Practical Improvements in Paper Calendering and Finishing

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ABSTRACT

A paper calender, whether it be a multiple hard nip, single soft nip, or a supercalender type operation has as its basic goal the achieving of some level of smoothness, gloss or caliper in the finished paper as well as the building of an uniform reel in a consistent and timely manner. The success of this operation depends on the design of the mechanical calendering equipment and the basic properties of the sheet ingoing to the calender. Uniformity of CD bone dry weight and CD moisture are especially important in creating satisfactory reel build but in this paper we will only discuss tools that can be applied at the calender stack. These tools allow the papermaker to improve the CD caliper and surface properties uniformity of his paper product, and allow the enhancement of paper properties without the necessity of major calender stack rebuilds. The specific tools to be reviewed are the profiling induction heating system and the profiling steam shower. The basics of operation of these devices will be first summarized, followed by a number of case studies to show the type of performance improvements that can be achieved using these tools one at a time and in combination. The importance of modern CD control algorithms in achieving these improved performance levels will also be discussed.

INTRODUCTION

Principles of operation

External induction energy operates by applying a high frequency AC current to a coil located close to the roll to be heated. This AC field induces eddy currents in the adjacent roll which heats the roll. This energy transfer mechanism is highly efficient with overall system efficiencies of approximately 94% possible. A local roll temperature surface increase of 10-30° C is typical in solid roll applications. The use of external induction heating on rolls with internal heating can be described with reference to (Fig. 1).

Fig. 1a shows the temperature profile through the roll shell that might exist when the roll heating comes only from internal fluids. Typically, a difference in temperature of 30°C (54°F) is seen across the roll shell thickness, so that a surface temperature of 70°C (158°F) would exist for a 100°C (212°F) internal fluid temperature. This delta T is caused by the cooler sheet taking energy from the roll surface. This also means that during long reel changes the delta T reduces to zero.

Fig. 1b shows that the difference in temperature across the roll shell thickness can be reduced, eliminated or reversed with an external induction heating system. In this example, the temperature of the roll surface has been

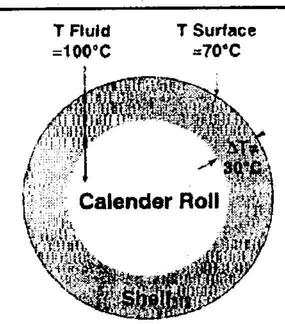

Fig. 1a. Internal heating only

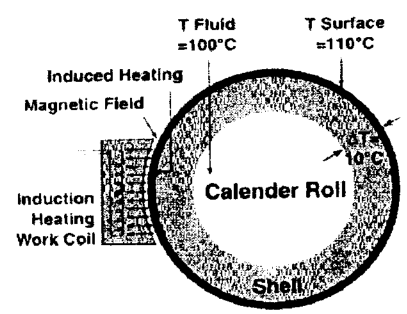

Fig. 1b. Internal heating plus external induction heating

increased to 110°C and the temperature difference across the roll shell is 10°C, but in the opposite sense giving a hotter surface temperature than the internal fluid temperature. In a real situation, the temperature will only be higher on the surface at some narrow cross direction areas during aggressive CD control. Average roll surface temperature is always lower than the interior of the heated roll. The difference between surface and interior in some cases will be very small. This extra surface energy provided by the Calcoil is therefore being used to lower the internal fluid temperature and in many cases may supply 50% of the total heat energy to the roll.

Fig. 2 shows that a practic al application of this technology would involve baseloading an external induction heating system with 30 to 80% of the energy

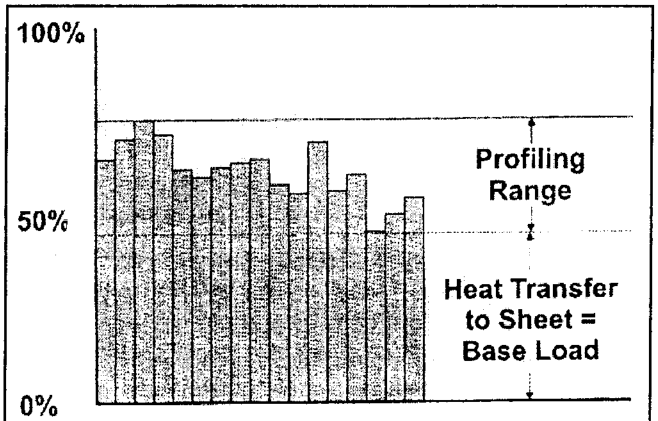

Fig. 2. Power setpoints for induction heating zones

available to achieve an average smoothness or gloss increase. The remainder of the power would be reserved for CD profile control purposes. Adjustment of the individual 75-mm (3-in). control zones above the baseline would be used to correct CD temperature, gloss, caliper or smoothness profile deviations. Fig. 3 can be seen for the general operational concept for CD caliper control.

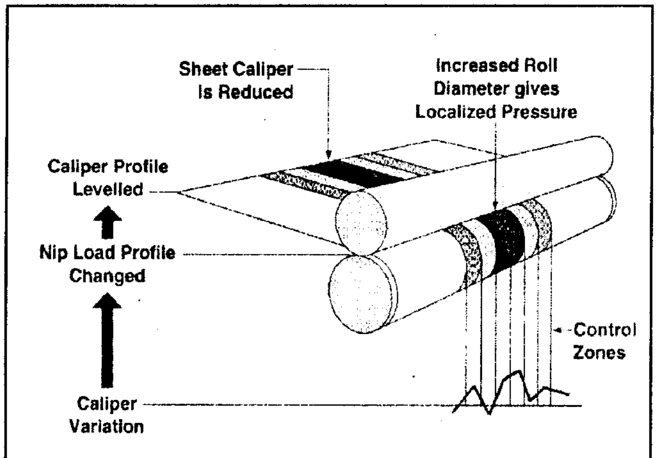

Fig. 3. General operational concept for CD caliper control

Steam (Calendizers)

The absorption of steam into a paper web has two immediate effects. (Fig. 4). Firstly, when the steam condenses, it releases its latent heat of vaporization, and this significantly increases the sheet temperature. Secondly, the condensed steam selectively enhances the surface sheet moisture content. The exact response to any given steam application is a complicated function of sheet weight, nature of the furnish, machine speed, incoming sheet temperature, and the location of the steam aplication device. Depending on the exact combination of circumstances, the process may be described by the use of terms such as hot calendering, temperature gradient calendering and/or moisture gradient calendering.

The major changes in sheet properties that can be achieved with this type of equipment are:

- improvements in sheet smoothness
- improvements in sheet gloss
- reduction in sheet two sidedness
- improvements in CD gloss and CD smoothness profiles
- correction of sheet curl problems

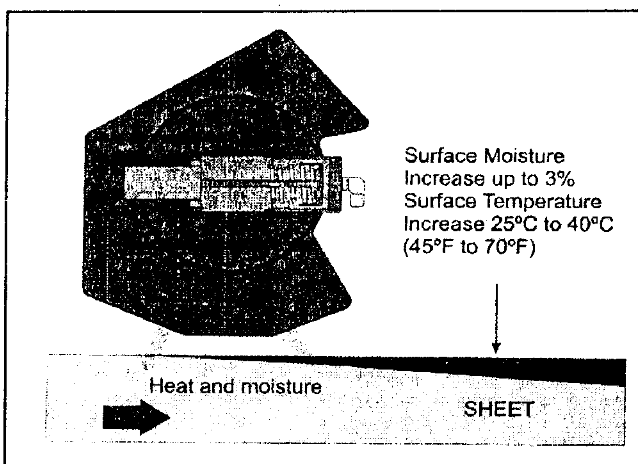

Fig. 4. Steam application on a paper web

Use of External Induction systems for Improved Paper Properties and Improved Reel Build

One of the major objectives of the use of external profiling induction energy systems is the improvement in sheet CD caliper profile and the improvements in reel build that this achieves. The major advantages of the profiling induction energy system over other heat transfer systems are (a) a high energy transfer efficiency for the induction system; 94% compared to less than 50% for the best hot air shower technologies; (b) the availability of significant amount of energy in narrow 3" wide zones. 4.5 kw is typical, although 6 kw is available for certan processes.

The use of a profiling induction system normally reduces the CD caliper spreads by 80-90% and the control can be very rapid with 2δs reduced to under 1 micron after a paper break in less than 10 minutes.

Fig. 5 shows a typical example from a high speed newsprint machine (7.2 meters) where a Calcoil CW reduced the CD caliper spread (2δ) from 9.1 to 0.87 microns; this is a massive 90% spread reduction. The average caliper was about 68 microns.

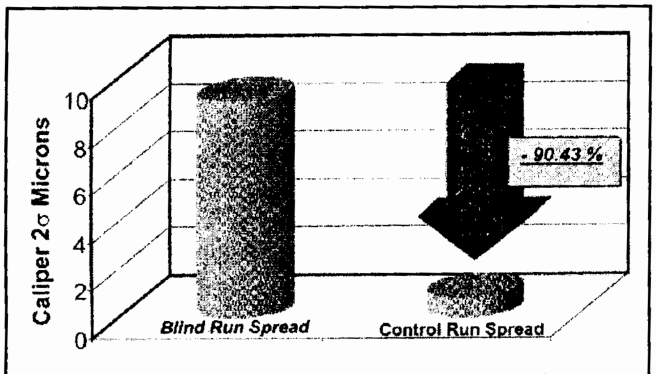

Fig. 5. Caliper spread reduction on newsprint machine

On this machine, the recovery from a web break to a saleable caliper variation level was about 5 minutes; (Fig. 6). Depending on the length of the break, this time can vary in the 5-10 minute range. Further improvements can be achieved but the mill chooses to run with low caliper on the edges which limits the ultimate 2 sigma achieved.

The rapid recovery can be extremely important in improving overall opeating machine efficiencies. Achieving this rapid recovery often involves the use of advanced control algorithms such as "fastback".

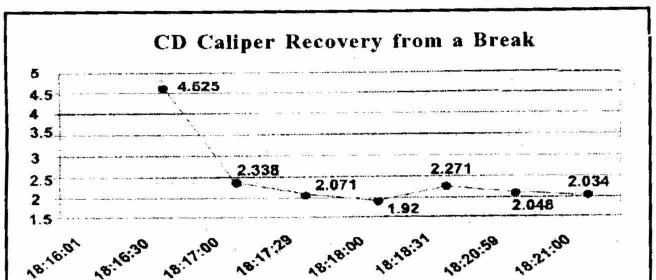

Fig. 6. CD Caliper recovery following a break

Improved Sheet Finish

Heating up a roll surface also results in improved sheet finish. Consider the example shown in Fig. 7 where an induction heater was installed on the solid roll of a hard nip calender producing container board. The induction heater was able to raise the roll temperature from 100°C to 180° C and improve smoothness from 7.0 pps to 5.5 pps, as shown in Fig. 8, despit low stack loading. The CD caliper 2-sigma was simultaneously reduced by over 50%.

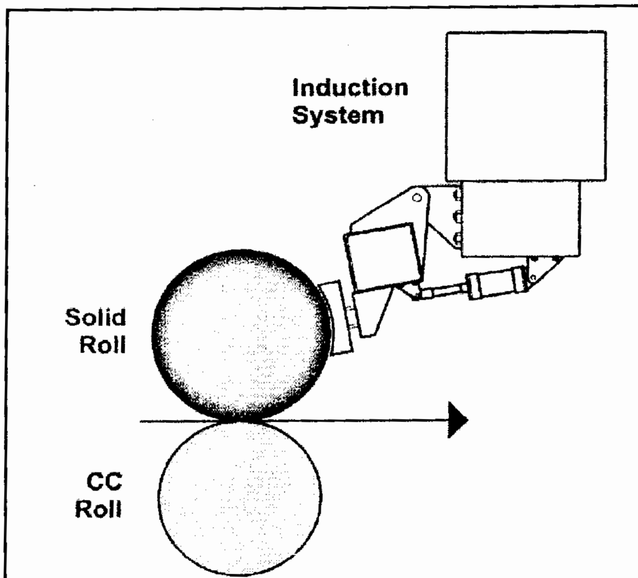

Fig. 7. Induction heating application on hard nip stack producing container board

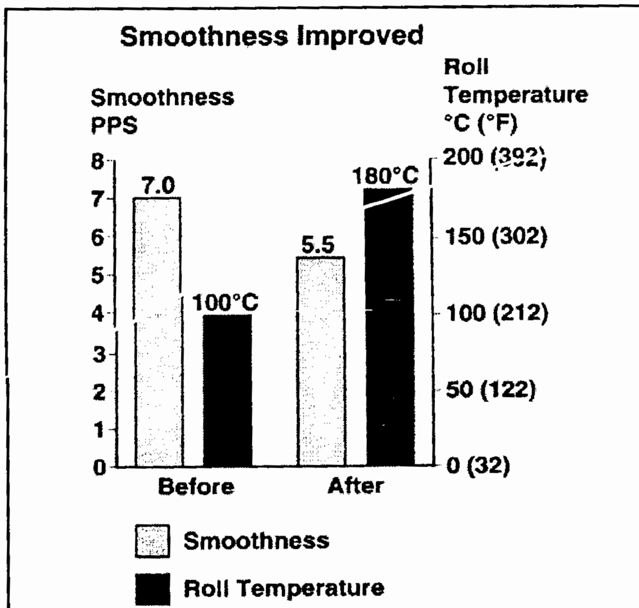

Fig. 8. Smoothness improvements from roll surface heating on hard nip stack producing container board

Application to a Supercalender

Fig. 9 shows the use of an external induction system on a supercalender, Here, a 58-zone Calcoil was installed on the 5th roll of an 11- roll supercalender. This production

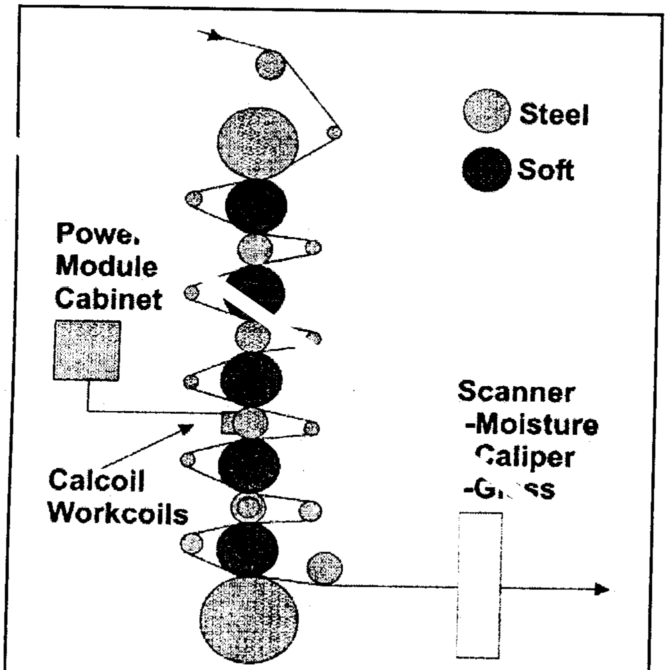

Fig. 9. Supercalender Induction System Installation

660 m/min and the speed was limited by the gloss levels that could be obtained.

The main benefits achieved with this profiling external induction system were as follows:

- The extra energy (up to 4 kW/75 mm zone) allowed a speed increase of + 37% and at the same time the average gloss improved by + 2.9%
- The energy available allowed the control of both the CD Gloss and CD Caliper profiles. A change of up to 12 points gloss and 3 microns caliper could be achievd in any specific zone. Actual control was a blend of these 2 requirements (1, 2).

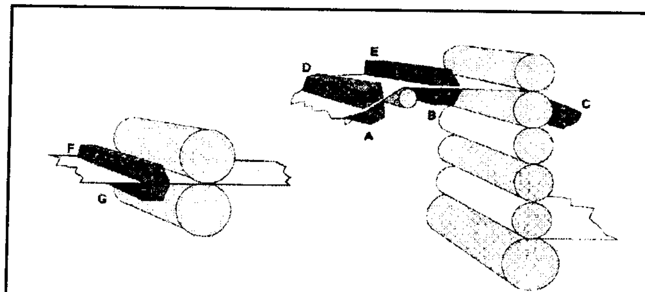

Fig. 10. Typical locations for steam showers on multi- and single-nip stacks

Use of Steam Showers for Improved Paper Properties

Fig. 10 shows where steam showers may be located on typical multi and single hard nip calenders. It should be noted that similar opportunities exist on soft nip calenders as well.

Results

Table 1 summarizes the major operational characteristics

Table 1 : Calender Steam Showers - Typical Results

Grade		Machine A Newsprint	Machine B Newsprint	Machine C Newsprint	Machine D Newsprint	Machine E Specialty Groundwood
Basis Weight (gsm)		45-52	45-55	48.8	43.8	50
Speed (map)		1300	950-1000	820	830	500
Steam shower Location (see Figure 2)		A	A	C	B	F
Incoming sheet Temperature (C°)		75-82	66	64	70	57
Sheet temp. increase across steam shower (C°)		9	18-19	15 min	17 min	23 min
Smoothness before	Top Bottom	96 Sheffield 90	101.5 Sheffield 110.5	3.90 pps 3.35	102 Sheffield 106	2.6 pps 2.8
Smoothness before	Top Bottom	92 Sheffield 82	89.5 Sheffield 90.5	3.28 pps 3.25	84 Sheffield 85	2.0 pps 2.4
% Smoothness Improvement Top/Bottom		4 9	12 18	16 3	16 20	23 14
% Caliper reduction		-	3	3	7	-
Note: Calender design		4 roll	4 roll	6 roll	6 roll	2 roll resilient nip

of five production calender steam showers. The smoothness data was obtained during start-up of the equipment and is based on mill supplied testing. Temperature results were obtained using an infrared temperature pyrometer set at 0.95 emissivity.

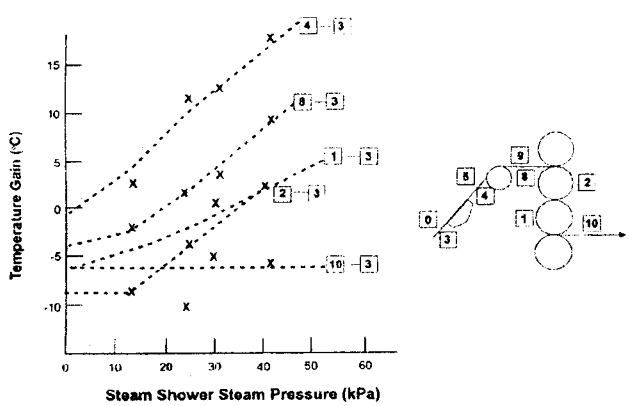

Fig. 11. Temperature increase as a function of steam pressure for steam shower installation on Machine B. Each curve plots the temperature increase from a location before the steam shower to one of the locations after steam application, as indicated. The curves show that at higher steam pressures, sheet temperature increses are higher and are maintained longer.

The results shown in Table 1 were for the steam shower operating at pressures typically in the 30-50 kPa range (4.5 to 7.5 psig). Fig. 11 illustrates, for Machine B, the temperature change across the steam shower and through the calender stack as the steam pressure was varied from 0 to 40 kPa. Measurements on the other machines produced similar results.

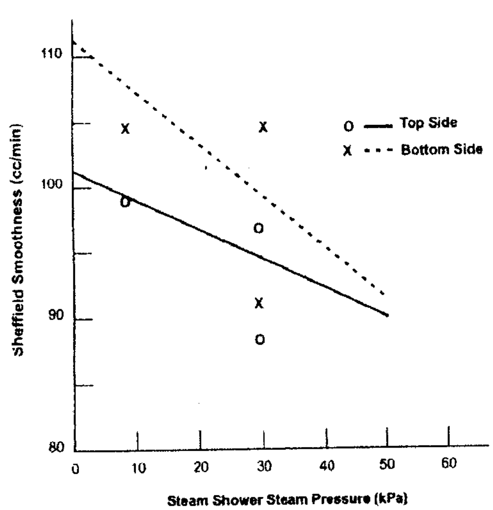

Fig. 12. Reduction in Sheffield smoothness number on sheet top side and bottom side as a function of steam shower steam pressure. Both top and bottom side smoothness are improved as steam pressure increases, with greater reduction in Sheffield smoothness seen on the side of steam application.

Fig. 12 shows, for the same machine, the smoothness change as the steam pressure was varied from 0 to 50 kPa. Similar graphs resulted from studies on the other machines. Some comments on Table 1 are appropriate.

Speed

Machines running between 500 and 1,300 mpm are covered in the study. Time of steam application might be expected to be a factor in steam pickup. This does seem to be the case for Machine A, where the sheet temperature increase is smaller than for the other machines. Other factors, such as incoming sheet temperature, discussed below, must be considered.

Incoming sheet temperature

Studies indicate that the lower the incoming sheet temperature, the larger the temperature increase across the steam shower. However, it is not possible to clearly separate this effect from that of machine speed; the lowest incoming sheet temperature is also the slowest machine, and the highest incoming sheet temperature is on the fastest machine.

Sheet temperature increase across steam shower

In some steam shower configurations, it is not possible to make a good temperature measurement immediately after the steam shower, and some sheet cooling may have occurred before the sheet temperature could be measured. In these cases, the temperature increase is noted as the "minimum". Further details on temperature increase and maintaining the increased temperature through the calender stack can be obtained from Fig. 11. It should be noted that in most calender stacks, there is significant sheet cooling once the sheet leaves the dryer section. The calender steam shower is very effective at reversing this cooling action.

Smoothness

Smoothness improvements of 3-23% are seen on the machines reviewed (3% being on the unsteamed side of the sheet). Significant improvements in gloss are also seen on machines where this is measured. In the case of machine E, gloss improvements between 23% and 47% were seen on the unsteamed and steamed side of the sheet, respectively. In general, the steamed side of the sheet shows a larger smoothness improvement than the unsteamed side, which can be quite useful in reducing sheet two-sideness. Fig. 12 shows the reduction in two-sideness achieved on one machine. Interestingly, this effect is related to sheet structure as the effect seems strongest for those sheets that are inherently two sided (i.e. Machine C), and weakest for sheets that are relatively even -sided (i.e:Machine D).

Caliper

As would be expected, a caliper reduction is generally seen when the calender stack loading remains constant and the sheet is steamed. In Table 1 Machines B,C, and D exhibit caliper reduction of 3%, 3%, and 7% respectively, when no stack loading changes were made.

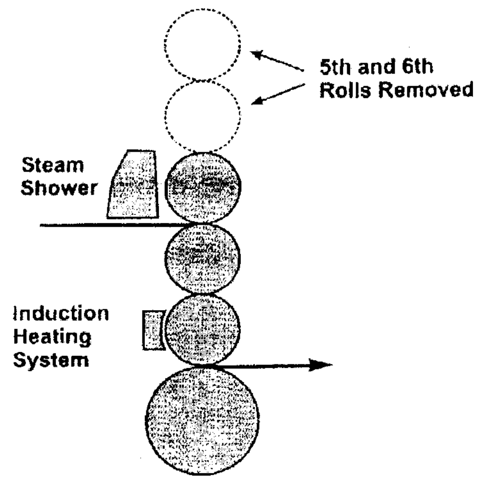

Fig. 13. Newsprint mill installation

Use of Combined Steam and External Induction Heating

Steam and induction energy have already been discussed as stand alone devices but they may easily be used in combination for enhanced results. One example on a hard nip newsprint machine is shown in Fig. 13.

This machine had a two-sidedness problem, a sheet strength issue and a sheet bubbling problem which resulted in calender cuts. The mill installed both a Calendizer dry-end steam shower on the top side of the sheet and an induction heating system on the Queen roll of the calender. This was done in conjunction with the machine builder who also worked with the customer team to reconfigure the calender from a six-roll calender to a four-roll calender, as shown in Fig. 13.

Results from the reconfiguration were excellent, as shown in Fig. 14, demonstrating not only the effect of dry-end steam application, but also the positive effect of increased roll surface temperature through the base loading of the external induction system at a minimum set point, as seen earlier in Fig. 2.

Advanced Combined Application on Supercalenders

In conventional off-line supercalendering, appropriate gloss levels are often achieved by reducing the operating speed to increase the dwell time of the sheet in the nip ; this often causes a major loss of productive capacity. Gloss levels can be readily enhanced by increasing the surface temperature of the metal rolls or by supercalendering at higher surface moisture levels. Poor CD gloss profiles are considered "normal" and often result in the need to "over super" the sheet to ensure that the minimum gloss level meets the required sheet specifications.

On-line supercalendering recently has seen a dramatic increase in the number of commercial applications, especially on high speed uncoated specialty grade machines, These applications have re-awakened an interest in CD and MD gloss and CD caliper improvements

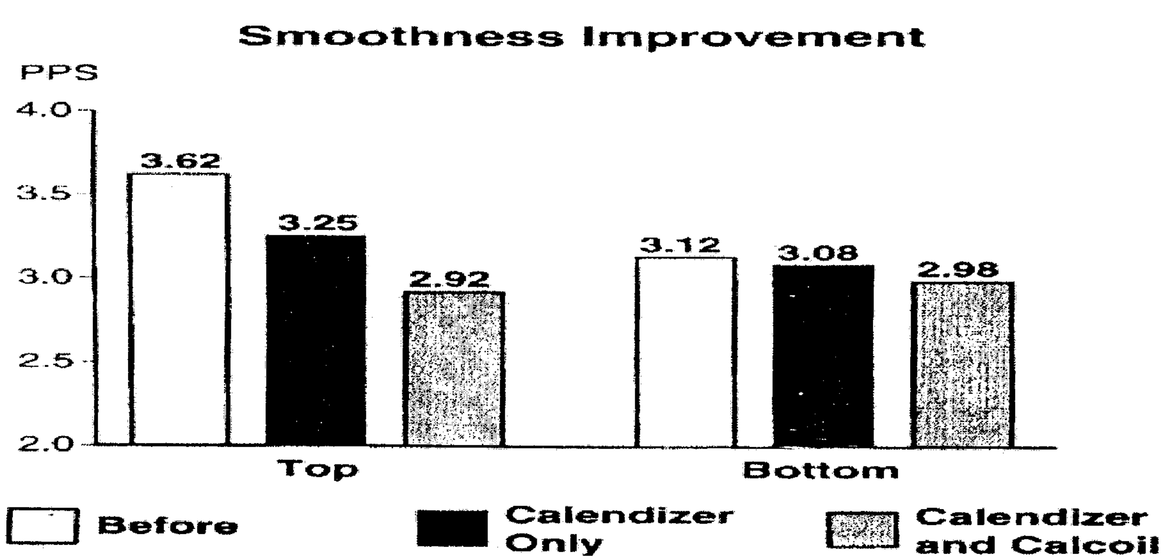

Fig. 14. Results from calender reconfiguration

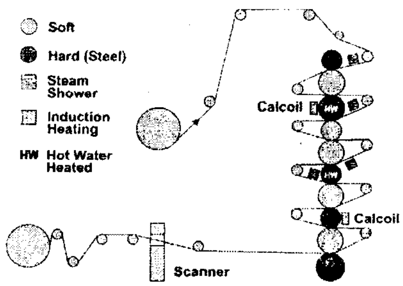

Fig. 15. SC Grade supercalender with multiple actuator sets

not just with the on-line supercalender application, but also on conventional supercalenders. Perhaps this latter interest is driven by a desire to improve the quality and productivity of the "conventional" supercalender installation. Debottlenecking the mill through supercalender optimization is a termheard often, along with the desire to improve operating efficiencies to complete with on-line calendaring. Regardless, many applications, both on and off machine, are seeking quality improvements that require additonal control mechanisms, such as external roll heating. The use of steam and induction energy to allow increased operating speeds while maintaining a specific MD target level and improved CD profiles is well known from conventional 2 or 4 nip hot soft calendaring application and is easily applied to the on and off line supercalender. An advanced application of both profiling steam and profiling induction energy is seen in the SC grade off machine supercalender shown in Fig. 15.

In this example, there are 4 profiling actuator sets; 2 induction sets with 75 mm zone widths and 2 steams and 2 steam showers with 160 mm zones. The process was studied by carrying out a series of bump tests with the induction and steam actuators and the effect on the top and bottom gloss and caliper were monitored to study the interactions. The units for all actuators are %. For the induction actuators, this refers to the percent of maximum operating power. For this application, the maximum operating power is 4.0kW per zone. For the steam shower actuators, % refers to the percent opening of the valve on the actuator . Gloss is measured as Hunter gloss and is in %, and caliper is measured in mils (thousands of an inch.) One mil equals 25.4 microns. Table-2 shows the relative process response interrelationships

Table 2. Process Response Matrix-Note Caliper in mils (thousandths of inch)

	Top Steambox	Top Calcoil	Wire Side Calcoil	Bottom Steambox
Top Gloss	0.021	0.082	0	0
Caliper	–0.00053	–0.0013	–0.0011	–0.00049
Wire Gloss	0	0	0.075	0.018

This table shows the effect of a 1% step in actuator set points. For this SC application, the top side actuators do not affect wire side gloss and vice versa. This is typically not the case but is true here. Both the steam actuators and the induction heating actuators have the same sign for the process gain and the gain of the induction heating actuators is, on average, four times as high as the gain for the steam actuators.

Complicated Applications require Advanced Control Strategies

From the results of the previous section, it is clear that the response matrix (Table 2) for a system with 4 sets of actuators and 3 controlled profiles (top and bottom gloss and caliper) can be quite complicated. Other factors such as speed and line loading will affect the MD values of the measure variables but these will not be considered here.

With such interrelationships, it is clear that optimizing one variable, such as CD caliper, may not result, for example, in an optimum CD top gloss profile.

There are several control strategies that can be used to optimize the supercalender production and quality requirements. A traditional blended control strategy works for some specific sites; this is where a fraction of two profiles is taken to control one set of actuators. A good example might be an installation where the desire is to improve both the CD caliper and the CD Gloss profile using one or two calcoil systems. In this case, a fraction of the CD caliper and CD Gloss error profile is blended together to produce a control error profile which is used to adjust the CD actuator set points of the calcoil system. This is a straightforward system and works well in many simple systems. It is, however, difficult to obtain optimal control solutions in many cases, especially when more than 2 actuator sets are involved.

A more advanced control strategy, which can be applied to a wider range of profiles and actuator sets involves the use of Cross Directional Model Predictive Control (CD-MPC). Basically, this control scheme that can look at a number of CD profiles - CD gloss and CD caliper as an example - and determine the optimum actuator output settings of a number of CD actuator arrays - steamboxes and/or calcoils as an example - to optimize any chosen CD profiles, gloss and caliper for example. The MPC scheme considers the process gain response interrelationships (as well as the time constant matrix and time delay matrix) such as shown in Table-1 to determine the optimum actuator set points. A practical controller must also consider the hard limits imposed by the actuators, e.g. the maximum effect of moving an actuator from 0 to 100% and must allow the operator to specify the relative CD variability reduction importance among

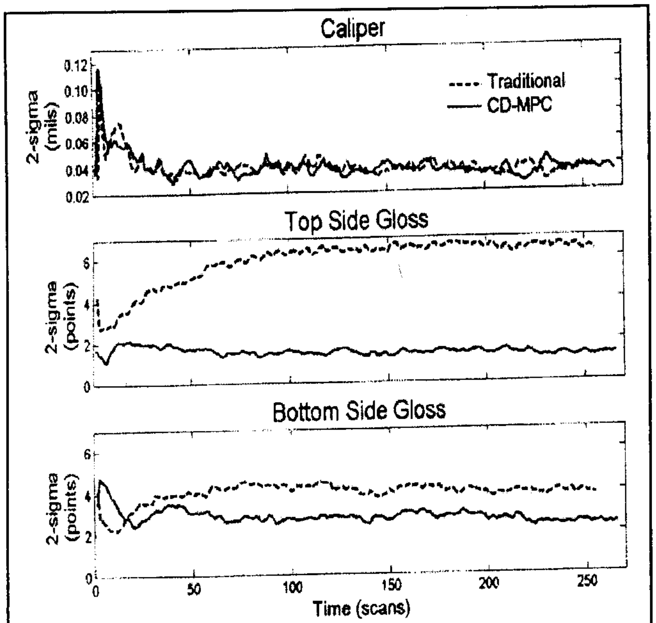

Fig. 16. Supercalender CD 2-sigma trends for coordinated gloss and caliper control using traditional CD control and CD-MPC.

different profiles, e.g. caliper or gloss. This type of control strategy provides the best possible control in a fashion consistent with the quality and production needs of the mill and gives the operator simple control over the final sheet properties for any given grade.

Let's look at some typical results from applications using the two control methods and then a comparison between the two methods.

Multivariable Control and a Comparison with Traditional Control

One supercalender (Fig. 15) was studied using both multivariable (CD-MPC) and standard control.

This supercalender is equipped with one profiling steam shower and one induction heating actuator beam for each side of the sheet. This requires that four CD actuator beams be coordinated to control three sheet properties; wire side gloss, caliper and top side gloss. As for most supercalender processes, the CD caliper has higher relative importance than the CD Gloss. MD Gloss control was also incorporated into the control scheme but is not discussed further here.

Multiple trials were conducted using both the CD-MPC and traditional controllers. CD profiles were collected for the entire length of the paper reels as they passed through the supercalender. Representative CD 2-sigma trends for caliper, top side gloss and wire side gloss are shown in Fig. 16.

The traditional CD controller did a good job controlling CD caliper, the primary CD sheet property, but could not do so without compromising the CD Gloss control. CD-MPC maintained the same low level of CD caliper variation as the traditional CD controller, but was able to simultaneously provide a CD 2- sigma reduction 80% for top side gloss and 39% for wire side gloss (3-5).

CONCLUSIONS

Achieving optimum and uniform sheet finish in a cost efficient manner at the calender stack in a consistent and timely manner requires the use of tools such as profiling induction and steam shower systems. This paper has discussed the principles of operation of these devices and reviewed some typical applications from the standard CD caliper control application to the complicated gloss and caliper control scheme used on a supercalender. As the applications become more complicated, the need for sophisticated control strategies is more evident and state of the art solutions are suggested with multivariable control.

Whatever the application, the papermaker mut continuously look for new techniques to improve his paper quality and operational efficiencies; the tools discussed here will help in this continuous improvement in an economical fashion.

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