

On- and off-machine soft-nip surface finishing of coated groundwood and wood-free paper grades

Heinz Winkels and Peter Svenka

With further improvements in components, roll covers, and coating formulations, the soft calender may become a viable alternative to the supercalender.

Finishing is the last step in the production of coated paper grades. It is also the step that is most decisive in determining the printability of the final sheet.

Papers coated on one side (C1S) and on two sides (C2S) are produced in a wide variety of grades. In addition to the typically produced grades 1-5, there is now a new No. 6 machine-finished pigmentized grade. These grades represent a wide range of end uses, and they differ with regard to the base paper composition, basis weight, coating formulation, and coating weight. These grades also differ in their finish, which is directly related to the parameters of the finishing process.

The finishing operation is a thermomechanical transformation process. This process involves passing a paper web through a series of (preferably) soft nips. The web is gradually treated under the influence of pressure and elevated temperature. The heat used in finishing operations is generated partly by the process itself. The rest of the heat is supplied by heated rolls.

Soft-nip calendering equipment

Supercalender

For decades, the supercalender has been the classic soft-nip finishing equipment for production of high-quality coated paper grades. **Figure 1** is a side view of a typical supercalender.

Although the supercalender has been used in finishing operations for many years, machine builders are always looking for ways to improve performance. The introduction of controllable heated rolls and center-driven rewind systems proved to be milestones in the ongoing development of the supercalender. Controllable heated rolls provide thermal energy independent of nip pressure, thus ensuring an equal temperature over the working width of the paper web. Center-driven rewind systems optimize

reel buildup by controlling the air volume between the sheet layers.

Recently built supercalenders have zone-controlled rolls in the top and bottom positions to improve distribution of the nip load, computer-assisted control, and flying splice systems at the unwind. Continued reductions in machine downtime have enabled supercalenders to keep up with the increased speeds of paper machines and coaters. The latest features include closed-loop systems for caliper or gloss in combination with zone-controlled rolls. "Thermo" zone-controlled rolls introduce externally generated thermal energy into the first nip. However, even with these improvements and speeds up to 1000 m/min, the supercalender is still limited by the fact that it is a purely "off-machine" operating unit.

Soft calender

The challenge for manufacturers of finishing machines has always been to design equipment capable of operating "on-machine" in paper machines and coaters at full machine speed. On-machine soft-nip calendering reduces space requirements and lowers operating costs through reductions in labor and broke. It also provides a uniform, gentle densification of the sheet without sacrificing opacity, strength, and brightness.

The key concept for an "on-machine" design has been to separate the interlinked nips of the supercalender and to engineer completely new equipment with individually controllable soft nips. This is the approach taken by the "soft-compact" supercalender (1). **Figure 2** illustrates the design features of an individual nip in a soft calender.

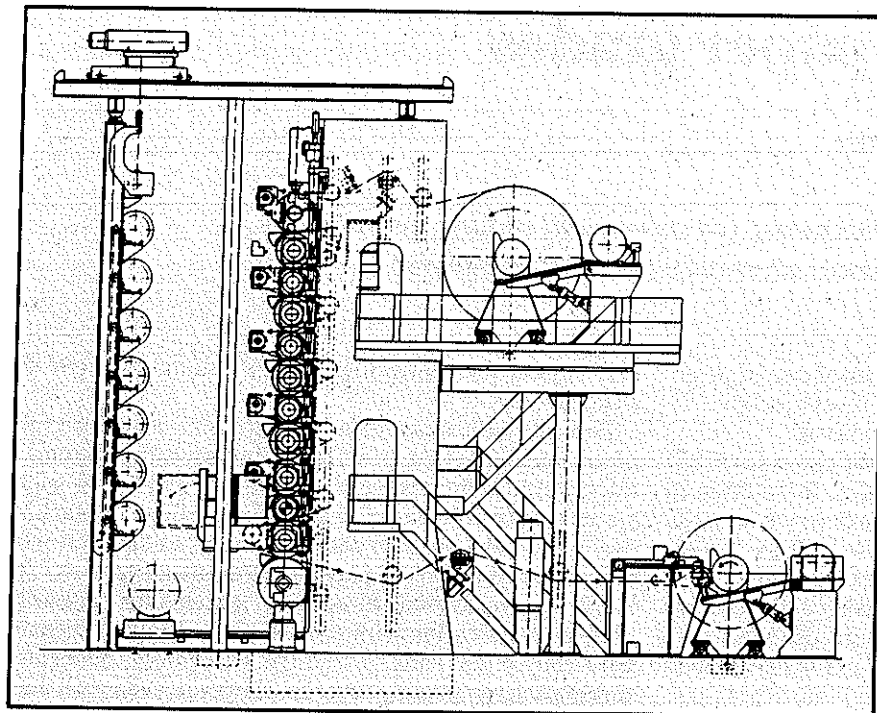
The soft calender allows the pressure and temperature in each nip to be controlled individually over a wide range. The flexibility in obtaining finishing effects is far superior to advanced supercalendering technology. This concept also reduces two-sidedness in the paper web.

Soft calenders are used mostly in on-machine operations. (Off-machine operation is also possible to meet specific production or customer requirements.) Thus the life span of the elastic roll cover is the dominant factor influencing the efficiency of the complete line.

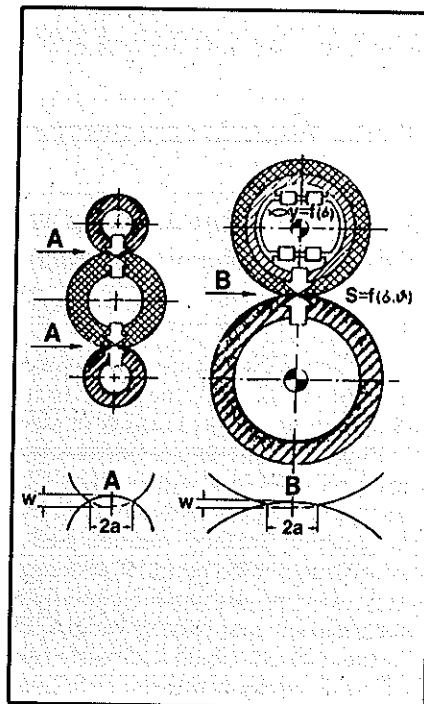
The roll system must create uniform nip pressures over

Winkels, general sales manager, and Svenka, manager of process engineering, work for Kleinfewefers GmbH, D-4150 Krefeld 1, Federal Republic of Germany.

1. Side view of a typical supercalender



2. Design features of an individually controlled nip in a soft-compact calender. The soft-compact calender breaks the interlinked multiple-nip stack into individually controlled nips. The physical functions active in each nip are controlled by precise adjustment of the corresponding roll-control system. Stress on the elastic roll covers is reduced by halving the number of load changes per revolution and by increasing the roll diameter.



the total width of the web. It must also be able to precisely adapt to specific operating conditions to avoid undesired heat generation. As a consequence, each soft nip should be formed by an adjustable crown-controlled roll with individual zone control.

Other roll systems can be used on narrow machines and on machines that run at lower nip loads, machine speeds, and temperature levels. But only a roll with positive zone control (including the roll edges) can assure the necessary adaptation of the covered roll to the web profile and, if desired, influence it within an admissible range.

Resilient covers made of synthetic materials have been developed to meet the requirements of an on-machine process. Covers made of natural fibers are also running on-machine at high speed and line load with good success. Some of the key criteria for selecting elastic covers for on-machine soft-nip calendering equipment include temperature and pressure acceptance, mark resistance, hardness, and wear behavior. These factors determine the obtainable finish and the necessary grinding intervals.

All covers differ in their properties, abilities, and limitations. To meet the requirements of each specific job, a roll cover must be selected to meet (a) the specific surface-finish requirements of the end user and (b) the operating speed dictated by the paper machine and/or coater.

Scanning infrared sensors for each covered roll are necessary for monitoring the on-machine soft-nip finishing process. The true temperature of the resilient roll must

be known at all times so that countermeasures can be taken when the surface temperature level or profile readings run beyond normal range.

One of the most important parameters in the surface-finishing field is the temperature. Machine builders had to resolve the problem of how to introduce continuously huge amounts of thermal energy into a fast-running finishing process with a limited number of nips. This thermal energy is needed to provide uniformly high temperatures over a wide web. Heated-roll surface temperatures up to 200°C and more are still challenging the machine builders and the manufacturers of rolls and resilient covers.

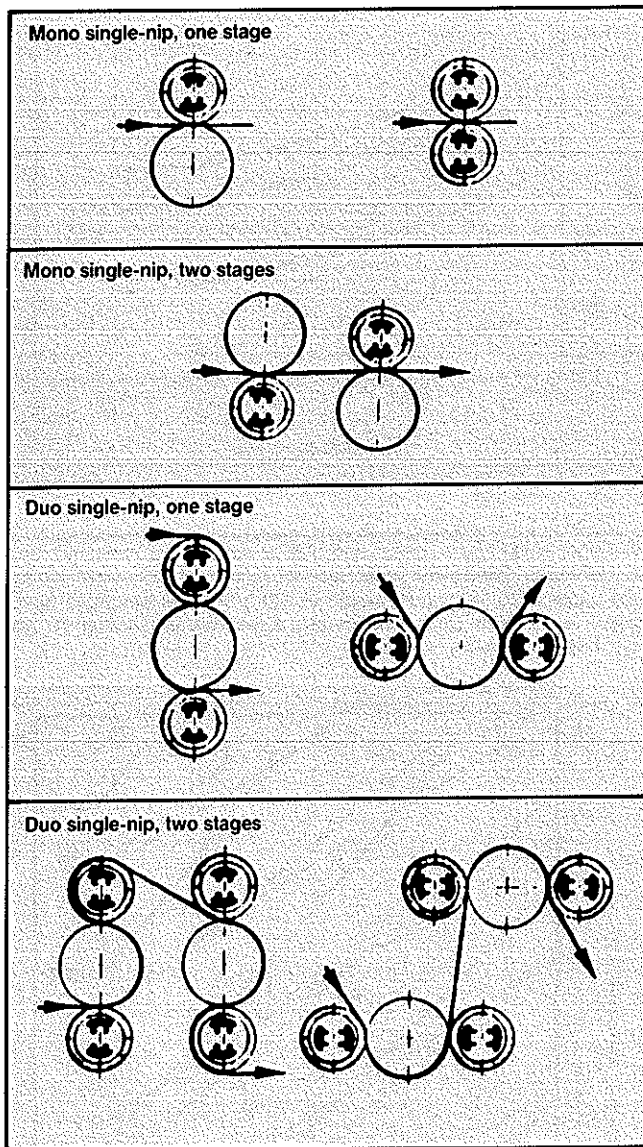
Other features instrumental to the successful operation of soft calenders include:

- Web threading system
- Open-nip threading with speed synchronization of all rolls and parallel nip closure at straight nips
- Web-break detectors
- Fast roll-separation units
- Web cutter
- Rapid roll-changing device
- Steam showers.

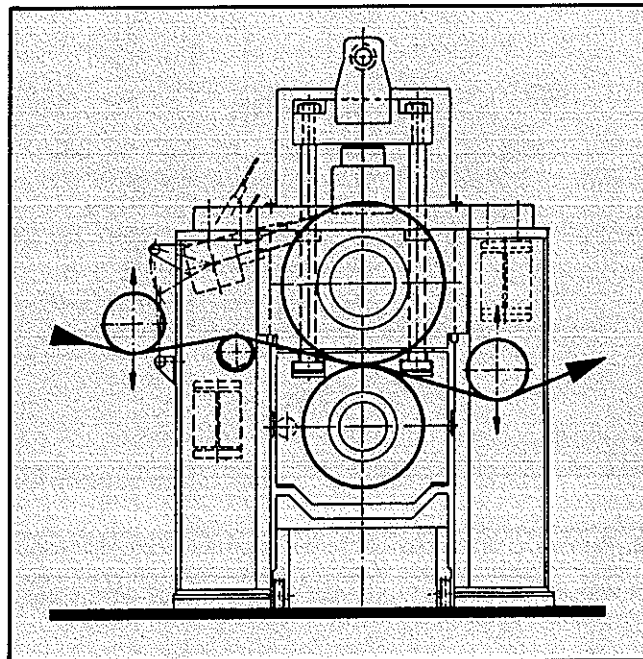
Soft calender configurations and specific applications

The configuration of the soft calender is determined by

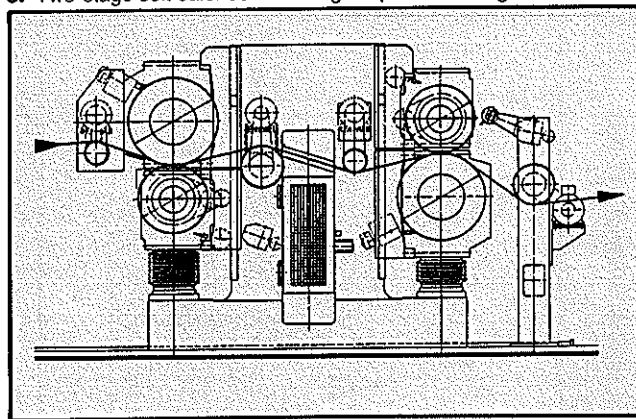
3. Four soft-calender configurations



4. Soft calender with a single nip



5. Two-stage soft calender with single nip in each stage



the paper grade to be finished and by the required surface finish. **Figure 3** illustrates soft-calender configurations. In each configuration, the nip is individually controlled, and nip loads can be varied independently from an absolute minimum (possibly less than the dead-weight of the roll) up to the design limits.

Individual nip control and the ability to match the number of nips to the specific finishing requirements provide a great deal of flexibility in finishing effects. This allows papermakers to use the soft calender for a wide range of uncoated and coated paper grades with a variety of finishes from matte, dull, and silk effects up to glossy paper grades. The most common application of on-machine

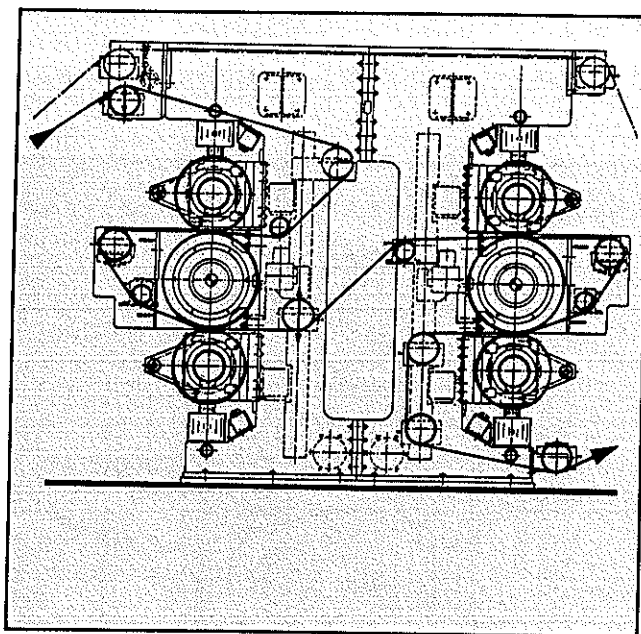
calendering is for matte/dull qualities.

Hard nips are used to smooth and strengthen the pressure-sensitive surface of the coated web. Replacing the hard nip with a soft nip increases sheet uniformity and improves printability. The advantages of soft-calendering on these papers are obvious: high temperatures and high pressures are not required.

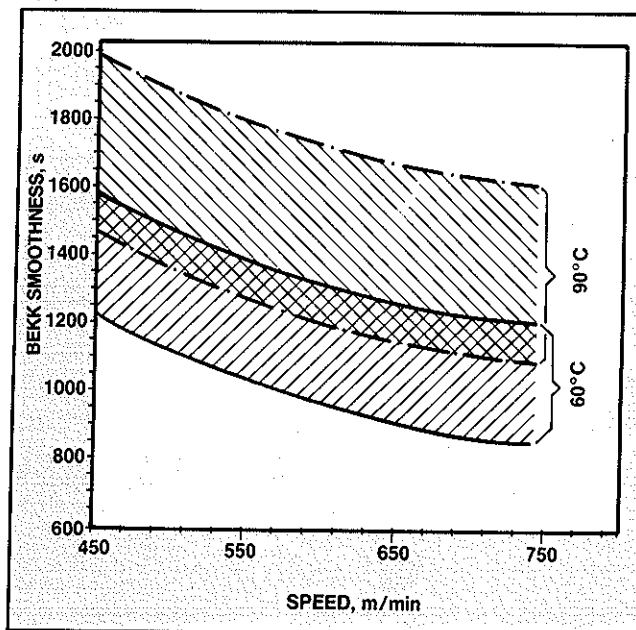
Typical grades for the single-nip soft calender are carbonless paper and label papers with lower smoothness requirements. The single-nip soft calender is illustrated in **Fig. 4**.

If elastic-covered rolls are installed in both the top and bottom positions, matte papers coated on both sides can

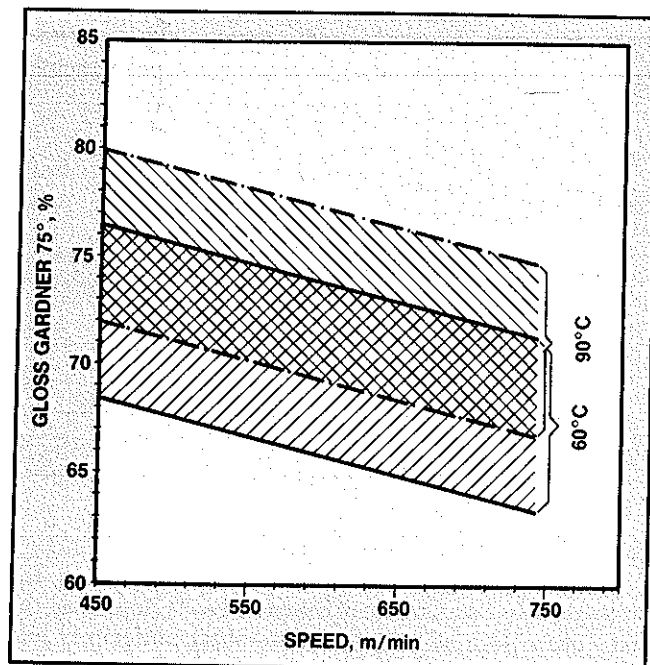
6. Two-stage soft calender with two nips in each stage



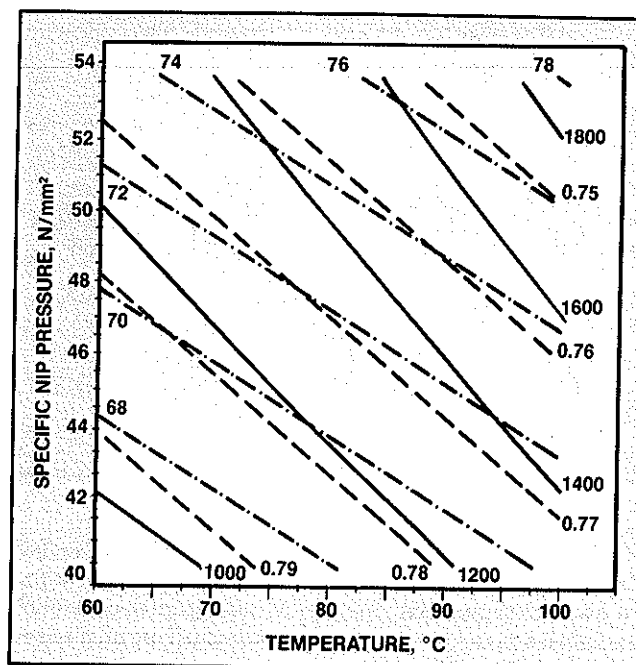
7. Paper smoothness as a function of speed at two roll temperatures. Twelve-roll supercalender; wood-free paper (C2S) with basis weight of 120 g/m²; coat weight 15 g/m²/side; 7% moisture; 60–90°C; specific nip pressure 40–54 N/mm².



8. Paper gloss as a function of machine speed at two roll temperatures. Twelve-roll supercalender; wood-free paper (C2S) with basis weight of 120 g/m²; coat weight 15 g/m²/side; 7% moisture; 60–90°C; specific nip pressure 40–54 N/mm².



9. Paper smoothness, gloss, and bulk at various nip pressures and temperatures. Twelve-roll supercalender running at 620 m/min; wood-free paper (C2S) with basis weight of 120 g/m²; coat weight 15 g/m²/side; 7% moisture. Bekk smoothness, s (—); Gloss Gardner 75°, % (---); bulk, cm³/g (---).

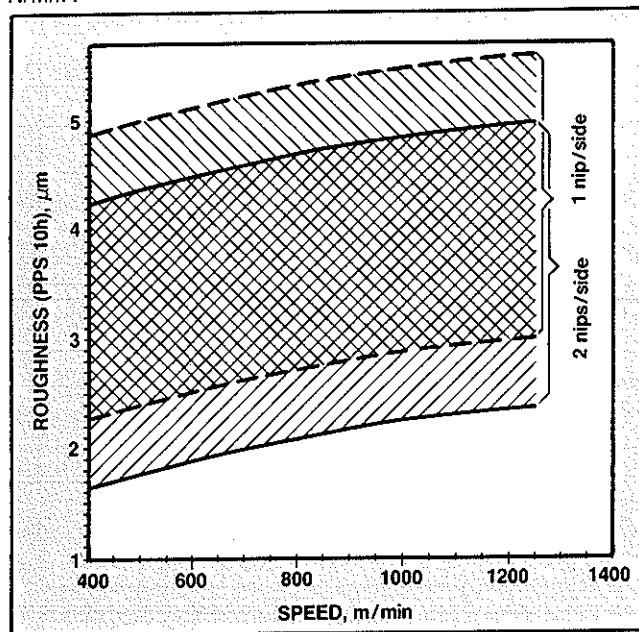


be finished with low gloss and good printability. High-quality label papers and heat-sensitive papers require a superior finish on only one side. For these products, a one-stage double-nip soft calender is suitable.

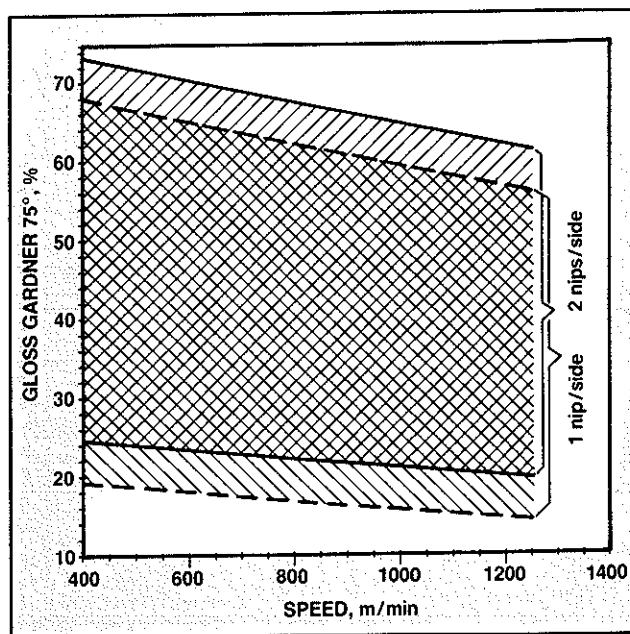
Figure 5 illustrates a single-nip soft calender with two stages. This configuration is used to finish both sides of the sheet by having the surface on each side come into

contact with the heated rolls. Finishing effects ranging from matte and silk to gloss grades can be obtained, depending on the maximum nip pressure, the temperature of the heated rolls, the operating speed, and the quality of the elastic cover. This configuration is being used to calender pigmented papers on-machine at speeds of 1000 m/min. These papers have roughness (PPS-10h) values in

10. Effect of speed on paper roughness for a soft calender with 1 nip/side and with 2 nips/side. LWC paper with basis weight of 60 g/m²; 4.3% moisture. Temperature 80–160°C; specific nip pressure 15–40 N/mm².



11. Effect of speed on paper gloss for a soft calender with 1 nip/side and with 2 nips/side. LWC paper with basis weight of 60 g/m²; 4.3% moisture. Temperature 80–160°C; specific nip pressure 15–40 N/mm².



the area of 2.0 μm and are aimed at a market niche between lightweight-coated (LWC) and supercalendered (SC-A) grades. Print evaluations show that this new coated-paper product is heat-set printable with brilliant colors. It is also laser usable, and its brightness and runnability are in the LWC class.

The configuration that produces the best finish while providing the highest flexibility is the one with two finishing nips per side. This configuration is illustrated in Fig. 6. Experience shows that soft-calendering with two nips per side can provide excellent results, comparable with high-gloss wood-free qualities.

Technological effects

Controlled variables for the calendering process

The paper web undergoes transformation in the nip through the supply of mechanical and thermal energy.

Mechanical energy. The flow of mechanical energy into the process is controlled by the line load. The specific nip pressure and the number of nips are decisive factors in the transformation of the paper web. While specific nip pressure depends on the set line load, it is also influenced by the diameters of the rolls and the physical properties of the elastic roll covers.

Thermal energy. The supply of thermal energy is controlled by the surface temperature of the heated roll. The amount of heat that is transmitted depends on roll temperature, the temperature of the ingoing paper web, and the dwell time of the paper web in the nip. Dwell time is, in turn, governed by the speed of the machine and by the width of the nip. Higher roll temperatures are needed to supply the necessary heat at high machine speeds.

For the calender operator, only line load and roll temperature remain to be set as process variables. In off-machine processes, machine speed must also be controlled.

Calendering results can be further influenced by using additional tools, e.g., steam boxes.

Specific nip pressure is a function of the mechanical properties of the roll cover and the dimensions of the roll. Thus, line load does not provide a true assessment of the actual forces acting on the web in the nip. Comparison of different finishes can be done only on the basis of specific nip pressures.

Effect of variables on supercalender operations

The influence of line load and roll temperature on the finish in a supercalender has been documented (2–4).

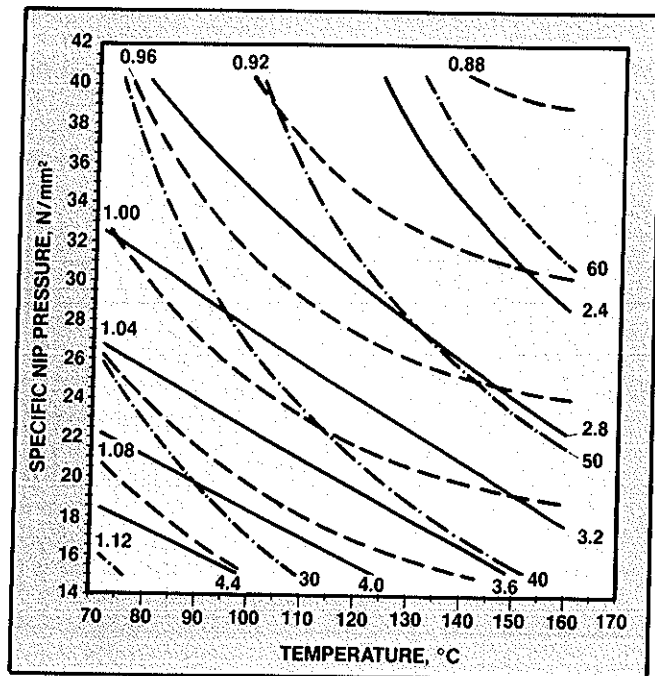
There is often a move to increase production by increasing the speed of the supercalender. However, an increase in speed can mean a loss in quality. The question is, how much loss in quality can be compensated by heating the steel rolls, and how much can the web properties be influenced by these higher temperatures.

Multiple, nonlinear regression analysis can be used to quantify the influence of individual operating parameters on respective web properties. We measured web properties and then determined regression coefficients with the help of a computer.

Figure 7 depicts smoothness development as a function of speed in a 12-roll supercalender. The area bounded by the limits at 60°C defines the obtainable smoothness at a roll surface temperature of 60°C at the full line load capacity of the stack. The area bounded by the limits at 90°C shows how an increase in the temperature of the center rolls from 60°C to 90°C increases smoothness, even at high speeds.

Figure 8 shows gloss development as a function of speed for the same paper. There was a 5-point drop in gloss over the speed range examined. The increase in gloss at the higher roll temperature was relatively small compared with the increase in smoothness, indicating that the higher

12. Paper roughness, gloss, and bulk at various nip pressures and temperatures. Soft calender with two nips per side running 60-g/m² LWC paper (4.3% moisture) at 800 m/min. Roughness (PPS-10h), μm (—); bulk, cm³/g (- -); Gloss Gardner 75°, % (-.-).



temperatures have had little effect on the coating used in that trial.

The gloss and smoothness of a paper web obtained through application of high specific nip pressure at low temperature can also be obtained by applying low pressures at high temperatures. These correlations are shown in Fig. 9 for a production speed of 620 m/min. Each of the curves in Fig. 9 represents a specific, constant value for smoothness, bulk, or gloss. Because the values remain constant, the curves illustrate how temperature and specific nip pressure in a supercalender can be varied without changing smoothness, bulk, or gloss.

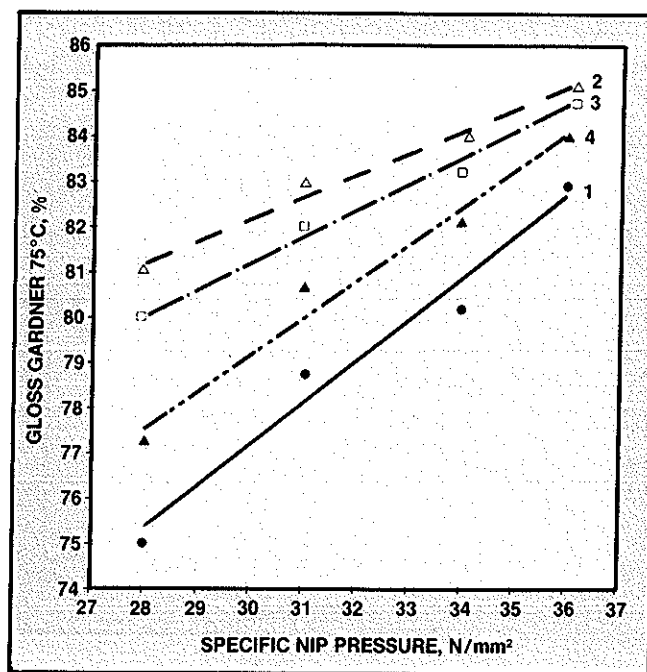
For example, a smoothness of 1400 Bekk s is obtainable at a specific nip pressure of 52 N/mm² at 75°C or at a specific nip pressure of 45 N/mm² at 95°C. Thus, if the temperature is raised, the same smoothness can be obtained at a lower specific pressure (lower line load). However, while these different conditions produce the same smoothness, they do not have the same effect on gloss. At 52 N/mm² and 75°C, a gloss of 74% is obtained. At 45 N/mm² and 95°C, a gloss of 72% is obtained.

The correlation between bulk and smoothness, on the other hand, is quite good at the given production speed (620 m/min). The pressure-temperature combinations that produce the same smoothness value do not cause the bulk value to change.

Figure 9 clearly shows that, at the given production conditions, varying the temperature and pressure in the supercalender will have little effect on the correlation of individual web properties.

This method of analysis can also be used to study other web properties such as brightness and opacity. Knowledge of the correlation between process variables and individual web properties facilitates operation of the supercalender

13. Paper gloss as a function of specific nip pressure for four coating formulations. Soft calender with two nips per side running 80-g/m² wood-free paper (C2S, 5.5% moisture) at 625 m/min and 110°C.



within optimal pressure and temperature ranges for the best finish.

Effect of variables on soft-calender operations

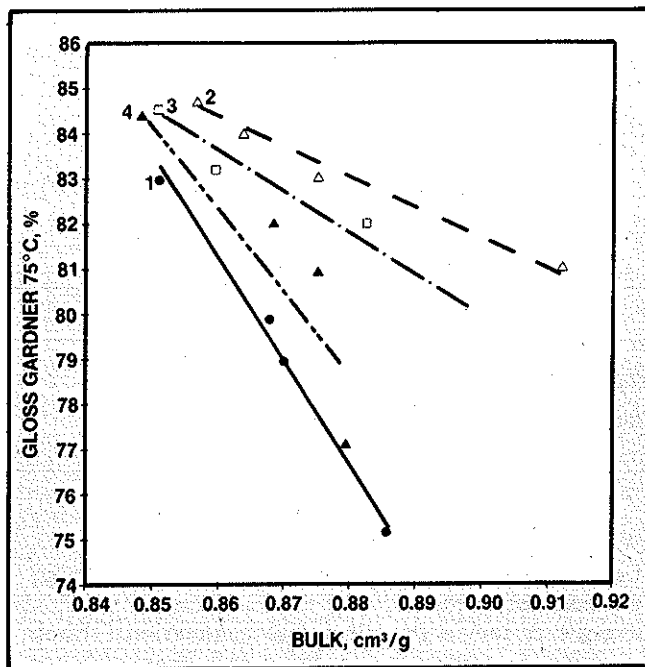
The variety of coated grades and the wide range of paper machine and coater speeds underscore the need for laboratory trials to determine whether the required paper properties can be achieved using soft-nip finishing equipment. In addition, trials are needed to determine the number of nips and the appropriate nip pressures and temperatures that will be necessary to obtain the required finish. The trials will reveal the most suitable soft-nip finishing equipment—supercalender or soft calender (on or off machine)—for a given production situation. Technical feasibility and economic factors can also be examined during laboratory trials.

We examined a variety of paper grades to understand the relationship between the process variables and the different paper and coating grades. The effect of speed on the roughness of a LWC paper is illustrated in Fig. 10.

The LWC paper was calendered at speeds ranging between 400–1250 m/min with one and two nips per side. The upper control for each nip configuration indicates the roughness at a specific nip pressure of 15 N/mm² and a roll temperature of 80°C. The lower control for each nip configuration indicates the roughness at a specific nip pressure of 40 N/mm² and a roll temperature of 160°C. Over the full speed range, the use of two nips per side reduces surface roughness (PPS-10h) by approximately 0.6 μm .

At constant specific nip pressure and temperature, the surface roughness (PPS-10h) obtained at 1250 m/min was 0.8 μm lower than that obtained at 400 m/min, regardless

14. Paper gloss as a function of bulk for four coating formulations. Soft calender with two nips per side running 80-g/m² wood-free paper (C2S, 5.5% moisture) at 625 m/min and 110°C.



of whether the surface was treated by one or two nips. For this particular LWC paper, smoothness did not meet the target requirements at high speeds. However, it is expected that a 1% increase in moisture (to about 5.5%), which is normal for this paper, will improve the smoothness.

Furthermore, the results with on-machine soft-nip calendering are enhanced when the temperature of the ingoing sheet is at machine temperature (ranging between 50° and 80°C). If the ingoing web temperature is already in that range, the calendering effects can be obtained at lower specific nip pressures and roll temperatures than would have been required with a cold web.

Figure 11 shows the effect of speed on the gloss of the same LWC paper. The lower control for each nip configuration indicates the gloss obtained at a specific nip pressure of 15 N/mm² and a roll temperature of 80°C. The upper control for each nip configuration indicates the gloss obtained at a specific nip pressure of 40 N/mm² and a roll temperature of 160°C. A comparison of the slopes of the upper and lower control limits shows that as speed increases, the decrease in gloss is steeper at high roll temperature and high specific nip pressure than it is at low temperature and pressure.

Figure 12 shows curves for roughness, bulk, and Gardner gloss for a LWC paper calendered with two nips per side at 800 m/min. Each of these curves represents a specific, constant value. Because the values remain constant, the curves illustrate how temperature and specific nip pressure in a soft calender can be varied without changing roughness, bulk, or gloss.

For example, the curve representing a roughness (PPS-10h) of 2.8μm can be achieved at 80°C and specific nip pressure of 40 N/mm² or at 160°C and specific nip pressure

of approximately 22 N/mm². If this smoothness is reached at low temperature, the resultant gloss is 42% and bulk is approximately 0.95 cm³/g. At 160°C, gloss is 50% and bulk approximately 0.98 cm³/g. This demonstrates that high-temperature calendering preserves bulk at the same smoothness values but increases gloss values. However, Fig. 12 also shows that even with relatively high roll temperatures, specific nip pressures must be close to those in supercalenders if paper with high smoothness is to be obtained at high speeds with treatment of only two nips per side.

The literature contains information about high-temperature calendering (5-7). While bulk can be preserved when calendering at high temperatures, this is more true of the heavier grades of paper. Preservation of bulk in the lighter-weight grades is less successful.

Application of only a few nips at high temperatures and high specific nip pressures can cause unacceptable cross elongations of the web that appear as corrugations. In such cases, or when a high finish at high machine speeds is needed, the number of nips must be increased.

The preceding examples show that gloss generation is influenced by finishing parameters. However, there are many coating formulations that cannot be calendered at temperatures beyond 100-120°C without sticking to the heated rolls.

Figure 13 shows the influence of coating formulation and specific nip pressure on the gloss of paper that was run through a soft calender with two nips per side at 625 m/min. At specific nip pressure of 28 N/mm², the difference between the coatings with the highest and lowest gloss was about 6 units. This difference dropped to 3 units when the specific nip pressure was increased to 36 N/mm².

Figure 14 shows the influence of coating formulation and bulk on paper gloss. The conditions in Fig. 14 are identical to those of Fig. 13. It is quite remarkable that the highest gloss was obtained at the highest bulk.

The changes in correlation between gloss and bulk, which are achievable by changes in the coating formulation or the web moisture content, are within or above the area obtainable by varying the parameters of the calendering process. However, comparison of measured gloss and smoothness values shows that a higher gloss is not necessarily linked with an increase in smoothness. Since smoothness values do not directly correlate with printability, tests on the latter are decisive for quality judgments. In the present case, the reel with the highest gloss value showed the best print results.

Literature cited

1. Pav, J. and Svenka, P., *Das Papier* 39(10A): V178(1985).
2. Münch, E., Schlunke, J., and Schmitz, W., *WfP* 106: 621(1978).
3. Baumgarten, H.L., *Das Papier* 32(10A): V164(1978).
4. Schmidt, S. and Kirbis, R., *WfP* 107(23/24): 933(1979).
5. Brecht, W. and Mueller, G., *Tappi* 51(2): 61A(1968).
6. Crotagino, R.H., *Tappi J.* 65(10): 97(1982).
7. Back, E. L. and Olsson, A. M., *Svensk Papperstid.* 86: R31(1983).

Received for review Jan. 20, 1988.

Accepted March 1, 1988.

Presented at the 1988 Coating Conference.