

calender has one and two roll stack designs for different paper grades. The OptiLoad, with one vertical roll stack, is today the most common multi-nip calender design for coated and specialty papers within the industry. The OptiLoad TwinLine, with two parallel vertical roll stacks, is designed for the most demanding SC paper grades. The ProSoft multi-nip calender from Andritz Küsters is based on a vertical frame design with two parallel roll stacks. Voith Paper has both one- and two-stack designs for its Janus MK 2 multi-nip calender. Like the one-stack design, the two stack design has a frame construction with two separate roll stacks in line at a 45-degree angle.

Each frame and roll stack design has its own advantages. Vertical roll stack configurations can offer advantages for daily maintenance and operation, in terms of ergonomics, visibility and safety. Roll surfaces can be easily seen from both sides of the roll stack. Movable maintenance platforms can be set up safely on both sides of the roll stack. This is not possible with the inclined roll stack, where typically one movable platform has to be placed above the roll stack. The benefits of the inclined roll stack can be seen as an easy fit into the machine layout. The height of the construction is not a limiting factor, even with configurations of 12 or more large rolls in the roll stack. With the inclined stack, free draws of the paper web can be designed shorter before and after the calender stack. A short free draw from the dryer section to the calender stack offers an advantage in on-line configurations where the moisture loss and web temperature are importance. Short free draws from the calender stack area to the reel area can also be seen as an advantage in most cases, minimising the moisture loss before reeling. However, a short free draw after the calender stack to the reel area may require additional cooling of the paper web, as the reeling temperature may remain too high. This can be the case with double-coated paper grades with on-line applications or fast off-line applications.

The methods of loading the calender roll nips can be divided into two main groups: nip loading with the aid of external hydraulic cylinders, and nip loading with the aid of the roll shell of a deflection-compensated roll. Nip loading by external hydraulic cylinders is the oldest and still a commonly used method in soft- and multi-

nip calenders. The development of a shell-loaded deflection-compensated roll made it possible to simplify the construction of soft calenders and leave out the external loading cylinders. Today, external loading cylinders are typically used in soft calenders for narrow and medium web width. Shell loading is the most common type for wide and fast soft calender applications.

Major changes took

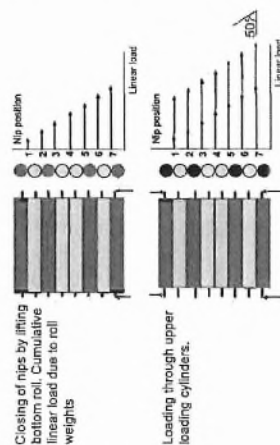


Figure 65. Traditional supercalender loading method.

place in the supercalender area when the new roll stack loading method and simplified stack construction were developed for modern multi-nip calenders (Figures 65 and 66).

Supercalenders generally had no or only a partial roll-weight compensation system for stack rolls. As a result, the linear load increased from the top nips toward the bottom nips, even without external

loading due to weight of the rolls themselves. External loading increased the load in the roll nips but did not change the cumulative load distribution from top to bottom. Supercalenders also had a complex roll stack construction, with a spindle system to accommodate the changes in the height of the roll stack due to changes in roll diameters. The spindle construction required a lot of maintenance and operation and adjustments also took more time. For these reasons, a new loading method was developed for multi-nip calenders, with a simpler and more robust roll stack design. The complex spindle system was replaced by a lever mechanism moved by hydraulic cylinders. The new loading method was first introduced by Metso in their OptiLoad multi-nip calenders. In the OptiLoad multi-nip calenders the roll weights were fully compensated by hydraulic cylinders. In this way, the same linear load level could be set in every nip in the roll stack, from the top to the bottom. This loading method increased the calendering capacity in the top part of the calender stack, as the linear load of the bottom nip no longer was a limiting factor. The roll stack is closed by moving the bottom roll with the aid of hydraulic cylinders, while the top roll is fixed to the frame. The roll stack in multi-nip calenders can be loaded with the same hydraulic cylinders as the stack is closed with, or by using shell-loaded deflection-compensated rolls.

The stack closing and relief system incorporates a quick-opening

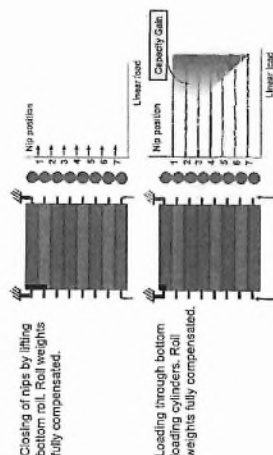


Figure 66. OptiLoad loading load.

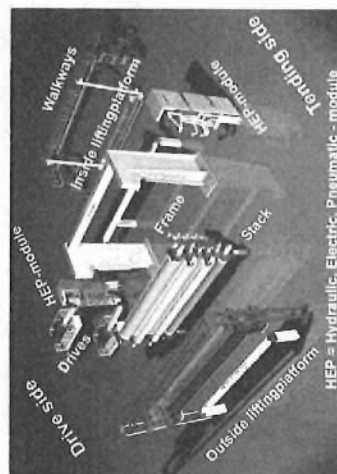


Figure 67. Modern calender design.

system. The main purpose of the quick-opening system is to protect polymer-covered rolls in the event of production disturbances, such as web brakes or coating disturbances, by separating the nip rolls rapidly. The quick-opening system is typically integrated into the nip closing and loading hydraulics of soft and multi-nip calendars. The quick-opening system has become more important as production speeds and temperatures in the calendaring processes have increased. A typical nip opening time in multi-nip calendars is 0.5 seconds.

5.1.1 Deflection-compensated rolls in calendars

Evolution of deflection-compensated rolls

The operation of the rolls forming the calendar nips is vital for the efficient running and high-quality production of a paper machine. Because the linear load deflects the rolls, this deflection must be compensated in some way. A few decades ago, this was almost always accomplished using fixed-crown rolls. The disadvantage of this method was that a uniform linear load was available only with one linear load.

Later in the 1960s, adjustable-crown rolls were introduced to overcome this drawback. The most common roll of this kind is known as the "swimming roll". This roll consists of a stationary shaft and a rotating shell. The shell is supported by the hydrostatic pressure between the shell and the shaft. Side seals form the pressure chamber, which is normally 180 degrees in circumference. The crown can be adjusted by changing the ratio between the internal pressure and the external load forces.

The problem with both of these methods is that local faults at the press nip cannot be corrected. Examples of these are paper caliper profile faults, uneven roll temperatures, and roll or cover wear. The most notorious fault of swimming rolls is perhaps the "gull-wing effect". The traditional explanation is the difference in bearing distance between the swimming roll and the mating roll. However, this is only one reason. Roll temperature non-uniformity faults also create this kind of phenomenon.

The next stage in the evolution was the introduction of hydrostatically supported zone-controlled rolls. Deflection compensation (Figure 68) was achieved by fitting

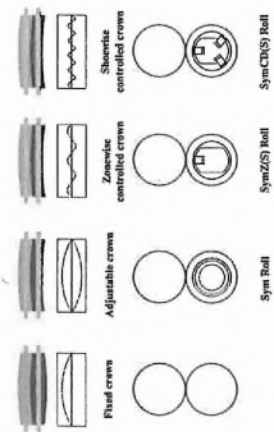


Figure 68. Evolution of deflection compensation.

The latest development is the profile control roll. In the original zone-controlled rolls, the loading elements are controlled in groups. When the elements are controlled individually and the shell sized accordingly, the caliper profile can be controlled as well as or better than with the conventional hot air or induction heating devices, making them redundant in these applications. To enable a suitable profile correction capacity at all line force levels, some kind of a shell pre-tensioning system must be available. For example, pre-tensioning can be achieved using a counter-zone construction or internal pressure.

Theory of deflection compensation

In a nip, the linear force and bearing forces load the mating roll. Considering the shell of the mating roll alone, there are three force components that affect its deflection mode. These are the bearing force F_1 , the linear force q_1 , and the moment M_1 , which is determined by the force F_1 and the distance a , as illustrated in Figure 69.

The magnitude of the deflection depends on the shell material and dimensions. These are constants in the cross-machine direction. To obtain exactly the same mode of deflection for the conventional deflection-compensated roll, its load must include similar force components. The difference $q_2 - q_1$ corresponds to the linear force q_2 in the deflection-compensated roll. In addition, at the edges of the shell, the force F_2 and the moment M_2 must be effectively present. When the ratios of these corresponding force components are similar, the deflection mode is also similar, as represented in the equation

$$\frac{F_2}{F_1} = \frac{M_2}{M_1} = \frac{q_2}{q_1} \quad (1)$$

Because the distance between the bearing and the shell edge on the mating roll is short, the effect of moment M_2 on the deflection mode is also relatively small. The lack of the corresponding moment M_2 in a conventional deflection-compensated roll can be seen as the so-called gull-wing effect in the linear force distribution. In a zone-controlled roll, the lack of this moment can in practice be easily compensated for by properly adjusting the zone forces acting in the roll.

The force F_2 on the other hand, is usually big. The lack of the corresponding force F_2 cannot in most cases be compensated for by adjusting the zone forces in the roll. At the edge of the shell of a zone-controlled roll, a sufficient radial force F_2 must be available. If the magnitude of this force component can also be adjusted, it pro-

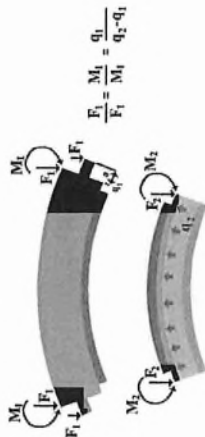


Figure 69. Condition for uniform nip profile.

vides an effective way to adjust the linear force distribution, especially at the edge of the paper.

Figures 70 and 71

show a comparison between a pair of normally sized two-roll calendars. When a radial bearing

force is available, the linear force distribution can easily be made uniform, so the capacity of the zone forces is not wasted in the basic adjustments. Similarly, when only zone forces are available, the shell must be bent by using very different zone forces. The result is not satisfactory. Also, the entire zone control capacity is used to correct the deficiency of the roll.

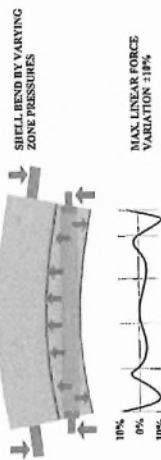


Figure 70. Line force profile without bearing forces.

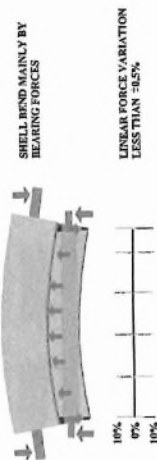


Figure 71. Line force profile with bearing forces.

Swimming rolls

The swimming roll is mainly used in narrow and/or slow-running calendars. It is not suitable for wide, fast calendars.

The construction of the swimming roll is shown in Figure 72. It consists of a fixed shaft, a rotating shell, and bearings that connect the shaft and the shell together.

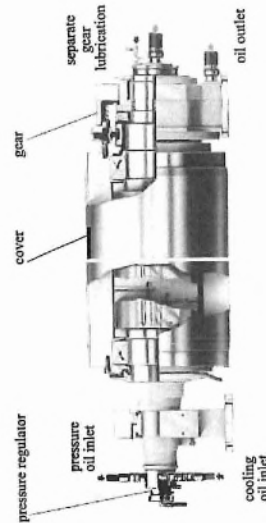


Figure 72. Typical swimming-type roll.

The swimming roll always has external loading cylinders. Between the shell and the shaft there are longitudinal seals, which form the pressure chamber on the nip side and the secondary chamber on the opposite side.

Zone-controlled rolls

Mechanical design

The zone-controlled roll consists of a stationary centre shaft and a rotating shell, which is supported by hydraulic loading elements embedded in bored holes in the centre shaft. The roll can be equipped with an integrated gear drive.

The shell is very accurately machined and ground to a cylindrical shape. In calender applications, the shell can be either chilled cast iron, polymer-covered cast iron or forged steel. The shell rotates on spherical roller bearings or on hydrostatic bearings. These bearings can either fix the position of the shell and the shaft together, or the shell can be self-loading, i.e., the shell can move freely in the nip direction.

Hydrostatic loading element

Figure 73 shows the design of the loading element used in SymZ (Metso) rolls. It uses a mainly hydrostatic bearing, which is fitted on a cylinder piston. There is only one oil pressure connection to the element, i.e., the load pressure also produces the lubrication for the hydrostatic bearing.

When the oil pressure loads the loading element, the element will come into contact with the shell. The pressurised oil flows from the pressure chamber beneath the piston through capillary ducts to chambers in the shoe surface. The oil begins to flow in the gap between the shoe and the shell into the roll's interior. The oil

flow is associated with pressure losses both in the capillary ducts and in the oil film between the shoe and the shell. Because of these losses, the shoe reaches equilibrium or a steady state in which the pressure ratio between the piston and the shoe is constant. Similarly, the oil film's thickness stays constant, regardless of the pressure acting on the pistons and the viscosity of the oil. The flow resistance of the capillary ducts determines the thickness of the oil film.

The surface is normally divided into four chambers because of its stabilising effect. If the oil film on a shoe quadrant is increased, the oil flow to the corresponding chamber is also increased. Consequently, capillary flow loss is increased, and the pressure in the chamber is reduced and the shoe is straightened.

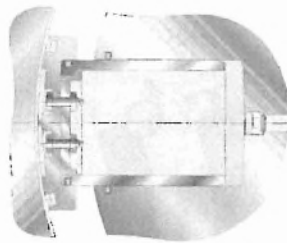


Figure 73. Hydraulic loading element. Copyright of Metso.

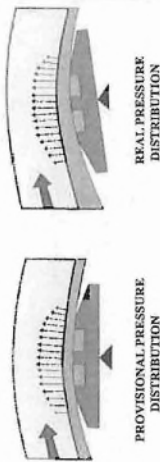


Figure 74. Dynamic wedge effect.

THICKNESS OF OIL FILM VS. SPEED

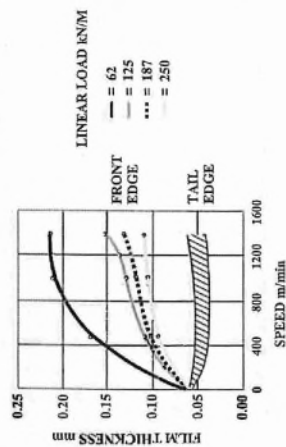


Figure 75. Oil film thickness vs. running speed.

tion depends on the average thickness of the oil film, its viscosity, and the area of the shoe ridges. Because the roll has conventional hydrostatic bearing elements, the power consumption is a compromise with the pumping power. The dynamic wedges, however, allow the mean thickness of the oil film to be increased, i.e., the rotating power consumption to be decreased without increasing the required pumping power.

The hydraulic loading element acts as a vibration damper. When the roll vibrates, a cyclic force interaction occurs between the shell and the stationary shaft, which tends to bring about a relative motion between the shell and the shaft. The oil film between the shell interior and the bearing shoe is practically incompressible. Therefore, the occurrence of such motion takes place between the piston and the cylinder, the movement of which is limited only by the flow resistance of the capillary ducts and the oil film. In other words, the loading piston and the cylinder form an ideal viscous damper.

Floating bearings

In many cases, it is advantageous to use self-loading rolls. In such cases, the external loading cylinders can be omitted, and the construction will be simplified. The chal-

lenge with this construction is how to design rolls without eliminating the adjustable bearing force. Figure 76 illustrates the construction of the SymZS roll. The bearing is mounted on a loading ring, which can move freely in the nip direction, and the bearing loading elements are located between the movable ring and the stationary shaft.



Figure 76. Self-loading zone-controlled roll. Copyright of Metso.

Control system

In a conventional swimming roll, there are two adjustable parameters, the relation of the internal pressure to the external load, and the tending side/drive side load ratio. In a zone-controlled roll, there are already ten parameters, which are not independent of each other. It is clear that without a computer it is impossible to manage the roll control system. Figure 77 illustrates the function of one control system. The operator adjusts only the line force profile in the nip, and the computer then calculates suitable zone pressures for each situation. The operator does not see the complex relation between the line force profile and the zone pressures. In addition, the parameters needed for roll overload protection can easily be built into the control system.

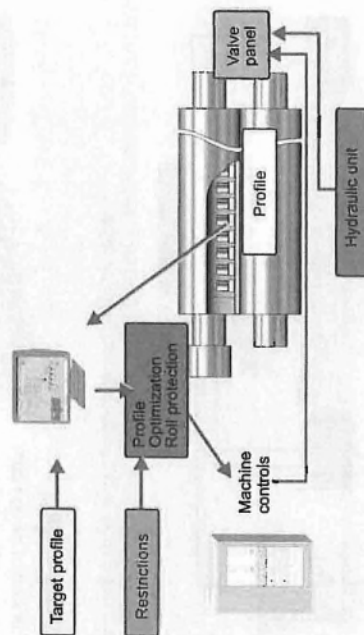


Figure 77. Control system of a self-loading zone-controlled roll. Copyright of Metso.

5.1.2 CD profile-control rolls

Nowadays, profile-control rolls are very common in new calenders. They can give the same or better performance in caliper control, provide better return on investment, and recover significantly faster in process changes than traditional equipment.

Mechanical design

Mechanically, profile-control rolls are very much the same as normal zone-controlled rolls. The main difference is that normally every loading element is individually controlled, which requires a different oil piping system. Thus, there can be from 20 to 70 individual loading elements in the roll, depending on the loading elements' size and roll width. The spacing of the elements is normally from 100 to 250 mm.

If the profiling ability

is also required at low line forces, there must be a system that increases the mean pressure level in loading elements so that suitable $\pm$ correction ability is achieved. There are different ways to design this;

Figure 78 shows the counter-zone construction used in a CD profile-control roll. Normally, the counter-zone is divided so that the deformations of the shell are minimised.



Figure 78. CD profile control with counter-zone. Copyright of Meiso.

Control system

Obviously, the control system in a profile control roll is even more complicated than in an 8-zone roll. Normally, in these applications a closed loop control system is very much recommended, and the operator's responsibility is only to give a target profile and the system takes care of the rest. The SymCD control system diagram is shown in Figure 79.

Hydrostatic bearings

Traditionally, spherical roller bearings have been the only option for deflection-compensated rolls. However, there are some problems related to these bearings. First, they cannot tolerate zero load. This is difficult in systems where the bearings are only lightly loaded or the total load range is needed for better control. Second, deflection-compensated rolls are often ground on their own bearings. In this situation, the run-out errors in the rotating ring of the bearing are also copied to the roll shell.

Figure 80 shows a new design, which gives some very important benefits. The spherical roller bearings have been replaced by hydrostatic bearings, i.e., the same type used in deflection compensation. There are individual elements in the nip direction to give adjustable load at the roll end and in the cross direction to keep the position of the roll constant during operation. A similar system also keeps the axial posi-

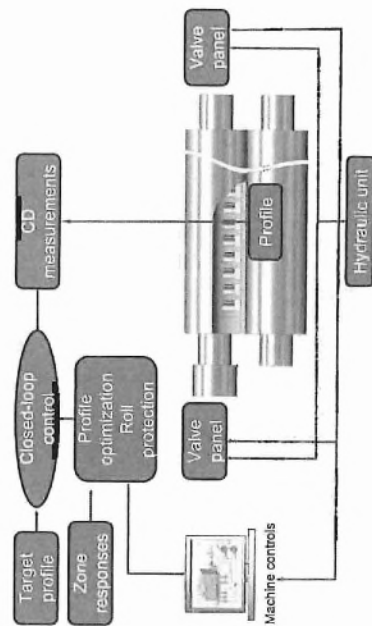


Figure 79. Control system of a CD profile-control roll. Copyright of Meiso.

tion of the shell constant.

This kind of design can withstand a load from zero to maximum, thus eliminating the zero load problem. Neither are there any run-out problems in the bearing, because all bearing elements are now stationary.

5.1.3 Heated rolls

Heat in calendering improves the attainable surface properties such as smoothness and gloss. The heat is applied in the process using heated rolls, thermo rolls.

Thermo roll design

The main process requirements for thermo rolls are they must provide the right heat transfer capacity from the roll surface to the paper web and an adequate uniform nip pressure^{67,68-69}. Depending on calender type, speed, trim width, and paper grade, thermo rolls must meet the following basic requirements:

- sufficient surface temperature
- stable nip load
- suitable surface roughness

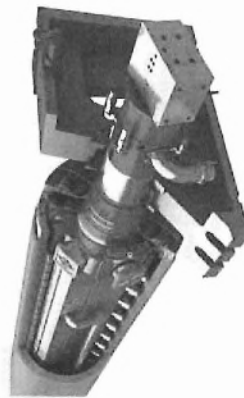


Figure 80. CD profile control with counter-zone. Copyright of Meiso.

- no vibration
- uniform profile
- wear resistance
- corrosion resistance.

The thermo rolls are heated using a heat carrying medium, such as oil, water or steam, which is circulating inside the roll. It is also possible to heat the roll externally or internally using induction heating.

The heating medium is fed into the roll through a rotary joint, which seals the rotating roll flow passage to the stationary oil piping.

Construction

Most modern heated calender rolls can be divided into two basic designs: displacer rolls and peripherally drilled rolls^{38,39,40}. The forerunners of these modern rolls simply use a small centre bore. For extreme heat, a special induction-heated roll, the Tokuden roll, can be used.

Centre-bore rolls

This roll type has only one smaller or bigger centre bore. The thermal fluid goes into the roll bore from one end of the roll and comes out the other end. Centre-bore rolls have rather small bore surface area and large wall thickness. The flow velocity on the surface is also low, because of the large cross sectional area of the centre bore. For this reason, the thermal power is low and heat transfer inefficient. Furthermore, the surface temperature across the face tends to be uneven.

When using a larger centre bore, it is possible to have lighter rolls. Still, a weakness is that the bore fills with thermal fluid, which means low thermal efficiency in relation to the amount of fluid.

Displacer rolls

The displacer type roll also has a centre bore. A steel volume displacer is inserted in the roll bore with a shrink fitting. The displacer diverts the heating fluid to the surface of the bore. The fluid then flows through the 7–10 mm wide annulus formed at the roll bore. The velocity of the fluid is increased to turbulent flow with excellent heat transfer. The heating capacity of this type of roll is much better than that of a simple centre-bore roll.

The heating fluid enters at one end of the roll, passes through the annulus across the roll face, and exits through the opposite journal (mono-flow) or travels back through the inner diameter of the displacer to exit through a duo-flow rotary joint.



Figure 81. Displacer-type thermo roll.

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Peripherally drilled rolls

In peripherally drilled rolls, the heating medium is circulating in flow channels, which are drilled in the roll shell. This brings the heating medium closer to the surface and increases the heating capacity compared to centre-bore and displacer body rolls.

Peripheral holes are normally drilled from both ends of the roll body and meet in the middle of the roll body. The holes are usually 20–60 mm from the roll surface, depending on the material used. The hole diameter is normally 25–50 mm and the number of holes 15–50, depending on the process requirements. The size of the central bore is determined based on the roll diameter and application.

The peripheral drillings create a circumferentially uneven temperature profile in the roll shell. The temperature deviation does not directly affect the calendaring process, because the differences are not very big. However, the temperature distribution causes roll shape distortion because of the different thermal expansions in the material. This distortion can be seen in vibration of the calendar when the roll is in operation. Careful sizing of the roll and flow system are very important to ensure smooth operation of the calendar.

There are several designs of peripherally drilled rolls.

Mono-pass rolls

The flow in all peripheral passages is unidirectional. To avoid an unfavorable temperature drop at the surface between one end and the other, the flow of thermal fluid has to be increased. The fluid velocity can be increased by changing the flow diameter of the hole with a special displacer rod. This type of roll is only used in applications with low heating requirements.

Duo-pass rolls

In this type of peripherally drilled roll, the thermal fluid is returned to the originating end in adjacent passages. The average temperature drop from one roll side to the other is zero.

Tri-pass rolls

In the tri-pass roll, the heating medium makes three passes across the roll face in alternating directions through three ad-

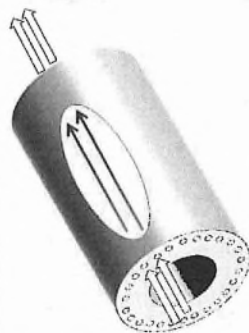


Figure 82. Peripherally drilled thermo roll with mono-pass flow design.

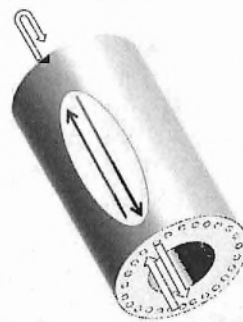


Figure 83. Peripherally drilled thermo roll with duo-pass flow design.

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adjacent connected peripheral holes. It exits through the opposite journal, or it can return through the central bore for exiting through a duo-flow rotary joint. In the tri-pass II design, the flow in the middle hole is increased in fluid velocity and heat transfer to compensate for the lower fluid temperature in the third hole.



Figure 84. Peripherally drilled thermo roll with tri-pass II flow design.

Tokuden rolls

A hardened steel shell rotates around a fixed shaft with integrated induction coils. The shell is heated by Eddy-current from inside. To overcome uneven heat generation, a system of peripherally bored heat-pipes evens out the temperature profile on the surface. These rolls are used in small calendars. The main use of these rolls is in converting. This design allows the use of very high temperatures, since there is no limitation from the heating medium. The disadvantage is that there is no possibility of cooling the roll.

Heating mediums

Water, steam and thermal oil are the three main heating media used in thermo rolls^{67,68}. Hot water can be used when the roll surface temperature is under 120 °C.

Steam can be used up to 170 °C surface temperature. The hottest roll surface temperatures are reached with hot oil, which can reach over 220 °C.

Direct steam heating is advantageous in a temperature range of 80 °C – 170 °C using peripherally drilled rolls. The steam can be taken from the existing mill steam supply. Another strength is that heat transfer in a steam roll occurs everywhere in the roll at the same pressure and temperature levels. Thus, steam provides good cross-machine temperature profiles. However, the steam-heated rolls need to have special arrangements for handling the condensate. Uneven build-up of condensate inside the rolls can produce vibrations as the roll is out of balance.

Most modern calendars use water or oil as a heating medium.

Roll materials

Thermo roll shell material requirements are complicated. The roll surface should be extremely smooth, have good wearing and corrosion properties, be shock-resistant (mechanical and thermal), and be easily cleaned. The strength of the material should be as high as possible with good thermal properties for heat transfer.

The dominant material is chilled cast iron. In this material, the surface layer is chilled iron and the inner part (core) of the shell is either gray iron or nodular iron.

Other commonly used materials are carbide-containing special steels, hardened and tempered forged steel, and gray or nodular cast iron with a hard coated surface.

Chilled cast iron has good wear resistance because of its surface hardness over 500 HV20. The usable depth of the chilled layer is 8–15 mm; therefore, the roll can be ground many times. Another good point is the easy drilling of the inner parts of the roll. However, the material has a hardness gradient towards the surface and when drilling long rolls this causes the drill to bend towards the softer material. This can be seen in long rolls having the drillings travel deeper under the surface in the centre of the roll. Another disadvantage is low heat conductivity of the white material, which is only one-third of the gray core material. Hot chill is also crack sensitive with cold water contact.

The casting process creates non-homogeneous material distribution in the roll. The chill layer may be thicker in some parts of the roll. Because the chill layer has a different thermal behaviour, namely different conductivity and thermal expansion, the roll can suffer from shape distortion when heated. This can have severe effects on the roll's dynamic behaviour. This has been compensated by balancing with heated rolls.

The forged steel materials can be made for high hardness on the surface using surface hardening technology. The dominant method is induction hardening, where the surface layer is heated with an induction coil and then the layer is cooled with water. The surface hardness can be up to 600 HV20, depending on the carbon content of the steel. The steel material is very homogeneous due to the manufacturing process. The forging process removes any voids or cracks in the material and the final heat treatment determines the microstructure. This makes drilling of long rolls easier, because there are no hardness gradients in the roll. Very precise drilling patterns can be achieved, which makes the temperature profiles and dynamic behaviour of the roll very good. The steels are also ductile materials, which means that even high stresses such as thermal shocks from water on hot surfaces can be tolerated.

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5.1.4 Elastic-covered rolls

Introduction

As has become evident from previous chapters, elastic-covered rolls play an essential role in calendering. A certain amount of elasticity is required in the calendar nip to provide enough time for heat transfer and subsequent deformation for both the cover and web of paper so that the targeted paper quality properties can be reached. Until the late



Figure 85. Chilled cast iron roll cracked by thermal shock.

1970s, filled rolls based on natural and synthetic fibres were used almost exclusively in supercalenders. However, with the introduction of on-line soft- and multi-nip calender technology, the development and use of polymer-based thinner covers became inevitable. In calendering the term 'elastic' is a relative property as both fibre and polymer covers are relatively hard, but still clearly softer than the mating metallic parts. The modulus of elasticity of these elastic covers typically ranges from 1 to 8 GPa, whereas the modulus of elasticity of a steel roll typically ranges from 140 to 210 GPa. The nominal hardness of roll covers is expressed in ShD units. The hardness of elastic rolls depends on the calendering application, but may vary from 70 ShD to 95 ShD.

Filled rolls

Filled rolls have been used for sheet compression purposes for a couple of hundred years and also specifically in supercalenders since about 1900. A typical construction of a filled roll is shown in Figure 86.

A filled roll is manufactured by squeezing selected fibre sheets with high pressure (typically ranging from 60 to 90 MPa) between metallic endplates. A wide range of fibre materials has been used since the start. Earlier, a well-performing fibre material was linen, but the most common choice today is cotton or a blend of cotton and wool. The hardness can be adjusted from hard to soft by



Figure 86. Typical construction of a filled roll. Copyright of Metso.

increasing the wool content (Figure 87). Besides the material composition, the homogeneity, direction and distribution of fibres are of great importance in managing the end properties of filled rolls.

The main disadvantage of filled rolls compared with polymer covers is their poor marking and wear resistance, which leads to frequent weekly roll changes and makes the old traditional off-line supercalenders the only viable application for filled rolls today. The most common type of damage seen in filled rolls is internal carbonisation due to excessive internal heat generation. Excessive heat generation may be induced by local overloading or a defect in the fibre structure.

In the past, many synthetic fibres have been tried to provide improved wear and marking resistance. A good example of this is the filled cover using Nomex (DuPont trademark) as the fibre material. This type of roll has provided longer run times between grindings, but has limited application due to its rough surface.

Commonly known manufacturers of filled rolls are Metso Paper, RHL Ltd (UK), RIF (Italy), and Voith. Some polymer cover manufacturers offer a special design where a polymer cover is fitted on a filled roll.

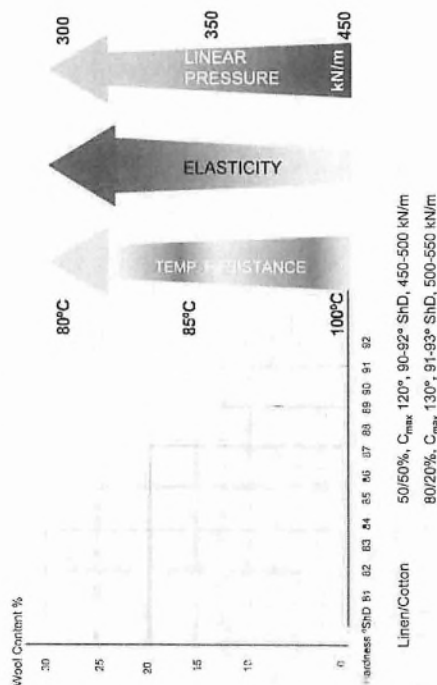


Figure 87. Effect of varying proportions of wool and cotton on the end properties of filled rolls. Copyright of Metso.

Elastic polymer covers

Introduction

Polymer covers are currently routinely used in soft-, super- and multi-nip calenders. The emphasis in this section is on discussing the elastic polymer covers used in these applications. The first elastic covers used in calendering were in fact used in gloss calenders. The gloss calender was the predecessor of today's soft calenders. Gloss calenders were typically used for calendering coated board grades, where the required surface finish could be achieved without sacrificing bulk by using a low nip pressure combined with a long enough thermal effect. The elastomers used in gloss calender covers were initially based on chlorosulphonated polyethylene rubber and later on polyurethane. The hardness ranged from 50 to 80 ShD (or in PU hardness units from 20 to 3 PU, respectively). The first epoxy-based roll covers were introduced in the early 1970s. As these covers had an elastic modulus of the same magnitude as filled rolls, the polymer was seen as potential material also for calendering. Beloit was the pioneer in introducing these covers in supercalenders. The first soft calenders, supplied by Küsters were provided with hard, ebonite-type rubber covers, but they were soon replaced by epoxy-based covers. Along with the evolution of calendering technology from off-line supercalenders to soft calenders, and then to modern on-line multi-nip calenders, the cover material technology has also constantly evolved to meet ever-growing requirements.

Requirements for elastic calender covers

The function of the elastic cover in soft-, super- and multi-nip calendering is to provide the nip conditions required to reach the targeted paper finishing properties. During calendering, the cover is subjected to both dynamic and thermal stress. Selecting a specific type of roll cover for a specific application is an important part of modelling the calendering process. From a performance standpoint, the most important requirements for the roll cover are

- nip conditions, under given linear load and thermal boundaries (nip pressure, nip width, nip dwell time), matching well with design values
- long enough running time between regrindings
- high enough dynamic loading resistance for the application
- durable surface smoothness
- reasonable safety margin for local marking, impacts, overloading and temperature variations
- good doctorability (if required by the process)
- easy reconditioning (regrinding).

From a design and manufacturing standpoint, it is important to relate the above users' targets to a selection of measurable cover properties, which help to reach the target, including:

- elastic modulus as function of temperature
- wear resistance
- impact and marking resistance
- temperature resistance (high enough glass transition temperature (T_g))
- barring resistance
- heat build-up under dynamic load (visco-elasticity, thermal conductivity)
- fracture toughness
- bond strength to metal core.

Typical cover structures

The most common cover structures in the market are presented in Figure 88.

The cover consists of two or more layers: a functional top layer and under it a base layer and a possible intermediate layer which links the top layer to the metal core. The covers are made by a wet wrapping or casting process or a combination of both. The desired top layer properties are achieved by carefully selecting and combining the polymer matrix (such as advanced epoxy), fillers (micro or/and nanofillers), fibres, and special additives contributing to easier processing and customised end properties. The base layer is typically more heavily reinforced than the top layer, providing a favourable elastic modulus step from the top layer to the metal core in axial, circumferential and radial direction.

New cover materials and structures are thoroughly tested during the development phase. The tests not only involve measurement of individual physical properties but also structural optimisation by FEA study and dynamic testing of the roll covers themselves.

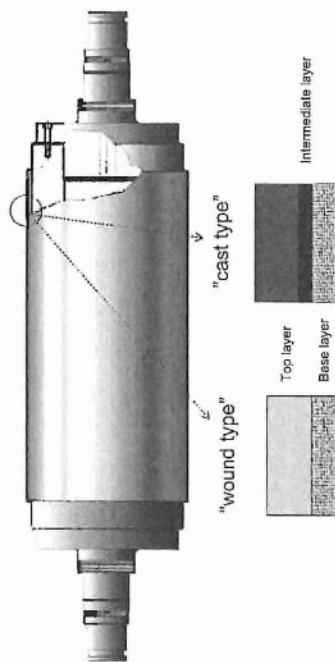


Figure 88. Examples of polymer cover structures. Copyright of Meiso.

Detailed knowledge of the elastic properties of the cover material is necessary for predicting the nip conditions. Cover properties that are of special interest include the dependence of the elastic modulus on temperature, temperature resistance and heat generation. Measurement of the dynamic mechanical properties of the cover material will give a relation between the dynamic modulus and temperature. Polymers are visco-elastic materials, which means that part of the energy for elastic deformation is lost in hysteresis. This loss energy is transformed into heat, and polymer roll covers under repeated loading do heat up. The dynamic modulus can also be divided into a storage (i.e., elastic) and loss (i.e., viscous) modulus. The ratio of energy lost and energy stored is called the loss factor, or tan delta. A polymer cover should have a dynamic modulus that decreases only marginally with increasing temperatures. Thus the cover's behaviour does not change with different operating temperatures or with local temperature variations. The temperature at which the modulus drops dramatically, the glass transition temperature T_g , should be far enough from the operating temperature of the cover. Still, there is no need for an extremely high T_g . These measurements can be carried out with instruments specifically designed for this type of material characterisation (Dynamic Mechanical Thermal Analysis, DMTA). An example of a DMTA curve for a high-performance elastic cover material is given in Figure 89.

DMTA and thermal property data of cover material layers is also needed for predicting and analysing stress and temperature distribution within the cover under given nip conditions. This type of analysis is valuable in evaluating calendering targets, application criticality and cover development. An example of this type of analysis is shown in Figure 90.

As the trend in calendering is towards constantly increasing speeds, loads and temperatures, adequate wear and barring resistance of the cover has become increas-

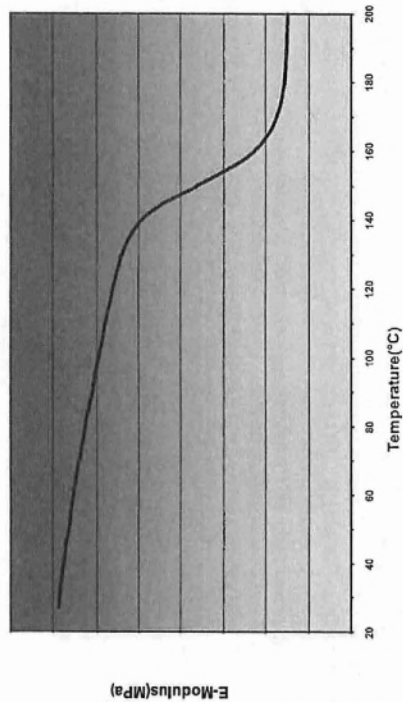


Figure 89. Example of dynamic elastic modulus of a polymer cover. Copyright of Metso.

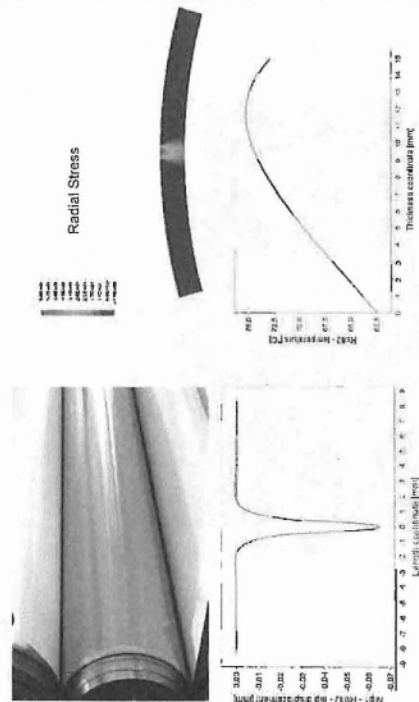


Figure 90. Polymer cover nip, stress and thermal distribution analysis. Copyright of Metso.

ingly important for achieving long enough running times between grindings. The cover itself is seldom the source of barring; rather, it is generated gradually as a result of wear and vibration in the calender process. Higher sliding and deformative wear resistance together with customised visco-elastic properties contribute to better barring resistance.

Application guidelines for polymer covers

The properties of the paper grade and productivity targets also dictate the requirements for the calendering process. Selecting the correct roll cover is essential for optimal productivity. As a rule of thumb for printing paper grades, the higher the requirements for paper smoothness, the more intense the calendering and the higher the elastic modulus of the polymer cover must be. General guidelines for selecting a polymer cover are presented in Figure 91. Deviations from these general principles may exist depending on application-specific needs, such as a need for preserving bulk or for doctorability.

Severity of Calendering Conditions	MULTI NIP SUPER SOFT		
Typical Paper Grade	WFC WFC NEWS SCB SCC LWC SCA RELEASE		
Typical Cover Hardness	88 – 92 ShD	91 – 92 ShD	91 – 94 ShD

Figure 91. General guidelines for selecting a polymer cover. Copyright of Metso.

The most commonly known globally operating companies making elastic polymer covers for calenders are Metso, Schäfer, Stowe, Voith and Yamauchi. There are some more locally operating manufacturers like Kinyosha in Japan and Kaiker in Europe.

Use and maintenance

Unlike filled rolls, polymer rolls are very elastic. Marking by irregularities in thickness/density in the web is much rarer. This means that the service life of polymer roll covers is much longer than that of filled rolls. If filled roll machining/grinding intervals are measured in hours or days, polymer roll cover grinding intervals are measured in weeks or even months.

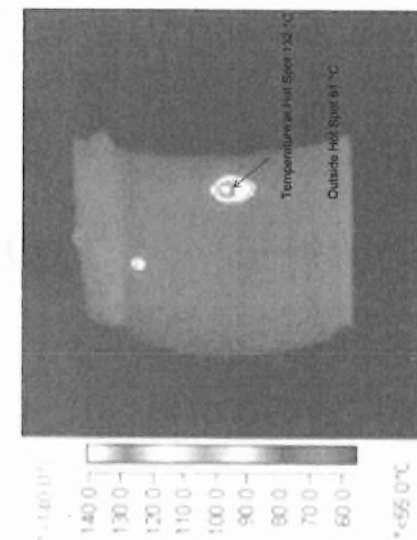


Figure 92. Thermo camera view of a "hot spot" on a polymer cover. Local overload generated by 80 μm thick piece of paper at a linear load of 300 kN/m and a speed of 1 500 m/min . Copyright of Metso.

The long service life puts extra demands on the cover and also on the user. It is up to the cover manufacturer to provide a cover that is impact-resistant and not susceptible to growth of so-called "hot spots". As with filled rolls, hot spots occur in polymer rolls as a result of increased local stress. This can arise for instance by repeated impact at the same spot or from internal damage. Part of the increased energy at the stressed point is transformed into heat, which causes the cover to expand. Thus more load is attracted and a chain reaction leading to hot spot is created. The formation of a "hot spot" due to a small piece of paper stuck on the cover is demonstrated in Figure 92. This thermo camera picture was taken after 5 minutes' running time from a polymer cover loaded to 300 kN/m at a speed of 1 500 m/min . Cover manufacturers provide users with good operating and maintenance instructions, and also training, if necessary. On the other hand, the user must ensure running conditions and monitoring systems which prevent unplanned application-related damage. Modern multi-nip calenders are equipped with monitoring and automatic nip opening systems which help to extend the service life of polymer covers to target level.

The next sections will discuss cleanliness, wear, cover end condition and damage.

Cleanliness

The long service life increases the chance of dirt sticking to the cover. In addition to coating colour and splicing tape, pieces of paper also tend to stick to polymer roll covers because of the static electricity charge typical of polymer covers. Thin pieces of paper or tape not only can cause marking of the paper web, but can also result in cover marking and, at worst, in damage. Taking into account that the radial deformation of the cover in

the stack is only 60–120 μm under loads of 300–450 kN/m , it is no surprise that a piece of 80 μm thick paper exerts very high local loads, which may lead to "hot spot", as demonstrated in Figure 92.

Especially in on-line calenders the polymer covers are kept clean with doctor blades. Best suited are carbon fibre doctor blades. The doctor blade loading parameters depend on the application, but typically the load is between 50–100 N/m , the angle below 20° and the load itself can be continuous or periodic.

Awareness of cover wear

To enable long intervals between grindings, the cover must be very wear-resistant, both in keeping its surface smoothness and in keeping its geometry.

Since calendering is a copying process, the smoothness of the roll surface is important. Although most of the gloss and smoothness is made on the thermo roll through high temperature, the soft roll surface does affect paper quality. Therefore, the roll cover's roughness must be low and remain low. Today's soft covers have run in soft and supercalenders for up to five or six months between grindings, but three months' grinding interval is more normal. The reason for grinding in these cases is often the cover profile and not the surface quality (i.e., marking). The geometry of the cover changes unevenly through wear under varying loads. The load profile over the cover width is never uniform but has regions of high and low load. Paper, coated or uncoated, is like sandpaper and with time grinds away, especially at the high load regions. To keep the paper caliper and gloss profile within specifications, more load will be applied in the worn region, in theory until calendering is impossible and the cover must be reground. After long operation in the calender, the paper wears itself into the cover, especially at the ends where there are usually higher loads (a crowned load profile). At the ends, outside the paper web, the cover does not wear. These ends can come into contact with the opposite thermo rolls, resulting in high load and heating. Therefore, a conservative grinding interval should be used for the first operation of the cover, after which the grinding interval can be increased based on the wear. Thermo rolls wear as well, and an incorrect thermo roll profile can result in non-uniform load of the cover. Thermo rolls have grinding intervals of 6–12 months, but they often operate longer. When installing polymer rolls into a stack, it is useful to check the thermo roll profiles.

Managing the condition of the cover end

Hot thermo rolls pose a problem for polymer roll covers. At the ends, the cover is not protected by the paper web, and heat radiation or direct contact causes higher temperatures and higher loads. Because of the typical high thermal expansion of polymers, limits have been set for the maximum temperature difference over a small distance. Temperature monitoring, either manual or automatic, will provide warning if these limits are exceeded. The following changes should be considered in case of cover end temperature peaks:

- Tapered ends in case of moderate temperature peaks. The taper should start from the web end. In case of small web width changes, a double taper should be applied with a microtaper over which the paper can run without affecting caliper. An example of a proper double taper design is shown in Figure 93.

- Edge cooling, either with air or mist spray. This is mostly used in soft calenders, but today is also used in multi-nip calenders.
- Taper plus overwide paper web, whereby the paper runs over the taper and affects the caliper. The uncalendered edges of the paper are cut away before the reel. This is necessary with very high thermo roll temperatures.
- Hot calendering with a range of web widths should preferably have the taper changed according to the present web width. Of course this is impractical if the web width changes repeatedly in a short period. In that case, effective cooling is necessary.
- Cover end damage, with these available measures and regular grinding, should not occur.

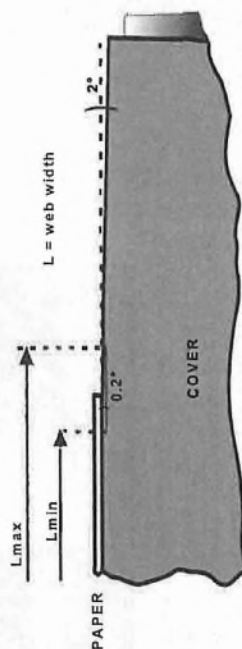


Figure 93. Example of cover edge taper design. Copyright of Metso.

Damage

There is no clear indication that polymer covers would lose their strength with time and become more susceptible to damage. Damage is frequently caused by impacts on the cover, and these impacts occur at random.

Failure often comes as a surprise. The high marking resistance of polymer roll covers has a soothing effect on calender operators. When covers are running for weeks without marking, the feeling that the process is under control comes easily and care for cover and process conditions does not seem so important. In fact, the covers take continuous beatings but do not show it, until they are hit too hard and suffer damage.

If the cover despite its high marking resistance shows many marks, it is advisable to analyse the calender process. Do web breaks occur often, where and why? Do certain rolls always get wrapped by paper? How well does the web break detection system function? Does the quick nip opening system (if present at all) work? Does the doctoring system work? Are covers dirty or do splice tapes stick to the cover? How good is the paper coming from the paper machine or coater, i.e., is everything in the paper formation process in order?

Colour changes in the cover may indicate non-uniform load or heating and should be checked. Dark cover edges can result from oil and grease, but also from an incorrect taper resulting in edge overheating. Similarly, hot spreader roll bearings can transfer the heat via the paper web onto the cover. If the steam boxes do not work properly, one steam zone may apply too much heat. Local load or heating under the web may sometimes be revealed by non-uniformities in paper caliper or gloss, but not always. A calender operator can find such hot areas, and the grinder should reveal if a cover wears locally.

Some impacts are caused by the paper web (wads of paper, roll wrapping, coating lumps, or streaks); others come from the calender environment. Calenders vibrate; parts come loose and go through the nip. This is not disastrous for filled rolls since bolts, screws, wires etc., can get embedded into the filling. But for polymer roll covers, this damaging situation can cost dearly. In extreme conditions, the impact can cause immediate failure of the cover. In less severe conditions, the impact can result for instance in internal damage which, with time, can grow to failure.

The usable thickness in commercially available polymer covers varies from 5 to 10 mm.

This leaves very little margin if a deep marking occurs. Moreover, in contrast to a filled roll, severe impact can result in immediate failure of the cover through cracking of the cover and breaking away of small pieces. Small holes can be filled up with cover material, but large damage usually mean premature scrapping. Wound covers can in some cases be repaired by making a so-called band repair.

5.2 Profiling Actuators

Paper quality is mostly affected by the calender itself, but the calendering effect can be boosted by additional equipment, such as profiling actuators. Steamboxes were originally used for increasing the gloss of paper in supercalenders and induction heaters and hot air showers were more common for CD caliper control in hard- and soft-nip calenders. Along with the development of new calendering techniques and moisturising technology, moisturising has come a more effective way to increase the web's surface moisture and create an effective moisture gradient in the web.

All paper polymers are softened by increased temperature and moisture content. By creating temperature and moisture gradients between the web surface and the middle part in calendering, the hotter and moist surface fibres are deformed more than the fibres in the middle of the web (for a discussion of gradient calendering theory, see Section 2.3.2). This is where profilers can help by creating the desired moisture and temperature gradients in the web. Surface properties of paper such as smoothness, gloss and printability improve without impairing other quality properties such as bulk, density and stiffness. Moreover, the absorption and consumption of printing ink as well as transversal stretch are reduced. With a higher paper surface temperature and moisture content means the same calendering and smoothing effect can be gained with lower mechanical (linear load) work.

A calender steambox can be used to increase web temperature clearly and create an effective temperature gradient. At the same time, the moisture content of the web

surface increases slightly due to condensation of steam. The steambox can improve quality especially in supercalenders with a limited roll temperature range. Following the development of multi-nip calenders with higher thermo roll temperatures and higher liner loads in the calender stack, moisturisers have become an alternative to the steambox, creating a bigger moisture gradient than the steambox. However, in a modern calender both are used simultaneously to reach higher temperature and moisture.

The steambox and moisturiser are good tools for improving the quality of uncoated grades but cannot be used with coated grades. With coated grades, more common is to use an induction heater to increase steel roll surface temperature and in that way help with the temperature gradient. Especially in supercalenders induction heating makes it possible to reduce gloss two-sidedness. However, an induction heater is more commonly used for caliper profile control.

The caliper profile is essential for good reel build-up and runnability on finishing machines. A big part of winder and printing machine runnability problems are caused by bad reel build-up and variations in CD roll structure. Peel build-up is becoming more important and more challenging because of higher speeds, bigger parent reels, higher filler contents (increased density) and increased calendering (smoother finish, lower coefficient of friction). Roll build-up is always a combination of many variables. It is affected by CD tension variations, air between the paper layers and of course variations in the caliper profiler. The impacts of these variations can be assessed by roll hardness measurement. All factors involved in reel build-up are not controllable, but caliper profiling on the calender allows reel build-up to be controlled to some extent.

5.2.1 Calender steam box

A steam box is commonly used to improve the smoothness and gloss level and the CD profile on the calender. For cross-direction gloss and smoothness profile control, the steam box is equipped with profiling zones, which can be 60 mm to 300 mm wide; the narrower the profiling zone, the better the profiling capability. Each zone has its



Figure 94. Calender steambox under the web for bottom side steaming. Courtesy of Metso.

own valve for controlling the steam flow out from a profiling zone. The valve is controlled by an actuator. Actuator setpoints are set by the quality control system. The most modern steam boxes are equipped with electromechanical actuators with position feedback, whose control accuracy is more than twice that of a conventional pneumatic actuator.

Smoothness and gloss levels are typically controlled by adjusting the average steam flow out from the box. Steam is

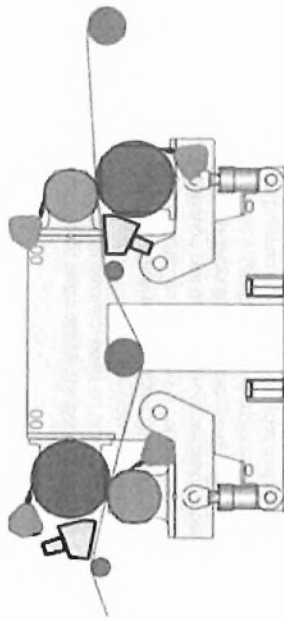


Figure 95. Calender steamboxes in a soft calender ahead of both calender nips. Courtesy of Metso.

typically supplied to the steam boxes at 20–60 kPa pressure and 5 °C – 20 °C temperature as superheated steam. The efficiency of steaming is a function of web temperature before steaming. The higher the web temperature before steaming, the smaller will be the improvement. This is due to the fact that steam condenses to the surface only if the temperature is lower than 100 °C. In practice, when the web temperature is over 70 °C, the effect of steaming is lowered dramatically. To gain an effective steaming result in on-line calendering, cooling of the web is recommended before steaming.

The location of the steam box in the calender has a big effect on the calendering result. Steam can be applied on the top side or bottom side, or both, to reduce the two-sidedness of the calendered paper and increase level. Gloss is increased on the side where the steam is applied. The smoothness effect is very sensitive to the distance between the steaming point and the calender nip. If the steam box is located near the calender nip, there is a minimal effect on caliper, whereas a bigger effect on smoothness can be seen on the side where the steam is applied. On the other hand, when the steam box is located well ahead of the calender nip, the smoothness effect is more equal on both sides of the sheet.

Uniform cross-direction steam distribution and condensate removal are critical factors in preventing production losses due to steam spitting and water dripping. The steam distribution beam has to be of rigid construction and always ready and heated for applying steam. The beam is normally equipped with a retraction system, which moves the beam off the sheet for tail treading and service.

5.2.2 Moisturiser

Moisturisers are commonly used for moisture profiling and for raising the web's moisture content on paper and board machines. They apply a fine water mist onto the sheet through nozzles. The mist is applied selectively in dry areas depending on the moisture profile or equally over the full web width. The moisturising equipment typi-

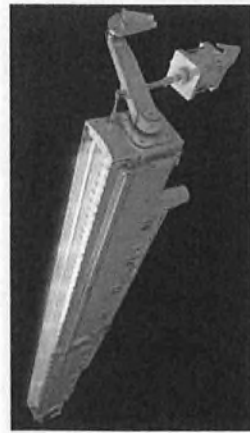


Figure 96. Moisturiser beam with retraction unit. Courtesy of Metso.

were a big droplet size and poor controllability. This led to the development of a nozzle in which water was atomised by air. Nozzles are generally equally spaced along the spray beam with a nozzle-to-nozzle distance of 25 mm to 100 mm, depending on the supplier. With air-atomising nozzles 40 % to 75 % of the water sprayed is absorbed by the paper. The efficiency is dependent on the application and nozzle technology, which varies between suppliers. The water flow to a nozzle is controlled by a water control valve. The control can be based on several small on-off valves in a one block, limiting the number of control steps or linear valve technology with higher control accuracy. Water control valves can be installed in a separate external actuator cabinet or in the nozzle beam to make the unit more compact. The moisturiser beam is normally equipped with a retraction system to withdraw the beam from operating position for tail treading and service.

The most common source of water for moisturising is condensate water, which is filtered in the water supply unit and then pumped to the control valves. The air is generally supplied by blowers, with one common supply to the nozzle beam. If the moisturiser is equipped with a mist removal system, a separate vacuum blower is included to remove excess spray mist from the beam.

The advantage of using a moisturiser is very good profiling resolution, because the number of individually controllable profiling zones can be relatively high in cross direction. High resolution is not only essential for profiling but also allows smoother increase in moisture content across the web width. However, the resolution is not enough to guarantee smooth moisturising; the uniformity is also affected by the droplet size and response shape of the water sprays, the nozzle layout in the beam and the mist removal system.

A moisturiser is typically used with uncoated grades. Applications vary from case to case, the most common being moisture profile control. Reducing the curling tendency of paper and board by applying water on the web surface after drying has also become more common recently. With calendered grades, moisturising was first used widely with SC grades to increase the moisture content after overdrying from 2 % to 10 % before calendering the paper in off-line supercalenders. Later, new moisturizing technology together with multi-nip calendering has made it possible to

apply water separately to the top and bottom side just before calendering without causing streaks or drop marks. Moisturising just before calendering allows effective control of moisture gradients in the web.

5.2.3 Induction heater

The paper caliper profile can be controlled by adjusting the calender nip pressure locally. An effective way to control the calender nip pressure profile is to heat a calender roll locally. Thermal expansion of the calender roll causes the nip load to increase at the point where heat is applied. A heated calender roll also affects the paper gloss profile to some extent as a result of the increased surface temperature. An induction heater directly affects the paper caliper and gloss and through caliper change indirectly also the reel build-up and hardness profile.

In induction heating, a high-frequency electric current creates a frequently changing magnetic flux on the calender roll surface. The magnetic fluxes cause eddy currents in the roll material. The eddy current finally heats up the roll surface. The heat is not led to the roll by means of an intermediate agent, such as air, but is generated directly on the calender roll surface. Induction heating is more effective than traditional hot-air heating of the calender roll. The efficiency in induction heating can be up to 95 %. An induction heater can be used on all kinds of calenders and with almost all paper grades. The basic precondition is that the calender roll material must be magnetic and heat-resistant.

With induction heaters the calender roll surface temperature can be increased locally by tens of degrees. The temperature increase causes the roll diameter to increase which has an impact on caliper. Depending on the type of calender, the caliper of paper can be reduced by 10–30 µm. With extremely high roll surface temperatures above 250 °C, the induction heater's capability might be limited.

An induction heater system consists of two main components: an induction coil and a frequency converter. The converter creates high-frequency power that is led to the coil. The coil will create a magnetic circuit with the calender roll, heating the surface of the roll. Coils are always installed in a beam structure very close to the calender roll. The distance from the coil face plate to the roll is mostly 3–5 mm. The distance between coils in a beam is 60 or 75 mm, depending on the supplier. With a 60 mm

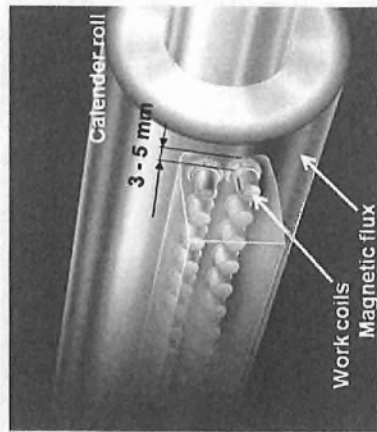


Figure 97. Operating principle of induction heating. Courtesy of Metso.

distance between coils it is possible to apply a maximum power of 4 kW to the roll. For profiling purposes, the frequency controller controls the power in the range 0–4 kW per zone depending on the need. The converters can be installed in a separate device cabinet outside the calender or in a beam structure close to coil beam. The converters can also be installed in the coil beam to make the unit more compact. The coil beam is normally equipped with a retraction system to withdraw the beam from the calender roll into service position.

Figure 98. Induction heating system with separate coil beam and converter beam. Courtesy of Metso.

The location where an induction heater is installed depends on the type of calender and the need for heating. On multi-nip calenders where the stack is equally loaded, the preferred location is the earliest convenient thermo roll because of the higher moisture content and higher elasticity of paper at this point. For caliper control in a supercalender, the induction heater is installed at the lower stack because of the higher linear load in this position. If there is a need for gloss control, the induction heater can also be installed in the upper calender stack. The induction heater is most widely used in hard- and soft-nip calenders for caliper control with almost all grades. In soft calenders, the effect on gloss is emphasized, so the heater is installed on a thermo roll.

Because of the high power density and high ambient temperature, the equipment needs to be cooled, especially the converter and coils. Cooling can be arranged with water or air. Water is generally required with full power applications and high thermo roll temperatures.

5.3 Tail threading in on-line calendering
Seen as a whole, the tail threading of an on-line calender in the finishing area starts from a pulper and ends at the next pulper. In between, there is the calender through which the threading is carried out. Alternatively, tail threading may end at the calender nip, after which the tail goes into the pulper. An essential feature of tail threading is that there is a draw point at both ends between which the tail or the web can be tightened.

In most cases, the tail is widened into a web straight after the tail has reached the next draw point and has stabilised. This requires a web-wide draw point, which can be either the reel or a hard-nip calender.

In some cases, another tail threading follows the first one without widening. Then, the next threading starts when the first one has stabilised and the tail is tight.

The widening occurs when the tail is tight in both sequential threadings. One example of this is the threading to the ValZone metal belt calender, which is followed by threading through the coater using the tail that goes to the pulper after the calender nip. Another example is the two-stage threading through the OptiLoad TwinLine calender, where the first threading ends at the pull-stack between the calender stacks. In this case, the draw point is the narrow pull-stack.

Each tail threading consists of a few typical stages (for example, cutting off the tail) that are carried out at normal machine speed. A preliminary step is to form a narrow sheet or so-called tail by separating it from the web that goes to the pulper before threading. This is done using tail cutting devices which are also used for widening. The next step, which is quite sophisticated, is to cut off the tail which is running into the pulper and instantly guide the head of the tail forward. This is done using tail cut-off devices. After this, the tail is drawn continuously by some device until it reaches the next draw point at the end of threading. This part of the threading is classified as rope-assisted or ropeless tail threading, which is typically used on the longest path of threading. In rope-assisted tail threading the head of the tail is transferred into a rope nip where two or three running carrier ropes converge on a rope pulley. In ropeless tail threading the tail is sucked onto a running belt conveyor followed by another, and again until the next draw point has been reached.

The use of ropeless threading is limited to straightforward threading paths or layouts, whereas rope-assisted threading is suitable for more complicated layouts, for example, in a multi-nip calender. Another dividing line in choosing the correct threading method is between paper and board machines. On board machines, only the straightest and shortest layouts can be designed with ropeless tail threading. The

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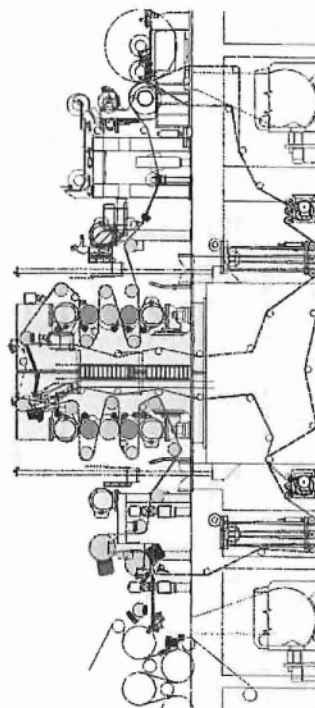


Figure 99. Rope-assisted tail threading in a multi-nip calender. In this example, the OptiLoad TwinLine tail threading is divided into two separate threadings without widening in between.

higher bending stiffness and tensile strength of board also has a strong effect on the cutting and tail cut-off devices to be selected.

The following typical calender threading arrangements can be listed:

- rope-assisted tail threading from the dryer section through an open multi-nip calender to the reel (Figure 99)
- ropeless tail threading from the dryer section through an open soft-nip calender to the reel (Figure 100)
- ropeless tail threading from the dryer section to a hard-nip calender or ValZone metal belt calender (Figure 101).

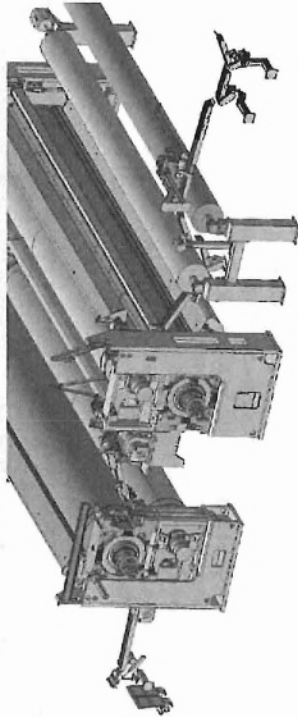


Figure 100. Ropeless tail threading in a soft-nip calender⁶⁴.

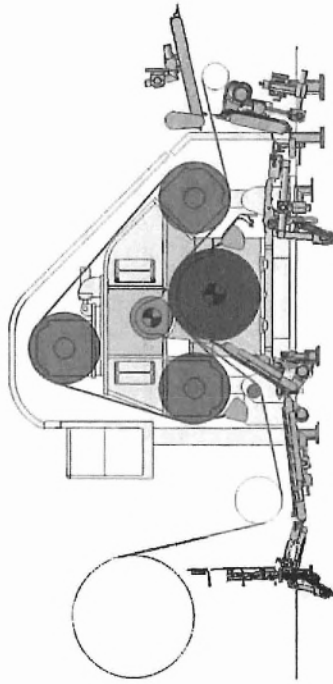


Figure 101. Ropeless tail threading in a ValZone metal belt calender. The web feed to the rope nip in coater threading after the ValZone calender can also be seen⁶⁵.

5.3.1 Cutting of the sheet

As stated earlier, the threading starts by separating a 150–200 mm wide sheet or tail from the web using a tail cutting device. The tail can be cut from the edge of the web using a single cutting (typical with board) or near the edge of the web using double cutting (typical with paper, Figure 102). In the latter case, the narrow sheet beside the tail is called trim.

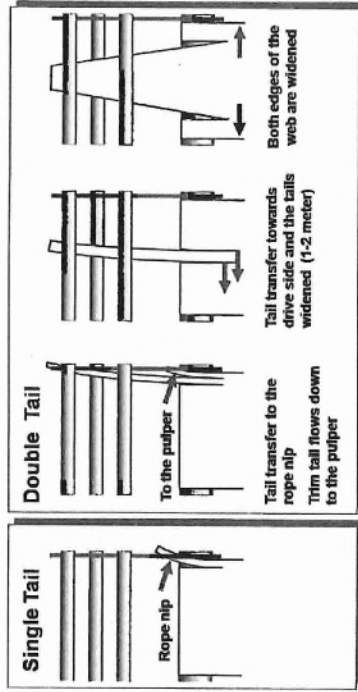


Figure 102. Illustration of centring and the widening of the tail using double cutting⁶⁶.

Paper or light board is cut by a water-jet tail cutter (Figure 103) using a high pressure of 150–1 000 bar. To avoid damage, a lower water pressure is used when the cutting is done against the web supported by the dryer fabric. The highest water pressure is used when cutting against the web running on the last dryer cylinder just before it runs down into the pulper. The nozzle size for water cutting is 0.1–0.5 mm. Too much water

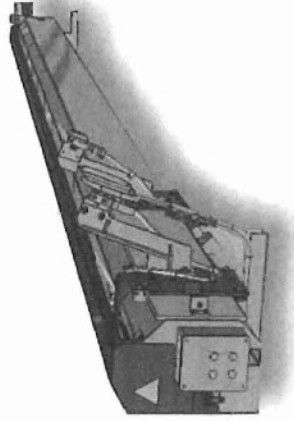


Figure 103. Water-jet tail cutter used for double cutting with two cutting heads⁶⁷.

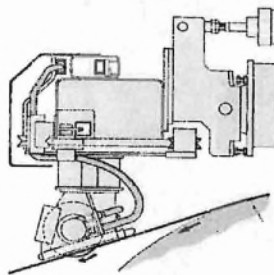


Figure 104. Blade tail cutter for board⁶⁸.

On the other hand, heavy board must be cut mechanically using serrated blades or fast-running rotating blades. Another basic component is some kind of transfer tool or device. It is used to draw the tail before and after cutting. The most common is an air blow which can draw the tail by the friction generated between fast moving air and the tail. After the tail has been cut, a belt conveyor may also serve as a transfer device.

For example, the following tail cut-off devices are in common use:

Air-jet tail cut-off device: First, the tail is released from the dryer cylinder surface above the doctor of the cylinder by the down-blow. Next, two air pipes beside the tail blow air between the tail and the cylinder, causing the tail to fold above the pick-up plate and against the corner of the plate. On the cylinder side of the corner, the down-blow attempts to draw the tail toward the pulper, but on the other side of the corner the

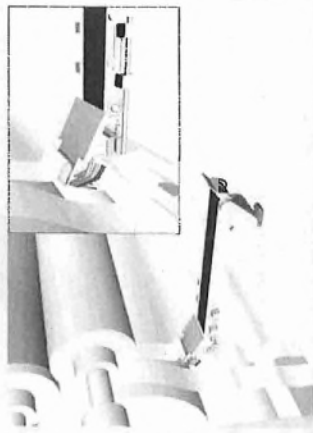


Figure 105. Air-jet tail cut-off device⁶⁹.

tail is sucked into contact with a cutting blow. In this conflict, the cutting blow tears the tail until it breaks within fragments of a second. After that, the role of the cutting blow is to transfer the tail forward and to deliver it to the next transfer blow, after which the tail may be transferred using a transfer blow, or as is more common today, a belt conveyor (Figure 105). The air-jet cut-off device is suitable for low grammages and for high-speed threading.

wets and weakens the edge of the tail, so a small nozzle size together with high pressure is beneficial, while also producing less cutting debris. A heavier board is cut mechanically by a blade tail cutter (Figure 104) at an open draw in the dryer section.

5.3.2 Tail cut-off device

The tail going into the pulper can be cut with several different tail cut-off devices. When a steady web of paper is sucked into contact with a strong air blow, the paper will be torn until it is cut through. A moving paper can also be cut if it hits a sharp knife.

paper can also be cut mechanically using serrated blades or fast-running rotating blades. Another basic component is some kind of transfer tool or device. It is used to draw the tail before and after cutting. The most common is an air blow which can draw the tail by the friction generated between fast moving air and the tail. After the tail has been cut, a belt conveyor may also serve as a transfer device.

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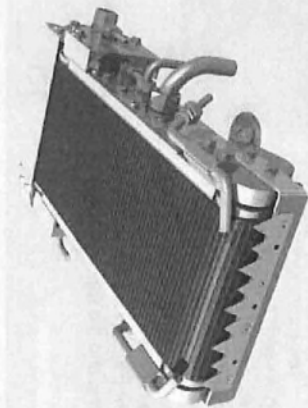


Figure 106. Compact belt conveyor with air jets and a serrated blade⁷⁰.

belt conveyor (Figure 106). The device is suitable for low grammages (30–100 g/m²) and for high-speed threading⁷¹.

Mechanical tail cut-off device for heavy grades: In this device, a toothed flipping tray is installed under the doctor beam of the cylinder and the toothed counter-blade. The tooth fit is precise. The air blow of the tray tightens the tail. Next, the tray flips up, passing the counter-blade. The air blows of the device transfer the tail to the belt conveyor or straight to the rope nip (Figure 107). This device is suitable for all board machines.

Rotary blade tail cut-off device: A light flipping tray, as in the mechanical tail cut-off device for light grades, is fitted just under the doctor of the cylinder and in front of the doctor blade. Instead of a serrated counter-blade, this device is fitted with a rotary blade. The air blow of the tray first tightens the tail and the tray then flips up, so

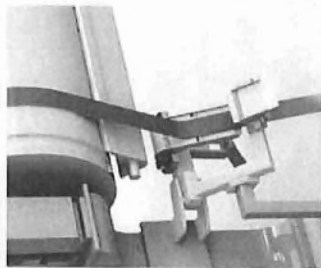


Figure 107. The mechanical tail cut-off device for heavy grades⁷¹.



Figure 108. Rotary blade tail cut-off device⁷².

that the tail passes the rotating blades. The air blow of the flipping tray transfers the tail to a vacuum conveyor, which is always a part of this cutting device (Figure 108). This device is suitable for heavier paper grades and for all board machines.

5.3.3 Belt conveyors

Belt conveyors are an essential part of a state-of-the-art tail threading system. They can be a part of the cut-off device, operating as described previously, or they can be used to feed the tail into the rope nip, in which case there are typically 1–3 conveyors before the rope nip. In ropeless threading, a queue of several conveyors transfers the tail up to the next drawing point.

The belt conveyors consist of two rolls, one of which is driven by an AC motor, and an air-permeable belt tightened between the rolls (Figure 109).



Figure 109. Belt conveyor.⁷³

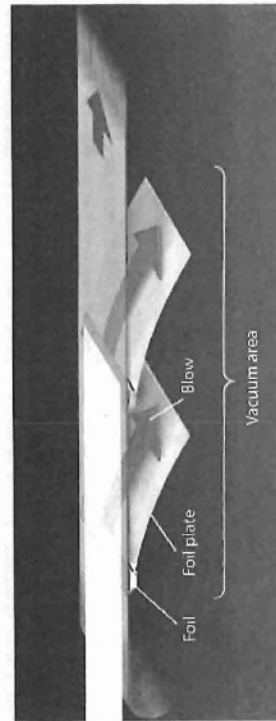


Figure 110. Underpressure produced by the foil blow.⁷⁴

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The inside space between the fabric and the frame of the conveyor is under-pressurised. This is done in several different ways and the main operating principles are the following:

- the air blow of a foil close to the fabric sucks compensation air through the fabric (Figure 110)
- the compressed air ejector sucks compensation air from the under-pressurised space of the conveyor
- the air motor blower sucks air from the under-pressurised space under the fabric (Figure 111)
- the external electric blower sucks air from the under-pressurised space under the fabric.

Figure 111. Underpressure produced by air motor blower.⁷⁵

The normal speed of the belt conveyor is slightly faster than the speed of the paper machine, generally in the range +1 – +25 %.

5.3.4 Rope-assisted tail threading

In rope-assisted tail threading the rope line and thus the rope nip are situated beside the web area and the tail cut-off device and vacuum conveyors are directed outwards and toward the rope nip. The rope nip is formed by the incoming carrier ropes converging around a grooved rope pulley (Figure 112). For paper, two or three ropes are used and for board three. The rope speed is very close to the speed of the previous draw point, which is the dryer section.

The carrier ropes form a loop in which the ropes, after running together in the tail threading area on the machine floor, return from the reel to the rope nip via the basement. The rope drive in the basement (Figure 113) drives the ropes, and the rope stretcher,

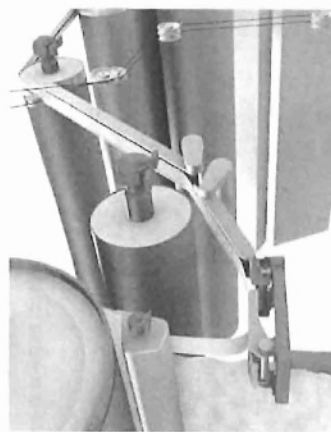
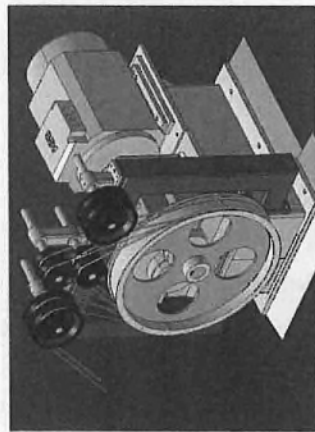


Figure 112. Feeding to rope nip.⁷⁶

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Figure 113. Rope drive⁷⁷.

also in the basement, controls the tension of the ropes. The diameter of the ropes is usually 7–8.5 mm for paper and up to 13 mm for board. The ropes in the loop are guided by grooved rope pulleys which can be either separate small pulleys or integrated into the guide rolls. The rope pulleys have a separate bearing, so the ropes are usually running at crawling speed during normal operation of the paper machine.

After reaching the reel, the tail is centred by moving the tail cutter position and finally the centred tail is widened into a full-width web.

If the threading path is very long, as in the largest Optiload Twinline multi-nip calender, the threading is divided into two sections by a pull-stack in the middle of the calender (Figure 114). The tail is brought without widening to the second threading section, which is similar to the first one, after which the tail is threaded to the reel, followed by centring and widening in the normal way.

In some mills, a pull-stack has also been installed after a Janus multi-nip calender to provide the possibility to thread the tail to the pull-stack either through the calender nips or bypassing them. The threading continues from the pull-stack to the reel without ropes using vacuum conveyors.

5.3.5 Automation

The air blows, the vacuum of the belt conveyors and the pneumatic cylinder movements are all timed by the automation system. The air blow volumes are, if necessary, controlled by hand valves or more accurately by flow control valves.

The tail threading system is operated from a control box near the machine,

Figure 114. Disc roll-type pull-stack⁷⁸.

where the threading can be supervised visually. Video monitors are also used to check when the tail has reached the reel and is ready for centring. The centring operation involves a number of preliminary actions such as starting the tail cutter, moving the ropes from the home position to the threading position, starting the rope drive, moving the belt conveyors from the home position to the threading position and starting the belt conveyors. The threading is started by pushing a button that starts the timing sequence of the blows, the vacuums and the movements. The preliminary actions can also be automated to some extent or grouped together.

The automation system includes interlockings which ensure that all necessary safety and process measures have been taken before a control sequence can be started.

5.3.6 Drives

The speed differences between the belt conveyors, the ropes, the calender nip and the reel nip are set from the drive operating panel. All the speeds are connected in a multi-drive system.

The correct speed difference ensures that the tension of a tight tail is kept under the tensile strength of the paper until the web is widened, after which the tension of the web is measured and controlled. Alternatively, it may be beneficial that the tail has some slack during threading, when the tension of the tail cannot yet be measured. The slack is then checked visually.

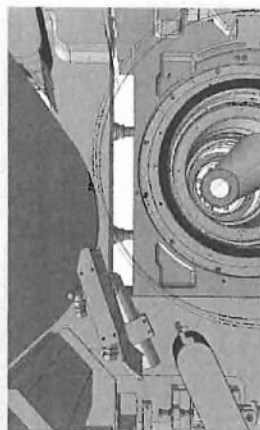
5.3.7 Paper quality

The three main factors contributing to successful threading are the threading devices, the drives and the paper quality. The moisture of paper has a strong influence on the success of rope-assisted threading in a multi-nip calender.

5.3.8 Ropeless threading

Ropeless threading starts in the same way as rope-assisted threading. At the start, the cut-off device is in machine direction and the tail is transferred to the reel through the open nip of the calender using belt conveyors and threading blow plates. The threading blow plates are 300–400 mm wide and equipped with transfer air blows, as in the cut-off devices.

The tail is transferred through the open nip of the calender by means of assisting air blows that prevent the tail from wrapping around the rolls of the calender. The threading blow plate just after the open nip starts to draw the tail quickly after passing through the nip (Figure 115).

Figure 115. Tail transfer through an open nip using belt conveyors and blow plates⁷⁹.

The belt conveyors together with the threading blow plates shoot the tail toward the closed nip of the reel drum and the reel spool. In high-speed threading the reel drum generally has a 500–1 000 mm wide under-pressure zone which transfers the tail to the reel nip.

If the next draw point is a hard-nip calender or a ValZone metal belt calender, the tail is threaded by belt conveyors straight to the calender nip.

5.4 Tail threading equipment in off-line calenders

In off-line multi-nip calenders the tail is threaded at crawling speed, usually 15 m/min. The calender is crawling and the nips are open. The web is taken from the unwind through the calender stack to the windup by the crawling tail threading rope at the tending side of the calender. The calender rolls may have their own drive, or they may be rotated by auxiliary roll starters up to the closing of the calender stack.

At first the unwind is steady and the web is taped to the "dragon", which is a triangular cloth. The dragon's auxiliary rope is taped to the tail threading rope (Figure 116).

The tail threading rope forming a closed loop is run by the rope drive and tensioned by the stretcher, which are both situated in the basement.

Next, the tail threading rope and the unwind are started (common start). The unwind speed is controlled by a potentiometer to ensure that web will have some visually observable slack until it is widened at the end of the calender stack. After this point, there is typically enough friction between the web and the calender stack to allow the dragon to be isolated from the unwind.

The rope speed can also be controlled with a potentiometer to keep the rope speed slightly below the calender speed.

After reaching the windup the rope is stopped and the dragon is removed. The web is quickly aided manually around the windup spool. The speed of the windup is then adjusted with a potentiometer until the web gets enough tension to make it ready for tension control, after which the calender can be speeded up to operating speed.

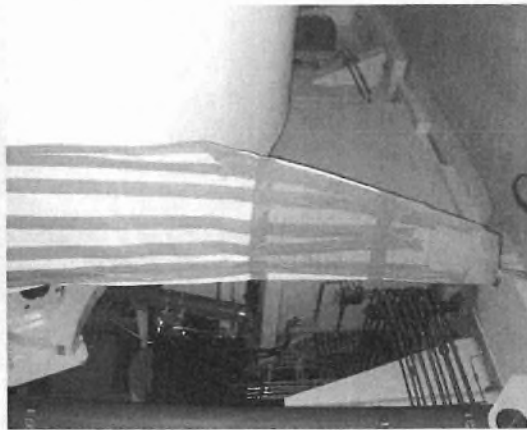


Figure 116. Attaching the web to threading rope⁸⁰.

5.5 Heating and cooling systems

The heat required in calendering can be provided by indirect heating with a circulating heat transfer medium between a heating unit and a thermo roll or by direct induction or hot-air heating of a thermo roll. Indirect heating is the most common method in calenders. In practice, only internal induction (cf. Tokuden roll) provides enough heating power for direct bulk heating of thermo rolls.

Calendering may require a lot of heating power. Typical values for a modern gloss calender are in the range of 50–120 kW/m. With a web width of about 8 metres this will result in 400–960 kW for a single thermo roll. Because the fluid volumes in thermo rolls can be relatively high (500–600 litres) and since the heating medium has limited heat capacity, the flow volume of the system must be large enough to prevent an excessive temperature drop over the thermo rolls. For large thermo rolls a flow of more than 3 000 l/min may be required.

5.5.1 Heat transfer

Heat is transferred by conduction, convection and radiation. Conduction occurs in solids or motionless liquids and gases. In convection, heat is transferred by moving liquid or gas. Radiation requires no material carrier.

The thermal conductivity of a substance determines the rate of conduction. In convection, the transfer of heat from a moving liquid or gas to a solid substance is influenced by flow dynamics, the turbulence of the flow, and the thickness of the boundary layer of moving material. If the flow is laminar (Reynolds number, Re , $< 2\,300$), the boundary layer is thick and the convection rate is small. In turbulent flow, heat is transferred through a relatively thin boundary layer (large Reynolds number). The thickness of the boundary layer also depends on material properties (described with the Prantl number, Pr).

In induction heating, a magnetic field is focused by coils on the surface to be heated. A high-frequency AC current is fed to the coils from a power unit. An alternating magnetic field induces eddy currents in the surface, which in turn produce heat.

5.5.2 Heat transfer media

Water is the most widely used and best known heat transfer medium. Water has superior properties compared to other heat carriers in the temperature range of 0 to 100 °C. It has high specific heat capacity 4.2 kJ/(kg·°C) and high thermal conductivity 0.6 W/(m·°C). Water also is cheap and non-toxic. Water systems are typically designed for flow speeds of 1...1.5 m/s. This corresponds to a heat transfer coefficient of 5 000...10 000 W/(m²·°C).

At temperatures above 100 °C, the use of water become more expensive because heating circuits must be pressurised, e.g., at 150 °C at least to 4 bar. Other problems with water are corrosion, deposits and scaling. Oxygen and carbon dioxide are main causes of corrosion and the pH of heating water should be clearly over 7. Also, chlorine and other ions in the concentration range of a few tens of PPM can cause severe pit corrosion. Therefore, the electric conductivity of heating water should be low. Scaling increases if the water temperature is above 100 °C. Scaling on the

surfaces of heating elements reduce heat transfer. For this reason, the hardness of heating water should be low. The use of condensate water is a risk-free choice.

Water has high evaporation enthalpy, 2 257 kJ/kg at 100 °C. Thus, condensation of steam is an effective way to transfer heat, and steam heating is generally preferred over water heating if the temperature target is above 150 °C. By careful design the condensate layer can be very thin and the heat transfer coefficient in the range 10 000...30 000 W/(m² °C).

Steam can be successfully used up to 235 °C. At this high temperature the whole system, including rotary joints and thermo rolls, must be pressurised to 25 bar. Extensive and expensive safety measures are needed. Another difficulty with steam is that a pressure difference is needed to remove condensate from inside the thermo roll. High rotation speed and large roll size make the discharge of condensate difficult. Because of the condensate problem, 140 °C is the lowest reasonable temperature target with steam. One more problem with steam is that it cannot be used for cooling a thermo roll.

Organic heat carriers are used to avoid the disadvantages of hot water and steam. Their high boiling point at atmospheric pressure makes "non-pressurised" systems possible. Also, there is no corrosion and scaling tendency. Furthermore, there is no remarkable volume expansion when an organic heat carrier freezes, and thus no risk of breaking heating elements. However, freezing should be avoided.

Organic heat carriers can be divided into two groups: natural and synthetic.

Products derived from natural mineral oils are mixtures of different hydrocarbons. Synthetically produced substances are mainly mixtures of isomers. Mixtures of these two groups are also possible. In general, mineral oil-based thermal oils can be used up to 300 °C, while the highest bulk temperature of synthetic oils is about 350 °C. The density of thermal oil at room temperature is nearly the same as that of water, but at elevated temperature it can be clearly lower, ~0.7 kg/m³. Some synthetic thermal oils are heavier than water and thus represent a risk in a water environment. The specific heat capacity of thermal oils is 1.5...2.5 kJ/(kg °C) and their thermal conductivity is 0.1...0.15 W/(m °C), which are clearly lower than those of water. A typical flow rate of oil is 1...1.5 m/s, which corresponds to a heat transfer coefficient of 2 000...4 000 W/(m² °C).

Thermal oil systems are not entirely trouble-free. One consideration is the toxicity of thermal oils, but the aging of oils is the main operational reason for trouble with these systems. There are two main types of aging: oxidation and cracking. Organic heat carriers react strongly with the oxygen in air. Oxidation increases rapidly if the temperature of oil is over 60 °C. Thus, one design principle is that oil must not get into contact with air if the oil temperature is over about 50 °C. Oxidation increases the molecular weight of hydrocarbons, causing the viscosity of oil to increase, which results in flow problems and formation of stickies on the surfaces of flow channels. Some metals, such as copper, have a catalytic influence on aging, so they are forbidden in thermal oil systems. In cracking, hydrocarbon molecules are cut off because of excess heat. The viscosity of the oil decreases and its flash point drops. Short hydrocarbon molecules are easily attached to the surfaces of flow channels, resembling oxidation. The viscosity and flash point of the oil should be measured at least once a year.

5.5.3 Flow circuits

A thermo roll water heating system includes a thermo roll, a rotary joint, field pipes and hoses and a heating/cooling unit (Figure 117). The unit itself consists of a circulation pump, strainers, a heater, a cooler, an expansion vessel, control valves, safety valves, thermometers and pressure gauges. The flow rate of the centrifugal pump is dependent on the thermo roll design. Every thermo roll has an ideal flow rate and it is calculated by the roll manufacturer.

The heater is a tubular heat exchanger heated by steam. The circulation water flows inside multiple pipe turns, which are inside the outer shell. Steam flows between the pipes and the shell. The cooler is a similar, tubular heat exchanger cooled by cooling water. The diaphragm expansion vessel has an air cushion that allows heat expansion of the system water and it also absorbs pressure pulses. Usually, the unit includes a filling unit that keeps the pressure of the water circulation high enough. The pressure before the pump has to be 1–2 bar higher than the saturated steam pressure at the circulation water temperature to avoid cavitation of the pump. Special attention should be paid to the condensate line. A pressure difference must be maintained over the steam trap after the heater. In practice, the filling-up pressure and the pump head cannot be used above a water temperature of 160 °C. The pressure limit of a rotary joint is about 10 bar.

Direct steam heating of a thermo roll is in principle very simple. Temperature is controlled by an automatic steam valve and condensate is removed by steam traps. This applies if the calender is always running with the same parameters (one paper grade at the same speed, temperature and linear load). In practice, the condensate removal is a compromise. Especially in multi-nip calenders with several thermo rolls condensate removal is a problem, because in the optimum case the thermo rolls should

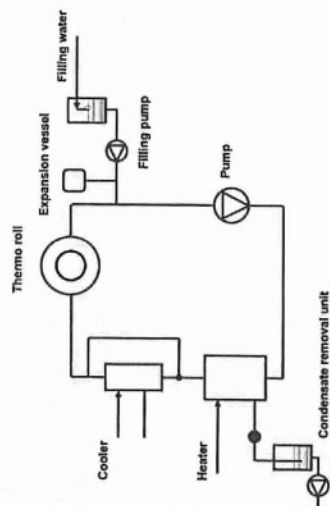


Figure 117. Diagram of steam-heated water system.

be run at different temperatures. Poor condensate removal commonly disturbs the mechanical balance of steam-heated thermo rolls in the calendar.

Thermal oil systems are divided into two main groups: single-circuit and double-circuit systems (Figures 118 and 119). In a single-circuit system, the thermo roll and the heater are in the same oil loop. The system has same components as the water system, but the expansion vessel is not pressurised. The filling and draining vessel also serves as a safety device.

In an emergency, the system oil can be drained into the vessel. Therefore, the vessel is situated in the lowest point of the system. The heater is a tubular heat exchanger heated by steam or an electrical resistor heater. The expansion vessel has space for thermal expansion of the oil and it keeps the suction pressure of the pump positive. The expansion vessel is situated at least one metre higher than the thermo roll. The expansion line is not insulated in order to keep the oil cool. Otherwise, the whole system is insulated.

In a double-circuit system the heater and thermo roll with its cooler have separate oil circuits and pumps, called primary and secondary circuits. There can be several

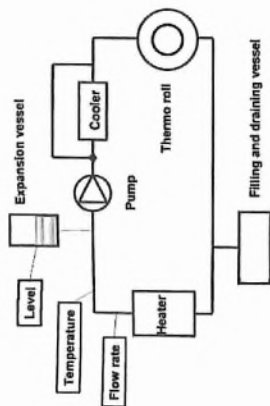


Figure 118. Diagram of single-circuit thermal oil system, including the most important safety measures.

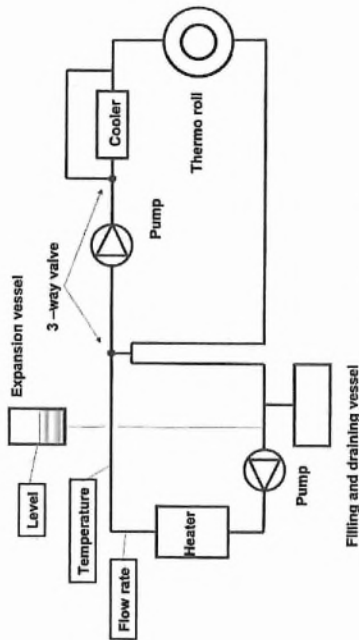


Figure 119. Diagram of double-circuit thermal oil system, including the most important safety measures.

oil thermo rolls after one primary circuit. The temperature of the thermo rolls is controlled by three-way valves between the primary and secondary circuits. To prevent the temperature of thermo rolls from fluctuating the oil temperature difference between the primary and secondary units should be at least 30 °C.

The heater can be of any design but in practice a directly fired heater is the best choice. The directly fired heater consists of a furnace, a burner, a pipe basket for the heat carrier and a flue gas duct and stack. Natural gas, liquid gas, town gas, heavy fuel oil or light fuel oil can be used as fuel. The biggest calendar heating system installed so far is heated by a natural gas burner. The total input power of the burner is over 15 MW and it serves six thermo rolls at the same time. Generally, the flame temperature inside the furnace depends on the fuel and the combustion air ratio and it can be above 2 000 °C.

Because of the complicated combustion reactions it is very difficult to calculate the heat transmission to the heat carrier. Thus, the burner is controlled in many ways. The outgoing oil temperature, the flue gas temperature and the oil temperature difference over the heater are the main parameters. Typically, three thermal oil pipes turn around the furnace and the flow rate as well as temperature of each are measured. A general trend is that the combustion technology continues to develop, while new and cheaper fuels are introduced.

The thermal efficiency of a directly fired heater is about 85 %. By preheating the combustion air with flue gas, the efficiency can be raised to 90 %, but still 10 % of the heat is lost through the stack. CO, CO₂ and NO_x emissions are becoming more and more regulated and low-NO_x burners as well as filtering and other cleaning systems are under active development.

5.6 HEP panels (hydraulic, electric and pneumatic)

Smart manufacturing logistics, short installation and start-up periods as well as ergonomics in design, such as easy maintenance and housekeeping, have been the main drivers for the development of modular designs in calendars.

HEP panels are part of the modular thinking in modern calendar design. Hydraulic, electric and pneumatic components are centralised in cabinets installed in the vicinity of the calendar frame and the actuators. A benefit of modular design is that more complete sub-assemblies can be produced before workshop assembly, thus making the supply logistics more efficient. In the workshop assembly phase the aim is to build larger entities of sub-assemblies and thus leave less work to be done on the installation site. Pumps, coolers and filters for each system can be centralised in compact pressure units to be located in the basement area.

Centralising components into HEP panels at the calendar frame and into pressure units in the basement will minimise the amount of field piping and cabling between pressure units and the calendar frame. Industrial design has played a major part in the design of HEP panels and walkways around the panels. Ergonomic factors influencing the work of operators and maintenance personnel have been the main drivers in planning the locations and design of the HEP panels and walkways. Grouping hydraulic, electric and pneumatic components into their own sections facilitates maintenance work and improves accessibility. Clear walkway constructions will increase safety in daily operation.

5.7 Auxiliary equipment

5.7.1 Fly rolls

The purpose of fly rolls in supercalenders and multi-nip calenders is to take the paper web off the roll surface and avoid excessive heating. There have been two different fly roll constructions. A sectional fly roll providing a spreading effect was a common solution in supercalenders and early multi-nip calenders. Separate spools were installed on a stationary shaft of the sectional fly roll. It was possible to adjust the spools and thus change the spreading effect. The sectional design involved speed limitations and resulted in an increased need for bearing maintenance as the production speeds continued to rise. Today, the most common fly roll design in multi-nip calenders is a tubular roll with a steel or composite roll shell (Figure 120). Light-weight composite materials are typically used in high-speed and wider multi-nip calender applications.

Because of the excellent corrosion resistance of composite materials also some off-line calender applications for calendering paper with a high web moisture content, such as release papers, can be run with composite fly rolls. From a maintenance point of view tubular rolls have less wearing components such as bearings and thus require less maintenance than sectional fly rolls.

Figure 120. Typical construction of guide roll from composite material.



5.7.2 Spreader rolls

Spreader rolls are curved rolls that have a curved shape, stationary support shaft, and short shell sections that rotate around the shaft. Sections have couplings and seals at the ends to allow the roll to rotate as one roll and prevent grease from the bearings to contaminate the web. The surface of the rolls can be plain steel, aluminium or rubber. The metallic surfaces can also be provided with an air removal groove to ensure stable operation at high speeds. The amount of bow in the curve depends on the width of the roll, wrapping angle of the web on the roll, paper grade, and position of the roll. There are also rolls with an adjustable bow for operating under changing conditions. Spreader rolls are used before the first nip in multi-roll machine calenders, supercalenders, and soft calenders. In soft calenders, spreader rolls are commonly used before all nips. In some supercalenders and multi-nip calenders, spreader rolls are used in the 3-4 position to ensure adequate spreading effect. In off-line calenders, spreader rolls are also used at the windup to prevent reel wrinkles.

5.7.3 Paper guide rolls

The purpose of guide rolls is to support the paper web as it travels through the paper machine. Guide rolls have a tubular construction and the roll shell is typically made from a composite material (Figure 120) or steel. In high-speed applications or in tension measurement positions the shell is typically made from a composite material. A steel shell is generally used in narrow or low-speed applications. A light-weight composite material reduces the unbalance forces during rotation, ensuring smooth running. In tension measurement positions, the light roll weight and lower unbalance forces allow more accurate tension measurement. Guide rolls and fly rolls can be covered with different materials. The most common cover of composite rolls is an anti-static cover preventing static electricity.

5.7.4 Cooling rolls

Cooling rolls are typically placed just before the reeler. The purpose of the cooling cylinders is to lower the paper web's temperature before reeling and thus avoid the negative effects of a too warm paper web, such as colour changes. The construction of the cooling roll can be similar to that of dryer cylinders, except that the cooling is provided by water. A disadvantage of this construction is poor heat conduction from cooling water to paper web. Modern cooling cylinders are designed with a double shell, where water circulates between the two shells. Double-shell cooling cylinders are more effective because of the thinner outer shell and turbulent water flow, resulting in better heat conduction from cooling water to paper web. The cooling roll's surface can be grooved or smooth. In high web speed applications the cooling effect is usually improved by grooving the cylinder surface. Without grooving, an air film would be generated between the paper web and cylinder surface. This would reduce the heat conduction significantly. Cooling water can be removed from the same end as it is fed in by using two-way rotary joints. It is also possible to have the inlet and outlet separately on each side of the machine by using one-way rotary joints.

5.7.5 Doctors

Doctors keep the calender roll surface clean and prevent accumulation of dirt which could lead to poor paper quality. Generally, doctors are more commonly used for hard thermo roll surfaces but less for soft polymer-covered roll surfaces. Depending on the calendering process, also polymer covered rolls may be fitted with doctors. Calenders for some paper grades, such as SC papers, are typically equipped with doctors for both thermo and polymer rolls.

There are several doctor beam constructions and doctor blade materials in the market. The doctor beam usually has a closed, round, oval or polygonal cross section. The most common material of doctor beams is steel but composite materials such as carbon fibre have become more common. Depending on the application, doctor beams can be heated to prevent condensation and formation of droplets. The doctor beam can be heated with circulating steam, electricity or circulating warm air.

Doctor blade materials are selected based on the roll surface material, temperature and calendering process. For most of the cases, carbon fibre blades can provide a

sufficient cleaning effect. Sticky and harder particles are more efficiently removed from soft roll covers by steel blades. There are several different blade materials and makes.

5.7.6 Trim cutters

Trim cutters are used to cut off the uneven or thick edge of the paper web before calendering and reeling. Trim cutters include mechanical blade cutters and high-pressure water-jet cutters. Mechanical blade cutters are designed according to the same principle as the web slitters in winders. Two rotating cutting blades are brought into contact with each other and the paper is cut at crossing point of the blades. In high-pressure water-jet cutting a continuous water jet cuts through the paper web. In high web speed applications, water-jet cutting is less sensitive to cutter-related brakes as there is no mechanical contact, though for heavier paper grades mechanical trim cutters can provide a more reliable cutting result. As the service lifetime of pressure units has increased and nozzle technology has continued to develop, the high-pressure water jet has become more common. The mechanical trim cutter still offers advantages in cutting heavier paper and board grades and also requires a lower investment cost.

5.7.7 Web break photocells

Web brake detection is an essential part of a modern calender roll protection system. Polymer-covered rolls are sensitive to hot thermal peaks and sudden mechanical loading. Fast detection of web breaks will save the polymer covers and prevent any paper from wrapping around the roll. Web break photocells are typically installed in pairs on both sides, before and after the calender. Modern multi-nip calenders incorporate one to three pairs of photocells in the roll stack area. Most commonly, the operating principle of web break photocells is based on reflection. Photocells transmit light to the paper web and light is reflected back to the photocells by the paper. If no reflection is detected, a web brake signal is activated. The web brake signals are usually hardwired to maximise reliability and to ensure a fast response. Based on the web brake signal, calender nips will open and the web cutting device will be activated to ensure that no more paper is fed into the calender stack area.

5.7.8 Web cutting devices

The purpose of the web cutting device is to cut the paper web when the web brake signal is received and thus protect the roll covers and roll stack, as the paper may wrap around the rotating roll. The web cutting device is usually a mechanical blade cutter with a full-width serrated blade. Pneumatic actuators are supported by a full-width cross beam and the cutting blade is connected to actuators. The number of mechanical web cutting devices depends on the calender application and machine layout. In addition to mechanical blade cutters, there are web cutters powered by compressed air. Compressed air is led from pressure vessels through nozzles to paper web.

5.7.9 Vibration monitoring systems

Vibration monitoring systems are used to collect information on the running condition of the calender stack. Based on the information provided by the vibration monitoring

system, the condition of nip rolls can be determined and decisions made, for example, concerning a roll change. It is also possible to detect increased nip vibration and barring, and to control the running parameters accordingly. More sophisticated vibration monitoring systems have been developed and connected to actuators such as a roll off-set device to avoid barring in the calender stack. Metso has introduced an on-line monitoring and control system for its OptiLoad calenders to measure and control the vibration levels during calendering. An automated system controls the roll off-set device and moves the centre line of a nip roll if elevated vibration levels are detected. The vibration monitoring system is usually integrated into the condition monitoring system.

5.7.10 Roll off-set devices

Roll off-set devices were developed to prevent nip vibration in the calender stack. The phenomenon itself is known from earlier hard-nip machine calenders, where the hard rolls with nip contact started to vibrate — a phenomenon called barring. Some on-line multi-nip calenders were found to have the same tendency for nip vibration. In on-line processes, the same calendering parameters, such as speed and linear load, are generally used for long periods of time. In some cases, using the same calendering parameters was found to cause slow deformation of soft-covered polymer rolls, gradually resulting in nip vibration. Roll off-set devices were developed to prevent and lower the nip vibration by deactivating the vibration caused by the rotation of a deformed soft-covered roll. The roll off-set device moves the roll from the centre line of the roll stack. In this way, the location of the nip contact in the roll's circumference can be altered, deactivating the vibration mechanism.

5.7.11 Lifting platform

Lifting platforms are used in supercalenders and multi-nip calenders to facilitate maintenance of the roll stack. Lifting platforms are typically situated at the back and front of the roll stack. Lifting platforms were used for manual tail threading in supercalenders and the first off-line multi-nip calender units. The tail was fed into the calender nips from the platforms on both sides of the stack. Today, as tail threading is automated with rope loops, lifting platforms are mainly used for local cleaning of the roll stack and naturally for roll change procedures. There have been two common lifting mechanisms for lifting platforms: hydraulic and electro-mechanical. The most common lifting mechanism today is the electro-mechanical one, with a chain or wire loop driven by an electric motor. Lifting platforms are equipped with safety devices, such as a safety bottom to detect obstacles on the underside of the platform, and safety fences for personnel on board.

5.7.12 WIS (Web Inspection System)

Web inspection systems are used to detect and track any runnability or process-related problems. WIS systems are generally based on the use of high-speed cameras placed in critical locations of the paper machine line and the use of a data logger. High-speed cameras record a visual image of paper web in specific locations. Visual data are stored in large-capacity data loggers where from which the data can be retrieved for analysis

and trouble-shooting. A system integrated with the web brake automation system is usually included for more accurate analysis and tracking. The WIS system makes it possible to detect holes, markings, wrinkles, streaks etc. in the paper web and to track the likely cause of the problem.

5.8 Unwind and windup

The off-line calender operates as a batch process, one parent roll at a time. The unwind unwinds the paper web from the parent roll to the calendaring process. The windup winds the calendared paper back into parent rolls for further processing, typically winders, in the production line. In their simplest form, the unwind and windup are operated manually. To maximise capacity with a quicker parent roll change sequence, to reduce operator work and to make handling of large parent rolls and reel spools repeatable and gentle, automated parent roll change equipment has been increasingly introduced in the mills.

5.8.1 Unwind

The unwind of an off-line calender consists of an unwind station (Figure 121), containing an unwind stand with hydraulically operated parent roll locking devices and devices for removing the empty reel spool.

The unwind stand is typically equipped with operating devices for cross-machine oscillation, which can also be used to centre the paper web. A brake generator is connected to the parent roll at the unwind station through a reduction drive and gear clutch. The brake generator controls unwind web tension.

To prepare the unwind station for the next parent roll, the empty reel spool is disengaged from the brake generator and unlocked from the unwind stand to roll freely to the return rail pick-up station. After this, the next parent roll is brought by crane to the unwind stand, locked and the gear clutch is engaged. The web can be unwound from either the top or bottom side of the parent roll, depending on which side of the paper needs to be calendared first. Crane operations related to the full parent roll and the empty reel spool trans-

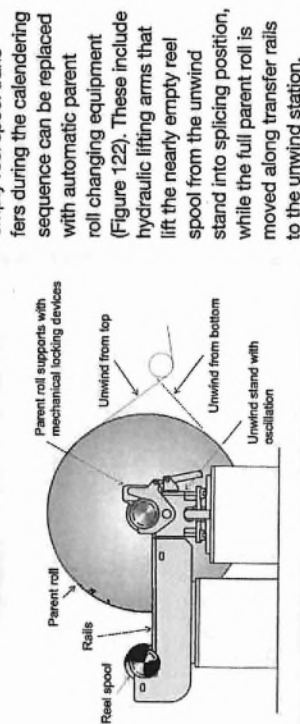


Figure 121. Unwind station.

a wedge-like tail on the parent roll surface edge. To minimise calender downtime this is typically done before the parent roll is brought to the unwind stand. Threading takes place semi-automatically by securing the end of the tail to the threading belt or rope, which follows the web geometry and takes the tail at crawling speed (15–50 m/min) to the windup, where the tail is cut and led around an empty reel spool manually or by using for example a cutting knife or an air jet.

Threading in every parent roll change can be avoided by automatically splicing the full width web of the next parent roll to the end of a nearly empty parent roll, this is done at crawling speed (Figure 123). In this procedure, a splice is prepared beforehand on the full parent roll surface using double-sided tape. The automatic sequence starts once the parent roll being unwound is nearly empty, and the calender decelerates to crawling speed. The brake generator is disconnected. Lifting arms raise the nearly empty parent roll to the splicing position. During this time, web tension is maintained with a mechanical brake in the lifting arms.

The next parent roll is brought and locked to the unwind station, the brake generator is connected, and the new parent roll is accelerated to the speed of the emptying parent roll. To complete the splice the unwinding web is pressed onto the splice tape on the next parent roll by using a splicing brush or roll. A brush is a more robust splicing nip, e.g. in cases where the roll diameter profile is skewed. After the splice is formed a serrated blade cuts the web coming from the emptying parent roll, and the web continues to run from the next parent roll. During splicing, the calender nips are open or relieved to nearly zero load. Once the splice has gone through the stack, the nips are closed and the calender is accelerated to running speed.

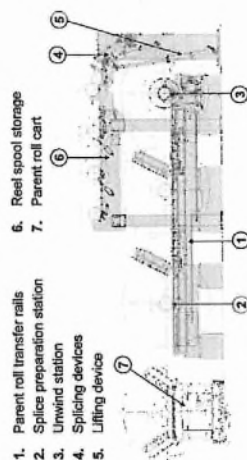


Figure 122. Unwind station with automatic functions.

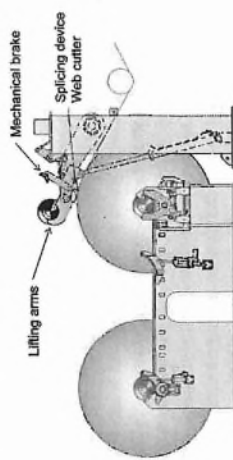


Figure 123. Unwind station equipped with automatic splicing.

5.8.2 Windup

The construction of the windup includes a reel stand, similar to that in the unwind station, to which an empty reel spool is locked, and an electric drive with an engageable gear clutch. The cross-machine oscillation function is used to even out variations in the parent roll structure caused by paper streakiness. In the simplest windup design, a crane brings an empty reel spool to the windup station transfer rails, along which it rolls to the windup station, once the full parent roll has been removed.

The windup also

includes a rider roll (Figure 124) to create the correct roll structure and to reduce air entrainment in the parent roll during winding. In conventional windups, the rider roll is mounted either on hydraulically loaded jointed arms or on carriages on linear guides, in order to follow the increasing diameter of the parent roll as reeling progresses. The web coming from the calender stack is led via a spreader roll to the reeling nip, with the spreader roll preventing web wrinkling. More information on spreader rolls can be found in the section on auxiliary equipment of this chapter.

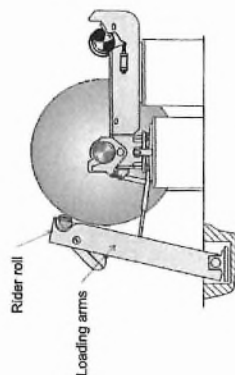


Figure 124. Windup station equipped with basic rider roll device.

In the automatic splicing sequence the calender decelerates to splicing speed. An auxiliary drive in the full parent roll transfer carriage is engaged to the parent roll, after which web tension control is transferred from the main drive to the auxiliary drive. The main drive is disconnected and transfer carriages move the full parent roll to the pick-up station, while constant web tension is maintained.

At the same time, an empty reel spool is brought automatically from the spool storage to the windup station. After the spool has been locked, the drive connected, and the rider roll device has been moved to nip contact, the web is cut by a cutting knife or an air blast or a traversing knife and led around the new reel spool. These events take place simultaneously with the parent roll change and splicing operations at the unwind. Usually, the splice from the unwind is run to the surface of the full parent roll on the windup to ease splice removal. After splicing and the change of parent roll, the calender is accelerated to running speed. The necessary parent roll and reel spool lifting and transfer operations are carried out during the calendering stage to be prepared for the next parent roll change.

The significance of windup control has been emphasized by a rapid increase in parent roll sizes and by the increase in calendering speeds following the development of calender roll polymer covers in the 1990s. Conventionally, the desired parent roll structure has been achieved by controlling the web tension level with the windup

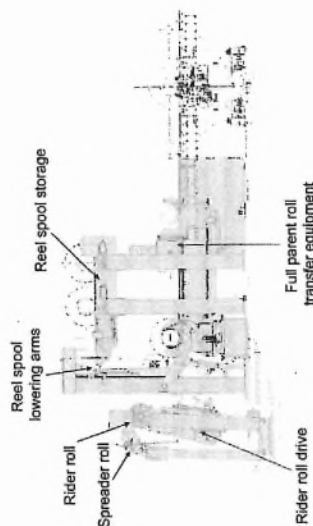


Figure 125. Windup station designed for large parent roll diameters and higher calendering speeds.

centre drive torque and nip load as a function of the parent roll diameter. Hydraulic pressure adjusts the nip load between the rider roll and the parent roll. In new windup designs, the rider roll drive acts as an additional reeling parameter (Figure 125). A drive attached to the rider roll provides braking power, which tightens the parent roll effectively, despite maintaining a lower incoming web tension level compared to the peripheral force. At higher running speeds and with low-air-permeability papers, the rider roll comes equipped with double spiral grooving (a deep, narrow groove and a shallow, wide groove), so that the air trapped in front of the nip can escape in the grooves through the nip both between the web and rider roll as well as on the parent roll side. Too big air bubbles become unstable and start falling into the nip, causing air bubble wrinkling. Eliminating extra air from the parent roll also improves layer-to-layer traction and reduces the risk of layer slippage-based reeling defects. Another windup feature optimises the spreader roll operation as the spreader has a rectangular joint geometry, which maintains a constant web angle over the spreader roll. Examples of the benefits of automation are the main unwind and windup movements in the splicing sequence. They are performed with closed-loop position controls, which allow short splicing times repeatedly despite the larger parent roll and reel spool masses and longer movements.

6 Process control and automation

Following the steadily increasing pressure to reduce life-cycle costs and to improve performance, a considerable number of new technological solutions have been developed for paper machines. Nearly without exception, these new solutions include, not only more, but also markedly more intelligent automation systems. Using computerised systems in manufacturing calendering equipment and calendered products can

be regarded as an established practice and the state of the art in the industry. There are naturally exceptions to this rule, such as small-scale PLC-based applications with rock-bottom manufacturing costs, normally used in rebuilds.

Pressures to maximise the return on investment are forcing papermakers to look for ever-newer means to reduce manufacturing costs. In this effort, focus areas include paper machine speed, raw material costs, end-product moisture, energy, broke generation, and paper machine availability. At the same time, fixed capital is minimised by making products in smaller production runs, for the current order stock only. In practice, the simultaneous optimisation of 10 to 20 parameters – which is quite common today – requires optimisation of paper machine running parameters on a daily basis, and a year-round development programme. And from all this follows a host of challenges for the calender control system. Today's control systems, apart from providing a very effective means of control, are in practice comprehensive computer systems. This development has been instrumental in meeting the above-mentioned challenges.

In designing a control system, for example the possibilities of minimising unscheduled downtime and its duration are taken into account in many different ways. The control system continuously and comprehensively collects paper machine operating data, and, based on these data, automatically generates reports, while offering operators a comprehensive tool for more thorough examination and analysis.

The role of industrial design is today reflected in the machines themselves but also in the design of attractive and user-friendly user interfaces. Using the operators' native language in the user interface makes it much easier to make the right decisions promptly, especially when working under pressure. Bilingual (operator's native language plus English) control rooms have in a very short time acquired an established position in all major new production lines. Accurate and detailed instructions and alarms (in the operator's own language) concerning any deviations support fast and safe resolution of problem situations. In addition, numerous functions integrated into the control system provide operators with important back-up and guidance, for example in start-up situations.

A modern paper machine is capable of producing superior products, but in the market the product's price is the ultimate deciding factor. In examining the profitability of producing calendered paper and paperboard grades, the focus is on the importance of reaching a uniform and high quality level, while fulfilling the strictest product specifications. Since meeting such extra-high quality standards generally requires an extra-high capital input, these same criteria also apply in assessing the functionality of adjusting quality parameters. For example, if the limit value for the CD thickness profile of a product has been set at $2\text{-}\sigma < 1.0$, it does not make much difference whether a value of 0.5 or 0.3 is reached. However, much more important is how fast a value below 1.0 can be reached after the restart of production. The software of modern calenders effectively minimises the amount of quality-, grade change- and start-up broke. This has been achieved by incorporating software that takes into account the special features of calenders and the calendering process into the same control system with the paper machine control system software.

Questions related to the environment and energy are today part of the daily routine of paper machine operation. Energy and water can also be saved in calendering by using modern operating and quality control algorithms. On the other hand, one needs to bear in mind that changes, for example, to reduce energy costs in the paper machine's drying section may impair the end result of calendering and coating.

The international harmonisation of authorities' regulations, machine safety regulations and standards – which is also significant with a view to calender automation systems – is proceeding and, indeed, largely on the basis of European practices. For suppliers of calender control systems this adds pressure to expand the use of diagnostics systems, such as comprehensive I/O diagnostics, and to take into account the need for maintenance work already at the design stage. When examining planned as well as unplanned downtime, one should also remember the need for repair and maintenance of the control system itself.

If the control system is highly complicated, including software produced with several different programming languages and tools, different hardware platforms and numerous links between them, arranging 24/7 maintenance around the year with an acceptable response time becomes prohibitively expensive in practice. Everyday operation or maintenance of a technical device should not require technical competence over and above the basic level normally required in such tasks.

In other words, a paper machine is not only a major investment, but also the focus of great expectations. During its lifecycle, there will generally be numerous rebuilds to improve its performance, availability, capacity utilisation rate, and end-product quality in response to varying requirements. Accordingly, the calender's automation system must be highly flexible, seamlessly forming a functional entity together with other sections of the production line, while at the same time representing a moderate lifecycle cost. For the above and several other reasons, consistently designed open-architecture control systems, flexible service by the supplier in implementing tailor-made systems, and knowledge of the machines and equipment to be controlled are highly appreciated in the industry. Comprehensive project and process know-how are appreciated in particular.

6.1 Machine automation

Today most new calenders and calender rebuilds include a computer-controlled system. Some of these systems use centralised hardware, others decentralised, distributed hardware. Some are based on direct process connections via separate interfaces, others are integrated with the process control system and effectively utilise data-highway and local network technology. However, in process control for the paper industry, there is a strong trend towards distributed control systems with an open architecture. Distributed control systems (DCS) can perform all of the control and operator interface functions traditionally provided by stand-alone, dedicated measurement and control systems^{57,61}.

These technology trends have naturally affected calender automation and hardware solutions. Smaller automation systems, and especially stand-alone rebuild implementations, are often realised with PLC systems. Large calender automation

systems with comprehensive quality measurements and interfaces to millwide information systems are commonly implemented into the DCS systems.

A modern DCS system, as shown in Figure 126, with process-specific control applications can provide several benefits for the user. Centralised operations, improved process performance through a higher level of control, cost-effective digitising of data for use by information systems, and the distribution of risk into smaller modules with higher system uptime and faster repairs are typical benefits. Of all these benefits, the most important are improved process control and improved process performance^{82,83}.

Requirements and methods for calendar control

There are several end-use properties and quality requirements which calendering is expected to achieve. However, these requirements cannot be achieved without appropriate actuators, quality measurements, process control systems and control strategies. Actually, the calendering process is the papermaker's last chance to reduce thickness variations along the length and width of the finished sheet. A smoother sheet results in improved print quality, while more uniform thickness and tension profiles improve the winding process and reduce sheet breaks in printing presses.

One major process requirement is that the web must have good runnability, i.e., that it passes through the process with a minimum of breaks. In addition, the web should have good uniformity in the cross direction (CD), since non-uniformities built-in during poor reeling are usually associated with web breaks. Thus, almost all paper and board is at least slightly hard-nip calendered in order to control overall thickness and to even out cross-direction thickness non-uniformities. Calendering reduces paper thickness and roughness by pressing the sheet between two or more large iron or soft-covered rolls. The high loads produced in a nip between two smooth calendar rolls flatten high spots in the rough sheet by permanently deforming wood fibres on the surface of the sheet, thus reducing the roughness of the sheet⁸⁴.

Paper bulk at the entry into a calendar can vary both in the machine- and cross-machine directions. Machine-direction variations can be reduced in the calendar by altering the average cross-direction load. Cross-machine variations can be reduced by varying the local radius profile, thus changing the local pressure profile.

Nip load and surface temperature of the rolls can be changed selectively across the width of the calendar. They are used to control the CD uniformity of bulk reduction, smoothness and gloss. Moisture content is not usually manipulated in the calendar, but moisture variations in the web entering the calendar, together with temperature variations, can be a major source of profile disturbances⁸⁴.

Controlling the temperature of rolls maintains a specified operating temperature over the width of the roll surface and hence over the web. Temperature control affects localised control to assist in good reel building. Control of temperature is now recommended; 1.5 °C can be achieved by means of circulating fluid, with alternating directions of flow from roll to roll.

Steam showers can be used in calendars as an effective calendering aid. They help to reduce bulk and improve surface properties. They can also be used to adjust

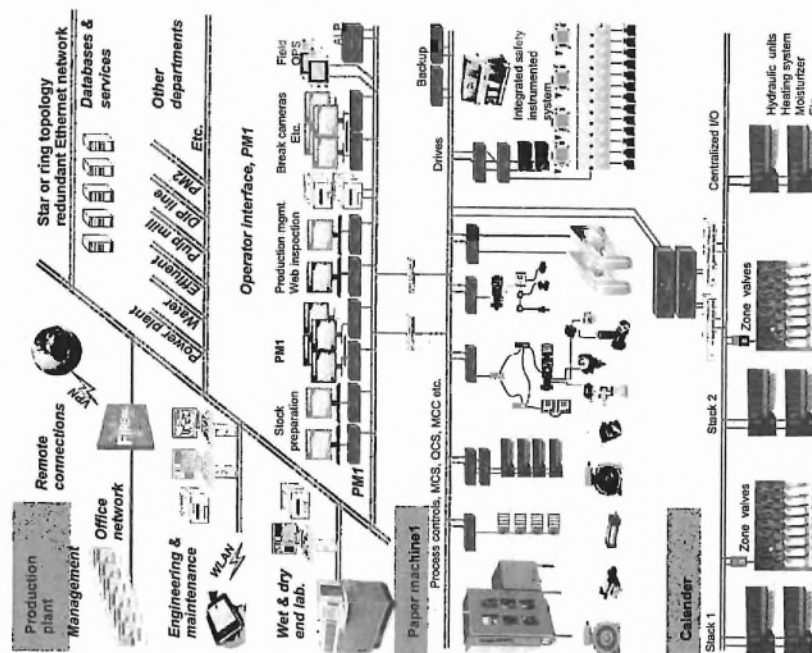


Figure 126. A modern distributed control system.

the two-sidedness of surface properties. Their effectiveness will depend on the initial temperature of the web. A cool web will be able to absorb more steam than a hot web. The cross-machine control of the hard nip calendering operation is traditionally accomplished by selectively heating or cooling one or more of the calender rolls at the desired cross-machine positions. Nowadays, an alternative method is to use zone-controlled CD rolls to accomplish cross-direction control as well as CD-controlled steam showers.

Practically all modern multi-nip calenders are equipped with heated rolls. By heating the web as it passes over the hard rolls, it becomes more pliable and can be calendered with lower nip loads. Modern multi-nip calenders operate with variable-crown rolls in the bottom (king) and top (queen) positions. Now many multi-nip calenders also use zone-controlled rolls to accomplish cross-machine control. Air showers or induction heaters are not generally used. However, steam showers have been used extensively on multi-nip calenders to improve finish and surface-property two-sidedness (smoothness and gloss) for uncoated grades⁴⁵.

Modern on-line soft calendering is designed to achieve the benefits of multi-nip calendering without paying the price. The modern soft calender is usually a single-nip design. Therefore, it consists of a pair of single-nip calenders in series, with roll positions reversed in the second pair. The calendering temperature is limited by the properties of the material used to cover the soft roll. Steam showers are used to improve finish and adjust two-sidedness of the paper. Two-sidedness is somewhat easier to control in on-line soft calenders than in off-line multi-nip calenders, because the load and temperature in each nip can be adjusted independently.

Today, soft calendering technology is directed toward soft temperature-gradient calendering and moisture-gradient calendering. The main idea of temperature-gradient calendering is to change the rheological properties of the fibres only at the surface of the sheet. The surface fibres become hot and pliable while the fibres in the middle of the web stay cold and resilient. The hard rolls can be heated internally with steam to a temperature of approximately 150 °C, or with hot oil or external electrical heaters (radiant or induction) to temperatures of 250 °C. On the other hand, moisture-gradient calendering operates with water sprays or steam showers and hot calender rolls. When water is applied immediately ahead of the nip, the moisture stays on the surface and softens only the surface fibres. With steam showers, water and latent heat are applied to the web. The heat penetrates into the web very quickly and causes an overall bulk reduction, but the moisture stays near the surface and softens only the surface fibres⁴⁶.

Machine controls

The calender's machine controls are lower-level basic controls which take care of the analog and binary I/O functions, binary control of pumps and valves, interlockings, alarms, and several functions of lower-level control loops.

However, competent design and installation of machine controls forms the foundation of the entire calender automation system. The machine controls manage all real-time measurement and control loops, as a part of the total process automation system. Especially in a DCS environment, the machine controls have been designed

to cooperate with more advanced control strategies, to provide an integrated calender automation system.

On the calender, the machine control applications can be grouped according to their main functions, which are related to calender operations and equipment. Machine controls ensure the functionality of the calender in different process and transient phases. A classification of control applications is shown in Table 8.

Table 8. Classification of control applications.

Process functions	Maintaining functions	Supporting functions	Special and recovery functions
Management of quality measurement	Control of linear load	Hydraulic units	Web break detection
Caliper CD/MD control	Control of nip and roll stack	Lubrication	Quick opening of nip and stack
Fast recovery of CD caliper	Control of polymer rolls	Heating and cooling unit	Control of brake system
Gloss CD/MD controls	Control of deflection-compensated top roll	Water unit of moisturiser	Tail cutting
(Porosity/Smoothness CD/MD controls)	Control of deflection-compensated bottom roll	Air unit of moisturiser	Web threading
Moisture CD/MD controls	Control of thermo rolls	Water unit of tail cutter	Speed-up control
Parent roll diameter CD control	Controls of steam boxes	Motor controls	Roll change monitoring
Parent roll hardness CD/MD control	Controls of moisturisers	Control of roll cleaning	Control of lifting device
Multi variable MD controls	Automatic splicing	Roll protection	Auto calibration of actuators of deflection-compensated rolls
	Automatic reel change	Vibration diagnostics	Auto check of moisturiser
	Control of electric drives	Barring prevention	And a number of other
	Edge trimmers	Automatic spool feeding	- machine protection
	Interlockings	Displays_customer lang.	- production protection
	Safety devices	Displays_english	- maintenance applications
		Help and info system	
		Alarms	
		Diagnostic applications	
		History	
		Remote services	

Maintaining functions include the operations that ensure that quality, runnability and productivity requirements can be fulfilled. Interlockings take into account the safety aspects of operations. Supporting functions provide the basis for the maintaining functions. For example, the loading hydraulic system produces pressure levels and flows required by the loading cylinders of the calender, as presented in Figure 127. Special and recovery functions are designed to take care of web break situations and to assist in service and maintenance operations.

Calender Fluid System

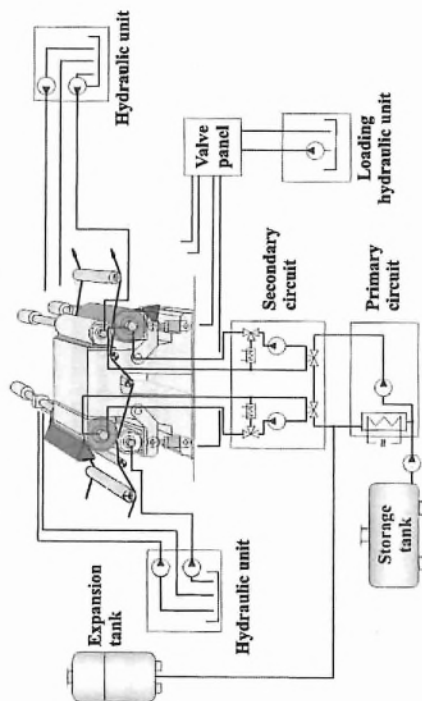


Figure 127. Fluid system for nip control.

Naturally, these operations are not entirely similar for off-line and on-line calenders. Likewise, hard-nip, soft-nip and multi-nip calender applications have distinct differences. However, machine control applications contain several important properties which contribute directly to productivity.⁶⁷

In off-line calendering automatic splicing and reel change are typical applications which have increased calender availability significantly⁶⁸. With a modern automatic reel change system, both the unwind and windup sections are equipped with sequence controls to enable fully automatic machine reel change. The only manual operation is the splice preparation on the unwind stand. A multi-nip calender does not need to be shut down while changing the reel; the system operates at reduced speed during splicing. At the windup, the reel spool is automatically transferred from the waiting station to the windup stand. When this kind of system is in operation, no crane is needed for the actual machine reel change.

6.2 On-line measurements

Continuous on-line measurements are necessary for precise and reliable process control. Because the calender traditionally represents the last opportunity to inspect the finished product, a number of on-line sensors are used to monitor paper quality properties. Typically, sensors measure and control key product variables, including caliper,

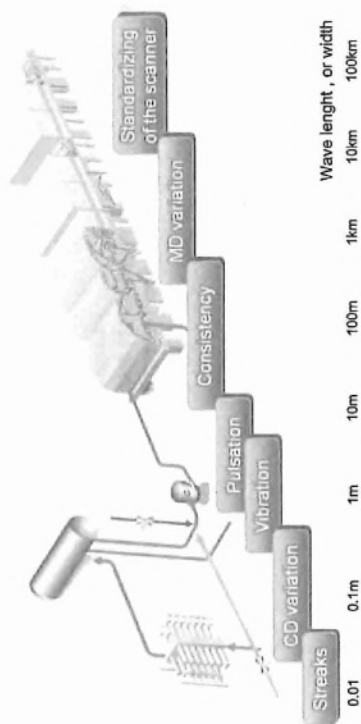


Figure 128. Spectrum analysis, typical disturbing elements.

gloss, moisture, temperature and roll hardness. On-line smoothness and porosity measurements are still being developed.

The development of measurement frames brings new sensor designs into the market from time to time. In addition to laser technology, the most important improvement is related to the way how the measurement itself is implemented. A conventional measurement frame traverses over the paper web at constant speed, which restricts access to process measurement data. State-of-the-art measurement frames are designed for adaptive operation as determined by the operator. As the rate of scanning and the area to be measured can be freely determined, the measuring head can for example, be stopped automatically for a preset time at desired points of the web in order to measure machine-direction variations with high resolution. As a result, more accurate information can be obtained according to need for specific problem area, such as the edges of the web. Spectral analysis based on high-quality measurement data reveals disturbing elements that cause profile defects and helps to guide the development work in this area (Figure 128).

Caliper

Caliper measurement is a common procedure in calendering. It is technically challenging. Figure 129 illustrates differences between measurement methods used, which also affect the internal correlation between these methods. The paper web always brings with it occasional particles and a laminar air flow, whose importance is accentuated especially at higher running speeds. In loading a contacting measuring head a compromise may thus have to be made — mostly with the very thinnest paper grades — between the measurement data noise (too low load) and web break sensitivity (too high load).

Typical laboratory caliper measurement:

- high pressure compresses sheet
- plates ride on the remaining peaks.

Typical contacting online caliper sensor:

- low pressure, very little compression
- buttons ride on the peaks.

Laser on-line caliper sensor:

- no compression
- measures some average sheet surface position.

Minor deviations from the target caliper rarely lead to scrapping of the paper as broke. However, copy paper is a good example of a paper grade with very strict limit values for caliper and its variations. The basic requirement originates from the increased sensitivity to operating disturbances in the paper feed if the caliper of the paper deviates from the optimum, or if the stack of paper sheets is the least skewed.

In practice, the real average caliper of paper does not vary, provided that the process is otherwise stable, and the caliper can easily be adjusted based on laboratory measurements. Contacting on-line measurement may accumulate some copy paper surface size, which is reflected as a step-wise drop in the average caliper trend when the measuring frame is calibrated (standardised) at intervals of 1-2 hours. Between calibrations, a contacting measuring head may erroneously indicate a gradual increase in average caliper. Contamination of the measuring head is of course as such an irritation, but experienced users can take this into account.

Typical caliper sensors

are electromechanical devices that either contact the sheet on one or both sides, or are non-contacting. Contacting caliper measurement is still the most popular option in on-line applications, but the new optical methods are serious new competitors. An example of such a new method is the partly non-contacting laser on-line caliper sensor, in which two proven techniques have been successfully combined (Figure 129). A new system based on the magnetic reluctance principle used in conventional caliper sensors for decades and the

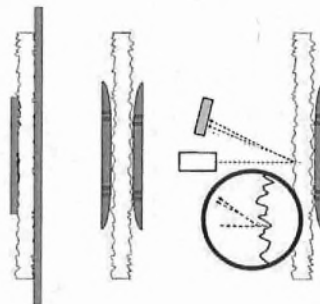


Figure 129. Caliper sensors.

new non-contacting optical technology based on laser triangulation leaves one side of the sheet totally free to move, thus eliminating all pinching forces and the possibility of scratching a coated sheet.

Smoothness

Smoothness sensors are laboratory instruments adapted for use with an on-line scanning mechanism. Using small on-board rollers, the sheet is held at a constant distance from this optical device. Parallel rays of light are projected onto the sheet at a low incident angle (15 degrees). The scattered light beam, which is a function of the degree of surface roughness, is collected by a lens and focused on a linear array of detectors. Smoothness is expressed directly in K.L. units. Sensors typically agree with similar laboratory tests to within at least two K.L. units. The popularity of smoothness sensors stems primarily from their close correlation with other laboratory tests of printability, i.e., Sheffield, Parker Print, and Gardner Gravure.

Gloss

A gloss sensor is also an optical device that determines the surface reflectance of paper. In certain applications, gloss correlates well with laboratory tests of surface and print quality, i.e., ink hold-out. The gloss measurement is made by projecting a high-intensity light onto the sheet at an incident angle of 15 degrees. Reflected light, a function of the degree of gloss, is collected by a lens and focused onto a photosensitive detector. A second light beam, which travels above the sheet on the same detector, is used as a reference to standardise the gloss measurement. Gloss is measured in units, 0 to 100, with on-line sensors being accurate to at least two units.

Moisture

A calender's non-contacting infrared moisture sensors are identical to those used with paper machine and coating processes. Where space is limited, a reflection or single-sided sensor is used. The sensor can monitor or provide indirect gauging of unmeasured variables such as gloss, sheet temperature or smoothness.

Temperature

Scanning and non-contacting temperature sensors use radiant infrared energy to provide a reading of actual sheet temperature. The absolute measurement can warn against the onset of scorching, but sheet temperature will be used more as an indirect measurement of gloss, smoothness, or caliper profiles. The manual or automatic control of steam showers, water sprays, or zone-controlled rolls could be tied directly to a temperature sensor, if gloss, smoothness or caliper sensors are unavailable.

Back tender's friend, machine roll hardness measurement (BTF)

Roll hardness sensors monitor the condition of the finished roll rather than sheet. The hardness sensor is a piezo-electric device mounted within a roller, which is held against the finished roll as it builds. The roll hardness measurement has the inherent advantage of combining several properties, which can affect the mechanical quality

of the roll, i.e., caliper, draw, tension profile and moisture. The present measurement technique also provides an accurate reel diameter profile at operating speeds up to 2 500 m/min.

CD nip load profile of reeling (iRoll)

Reeling is a cumulative process in which paper layers are set on top of each other. Thus, defects such as profile variations may coincide and their effects may be magnified in the paper roll. The proper control of CD profiles, especially caliper, but also the tension profile, is a basic element in successful reeling.

It is sensible to control reeling on the basis of direct reel measurement. Manual measurements are slow and tedious. Thus, on-line measurements have been developed. One is the so-called back tender's friend, which measures reel hardness and reel diameter profiles with an external roller. Another method is pressure measurement of the reeling nip, called iRoll. The nip pressure depends on the contact between the reeling cylinder and the paper roll. Thus, the pressure is determined by roll hardness and roll diameter. There are practically no external devices, which makes iRoll very convenient and easy to use.

The principle of iRoll measurement is shown in Figure 130. The signal indicating the nip pressure is obtained from a pressure-sensitive film. Strips are laminated into the cover structure of the reeling cylinder in spiral form to obtain local pressures in the cross-machine profile. The raw signal is amplified, synchronised and sent to the central unit by a wireless link.

Figure 131 shows a block diagram of iRoll calendar controls. The amplifier at the head of the reeling cylinder sends the raw profile to the central unit. The raw signal is converted to the correct nip pressure values and filtered. The filtered profiles are used to calculate a difference profile between the measured and target nip profiles. Finally, the

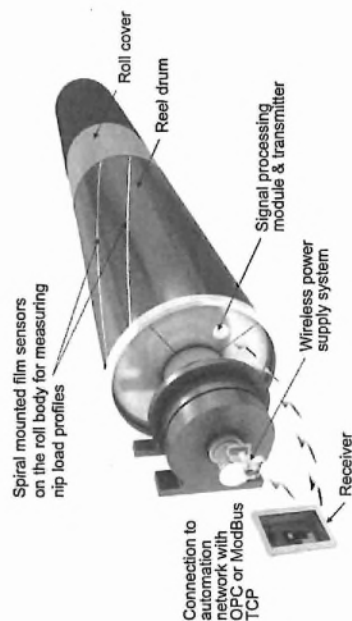


Figure 130. Principle and components of iRoll measurement.

controller uses the difference profile to make the necessary changes in the load profile of the profiling calendar rolls. Another possibility is induction profiling in the calendar stack. Dry weight profiling can also be coupled to iRoll feedback.

In several cases, a suitable iRoll nip pressure profile has been found to reflect a

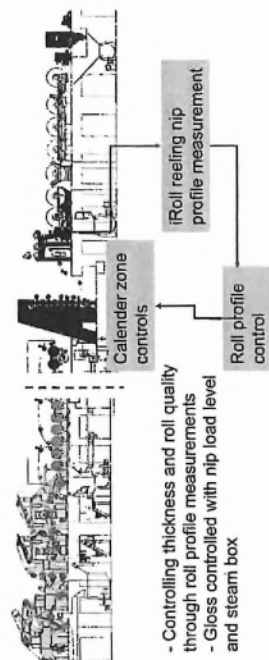


Figure 131. Block diagram of iRoll calendar controls.

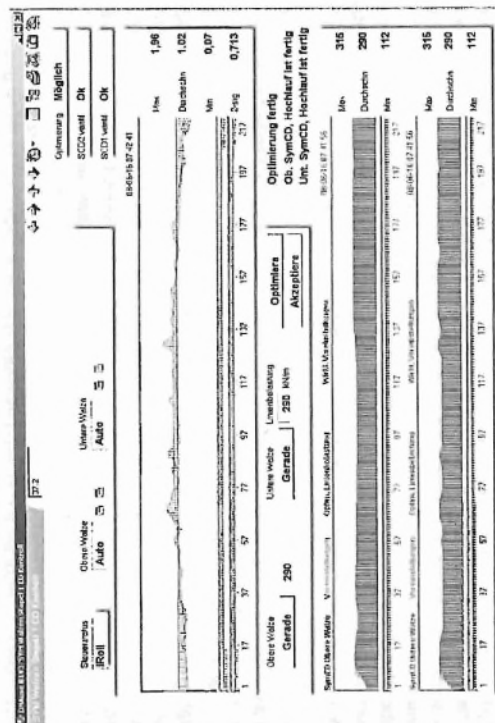


Figure 132. Operator interface of iRoll measurement and control. Smooth slightly curved line in the top graph shows the target iRoll profile and the line around target profile on top shows the measured iRoll profile. The bottom graphs show the corresponding load profiles of profiling calendar rolls.

smoothly decreasing pressure towards the edges of the roll (Figure 132). A small bias at the edges has been optimal for the unwinding tension profile and for the diameter profiles of customer rolls at the winder.

6.3 Quality controls and actuators

Actuators for control of paper surface properties

Thickness, smoothness and gloss are the main quality variables in calendering. Three main technologies for controlling paper cross-direction (CD) thickness are available: zone-controlled rolls, induction heating systems and confined air showers. Induction heating and confined air showers externally heat the roll to increase its diameter which in turn increases the nip load, but high temperatures also affect the CD gloss profile (risk of gloss stripes/streaks). Zone-controlled rolls vary the nip pressure by mechanically deflecting the roll shell.

For controlling paper smoothness and gloss, steam shower technology has an established position. Steam showers improve calendering by heating the sheet and increasing the surface moisture. However, it is not entirely clear which, if either, of these effects dominate. Anyway, the most important performance parameters for cross-directional control, regardless of the actuator technology used, are energy efficiency, control range, response- and recovery time, width of response and robustness^{89,90}.

Table 9. CD actuators.

	Zone-controlled roll	Zone-controlled induction heating	Zone-controlled air showers (heating and cooling)
Investment cost	+	++	+++
Energy efficiency	+++	++	+
Control range	+++	++	+
Response time	+++	+	++
Recovery time	+++	+	++
Robustness	+++	+	+
Total cost, 3 years	+++	++	+

Zone-controlled rolls

Zone-controlled rolls developed rapidly during the 1990s. The swimming roll construction, made it possible to create a uniform distribution of the nip force over the width of the roll, independent of the average nip force level. These rolls allowed general nip force corrections at the edges and in the centre of the roll.

On the other hand, the first zone-controlled rolls offered a tool for CD profile corrections in six to eight zones. However, neither the swimming roll construction nor the original zone-controlled roll provided a possibility for localised high-frequency profile corrections. This was the starting point for the development in the early 1990s. Currently, all major roll suppliers have their own designs for zone-controlled CD rolls.

A new type of zone-controlled CD roll with individually controlled elements is an

appropriate actuator for caliper control (see Figure 133). The average thickness is adjusted with the force applied on the roll journals. The shape of the CD thickness or gloss profile is adjusted with zone control. The centre-to-centre distance of the CD control zone elements is typically 150–250 mm. Because of the stiffness of zone-controlled roll shells, profile shape adjustment can typically be made over a bandwidth of 400–800 mm. An apparent advantage of zone-controlled rolls is that the control actions by hydraulic pressure can be accomplished in a few seconds, providing a fast rate of response and repeatability as well. Figure 134 shows the response effect of control action at a median nip load of 30 kN/m on a soft calender. A change of 20 kN/m and +25 kN/m produced caliper changes of +4 and -6 μ m, respectively⁹¹. See also Section 5.2.1.

Induction heating

Figure 135 illustrates the operating principle of an induction heating system. The system consists of a number of magnetic-induction coils shaped to conform closely to the contour of a calender roll, at a proximity of 3.0–4.5 mm. The coils are encapsulated in a flameproof and isolating resin compound. High-frequency AC current is fed to the coils from a solid-state power unit, one for each coil. An alternating magnetic field produces eddy currents in the iron roll surface, which in turn produces heating. The centre-to-centre distance of the coils is 76.2 mm. However, because transfer of heat in cross direction cannot be prevented, the real response does not differ significantly from the response of a zone-controlled roll. The maximum power usage is 6 kW/coil and conversion efficiencies of over 90 % have been reported⁹².

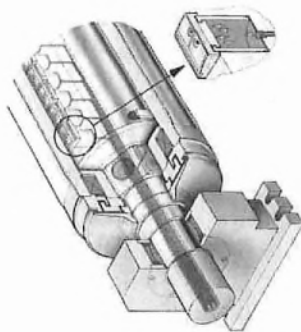


Figure 133. Operating principle of a zone-controlled roll.

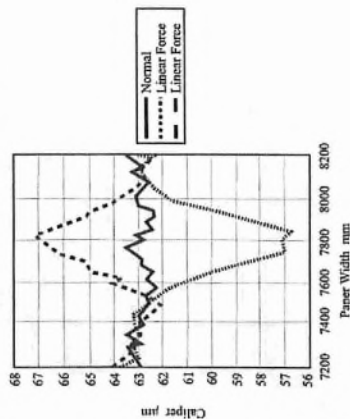


Figure 134. Effect of local nip force corrections on newsprint caliper in a soft-nip calender⁹¹.

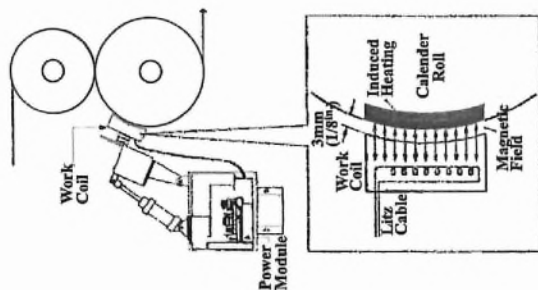
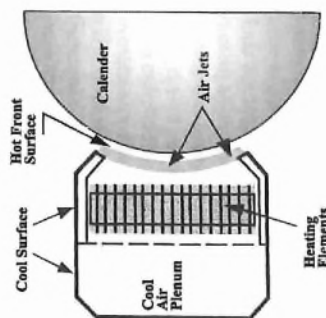
Figure 135. Operating principle of an induction heating system⁸².

Figure 136. Operating principle of an air shower system.

Zone-controlled moisturiser

Moisturisers with spray nozzles are used to rewet the paper as a means to adjust the moisture CD profile. The spray nozzles can usually be controlled individually or in pairs. Rewetting for profiling purposes is usually kept as low as possible. Rewetting is in fact a waste of drying energy, if it is not needed for other reasons, such as curl control.

Moisturisers usually have a zone width from 50 mm to 150 mm. A typical design consists of four rows of nozzles. To avoid streaks, the nozzles have a predetermined spray angle and predetermined distance to the sheet. The spray angle and distance are chosen to ensure an overlapping spray pattern. Thus, each nozzle typically sprays 50 % of the water into neighbouring control zones. This eliminates moisture streaks in the rewetting process.

Air water moisturisers are used to control droplet size and droplet speed over a wide operating range. Droplets are much finer and faster than with pure hydraulic moisturisers. This allows one to apply more water. Air water moisturisers usually have only one nozzle per CD control zone, which is controlled continuously. In addition, the CD spacing of the nozzles is much smaller. In some applications more than 300 nozzles are controlled individually, having a CD distance of 15 mm.

Air water moisturizers are used:

- in sensitive applications where too large droplets have a negative impact on paper quality, e.g. on printability
- in applications where paper is overdried for quality reasons in the drying section, and then rewetted, for example to:
 - improve quality
 - increase moisture-gradient effect (bulk saving)
 - reduce two-sidedness
 - prevent over drying
 - control curl
 - improve web tension CD profiles
 - achieve good moisture CD profiles. See also Section 5.3.

Zone-controlled steam showers

Steam showers are effective in improving the surface finish of many paper grades. Besides improving gloss and smoothness, two-sidedness and final sheet moisture can be affected by the proper placement and use of steam showers. For cross-direction gloss and smoothness profiling, the steam showers are segmented into zones, generally from 150 to 300 mm wide. Profiling is naturally improved with the increased number of cross-direction zones. Each zone is controlled individually. Uniform cross-direction steam distribution and condensate removal are important in preventing steam spitting and dripping. Steam supplied to the showers will typically be less than 60 kPa and will be at a temperature of 115 °C – 125 °C.

Pocket showers are used for uncoated groundwood papers, which are very responsive to added moisture. Steam showers for coated papers cannot be located in the pocket because of the danger of pulling the coating. Instead, the showers are installed outside the sheet run. Some coated grades cannot take any steam at all. The use of steam on coated papers is closely related to coating formulations. See also Section 5.3.

Quality controls

The importance of well-functioning quality controls can also be evaluated by examining the reasons why paper may have to be scrapped as broke on the basis of quality control functions. Such reasons are, for example:

- start-up broke
- grade-change broke
- parent reel structure
- poor web tension profile
- caliper
- poor caliper profile
- total moisture
- poor moisture profile
- gloss (smoothness)
- poor gloss / smoothness profile
- two-sidedness of gloss / smoothness
- brightness (calender blackening)
- opacity

Strongly simplified, quality controls always involve at least one or more measurable variables, which one or more actuators are designed to influence.

In these processes, the measurement itself generally represents the biggest source of error, even if its quality may be entirely acceptable. Measurement noise and other minor inaccuracies related to the measurements can rarely be fully eliminated, though they can be filtered and processed in many ways.

The type of actuator selected for each application always influences the achievable performance level of the control in question. During the past ten years, a steady flow of innovative control algorithms, predictors and boosters for controlling temperature profilers have been published, which undoubtedly are better than their predecessors. However, even the very best algorithm cannot nullify the laws of physics, which is seen in a concrete way for example when examining the time it takes for thickness profiling actuators to recover after a break. In comparison, a light hydraulic roll equipped with an intelligent control can provide net savings in start-up broke amounting to, for example, one million euros at annual level. In estimating the lifecycle cost, it is also worth remembering the importance of the selected control strategy. In defining even the very simplest control loop, one should always consider the objectives set for the control, at least in terms of quality and cost optimisation. So in discussing quality controls, there is always a major economic component involved, which tends to distort the discussion to some extent (in sales talk, for example).

In calender automation systems (as in the entire paper machine automation), quality controls are a completely separate issue. There are MD- and CD-, as well as lower- and higher-level controls, and on top of them a host of special applications. At a general level, modern calender quality controls can be described as adaptive, robust, maintenance-free and energy-sensitive.

The reader is also referred to the section on Process control and automation and Table 8 (Classification of control applications).

Structure

At the present time, MD and CD caliper controls represent standard quality control applications for calenders. Several possible actuators and control strategies are available to accomplish this control^[97, 98-99]. Caliper is unquestionably the most commonly controlled quality variable in calendering.

The development of caliper control systems has been firmly connected to the progress of suitable actuators. Simple, easily understandable and maintenance-free closed control loops have become the *de facto* standard in calender control systems during the past two decades. See also Section 5.2.1.

In connection with some temperature profilers and multi-nip calender controls involving several actuators it may also be justified to use massive upper-level model-based multi-variable controls, which are familiar from paper machine control systems. Their functionality and performance generally relies on an advanced control algorithm, the accuracy of process and actuator modelling, and users' readiness to maintain this level of accuracy.

Management of quality measurements, CD profiles

The CD measurement data provided by the measuring frame, i.e., the profile data, must unconditionally be unfiltered raw data that have not been processed or delayed in any other way. If functions closely related to the control are decentralised, overall control will be lost.

Measured profiles are processed in many ways in the control loop before they are transferred for calculation:

- Profile data are checked and the profile is either accepted for use or discarded in accordance with given criteria (if, for example, half of the profile is missing).
- The handedness of the profile is possibly changed.
- The profile is scaled to calculation resolution.
- Profile edges are possibly modified (for example, missing measurement data may be replaced with other data).
- Significantly deviating measurement data are filtered (individual peaks).
- Noise is filtered by reducing the averages of several profiles.
- Statistical data are produced - Parent roll average profiles / roll/ day/ week/ and month.

In addition, measurement data are as a minimum aligned in relation to the actuator. In this alignment, the calender differs significantly from the rest of the paper machine. When discussing the accuracy of aligning profile actuators, a centimetre-scale accuracy (e.g. 1-5 cm), for example achieved with the pump test, is generally considered sufficient. The impact area of a single zone of calender zone actuators is quite wide, however, compared with the zone itself. From this follows that the con-

trols have a strong tendency to cumulate the impacts of even a very small alignment error, which impairs the result of the profiling control. Still, the correctness of the alignment is very easy to estimate by keeping an eye on the relative stability of the edge-most zones, provided that the control system includes sufficient trend calculation tools for this. In practice, to finalise the alignment the operator will need experimenting and patience (time).

Caliper control

Regardless of where the process is affected, uneven caliper always represents lost benefits. It usually shows up as uneven draws at the reel, winder, printing press, or converting machine and can cause problems in such diverse operations as coating and die-cutting. Variations in sheet caliper can even result in lost production due to sheet breaks. Caliper variations can originate from many sources including uneven grammage, moisture, and temperature.

The MD caliper is controlled by loading or relieving the average CD load.

Hydraulic loading systems respond relatively quickly, so the real-time control of long-wavelength MD caliper or bulk variations is straightforward. Another way is to alter the surface temperature of the calender rolls. However, it is not common to use the roll temperatures to adjust the caliper, because the response time of the temperature change is rather slow. Furthermore, to minimise strength losses in calendering, it is desirable to operate the calender at the maximum temperature, but this will ways some effect on gloss and smoothness.

CD caliper is controlled by using zone-controlled rolls with individually controlled elements, or controlling the CD temperature profile of one or more calender rolls. The roll temperature affects the roll diameter, and thus the nip pressure at any given point. Controlling the CD temperature, therefore, controls the CD distribution load as the zone-controlled rolls.

With soft calenders it is important to keep in mind that satisfactory running of the calender requires a base sheet with significantly better grammage and moisture profiles than with hard-nip stacks. Even with the best of base sheets, local CD caliper control is often required to operate efficiently at high speeds. In addition, any caliper actuator applied to a soft nip will provide only a part of the response range that the same actuator provides in a hard nip. Naturally, the exact response depends on roll cover hardness, grammage, calender load etc.

Fast recovery of CD caliper

It is a well-known fact that after the nip has been closed, the changes in the geometry of the nip rolls disturb CD caliper profiling. The reason is also well known. Each nip roll has its unique way of going from stable open state to stable loading state. A change in the roll's specific internal heat energy flow (temperatures) balance from one state to another state.

Today, most suppliers of caliper profiling actuators have their own solution for shortening the time of recovery from an interruption in profiling (Figure 137).

When assessing the recovery from a break, the most important criterion is of

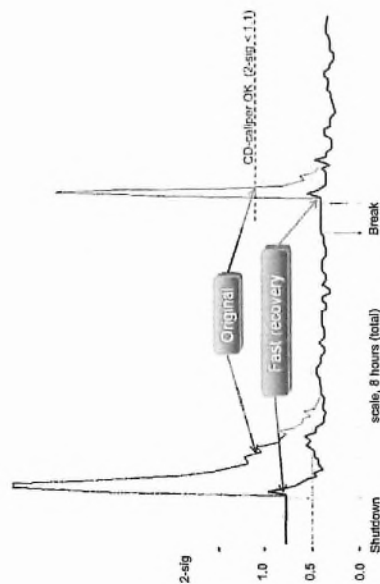


Figure 137. Recovery time.

course how fast the 2-sigma of saleable-quality paper is achieved. In measuring the time for recovery, it may also be necessary to examine the situation preceding the break (Figure 137). For example, are ground nip rolls and other parts of the process in good condition? Have nip rolls run for a prolonged period of time? Are there disturbances in other MD and CD profiles? The state of the process and the level of CD caliper 2-sigma before a break may vary a lot. So, considering the values before and after the break, instead of absolute values, the most relevant and practical method for assessing the recovery time is the following:

The value of CD caliper 2-sigma is lower than 1.5 times the last value of CD caliper 2-sigma before the break.

See also the examples in the figure:

- after shut-down (soft roll changed) $0.78 \times 1.5 = 1.17$
- typical web break $0.40 \times 1.5 = 0.6$
- smoothness, gloss and moisture controls, tension, two-sidedness and roll structure controls.

In contrast to caliper control — in which the hydraulic actuator (pressure) can be used to influence a single quality parameter — moisture and temperature combined with pressure always influence more than one quality parameter. In lower-level CD controls, a traditional closed control loop is generally used in this connection. CD optimisation of several quality parameters, based on specific criteria and within given limits, in practice requires advanced upper-level multi-variable control, and very good knowledge of the process and the equipment.

An example of a steam shower (SC paper):

Smoothness is a function of formation, felt marking, shrinkage and calendering. CD smoothness variation is often caused by the need to build a reel. High-caliper areas must be calendered more, causing higher smoothness. Variations in sheet temperature and moisture, because of their strong influence on the sheet's response to calendering, can also cause smoothness variations.

The average smoothness and gloss are typically controlled by adjusting the average cross-direction operating pressure of steam showers. On a calender, the setpoints for caliper and gloss are rarely changed. The CD profiles of smoothness and gloss can be controlled by controlling the CD application of steam. Furthermore, smoothness and gloss can be controlled independently from caliper. The smoothness effect is very sensitive to the distance between the point of steam application and the last nip. If the steam shower is located near the last nip, there is a minimum effect on caliper and all of the smoothness effect occurs on the side of the sheet to which the steam is applied. On the other hand, if the steam shower is located well ahead of the first nip, the smoothness effect is balanced on both sides of the sheet. Therefore, there is a possibility to affect the sheet's two-sidedness as well as the smoothness and gloss profiles.

Control of reel building

The methods available for controlling the parent roll's structure (Figure 138), which is very important for the runnability on printing presses and winders, have experienced major progress (in the form of iRoll technology) following the introduction of new systems for measuring the nip force in a high-resolution roll nip, and new methods, based on the same technology, for on-line measurement of CD and MD web tension.

In addition to being economically advantageous, these simple measurements have proven reliable and maintenance-free in practice, especially for glossy paper grades, which have represented a challenge for conventional contacting caliper measurement. Even very small variations in thickness cumulate rapidly in the parent roll, so the resolution of the measurement and its correlation with the parent roll's diameter and hardness profiles are excellent. Because this new technique can be used to improve the structure of the parent roll,

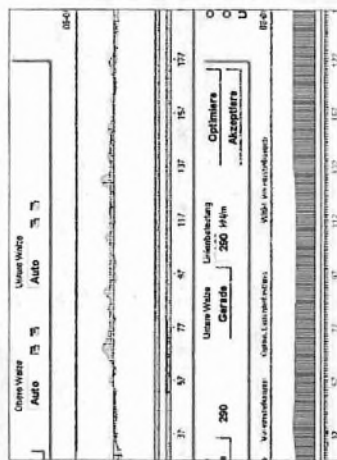


Figure 138. User interface of parent roll profile control system based on reel nip load measurement.

without impairing caliper or gloss profiles, it has rapidly achieved an established position in new machine deliveries. See also Section 6.3.

For example a tension profile that is loose along the edges of the web causes a corresponding tension profile in customer rolls produced on the winder, from which follows that the customer rolls wound from the edges of the parent roll will have a skewed tension profile. For example the measurement of the paper web's high-resolution CD tension profile, integrated into the guide roll preceding the calender, can be used for feedback control of the tension profile. Two alternatives for how this kind of control can be implemented are described in the following.

The first alternative is based on cascade control, in which the actuator influencing the tension profile is a steam box in the press section. The existing moisture profile measurement and control system remains unchanged. The tension profile control is added together with the existing control to the cascade so that the tension profile control is given the possibility to influence the target profile of the moisture profile control within the limits of an allowed window. In this way, the tension profile can be optimised and the moisture profile kept within the limit values.

This kind of cascade control system was installed in a newsprint production line. First, the response of the press section steam box, machine calender SYM roll profiling system and the machine calender's induction profiling system to the tension profile were measured. Providing the best response, the press section steam box was selected to serve as the actuator. The new control system allowed a significant correction of the tension profile within the given control window.

The second alternative for tension profile control allows controlling the tension profile without any moisture error. To this end, a separate moisturising unit must be available before the windup. The guide roll's integrated high-resolution CD web tension profile and CD moisture profile are measured at the same point, before winding. The press section steam box provides a good response to the tension profile, so the tension profile is controlled after the tension profile measurement at the press section steam box, whereas the moisture profile is controlled in the drying section or at the moisturiser ahead of the winder. The moisturising system has a small impact on the tension profile, because even the dried web's tension characteristics change relatively little as a result of moisturising. The moisture profile errors caused by the tension profile control can be compensated with the aid of a moisturising device. It is also possible to use multi-variable control, in which case both actuators can be assigned a certain ratio to the tension profile and moisture control, according to a certain weighting factor.⁹⁸

Automatic grade change

With multi-nip calenders special software may be used to speed up grade changes. The objective of automatic grade change is to transfer the calender control from one grade to another as fast as possible, while minimising off-grade paper and downtime due to breaks. A grade change occurs when the new grade targets have been entered into the control system. These variables usually represent quality variables that define a particular grade. However, they can also be variables that have an effect on the

properties of calendered paper. All grade-specific parameters can be pre-tuned and stored in the recipe database.

Coordinated speed change control

A change in calender speed typically requires changes in linear loads, steam pressures and roll temperatures. Simple feedforward and feedback control might not be adequate in adjusting these variables in response to a speed change because of differences in delays between when these variables affect the sheet. Coordinated speed change control is used to coordinate the response of these variables to the speed change.

Machine speed optimisation control

Maximum production on an off-line calender is achieved by operating at the maximum speed while remaining within quality specifications. The basic principle of machine speed optimisation control is that it helps in attaining maximum speed by monitoring several variables that constrain the speed of the calender. Calender speed can be gradually increased until one of these constraining variables reaches a limit. Once a constraint target has been reached, machine speed optimisation will maintain a constant speed until either a constraint limit is violated, in which case speed is decreased, or until it is considered safe to further increase speed.

Start-up control

The fundamental principle of start-up control is to bring an off-line calender from full stop or from web threading speed up to production speed. The start-up control may perform machine-direction quality control while compensating for speed changes. The start-up control can simultaneously ramp the speed, steam pressure and linear load to

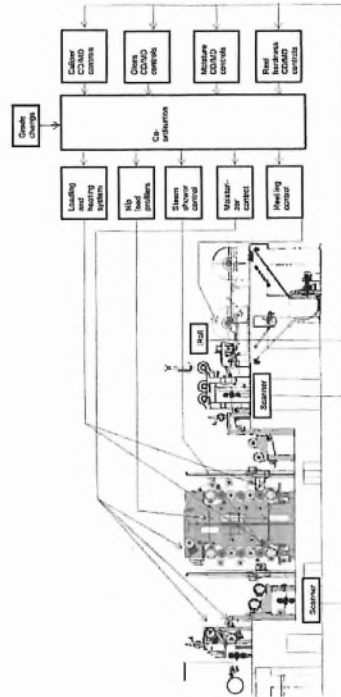


Figure 139. Multi-nip calender control system for SC paper.

minimise the speed's effect on gloss and moisture. The start-up control can use either speed tracking or automatic start-up control. With speed tracking control, the system follows the operator's manual speed changes. With automatic start-up control, the system ramps automatically and performs speed changes in several phases.

7 Runnability of calender

In wide scope runnability can be considered to be specified by anything that affect overall efficiency of production and in this particular case to the production efficiency of calenders. Typically, a major portion of the calender runnability relates to availability of calenders (time efficiency), i.e., planned or un-planned shutdowns and web breaks. A lesser portion relates to material or area efficiency, i.e., trims, sellable paper quality and proper reeling.

7.1 Shutdowns

The bigger and the more complicated calender is in use, the more time is required in different maintenance tasks. Proper choices of used materials and technical solutions decrease the amount of necessary maintenance work.

In maintenance, the basic logic is to prefer planned shutdowns over un-planned ones. The latter come by no warning. Thus, the all preparation work and reservations which reduce the amount of shutdown time are not available.

In calender area, there are several small objects, such as filters, lubrications, doctors, hoses, bearings, valves, nozzles etc. to be checked, cleaned or replaced within certain time intervals. However, in most cases the major factor to adjust shutdown intervals in calenders is the necessary roll grinding interval of soft covered rolls. In traditional supercalenders, wearing and marking of filled rolls may require roll change in daily basis. Modern composite covered rolls are changed in weekly or even in monthly basis due to uneven wearing profile or high frequency vibration (barring).

7.2 Barring

The word barring comes from narrow, typically around 50–100 mm, CD stripes in paper. These bars of different web thicknesses are caused by high frequency vibration of calender rolls. Typical, barring frequencies exist from around 100 Hz up to several hundreds of Hertz.

The most harmful modes of vibration are those which create variation of nip pressure and are self-excited. Under such conditions vibration is heavily amplified and it generates severe barring of calender.

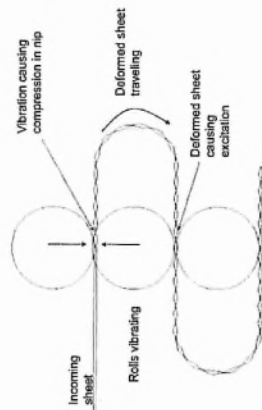


Figure 140. Illustration of regenerative feedback of barring by paper web.

The exitation may come with paper between consecutive calender nips (Figure 140) or with deformation of calender roll (Figure 141).

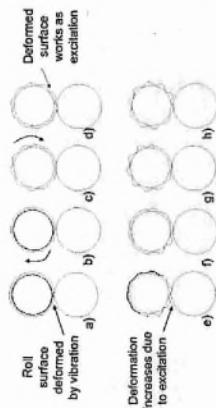


Figure 141. Illustration of regenerative feedback of barring by deformation of calender roll.

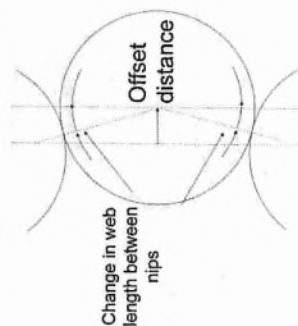


Figure 142. Principle of roll offsetting to dampen barring.

ment is based on measured barring frequency and it is used to unsynchronise vibration modes between calender rolls. Also, fly rolls can be moved to unsynchronise web induced vibration.

There also are other possibilities for passive or active damping of vibrations in calenders. The idea is either to absorb the prevailing vibration energy to a damping element or to change the resonance frequency of calender out of the existing running condition. Due to large structures, successful damping is challenging task.

7.3 Web breaks

In calendering, the applied average web tension is typically around 20 % of the apparent breaking tension of paper, while in press section, the required web tension to exceed forces caused by adhesion and air pressure may reach apparent breaking tension of wet paper. Still, in many cases 70–90 % of the web breaks are seen in dry end of paper machine around calender area.

7.3.1 Simplified view of web breaks

There are two major differences between the wet end and dry end of paper machine to explain large amount of breaks occurring with dry paper. The first is different material properties of paper and the other is different geometry of paper machine.

Elastic modulus of wet paper is around 10 % of dry paper. This, on one hand, means that large draws are required in press section but, on the other hand, a little elastic energy is stored into web. Also, wet paper has a lot of plastic deformation compared to dry paper.

It means that any crack initiation in web is surrounded by a large plastic deformation zone around it. Therefore, fracture energy of wet paper is on the magnitude of dry paper and crack propagation is relatively insensitive to the size of initial defects in web. In dry paper web, already a small defect reduces critical tension a lot.

The differences

of the probability of web breaks in the wet end and dry end of paper machine are illustrated in Figures 143 and 144. A modification of fracture mechanics by Niskanen et al.⁵⁹ is used to estimate critical tension level of web against the size of defect in web. If the critical tension is exceeded an initiation of web break occurs. However, crack propagation across the web does not occur if the stored elastic strain energy does not exceed fracture energy of paper. The amount of available elastic strain energy depends on the length of open draw

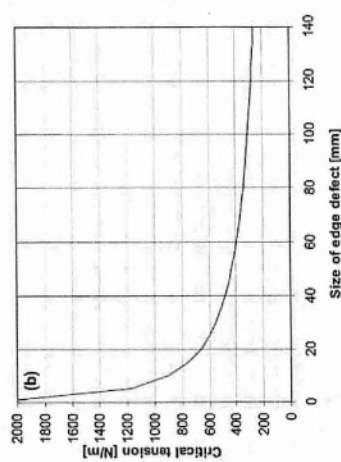
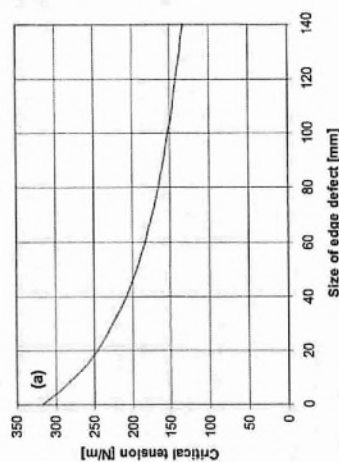


Figure 143. Critical tension against size of edge crack in web according to model of Niskanen et al.⁵⁹ In (a) dry solids content of 55 %, dry weight 40 g/m², elastic modulus 400 Nm/g, fracture energy 9.0 Jm/kg and size of fracture process zone 30 mm are used and the corresponding values in (b) are 92 %, 40 g/m², 4 000 Nm/g, 8.0 Jm/kg and 2.0 mm.

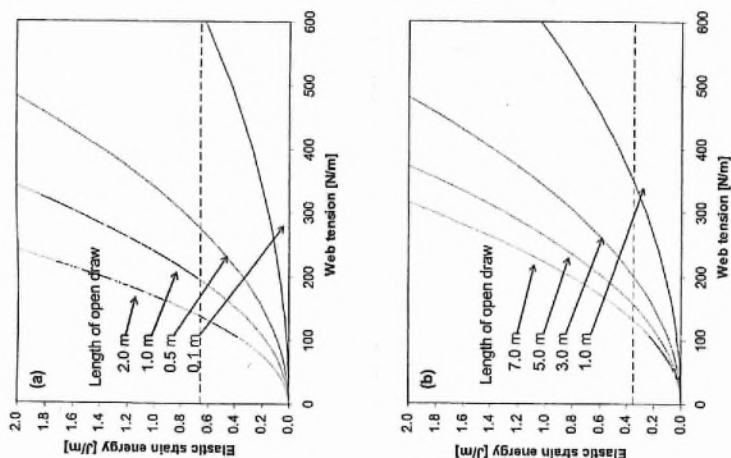


Figure 144. Elastic strain energy against web tension. In (a) dry solids content of 55 %, dry weight 40 g/m² and elastic modulus 400 Nm/g are used and corresponding values in (b) are 92 %, 40 g/m² and 4 000 Nm/g. Dashed lines show level of fracture energy for (a) 9.0 Jm/kg and (b) 8.0 Jm/kg (visco-elasticity of paper is not taken into account, cf. Tanaka).

In dry paper, the initiation of web breaks is virtually not possible without initial defects in the sheet (Figure 143b) or without some local stress concentration. However, because of typical long open draws, the available elastic strain energy is mostly larger than the required energy of crack propagation (Figure 144b). Thus, crack propagation does not stop easily if it starts. E.g., in a 3.0-m open draw with tension level 300 N/m crack propagation would continue out of horizontal scale of Figure 144b. Thus, initial defects easily grow in size to final web break.

7.3.2 Tension control

As demonstrated in Figure 143b, in most cases a web break in calender area starts from a small initial defect in web. This may come from the beginning part of paper machine or from a local stress concentration. In calender area, local stress concentrations exist around nip ends where paper web is run over the nip width to protect soft roll covers from the heat of thermo rolls. Also, shrinkage and other changes in deformation of web induce extra stress around sheet edges.

As the open draws area typically long in calenders, it is important to keep web tension as small as possible to minimize elastic strain energy. On the other hand, too small a tension level leads to excessive flutter of web or to other problems. Thus, a precise control of web tension is important.

A control loop of web tension includes a draw point (nip or gripping roll) and a preceding tension measurement. The controller changes the speed of draw point to reach targeted tension level of web. Tension measurement is read in high frequency and the raw signal is filtered to adjust web tension in second scale.

In modern calenders, there are several consecutive loops of tension control before the calender, between calender stacks and after the calender. These are necessary, because moisture content of paper changes in different phases on calendering. Also, dimension changes of paper in calender nips affect web tension.

In on-line calendering a special moment of tension control is recovery after web breaks or shuts. During tail threading and centering of tail, machine is run under speed control, i.e., proper tensions are achieved by constant speed differences over the open draws. Then, at some point of spreading of the web tension control loops are triggered on. Special procedures with multiple speed and tension targets may be necessary to get calender in stable run.

In off-line calendering, threading and widening of web are done on crawling speed. It allows easier and more simple procedures of tension control. Special moments of tension control come with acceleration and deceleration of calender.

7.3.3 Break detection

Calenders are in many cases equipped with several optical sensors along the machine to detect web breaks. Break signals are used to quickly open calender nips to avoid cover damages by wrinkling of paper and by bundles of paper. Also, to eliminate roll wrappings and other incidents and to make cleaning work easier web is cut into smaller pieces. Blade cutters or air blows are used.

7.3.4 Break cameras and defect sensors

In case the amount of web breaks is large or increase in time, it is important to quickly find proper reasons of breaks to fix the situation. In a big machine, it is difficult or even impossible to make conclusions based on just break detectors and visual observations of breaks. Thus, many paper machines are equipped with a high speed camera system, which is triggered by the web breaks. Around a big calender, up to 20 cameras are required to properly analyse all kinds of web breaks.

Figure 145 shows an example of break camera recordings. A small defect at pick-up nip grows in size along a paper machine and finally ends up to web break at calender stack in a long open draw.

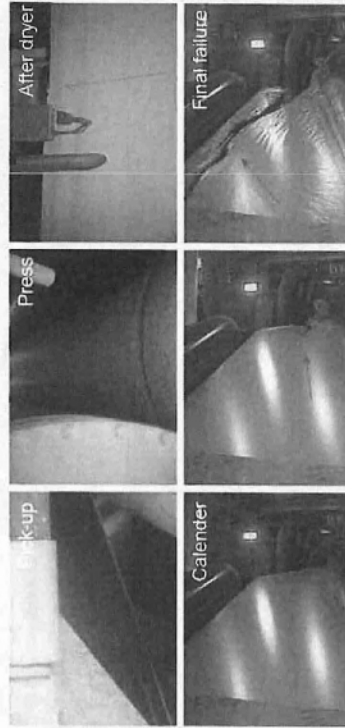


Figure 145. Crack growth and final failure of paper web in different sections of paper machine. Recordings are done with a high speed break camera system.

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