 1350 m/min)



23. CD caliper control with two rolls with individually controlled elements