

Papermaking Science and Technology



Pentti Rautiainen

Papermaking Part 3, Finishing

Totally updated

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Papermaking Science and Technology

a book series
covering the latest
technology and
future trends

Book 10

Papermaking Part 3, Finishing

Second Edition

Totally updated version

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Foreword

**PAPERMAKING SCIENCE AND TECHNOLOGY,
SECOND EDITION**

Papermaking Science and Technology book series published by Finnish Paper Engineers' Association, TAPPI and Fapet Oy has been the largest and most comprehensive book series in the field of pulp and paper technology ever since its publishing in 1998—2000. The original 19-part book series does not concentrate solely on the production of pulp, board and paper or the technologies related to that, but covers the entire chemical forest industry from raw materials and economics to printing and converting of paper and board, process control, maintenance, and environmental issues. The books are used globally as course material on B.Sc. and M.Sc. level, in further professional training, and as hand books for professionals in industry and research centres.

Updating of the book series has become necessary as it has been already 10 years since the publication of the first volumes. Regarding the development of trends, EU legislation and technology as well as the overall situation and changes in the field of pulp and paper industry, a vast majority of the books will have to be completely rewritten. Most of the 19 original books will be updated. The first updated books were available in 2007.

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Global forest industry cluster companies need professionals with ever better skills and abilities. Together with forest industry cluster companies, Paper Engineers' Association is strongly participating in the development of training and education in the field of forest products technology. Updating of the Papermaking Science and Technology book series can be seen as a concrete example of this.

Paper Engineers' Association with its publishing company Paperi ja Puu Oy wishes to warmly thank all those, who have personally contributed to the updating of the book series as well as the companies who have supported the achievement financially.

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Preface

Pentti Rautiainen

This book is a fully updated edition of Volume 10, Paper making Part 3, "Finishing" in the Papermaking Science and Technology book series originally published by Fapet Oy in co-operation with the Finnish Paper Engineers' Association and TAPPI.

Since the first edition of this book was published, there have been several major changes in the paper and paperboard industry and in paper finishing technology.

Electronic media has taken market share from publication papers, especially in North America but also in Europe. For the first time in the history of papermaking, we now see a declining trend in paper consumption in major developed markets.

Most new investments in the paper and paperboard industry have been made in China. As a result, China is becoming the world's biggest paper and paperboard producer; it is already biggest in carton boards — bigger than North America and the European Union (EU27).

The technology has also changed.

On-machine multi-nip calendering is today the state of the art in publication papers, and the first wide and fast unit of this kind for coated woodfree was started up recently. The widest on-machine multi-nip calender today is over 10 m wide and some multi-nip calenders have been running at production speeds above 1 800 m/min.

Metal belt calendering has been successful in coated boards and is now being introduced for uncoated woodfree grades.

New wind-ups are almost always centre-driven and capable of producing 4-m diameter parent rolls.

The fastest winders run at production speeds above 3 000 m/min, so a medium-speed paper machine can manage with a single winder. Winders must today produce bigger customer rolls than earlier. The widest printing presses are over 4 m wide, so a single customer roll can weigh about 10 tons.

Roll handling and wrapping technology has been developed to handle big customer rolls and automation and robotics are being used increasingly as a means to cut labour costs.

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Sheet finishing has also developed towards greater automation and higher speeds.

To summarise, paper and board making technology has continued to develop towards ever-wider and faster machinery and equipment during this millennium. Perhaps we shall soon see the end of this path because of limitations related to paper machine manufacturers, paper mills and communities infrastructure.

In addition, because of this technological progress, the capital investment required for building a new paper or board production line is today quite high, so we may be at the beginning of a trend change. The paper and paperboard industry and its suppliers will have to focus more on capital and operating costs rather than on high production capacity.

Moreover, paper and paperboard as a product must meet stricter environmental requirements and resource scarcity, which means that energy, water and raw material efficiency will have to be improved further.

As the editor of this book I would like to thank everyone who has made this book possible. Especially, I would like to thank all the authors for their professional contributions, Ms Laura Ristimäki for her expertise and perseverance during this book project, and my wife Taimi for her patience and support.

Järvenpää, January 2010



Table of Contents

1 **Calendering** **10**

2 **Reeling and winding** **173**

3 **Roll wrapping and handling** **284**

4 **Sheet finishing** **326**

Conversion factors **399**

Index **401**

BILLERUD EXHIBIT 1005-0006

CHAPTER 1

Calendering

1 Introduction 14
1.1 Introduction to calendering 14
1.2 History of calendering 15
1.3 Current trends 17
2 Calendering process 18
2.1 Basic mechanisms in calendering 18
2.2 Calendering parameters 19
2.2.1 Nip pressure 19
2.2.2 Residence time 21
2.2.3 Surface roughness 23
2.3 Plasticity of paper 23
2.3.1 Deformation of polymers 23
2.3.2 Softening of polymers in calendering 25
2.4 Modelling of the calendering process 28
2.4.1 Mathematical and empirical modelling approaches 28
2.4.2 Considerations on calender nip mechanics 29
2.4.3 Modelling of paper compression in calendering 30
2.4.4 Modelling of heat and mass transport in calendering 33
3 Calender types 35
3.1 Hard-nip calender 35
3.1.1 Hard-nip calendering process 36
3.1.2 Hard-nip calender concepts 38
3.2 Soft calender 42
3.2.1 Soft calendering process 42
3.2.2 Soft calender concepts 43
3.3 Supercalender 48

3.4 Multi-nip calender 54
3.4.1 Janus calender 55
3.4.2 OptiLoad calender 57
3.4.3 ProSoft calender 59
3.5 Shoe-nip calender 60
3.6 Metal belt calendering 61
3.7 Special calenders 64
3.7.1 Wet stack 64
3.7.2 Breaker stack 65
3.7.3 Friction calender 66
3.7.4 Other special calenders 66
4 Calendering process application areas 67
4.1 Wood-containing paper grades 67
4.1.1 Newsprint 67
4.1.2 SC paper 70
4.1.3 Coated wood-containing paper grades 72
4.2 Woodfree paper grades 74
4.2.1 Woodfree uncoated papers 74
4.2.2 Woodfree coated papers 76
4.3 Containerboards 79
4.4 Cartonboards 80
4.4.1 Introduction 80
4.4.2 Precalendering before coating 81
4.4.3 Final calendering 82
4.4.4 Uncoated liquid packaging board 83
4.5 Specialty papers: Release and coated label paper 83
4.5.1 Introduction 83
4.5.2 Calendering method 84
5 Calender construction 84
5.1 Calender frames and loading 84
5.1.1 Deflection-compensated rolls in calenders 88
5.1.2 CD profile-control rolls 94
5.1.3 Heated rolls 95
5.1.4 Elastic-covered rolls 99

BILLERUD EXHIBIT 1005-0007

5.2 Profiling Actuators 109
5.2.1 Calender steam box 110
5.2.2 Moisturiser 111
5.2.3 Induction heater 113
5.3 Tail threading in on-line calendering 114
5.3.1 Cutting of the sheet 117
5.3.2 Tail cut-off device 118
5.3.3 Belt conveyors 120
5.3.4 Rope-assisted tail threading 121
5.3.5 Automation 122
5.3.6 Drives 123
5.3.7 Paper quality 123
5.3.8 Ropeless threading 123
5.4 Tail threading equipment in off-line calenders 124
5.5 Heating and cooling systems 125
5.5.1 Heat transfer 125
5.5.2 Heat transfer media 125
5.5.3 Flow circuits 127
5.6 HEP panels (hydraulic, electric and pneumatic) 129
5.7 Auxiliary equipment 130
5.7.1 Fly rolls 130
5.7.2 Spreader rolls 130
5.7.3 Paper guide rolls 131
5.7.4 Cooling rolls 131
5.7.5 Doctors 131
5.7.6 Trim cutters 132
5.7.7 Web break photocells 132
5.7.8 Web cutting devices 132
5.7.9 Vibration monitoring systems 132
5.7.10 Roll off-set devices 133
5.7.11 Lifting platform 133
5.7.12 WIS (Web Inspection System) 133
5.8 Unwind and windup 134
5.8.1 Unwind 134
5.8.2 Windup 136

6 Process control and automation 137
6.1 Machine automation 139
6.2 On-line measurements 144
6.3 Quality controls and actuators 150
7 Runnability of calender 161
7.1 Shutdowns 161
7.2 Barring 161
7.3 Web breaks 162
7.3.1 Simplified view of web breaks 163
7.3.2 Tension control 165
7.3.3 Break detection 165
7.3.4 Break cameras and defect sensors 165
References 167

BILLERUD EXHIBIT 1005-0008

Calendering

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1 Introduction

1.1 Introduction to calendering

Paper is calendered to the degree required by the next process stage, such as coating or printing. Calendering is a unit process where the thickness of paper or board is reduced by applying the compression forces formed between two or multiple rollers or a combination of a belt and a roller. Paper surface properties develop as a result of the thickness reduction.

The calender applies compression forces and improves the mouldability of paper or board by using heat, moisture or other substrates. Calendering can be simplified into a process where the thickness of paper or board is reduced (moulded) by mechanical compression work and by plasticising the paper or board.

The web is compressed mechanically in the calender nips. The compression effect of the nip is often described by the nip pressure and nip length, or the duration of the compression. The plasticising of paper or board is typically expressed in terms of calender control variables, such as the heat of the nip rolls, the moisture of the paper or board before the nip, or the amount of water added during calendering. There is a multitude of good theories that combine the nip compression forces with the thickness reduction after the calender. The plasticising of paper or board is a more demanding phenomenon and thus more difficult to describe in terms of a simple and generally applicable theory.

Other theories concerning calendering and how the paper surface is smoothened in the thickness reduction process focus on

- the copying of the smooth calender roll surfaces to the paper
- the orientation of material in the plane of the paper.

Compared to wet pressing, calendering of paper or paperboard takes place at a low moisture content, so the substrate responds more flexibly to the compression. If permanent changes are aimed at, higher nip pressures are needed.

A typical approach is to divide calenders into two groups: 1) precalenders and 2) final calenders. Precalendering is intended to modify the paper or board for a subsequent papermaking sub- process, such as coating, whereas final calendering is typically carried out to optimise the paper or board properties for printing or converting. The calendering process is designed to achieve a balance between desirable improvements in the paper surface and undesirable changes resulting from the reduction in paper thickness, such as loss of opacity, loss of brightness and increased blackening.

For printing and writing paper grades the final calenders are typically multi-nip calenders which can provide the amount of calendering required for producing a high-quality paper surface for demanding printing applications. In this case, the primary focus is on optimising the surface properties of paper. In precalendering applications the calender is typically a much simpler single-nip machine configuration.

The calender also has an important role in securing good runnability on the paper/board making line. Precalendering can be used to correct paper CD profiles as a means to improve runnability in the next papermaking process. The final calender controls paper CD profiles like the thickness CD profile and tension CD profile, which both have a strong impact on the performance of paper reeling process.

The performance of the calender itself is most strongly affected by the properties of the paper entering the calender, such as paper edge cracks, large holes, moisture level and paper profiles that may cause wrinkling in the calender and result in breaks.

1.2 History of calendering

Treatments designed to improve the surface properties of paper and smoothen the paper web have been in use throughout the history of papermaking. Handsheets were finished after drying by treating them with a smooth stone (agate or pumic stone)[1]. This process improved the smoothness and flatness of the paper sheet. Later on, more uniform finishing of the paper surface was achieved, with less physical work, by introducing water-driven hammers and roll presses that calendered the sheet between very smooth copper plates. This machine, which pressed the plates with the aid of metal rollers with a force of 20 to 30 tons, can be regarded as the first calendering machine. Paper treated with three or four passes through the rollers was called "rolled paper" and paper treated with more passes was called "glazed paper"[2].

In the early 1800s, when the first paper machines started to produce paper in the form of an endless web, the paper was still calendered in the form of sheets after

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the paper machine. In 1830 a calendering machine with rolls for calendering a continous web was patented. At the same time, a new method for grinding calender rolls was patented[3]. Around the mid-1800s, the first calenders were installed on paper machines, gradually eliminating the need for off-line finishing of paper in the form of sheets. These were the first machine calenders, which utilised at least two hard metal rolls to form the calender nip. Soon thereafter, another more effective calendering process, supercalendering, was invented. This made use of alternating soft and hard rolls between which the web was pressed to produce higher gloss and smoothness. The finishing effect was also more uniform than that achieved in machine calendering, as the soft filled rolls evened out the pressure in the nip. The filled rolls were manufactured by using natural fibres (cotton and wool) by pressing a pile of fibre sheets with high pressure and locking the pile around a steel shaft. The filled rolls were easily marked by web defects and web breaks, so they had to be changed relatively often. For this reason, the supercalendeers remained as off-line machines for the next more than 150 years.

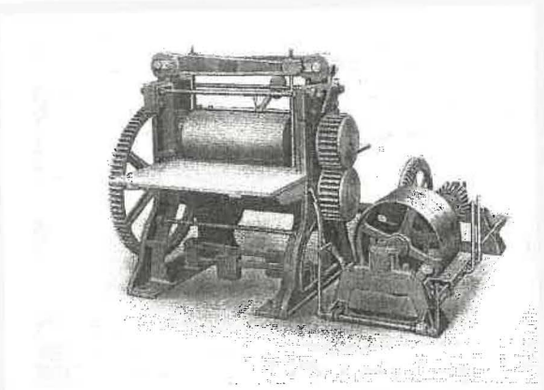


Figure 1. Plate-glazing calender.

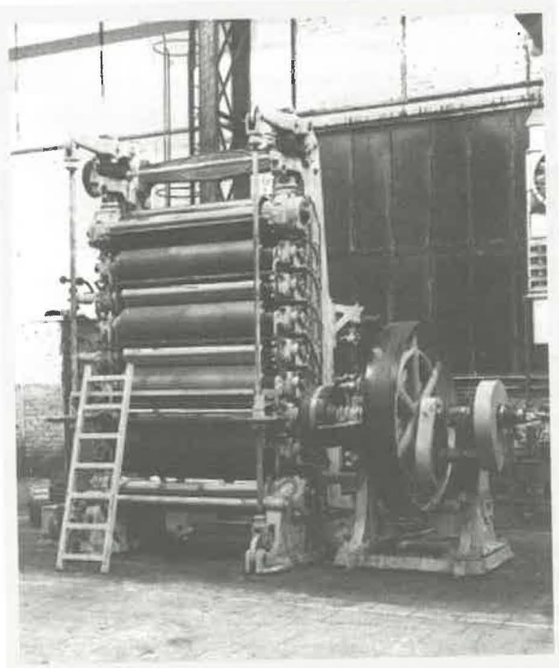


Figure 2. Early supercalender.

Hard-nip machine calenders and filled-roll supercalenders have dominated the calendering of paper and board until the last couple of decades. Wider and faster calendering machines were developed in step with the general development of paper machines and many improvements were made to the calenders and their main components. Deflection-compensated rolls made it possible to use a wide calendering load area without losing profiles or marking the rolls. Heated hard rolls made it possible to increase the calendering process temperature, and many inventions were made to improve the efficiency of the off-line supercalendering process (arrangements for easier roll change, rapid roll separation in web breaks). However, the filled rolls of supercalenders remained a limiting factor for raising the loading level and speed.

Heavier grades could be calendered with higher process temperatures by using soft rubber-based marking-resistant calender covers. This process was called gloss calendering and the introduction of plastic polymer rolls made it possible to use this process also for paper grades which needed higher pressures than rubber covers could cope with. In the early 1980s, these soft calenders were introduced for on-line calendering of matt and semi-glossy papers. In less than twenty years the on-line soft calender became an industry standard for these grades, providing a good combination of an efficient on-line process and a uniform finishing result with a resilient soft nip.

In the 1990s, after better soft covers had been developed, the soft rolls could finally withstand the loads used in supercalenders and thus started to replace the filled rolls. This greatly increased the efficiency of supercalendering as the rolls could be used for several weeks instead of changing and grinding them almost daily as had been the case with filled rolls.

In mid-1990s, multi-nip calenders were introduced. They were first used as off-line calenders with polymer rolls to achieve higher process temperatures and linear pressures than with supercalenders. Soon the web threading and drive arrangements were developed to a level where these calenders could be installed on-line in the paper machine, making them true "on-line supercalenders". Today, most paper grades can be produced using on-line calendering, even on high-speed paper machines.

Another new calendering process was developed in the mid-1990s by combining the extended nip of the paper machine shoe-press with the high temperatures of the soft calenders. These calenders were called shoe calenders, proving true the theory that bulk can be preserved by utilising high process temperature, long dwell time and low pressure in the nip.

On this basis, a totally new extended nip calendering process has been developed in recent years. This metal belt calendering utilises a calendering zone that is one metre long and formed between a heated roll and a heated smooth metal belt. The metal belt calendering produces a more uniform calendering result with a smaller reduction in bulk compared to the shoe calendering process.

1.3 Current trends

Both precalendering and final calendering have undergone major changes in the past 15 to 20 years.

In precalendering the focus has been on enhancing paper / board properties by using an extended or long-nip calender instead of a conventional single-nip hard-nip calender. For coated board these benefits have been achieved by replacing the Yankee cylinder with an enhanced precalendering configuration of this type. This has resulted in increased production and higher bulk.

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In final calendering the trend has been towards all-on-line solutions, especially for printing and writing grades. This trend started with all-on-line SC-B paper production lines, peaking before the millennium change with all-on-line LWC paper production lines. In the new millennium, all-on-line systems for SC-A and WFC paper have been designed and started up. These improvements have resulted in a speed increase from 600–700 m/min in supercalendering to 1 900 m/min in multinip calendering, while maintaining equivalent paper quality. In other words, there has been a dramatic speed increase which has affected the whole calender. The calendering process itself has also been improved through innovations, such as thermal gradient calendering, moisture gradient calendering and metal-belt calendering with extremely long dwell time under high temperature. One common denominator and technology that has enabled this development has been the introduction and development of polymer-covered elastic rolls. The filled-roll technology used in supercalenders limits speed, load and temperature to moderate levels. The development of polymer materials, manufacturing technologies and polymer roll structures enables a nip with low hysteresis and heat generation, paving the way for using higher speeds, loads and temperatures in all calenders. The invention to use equal nip load in all nips of a multi-nip calender has been one of the most important innovations in the development of multi-nip calenders.

2 Calendering process

The main target of calendering is to prepare the surface of paper for the next process phase, such as coating or printing. The desired changes in paper properties are achieved by compressing the paper web between two rolls in a calender nip. The pressure applied in the nip, together with heating, compacts the paper and flattens its surface structure. The changes in the paper are largely permanent. While some targeted paper properties, such as roughness, porosity, absorption and gloss, improve as a result of the densification of paper, the improvements are balanced against reductions in bending stiffness and optical properties (brightness, opacity and blackening).

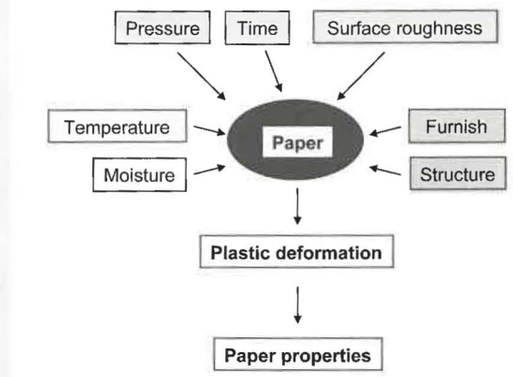


Figure 3. Block diagram of basic calendering parameters.

2.1 Basic mechanisms in calendering

A combination of basic calendering and paper parameters determine the amount of compression of the paper and the final paper properties after calendering (Figure 3). The main calendering parameters affecting the end result are the pressure in the calender nip, the residence time of compression and the roughness of compressive surfaces. The main calendering parameters of paper are the temperature and moisture content in the calender nip, the furnish components and the structure of the sheet (e.g. formation, filler distribution and coating layer).

2.2 Calendering parameters

The combination of calendering parameters varies between typical calender constructions. In practice, adjustable parameters include the type of nip (roll nip, shoe nip or belt nip), roll materials and dimensions, the number of nips, machine speed and linear load.

2.2.1 Nip pressure

The average pressure in a calender nip can be calculated as the external force of the loading system divided by the area of the calender nip. A typical unit for the nip pressure is MPa and the level of maximum pressure in a calender nip may vary from 0.2 MPa in some belt nip applications up to 100 MPa in hard nip calenders. Typical maximum pressures of soft nips vary from 10 MPa to 60 MPa.

Although pressure is a suitable physical parameter to characterise the compression of paper in a calender nip, linear load (external force divided with cross direction width of nip) is mostly used instead. The pragmatic reason for this is that the exact pressure in the nip is not always known, because the machine-direction length of the calender nip varies with roll dimensions, roll materials, external force and paper. In addition, nip pressure is not constant but has a distribution in machine direction (cf. Section 2.4.2). A commonly used unit of linear load is kN/m, with typical linear loads ranging from 10 kN/m up to 600 kN/m.

In principle, the pressure distribution is uniform in the thickness direction of paper and a possible thickness-direction variation in the densification of paper originates only from the properties of paper. In the surface direction of paper, local pressure may vary due to an uneven paper structure or uneven topography of compressive surfaces. In addition, the conformability of compressive calender surfaces affects the surface-direction variation of nip pressure (Figure 4). With hard rolls all local non-uniformities are seen as pressure differences, while the deformation of soft surfaces in the calender nip partly equalises the pressure variations originating from local non-uniform-

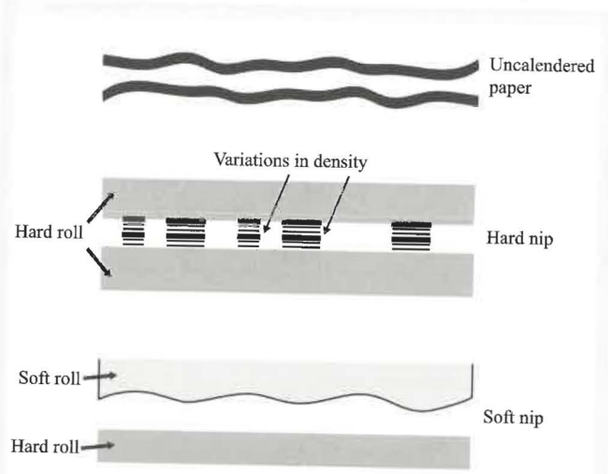


Figure 4. Sheet structure after hard nip calendering and soft calendering.

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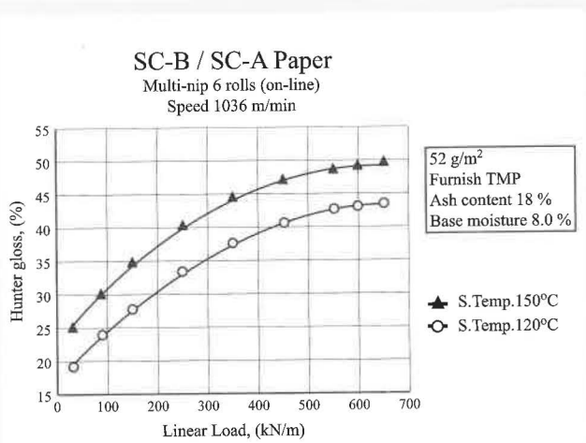


Figure 5. Hunter gloss vs. linear load in a six-roll multi-nip calender.

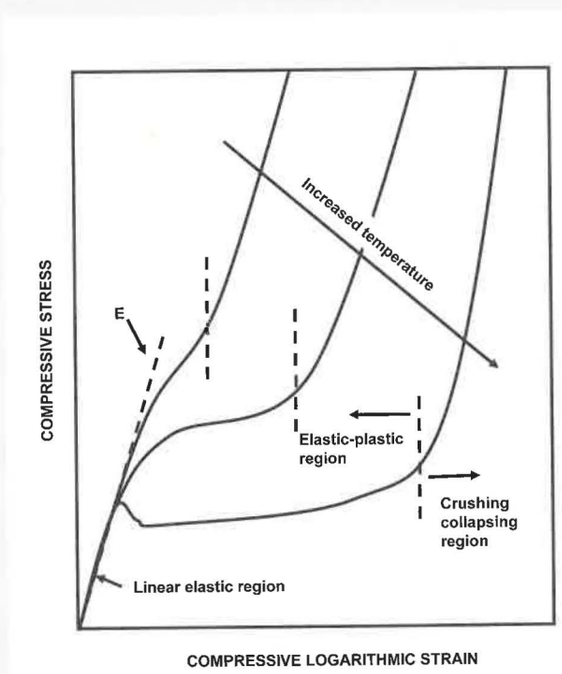


Figure 6. Compressive stress-strain diagram according to Rodal[4].

ities. As a result, hard nip calendering gives uniform thickness but uneven local density of paper. With softer calender rolls, the density of paper becomes more uniform but thickness remains more uneven.

As an average calendering parameter, increased nip pressure simply means a more densified paper structure and greater improvement in targeted paper properties. Figure 5 demonstrates the effect of linear load on the gloss of SC paper in a six-roll multi-nip calender where paper is treated with two hard-soft roll nips per side. Hunter gloss increases from 19–25 % to 43–49 % when the linear load increases from 40 kN/m to 650 kN/m.

Figure 6 demonstrates typical stress-strain behaviour of paper in compression[4]. At a low pressure level the compression is all elastic (no permanent deformation). Then, at a higher pressure in elasto-plastic deformation (above yield stress), part of the compression remains permanent as fibres and inter-fibre pores collapse. Finally, at very high nip pressure, fibres and the fire network start to crush.

The exact yielding pressure of paper is in

many cases difficult to define. A certain low level of plastic deformation (e.g. 0.02 %) can be chosen as a practical limit. In addition, the yielding and crushing pressure may vary widely between different papers. Under certain conditions, a small plastic deformation can be seen already at a very small compression pressure, above 0.5 MPa, but some dry and stiff fibres may require over 50 MPa pressure for permanent deformation. Fibre crushing typically occurs at 50–150 MPa pressure.

2.2.2 Residence time

The behaviour of paper is viscotic in compression. In practice, this means that the compression time affects the amount of plastic deformation in calendering. The typical loading rate-related visco-elasticity does not seem to be very large in the compression of paper, as the loading rate of compression shows only a small change in compression modulus[5]. However, under constant pressure, compression creep is clearly observed, e.g. Popil[6]. Figure 7 shows examples of compression rate and creep tests with SC paper.

Despite the fact that the behaviour of paper is viscotic, most of the effect of the nip residence time comes from the heat flow from the thermo roll to paper. The longer the nip residence time, the deeper the paper is heated, and the more the paper polymers are softened.

The residence time of the calender nip is calculated by dividing the machine-direction nip length by the calender speed. As mentioned

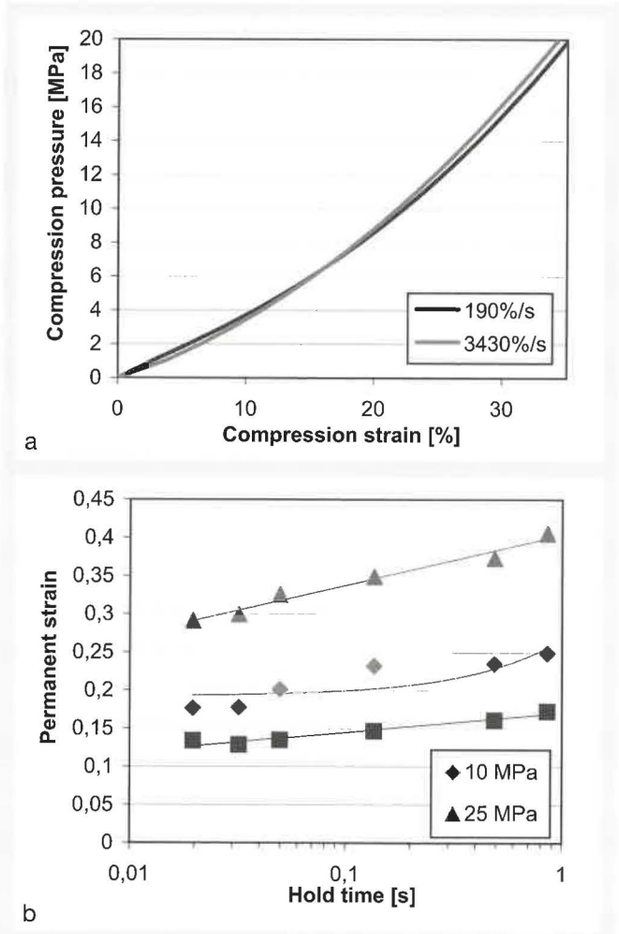


Figure 7. Compression behaviour of SC base paper at room temperature: a) compression pressure vs. compression strain with two different compression rates and b) plastic compression strain vs. nip hold time at constant pressure.

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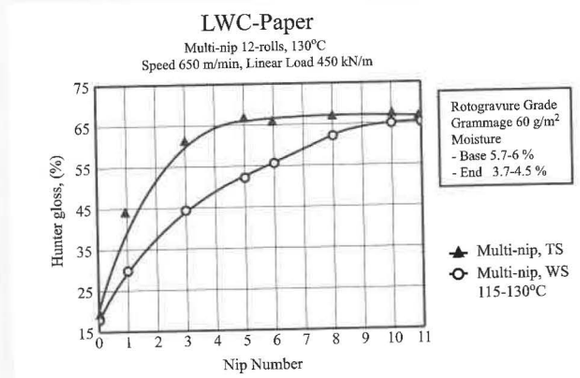


Figure 8. Nip-by-nip gloss development of LWC paper. Linear load 450 kN/m, thermo roll surface temperature 130 °C, and speed 650 m/min; top side of paper first calendered against thermo roll.

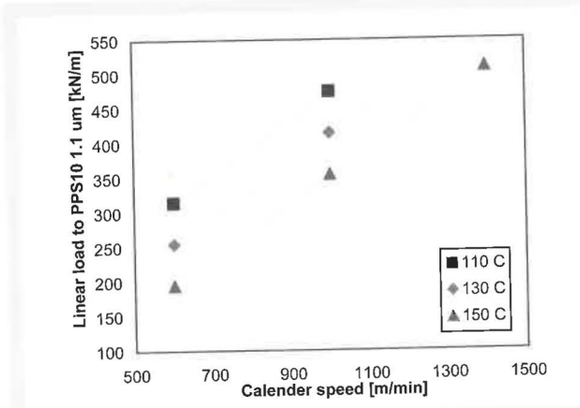


Figure 9. Linear load levels of 10-roll multi-nip calender to reach a PPS-10 level of 1.1 µm vs. calendering speed. Different curves show different temperature levels for thermo roll surfaces.

above (Section 2.2.1), the length of the nip is not always known exactly. However, a good estimate of the length of a typical roll nip is 1–10 mm (hard to soft nips), which means less than 1 ms residence times in a typical calendering process. As the contact resistance of heat flow in the contact between calender roll and paper is high and the thermal conductivity of paper is poor, only the surface of paper reaches the temperature of the compression surfaces if the nip contact time is short. With some belt nip calenders the whole structure of the base sheet can be heated throughout with residence times of 100 ms.

One way to increase the effectiveness of calendering is to use more nips. A small proportion of the effect comes from the viscotic behaviour of paper (creep), but most of the effect comes from the increased heat flow from thermo rolls to paper in consecutive nips. Figure 8 shows the gloss development of LWC paper in a 12-roll multi-nip calender. After each nip, gloss is increased, especially in contact with thermo rolls.

Calender speed is one of the control variables affecting the residence time in the nip. Figure 9 shows the necessary linear loads against calender speed to reach a certain quality of SC paper. A higher nip pressure or thermo roll surface temperature are required to compensate for the increased speed of the calender.

In practice, calender speed has been used as a paper quality control parameter with off-machine calenders. On-machine calenders run at the paper machine's or coating machine's speed and speed is considered as a fixed design parameter of the papermaking line.

2.2.3 Surface roughness

In a calender nip the surface patterns of compressive surfaces are partly replicated to the surface of paper because of local variations in nip pressure. The replication is more complete with a well softened paper surface and with a low roughness level of paper (coated grades). In practice, this means that the roughness of thermo rolls should be low to obtain a high level of gloss. On the other hand, some matte paper grades are produced with rough thermo rolls.

Figure 10 shows a topography image of a compressive thermo roll surface and the corresponding topography of the paper surface. The same details of microtopography can be seen on the roll and on the paper surface.

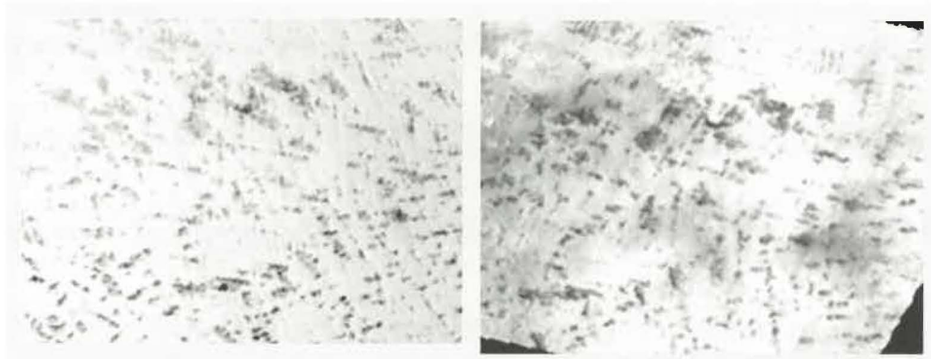


Figure 10. Topography images of compressive thermo roll surface (left) and paper surface (WFC) (right) at the same position (image size is 1.0 x 0.7 mm, view of observation is slightly distorted between the images).

2.3 Plasticity of paper

Because inorganic fillers and pigments have a large elastic modulus in compression, the deformation of paper in the calender nip is mainly determined by the properties of paper polymers. The proportions of different paper polymers depend on the grade and furnish.

Wood material contains three amorphous polymers: lignin, hemicellulose and cellulose. Cellulose also contains some crystalline structures (cf. Volume 3, Forest Products Chemistry, of this book series). In coated grades, the coating layer contains binders, either synthetic amorphous polymers, such as styrene butadiene latex, or natural polymers, such as starches. Starches are also applied with uncoated grades. Other polymers are used for filler retention, pitch control and other special purposes.

2.3.1 Deformation of polymers

Typically, all polymers in paper soften, i.e., with increased temperature and with increased moisture content the elastic modulus decreases and plastic deformation at a certain pressure level increases. The relationship between temperature and elastic deformation of amorphous polymers has a characteristic shape, as presented in Figure 11. Typically, five regions of material behaviour can be distinguished[7].

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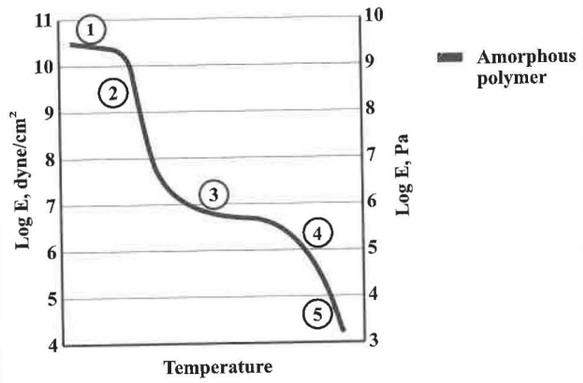


Figure 11. Elastic modulus of an amorphous polymer vs. temperature. The numbers from 1 to 5 correspond to regions called[7] glassy, glass transition, rubbery, rubbery flow and liquid flow regions.

At low temperatures, in glassy region 1 of Figure 11, polymers are mainly elastic and brittle. The elastic modulus is large and changes minimally with temperature. At elevated temperatures, the elastic moduli of polymers decrease quickly in relation to temperature. The region 2 in Figure 11 is called glass transition. In most cases, glass transition is the targeted operation region of calendering because the mouldability of paper in calender nips is greatly improved compared to calendering in the glassy region. On the other hand, the required heat flow from thermo roll to paper is still reasonable.

The transition temperature between regions 1 and 2 varies widely. Some polymers of coating colours start to soften already at room temperature, while dry lignin requires above 150 °C and dry cellulose up to 250 °C temperatures (Figure 12)[8].

Water is a very effective softener of paper polymers. An increased water content decreases the glass transition temperatures considerably[9]. Figure 13 shows the glass transition temperatures of lignin and cellulose-hemicellulose material (carbohydrates) vs. the overall moisture content of TMP paper. Native lignin can absorb only a limited amount of moisture. Thus, the curve of glass transition temperature saturates at around 2 % moisture level to a temperature of 115 °C, as shown in Figure 13. Because of the limited moisture content of lignin mechanical pulps at higher

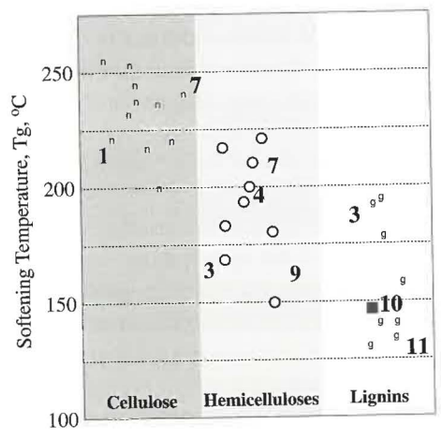


Figure 12. Glass transition temperature between regions 1 and 2 of wood polymers according to Back and Salmen[8].

moisture content show two glass transition temperatures, one for the cellulose-hemicellulose fraction and one for the lignin[9,10].

Above the temperature levels of glass transition, the elastic moduli of amorphous polymers decrease less with temperature (Figure 11). This region is called rubbery plateau[7]. As the temperature is still increased past the rubbery plateau region, the rubbery flow region 4 in Figure 11 is reached. Finally, at still higher temperatures, liquid flow region 5 is reached[7].

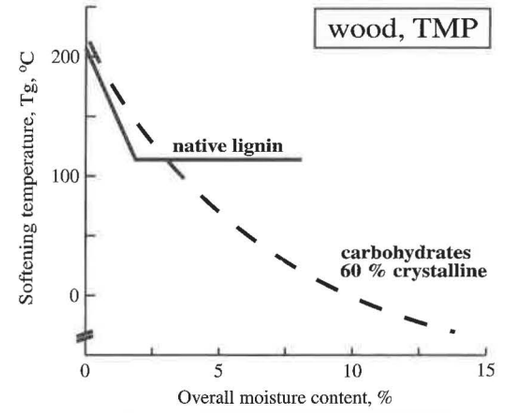


Figure 13. Glass transition temperature between regions 1 and 2 of native lignin and cellulose-hemicellulose material (carbohydrates) of TMP of pulp according to Salmen and Back[9]. Curves for cellulose and hemicellulose are very close to each other, so only one curve is shown.

2.3.2 Softening of polymers in calendering

The machine layout affects the temperature of incoming paper before a calender nip. The temperature can vary from room temperature, which is typical of off-line calendering, up to 100 °C in some on-line calendering applications. The temperature of paper in calender nips can be increased most effectively by increasing the surface temperature of thermo rolls. Steaming of paper immediately ahead of a calender nip can also be used to increase the temperature of paper in calendering.

Increased paper temperature means softer paper polymers. Thus, the same calendering effect can be achieved with a lower mechanical pressure (linear load). Figure 9 above demonstrates this effect for SC paper. A 20 °C increase in the temperature of the thermo roll surface corresponds to a liner load of about 50 kN/m.

The limited heat flow in roll nips with a short residence time is considered to be an advantage in temperature-gradient calendering[11]. The topmost fibres on the paper surface are heated to the temperature of the thermo roll, but because of the poor heat conduction of paper the interior of the web remains cooler. Under proper conditions, the surface fibres of paper are well softened and calendered while the middle part of paper is still glassy and does not densify easily. Thus, the densification of paper is not uniform in the thickess direction of paper. This temperature-gradient calendering is illustrated in Figure 14. In Figure 14a the temperature differences between the thermo roll and web are small, or the residence time in the calender nip can be considered long. In Figure 14b a cold web is in contact with a hot calender roll and the residence time in thecalender nip is short.

Temperature-gradient calendering improves the surface properties of paper (such as gloss) over bulky paper properties (such as air permeance). The optimal cal-

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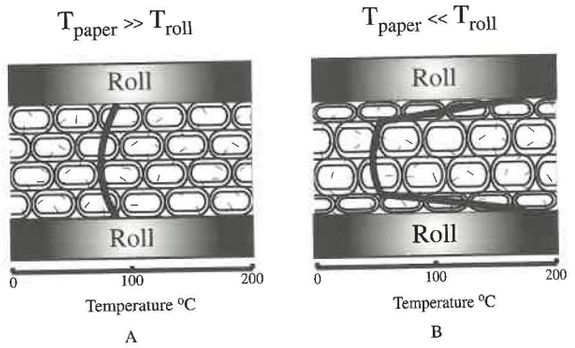


Figure 14. Schematic view of thickness-direction temperature profile and densification profile of paper in a) uniform calendering and b) in temperature-gradient calendering.

adjusted independently of paper moisture. The final moisture level of paper after calendering is generally fixed close to the equilibrium moisture content of paper (4 % – 9 %) at normal atmosphere (RH 50 %, room temperature). Thus, the moisture level before calendering is determined by the drying of paper as it passes through the calender, so it needs to be adjusted in relation to changes in calendering temperature.

The moisture content of paper in calendering is controlled by the preceding drying section and in some cases by using extra moisturisers before the calender. Steaming also affects paper moisture. The extra moisturisers before the calender can be used to create a moisture gradient in paper analogous with the temperature gradient. In addition, steaming creates a weak moisture gradient in paper but in practice the amount of added water is 10–50 times small than the water added by the spray dampeners.

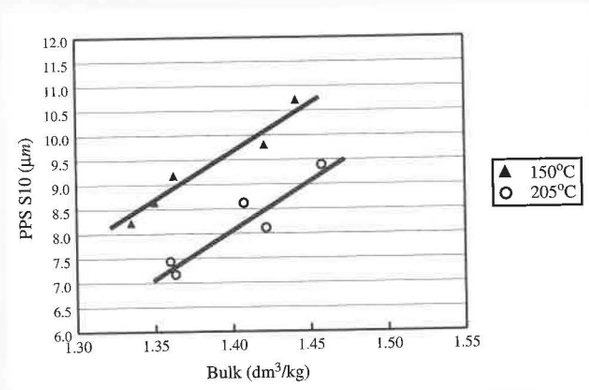


Figure 15. PPS-10 roughness of linerboard vs. bulk after single-nip soft calendering with thermo roll temperature levels 150 °C and 205 °C.

Moisture-gradient calendering gives benefits similar to those of temperature-gradient calendering, i.e., increased surface water of paper in calendering promotes the surface properties of paper, while bulk water promotes bulky paper properties.

The temperature and moisture content of paper are controlled with the aid of the machine layout and actuators. Another important factor in calendering depends on the targeted combination of paper properties.

Figure 15 demonstrates the positive impact of temperature-gradient calendering on the bulk of linerboard. The board was calendered in a single-nip soft calender with two different thermo roll surface temperatures. Increased calender temperature gives a lower roughness at the same bulk level[11].

Typically, calendering temperature cannot be

are the raw materials of paper. The furnish composition has a big effect on the calendering result because of the different softening and collapse characteristics of fibres.

Typical furnishes are based on mixtures of GW (groundwood), PGW (pressure groundwood), TMP (thermomechanical pulp), DIP (deinked pulp) or chemical pulp. In addition, different fillers are added to the furnish. The preceding defibering, refining and bleaching processes are specific for each furnish and paper grade, affecting the structure and densification potential of fibres. TMP furnishes have usually been found to be more difficult to calender than GW or PGW furnishes. Deinked pulp is also easier to densify than virgin-fibre pulp.

Figure 16 demonstrates the importance of furnish components for the final properties of paper after calendering. The DIP content and filler content of TMP-based paper vary. Calendering varies by 100 kN/m but in practice no changes in roughness or blackening are seen. This means that the densification of paper is strong already at a lower linear load. However, if the amount of any of the furnish components is changed with a constant linear load, big changes in paper properties are observed.

The coating colour formulation also affects the plasticity of the coating colour and thus has an effect on the calendering result. The coating colour consists of both pigments and binders. Commonly used pigments are kaolin, calcium carbonate and plastic pigments (cf. Volume 11, Pigment Coating and Surface Sizing of Paper, of this book series). Mineral pigments (kaolin and calcium carbonate) have different shapes. Kaolin particles are more plate-like than sub-round calcium carbonate particles. The shape and size distributions of the particles affect how coating colour is densified in the calender nip. In addition, the glass transition temperature of the plastic pigment affects the calendering result.

Commonly used binders in coating colour include synthetic latexes (for example styrene butadiene latex) and natural binders such as starches (cf. Volume 11, Pigment Coating and Surface Sizing of Paper). The glass transition temperature of SB (styrene-butadiene) latex varies with the type of structure (single vs. multi-component) and has a significant effect on paper and printing properties after the calendering process. Moisture has a minor effect on the glass transition temperature of styrene-butadiene latex, while it has larger effect on starches.

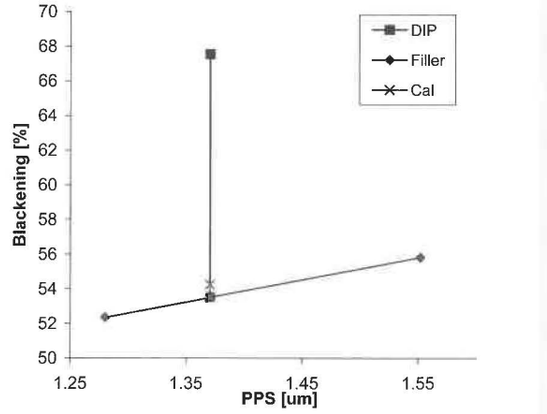


Figure 16. Blackening against PPS of SC paper in a calendering test. Change in DIP content from 0 % to 80 % in TMP base sheet is shown with squares, change in filler content from 20 % to 35 % is shown with diamonds and change in linear load by 100 kN/m is shown with crosses.

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2.4 Modelling of the calendering process

There are several areas in calendering where modelling can contribute useful results. Perhaps the most interesting are the questions whether modelling can help to achieve the quality targets, and how well the model can characterise the process response to control actions. In particular, the question arises as to how the process control parameters need to be set in order to optimise the process and how to obtain the best final product quality. Direct answers to all these questions are not readily available; in fact, there is a growing need to deepen the modelling studies as the process conditions get rougher with increasing productivity demands. A deeper understanding is highly desirable for many reasons; the design and planning of the machinery, as well as process control and optimisation, require quantitative characterisation of relevant process features. Many of the mechanisms in calendering, in particular the transport of heat and moisture within the paper web, can only be studied by modelling, since direct observation here is difficult or impossible.

Like most real-life processes, paper manufacturing and calendering can be considered a dynamic process involving stochastic elements. This kind of process is too complicated to be modelled precisely. Even if we were able to construct a fully detailed model, it would probably be far too complicated for our purposes. Therefore, it is natural to simplify the situation by including in the model only the relevant process features. This is fully justified and advisable since in most cases we wish to limit our scope of interest to the most essential process features. For example, we might be interested only in the average behaviour of the system, and then we could possibly neglect the random variations and consider the process deterministic. As well, we could concentrate on the final equilibrium state only, ignore the dynamics, and consider the process as a static one. In each case, the modeller must decide what kind of modelling is reasonable and consider the justification of every simplifying assumption separately case by case.

2.4.1 Mathematical and empirical modelling approaches

One way to classify different modelling approaches is to consider whether the developed model is based on exact scientific reasoning and common physical laws or on experimental knowledge on process observations. Correspondingly, one then regards the model either mathematical (or physical) or empirical (experimental). It is also possible to construct a so-called semi-empirical model that includes features from both mathematical and empirical models.

The mathematical modelling of processes such as calendering clearly suffers from difficulties in obtaining the necessary input and verification data for the model. In addition, there is a need for advanced expertise in modelling. Modern numerical software has somewhat helped in this respect, but it is vital to realise that even the most sophisticated software does not remove the need for properly understanding the principles behind the model. The model is indeed a description of a physical process, and the software is merely a tool to realise the existing model.

The empirical modelling approach is different compared to mathematical modelling. Instead of setting up the model from well established physical laws, one tries to find the characteristic process behaviour by analysing the collected process data. These

data are collected from the relevant process variables of interest, usually in planned and controlled experiments. One analysis method here is regression analysis, where the idea is to find the relationships between the observed process variables by using statistical methods. Despite of its limitations, empirical modelling seems to be the most common approach in calendering research. Undoubtedly, empirical models have certain advantages, such as the straightforward approach to a rather complicated phenomenon. Also, once the expression is fitted, the model is extremely easy to use.

2.4.2 Considerations on calender nip mechanics

The theory of rolling contact mechanics has been the subject of many theoretical and numerical considerations in calendering[12,13,14]. Many papers have dealt with studying the calendering of various materials, i.e., nonwovens in Reference 15 and paper in References 16 and 17. Extensive reviews of theoretical, numerical, and empirical modeling of paper calendering are contributed in references[16,18,19].

A pioneering work in mechanical effects of calendering is the Hertz contact theory[20], which considers the problem of contacting elastic bodies in the static case. For a cylinder contacting another body, one obtains

$$a\sqrt{\frac{4FR}{\pi E^*}}, \qquad p(x) = p_0\sqrt{\frac{x}{a}}, \qquad p_0\frac{2F}{\pi a} \tag{1}$$

Here a is the half contact length, and the symbols $p(x)$, p_0, and F denote the normal contact pressure distribution, the maximum pressure, and the total compressive load (line load), respectively. Parameters R and E^* are the relative roll radius and the composite elastic modulus of the contacting bodies, and they are obtained as

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \qquad \frac{1}{E^*} = \frac{1-v_1^2}{E_1} + \frac{v_2^2}{E_2} \tag{2}$$

Parameters R_1, R_2, E_1, E_2, n_1, and n_2 denote the curvature radiuses, Young moduli, and Poisson ratios of the contacting bodies, respectively. Notations are consistent to account for the cases where one of the contacting bodies is rigid or flat; one then simply takes the corresponding moduli E_i or radius R_i to infinity.

In principle, Equation 1 applies to frictionless contact of isotropic, homogeneous elastic bodies only. Further, the characteristic size of the contact area is assumed to be small compared both to the sizes of the contacting bodies and to their curvature radiuses. In other words, rolls with elastic covers can be analysed, provided that the cover thickness is large compared to contact length. Filled cotton or paper rolls comply with this requirement easily, but the case of a thin polymer cover on the rolls is somewhat more questionable. Paper between the rolls cannot be accounted for because of its moderate thickness.

More rigorous theories and numerical methods have been considered to overcome the restrictions in the Hertz theory. For more details, see references 12, 13, 16, 14, 17, 21 and 22.

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2.4.3 Modelling of paper compression in calendering

There are rather few theoretical works available that relate the micro-scale properties of fibres and the paper web to the corresponding effective macroscopic compression properties. Osaki, Fujii, and Kiichi[23] considered theoretically the compressibility of paper. They proposed that the non-linearity in compression results from the different mechanisms acting at different loading regimes. The moderate compression at a low-pressure regime is due to the bending of single fibres in the coarse network whereas, at higher pressures, where the structure becomes denser and stiffer and where the number of fibre-to-fibre contacts increases, the behaviour is dominated by fibre collapses.

Ionides et al.[24] rejected the idea of fibre bending even at low pressures and proposed instead that the total compression of the sheet was effectively a sum of the compressions of single fibres in a stacked pile. On the other hand, Rodal[4] proposed that the compressive behaviour consists of three more or less distinct parts. It was assumed that at moderate loads the linear elasticity law applies, while at somewhat higher loads the fibre network structure begins to collapse and the behaviour becomes non-linear. Ultimately, at very high loads the structure is thickened and the additional compression is due to fibre collapse. A non-linear phenomenological stress-strain law, including this characteristic behaviour at different load regimes, was proposed.

Schaffrath and Gottsching[25] considered the compression model that accounts for the structure of paper. The compressive behaviour was separately considered both at the surface and in the interior of the web, and the material non-uniformities in the structure were accounted for in this model. The total compression of the sheet was summed up from the compressions in the separate layers. The effect of different fibre and network properties to compression mechanisms has also been discussed by Ellis[26] and Han[27].

As the theoretical micro-scale approach to compressibility of paper is difficult, empirical studies on the relationship between calendering parameters and paper deformation have been presented. Chapman and Peel[28] performed plate compression studies and related the compression behaviour of paper to the compression residence time and the applied load. They noted that the final deformation of paper follows the logarithm of the applied pressure and residence time. Colley and Peel[29] continued the work in this area and included the effects of temperature and moisture.

Crotogino[30] presented this as an empirical calendering equation which relates permanent compression, ε_p, (relative bulk reduction) of a paper web in a single calender nip to the nip intensity factor, μ.

$$\varepsilon_p = \frac{B_i - B_f}{B_i} = A + B_i\mu \tag{3}$$

where B_i and B_f are the initial and calendered bulks parameter and A is the fitting parameter. The nip intensity factor is calculated as

$$\mu = a_0 + a_F \log F + a_S \log S + a_R \log R + a_T t + a_M M \tag{4}$$

F, S, R, T, and M correspond to line load, machine speed, average roll radius, web temperature, and web moisture content and a_0, a_F, a_S, a_R, a_T and a_M are corresponding fitting coefficients.

Equation 3 can be applied repeatedly over several nips to obtain the final bulk in a multi-nip calender process.

Equation 4 was primarily developed for a hard-nip calender, and it has been slightly modified by Gerspach[31], by replacement of parameters S and R with nip pressure and nip residence time, primarily, to better account for soft-nip calendering.

Van Haag[17] also considered non-linear mechanisms in static compression and proposed

$$\sigma_Z = \frac{E_0 \varepsilon_Z}{1 - \frac{\varepsilon_Z}{\varepsilon_{max}}} \tag{5}$$

The compressive stress, σ_z, increases rapidly against strain, ε_z. At the asymptotic limit, ε_{max}, it tends to infinity. At this limit, the void space in paper can be assumed to be compressed to zero. The relation in Equation 5 was also confirmed by compression measurements. Figure 17a shows the measured paper thickness during two subsequent compression tests. The permanent deformation that appeared in the first loading is clearly visible. Figure 17b shows the measured stress-strain relation and the model prediction according to Equation 5.

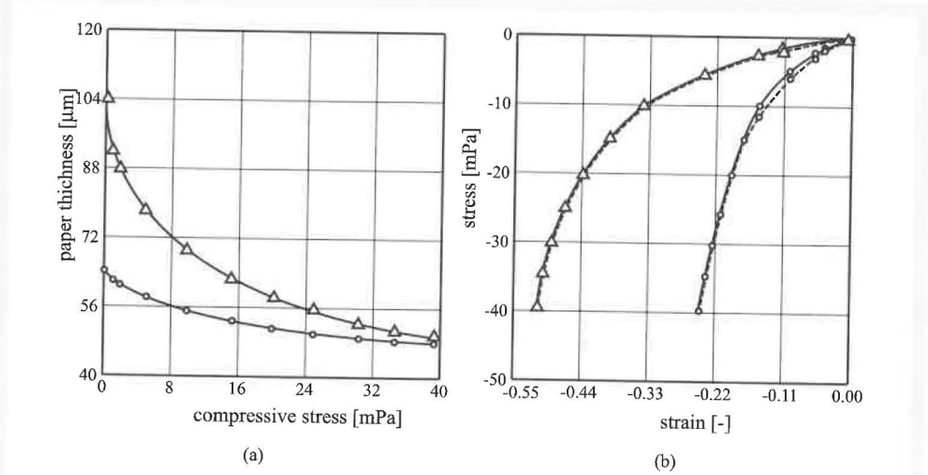


Figure 17. a) Stress-thickness and b) stress-strain relationship of paper in two subsequent compressions[17]. The first and second leadings are indicated with trianges and circles, respectively. The solid curve denotes the measured result, the dotted curve is the model prediction.

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Besides the permanent reduction in thickness, compressive loading also involves changes in the surface structure. Heikkilä[32] considered the subject of surface compressibility. He developed a non-linear viscoelastic model for coated paper that accounts for the web compression and the flattening of the rough surface under the contact pressure. Heikkilä also carried out experiments on measuring the effective contact area under dynamic nip conditions. The contact smoothness was characterised in terms of relative contact area, and it was found to be a function of nip pressure and dwell time.

The classical semi-empirical approach to deformation of viscoelastic materials is to use simple mechanical models involving spring and dashpot elements. The spring element is used to describe idealised elastic behaviour, and the dashpot is used for the viscous effects. The most common linear viscoelastic models are shown in Figure 18. Connecting a spring and a dashpot serially one obtains the Maxwell model, which characterises the viscoelastic deformation of fluids (permanent deformation). The linear viscoelastic deformation of a solid (delayed elasticity) is described by the Kelvin (or Voight) model.

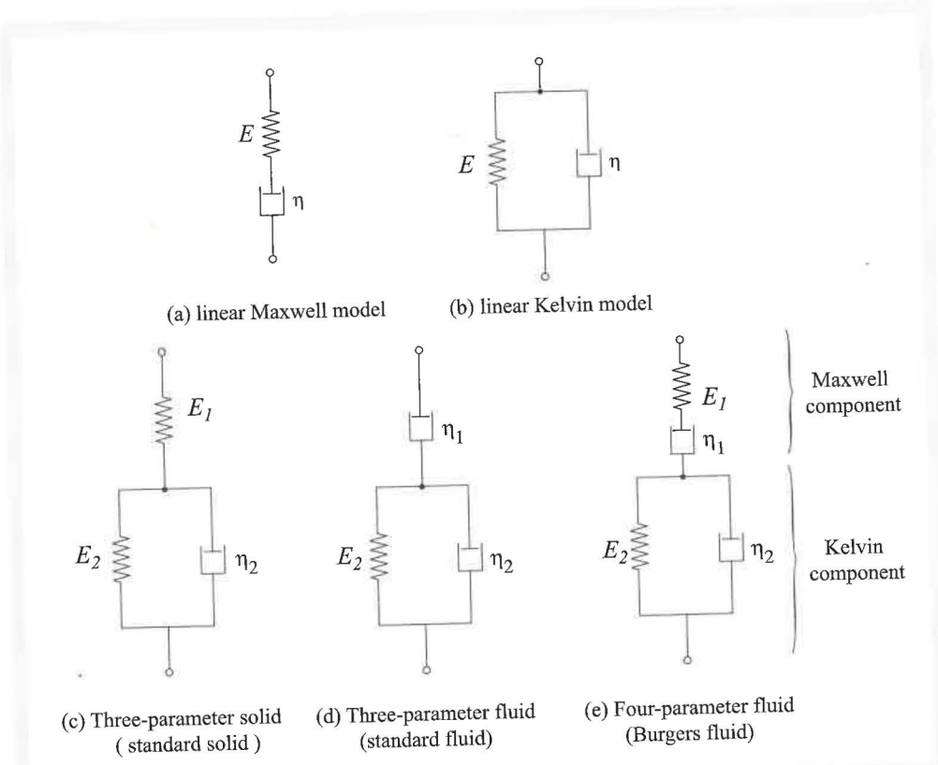


Figure 18. Examples of rheological models: a) Maxwell, b) Kelvin, c) three-parameter solid, d) three-parameter fluid and e) four-parameter fluid.

Especially, the four-element Burgers model has been utilised for compression of paper[6,33], because it accounts for many substantial effects observed in paper, such as instantaneous deformation and recovery, permanent deformation, and delayed recovery. The strain in the Burgers model is given by

$$\varepsilon(t) = \frac{\sigma}{E_1} + \frac{\sigma}{E_2}\left(1 - e^{\frac{-tE_2}{\eta_2}}\right) + t\frac{\sigma}{\eta_1} \tag{6}$$

Here E_i and η_i, i=1,2, stand for the elastic and viscosity coefficients and the subscripts refer to corresponding elements in the model. The first and second term represent the instantaneous and delayed elastic strains, which are fully recoverable, whereas the third term accounts for the viscous, permanent deformation. However, the practical calendering situation is more complicated, since the deformation strongly depends on process conditions, especially temperature and moisture. Therefore, these idealised models are also inadequate in this respect.

2.4.4 Modelling of heat and mass transport in calendering

The heat and moisture transport mechanisms in porous materials have been extensively dealt with in many review articles, for example in references 34 and 35 and in references therein. The heat conduction in the paper has been considered experimentally in references 36 and 37, theoretically in reference 38, and using numerical methods in references 39 and 40.

A first and straightforward approach to consider the temperature gradients in a paper web passing a calender nip is the solution of the transient heat conduction equation. We can simplify the situation by assuming that heat transport in the web in the machine direction is dominated by the large convective velocity; thus, we neglect the conduction in this direction. If we attach our coordinate system to a particle flowing with the web, i.e., we follow a cross section in thickness direction passing a nip, we are then left with the one-dimensional time-dependent heat conduction problem. If we focus on the behaviour near the contact surface, say on the hot roll side, we can consider the problem in a semi-infinite one-dimensional domain. The conductivity properties as well as the initial temperature in the paper web might in the first approach be taken to some representative constant value and assumed uniform in the whole domain. At the contact surface, we might require that the web temperature takes some prescribed value, for example that of the hot roll. The solution in this case will then be

$$T(z,t) = T_0 + (T_S - T_0)\left[1 - Erf\left(\frac{z}{2\sqrt{\alpha t}}\right)\right] \tag{7}$$

Here T_0 and T_s are the initial web and heated roll temperatures, z is the thickness coordinate, α is the thermal diffusivity of the paper, and t refers to the residence time spent in the nip.

To account for a more accurate and detailed model, one needs to consider the situation further. An important thing in thermodynamic behaviour of paper is the strong

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coupling effect between temperature and moisture. If paper is heated, some part of the applied heat energy is used to evaporate the water residing in fibres and void space. In fact, the system always tends toward the thermodynamic balance, which is uniquely determined by the material properties, the temperature, the moisture content in the paper, and the relative humidity in the surrounding air[41]. Any departure from this balance will cause a balancing heat and mass transport to take place. Since practically all the water in the calendered paper is in bound water form (due to its low moisture content) and the evaporation heat of the bound water is high, the coupling between heat and moisture transport is strong.

Heat and mass transport also are strongly influenced by the porous web structure and properties. The degree of compaction influences the transport and therefore the temperature and moisture content in the web. On the other hand, we have already seen that the compression mechanisms in the porous structure are largely controlled by moisture and temperature levels. In fact, all three phenomena — deformation, moisture and temperature — depend on each other.

Let us now consider an improved model where we include the effects of moisture transport and the coupling phase change phenomena. Since capillary transport is considered negligible, the moisture transport is solely due to vapour movement. The heat transport will be assumed to be due to conduction, as shown in Equation 7. The simultaneous transport of temperature and moisture within the porous media can be described by the following type of model:

$$\frac{\partial U}{\partial t} = \frac{\partial}{\partial t}\left(D^* \frac{\partial U}{\partial z}\right) - E \tag{8}$$

$$\rho C_p \frac{\partial T}{\partial t} = -\frac{\partial}{\partial z}\left(\lambda^* \frac{\partial T}{\partial z}\right) - \Delta H E \tag{9}$$

$$\frac{\partial T}{\partial n} = \alpha(T - T_{ext}) \tag{10}$$

$$\frac{\partial U}{\partial n} = \beta(U - U_{ext}) \tag{11}$$

$$U(z,t_0) = U_0(z) \tag{12}$$

$$T(z,t_0) = T_0(z) \tag{13}$$

The primary variables $U(z,t)$ and $T(z,t)$ denote the moisture content and the temperature fields at the location z at time instant t. We have assumed that the process conditions correspond to a steady-state situation. Also, we have assumed that the convective transport due to web movement is highly dominating over the diffusion and conduction in the machine direction, which are therefore neglected. The relative transport with respect to the web is therefore essential only in the thickness direction and the transport system can thus be considered with one space and one time coordinate. The time coordinate t is associated to the lateral space coordinate x, and we can imagine that we follow a fixed cross-cut section in time as it passes through the process.

The variables describing the internal behaviour of the system are: E stands for the internal phase change (water evaporation) rate, and ΔH is the evaporation heat of bound water. Moreover, the parameter functions D^*, l^*, r, and C_p that denote the effective diffusivity, the thermal conductivity, the local mixture density, and the heat capacity of the paper, have been derived from the constituent properties using the mixture theory. In general, they all are functions of the porous structure, the mixture composition (i.e., fibre, fine particle, water concentration), and temperature.

The boundary conditions (Equations 10 and 11) describe the interaction between the field variables U and T and the exterior of the paper web. They have here been formulated in terms of heat and moisture fluxes. The proportionality parameter functions a and b include the transfer resistance effects at the surface. The boundary conditions in the above system can change with respect to time (or in fact with respect to the location) so that different types of surface interactions can be modelled, including the roll nip contact as well as the conditions in the open draw. The initial conditions in Equations 12 and 13 describe the initial solution fields of the simulation.

Things that we have neglected so far, but that might be worth considering, include at least the considerations on deformation and the connection between deformation and transport phenomena as well as more accurate descriptions of boundary interactions etc. However, it is clear that the necessary information for a complete and fully coupled thermo-hygro-deformation system of porous material, possibly with complicated interaction with its exterior, is not available and the complete model is therefore out of the question.

3 Calender types

3.1 Hard-nip calender

Hard-nip calenders are used for a variety of paper and board grades. In this calendering process, the web is pressed between two or more hard rolls. Hard-nip calenders of two main categories are used:

- two-roll hard-nip calenders
- multi-roll hard-nip calenders.

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Figure 19. Calender stack in a paper machine.

Two-roll calenders are primarily used for calendering webs that do not need heavy calendering: for pre-calendering before coating and for finishing of uncoated woodfree papers. Multi-roll calenders most commonly have four or six rolls and are still used for newsprint, smooth woodfree papers, and specialty papers (Figure 19) in older paper or board machines. In even older paper machines, there might still be two or three stacks, each having six to eight rolls.

3.1.1 Hard-nip calendering process

In the hard-nip calendering process, the pressure between the nip rolls affects the web. The control parameters are linear pressure between the rolls and the roll surface temperature. The number of nips can also be used as a control parameter. Traditionally, hard-nip calenders have had heating systems that were unable to influence the surface temperature of the rolls and the process. In today's two-nip hard calenders with heated rolls that are able to operate at elevated temperatures, the temperature has become an active parameter.

The hard-nip calendering process is straightforward and works almost solely on two principles: densifying the web with pressure and copying the surface of the rolls onto the web. This process has advantages over more complicated processes, but it also has drawbacks.

The nip that is formed between the relatively small-diameter hard rolls is short and the actual contact pressure in the nip (the pressure applied to the web) is high, even with a low linear load in the nip. As a paper web always has unevenness due to the formation of the paper (different fibre floc sizes), this kind of high pressure can cause blackening of the paper web. A hard nip can only calender the hills of the paper structure, not the valleys, so it always looks uneven in sidelight, "hammered". This can also be seen as black, transparent points in the paper. A similar kind of unevenness can cause mottling in a printed result due to uneven oil (and printing ink) absorption. High pressure densifies the paper web and crushes some of the fibres and breaks fibre bonds in the sheet.

For paper grades that must have a good caliper profile and reel build-up, the hard-nip calender used to be the only process machine that could address small-scale profile problems. Profiling was done by using air showers (cold and/or hot) or by induction heating beams that were controlled zone-wise. Nowadays zone-controlled rolls with narrow zone width are used more often for this purpose, see Section 5.2.1.

Special problems related to multi-roll hard-nip calenders include the runnability

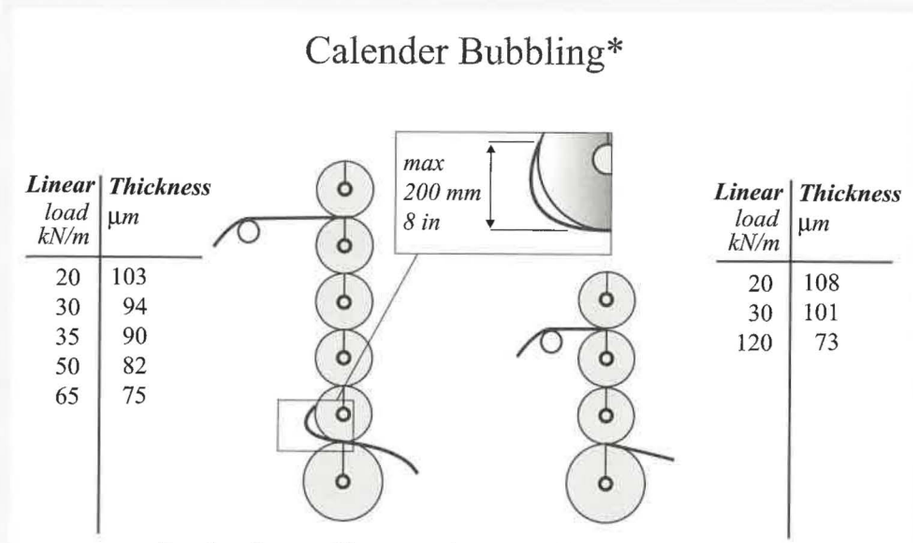


Figure 20. Web-handling problems in a hard-nip calender.

problems caused by the widening or elongation of the web in the process (Figure 20). The nip pressure compresses the paper. At the same time the sheet is getting wider, but as the web is transferred to the next nip, it has no chance to widen out. This can cause wrinkles at the next nip and might cause web breaks. This phenomenon limits the amount of pressure that can be applied to the paper web. Elongation of the paper web can cause blowing, a problem in which the web loses contact to the rolls and forms an air pocket before a nip. In a multi-roll calender, widening and elongation must be compensated for by the tension, nip loads, and shrinkage of the web.

Another problem in multi-roll calenders is barring. This is a vibration behaviour of the calender roll stack that begins due to unevenness of the paper web entering the calender, or due to mechanical vibration induced by the calender, drives, surrounding machinery, or out-of-roundness in rolls. Because all rolls in the calender work together in the calender stack, the vibration pattern is transferred from one roll to another, finally causing the rolls to acquire a shape that has several waves in the surface. This marking of the roll causes excessive vibration and a howling noise, resulting in MD thickness variations in the calendered paper web. Earlier, barring used to be eliminated by changing the paper machine speed or linear load or the offset of rolls. A new and special solution is to change the roll offset during normal production run, with the paper web on and with

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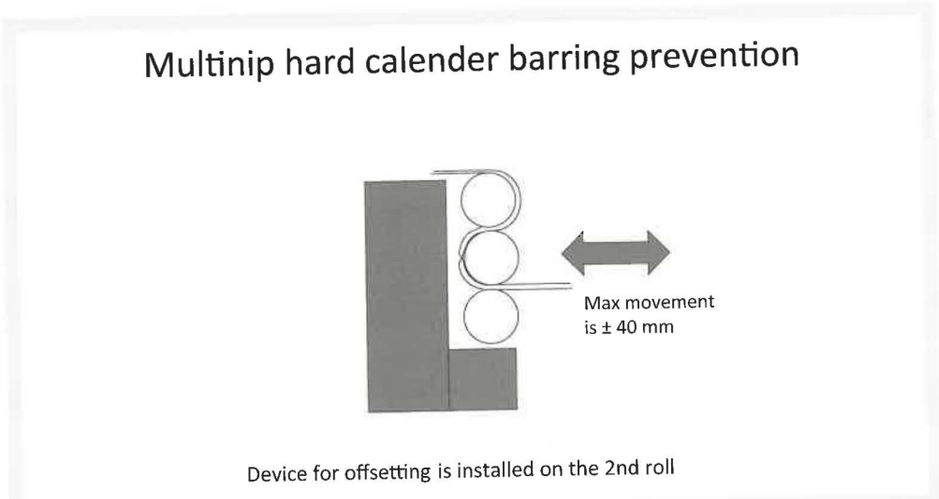


Figure 21. Barring prevention.

calendering loads on (Figure 21). This solution means that loads previously limited by barring are now available, and provides a tool which does not disturb the papermaking process, while barring streaks no longer disturb the winding process.

Advantages of hard-nip calendering:

- cost-effective operation
- effective influence on caliper profile
- simple tail threading.

Drawbacks of hard nip calendering:

- danger of blackening
- mottled surface of the web (gloss mottle and oil-absorption differences)
- loss of strength
- loss of bulk
- limited printing results
- runnability of the process limits operating range
- severe operational problems caused by barring and vibration.

3.1.2 Hard-nip calender concepts

Two-roll hard-nip calenders

Almost all new hard-nip calenders are two-roll calenders. Most commonly, a two-roll hard-nip calender is composed of a heated cast-iron roll and a deflection-compensated roll (Figure 22). One of a group of varying frame types supports the rolls. Most common is an open frame that supports the bearing housings of the rolls from one side. Rolls are usually vertically arranged with one above the other, but they can also be at a 10–15°

angle to avoid vibrations. Closed framing can also be used together with self-loading deflection-compensated rolls.

The main rolls in the calender can be of various designs. Heated rolls are either double-walled rolls or peripherally drilled rolls. Hot water is circulated through the rolls for heating the roll surface to temperatures of 80 °C – 120 °C and oil to even higher temperatures. The lower end of this temperature range has no real influence on the surface quality development of the web. More important is that the water circulation evens out the roll surface temperature in the cross direction (CD) and therefore helps to produce a better caliper profile. The higher end of the temperature range significantly increases the smoothness development potential of the calender. Deflection compensation in the other roll is a necessity because paper machines have become so wide that the deflections of the rolls disturb web profiles. Theoretically, solid chilled cast-iron rolls could be used, but then these rolls should be crowned to compensate for the deflection. This kind of crown only operates in a narrow linear pressure range. In wider calenders, this range would be so narrow that only one linear load could be used in practice.

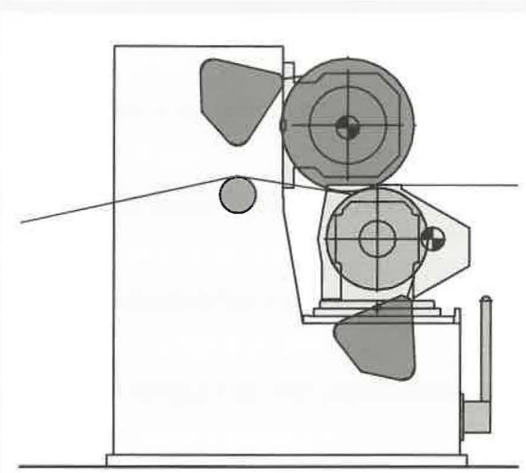


Figure 22. Two-roll hard-nip calender.

The most common deflection-compensated rolls are swimming rolls, CC rolls, and hydrostatically supported deflection-compensated rolls. These rolls enable adjustment of the linear pressure without negatively influencing the linear pressure distribution in the cross-machine direction. Hydraulically deflection-compensated swimming rolls were a major breakthrough, but in wide calenders there are still some variations in CD pressure distribution. Therefore, today's wide calenders commonly have zone-controlled deflection-compensated rolls. These rolls normally have 3–8 zones, but they can have 40–60 zones for accurate caliper control at a narrow scale.

Nip rolls are loaded against each other with pneumatic bellows, pneumatic cylinders, hydraulic cylinders or, as already described, with the hydrostatic roll itself. The pneumatic system is simple and does not leak oil, but is not as accurate as hydraulic loading, which also has more vibration dampening capability. Therefore, in wide fast machines the hydraulic loading system is used exclusively.

In slower machines, only one drive is used, normally for the heated roll. High-speed machines require drives for both nip rolls to prevent speed differences in the nip. The drive arrangement can be operated either in speed difference mode with the other paper machine drives or in tension mode by using tension measuring rolls as paper carrying rolls before and/or after the calender.

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Web spreading rolls are used before the nip to ensure that the web enters the nip evenly without wrinkles. In the calender, other main components are doctors for keeping the roll surfaces clean and preventing the paper from wrapping the rolls, threading devices, and caliper actuators.

Temperature and moisture gradient calender

The temperature gradient calender is a two-roll hard-nip calender with at least one of the rolls heated to high operating temperatures. This is normally done with heat transfer oil. High temperature produces better web surface quality, uniformity and smoothness (Figure 23), and preserves bulk and strength properties. Heating up both nip rolls, however, is complicated because the other roll is a deflection-compensated roll. Because of the benefits of soft-calender technology, this kind of a calender has remained very rare in spite of the amount of research work done.

Another type of gradient calendering process is moisture gradient calendering. In this process, water is applied to the surface of the web and the web is calendered before the moisture gradient in z-direction disappears; the moisture film does not have time to wet the surface of the web before it is calendered.

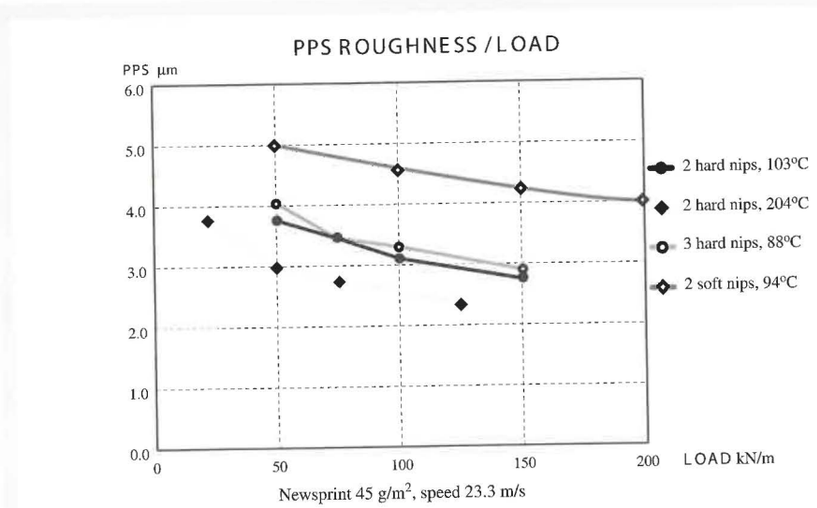


Figure 23. Calendering with different calendering concepts.

Multi-roll hard-nip calender

Research has shown that the surface properties of the web develop according to the total pressure pulse applied. For example, if multiple nips are used, the surface quality is the same as if only one nip of the same total applied pressure were used.

However, this calendering with only one nip has other drawbacks. The calender itself must be very precise, and the rolls have to be in perfect condition (no marking or

surface defects). Also, rolls big enough to withstand these high linear loads have not always been available, not to mention the problems with crane capacity in the paper mill. In addition, grinding heavy rolls is more problematic.

For these reasons, multi-roll calender stacks were and are still used (Figure 24). They comprise more than three rolls, most commonly four to six rolls. These rolls are relatively small in diameter, and the linear load is achieved by the weight of the roll shells. Having more rolls in the stack increases the linear load in the bottom nips. This method of creating linear load is simple and rather precise because the linear load generated by the weight of the rolls is naturally distributed along the whole width of the roll face. Because of this fact, multi-roll hard nip calenders are widely used in versatile paper or board machines.

The linear load of multi-roll calenders can be easily adjusted by increasing the number of rolls that are in contact with each other. Every roll increases the linear load by its weight. A problem occurs in the bottom nip of the calender, because the bottom roll deflection varies according to the changing linear load due to the number of rolls in use. In this bottom position, a deflection-compensated roll is commonly used. Calender load control can also incorporate a hydraulic cylinder at the top of the calender, often on the second or third roll from the top. When this cylinder is used for controlling the linear load level of the calender, there is a need for a deflection-compensated roll also at the position where the external force is applied.

Another calender design issue results in variations in the CD linear pressure profile. The weight of the intermediate rolls is distributed over the whole width of the roll face. Roll journals, bearings, bearing housings, part of the loading arm, and nip guards — all devices that are attached to the bearing housing or loading arm — load the roll journal with their weight. These overhanging loads cause the intermediate rolls to de-

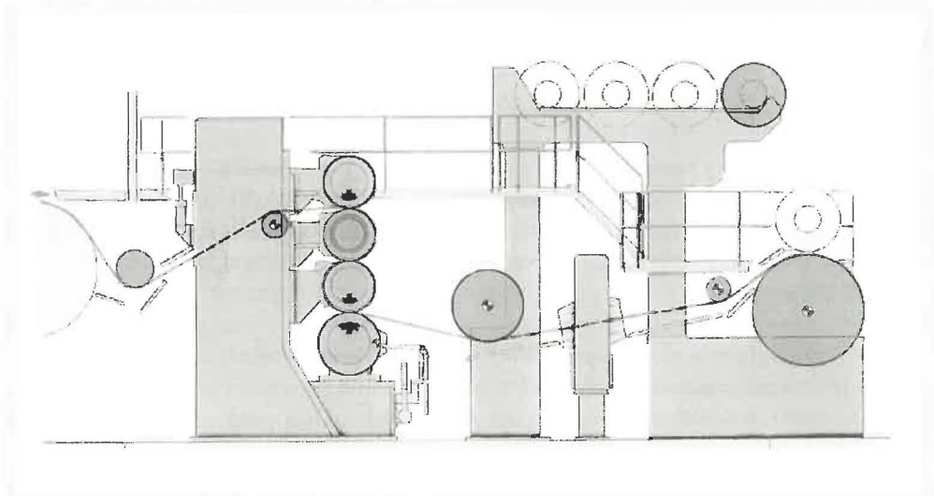


Figure 24. Multi-roll calender.

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flect. This deflection causes variations in linear load at the edge areas of the nip. These variations can be seen in the calendering result as variations in the caliper profile.

In practically all multi-roll calenders, there are roll support arrangements that permit adjusting the edge support forces pneumatically or hydraulically. These overhanging load compensation devices open the nips of the calender by lifting the rolls with the loading arm using high pressure in the loading element. When the calender is closed and at operating pressure, the loading element is adjusted to a lower level that is just enough to compensate for the overhanging loads.

Multi-roll hard nip calenders normally have only one main drive. The driven roll is either the bottom roll or the second roll from the bottom. As the bottom roll is a deflection-compensated roll, the drive is more complicated and costly. In some calenders, more driven rolls are used to ensure draw control at high speeds.

Tail threading through a machine roll calender is accomplished while the nips are closed. At the tending side, a 100–300 mm-wide strip is led from the last drying cylinder to the top portion of the calender, through the calender, and from the last nip of the calender to the reel. There is a wide variety of threading devices.

Paper surface quality development by improved raw materials (fibre, pigment, process technology) has changed the requirements set for the calendering process. Today, there is a need for low as well as high linear loads. Therefore, there are multi-roll hard nip calenders that allow linear loads lower than the cumulative weight of the intermediate rolls. This is done by hydraulically supporting intermediate rolls and by using a deflection-compensated roll in which the direction of the pressure zone can be turned by rotating the roll shaft. However, multi-roll hard-nip calenders are very rarely needed for new machines.

3.2 Soft calender

A soft calender (or soft-nip calender) has a soft roll cover on at least one of its two nip rolls. Most commonly, one of the two rolls is a soft roll and the other is a heated hard roll similar to the hard-nip calender heated rolls. For matte paper grades, there is a variant where both of the rolls are soft rolls.

3.2.1 Soft calendering process

The soft calendering process is different from the hard-nip calendering process in one significant way: the nip backing roll has a soft surface. This difference changes the nature of the whole process. In the soft calendering process, the process variables are

- linear pressure
- running speed
- hot roll surface temperature
- soft roll cover material
- soft roll position (against top or bottom side of the web)
- steaming (when applicable).

The main difference in the nip behaviour of soft calenders is that both the web and the roll cover are compressed, which results in a significantly lower actual pressure in the nip compared to hard nip calenders. The nip is longer, allowing better heat transfer and subsequent deformation of the calendered web. Another significant difference is that the compression of the web in both high and low spots is more evenly distributed. The deformation of the soft cover reduces the maximum local nip pressure, resulting in more uniform calendering. A hard-nip calender tends to equalise the caliper of the paper web, resulting in small-scale density variations in the web. The soft calender tends to equalise the density of the web, resulting in differences in caliper (Figure 25).

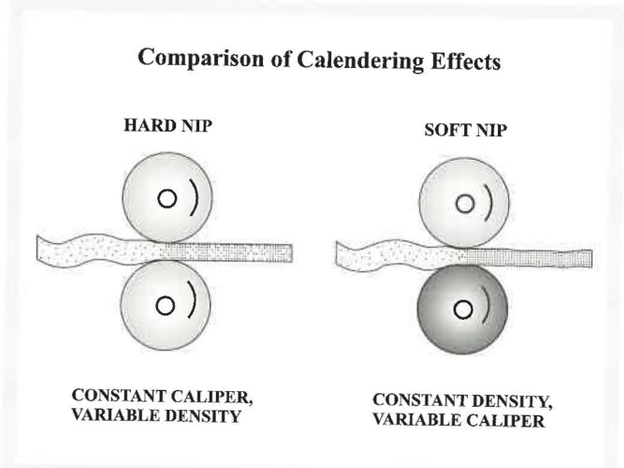


Figure 25. Hard- and soft-nip calendering.

Soft calendering offers many benefits over hard-nip calendering. Because of the more uniform density, the absorption properties of the web and printing results are more uniform. As the local high spots are not compressed very hard, there is less gloss mottling in the printed image. Lower maximum pressure allows the web to be calendered to better smoothness without the risk of blackening. The strength properties of the web are easier to maintain than in hard-nip calendering.

The above-mentioned benefits have resulted in a change in the calendering method in the majority of new paper machines. Also, in several cases, older machines have been equipped with a soft calender. The capability of soft calendering to be installed on-line has even allowed two- to six-nip soft calenders to replace old supercalenders in processes that do not require the full potential of supercalenders.

3.2.2 Soft calender concepts

Gloss calender

The predecessor of today's soft calender was the gloss calender. For high-grammage board grades, the formation sets limits for hard-nip calendering. Local variations lead to very significant gloss mottling and poor printability. High-quality board grades also used to be supercalendered (see the section on moisture), but as this was an off-line process that resulted in a high amount of reel waste with high-grammage products, it never became popular.

High-quality board grades are coated with a heavy coat weight that allows them to be calendered fairly easily to a high surface finish. Temperature is a key parameter in this process. Therefore, a calendering process was developed that used high temperatures (120–150 °C) and low linear pressures. This is called gloss calendering.

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Because the backing roll is soft, there is no gloss mottling. For these board grades, high temperature and low pressure together produce a very good structure. The surface is plasticised for a good printing result, and the rest of the board structure remains less compressed and bulky.

A gloss calender (Figure 26) has a polished cylinder heated to a high surface temperature with steam, hot oil or electricity. The cylinder is usually chrome-plated. The calendering nip is formed between this cylinder and a soft-covered roll that is pressed against the cylinder. Traditionally, the soft roll material used to be rubber, but today polyurethane is commonly used. Though the temperature of the hot cylinder is high, soft rolls can be used; because of the thick board, the soft roll has no contact with the hot cylinder surface. Therefore, rubber and polyurethane, which can only withstand temperatures up to 80 °C, can be safely used.

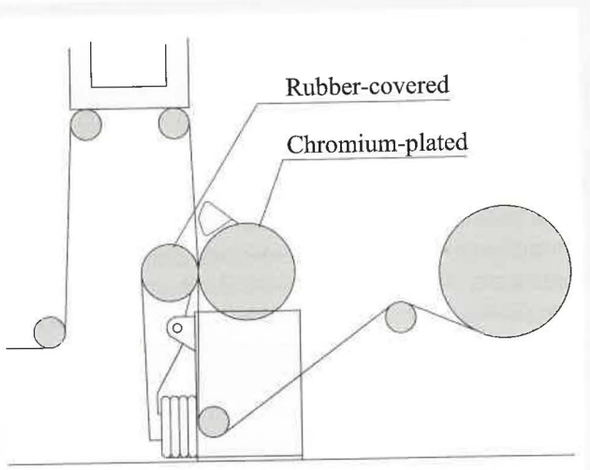


Figure 26. Gloss calender.

Since the linear pressures are low, 20–80 kN/m, the soft surface rolls are normally not deflection-compensated. The softness of the roll cover and the low pressure do not demand high accuracy. In addition, board machines have traditionally been narrow machines, so the roll deflections are low. For better calendering results, two-nip gloss calenders with two soft-covered rolls against one heated cylinder are also used.

Two-roll soft calender

Gloss calendering was a good process for board grades before soft calendering was developed, but it could not be used for paper because the required pressures are higher than can be tolerated by the gloss calender covers. This is due to higher running speeds and less compressible material. Also, the paper is so thin that there would be direct contact with the hot roll surface and the soft backing roll. However, the benefits of gloss calendering were so promising that attempts were made to develop a roll cover that could withstand higher linear loads and also produce a higher specific pressure in the nip. The soft calendering process was first used for all kinds of woodfree specialty papers and matte papers. The resulting soft-soft calender was called a matte calender or "matte-on-line" calender as the product was called by the first major supplier of these calenders, Küsters Corporation.

By combining the technology of oil-heated thermo rolls with new soft cover

technology, the soft calender transformed into the very versatile machine for on-line finishing that we know today (Figure 27). The main components of a two-roll soft calender are the deflection-compensated soft-covered roll and the heated roll with a smooth, polished surface. The linear pressure range of a soft calender is much higher than that of a two-roll hard-nip calender, and the roll diameters are larger. The designed linear pressure of a soft calender varies from 150 to 450 kN/m. The surface temperature of the hot roll can be clearly above 200 °C.



Figure 27. Soft calender.

For two-sided calendering, two nips with an inverted roll order are combined to get a total of four rolls. The roll order is selected by taking into account the two-sidedness of the web, the coating order, and runnability at the calender. The soft calender's linear loads can be high, so the hot roll diameter must be large to mechanically withstand the loading and create a straight nip together with the deflection-compensated mating roll. Soft calenders are used in a wide variety of layouts (Figure 28). The simplest design is a true matte calender with two soft-covered rolls. This design concept, in which at least one of the rolls is deflection-compensated, is an alternative for producing coated matte grades. Most soft calenders are designed with one soft-covered roll and one hard roll. The hard roll can be heated or unheated. It produces a higher surface finish and can be either the top or bottom roll, depending on the side to be finished.

Two-roll soft calenders can be combined for higher surface finishing. Normally, there are two nips with an inverted roll order, but there are also calenders with two nips finishing the same side twice and calender arrangements with up to six two-roll soft calenders finishing both sides three times. There are also special calenders combining a hard nip calender and a soft calender.

The main design of a two-roll soft calender is very similar to that of a two-roll hard-nip calender. However, there are significant differences. Because the deflection-compensated roll has a soft cover, threading cannot be done with closed nips as with a hard nip calender. In a soft calender during web threading, the nip is opened and the rolls rotate at the same surface speed. When the tail is on the reel, the paper is spread to full width and the nip is then closed.

The soft roll cover is a critical component in a soft calender. The first soft calenders for paper introduced in the late 1980s experienced almost continuous roll

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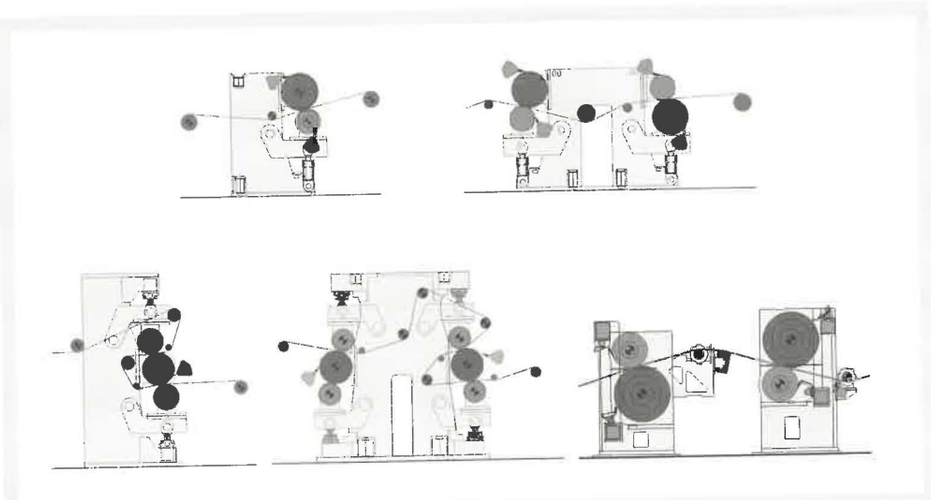


Figure 28. Soft calender concepts.

failures. This speeded up the development of roll covers, and today's covers perform very safely, provided that operating and maintenance procedures are correctly performed. In this sense, a soft calender can never be as easy to operate as a hard-nip calender. The edge areas are especially critical, as there might be direct contact with the hot roll. Because the roll cover cannot withstand this contact at very high temperatures, several methods have been developed to cope with this problem. Cooling the edge of the soft cover with cold air and the thermo roll with water are very frequently used alternatives. Another possibility is to taper the edges of the soft roll to eliminate direct contact. The safest method of operation is to use edge slitters after the calender and run overwidth in the calender to prevent contact with the hot roll at the edges. This method loses some trim and can also cause trimming problems if the machine width is critical.

The soft-covered roll wears more rapidly than a hard-surfaced roll, so the roll change procedure must be efficiently designed. The change time should be minimised, and the roll change must be easy and safe. In some cases, the roll change can even be performed while the paper machine is running without shutting down. Note that the hot roll might be the heaviest component in the paper machine and therefore can dictate the crane capacity, grinding machine capacity, and transport methodology from the machine to the roll maintenance area.

Another important aspect in designing the machine layout is the space required for hydraulic systems, oil-heating systems, electrical drive arrangements etc. A soft calender is a compact unit, but the peripheral units and systems take up a lot of space; with narrow calenders, the peripheral systems can take more space than the calender itself. In placing the units, there are also limitations regarding the distance to the calender and the relative vertical levels.

The calender frame design also has a significant influence on the layout. Narrow machines are usually open-faced arrangements, allowing roll change with a crane, especially when the nip rolls are not quite vertically arranged but instead are built on a slight angle. In this kind of framing arrangement, room has to be reserved for lifting and transporting both top and bottom rolls. In wider calenders, however, an open-faced arrangement has limitations. The forces that are transferred from the bearing housings to the frame grow rapidly with wider machines, and affixing the bearing housings to the frame becomes critical. This problem can be overcome by two different designs: by having a "nose" in the frame above the top roll bearing housing, or by fixing the bearing housings together.

Because of the need for accurate control of surface speed during threading and the different modes of operation, the drives must have an effective control system. The DC drives are very often replaced by frequency-controlled AC drives. The mechanical drive arrangement varies depending on the speed and load of the calender. Heated rolls are driven with a universal shaft and a gear reducer. Deflection-compensated rolls in narrow and slow calenders are driven with a timing belt drive (toothed belt). In wide and heavily loaded calenders, the deflection-compensated rolls are driven with an integrated gear arrangement.

Other major components of a soft calender are spreader rolls before the nips, paper lead rolls, steam showers, doctors, roll edge cooling devices, and caliper actuator. As the soft roll cover can be influenced negatively by the wrinkles entering the nip, the function of the spreader rolls is very important. When operating a calender with a furnish that contains stickies and other impurities, doctoring of the nip rolls is a key factor for safe operation of the soft rolls. Stickies have to be removed from the surface of the rolls before more fibres, fillers, or other material build up on the roll surface.

Three-roll soft calender

One nip per side of the paper is not always enough for finishing the sheet. More finishing capacity can be obtained by adding more similar nips. This, however, is an expensive way because the soft calender nip rolls are large in diameter and expensive. The soft calender thermo roll has to be able to withstand the full linear load from one side of the nip. Less stresses are exerted on the thermo roll when there are two soft rolls fitted on opposite sides of the thermo roll. In this situation, the nip loads equalise each other and the thermo roll can be sized in a totally different way. However, there are now two nips that consume heat from one roll, and this will limit the maximum surface temperature obtained.

As the paper web passes from the first to the second nip in the same three-roll calender unit, only a one-sided finish can be achieved. By adding another three-roll unit, a serpentine sheet run provides calendering with four nips (Figure 29). Some mills use this kind of arrangement, with vertical rolls or horizontal rolls, for finishing wood-free coated papers. The vertical roll arrangement is used for off-line soft calenders or low-speed on-line calenders. For higher-speed on-line calendering, a horizontal roll arrangement is used.

The three-roll unit is a good process tool, especially for one-sided finishing, offering a high finish capability at a reasonable price. It is an interesting unit for two-sid-

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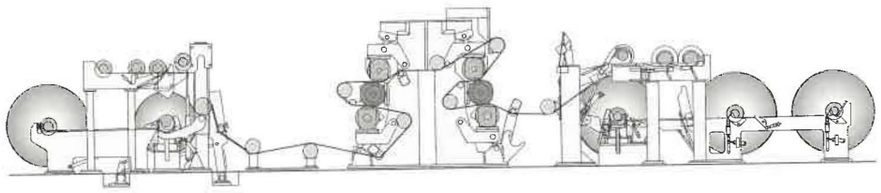


Figure 29. Four-nip soft calender.

ed finishing — if the paper web can be plasticised with high temperature and the fairly limited development of smoothness is not a problem. In high-temperature soft calendering, high gloss is easier to reach than good smoothness.

3.3 Supercalender

Before the introduction of polymer rolls, supercalendering was the main multi-nip calendering method. Consequently, the text in this paragraph applies mostly to calenders installed before the end of the 1990s. Still, there are a large number of supercalenders all over the world, though very few new ones have been installed during the past ten years.

A supercalender is a multi-roll calender composed of alternating hard and soft rolls. The soft rolls allow heavy linear loads to be used to obtain good smoothness without severe blackening or mottling of the web. The control parameters of a supercalender are

- linear load in the bottom nip
- surface temperature of heated rolls
- hardness and material of filled rolls
- calender speed
- steaming
- position at double finisher nip.

The supercalender soft roll used to be almost solely a filled roll. The filled roll has a steel shaft around which specialty paper sheets with a hole in the middle are slid. The paper is then compressed with a hydraulic press. The paper is normally either a blend of wool and cotton or cotton only. When the desired hardness of the roll has been reached, the compressed paper is locked into place with locking nuts. This technology of manufacturing soft filled rolls has been in use for more than 150 years.

Supercalenders are always off-machine units (Figure 30). The most common number of rolls is 9–12, but specialty calenders for producing release and grease-proof papers can have up to 16 rolls. If there is an even number of rolls in the supercalender, there will be a double finisher nip in the middle of the stack that has two filled rolls against each other. The side of the paper facing the hard roll changes in this

nip so that the top portion of the calender finishes the opposite side of the web from the bottom portion. The most common number of rolls is 10 or 12.

An uneven number of rolls results in calendering that favours one side of the sheet, i.e., one side will be calendered more than the other. This is desired when making a one-sided product or in a case where the incoming web already shows two-sideness in smoothness or gloss. At one time, this was common in North America where fourdrinier paper machines would produce a two-sided sheet and final quality was controlled with coating colours and supercalendering. The most common number of rolls in such a case is 9 or 11.

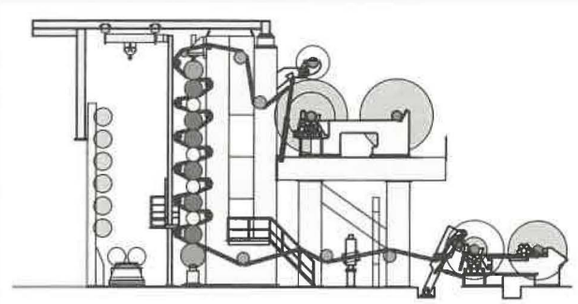


Figure 30. Supercalender.

The supercalender roll stack is arranged vertically. When running, the bottom roll, sometimes called the king roll, supports the weight of all the rolls above it. The linear load of the calender is developed by the weight of the intermediate rolls. Because this load corresponds to the weight of the rolls, it is evenly distributed and creates a fairly uniform linear pressure distribution in the cross-machine direction. Since the intermediate roll weight load is not enough for the majority of paper grades, there is a need for extra load to be developed by pressing the top roll bearing housings with hydraulic cylinders. This external force and therefore the linear pressure level of the supercalender can be easily controlled. As each roll adds to the total linear pressure, the maximum pressure is in the bottom nip and the minimum pressure in the top nip. Because the linear pressure range of a supercalender can be fairly wide and the load level quite high, there is a need for deflection-compensated rolls in the top and bottom positions. To have uniformly performing nips, the internal pressure for deflection compensation must be synchronised with the external loading cylinders.

The supercalender is an off-line operation, so each time the machine reel is changed, the calender is stopped. This operation is the main reason for the low capacity of supercalenders. Some of this lost capacity can be regained by using splicing unwind and windup units. Regardless, each reel change causes loss of production because the reels cannot be run to the end. Another cause of low capacity is the low running speed. To meet quality targets, in some cases the supercalender speed cannot exceed 500 m/min. Normal maximum production speeds are 750–850 m/min. The main speed-limiting factor is the filled roll. Normally, the maximum calender speed, maximum linear pressure, and maximum temperature of the heated rolls cannot all be used at the same time because of potential filled roll failures in the two bottom positions.

As the surface of the soft filled rolls is easily marked by paper defects, web breaks or bad profiles, the filled rolls have to be changed fairly often. It is quite

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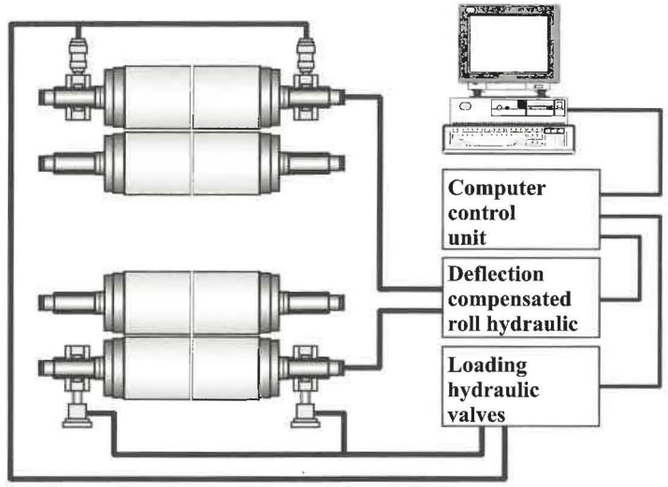


Figure 31. Supercalender loading hydraulics.

normal to change at least one filled roll per day in any given supercalender. If the calender speed is high, up to three rolls per day have to be changed in the supercalender. This changing of filled rolls is another factor that influences calender capacity. To prevent the rolls from being marked by web breaks, supercalenders are equipped with a quick-opening feature. Hydraulic cylinders support the bottom roll (Figure 31). When a web break occurs, the pressure of these cylinders is released very rapidly, causing the bottom roll to drop. When the roll has dropped so far that all the calender nips are open, the bottom roll is softly stopped at the end of the cylinder stroke. This kind of quick opening, combined with a web-cutting device that cuts the full width of the incoming paper web, greatly reduces the risk of marking the filled roll.

After the used filled rolls have been dismantled from the supercalender, they are left to cool to room temperature. After cooling down, the rolls are refinished by turning or grinding. The refinished rolls, in turn, are put back on the supercalender. In wide calenders, the grinding can take place several times because the grindable surface is 50–65 mm in radius. If the roll diameter is too small to be reground, the roll is sent for refilling to get it back to the original diameter.

Because of this constant variation in filled roll diameters, there must be a way to adjust the nips. This is extremely important for modern calenders with quick opening of the nips. If the distance the rolls travel during quick opening is too long, the impact forces on the spindles and other equipment become too high, causing the equipment to fail under fatigue loading. Normally, the nip opening between each of the rolls is maintained at 5 mm in wide calenders and 3 mm in narrow calenders. This is accomplished by means of spindles that carry the intermediate rolls when the calender stack is opened.

There are basically four different ways to support the rolls in an opening situation. The most simple is a one-piece spindle. The nuts on the spindle support each of the intermediate roll housings, and they are manually adjusted. The opening between each of the rolls is 5 mm; therefore, the travelling distance of each roll is an extra 5 mm when opening the stack. The rolls at the bottom portion of the calender travel the longest distance. To quickly get to the adjustment area of the spindle, the support nut can be mechanically adjustable with the help of an electric motor. The spindle adjustment after a roll change can take up to 1–2 hours.

A more advanced version of the spindle adjustment system is a split spindle, which has short spindle sections between each of the rolls. The spindle adjustment is accomplished by turning the spindle at each of the rolls to be changed. At each end of the spindle section, there are threads that have a different turning direction. Therefore, the spindle is able to open a gap above and below the roll to be changed. With the split spindle calender, operators have a set of keys so they can test the gap at each spindle nut with the corresponding key. The split spindle section is normally rotated with the help of a pneumatic tool and a built-in gear. The spindle adjustment time after a roll change is 15–30 minutes. This kind of spindle can also be automated. In this case, every spindle section has its own drive motor and a proximity switch to set the exact gap.

Another widely used automatic spindle system has one drive motor and a one-piece spindle (Figure 32). The exact gap is set with a pneumatic device that either locks the nut in place or allows it to travel with the spindle. There are proximity switches set for the right gap at each spindle nut. The roll position to be changed is selected with a push button or via the automation screen. The automation takes care of the gap for the roll change automatically and, after the roll change, sets the right gaps. Normally, one roll at a time is changed, to prevent gap setting problems. The spindle adjustment time before and after a roll change is 1–2 minutes.

In closed-frame supercalenders with quick-opening, a special arrangement for set-

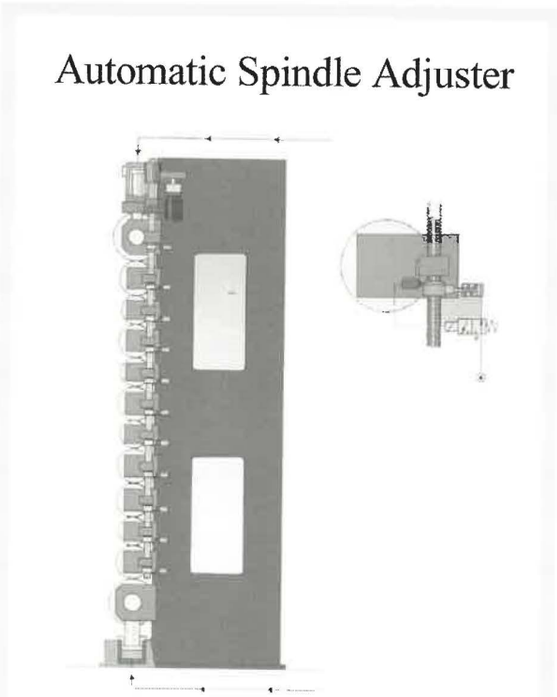


Figure 32. Supercalender spindle arrangement.

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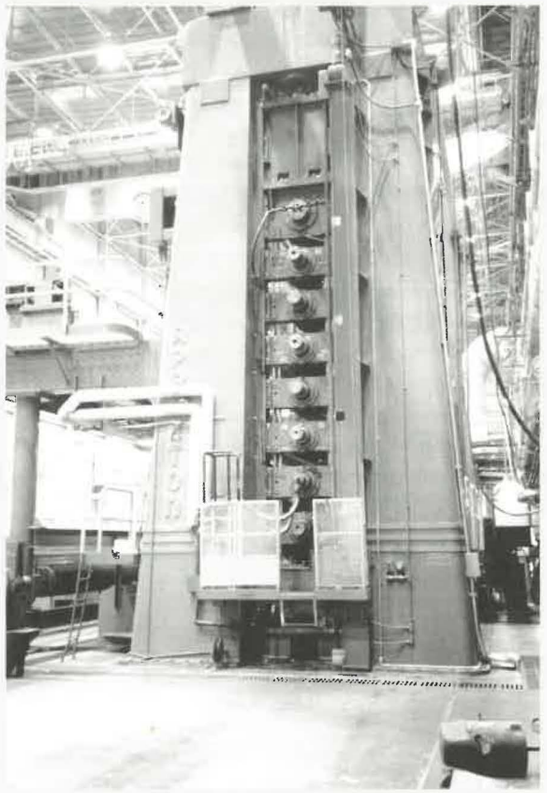


Figure 33. Closed-face supercalender.

ting the gap is used. The rolls are supported with hydraulic cylinders, and the gap is set automatically as the calender stack is closed (Figure 33). The quick-drop gap is done with an arrangement that has more room for the rolls to drop toward the bottom of the calender. This kind of arrangement is easy to operate on closed-frame calenders that would require four spindles for setting the correct gaps.

Because the filled rolls in a supercalender are changed practically daily, all other tasks to be performed during a roll change should be easy and fast. The procedure to change the filled rolls includes the following: adjusting the spindle for the change; lifting the fly roll to the roll stand if it is in front of the roll to be changed; rotating the nip guard to take it out of the way; sliding the crane lifting attachments to the roll journals; and lifting the roll slightly with the crane prior to opening the bearing housing bolts. When moving the roll with the crane, the movements have to be very carefully controlled because, especially in wide calenders, the rolls are heavy and can cause damage to the calender if they are not handled carefully. There is also a risk of injury during roll change; therefore, only qualified personnel should perform the roll change. After the roll has been removed, a new roll is installed in the calender in the reverse order. A normal roll change time is 10-30 minutes but can be much longer with closed-frame calenders without automated spindles.

Luckily, there has been rapid progress in the development of soft polymer-covered rolls. Today, polymer rolls can be used in any position in almost any supercalender, regardless of the mechanical loading. The only reason that might still require traditional filled rolls to be used is paper quality. Polymer-covered rolls do not require as much mechanical energy to rotate as filled rolls. Therefore, an equivalent amount of heat is missing from the process. If there is no capacity to increase the surface temperature of the heated rolls or the linear pressure of the calenders, polymer rolls cannot produce the same paper quality as filled rolls. But, even in this case, two or three filled rolls can be replaced by polymer rolls to achieve the same quality.

Polymer rolls have a changing interval of 3–4 months; therefore, they substantially increase supercalender capacity. Another benefit of polymer rolls in supercalenders is the improved caliper profile. When filled rolls are used, active profiling cannot be done because the roll is deformed so easily that the linear pressure profiling is lost within 15–30 minutes. A traditional supercalender, therefore, cannot influence the caliper profile with linear pressure profiling. However, zone-controlled steaming influences both gloss and caliper. The incoming profiles must be good, and the filled roll should be accurately ground. Polymer rolls make it possible to influence the paper rolls' profiles for a longer time, but the grinding quality of the rolls has to be more precise; the polymer roll is not deformed in the same manner as the filled roll.

The filled roll surface is rather rough when taken to the calender. The normal Ra roughness is 0.5–0.8 micrometers. This rough surface produces lower gloss values, especially when several rolls are changed at the same time. However, the roll is getting smoother in the calender and, after a few hours of running, the surface roughness is close to the roughness of the hot roll surface (0.2–0.3 microns Ra). The behaviour of the polymer roll can be quite different. Some rolls get rougher in the calender, and some become extremely smooth. This phenomenon has a strong effect on the paper quality achieved.

Swimming-type single-zone rolls provide sufficient control for narrow calenders, but zone-controlled rolls are necessary on wider calenders. Supercalenders have the same linear pressure distribution problem that affects multi-roll hard-nip calenders: overhanging loads. Because a supercalender has rolls of different rigidities and also overhanging loads that vary from nip to nip, the linear pressure CD-distribution is never flat, unless overhanging load compensation devices are used (Figure 34). These devices are rather new, dating from the late 1980s. Supercalender slideways experience substantial friction, so only overhanging load compensation devices that operate with pivots tend to work in the long run.

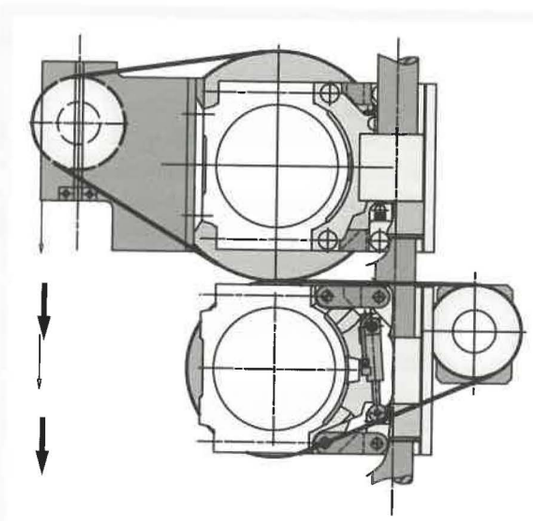


Figure 34. Overhanging load compensation.

Steam showers are also a part of the calendering process, especially in calendering uncoated SC grades. The effect of steam showers is based on two factors: heating the paper

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web and moisturising the surface. Showers are most effective in the top portion of the calender and can effectively be used for controlling two-sidedness and CD gloss. If the coating withstands it, steaming can even be used with LWC and WFC grades but only in small quantities. If the steam amount gets too high, the coating is loosened from the surface of the web and sticks on the surface of the calender rolls.

Because the supercalender is a separate process, it is very important that the machine reel quality after the calender is so good that winder runnability and reel quality after the winder are not influenced by the calender windup. In any case, every winding stretches the paper slightly as it is under tension and thus consumes part of the stretch potential of the paper. There still has to be enough stretch potential for the printing machine to ensure runnability in the printing process. Today, centre-driven windups with adjustable rider roll load are used almost exclusively. Centre windups without rider rolls have air-trapping problems. Surface-driven pope-type windups use very high nip loads to prevent slipping of the smooth paper surface at the reel. The centre drive, together with the rider roll, does not have these problems. There are several types of centre-driven windups that work basically the same way. Most modern high-speed off-line calenders are equipped with windups with a driven rider roll for torque adjustment.

3.4 Multi-nip calender

The term multi-nip (or multi-roll) calender was taken into use in the mid-1990s to distinguish the newly developed calendering technology from supercalenders and also from the soft calenders developed in the previous decade. The new term was, and still is, justified because of the strong development in the machine technology and in the calendering process. The number of potential applications of multi-nip calenders is remarkably larger than with supercalenders, as shown by the following list of key features:

- Multi-nip calenders are suitable both for on- and off-line applications.
- The number of rolls in the calender stack can vary between 3 to 13.
- Divided or two-stack configurations as well as single-stack configurations are possible.
- The construction speed of the calender can be up to 2 200 m/min.
- Loading and unloading systems are fast and accurate.
- All elastic rolls in the stack are polymer-covered.
- Thermal capability up to 280 °C with oil as heating medium (surface temperature 150–170 °C while running).
- Inverted roll order in the stack to have the first nip heated.

Whereas supercalenders are always off-line systems with low speed potential (typically under 1 000 m/min), the elastic rolls in multi-nip calenders are generally filled rolls. The number of nips in a single-stack configuration is typically 12 or 10.

Multi-nip calenders are normally configured to have an inverted roll order (compared to a supercalender), which means that the top and bottom deflection-compensated rolls have a soft cover. This allows the first nip to have a hot roll of a higher temperature than that of a normal deflection-compensated roll in the normal roll order.

Therefore, the first nip is more effective than in a supercalender.

Since the multi-nip calender is designed for polymer-covered soft rolls, there are no slideways or spindles. The rolls in a multi-nip calender are supported from their bearing housings with loading arms. This allows low friction and high loading accuracy. Furthermore, this arrangement incorporates a roll weight compensation function. The roll weight is either compensated partly or fully, depending the make of the calender.

The driving forces for the development of multi-nip calenders were two-fold. 1) A soft calender could not cover the whole spectrum of calendering applications due to its limited calendering power, especially for the most demanding paper grades or high-speed operations. 2) Because of the ever-increasing paper machine speeds and production capabilities a total of four off-line suprecalenders were needed to serve a high-capacity paper machine, so the investment and operating costs were too high — even though the unit price of one multi-nip calender has increased significantly (compared to that of a supercalender) the total investment and operating costs are clearly lower, because one multi-nip calender is sufficient in on-line applications and two in off-line applications.

As the operating conditions in multi-nip calenders are a combination of high temperature and high linear load, the soft roll covers have to perform safely and allow long grinding intervals.

Multi-nip calenders are used in the final calendering position. Tests have also been carried out with multi-nip calenders in a precalendering position for coated grades, but the cost/benefit ratio has not been good enough to justify investments.

The latest development in multi-nip calenders has been in dividing the calender stack into two separate sections. There are two ways to design a divided stack. A singe stack can be divided into two separately loaded sections using deflection-compensated rolls inside a single stack. In this case the stack is still in a single frame. Another possibility is a so-called two-stack calender, with two separate stacks. Regardless of the design, the benefits of dividing the stack are related to better runnability due to less vibrations and less calender roll barring, and higher total calendering capacity due to more nips and better control of two-sidedness.

The rapid development of multi-nip calenders in the 1990s made calendering a focus area in papermaking, resulting in more than 100 new multi-nip calender installations to this day.

At this point, there are three calender designs in the market that make use of this technology: the Janus calender from Voith, the ProSoft calender from Andritz-Küsters, and the OptiLoad calender from Metso. These multi-nip calenders are briefly presented in the following under their respective brand names.

3.4.1 Janus calender

The Janus calender was the first multi-nip calender that could be installed on-line in a fast paper machine. This represented an important landmark and trend-setting event in the on-line use of multi-nip calenders.

The Janus calenders built in the 1990s featured a vertical stack configuration. In the late 1990s the calender design was changed to the Janus MK2 design concept,

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characterised by the fact that the frame is no longer arranged vertically but inclined at an angle of 45 degrees, see Figure 35. This frame configuration is unique among multi-nip calenders.

Divided stack configurations have also been designed with a 45-degree frame, see Figure 36.

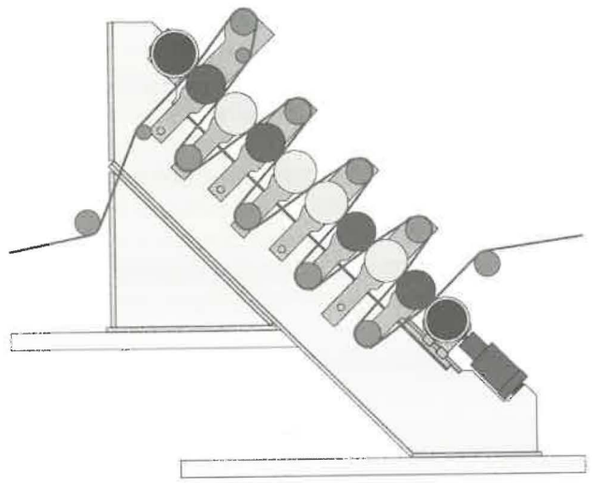


Figure 35. Janus calender, configuration 1 x 10.

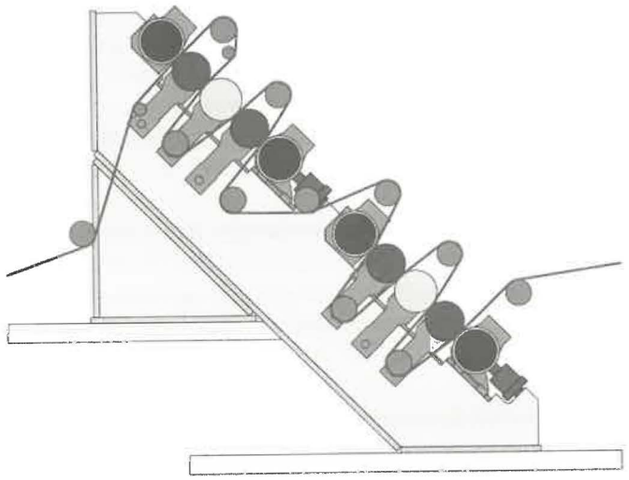


Figure 36. Janus calender, devided stack configuration 2 x 5.

The benefits of the 45-degree frame:

- smooth running due to extremely high rigidity of the frame in con-junction with its low centre of gravity and the frame's optimum connection to the base
- rapid, simple and safe roll change, further improved by specially developed functional changing tools
- direct access to all main calender sections from platforms and stairs.
- lower height
- compact lay-out as a part of the paper machine line.

General features of Janus calender:

- Janus calenders have all the main features described in Section 3.4.
- The number of rolls in a Janus calender stack can vary between 6 and 12. For different paper grades the number of closed nips within the roll stack can be set individually. For example a 10-roll Janus calender can also be operated with 1, 2, 3 or 4 closed nips only.
- Design linear nip loads up to 550 kN/m are used.
- The heated rolls are peripherally drilled rolls with direct water or oil heating, producing roll surface temperatures of 100 to 170 °C. The top and bottom rolls are deflection-compensated, normally multi-zone rolls of the Nipco or Nipcorect type.
- In on-line applications, the tail threading is carried out with rope systems and with the nips open. The tail is fed into the rope nip by suction conveyors. Dual ropes feed the tail through the calender stack up to the reel.

The total number of Janus calenders installations today is over 40, including off- and on-line installations of new calenders and rebuilds.

3.4.2 OptiLoad calender

The OptiLoad calender was the first multi-nip calender with a 12-roll stack for high calendering capacity. The OptiLoad calender came onto the market at about the same time as the Janus calender.

The loading arrangement of the OptiLoad calender is unique (Figure 37). By designing the calender stack according to the principle of even roll deflection, the weight of the intermediate rolls can be completely compensated, rather than partially, which is more typical. The weight of the intermediate rolls does not influence the loading and

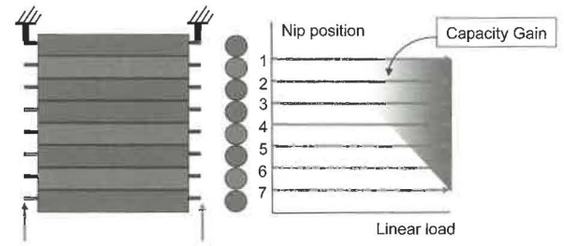


Figure 37. OptiLoad loading principle and relieving cylinder. Source: Metso 2008.

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the process of the calender, because the linear load is totally created by the external loading cylinders. This means that the linear load is the same in all calender nips.

The loading principle allows the calender to produce the same surface properties at a linear load level about 100 kN/m lower than in traditionally loaded multi-nip calenders, which means safer operation of the polymer rolls in the bottom area of the stack. Because the OptiLoad multi-nip calender can have the same load in all the nips, the nip length is also the same in all the nips, allowing the calender to produce the required paper surface properties at extremely high speeds.

The degree of relieving intermediate stack rolls can be altered, which allows the calender to have one more control parameter than other multi-nip calenders. This parameter can be used for controlling two-sidedness by adjusting the linear pressure level between the top and bottom rolls.

General features of the OptiLoad calender:

- The OptiLoad calender has all the main features described in Section 3.4.
- The number of rolls in the OptiLoad calender can vary between 6 to 12, see Figure 38.
- Design linear nip loads up to 500 kN/m are used.
- The heated rolls are normally peripherally drilled rolls. This calender uses typically oil- or water-based heating systems, with capability up to 170 °C surface temperatures.

In on-line systems, tail threading is carried out with a rope system and performed with the nips open. The tail is fed into the rope nip by suction conveyors and two ropes that lead the tail threading strip through the calender stack up to the reel. A special two-phase threading procedure is used for the Twinline calenders where the

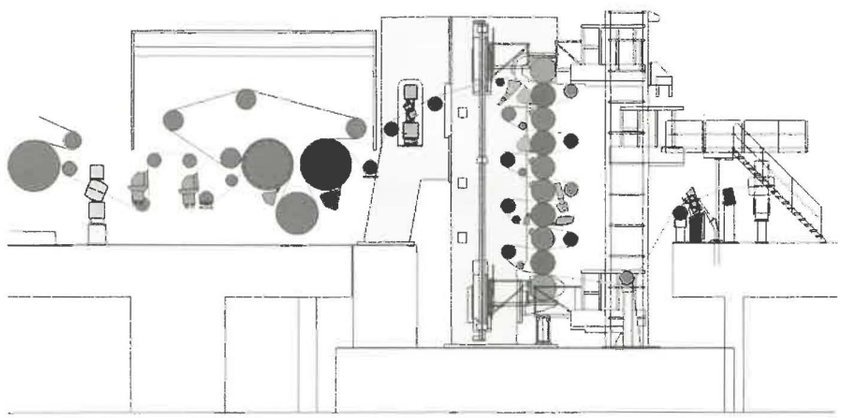


Figure 38. OptiLoad 1 x 10 on-line calender. Source: Metso 2008.

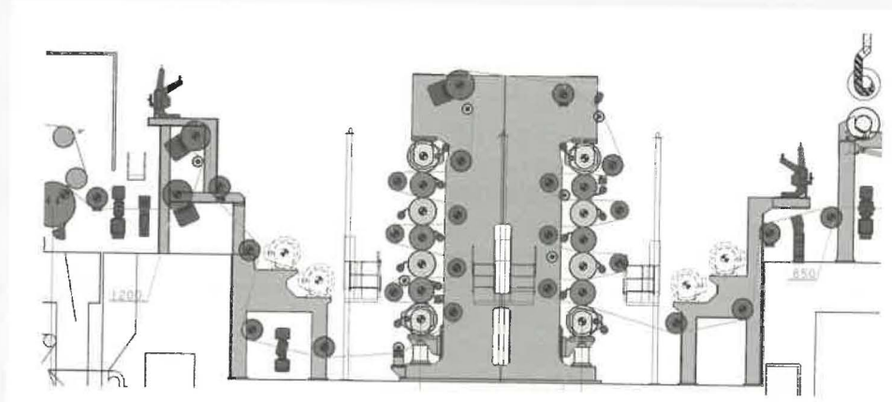


Figure 39. OptiLoad TwinLine 7+7 on-line calender. Source: Metso 2008.

tail is taken out from the ropes between the calender stacks for stabilising the tail and ensuring successful forward tail threading.

The two-stack version of the OptiLoad calender, called OptiLoad Twinline, was introduced in the current millennium. It incorporates advanced moisturising equipment to cope with paper moisture evaporation due to the high temperature of the calender and more open draws, see Figure 39.

Total number of OptiLoad installations so far is over 50, including off- and on-line installations of new calenders and rebuilds.

3.4.3 ProSoft calender

The ProSoft calender is similar to the other multi-nip calenders in that it uses polymer rolls and elevated process temperatures.

The ProSoft has a vertical frame, either in one or two stacks. This multi-nip calender entered the market somewhat later than the Janus and OptiLoad calenders.

One specialty of the ProSoft calender is the electrical drive control system that can eliminate or minimise stack roll deflection out of the plane of the nip.

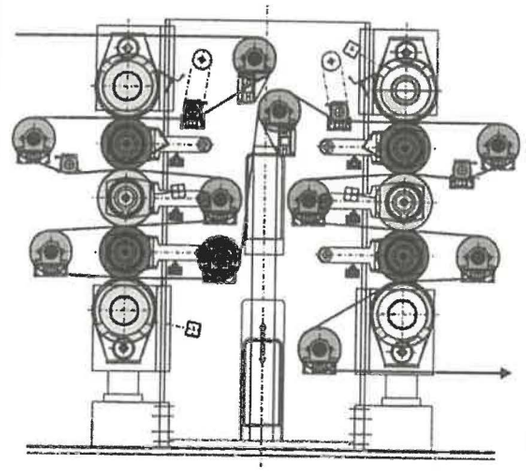


Figure 40. ProSoft 5+5 calender. Source: AEL 2006 Calendering Methods seminar publication.

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General features of the ProSoft calender:

- The ProSoft calender has all the main features described in Section 3.4.
- The main application has been the 2x5 roll on-line ProSoft calender, see Figure 40.

3.5 Shoe-nip calender

The shoe-nip calender is a long-nip calender, whose calendering dwell time can be many times longer than in hard- or soft-nip calenders. The shoe nip is formed between a thermo roll and a polymer belt, which is supported by a shoe. Lubrication oil is applied between the shoe and the polymer belt. The length of the shoe in MD direction varies from 30 to 300 mm. The mechanical design of the shoe calender nip is basically similar to that of the shoe press nip, though of course without any felts. With

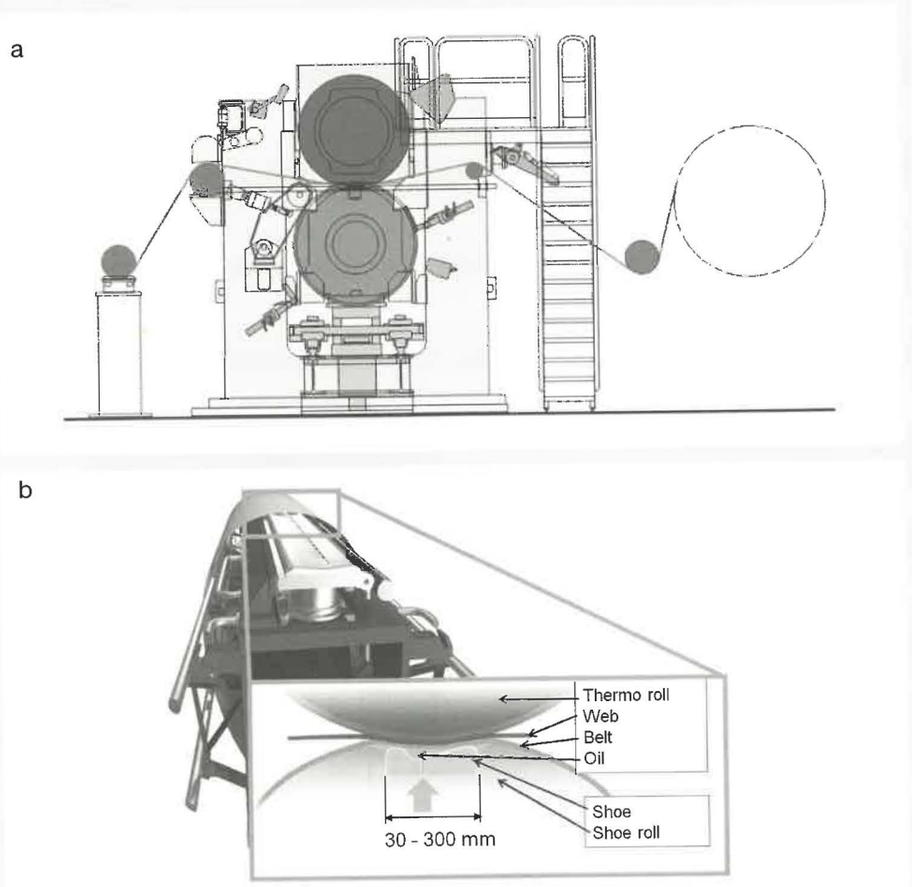


Figure 41. Shoe nip calender (a) and its structure (b). Copyright of Metso.

the shoe nip the thickness profile cannot be adjusted, so profiling should be done somewhere else in the paper or board making line. The design of the shoe-nip calender is shown in Figure 41.

The benefits provided by the shoe nip include preservation of bulk, low micro-scale (~PPS s10) roughness values, and high gloss without gloss mottling. The preservation of bulk is based on the moderate pressure in the shoe nip. Low micro-scale roughness and uniform gloss are achieved, because the soft polymer belt gives very uniform pressure distribution in the shoe nip. Shoe-nip calendering is a kind of "contour" calendering. On the other hand, macro-scale roughness (~Bendtsen) values may be high, if the formation of the base paper or board is not good enough.

The shoe-nip calender is used for final calendering of uncoated and coated paper, and for precalendering of board grades. Shoe length in a final calender position is usually 30–80 mm. In precalendering of coated boards a combination of a shoe-nip calender and hard-nip calender is used, not a shoe calender alone. Shoe nip length in precalendering is usually 100–300 mm. The hard-nip calender is used for profiling and creating macro-scale smoothness, which is important in precalendering. Despite offering some benefits over hard- and soft-nip calenders, shoe-nip calenders have not become very common.

3.6 Metal belt calendering

In metal belt calendering a one-metre-long calendering zone is formed between a heated metal belt and a heated thermoroll[42,43]. Figures 42 and 43 show schematic drawings of a metal belt calender. The extended calendering dwell time and high thermal energy of the calendering zone effectively plasticise the web surface. Only low pressure is needed in calendering because of the plasticised web. Therefore, a significant preservation of bulk is possible with metal belt calendering compared to conventional calendering methods.

Despite the new kind of calendering process, standard paper machine components are used in the construction of the metal belt calender. Steel belts have earlier been used in CondeBelt drying machines. The thickness of steel belts is between 0.6 and 1.2 mm (Figure 44). The thermo roll used in a metal belt calender is of the same standard construction as the one used in conventional heated calenders. It is peripherally drilled and heated by internal

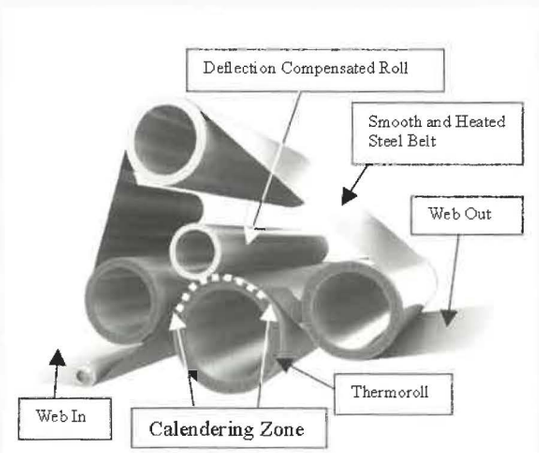


Figure 42. Schematic drawing of metal belt calender. Copyright of Metso.

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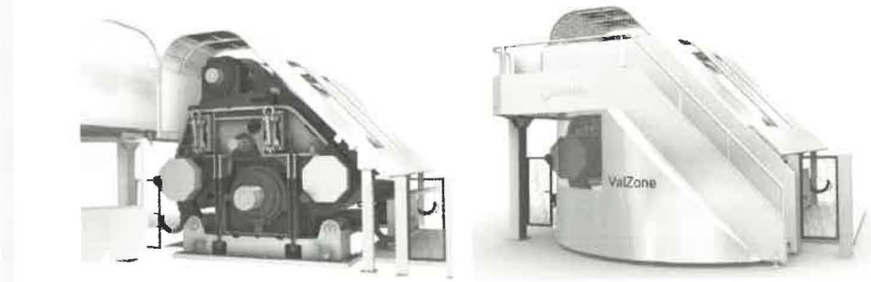


Figure 43. Metal belt calender cover open and closed. Copyright of Metso.

thermal oil circulation. The steel belt is heated with heatable belt guiding rolls, which are basically conventional calender thermo rolls. The deflection-compensated roll is similar in design to the rolls used in CD-controlled conventional hard-nip calenders.

The metal belt calendering process is based on the use of heat and a long calendering dwell time. The metal belt calendering zone is approximately 100 times longer than in soft nips. The shoe nip also has a long extended calendering nip (30–300 mm), but the metal belt calendering zone is still more than three times longer than the longest shoe calender available. In Figure 45 different calendering processes are compared.



Figure 44. Steel belt and belt guide roll. Copyright of Metso.

Metal belt calendering is the only symmetrical calendering process where heat can be applied simultaneously to both sides of the web. This is possible, because both the steel belt and the thermo roll can be heated. In hard-nip, soft-nip or shoe-nip calendering, only the thermo roll side of the nip can be heated. Thus, two nips or more are required for symmetrical conventional calendering. In metal belt calendering, differences in roughness between the

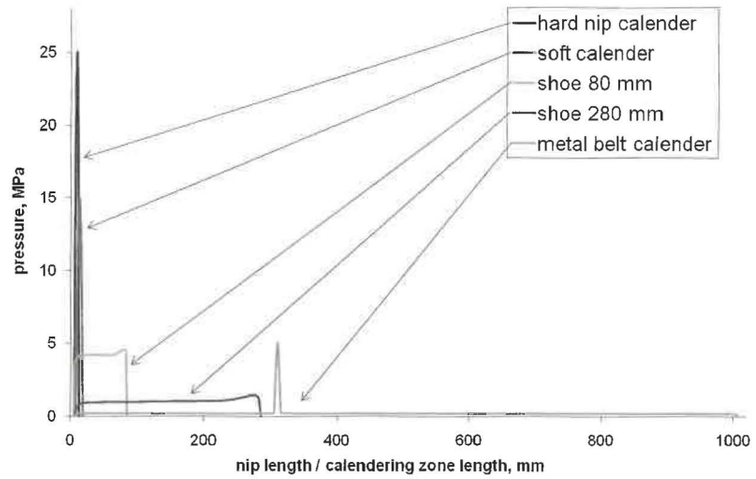


Figure 45. Pressure and calendering area of different calenders. Copyright of Metso.

two sides of the web can be minimised, as the surface temperatures of the thermo roll and metal belt can be adjusted independently of one another. Thermo roll and metal belt surface temperatures are typically in the range 80–170 °C.

The one-metre calendering zone is subdivided into three distinct phases; 1) pre-treatment phase, 2) profiling phase and 3) post-treatment phase (Figure 46). Light pressure (0.2 MPa) is applied in the pre-treatment phase through belt tension. The main purpose of the pre-treatment phase is to heat up and plasticise the web. Most of the calendering effect is produced in the profiling phase. A deflection-compensated roll applies additional pressure to give the desired caliper and smoothness. CD caliper profile corrections can also be made at this phase. Only light pressure is

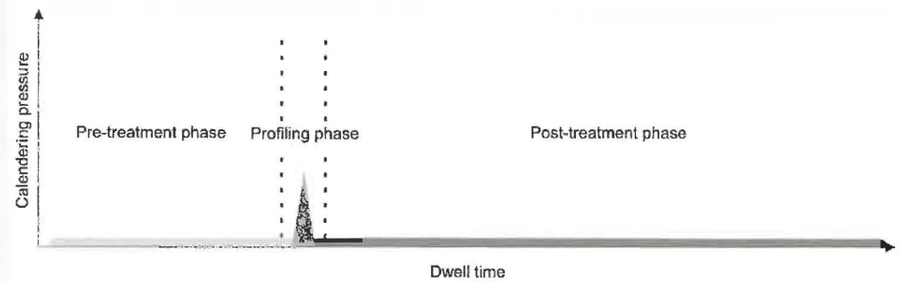


Figure 46. Pressure in metal belt calendering zone. Copyright of Metso.

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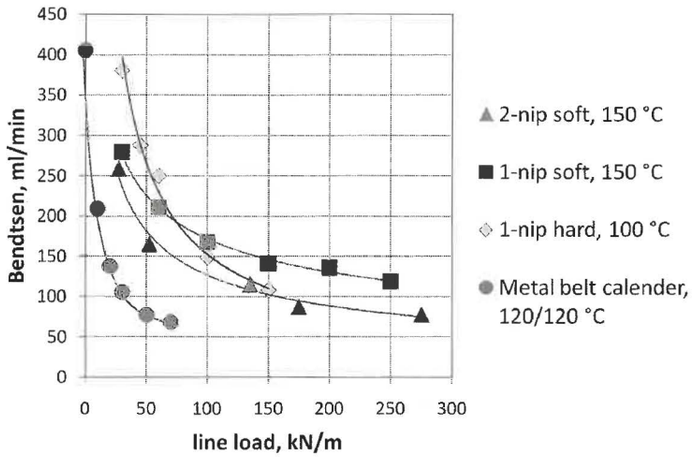


Figure 47. Line load of hard nip, soft nip and metal belt calender. Copyright of Metso.

generally required because the web is already plasticised in the pre-treatment phase. The profiling phase load is only roughly 10 % to 30 % of soft nip calendering loads, usually between 10 and 70 kN/m (Figure 47). The post-treatment phase stabilises the calendering result. Heat treatment continues in a controlled manner under reduced calendering pressure created by the tension of the metal belt (0.2 MPa). The spring-back behaviour of the web is reduced compared to conventional calenders.

Metal belt calendering allows a significant preservation of bulk and stiffness of paper or board because of the thermal plasticisation of the web and the low pressure levels. Bulk values achieved with a metal belt calender have been up to 10 % higher than with conventional calendering. The first metal belt calenders were used as a pre-calender before coating of cartonboard grades, such as folding boxboard. The metal belt calender can also be used as a precalender for coated paper grades or as a final calender for uncoated paper or board grades[44].

3.7 Special calenders

3.7.1 Wet stack

The wet stack (see Figure 48) is usually used as a precalender for coated carton board grades, but it can also be used as a final calender for uncoated board. The roll configuration of a wet stack is almost identical to the multi-roll hard-nip calender (4–11 rolls), but the process differs totally from standard hard-nip calendering. In the wet stack calender, there are water boxes on 1–3 rolls to apply a film of water to the surface of the roll before the nip. Usually, the water amount is 10–25 g/m²/side. This film is pressed onto the surface of the web in the nip. The web entering the wet-stack

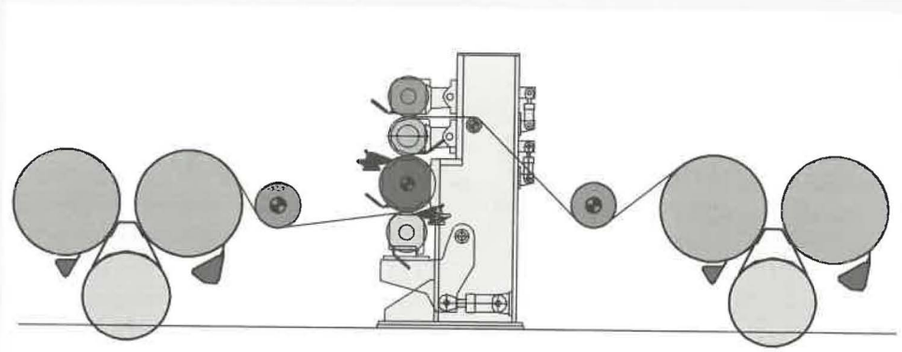


Figure 48. Wet stack.

calender usually contains only 1 % – 2 % moisture, because a lot of water is applied on the surface of the board. Drying is needed before and after wet-stack calendering. The smoothness of the board after the wet stack is generally good, but the bulk level is usually quite low as a result of heavy calendering.

The critical factor in a wet stack is runnability. If the pressure distribution in the nips with the water boxes is not good enough, water can pass through the nip and form a pocket of water underneath the web. This causes breaks at the next nip. Because bulk is a critical for board grades, there must be a linear pressure range suitable for all the products to be produced with profiles that allow the use of water boxes. This is normally accomplished with a design that allows for running with a varying amount of rolls and by selecting the position of the deflection-compensated roll(s) so that the nips used with water boxes operate with good profiles.

Because the wet stack involves runnability problems and requires overdrying of the web before as well as drying of the web after the calender, it is only used in processes in which excellent smoothness is an absolute requirement. In other cases, hot hard-nip calenders and soft calenders are used. Nowadays a wet-stack calender can also be replaced with a metal belt calender, which gives the board good smoothess. The benefits of the metal belt calender compared to a wet stack include higher bulk and stiffness values, better runnability and higher production capacity.

3.7.2 Breaker stack

A breaker stack (see Figure 49) is a hard-nip calender installed inside the paper machine near the middle of the main drying section. The moisture of the web entering the breaker stack is about 15 % – 30 %. Breaker stacks were commonly used with newsprint and liner grades, but many of them have since been dismantled. The breaker stack produces good smoothness and can also have a positive influence on the strength properties of the web. However, on the negative side, the web has a tendency to lose bulk. In addition, brightness and opacity can be reduced. Soft nips have

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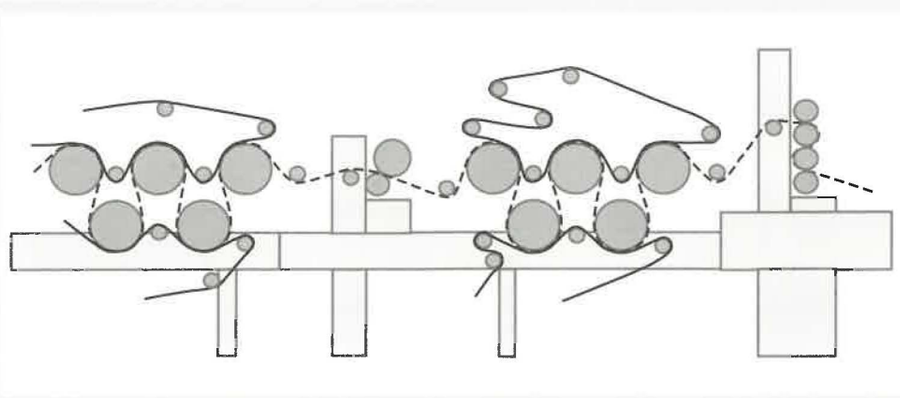


Figure 49. Breaker stack.

also been installed in the breaker stack position in a few paper machines[45]. However, modern paper machines are not fitted with breaker stacks.

3.7.3 Friction calender

Friction calendering improves the surface quality of the base paper as a result of slippage between the paper web and calender roll surface. In other words, the calendering work is concentrated on the paper surface. The slippage generates heat and reduces the roughness of the web by densifying the sheet surface, by influencing the particle orientation and by causing abrasion. Additional surface chemicals, such as waxes, have also been applied to further improve paper quality.

In a typical friction calender, the smaller-diameter hard roll rotates at a higher peripheral speed than the soft counter roll, which runs at the same peripheral speed as the paper web. Separate high-speed small-diameter friction bars have also been used in fly roll positions. The friction calender may have one or more nips in a single- or multi-nip calender configuration.

Friction calenders have been known from early years of industrial papermaking in the 19th century as a method for finishing paper surfaces. In modern papermaking, friction calendering is seldom used because of runnability, control and linting problems. More applications are found in textile and rubber industries.

3.7.4 Other special calenders

3.7.4.1 Brush finishing

Brush finishing improves the surface gloss of the web. Because there is no actual nip, the smoothness is only slightly affected. The web is brushed by rotating brushes made from horse hair (Figure 50). The control parameters are the speed difference between the web and the brush rolls and the direction of brush rotation. There are two ways to apply brush finishing: to the web supported by a mating roll or to the free

web between supporting rolls. Brush finishing has mainly been used with board grades because it does not reduce bulk, but some paper grades have also been finished with brush units. Brushing has only marginal importance today because of the increased running speeds of coated board machines, dust problems with the finished web and the introduction of hot soft calendering as an alternative method.

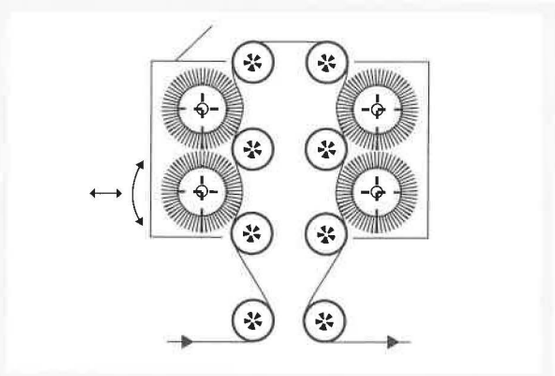


Figure 50. Brush calender.

3.7.4.2 Embossing calenders

Embossing calenders are special calenders that are designed, not to develop smoothness or gloss, but to create a desired web surface topography. These calenders are used in the production of wallpaper, tissue and some other specialty papers and boards. Embossing can take place either with a hard nip or with a soft nip. In the hard-nip process, rolls with a special engraved surface rotate synchronously to compress the web. In the soft-nip process, rolls can also rotate independently, with engraving only in the hard roll.

4 Calendering process application areas

4.1 Wood-containing paper grades

4.1.1 Newsprint

Introduction

This section describes calendering concepts for newsprint grades. Today's newsprint furnishes mostly contain between 80 and 100 % deinked pulp (DIP). The rest of the furnish is mechanical pulp (typically TMP). However, there are *also newsprint made* of 100 % mechanical fibre furnishes. DIP *based newsprint* may contain up to 20 % filler. The filler content of a virgin-fibre based newsprint furnish is about 8 %. The grammage of newsprint is typically between 40.0 and 48.8 g/m². Newsprint with a grammage down to 25 g/m² is often produced for directories.

The way how newsprint is calendered is highly dependent on the printing method: coldset web offset (CSWO), heatset web offset (HSWO), flexo, or rotogravure printing. Standard newsprint is typically printed with CSWO and requires the lightest calendering conditions, and its surface roughness requirements are the least demanding. A typical Bendtsen roughness target for CSWO printing is about 150 ml/min. This equals a PPS-s10 roughness between 4 and 4.5 µm. The surface requirements for

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flexo printing are slightly tighter than for CSWO. For example, a smoother surface is required. The Bendtsen roughness is typically about 90 ml/min, equalling a PPS-s10 roughness of 3.5µm. Obviously, more intense calendering is required to meet the more demanding surface properties. HSWO printing requires an even more uniform surface, with a PPS-s10 roughness between 2.5 and 3.0 µm. For rotogravure printing even lower PPS-s10 values than 2.5 µm are required.

Calendering method

Newsprint is calendered with an on-line calender, traditionally a 4- to 6-roll hard nip calender. Linear loads are around 100 kN/m and thermal roll water temperatures are between 80 °C and 120 °C. These newsprint paper machines generally run at speeds between 1 100 m/min and 1 700 m/min.

There has been trend towards fewer calender nips and a lower linear load. This is because the structure of paper has become more mouldable (i.e., the use of DIP has increased and the freeness level has decreased), and smoothness properties after the forming and press sections have improved. In addition, the dwell time in soft calender nips has increased in comparison to that in hard nips.

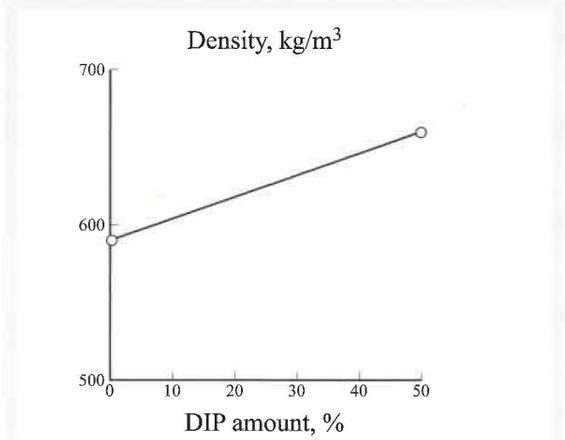


Figure 51. Density of paper as a function of DIP content. Constant calendering conditions[46].

Figure 51 shows the relation between the DIP content in the furnish and calendered paper density. When the DIP content increases, the calendered paper density also increases. Calendering running conditions are kept constant. This relates to the increased mouldability of paper.

The technology for calendering newsprint grades has gradually moved towards soft-nip calendering. Modern newsprint machines with soft-nip calenders run as fast as 2 000 m/min. A single-nip soft calender is a typical configuration for standard CSWO production using a 100 % DIP furnish. However, depending of the DIP content, the press section design, the running speed, or the targeted end quality, a two-nip soft calender may be required. The calender linear loads are typically below 100 kN/m and thermal roll surface temperatures between 80 °C and 150 °C. However, these conditions vary greatly depending of the above-mentioned factors.

TMP-based newsprint requires a two-nip soft calender as well as more intense calendering conditions than a DIP-based newsprint. Linear loads typically vary from 200 to 350 kN/m and the thermal roll surface temperature goes up to 200 °C. Similary, the conditions depend greatly on the furnish properties and the targeted end

quality (CSWO vs. HSWO). However, TMP-based newsprint is often used for low-grammage directory grades for rotogravure and HSWO printing. For TMP-based furnishes, steaming is often utilised to boost the calendering effect. Steaming has also been used very effectively in new paper machines with one-sided drying for curl control. With rough furnishes (e.g., southern pine) pre-calendering is also considered in the dryer section (breaker stack).

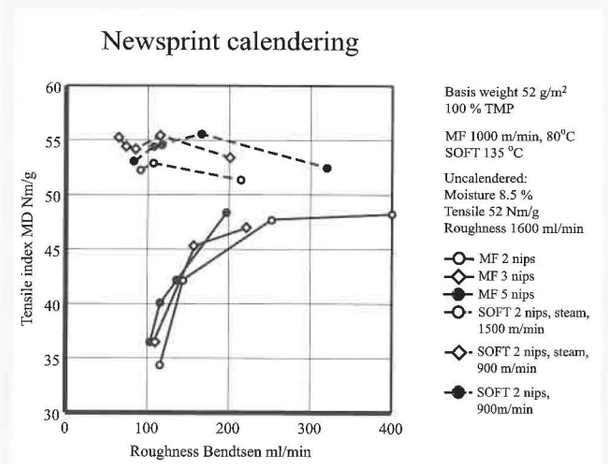


Figure 52. Tensile index of soft- and hard-nip-calendered paper.

Paper caliper control is an essential part of newsprint calenders. Traditionally, the CD caliper profile has been controlled by hot/cool air-jets, induction coils, and/or zone-controlled calender rolls. The latest individually zone-controlled rolls are capable of controlling the CD caliper profile without any external devices (Section 5.1.1, Zone-controlled rolls).

The advantages of soft-calendering newsprint are as follows:

- The strength of the soft-calendered paper is high compared to hard-nip-calendered paper at the same smoothness level, especially in smoother sheets. This is because the actual pressure in the soft calender nip is at a much lower level, causing less breaking of fibres, while also producing the correct temperature and moisture content to form new fibre bonds (Figure 52).
- Soft-calendered papers have less linting tendency and cause fewer problems in the printing process, since the higher temperature of soft calendering promotes fibre bonding. The paper surface density as well as ink absorption are very uniform, resulting in a less mottled printed image.
- Increased use of DIP in the newsprint furnish will lead to lower thickness, i.e., a reduction in bulk. Higher temperatures will allow the use of a lower linear load and thus preserve bulk.
- The paper can be left rougher and bulkier than hard-nip-calendered papers and still achieve the same printability.
- The blackening tendency is reduced at high moisture levels, so the moisture level can be increased.
- Soft calendering can also control two-sidedness of roughness by using different linear loads, temperatures, steam amounts, and roll cover hardnesses in individual nips.

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The trend is toward multi-grade processes that allow different paper grades, from standard newsprint to SC grades, to be produced on the same machine. New multi-nip calenders are a recent trend in newsprint calendering, especially in connection with paper machine rebuilds and when the aim is to upgrade product quality. Lightly calendered grades can be run though only one nip or with low linear loads in each nip throughout the entire calender stack (see the section "OptiLoad calender"). Polymer rolls have made elevated temperatures and high linear loads possible, enabling production of higher-quality grades on the same calender. Table 1 shows typical quality data for calendered newsprint.

Table 1. Typical quality data for calendered newsprint. Copyright of Metso.

Printing method for newsprint	Grammage, g/m²	PPS-s10 roughness, µm	Bendtsen roughness, ml/min	Density, kg/m³	Brightness, %	Opacity, %
CSWO	40–48.8	4.0–4.5	150	600–750	58–59	92–95
Flexo	40–48.8	3.5	90	750–900	58–59	92–95
HSWO	40–55	2.5–3.0	50	800–900	58–75	89–95
Rotogravure	28–55	< 2.5		800–900	56–75	86–92

4.1.2 SC paper

Introduction

SC grades usually contain 50 % – 75 % mechanical pulp, 5 % – 25 % chemical pulp, and 10 % – 35 % filler. The paper may also contain DIP. Typical grammage are 40–60 g/m².

Calendering method

SC paper is traditionally calendered with 10- or 12-roll supercalenders. Two or three off-line calenders can generally keep up with the production of one paper machine. Calendering speeds vary from 500 to 700 m/min. Linear loads are typically 300-400 kN/m and thermo roll water temperatures 80 °C – 120 °C. Paper two-sidedness can be controlled by reverse nip positioning, and by using different temperatures or steaming levels in the top and bottom parts of the calender.

Steaming of SC paper with steam showers is an essential part of supercalendering. Three or four steam boxes are usually installed in the calender stack to improve paper quality. The most recently installed steam boxes are zone-controlled and closed-loop gloss control enables good CD gloss profiles. Paper caliper is controlled with top and bottom deflection-compensated rolls.

SC-C and SC-B grades, which range between newsprint and smooth SC papers, can also be produced with two-nip soft calenders. The surface temperature is 160 °C – 200 °C and linear load up to 350 kN/m. Steaming is also an essential part in calendering of these paper grades.

Polymer covers and high temperatures have gradually entered supercalendering. The technology in this area is now moving toward multi-nip calenders. New

paper machines running in the near future at 1 800–2 000 m/min will require up to four supercalenders per paper machine. The polymer covers included in new calender design concepts enable higher calendering speed, temperature and linear load. The number of rolls for the most demanding grades is 10 or 12.

When calendering SC paper at higher speeds and temperatures, controlling the moisture is of primary importance. This is achieved through optimum moisturising of the paper surfaces by adding moisturising water during the calendering process. Originally, all the moisturising had to be done ahead of the calender at the end of the paper machine dryer section. The new moisturising system enables on-line calendering on SC paper machines. The effect of multi-nip calendering on paper quality is illustrated in Figure 53.

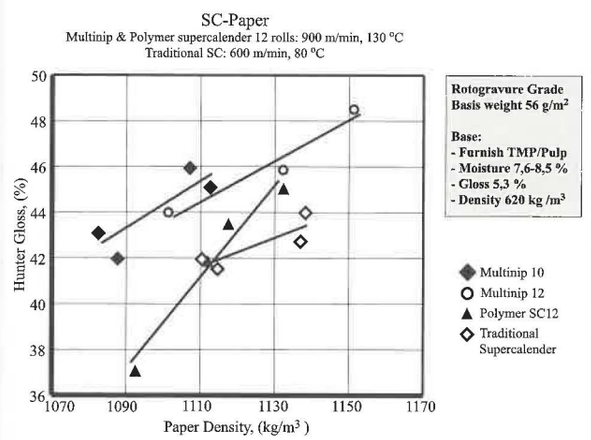


Figure 53. Hunter gloss vs. linear load with 12-roll traditional and polymer supercalender and 10- and 12-roll multi-nip calender.

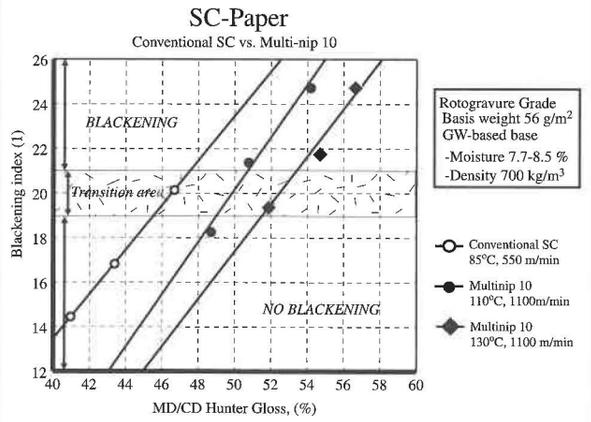


Figure 54. Paper blackening with conventional supercalender and multi-nip calender.

The new multi-nip calenders also provide new tools to control the blackening of SC paper. The desired calendering result should be achieved without impairing optical properties, brightness and opacity to any major extent. Good paper surface properties should be achieved without making the paper too dense, i.e. preserving the bulk of the paper. Multi-nip calendering reduces paper blackening compared to conventional supercalendering, as shown in Figure 54. Table 2 shows typical quality data for calendered SC papers.

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Table 2. Typical quality data for supercalendered papers.

	SC-C/ Improved news	SC-B	SC-A/A+
Grammage, (g/m²)	45–52	48.8–55	40–60
Ash, (%)	0–10	10–30	25–35
Hunter gloss, (%)	< 20	25–35	45–55
PPS S10 roughness, (µm)	2.0–2.5	1.5–2.1	1.0–1.2
Density, (kg/m³)	700–850	900–1 100	1 100–1 250
Brightness, (%)	62–64	62–67	65–75
Opacity, (%)	92–95	92–93	90–93

4.1.3 Coated wood-containing paper grades

Introduction

This section examines the calendering of wood-containing coated paper grades, such as MFC (machine finished coated), LWC (light weight coated), MWC (medium weight coated), and HWC (heavy weight coated) grades. Both film and blade coating methods are used for MFC and LWC grades. All new LWC machines installed during the past ten years have been film coating machines. MWC and HWC grades are typically blade-coated.

Calendering often includes precalendering before coating and final calendering of coated paper.

Coated mechanical papers usually contain 45 % – 75 % mechanical or recycled fibre and 25 % – 55 % chemical pulp. Semichemical pulps are typical in LWC paper grades made in the Far East. The filler content is about 5 % – 10 %. The grammage is typically in the range 40–80 g/m².

Calendering method

Precalendering

The target of precalendering is to reduce roughness and porosity to the required level before coating. Traditionally, LWC paper has been precalendered with a two-roll hard-nip calender comprising one water-heated roll and one deflection-compensated roll. The linear load varies usually from 10 to 40 kN/m and water temperature in general from 80 °C to 100 °C.

Another very important function of precalendering is caliper control. The same tools as in newsprint calenders are also used here.

Final calendering

Blade-coated LWC and MWC paper is traditionally calendered with two 10- or 12-roll supercalenders. Calender running speeds typically vary from 600 to 900 m/min. Linear loads are 300–350 kN/m and thermo roll water temperatures 80–120 °C. Film-coated LWC grades are generally calendered with 8- or 10-roll on-line multinip calenders. The linear load level is 250–400 kN/m and oil temperature 150–230 °C.

Matte paper grades are often produced by using only some of the nips of a super- or multi-nip calender. Paper caliper is controlled with the top and bottom deflection-compensated rolls.

Blade-coated machine finished coated (MFC) paper is being replaced more and more by film-coated satin grades, which are often produced with the same machines as glossy LWC papers.

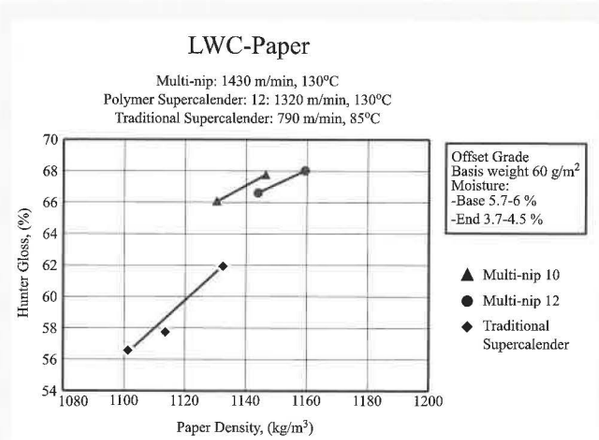


Figure 55. Hunter Gloss as a function of paper density with different calenders and running conditions.

Blade coated MFC is calendered with a two-nip on-line soft calender with relative mild calendering conditions because of the low gloss target for these grades. Roll temperatures are typically 70 °C – 90 °C and linear loads 70–120 kN/m. Film-coated satin grades are calendered using a low linear load level (80–120 kN/m) in a multinip calender.

Polymer covers and high temperatures are very useful in calendering LWC paper. The new multi-nip calender concepts allow remarkably higher running speeds, as shown in Figure 55. New paper machines running at 1 800–2 000 m/min need only one on-line multinip calender instead of 3–4 traditional supercalenders.

Table 3 shows typical quality data for calendered wood-containing coated paper grades.

Table 3. Typical quality data for calendered wood-containing papers.

	MFC and LWC Satin	LWC	MWC
Grammage, (g/m²)	48–70	40–70	70–90
Hunter gloss, (%)	25–40	50–65	65–70
PPS s10 roughness, (µm)	2.2–2.8	1.0–1.5 offset 0.6–1.0 roto	0.6–1.0
Density, (kg/m³)	900–950	1 100–1 250	1 150–1 250
Brightness, (%)	70–75	70–75	70–75
Opacity, (%)	91–95	89–94	89–94

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4.2 Woodfree paper grades

Woodfree paper is divided into two segments: uncoated and coated. The most common end uses of uncoated woodfree papers are office papers, different photocopy and printer papers, and book papers. Coated woodfree grades are also used in top-quality printed books and brochures. Conventionally, the furnish of woodfree papers consists of bleached chemical pulp, with less than 10 % mechanical pulp.

4.2.1 Woodfree uncoated papers

Introduction

This section describes calendering of woodfree uncoated (WFU) paper grades, such as office papers and copy papers. The end uses of copy and printer papers differs remarkably from those of conventional printing papers. Dimensional stability and non-curling behaviour in one-side heated printers is critical. Also, four-color printing demands a good surface finish. Because these grades are uncoated, the calendering finish must be accomplished by compressing the individual fibres and the fibre network to specified quality targets.

Calendering method

WFU grades are usually calendered with an on-line hard-nip calender operating with one or two nips. The typical running speed of a PM producing WFU is moderate, around 900–1 200 m/min.

Soft calendering is the preferred technology for WFU grades. The advantages obtained by using a soft calender instead of a hard-nip calender are briefly listed below (for a more detailed list of advantages, see the section on "Wood-containing paper grades"):

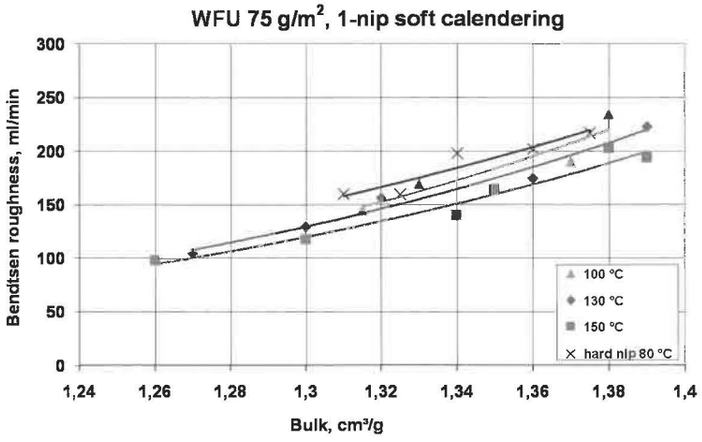


Figure 56. Soft calendering and hard-nip calendering of WFU 75 g/m² copy paper. Copyright of Metso.

- better control of two-sidedness
- bulk is preserved at a constant smoothness level
- better surface strength
- higher surface smoothness achievable without unevenness.

Figure 56 shows Bendtsen roughness of paper as a function of bulk for soft and hard-nip calendering. In this case, hot soft calendering gives roughly 40 ml/min smoother paper at constant bulk than hard nip calendering. Table 4 shows typical quality data for WFU papers.

Table 4. Typical quality data for standard copy, offset and four-color copy paper.

	Copy	Offset	Color copy
Grammage, (g/m²)	70, 75, 80	60–240	100
Bendtsen roughness, (ml/min)	150–250	100–200	~50
Bulk, (cm³/g)	>1.3	1.2–1.3	1.1

A new potential calendering method for woodfree uncoated papers is metal belt calendering. If a hard-nip or soft calender is replaced by a metal belt calender, significant benefits in bulk and stiffness can be achieved at a constant print quality level, or better printed quality at the same bulk. Metal-belt-calendered paper has also provided very good roughness values measured with the touch and feel method. This method is based on an expert panel evaluating the feel of paper samples as well as the degree of difference between them. According to touch and feel panelists, papers calendered with a metal belt calender feel smoother than samples calendered with traditional

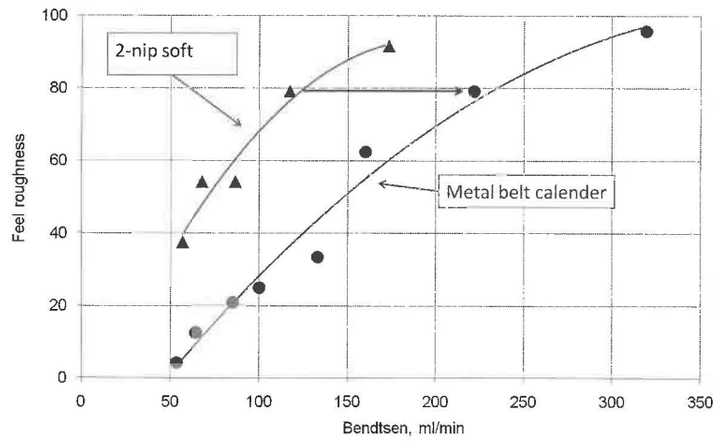


Figure 57. Feel roughness of soft-nip-calendered and metal-belt-calendered WFU papers. Copyright of Metso.

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calendering techniques at the same Bendtsen roughness level (Figure 57). For more information about this new calender, see the section "Metal belt calender". The touch and feel method is described in the Volume 13, Print Media – Principles, Processes and Quality, of this book series.

4.2.2 Woodfree coated papers

Introduction

Woodfree coated (WFC) printing papers are used for demanding printing applications like art books, brochures and annual reports. The end-use requirements of the paper determine the amount of coating colour applied, gloss targets and other special characteristics. WFC grades can be single-, double-, or triple-coated. The total coating layer can be up to 40 g/m² per side. In WFC production, precalenders are used before the coater in order to calender the surface for coater-specific requirements. The final surface finishing can be matte or glossy. Some of the grades are used either in sheet format or reels. All these variations in paper structure, surface finish, and format have an impact on the calendering configuration used to reach the grade-specific quality targets.

Calendering method

Precalendering

The target of precalendering is to reduce roughness and porosity to the required level before coating. Traditionally, WFC precalendering has been done with a two-roll hard calender comprising one water-heated roll and one deflection-compensated roll. The linear load typically varies from 10 to 40 kN/m and temperature from 80 °C to 100 °C. Soft calendering technology is also increasingly used as a precalendering method because of its good two-sidedness control and calendering results. Softcalendering is often done between the pre- and topcoat.

Final calendering

The most common calendering process for WFC grades is supercalendering or multi-nip calendering. Typically, one or two off-line calenders are able to cope with the production of one paper machine. Running speeds of the calenders vary from 500 to 1 500 m/min. A matte finish can generally be achieved with on-line calendering in a coating or paper machine, or using only some of the nips in the multi-nip calender.

Glossy grades

New multi-nip calenders are the upcoming technology in calendering WFC grades. Elevated temperatures together with polymer-covered soft rolls and sophisticated loading systems help to reduce the linear loads needed to reach quality targets, resulting in bulk savings[47–50].

With new multi-nip calenders, WFC grades can be produced with many different calender layouts. Figure 58 shows the calender application area for WFC grades. A modern calender can meet production targets using 8- to 12-roll layouts. The selection of the most suitable option must be based on quality, since quantity is no longer

an issue. The calendering parameters of an 8-roll calender are somewhat different from those of a 12-roll unit handling the same production: more load and heat are required with the 8-roll stack.

Elevated temperatures in calendering WFC grades produce quality benefits in terms of higher gloss at constant bulk, as can be seen from Figure 59. Comparing a standard supercalender operating with filled rolls and 80 °C temperature to a modern multi-nip calender with polymer rolls and higher temperature, an increase of 4 % – 5 % Hunter can be seen at a constant paper density level.

In some cases, there has been a brightness loss with high-temperature calendering. This risk can be eliminated by keeping the windup paper temperature low enough (35 °C – 45 °C).

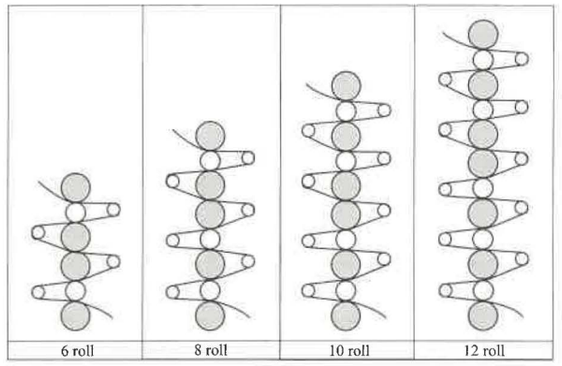


Figure 58. Multi-nip calender applications for WFC calendering.

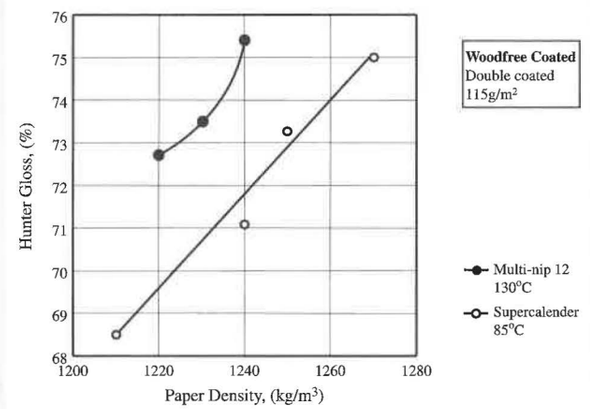


Figure 59. Effect of calendering method on density-gloss curve.

The effect of soft-covered rolls in WFC calendering is very important. The target is to avoid excessively high-modulus covers, i.e., a nip that is too hard. Suitable covers are normally between 88 and 91 ShD. The rule of thumb in covers for WFC is "the softer, the better". A cover that is too hard can cause uneven calendering (gloss mottling). This also relates to the formation of the paper. The better the formation, the lower the risk of uneven calendering when using a harder (higher-modulus) cover.

In Europe, steaming is not used in WFC calendering, whereas in North America steam is used to fine-tune gloss two-sidedness and profiles. Only low steam amounts, under 20 kg/h/m, can be used without the risk of losing the coated layer and causing runnability problems.

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During the last couple of years, on-line multi-nip calendering has been introduced in WFC calendering. Coating and moisture streaks are challenges in on-line calendering. The streaks may cause build-up on the rolls, resulting in more downtime on the paper machine due to extra heating, cooling and cleaning time. In the worst case, the streaks may cause a hot spot in the polymer cover and finally break the cover.

Matte grades

WFC matte grades account for a growing proportion of all WFC production. Typically, the gloss level is kept under 35 % Hunter. The human eye sees paper as matte when the gloss level is less than that. It is not critical to minimise the gloss; it only has to be low enough. To achieve this matte finish, the calendering work has to be reduced, generally by making use of only a few nips. For the same reason, the calendering temperature is low. A matte finish is traditionally produced by an on-line soft calender equipped with two soft rolls forming the nip. Another common solution for matte production is to use a multi-nip calender with a special web run where some of the nips are bypassed.

The target in matte calendering can be expressed in terms of paper gloss and smoothness. The object is to maximise the smoothness while minimising the gloss. In matte production, the coating colour formulation plays an important role. Selecting the right components for the coating colour recipe is an easy way to influence the gloss/smoothness ratio of calendered paper. Plate-like pigments, such as clay and easily gloss-forming pigments such as plastic pigments, are not used in matte colours. Figure 60 shows the effect of carbonate particle size on the gloss/roughness ratio. By adding finer carbonate in the coating colour the paper gloss can be increased by about 15 % Hunter at a constant roughness level.

In matte production, the softness of the nip becomes the critical calendering parameter. Since the paper is only slightly calendered, low linear loads are required to reach quality targets. If the nip is too hard, i.e., the elastic modulus of the soft cover is high, gloss mottling can occur.

The new multi-nip calenders also serve as a good tool for matte production. Using the full benefits of new loading systems, a multi-nip calender can be run with low enough calendering work on the paper, not overglossing the paper finish. The quality of WFC papers is more commonly judged on the basis of the printed visual appearance rather than blindly following the measured paper properties. High-brightness WFC grades compete against coated mechanical grades. However, WFC grades usually have lower opacity. Some key quality data are presented in Table 5.

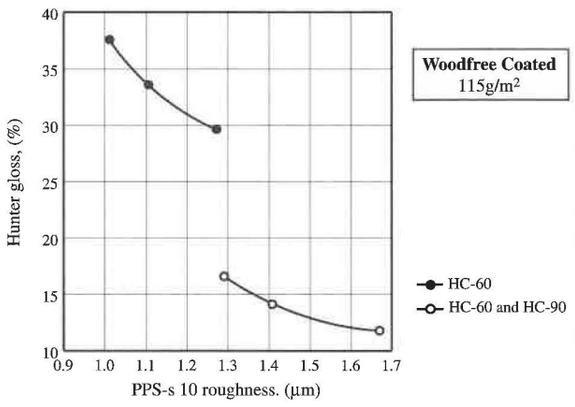


Figure 60. Impact of coating colour recipe on paper gloss/smoothness ratio after calendering.

Table 5. Typical quality data for WFC grades.

	Single-coated	Double-coated
Grammage, (g/m²)	90	130
Hunter gloss, (%)	65–80	70–80
PPS-s10 roughness, (µm)	0.75–1.1	0.65–0.95
Brightness, (%)	80–88	83–90
Opacity, (%)	91–94	95–97

4.3 Containerboards

Introduction

Containerboard includes both linerboard and corrugating medium. This section concentrates on different liners, since calendering is not needed with corrugating medium. Liners are divided according to their furnish base into kraftliner, recycled liner and white top liner. Liners are typically 1- to 3-ply boards with grammages varying in the range 100–300 g/m².

Linerboards are generally uncoated, but the production of coated white-top liner is increasing to meet higher demands for printability.

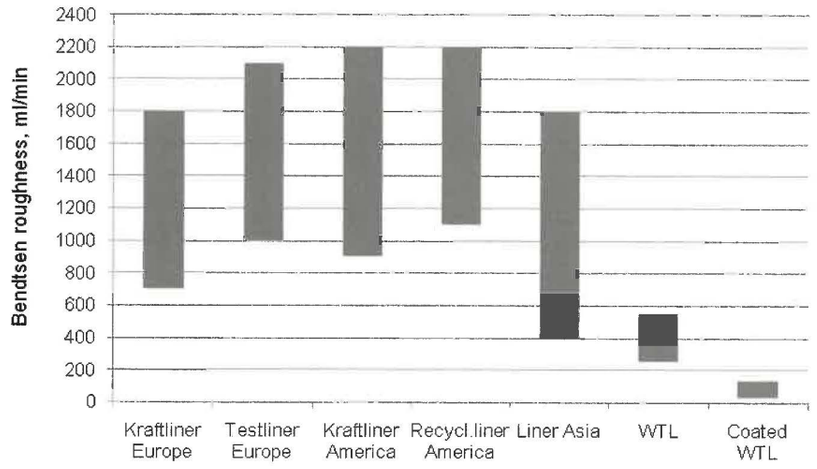


Figure 61. Roughness level of different liner grades. Copyright of Metso.

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Containerboards are used for packaging purposes. The surface properties of liners are tailored to their end use. Other requirements are good strength properties, stiffness and convertability.

Calendering methods

The need for calendering can vary widely depending on the target roughness level and printing method. Liners are non-homogeneous group with big variations in roughness, see Figure 61. Hard-nip calenders have traditionally been used for calendering liners. The appearance and advertising function of corrugated packaging has become more and more important. This has boosted, for example, the demand for better-surface white top liner. For this reason, soft calenders are used with linerboard grades where good printability is needed. The production of coated liner includes both precalendering and soft nip final calendering, see Section 4.4. The trend in linerboard calendering is toward higher calendering temperatures, both with hard and soft nip calenders. Steaming or water spray moisturising ahead of the calender can be used to further improve the calendering result.

4.4 Cartonboards

4.4.1 Introduction

The main cartonboard grades are folding boxboard (FBB), white-lined chipboard (WLC), solid bleached board (SBS) and liquid packaging board (LPB). In general, these grades are typically used for different kinds of packaging of consumer goods. Carton board grades vary from one- up to five-ply boards (150–400 g/m^2). The top side is usually coated with from one to three layers (20–40 g/m^2). The board is normally one-sided, so the back side has less coating or no coating at all. The most important properties are high bulk, stiffness and smoothness. There is a wide range of different quality data for the same board grade. Figure 62 shows typical PPS roughness and bulk data for coated board grades. FBB has the highest bulk thanks to the mechanical or chemimechanical pulp used in the middle layer of the base board. The middle layer of WLC consists mainly of recycled fibre, whereas SBS is made from chemical pulp, exclusively.

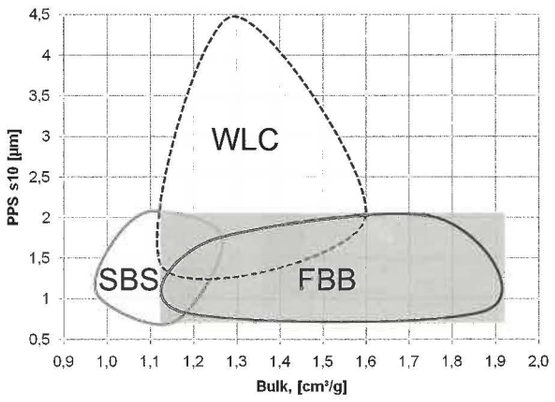


Figure 62. Typical bulk and PPS s10 roughness values for coated board grades. Copyright of Metso.

Calendering configurations for coated board grades are very different compared to those

for coated paper grades, (e.g. WFC or LWC). A basic difference is that coated paper grades are produced with light precalendering, leaving most of the smoothening to take place in final calendering (e.g in a multi-nip calender). In contrast, cartonboards are calendered relatively heavily before coating and final calendering after coating can be very light or there is no final calendering at all.

4.4.2 Precalendering before coating

Precalendering is used before the coater to reduce roughness and porosity to coater-specified target levels. CD caliper control is also important. Precalendering configurations for coated cartonboards are listed below. Different types of precalender are illustrated in Figure 63.

- hard nip (after yankee cylinder)
- heated hard nip
- heated soft nip
- wet stack
- shoe + hard nip
- metal belt calender.

European FBB or WLC machines are generally equipped with a Yankee cylinder (also called MG cylinder). The Yankee cylinder produces a relative smooth surface in the drying section, so a board machine with a Yankee does not need an effective precalender. Precalendering is usually carried out with one hard-nip calender before the

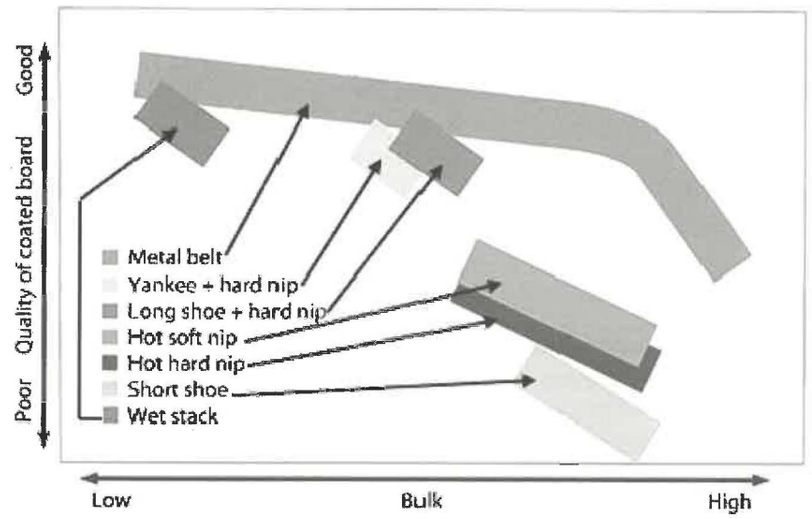


Figure 63. Typical precalendering operation windows of coated board grades. Copyright of Metso.

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coating section. Linear loads are typically very low, from 10 to 30 kN/m, and thermo roll surface temperatures are 70–100 °C.

A modern cartonboard line as a rule has one hot hard-nip precalender before the coating section, especially in Asia. High thermo roll temperatures (in some cases over 200 °C) result in bulk savings because of the temperature gradient. The linear load may even exceed 100 kN/m. The quality of coated board using only hard-nip calendering is not as good as with a Yankee-equipped machine. However, the benefit of hard-nip precalendering is good efficiency of the board making line. The drying section with only hard-nip calendering (without a Yankee cylinder) is more efficient and easier to run. On-line moisturisers or steam dampeners can be used before the hard nip. Hot soft calenders are also being used as a precalender for board, but soft nips are less common than hard nips.

Wet-stack calendering (see Section 3.7.1) is the traditional precalendering method, especially in the United States and Europe. The number of rolls varies from 4 to 11, depending on the board grade. Easily calendered European fibres do not need as many nips as rough and stiff southern US fibres. Wet-stack calendering is used only with virgin fibre (typically SBS board or coated brown board). However, problems of wet stacks include varying runnability and the need for drying before and after the wet stack. Because of these problems, some wet-stack calenders have been replaced by normal hard-nip calenders, with or without a moisturiser.

In some cases, the Yankee+hard-nip configuration has been replaced by shoe-nip and hard-nip precalendering (see Section 3.5). The main benefit of the shoe+hard-nip configuration, compared to the Yankee, is better efficiency of the cartonboard line. The quality of shoe+hard precalendering can be as good as that of yankee+hard-nip calendering. The surface temperature of a shoe calender can be over 200 °C and shoe length more than 150 mm.

The metal belt calender (Section 3.6) is the latest innovation in precalendering of coated cartonboards. Metal belt calenders can replace Yankee+hard-nip, wet-stack or hot hard-nip precalendering. The runnability and efficiency of the board making line are much better with a metal belt calender than with a Yankee or wet-stack machine. The quality and/or bulk of coated board are high as well. Surface temperature in metal belt calendering typically varies in the range 130–170 °C and linear loads in the range 10–70 kN/m.

4.4.3 Final calendering

Final calendering of coated carton boards is as a rule done with hard-nip or soft-nip calenders. In some cases there is no final calendering at all after coating (e.g. WLC, LPB). Thermo roll temperatures can be 100–200 °C. Lower temperatures are used with matte grades. The linear load typically varies from 10 up to 150 kN/m. In general, WLC and FBB grades need less final calendering than SBS.

Many years ago, brush calenders were used as final calenders. However, brush calenders are almost extinct because of their high running costs and dust problems. The gloss calender is another early type of calender. This calender was the predecessor of today's soft calenders, which give much better uniformity than hard-nip calenders. The gloss calender has a rubber roll as a soft roll, and thermo roll temperatures are relatively low. The thermo roll is a chrome-plated steam- heated cylinder. Nip loads are lower than in modern heated soft calenders.

4.4.4 Uncoated liquid packaging board

Uncoated liquid packaging board (including cup board) is the most important uncoated cartonboard grade. Containerboards, described in Section 4.3, are other major uncoated board grades. As in the calendering of coated cartonboards, the calendering of uncoated liquid packaging board calendering must save bulk and stiffness. Traditionally, wet-stack calenders and hard-nip calenders have been used for calendering of uncoated liquid packaging board. However, shoe-nip and metal-belt calenders are used today for calendering liquid packaging board. The benefits of shoe and metal belt calenders are higher bulk and stiffness.

4.5 Specialty papers: Release and coated label paper

4.5.1 Introduction

Release paper is used in label base paper in various end-use applications, such as food packaging and office labels. The most common release paper in Europe is supercalendered glassine paper coated with silicone to provide good release properties. Table 6 shows typical paper properties for supercalendered release paper.

Table 6. Typical paper properties for supercalendered release paper.

Paper properties	Europe 60–65 g/m²	Europe 80–90 g/m²
Caliper (µm)	55–57	71–79
Density (kg/m3)	1 080–1 200	1 150–1 250
IGT cm	12–14	13–15
Cobb Unger (g/m2)		
dense side	0.9–1.4	1.0–1.6
open side	1.2–2.5	1.8–2.2
Transparency	45–55	40–45

Critical release paper properties affected by calendering are good silicone hold-out (high density and smoothness), even absorption of silicone, and an even caliper CD profile. Also, in some grades, high transparency is needed.

Coated label paper is used as face paper for release, but also for coated backing paper and flexible packings. Coated label paper has a grammage of 60–120 g/m² and is typically sized or precoated with a sizer and single-blade coated on one side. Table 7 shows typical paper properties for coated and calendered label paper.

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Table 7. Typical paper properties for coated and calendered label paper.

Paper Properties	
Grammage (g/m^2)	50–100
Hunter gloss (%)	70–85
PPSs10 roughness (µm)	0.6–1.0
Bekk smoothness (s)	1 500–2 000
Caliper (µm)	45–90

Coated label paper needs to have excellent caliper uniformity for converting, because the die-cutting tool has to penetrate the label fully, but not the base paper.

4.5.2 Calendering method

Release paper is typically calendered with off-line supercalenders. The typical number of nips ranges from 11 to 17. There is no reverse nip because only one side is treated (silicone side). The soft rolls can be paper or polymer. Thermo roll surface temperatures vary from 90 °C to 140 °C. The maximum linear load in the bottom nip is 450–500 kN/m. Paper is moisturised before the paper machine reel to achieve a high moisture content, from 15 % to 20 %. This is needed to gain high density and a closed surface. Because of the high incoming moisture, drying is needed after the calender. Air dryers are generally used. The final moisture is from 5 % to 7 %. The typical running speed varies from 300 to 500 m/min. Two supercalenders are needed for one release paper machine.

Multi-nip calendering of release paper has become possible because today's polymer rolls can withstand high linear pressures and load cycles. Modern steel thermo rolls also bring high heat energy to the process. Multi-nip calenders typically have 11 nips and running speeds are in the range 700–1 100 m/min. One or two multi-nip calenders are needed for one release paper machine.

Label paper for standard backing and face papers is precalendered with a single hard or soft nip before coating. Final calendering is done with an on-line hot two-nip soft calender. Thermo roll surface temperatures vary from 90 °C to 120 °C and the maximum linear load is 200–300 kN/m. Rotogravure grades are calendered with an off-line supercalender or a multi-nip calender. The supercalender generally has 11 nips, whereas the multi-nip calender has 5 to 9 nips. There is no reverse nip in these calenders. Calendering speeds vary between 800 and 1 300 m/min.

5 Calender construction

5.1 Calender frames and loading

The main function of the calender frame is to support the rolls and roll stack and to connect the construction to the foundations. Calender frame designs can be divided into two different types: open frames and closed frames. In soft calenders both types of frame are common, whereas in supercalenders and modern multi-nip calenders the open frame design has been the most common. The main factors determining the type of frame in soft calenders are the linear load, web width and web speed. At the

same linear load, a wider web width will generate more load into the frame construction. A higher web speed will also require bigger and heavier rolls, thus requiring a stronger frame construction. The closed frame design enables designing a more rigid frame for wide and high-speed soft calenders, while requiring less space. The closed frame constructions in the market are Metso's OptiSoft SlimLine, Küsters' Mat-On-Line and Voith's EcoSoft Delta. The most common frame design in soft calenders for lower production speeds and narrow web widths is the open frame. The advantages of an open frame in this category include the frame size and manufacturing cost.

Supercalender frame constructions have developed from the early closed A-type frame (Figure 64) to modern open-type multi-nip calender frame designs. As the production capacity of paper machines has increased as a result of higher speeds and greater web widths, the calendering capacity has had to be increased accordingly. Downtime during roll changes and maintenance has become a significant factor in determining calendering capacity. The main reasons for the change from the closed A-type frame design to the open-type frame have been the need for more frequent change of filled rolls and to minimise the roll change time. The increase in calendering capacity due to greater web widths and higher production speeds has led to bigger and heavier rolls. When handling large-diameter heavy rolls in a closed A-type frame, strict attention has to be paid to protecting the roll cover when removing filled rolls sideways through the frame construction. Because of its evident advantages during a roll change, the open frame construction has become common in supercalenders and more recently also in modern multi-nip calenders.

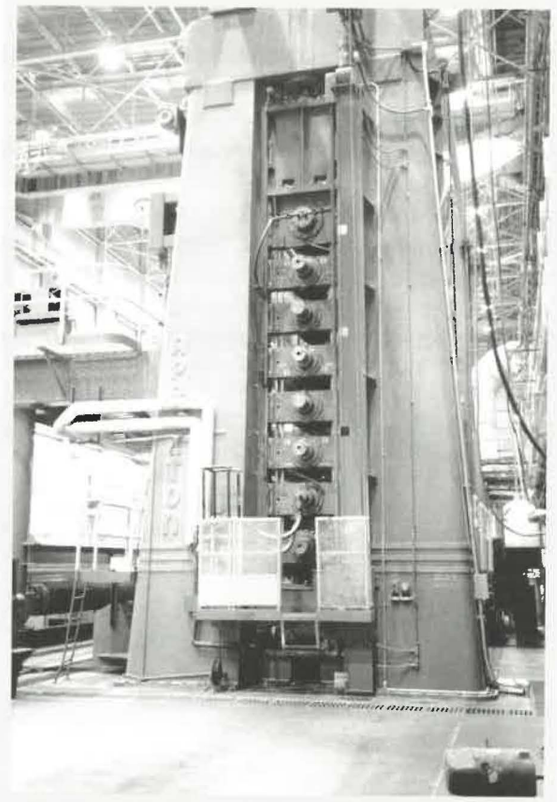


Figure 64. Closed-frame supercalender.

Modern multi-nip calenders feature two main types of roll stack design: vertical and inclined. Metso and Andritz Küsters have based their multi-nip calender technology on a vertical frame and roll stack design. Voith Paper's Janus MK 2 multi-nip calender represents a different type of design, where the frame and roll stack are inclined at a 45-degree angle. Metso's OptiLoad multi-nip

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