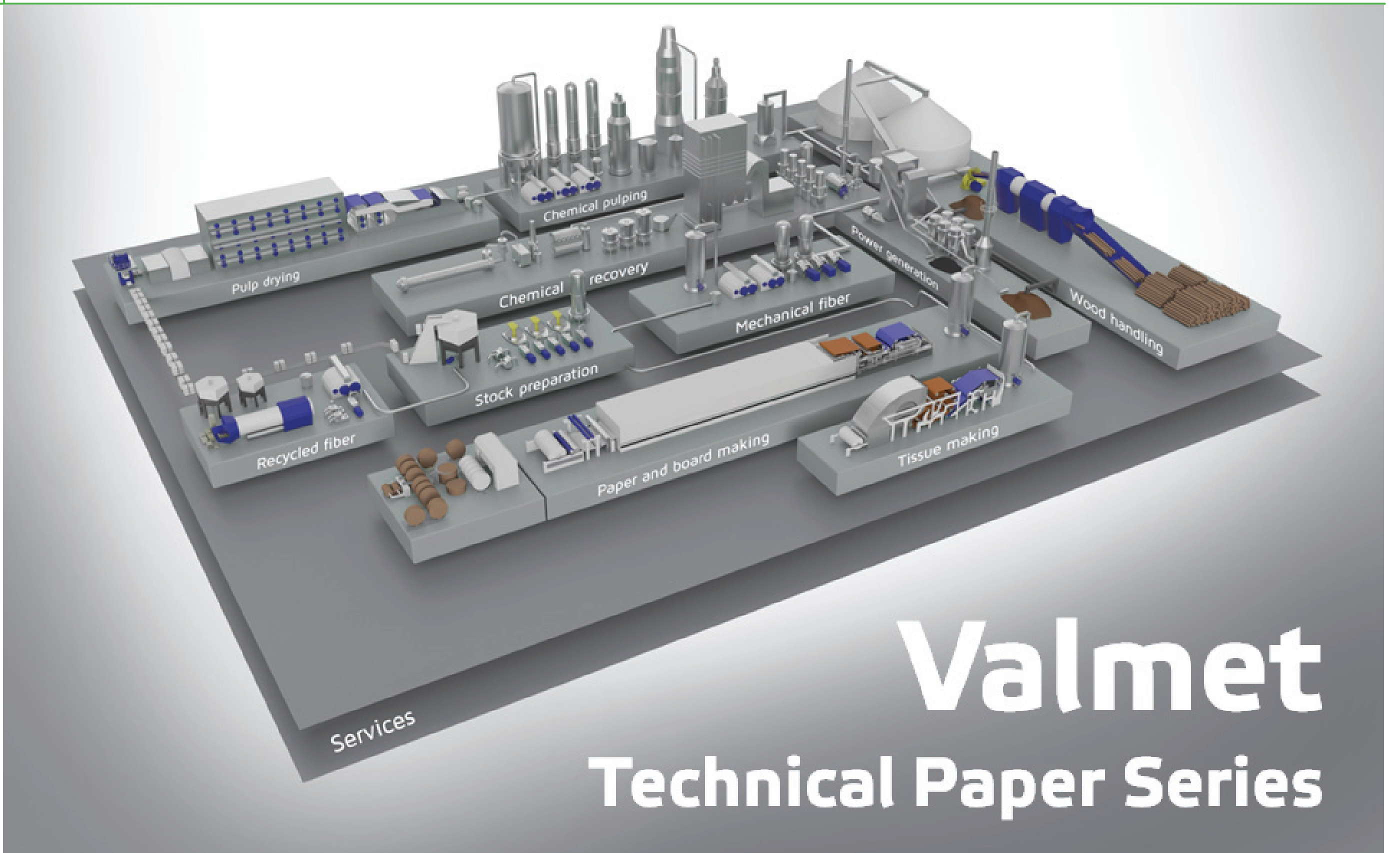

iRoll™ - the intelligent roll

Executive Summary

Valmet's intelligent roll, iRoll, is a mechatronic system consisting of a roll in a web handling machine that also is used as a transducer for sensing cross-machine tension or linear load. The iRoll has force sensors mounted on it in a helical arrangement. The sensors measure the force applied by the material being produced, such as a paper web, and thus provide information about the behavior and quality of the product. In addition to the force sensors, the iRoll system has an electronic signal processing module on the roll end and a digital radio link to transmit the data from the rotating roll. The receiver is connected to an automation network.

iRoll can be used to measure the tension profile online without separate scanning devices. iRoll used as a reel or winder drum enables online measurement of linear load profiles during reeling and winding. iRoll technology also enables temporary process and runnability analysis measurements by using tape-mounted sensors. Problems such as loose web edges, off-machine coater web shifting, winding problems, and reeling defects have been solved with these measurements. This paper describes iRoll technology and presents examples of its application to improve process runnability.

Need for reliable, accurate tension measurement

In reeling, the flat paper web is wound into a compact coil form to move all the production of the paper machine to the winding stage. When the reeling process is well tuned, the transfer of paper seems to almost happen by itself. Also, the runnability of winders is good and final customer rolls can be produced without defects. However, reeling is a cumulative process where paper layers are set on top of each other. Thus defects, such as profile variation, may coincide and their effects are magnified in the paper roll. A proper control of CD profiles, especially caliper but also tension profile is a basic element of successful reeling.

Roll defects such as wrinkles, corrugation and hard edges, caused by cross machine profile errors become more evident as the less compressible paper is wound onto the roll. One possible resolution could be to decrease sheet tension at reeling and make softer rolls. However, a roll which is too soft can partially collapse and become non-uniform in shape. Also, decreased friction between paper layers generates roll slippage. This can be seen in various defects, such as telescoping and other sheet offsets as well as crepe wrinkles.

Figure 1. iRoll installed in a tension measurement application.

Profile errors also affect accumulation of air under the topmost paper layer of a paper roll. Dense low porosity papers are especially sensitive to air accumulation. In many cases one can run the paper machine with a stable air bubble before the reeling nip. However, the topmost paper layers are not stabilized and an air bubble hitting against the tight part of the roll easily creates foldovers and wrinkles. Proper control of the cross machine calender load profile has been successfully used to totally eliminate the accumulation of air.

Traditional controls of paper profiles for reeling purposes have been based on visual observations of reel defects and manual measurements of the reel hardness profile. Hardness measurements are done by hitting the roll with a wooden stick or by instrumented impact devices. The received information is used to manually change calender load profiling or basis weight profiles. In the best case, manual profile control gives a sufficient result. However, the feedback is slow. Thus, reaction time to process changes such as grade changes, restarting after shutdowns and wear of machine parts, is slow. A paper maker may lose several parent rolls before the manual process completes.

There also are profile controls based on online measurements of the paper web. Caliper is used the most but also gloss is sometimes applied to control runnability of reeling. Typically, caliper measurement is problematic especially with dense and low basis weight paper grades like SC and LWC. The required precision, in the order of 0.1 µm, is demanding. Any fluctuations of the sheet as well as dirt accumulation on the measurement head create inaccuracies in the measurement. In some cases caliper heads also are prone to create holes into the paper web. One could expect that in the case of caliper control a papermaker requires a continuous service program for the measurement - and still it would be demanding.

The problem of gloss control is the fact that gloss is not a parameter of reeling. In many cases process parameters which affect gloss such as calender load, also correlate with the main parameters of reeling (caliper, tension). However, there are multiple cases where the correlation does not exist. Therefore, the control of reeling after gloss measurement is pretty uncertain and requires continuous follow-up of the situation. In addition, gloss measurement also heavily suffers from sheet flutter. It is difficult to adjust the measurement such that all paper grades in one machine show the correct result.

Figure 2. iRoll control off (left) and on (right)

Traditional tension measurement insufficient

Variations in the tension profile of a web adversely affect runnability in web handling processes. In papermaking, these variations can lead to web breaks, flutter, wrinkles, and calender cuts. In printing, tension profile variations can cause web breaks, wrinkles, and color registration errors. Historically, profiles such as basis weight, moisture, and caliper were measured and controlled in the paper-making process. However, tension profiles did not attract much attention until the late 1980s and early 1990s.

As a result of the interest in tension profiles, a variety of sensors were developed. Longitudinal (machine direction, MD) web tension has typically been measured with a roll mounted on load cells; one load cell at either end of the roll. This arrangement provides a signal that represents the average value of the MD tension but provides no information about the tension profile. A small improvement on this setup can be achieved by mounting multiple load cells under the bearing housings of sectional rolls. Perhaps a half dozen discrete tension levels can be measured in the cross-machine direction (CD) using this method. However, costs rise significantly as additional bearings and load cells are required and resolution is approximately 1 m. In addition, proper calibration and interpretation of the signals can become confusing. Other tension measurement methods (Eriksson three load cell arrangement, ABB Tenscan method, Hellentin CTSensor, etc.) have specific drawbacks related to portability, accuracy, usability and reliability.

Due to the problems of sheet measurement it is straightforward to control reeling based on direct reel measurement. Manual measurements are slow and tedious. Thus, online measurements have been developed. One is the so-called "*backtender's friend*," which measures reel hardness and reel diameter profiles with an external roller. Another method is the pressure measurement of the reeling nip, which is called iRoll. The nip pressure depends on contact between the reeling cylinder and the paper roll. Thus pressure is defined by roll hardness and roll diameter.

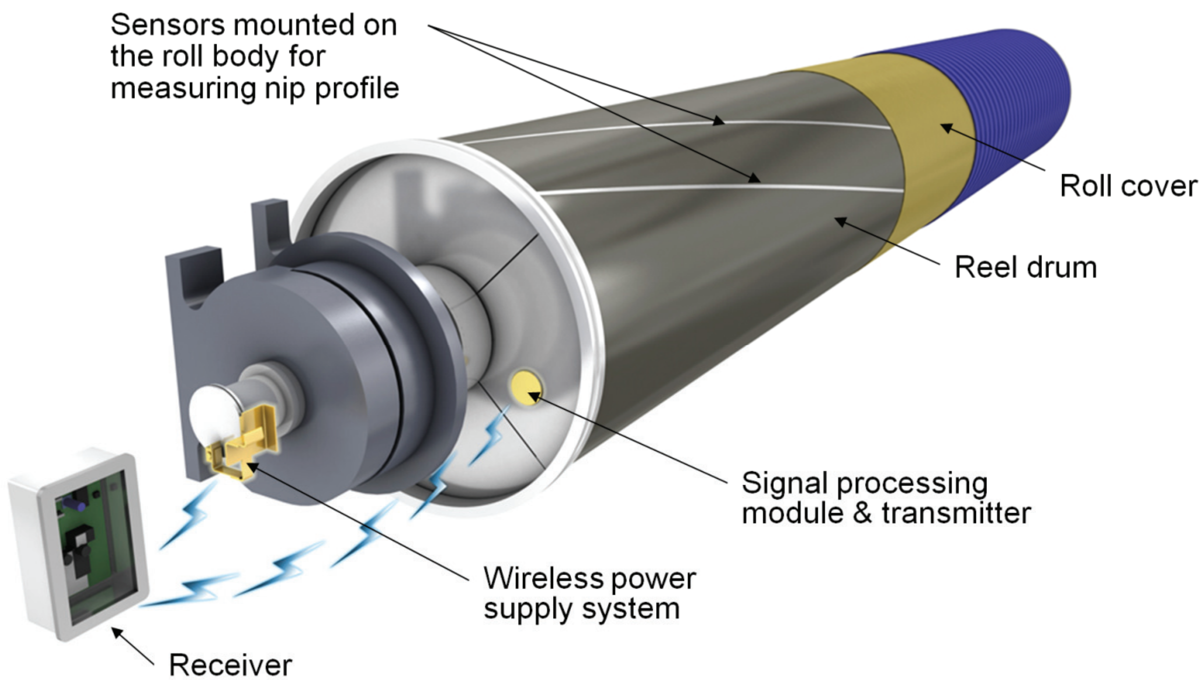

Figure 3. Principle of iRoll measurement

iRoll fills the need for tension and nip load measurement

The principle of iRoll measurement is shown in **Figure 3**.The nip pressure signal is measured with force sensitive film sensors. Sensors are laminated into the cover structure of the reeling drum in spiral form to measure the local pressure of the cross machine profile. The raw signal is amplified, synchronized and sent to a central data unit by a wireless link.

The iRoll "intelligent roll" is a mechatronic system consisting of a roll in a web handling machine that also is used as a transducer for sensing cross-machine tension or linear load. It is a robust sensing system that has been in use for three years and can measure loads up to 50 kN/m. iRoll can be calibrated quickly in units of linear load by applying a known nip load and scaling the output accordingly. This can be done automatically by the control system in permanent installations. Calibration can also be verified with nip impression paper. Once calibrated, the output is very stable and only needs to be checked once per year as part of normal preventive maintenance. iRoll also is not speed limited, its output signal is independent of basis weight, the resolution is approximately 50 mm, and it requires no machine-direction space for mounting.

iRoll consists of a high-precision roll with helical grooves machined in the shell, force-sensitive electret film sensors mounted in the grooves, a roll cover, signal processing electronics, a digital radio transmitter, wireless power transmission, and a receiver connected to the mill automation network. There are practically no external devices with the iRoll concept, which makes it very convenient, easy-to-use and maintenance free. A portable version of this system, which is easily transported, uses the same technology for temporary measurements.

iRoll creates new possibilities for optimizing the runnability of a web handling process. iRoll can be used in place of a tension roll to measure web tension profiles online. Unlike previous tension profile measurement devices, however, the same technology can be used for nip load profile measurement. iRoll can be used in place of a reel drum to measure the nip load profile and the roll profile online. This capability facilitates the online control of roll profiles and web tension profiles in permanent installations. The portable version of this system allows almost any roll to be converted into an intelligent roll by using tape-mounted sensors. This technology enables temporary roll profile, nip load profile, and tension profile analysis to be performed by field technicians. In this manner, economic benefits can be achieved by solving difficult problems without major capital investments. iRoll eliminates the need for external measurement devices such as scanners and their associated space requirements. iRoll acts like a conventional roll in the process, making it possible to measure how the web tension or nip profile behaves online in real time. Moreover, it can be located in various positions in the process, wherever the tension profile is critical or the nip-paper roll profile needs to be measured. The portable system enables the line to be equipped with several profile measurements simultaneously.

Implementations of the iRoll

The iRoll intelligent roll system can be installed in one of three ways: as a permanent nip load measurement tool, as a permanent tension profile measurement tool, or as a temporary nip load and/or tension measurement tool. For permanent iRoll applications, it must be used in conjunction with a compliant cover.

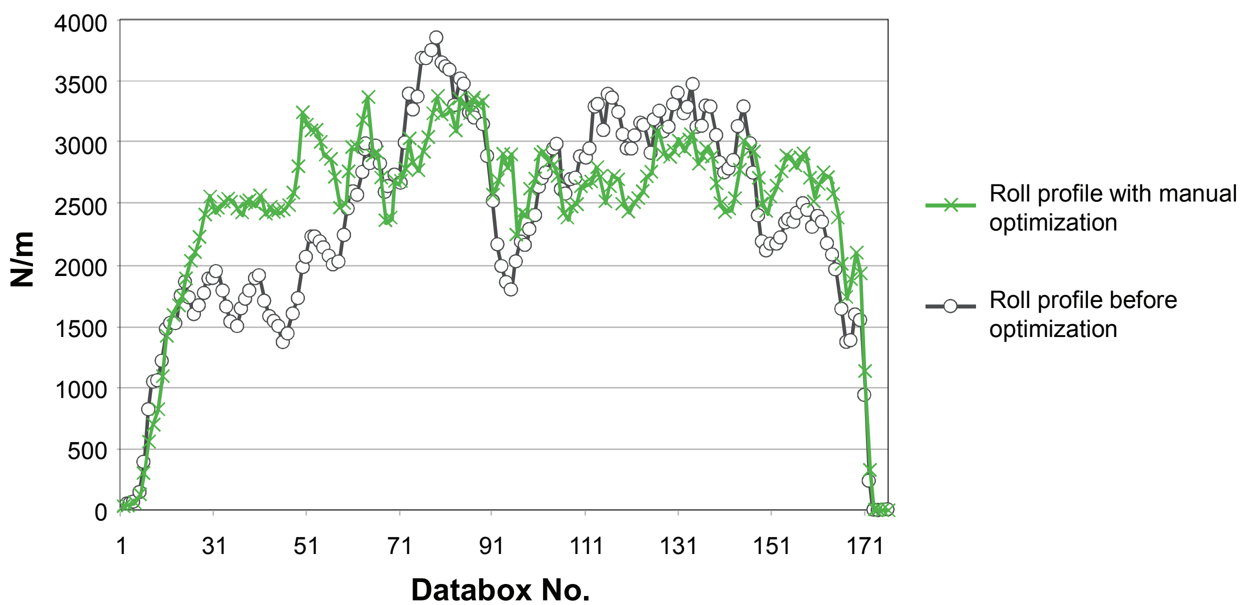

Figure 4. Example of a reeling nip load profile that shows peaks and valleys in the roll caused by variations in the caliper profile. The optimized profile (green) was measured after manually adjusting the zone controlled roll on a multinip calender.

Nip load measurement

iRoll can be used as a reel drum for online nip force profile measurements. (iRoll is not limited to reels, it can also be used on supercalender windups, winders and any nip under 50 kN/m.) The nip profile measured at a reel has a direct correlation with the diameter and hardness profiles of the paper roll. The reeling nipload profile clearly shows the peaks and valleys caused by variations in the caliper profile. The high resolution of the profile measurement is based on the inherent nature of roll building. Thousands of paper layers are reeled on top of each other as the parent roll is wound, so thickness variations accumulate and can produce relatively large variations in the parent roll diameter profile.

iRoll not only facilitates control but also reduces reeling problems. Because it measures the reeling nip load profile directly at the nip, iRoll immediately reveals force peaks, discontinuities in reel build-up, skewed nip profiles, and "carrot shaped" rolls. Force control problems caused by friction and wear in the machine parts also are exposed. This results in less broke from reeling-related quality defects.

Using iRoll as a reel drum combined with actuators such as calender zone controls, calender induction profilers, basis weight profilers, or coat weight profilers allows for closed loop control of roll profiles. This enables an immediate response to profile-related quality variations and runnability problems, and reduces the recovery time after grade changes.

Tension profile measurement

Another implementation of iRoll measures the tension profile online without using a separate scanning device. This also improves the accuracy when compared to traditional methods such as load cells. With iRoll, the tension is measured directly between the paper web and roll body. Therefore, the dead weight of the roll and thermal expansion have no effect on the measurement system.

iRoll can be used for closed loop tension profile control to reduce runnability problems. Higher shrinkage at the edges of the web in the drying section leads to a tension profile that decreases near the edges. Also, variations in the moisture profile before the drying section can cause a nonuniform tension profile. iRoll can be used to measure the tension profile and make corrections to the moisture profile before the drying section. However, tension profile control is more complicated than traditional profile control systems where one set of actuators controls one paper property. The actuators used to control the tension profile also will affect the moisture profile.

Two basic topologies can be used for tension profile control. The first topology is based on traditional moisture profile control using the paper machine press section steam box as an actuator. Moisture profile measurement and control are applied as normal. Tension profile optimization is added to the system in cascade with the moisture profile control. The tension profile is measured by iRoll located in a suitable position and a moisture profile set point is calculated by the tension profile controller. This set point is sent to the moisture profile controller. A cascaded control system such as this is well understood and straightforward to tune. The tension profile control sets a certain range for operation, which limits the moisture profile variation. Thus, the tension profile may be optimized while keeping the moisture profile within its limits.

The other topology used for web tension profile control is based on two actuators affecting the tension and moisture profiles separately. The first actuator (press section steam box or first drying section moisturizer) is used to control the tension profile and the second actuator (a moisturizer) is used to correct the moisture error of the end product. This topology can decouple the moisture and tension control. The two controllers limit each other to reduce the moisture error caused by too much profiling in the press section steam box. The system also can be tuned with optimal weighting for each actuator versus each measurement. For example, the press section steam box can have 80% weight for controlling tension profile and 20% weight for controlling moisture. The second moisturizer can have the opposite weighting: 20% to control tension profile and 80% to control moisture profile.

Portable system

Portable iRoll technology brings a new online nip load and tension profile analysis tool for paper and board makers and maintenance experts. This portable system provides information about cross-direction and machine-direction tension profile variations and nip load profiles. The system also makes it possible to perform bump tests to measure responses of upstream actuators to help optimize paper web properties. The portable system allows quick and cost effective use of intelligent roll technology.

Figure 5. Installation of portable measurement sensors on a roll surface.

The portable technology requires temporary installation of intelligent roll sensors onto a roll surface. A signal processing module with a transmitter must be attached to the roll head or shaft. The sensors provide a complete CD profile on each revolution of the roll, and the profile measurement is transmitted wirelessly to a receiver and from there to a computer. The portable system allows large amounts of data to be collected in a short period.

Applications of iRoll intelligent roll technology

The following examples of iRoll technology in successful use at mills illustrate the different measurement applications for which iRoll can provide accurate, real-time results in a cost effective manner.

Case Study: Online control of web tension profile

A linerboard production line had difficulties with runnability of its film sizer. Loose edges on the web often caused fluttering and wrinkling before the sizer. To remove wrinkling, the web tension level was increased 300 N/m above the usual level. A higher tension level naturally caused more frequent web breaks, and thus reduced production efficiency. An iRoll was installed before the sizer, along with a tension profile controller, to improve the web tension profile.

Controlling the tension profile is most effective when done as early as possible in the papermaking line. In the drying section, the web is stretched and dried at the same time, causing permanent changes in the tension profile. In this application, a moisturizer on the first drying section was used to control the web tension profile. Another moisturizer at the second drying section was used to remove the moisture error from the end product. Because the second moisturizer was located later in the process, it had only a small effect on the tension profile. Thus, the effects of the first moisturizer dominated the shape of the tension profile.

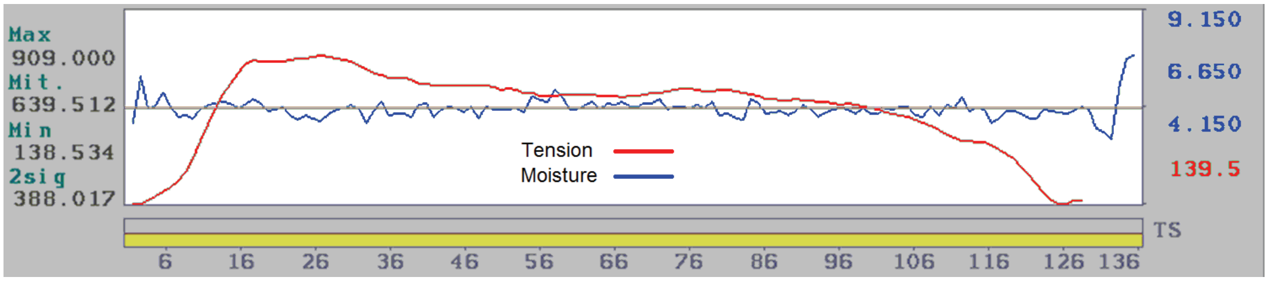

Figure 6. Profiles before the control system was turned on.

Figure 6 illustrates the tension and moisture profiles before the control system was turned on. The loose edges of the web were reflected in the profile by the low tension at the edges. This was most likely caused by the higher moisture levels seen at both edges. In addition, the tension profile is skewed, being high on the drive side of the machine and dropping off toward the tending side.

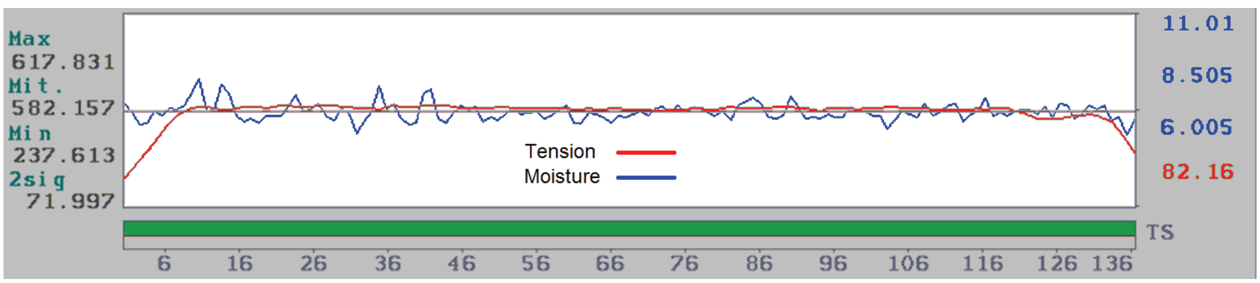

Figure 7. Profiles after the control system was turned on

After the control system was turned on, the profiles changed to those shown in **Figure 7**. The control system lowered the moisture at the edges, which increased the tension in those areas. The tension profile also became uniform and was no longer skewed higher on the drive side. The relationship between moisture and tension is not always obvious because the second moisturizer corrects moisture error with little effect on tension. However, slightly higher moisture peaks do appear on the drive side (**Figure 7**), resulting from the first moisturizer lowering tension in that area.

With the control system, the tension profile was clearly improved and the end product moisture profile still remained within limits. The improved profile reduced wrinkling and enabled a lower web tension, which resulted in fewer web breaks.

Case Study: Online control of roll hardness profile

iRoll has been used as a new reeling control method at Plattling-Papier PM1, one of the largest SC paper machines in the world. The innovative control is based on a novel measurement of pressure in the reeling nip. The iRoll measurement has been successfully used to optimize the production of this gigantic machine by fine tuning the CD caliper profile of the paper web entering the reeling nip. Paper grades produced at Plattling-Papier are SC-A and improved SC-A grades and cover a full range of basis weights.

In the Plattling PM1 case, the width of the reeling nip is 11.00 m. The spiral angle of four sensors is adjusted so that about 0.2 m cross width of the film is exposed at the same time (the exact width depends on nip pressure). However, the corresponding signal rate is larger, providing 200 control zones with resolution of 0.055 m.

Figure 8 shows the block diagram of iRoll control at Plattling PM1.The amplifier at the head of the reeling cylinder sends raw nip load profiles to the central unit every 0.5 seconds. The raw profile is scaled to nip pressure values and then filtered. After this, the nip load profile is shown in the control displays. The nip load profile has a direct correlation with the hardness profile of the parent roll that is being produced. The hardness profile is used for online control of the multinip calender zone-controlled SymRolls.

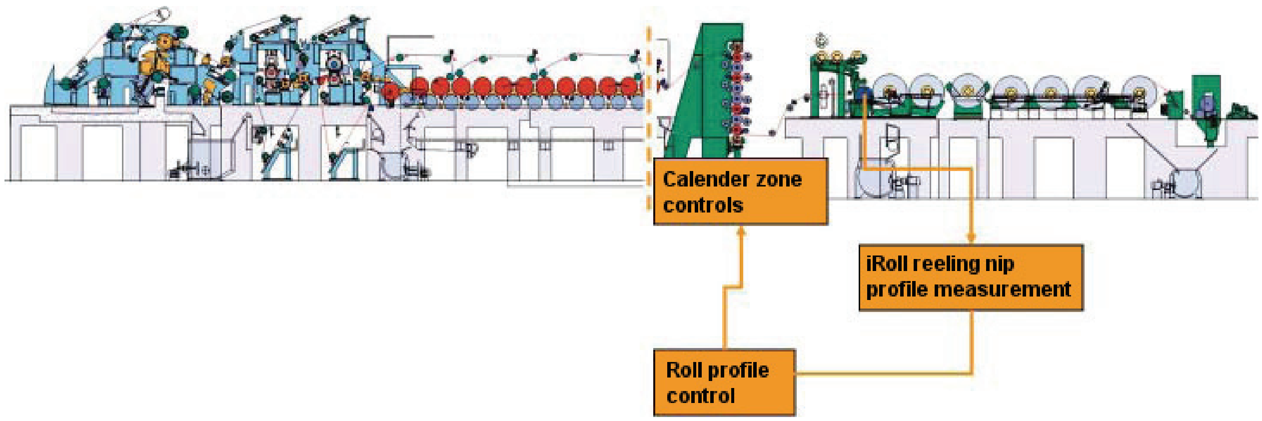

Figure 8. Block diagram of iRoll control

iRoll provides measurement immediately from the beginning of the roll. Typically, after turn-up it takes a few minutes of paper accumulation on the reel spool before the nip pressure profile stabilizes. It is reasonable to wait until that time passes before control actions are made.

At Plattling, iRoll automatic profile control uses profiling SymRolls as the actuator to adjust calender linear load and caliper profile. Another possibility could be induction profiling, but in this case there are no such devices. Also, the dry weight profile target has been manually tuned to optimize reeling and winding. There are no obstacles to use dry weight behind automatic iRoll feedback.

On the Plattling PM1 iRoll, closed loop control has been used continuously since startup. After the measurement was setup and calibrated for the first time it has been stable and further calibrations have not been necessary for several months. However, the calibration procedure is simple and the whole procedure is assisted by the operator interface. Calibration can be performed within a half hour during downtime such as during a wet end break or felt change.

A suitable nip pressure profile has smoothly decreasing pressure towards the edges of the roll (**Figure 9**). A 5% bias at the edges has been optimal for the unwinding tension profile and for diameter profiles of customer rolls at the winder. Also, despite a high speed (>1500 m/min), wide paper web and low porosity SC-A paper grade there has been no air accumulation in the paper rolls. Air removal between paper layers can be ensured with a properly shaped nip pressure profile. Also, when the overall shape of the reel is correct, there is more tolerance for small scale defects.

Figure 9. iRoll measurement and control operator interface as used on Plattling-Papier PM1

In some occasions the iRoll measurement has been useful to quickly detect special problems. Sometimes worn calender roll problems are not adjusted correctly. This can be quickly seen as an increasing pressure at the edge of a roll (**Figure 10**). A correction that is too slow, such as visual observation of the paper roll would lead quickly to parent roll failure and subsequent breaks. Also, edges can be problematic after a shutdown when the machine is restarted because paper machine profiles are unstable and machine elements are in transient conditions.

Special procedures can be designed based on iRoll measurement. In addition, wear of polymer rolls at roll edges are seen as hard edges, but this develops slowly during several weeks. On the other hand, dirt accumulation on calender rolls creates excessive calender pressure and is seen as low pressure areas by iRoll. Thus, iRoll measurement can give guidance for planned shutdowns and help maintenance work significantly.

iRoll control of reeling has been successful at Plattling PM1. It has provided a basis for control of calender load profiling based on direct roll measurement. Also, the measurement gives important information on changes in process conditions and problems can be solved quicker.

The measurement instrumentation has been reliable and it is robust in different process conditions. The typical maintenance period so far appears to be more than several months, and maintenance can even be done during a wet end break if necessary.

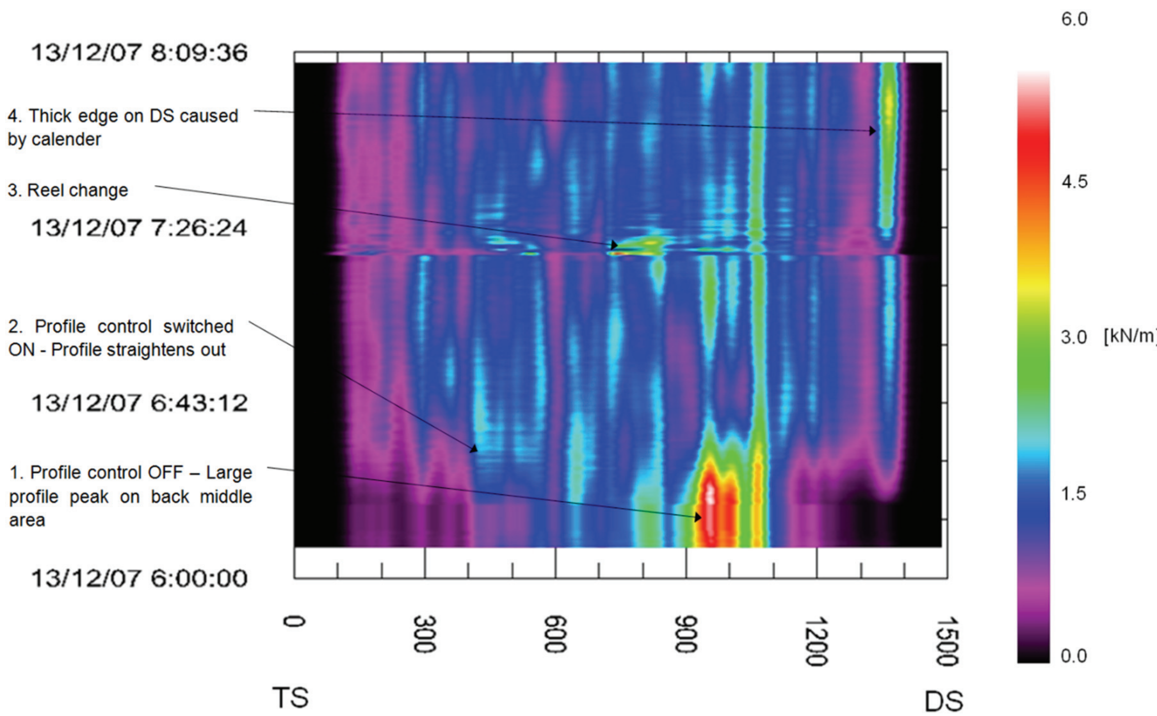

Figure 10. iRoll profile showing the beginning of a hard edge due to a worn-out calender roll

The current experience is based on a range of improved newsprint to SC-A paper grades. However, there is no reason why iRoll could not be used to control reeling of any other paper grades. Naturally, automatic controls do not solve everything, such as problems related to mechanical failures of machine elements - but they will better tolerate them.

Case Study: Solving a lateral web shifting problem

A mill producing high quality wood-free coated paper had a constant problem with lateral web shifting in its off-machine coater. The lateral movement caused web breaks, especially during splicing, and difficulties in web edge cutting. The reason for the web shift had been a mystery for years; various modifications were made to the papermaking line to attempt to fix the problem, but none were effective. Over the years, the speed of the line was increased, but the web shifting became a bottleneck to increasing production. Time and material efficiency of the line also were lower than considered possible, which caused additional production costs and indirectly higher energy consumption.

We assumed that a tension profile variation was the reason for the web shifting. Several portable iRoll systems were installed along the line to separately identify the profile effects of each subprocess. The tension profile was measured before the machine calender, before the reel, at the rereeler, and after the coater unwind. The nip load profile was measured on the reel drum and rereeler drum. Web edge position sensors were installed in the coater to measure the lateral translation of the web. Approximately one profile per second was collected during an actual production run.

When the measurements were complete, the first observation was that the web shifting was directly correlated with the skewness of the tension profile measured after the coater unwind. The skewness was quantified by calculating angular coefficients of straight lines fitted to each tension profile. These coefficients were recorded for each paper roll and compared with the measured edge position of the web, as **Figure 11** shows. In this manner, we determined that the skewed tension profile was the reason for the web shifting. The cause of the tension profile skewing needed to be determined next.

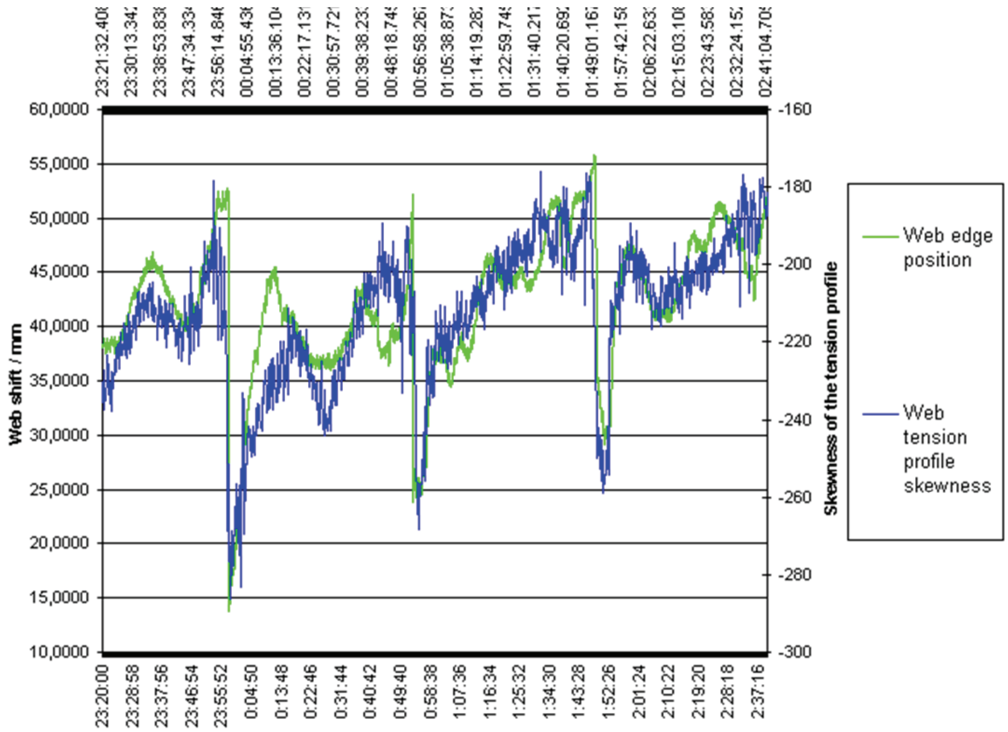

Figure 11. Correlation of the web shifting and tension profiles at the coater

We observed that tension profiles measured at the paper machine did not correlate with the tension profile at the coater. This surprised the analysis team because they initially expected that the tension profile errors would originate in the paper machine wet end. However, this was not the case and the paper machine with all of its subprocesses could be ruled out.

Next, the team found that the tension and roll profiles at the rereeler correlated very well to the coater tension profiles. This narrowed the cause of the tension profile variation to either the rereeler or the paper machine reel. Finally, the paper machine reel nip load profile was measured, revealing that the nip profiles had excellent correlation to the tension profile at the coater. Because the paper machine reel was the first location in the line where this correlation occurred, it had to be the primary cause of the web shifting.

The analysis team concluded that the wound-on tension (WOT) profile of each roll was skewed and the amount of skew also changed during reeling. When the rolls with variations were unwound at the coater, the web shifting occurred. The nip load controls of the reel were updated and adjusted to have a uniform WOT profile. The reeling recipes also were adjusted to improve the roll structure.

After the reel control system was modified, the tension profile changes at the coater were reduced significantly. The web behavior was stable and web shifting no longer occurred.

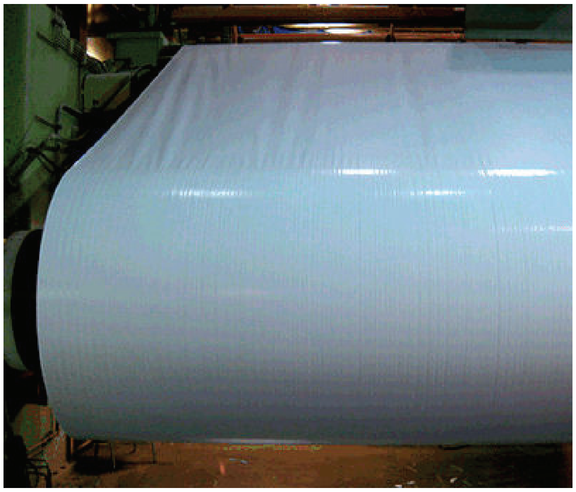

Figure 12. Sheet with uneven CD profiles being reeled.

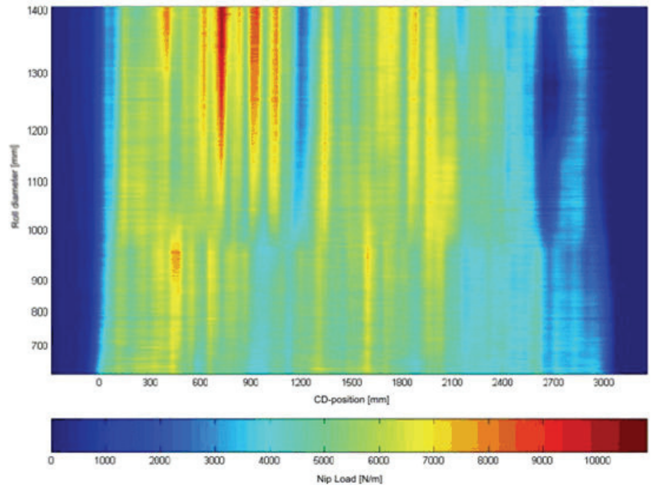

Figure 13. Same reel as displayed by iRoll, note uneven CD nip load

Summary

iRoll intelligent roll technology is a proven tension and load profile measurement system which turns a roll into a mechatronic sensor that can be located in place of a conventional roll in a web handling process. The roll can then be used for tension profile measurement or nip load measurement. In addition, a portable version of the system can be installed temporarily to troubleshoot web handling problems on a process line. Although all three case studies presented involved paper webs, iRoll is not limited to this material. It can be used with polymer film, tissue and even webs made of woven materials. The iRoll system is accurate, reliable and acts in real-time to give the papermaker timely measurements to monitor and solve problems on-the-run, before they become worse.

This white paper combines technical information obtained from Valmet personnel and published Valmet articles and papers.

Valmet provides competitive technologies and services to the pulp, energy and paper industries. Valmet's pulp, paper and power professionals specialize in processes, machinery, equipment, services, paper machine clothing and filter fabrics. Our offering and experience cover the entire process life cycle including new production lines, rebuilds and services.

We are committed to moving our customers' performance forward.