Enhancing tissue wet pressing performance and dry end material efficiency for cost savings

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ABSTRACT: The steadily growing global tissue paper demand lays a foundation for new technologies targeting tissue production optimization, as well as improved material and time efficiency. Tissue making is an especially energy-intensive field of paper industry, creating unique demands for performance in wet pressing and drying processes to cut energy usage. Intelligent roll solutions offer new tools for tissue making to achieve these goals. These tools aim at improving press nip, moisture, and tension profiles; reeling nip and parent roll hardness profiles; rewinder runnability; and end product web handling characteristics in converting.

Intelligent rolls can be utilized in all the main processes and positions on tissue production lines. With these tools, production cost reductions and energy savings can be obtained by optimizing the press nip-to-Yankee cylinder contact, avoiding moisture profile errors requiring overdrying with the Yankee hood and reducing reeling/winding broke under low nip load conditions typical to tissue windups.

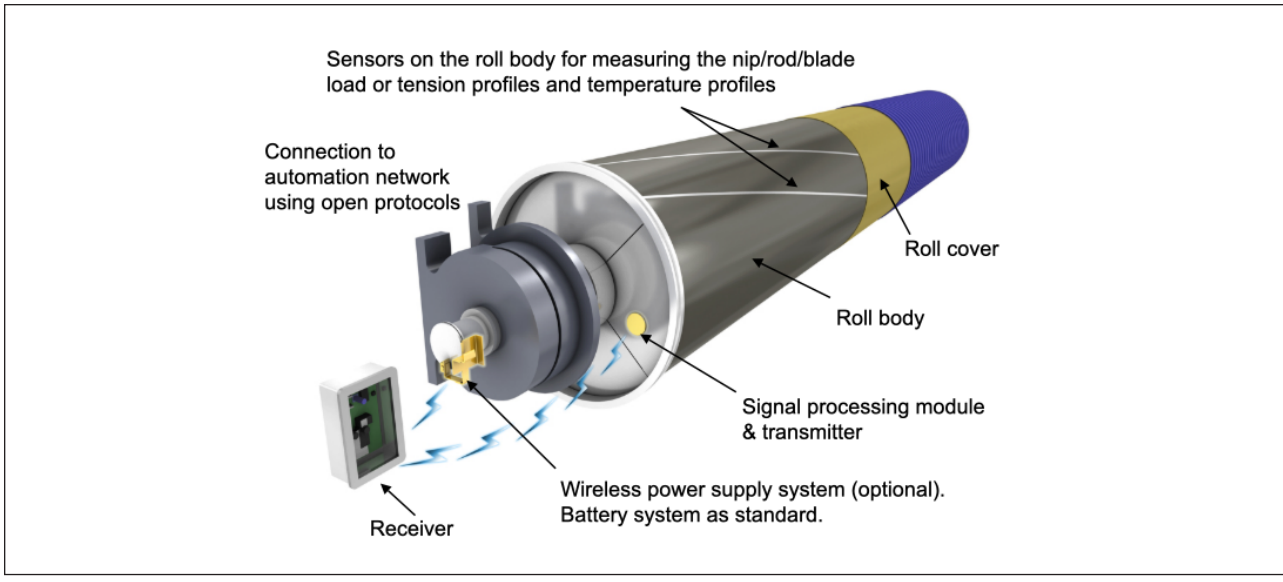
The intelligent roll system consists of a helically mounted force or temperature sensors, roll covers, measurement electronics, digital radio transmission, and a receiver system connected to a user interface or the mill automation system. What distinguishes these implementations is that no layout changes or added external measurement devices are required, helping to fit into compact tissue machine environments, regardless of the equipment type – traditional, hybrid, or through-air drying (TAD) concept. In tissue processing equipment, the optimal positions for these rolls are press nip rollers, reeling cylinders, rewinder or converting line paper lead rolls, or rewinder winding drums. In addition to these, temperature profile measurements are utilized, with the main application being the sheet temperature profile detection after Yankee drying for moisture profile and drying process optimization.

Application: This paper introduces the applications of intelligent roll technology in tissue making from wet end to converting, illustrating the benefits with practical example cases and data sets.

One of the tissue industry's challenges is low overall efficiency levels. Improvements in time and material efficiency are required. Globally, in 2021 the average operating rate (overall efficiency ratio) in the tissue industry was around 75%, having slightly declined for more than a decade. This varies between areas and countries, as well as between the producer's product mix and strategy. The highest average operating rate was in North America at 93%, and China had the lowest rates, even below 60%. Western Europe, Eastern Europe, Japan, and South America fall between these [1]. In tissue converting, efficiency rates are even lower, at 40%–70% [2].

The total productive maintenance (TPM) strategy describes overall efficiency as a combination of availability, performance efficiency, and the quality product rate. In the optimal situation, availability should reach more than 90%, performance efficiency more than 95%, and quality 99%, resulting in an overall efficiency rate above 85%. This can be considered a universal target for a properly operating production facility, but the best can achieve significantly higher figures [3]. Tissue industry figures can be also compared with printing grade figures, which are reaching well above 80% despite a more challenging market situation [1].

The tissue industry's low figures obviously mean lower profitability and an inefficient use of investments and resources. Material efficiency issues cause lost production due to broke and excess energy consumption. Low performance rates and the great need for drying energy is a challenging equation from the profitability perspective in a high-energy cost situation. Real-life examples are broad, including low efficiency production lines that stop operating during natural gas price peaks. Another example could be the elevated demand at the beginning of the COVID-19 pandemic, during which low operating rate tissue producers could not supply enough product, thus losing opportunities in the high market. A probable cause of low efficiency, besides the industry culture, is the increasing ratio of aging machinery that can be inefficient at dewatering and drying, as well as prone to profile and runnability issues. Increasing energy and production efficiency requires a focus on the entire production line, including product quality, to ensure trouble free converting. Tools for better performance and energy efficiency include improving press area dewatering, as well as saving dry end broke and improving converting area runnability with more uniform customer rolls [4]. Online measurement and optimization



1. Intelligent roll operating principle.

with intelligent rolls offer novel opportunities here, proven in experiences from the tissue industry. This paper introduces these opportunities, targeting the aging machinery with traditional press concepts and reeling/winding equipment. These production lines can be considered as the most lucrative target for improvement. After utilizing intelligent roll opportunities, 5% lower drying energy consumption, 3%–4% higher post-press dryness at the edges, a 128 m/min faster running speed, and 1%–2% more production due to less reeling waste are examples of the results this technology has achieved.

INTELLIGENT ROLL SYSTEM DESCRIPTION

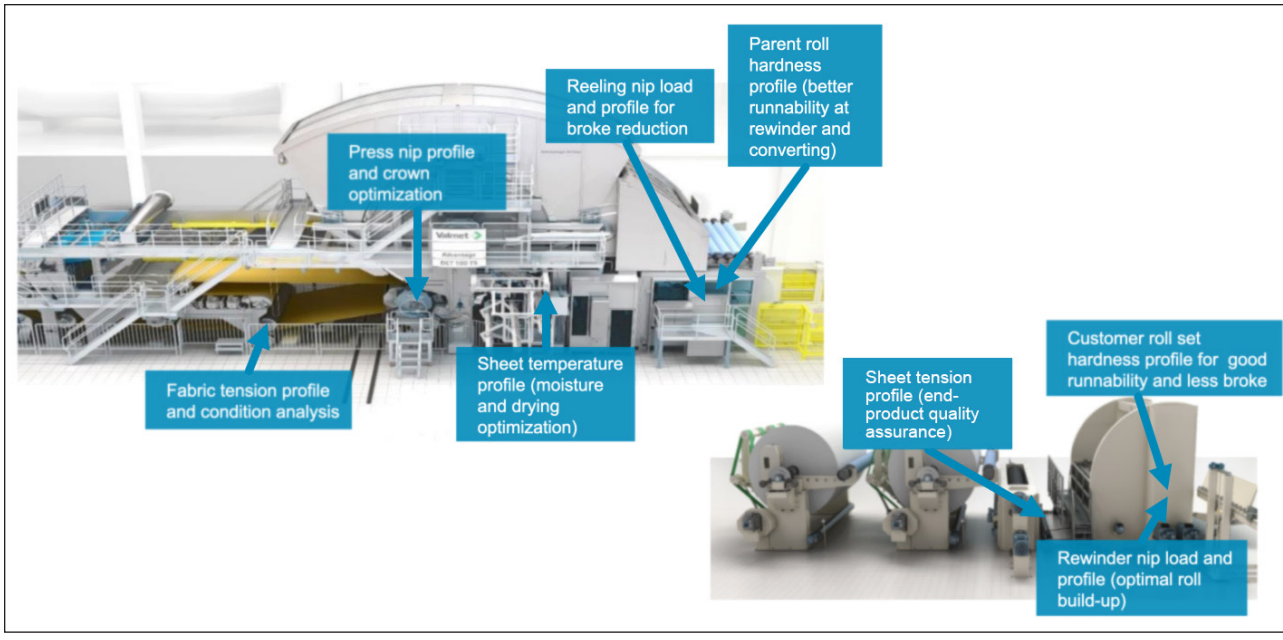
System components and benefits

The intelligent roll system consists of a roller, helically mounted force or temperature profile sensors, roll covers, measurement electronics, digital radio transmission, and a receiver system connected to a user interface. What distinguishes the intelligent roll is that no layout changes or external measurement devices like scanners are required. This is especially beneficial in tissue production equipment, in which the layout or investment cost demands can limit the possibilities for automation equipment. Intelligent rolls can be fitted to existing machinery and connected to mill automation systems or industrial internet platforms through open protocols. **Figure 1** illustrates the intelligent roll's operating principle [5-9].

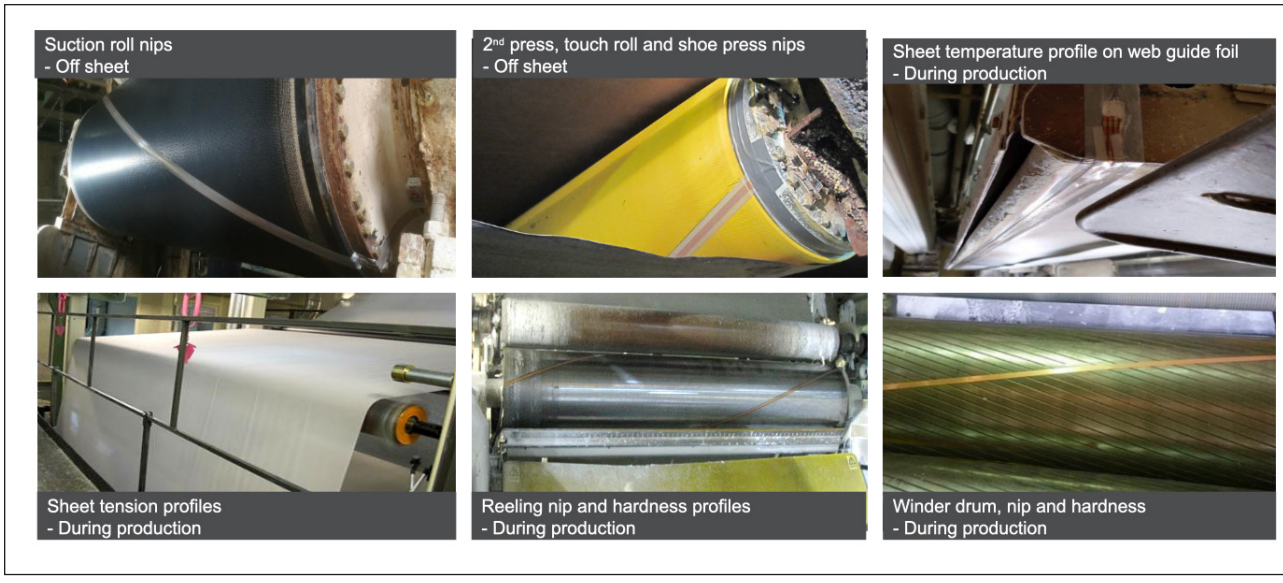
Measurement applications and sensor arrangements have been specially developed to suit tissue applications, which differ from other paper or board machines. Intelligent roll solutions for tissue offer various online measurement tools for improving press nips against Yankee cylinders, tissue web moisture after dry creping, tension profiles at rewinders, reeling nip and parent roll hardness profiles, rewinder runnability, and end product web handling characteristics in converting. These tools can help tissue makers obtain cost and energy savings for their operations. The intelligent roll for tissue machine wet pressing is a tool for measuring the profiles of press section nips during production. **Figure 2** illustrates an intelligent roll being used on a tissue machine 2nd press nip position. The intelligent roll for reeling is a tool for measuring parent roll hardness profile online – a method to analyze and control the sheet cross dimension uniformity in high sensitivity. It also allows analysis of reeling nip functioning through nip load trends, which is important in typical tissue reeling with very low nip loads. The intelligent roll for paper lead rolls is a tool for measuring web tension profiles online at rewinder or converting. Tissue sheet tension profile measurement demands extreme sensitivity due low tension levels in use and



2. Intelligent roll system operating on a tissue machine press section.



3. Illustration of applications of intelligent roll technology on a tissue machine and rewinder.

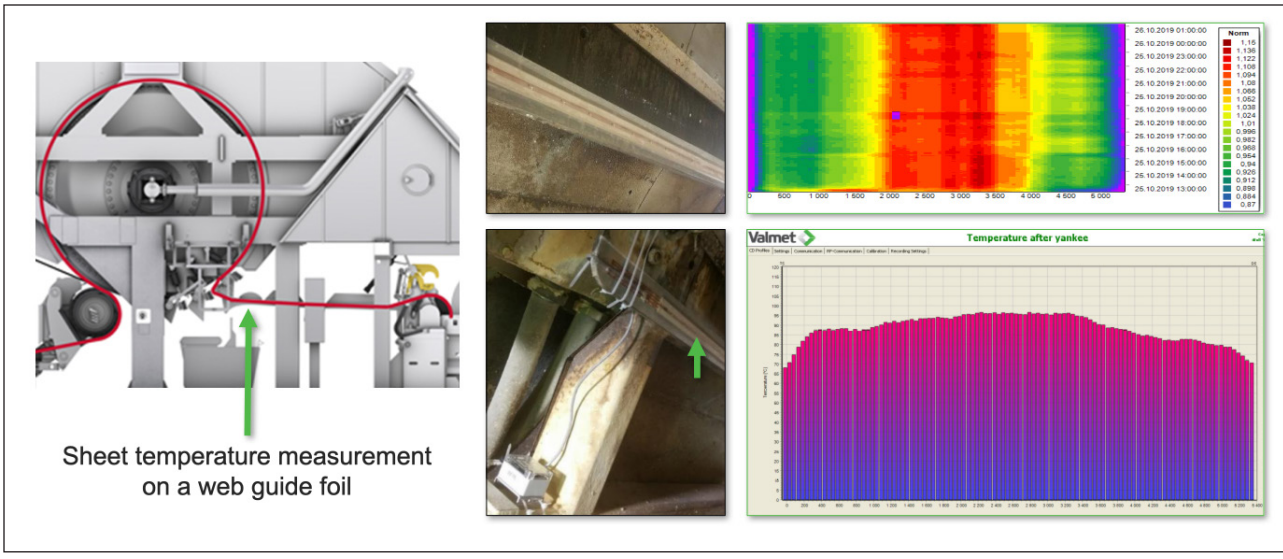


4. Intelligent roll application with the iRoll Portable for temporary process and nip analysis purposes.

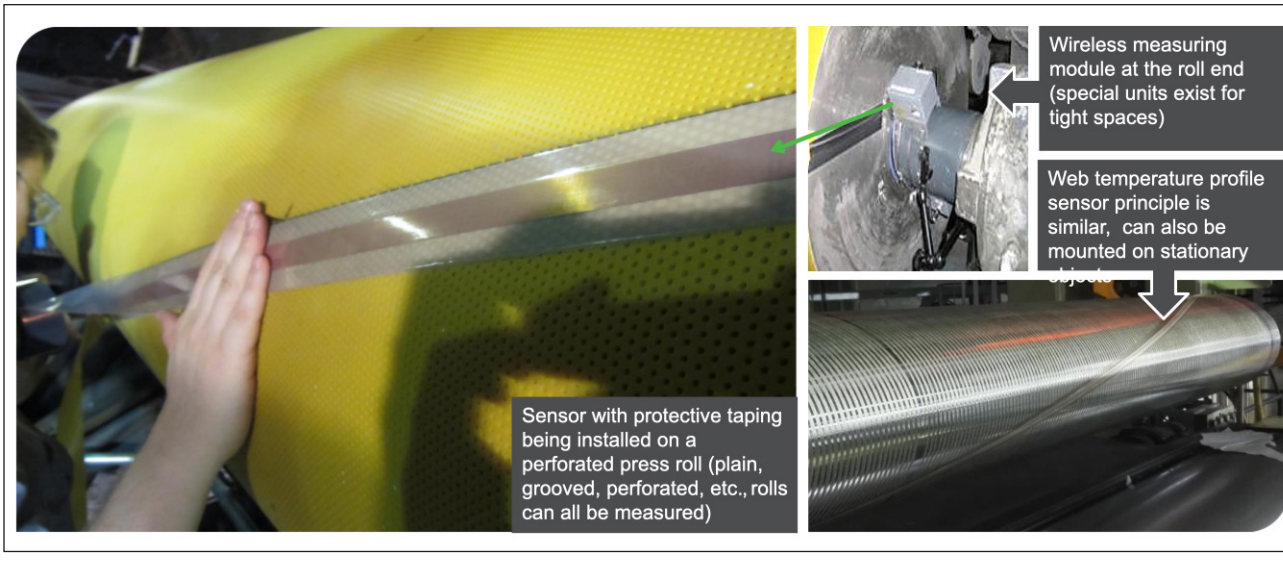
is specifically designed to suit tissue applications. Tension profile measurement can also be used for wire and felt profile analysis on the tissue machine forming or press section. The intelligent roll for winding processes enables online measurement of the nip loading in the tissue rewinder nip and customer roll set hardness profiles.

Figure 3 points out the possible utilization of intelligent rolls in a tissue production line [10-12]. Intelligent roll technology also enables temporary nip profile, process, and runnability analysis measurements using tape-mounted sensors. The analysis includes the installation of intelligent roll sensors taped onto a roll surface and a signal-processing module with a transmitter attached to the roll head or shaft. The analysis also includes measurement and data collection for an agreed period, as well as expert analysis, including recommendations for further nip or process development. The portable intelligent roll can be used in press nips, reels, rewinders, and converting lines, and to measure paper and fabric tension profiles. **Figure 4** illustrates the installation of the portable intelligent roll sensors.

When used for process analysis, the portable intelligent roll measures parent roll hardness profiles, sheet temperature profiles, or web tension profiles during production. The aim is to obtain tissue web quality, converting area runnability, and parent roll hardness profile improvements by undertaking response testing and process tuning. When the system is



5. Examples of applications with a portable intelligent roll arrangement. Some measurement positions are done during tissue machine shutdown conditions, and some are done with paper during production.



6. Principle and example of high-resolution, contact, online sheet temperature profile measurement application with a sensor arrangement on a web guide foil. Example data sets are illustrated on the right.

used to improve the nip profile, the tool is employed during shutdowns to analyze tissue press nip profiles in dynamic conditions with a pressurized Yankee. In typical tissue machine layouts, the same sensor arrangement can be used to detect fabric tension profiles and analyze the condition of the felt. This tool offers new information in addition to the traditional nip impression film and electronic blanket type of nip measurements, which are not optimal to use with high temperature pressurized Yankees. With the portable intelligent roll, the rolls rotate during measurement, which shows the nip profiles in genuine running conditions, with the Yankee cylinder at a normal temperature, wet felt in the machine, the suction roll vacuum on, etc. **Figure 5** shows examples of the positions in which this measurement and analysis method can be used in tissue making.

A new addition to intelligent roll technology is the embedded high resolution temperature profile detection system [12]. The two main purposes are the online temperature profile measurement of the moving web and the monitoring of the roll covers' internal temperatures. In tissue machines, the sheet temperature measurement system can be embedded in a web guide foil rather than a roll (**Fig. 6**). In tissue production, the sheet temperature profile is a good indication of the moisture profile, and the sensor system therefore provides a cost-effective alternative to more complex moisture profile measurement arrangements. The online sheet temperature profile's main utilization lies in improving moisture profiles by optimizing Yankee drying. It can also be used to remove speed and runnability bottlenecks by detecting inadequate drying ca-

pacity across the sheet's cross dimension, monitoring the condition of the drying equipment or optimizing drying energy consumption by preventing unnecessary overdrying. The roll cover internal temperature profile measurement can help reduce roll maintenance costs and machine downtime. This sensitive measurement helps prevent cover failures caused by thermal effects or overloading.

Drawbacks in applying intelligent rolls

As mentioned, the benefit of the intelligent roll is that it can be applied without machine layout changes to a desired position by upgrading an existing roll. There are still some drawbacks, which create targets for future development. The intelligent roll in continuous use requires a polymeric roll cover to be applied. Not all rolls have roll covers, though. Reeling cylinders, winder drums and paper lead rolls are typically such roll positions. In these cases, a roll cover, for instance a hard epoxy composite structure, must be added, causing higher cost for implementation and also in many cases requiring a new spare roll to be added in the stock. The added roll cover can require changes in roll diameters or special care in the machine's operation, for example, when cleaning the rolls mechanically. The temporary portable installation allows using the technology on non-covered rolls, as well for short periods of troubleshooting, but it does not allow continuous operation for long periods.

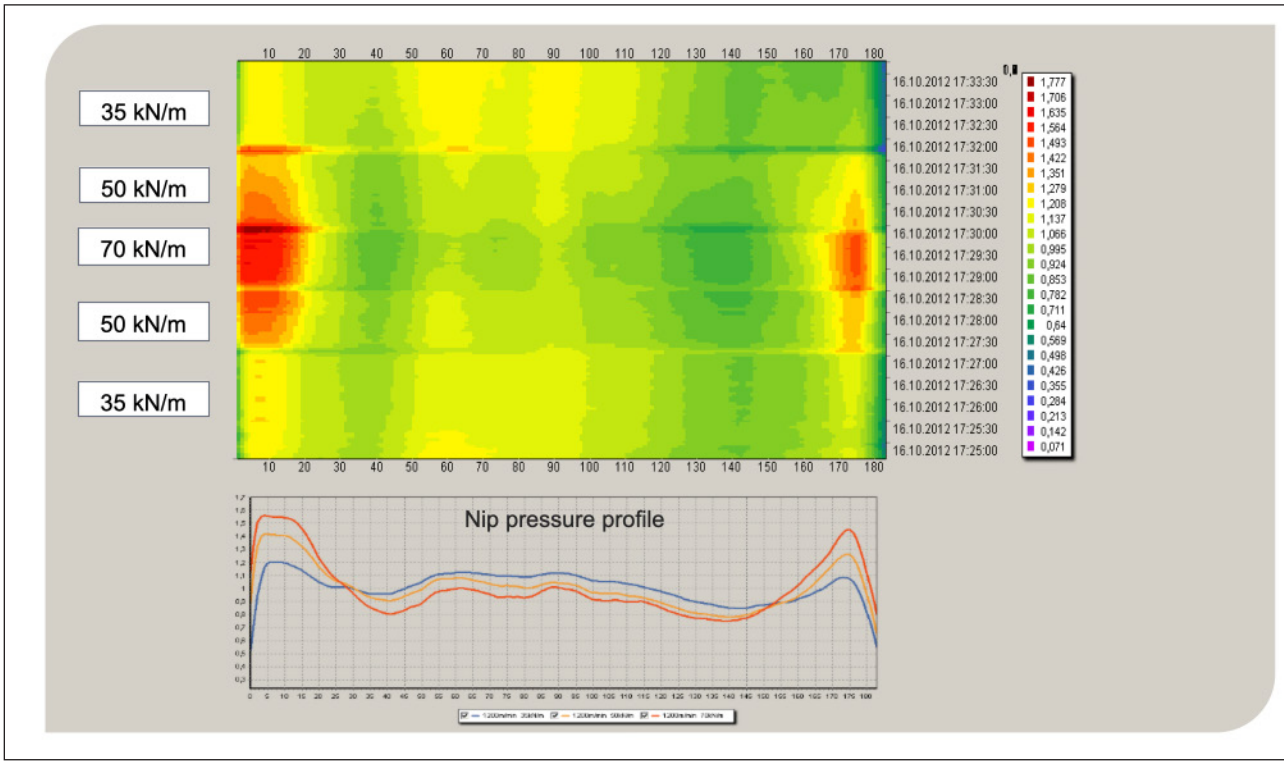
Another remaining drawback is that the industry's experience with intelligent roll technology is still mainly limited to traditional tissue machine concepts. The tissue industry is swiftly moving towards updated technologies; in addition to through-air drying (TAD), there also new "hybrid machines." These hybrid machines differ from earlier tissue machine concepts, as they incorporate shoe presses in various forms for dewatering and "wet creping" nip positions for tissue web quality optimization. On the other hand, the traditional wet pressing nips are not used any more against the Yankee cylinders in these. Some intelligent roll applications have been done on TAD and hybrid machine transfer roll positions against Yankee cylinders with good results. However, the experience is limited, and shoe press or the wet creping positions require more research to determine the possible benefits of intelligent rolls in these.

APPLICATIONS IN TISSUE MACHINE WET PRESSING AND DRYING

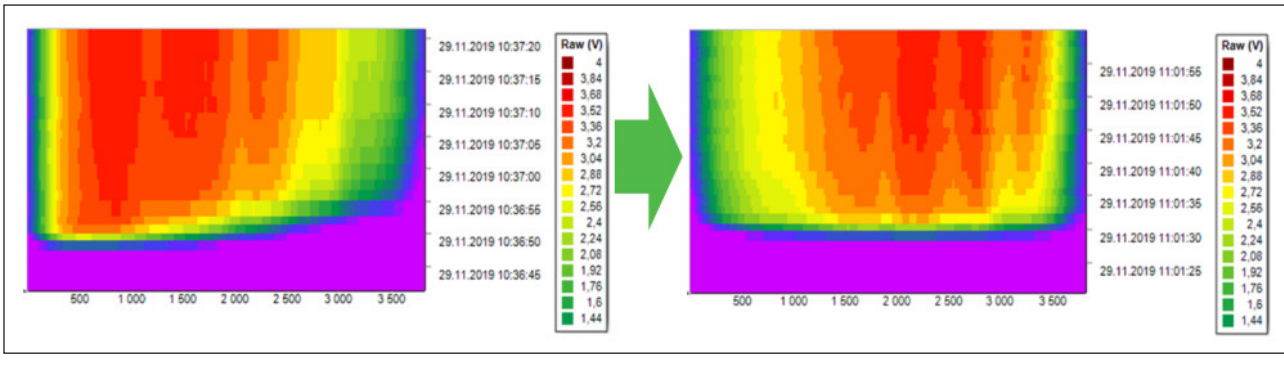
Enhancing tissue machine wet pressing performance is an essential efficiency factor for the entire production line. In tissue presses, this can be obtained by utilizing modern polyurethane roll covers with a grooved topography, aiming to maximize groove volumes for optimal nip dewatering. With well-chosen machine clothing, this can increase post-press dryness by 1%–3%, resulting in a corresponding energy savings in Yankee drying of around 5% or perhaps a faster machine speed. However, this improvement can be undermined by problems arising from poor nip cross-dimensional uniformity, for example, resulting in moisture peaks at sheet edges that requires use of excess drying power, thus eradicating nip dewatering enhancements. In addition to a poor moisture profile, uneven press nip loading can result in reduced time efficiency due to bad runnability in converting. It can also create increased operating costs through uneven felt compacting and quick wearing or damage to roll covers. These issues can be addressed by using the intelligent roll in a press nip position. This provides nip profile readings, revealing the nip load variations and any nip skewness and enabling the optimization of crowns. In tissue presses, dynamic measurement allows detection of the Yankee cylinder pressure and temperature effects on the profile, as well as their tuning. This results in a more uniform nip against the Yankee and a better moisture profile. **Figure 7** illustrates suboptimal press nip load profiles with various nip load levels. Skewed nips due to alignment errors or skewed movement during nip closing often lead to the nip profile remaining permanently skewed. **Figure 8** illustrates a case example addressing a skewed nip closing problem.

Other typical problems are inaccurate press roll cover cross dimensional diameter profiles, known as "crowning" issues, and nip load errors on edges due to the press roll cover shape not matching the Yankee cylinder during running conditions. Sophisticated calculation tools and models are used for calculating crowning parameters during the new machine's engineering phase. Theoretical calculations give a good baseline, but they may include inaccuracies, especially at the web edges; the bending and flattening of the press roll and Yankee shape differs at edges vs. the center, which may be difficult to model with perfect accuracy. During the tissue machine use phase, several factors may also result in a need to update the crowning shapes. The Yankee cylinder, press roll cover, and fabrics do wear over time, and they are therefore not constant. The press roll covers and felts may be refreshed by changing rolls and fabrics, but slow Yankee cylinder wear requires heavier actions that are impossible on a frequent basis. The Yankee cylinder operating pressure, temperature, and press nip load affect the nips' profiles, as do thermal impacts from Yankee internals, the hood, and profiling equipment, such as hood dampers or the steambox. All these factors need to be considered when making a crowning calculation for existing machinery. Adapting to real production conditions requires high-resolution data, which are available from intelligent roll measurements. With this data, it is possible to determine the required crowning changes using nip simulation tools. Modern computerized numerical control (CNC)-controlled grinders are typically utilized to implement the required crowning updates, allowing an entirely free form to be used for the roll shape instead of traditional cosine curve-based shapes.

Intelligent roll data are especially suitable for tissue



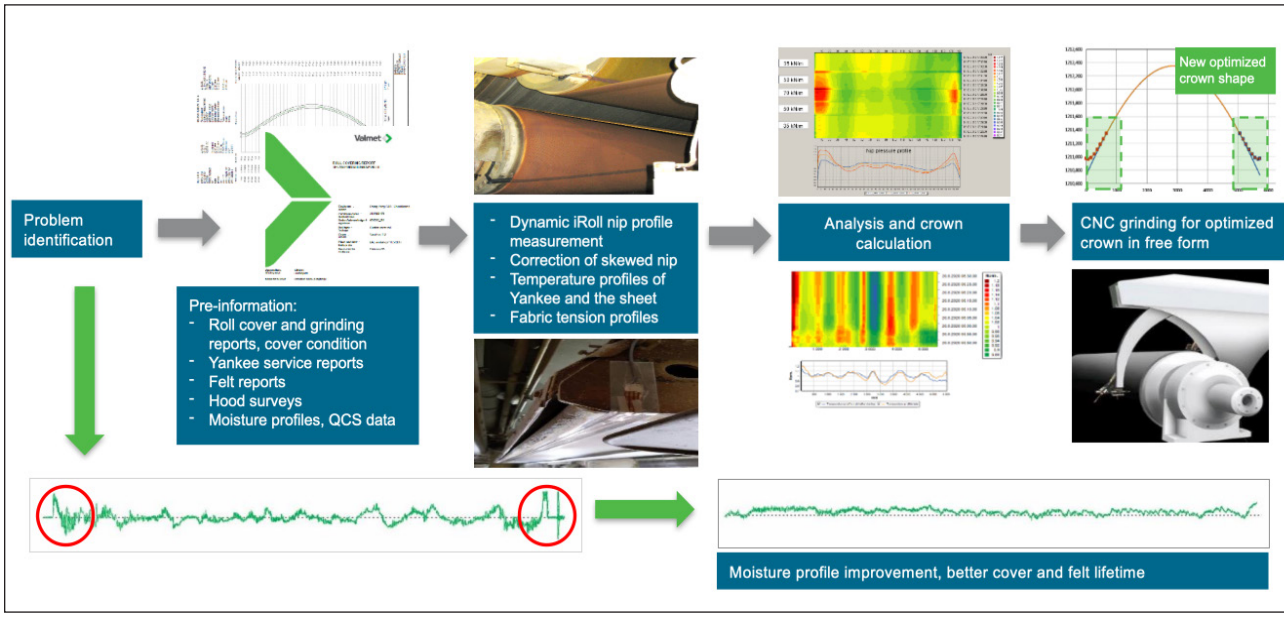
7. Nip load profile data measured from a tissue press nip with the intelligent roll system while testing various loading settings.



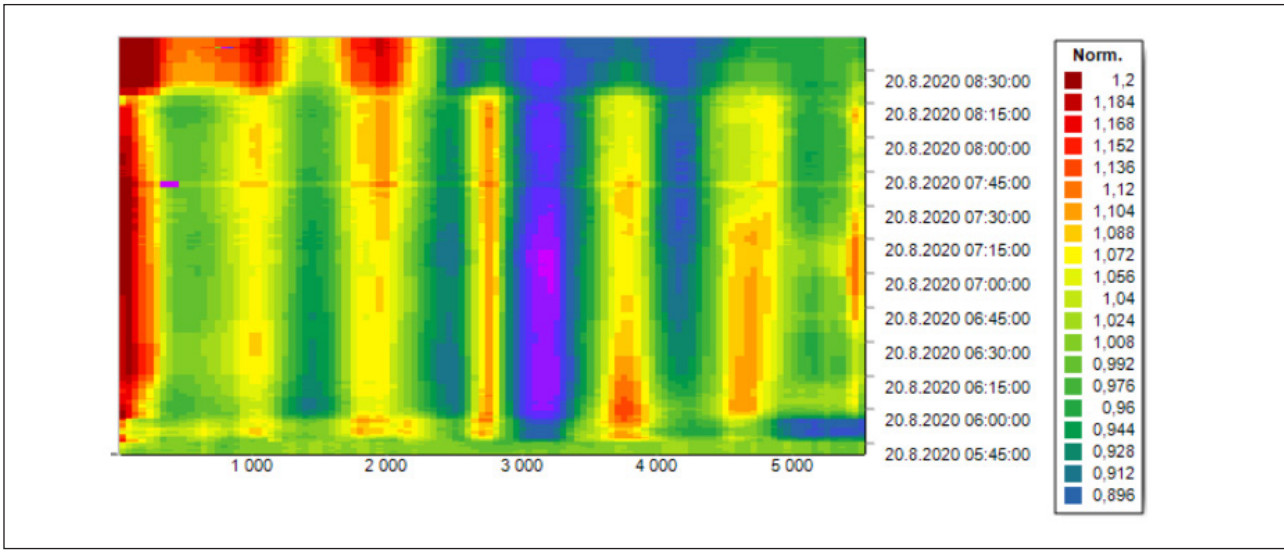
8. Nip load profile color map showing skewed nip closing (left) and corrected symmetrical closing (right). The nip load profile remains more symmetrical after the nip closing speed has been adjusted to be equal on both sides.

press applications, as they enable access to nip profile readings in dynamic conditions with press rolls and Yankee rotating, with various nip load levels and Yankee pressure settings. The data can be obtained from a sensor arrangement under a roll cover or a temporary portable measurement installed for analysis. Usually, a temporary sensor system is used, as it enables any nip-induced issues to be quickly and cost-effectively addressed. In addition to nip load measurements, other important data sets are utilized in the analysis as background information to support decisions about crowning. These can be Yankee cylinder temperature profile measurements; roll covering and grinding reports; moisture profiles and other profile scanner data; post-press dryness samples; and felt reports. The Yankee cylinder and sheet temperature profile data are utilized to take the sheet cooling effect on the Yankee shape into account, as well as impacts from the hood and the profile dampers. Based on these items, an update to the existing crowning dimensions of the press roll covers can be determined with the highest possible accuracy. **Figure 9** illustrates the typical phases of the entire crowning optimization process.

The previously mentioned contacting high-resolution sheet temperature measurement, installed on a web guide foil after dry creping, is a tool for bringing more depth to press nip optimization. Press nip load adjustment, Yankee cylinder, and profile damper impacts can be observed, and response testing can be undertaken. This allows the drying related factors to be separated from the press adjustments. For example, excessive pro-



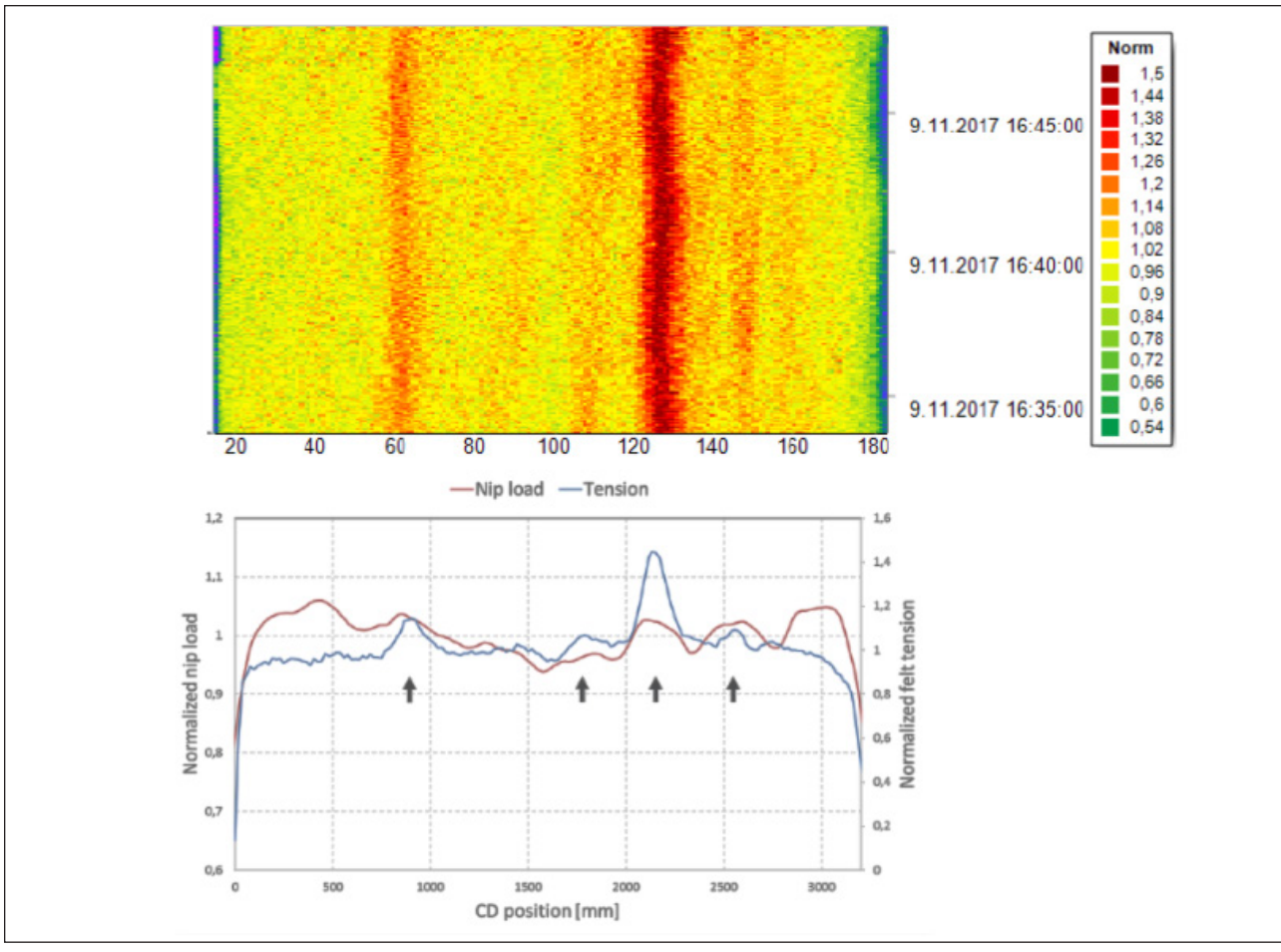
9. Tissue press nip crowning optimization process using intelligent roll nip profile data and supporting information (QCS: quality control system; CNC: computerized numerical control).



10. High-resolution sheet temperature profile data set, gathered with sensor on the web guide foil, is depicted in normalized color map format.

file damper profiling can cause nip profile impacts on the press nips, resulting in profile errors due thermal crowing of the Yankee. **Figure 10** illustrates an example of temperature profile data. The high-resolution sheet temperature profile data set, gathered with sensor on web guide foil, is shown in normalized color map format. The high temperature peak on the left was caused by heavy profiling with the Yankee hood profiling damper, and it also had an impact on the press nip profile and was eventually one reason for roll cover damages. The sudden profile change on top of the color map was the result of press nip load bias changes. In this case, the sheet temperature profile data could be combined with other data from press nip profiles and machine operating parameters, bringing more depth to the optimization actions.

In addition to the press nip load profiles and surrounding items, press felts also naturally have a major impact on press area dewatering and overall performance. It is important that press felts match efficient nip dewatering with grooved press roll covers. In this case, the felts should be denser, thinner, and have faster water saturation than is customary. This guides the water to the press roll grooves and on to the save-all. After all the optimization and upgrading of the press rolls and their topography, the importance of felt properties, condition, and uniformity becomes more critical.



11. Example of a normalized felt tension profile measurement with an intelligent roll in a tissue press as a color map (CD: cross direction).

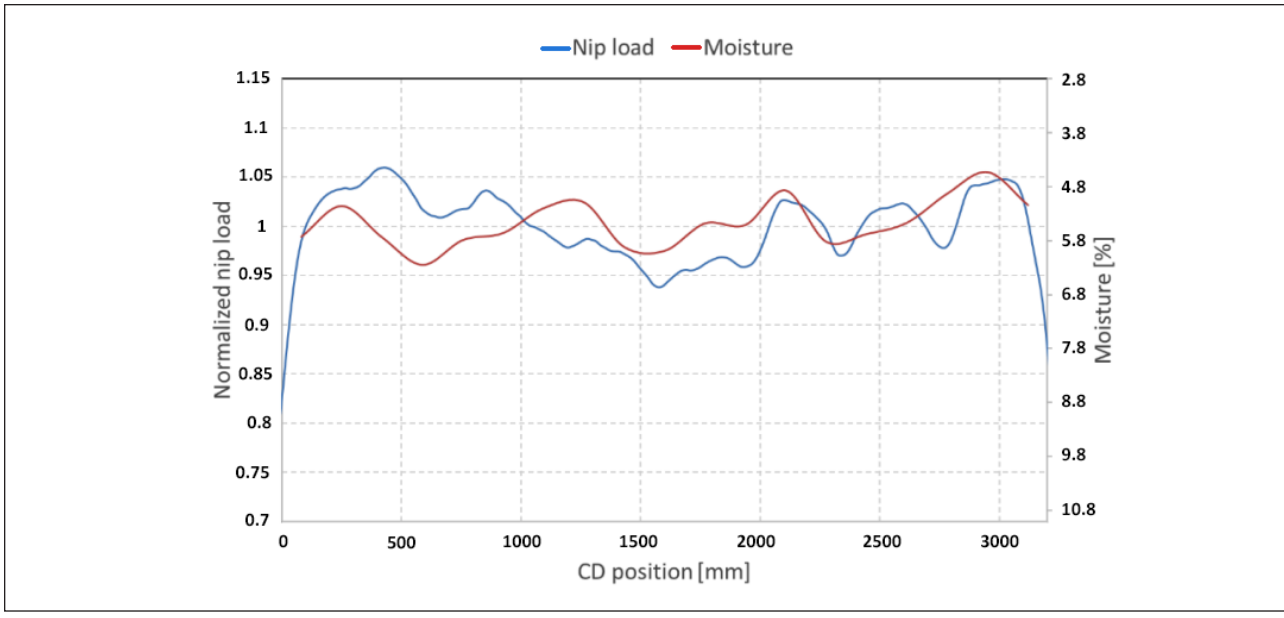
Felts are wearing components, and they may have manufacturing imperfections. With low grammage tissue sheets, the lack of profile uniformity in machine clothing can create related profile issues, overriding some of the previous improvements from equipment optimization. Intelligent roll technology adds another tool for monitoring felt uniformity and condition by allowing the felt tension profile to be measured in dynamic conditions. This measurement can be taken with an installation on a felt lead roll, but it can also be taken with sensor arrangement at the same time as the press nip profiles are measured.

Figure 11 illustrates a tension profile color map of an unused new press felt. This felt was found to have an obvious lack of uniformity in its cross-dimensional tension distribution, revealing a variation in quality. The graphs shown under the color maps illustrate the normalized average tension profile (blue) mapped with the corresponding normalized suction press nip profile (red), which are measured simultaneously. Areas where the press felt's lack of uniformity cause nip load profile errors are marked with arrows. The high-tension peaks in the nip load profile indicate that the felt's high-tension areas create higher nip load areas in the press nip, suggesting that the felt is either thicker or denser in these spots in addition to being less elastic.

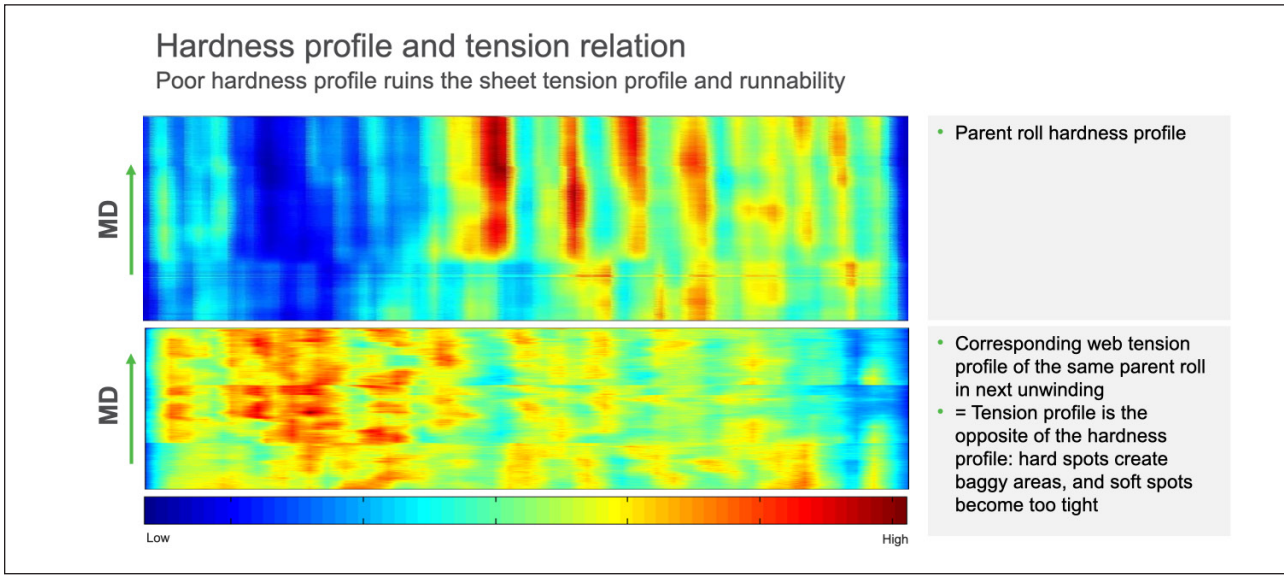
Figure 12 illustrates a comparison of a normalized press nip profile (blue) with a normalized moisture profile (red) when using the felt with the previously mentioned lack of uniformities. Note that the moisture profile has a flipped vertical axis to allow easier comparison with the nip profile. High nip load areas result in lower moisture areas and vice versa. The load peaks originating in the lack of felt uniformity result in drier areas in the sheet moisture profile. Based on this example, one can conclude that along with the nip profile, roll covers, the Yankee cylinder, and drying hood, felts also play an important role when aiming for optimal wet pressing profile performance on a tissue production line.

APPLICATIONS FOR TISSUE MACHINE DRY END AND CONVERTING

Broke paper in reeling and winding or runnability issues in converting are among the sources of tissue production material efficiency loss. These can originate from roll buildup issues due to reeling nip load inaccuracies, parent roll structure variation, rewinder nip loading problems, and baggy web edges in converting, causing wrinkles. Parent roll pro-



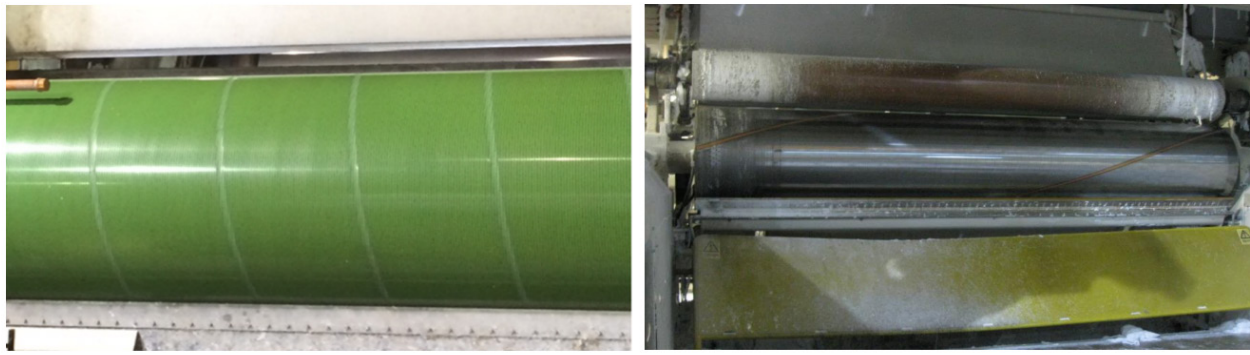
12. The graph illustrates a comparison of a normalized press nip profile (blue) with a normalized moisture profile (red) when using the felt with lack of uniformities.



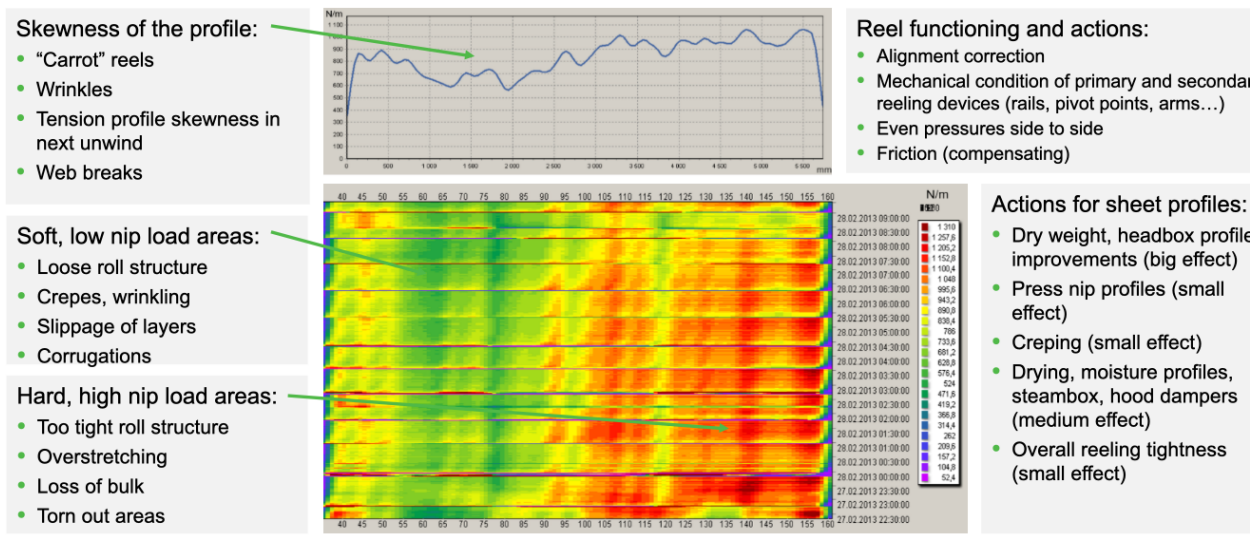
13. The mechanism of the parent roll profile impact to tension profile, resulting in web handling issues after the next unwinding (MD: machine direction).

file errors may be related to headbox profiles, press nip operation, moisture profiles, dry creping, or the reeling equipment itself. Hard areas on the parent roll cause bagginess and wrinkling in the next unwinding or cracks and a loss of product bulk. Meanwhile, soft areas are sources of a loose roll structure, causing corrugations, crepes, or high-tension peaks in the next unwinding that results in sheet breaks in the rewinder unwind. **Figure 13** illustrates the relationship of the hardness profile with the sheet tension profile and the mechanism of roll buildup-induced uneven tension distribution. On the top in Fig. 13 is the parent roll hardness profile color map of a data set measured with an intelligent roll on a reeling cylinder. On the bottom, the color map illustrates the same parent roll's web tension profile, measured with an intelligent roll on a paper lead roll at the next unwinding. The data reveal that high hardness spots (red) become low in tension (blue or green) when the parent roll is unwound. Correspondingly, the low hardness spots (blue) become tight (red, yellow). This mechanism is related to the sheet's uneven stretching and relaxation while being impacted by uneven tensions in the parent roll. This is a phenomenon that is often ignored in tissue production, although it can cause significant material loss.

Using the intelligent roll as a reel drum (**Fig. 14**) intro-



14. An intelligent roll application for reels and a sensor arrangement inside a reeling cylinder roll cover as a "portable" installation. These can be applied in hardness profile optimization or tuning the reel parameters, checking the reeling equipment condition, finding discontinuities due to mechanical problems, and optimizing the reeling nip load settings.



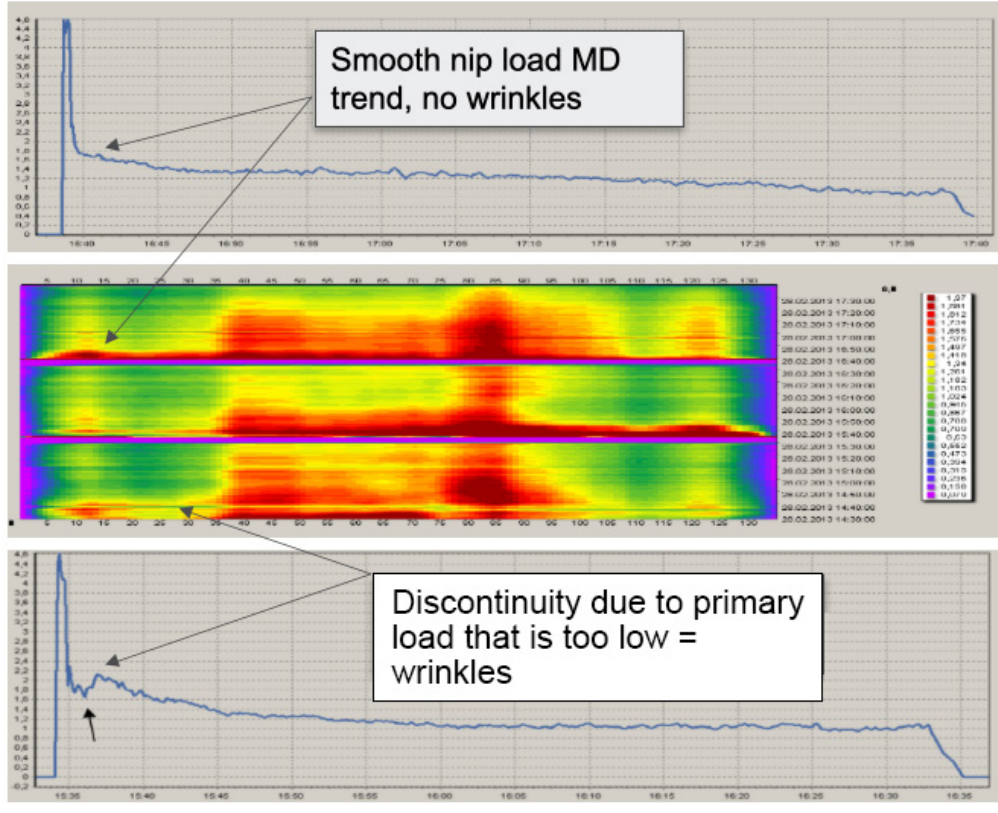
15. Illustration of parent roll profiles as a graph (average profile) and a color map (several parent rolls). The reeling problems caused by the profile variations are listed on the left. Possible corrective actions and optimization tools for the variations are listed on the right.

duces a new system of online profile measurements, providing information about tissue web properties in high resolution. The nip profile measured at a tissue reel is correlated with the paper roll's hardness and diameter profile. In tissue paper machines, it is impossible to use traditional manual parent roll hardness profile measurements due to the soft and elastic parent roll structure. With the intelligent roll system, the hardness profile measurement can be taken online, showing profile variations that one-sheet measurement with scanners are not able to show. This profile measurement method's high resolution is based on the nature of roll building: As thousands of paper layers are reeled on top of each other in the parent roll, thickness and density variations accumulate and multiply, making big shapes in the paper roll. Intelligent roll-based quality and roll hardness measurement adds a new tool for tissue quality control. **Figure 15** illustrates a parent roll's profiles as a graph and a color map, with a linkage to the problems caused by the profile variations and tools for corrections. **Figure 16** illustrates a tissue paper parent roll with rope marking due to hardness profile errors.

Intelligent roll reeling nip measurements are also a toolset for the precise measurement of the reeling nip load inside the nip. The nip load in tissue reels is typically very low, which makes accurate nip load control challenging and sensitive to errors. Any friction and discontinuity in the reeling process can easily cause roll buildup issues. The intelligent roll's operating principle means the reeling nip can be optimized with high accuracy, resulting in a better reeling process and the avoidance of broke. For ex-

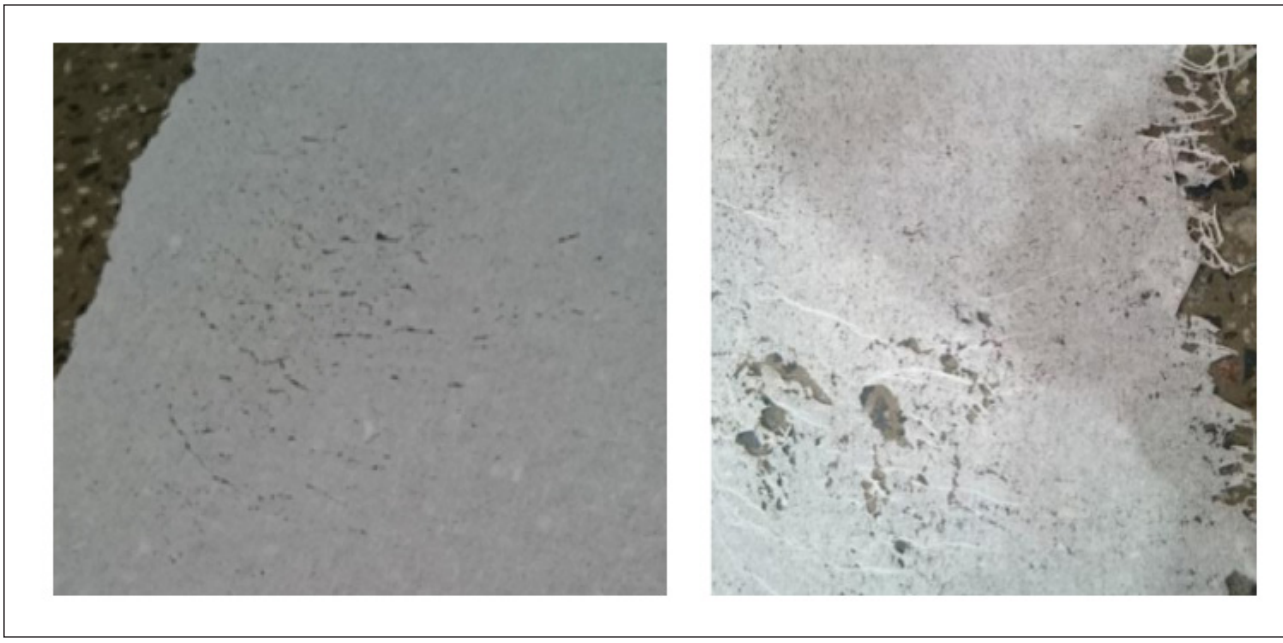


16. A parent roll surface with rope marking due to hardness profile errors on a tissue paper parent roll. The rope marks cause wrinkles and broke in the next processes.

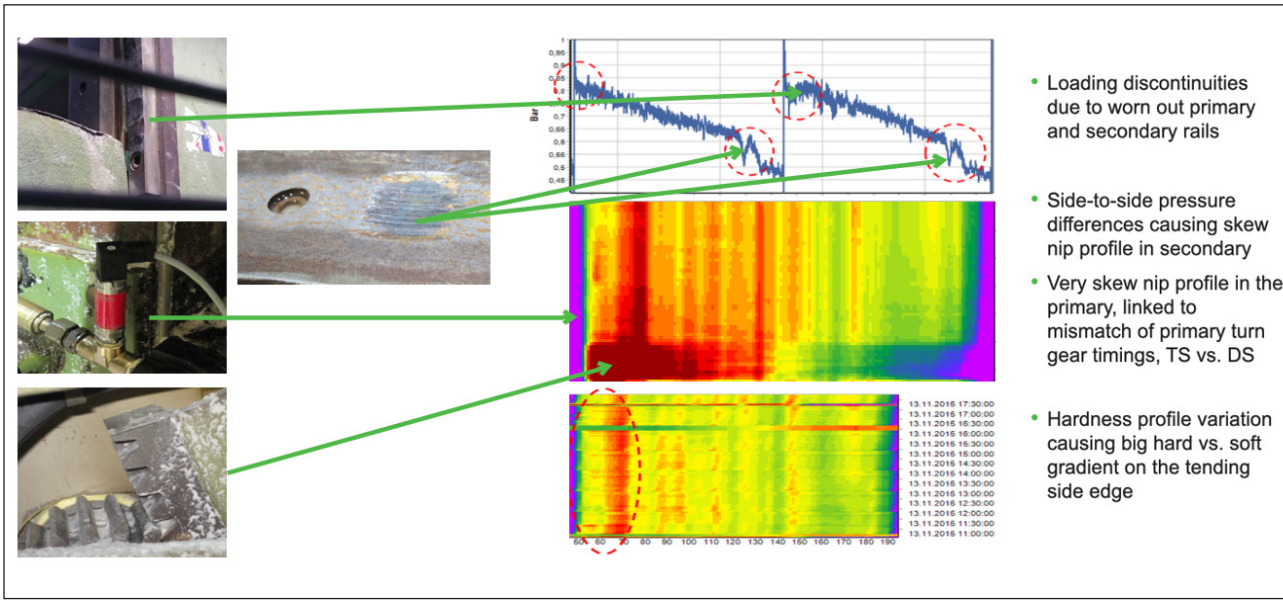


17. Data from a tissue reel measured with the intelligent roll system.

ample, a good roll structure directly from the core enables less bottom broke to be left in the rewinder/converting line unwinder, resulting in improved material efficiency. **Figure 17** illustrates an optimal and problematic reeling nip load trend, impacting reeling and production line material efficiency through bottom broke. In this figure, the example of a nip load trend on the bottom shows a typical issue with reels, with a nip load discontinuity in primary reeling causing reeling defects in the parent roll. The graph on the top shows an optimal reeling trend without a risk of bottom broke. In this case, the intelligent roll data are used to tune the reeling nip load control settings in the automa-



18. Examples of cracks and torn outs in a tissue sheet caused by roll buildup problems due to reeling nip load discontinuities.

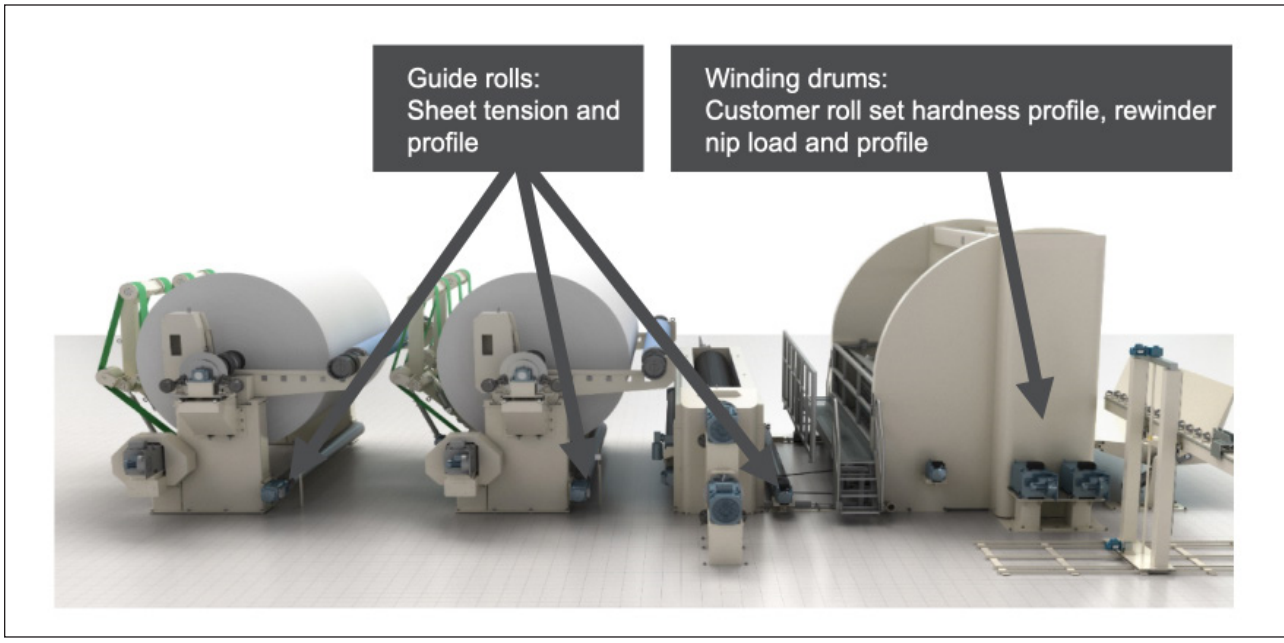


19. Examples of issues in tissue reel equipment causing nip load discontinuities, nip skewness, and roll buildup issues, leading to a loss of material efficiency (TS: tending side; DS: drive side).

tion system, resulting in a good roll buildup and the avoidance of reeling broke. **Figure 18** illustrates torn outs and cracks in the tissue sheet caused by reeling nip load inaccuracies. **Figure 19** illustrates issues in tissue reel equipment causing nip load discontinuities, nip skewness, and roll buildup issues, leading to a loss of material efficiency.

Tissue products are thin, low-grammage sheets and sensitive from the web handling perspective. Tissue webs are handled with minimal tension compared to other paper products. This has traditionally made it difficult to adjust the correct web tension, and tension profile measurement has been impossible with tissue paper. Intelligent roll technology helps overcome these limitations. The intelligent roll for tension profile detection has the force sensor arrangement mounted on the guide roll surface instead of measuring from bearing housings with load cells. The intelligent roll-based tension profile measurement tool is best used in the converting or rewinder area. It enables web tension profiles to be measured on line, even with the lowest tension levels, allowing the troubleshooting of bagginess or sheet break issues.

At the winder, rope marks, wrinkles, or folds in cus-



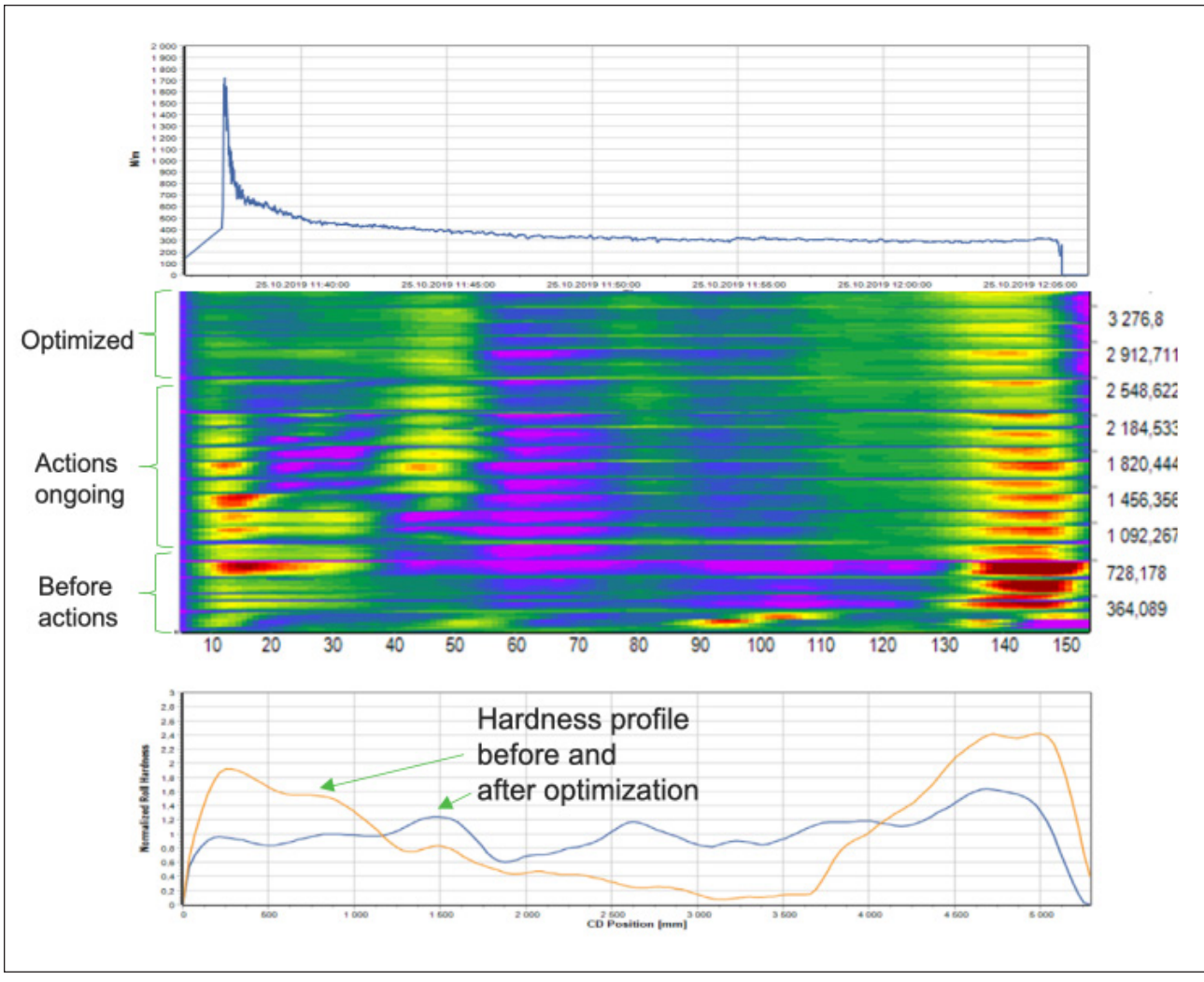
20. Intelligent roll measurement positions for ensuring customer roll quality, improving nip load conditions, and reducing broke at the rewinder.

tomer rolls can cause expensive broke and production losses. Intelligent roll tools enable the online measurement of the unwind tension, winding nip loads, and customer roll set hardness profiles at the rewinder. These reveal the true winder nip operation and equipment condition, helping optimize winder recipes and tension controls. Other useful characteristics are an exact winder nip load machine direction trend analysis and optimization capability. When utilized at the rewinder, the intelligent roll arrangement is mounted on one of the winding drums to detect the nip loads and hardness profiles, which is strongly analogous to the application on the tissue machine reel. **Figure 20** illustrates intelligent roll measurement positions on a rewinder.

In rewinder optimization, the customer's roll buildup is often the most critical target, with low nip loads and tissue roll softness increasing the difficulty. Performance is impacted by the nip load recipe, which is influenced by the rider roll loading and its adjustment as the diameter grows. Another item is the uniformity of the customer roll set hardness/diameter profiles. If the profile is uneven, the rider roll loses contact with low areas, causing a loose windup and risk of vibrations. High spots can cause torn out areas and crushing. The gradient points between soft and hard areas are prone to fold outs or wrinkles. **Figure 21** illustrates data from a rewinder nip load and profile optimization done with the intelligent roll system mounted on a winder drum. In Fig. 21, the topmost graph illustrates a machine direction nip load trend, measured from the winder nip with the intelligent roll system. As it should be, the load is highest near the core and then drops smoothly toward the end as the diameter grows. This can be seen as a good winding nip load trend, and no action is required. The graphs on the bottom and the color map illustration in the middle show customer roll hardness profiles during the winding of several customer roll sets. The profiles on the bottom of the color map and the average graph before optimization (orange) show the situation with very high hardness at the paper edges and the soft area in the middle. This profile obviously presented a risk of winding defects and broke paper. As the profiling of the calender nip at the rewinder was utilized for optimizing the hardness profile, the hardness profile could be improved by adding more load to the edges vs. the center. The color map profile on the top and the optimized average profile (blue) show the improvement achieved, resulting in better customer roll quality and the avoidance of broke production.

CASE EXAMPLE FOR PRESS NIP PROFILE OPTIMIZATION

A two-press nip tissue machine had been suffering wet sheet edges due to uneven press nip profiles. The moisture peaks at the edges meant the sheet was prone to wrinkles, causing broke. This either required overdrying, which led to reduction in machine speed, or narrowing of the web width, impacting the production efficiency. Determining exactly the right crowning for the press nips was considered key. Nip films, Yankee cylinder shape measurements, and theoretical crowning calculations had been used in the past without complete success. The intelligent roll profile analysis was therefore utilized to determine the optimal crowning. Nip measurements were taken with the rolls rotating, wet felts in the machine, and the Yankee cylinder at normal heat and pressure, being as close as possible to



21. Intelligent roll data from a rewinder's measurement and optimization case.

normal running conditions. **Figure 22** illustrates the measurement positions at the press section.

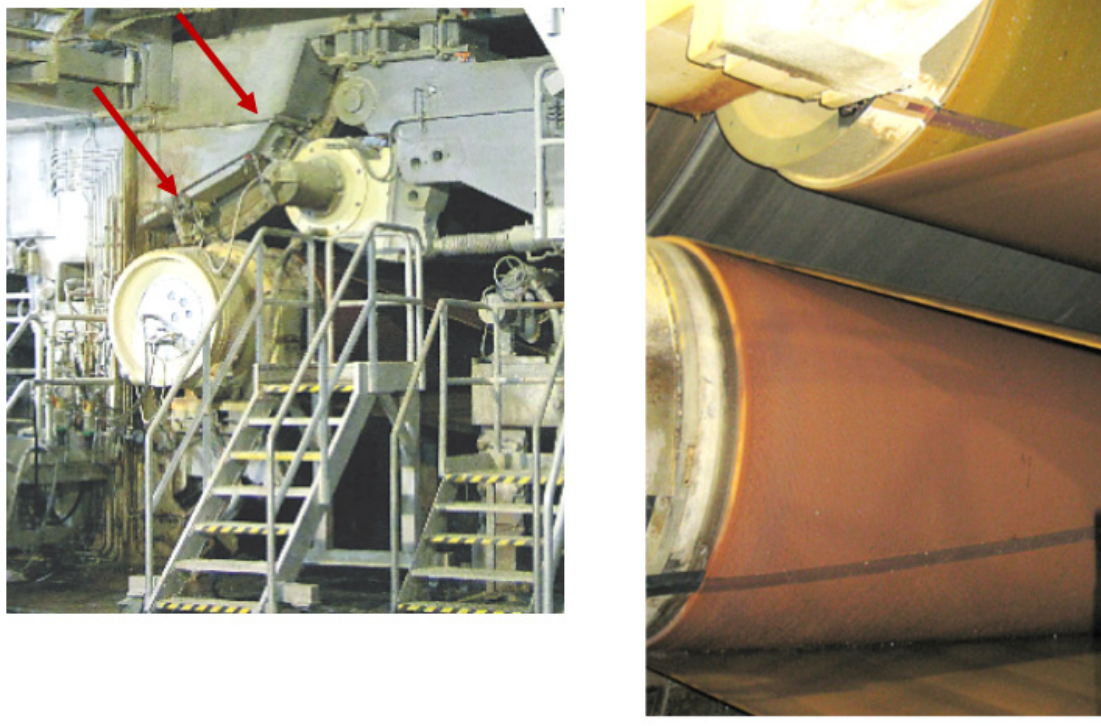
Several nip loads and machine running parameters were tested during the measurement session. The nip measurements revealed the situation: The central area was fairly good and did not need corrections. On the other hand, the loading of edges on the areas still on the sheet width was clearly too small. The loading dropped down sharply toward the outermost edges. **Figure 23** illustrates the moisture profile and corresponding suction press nip profile. **Figure 24** illustrates data gathered by dynamic nip profile measurements during loading tests.

When analyzing the results of the measurements, it was concluded that the standard cosine curve crowning was inadequate to straighten the loading at the edges. An optimized new double crowning was determined. The new crown shape (**Fig. 25**) uses a free form shape and implementation with a high accuracy grinding machine. With the optimized crowning shapes for both the 1st and 2nd nips, the nip loading could be straightened at the edges, improving the moisture profile. After implementation of the crown updates, the post-press dry content at the edges increased by 3%–4%, which improved runnability, enabled a higher running speed, and helped decrease Yankee drying energy consumption.

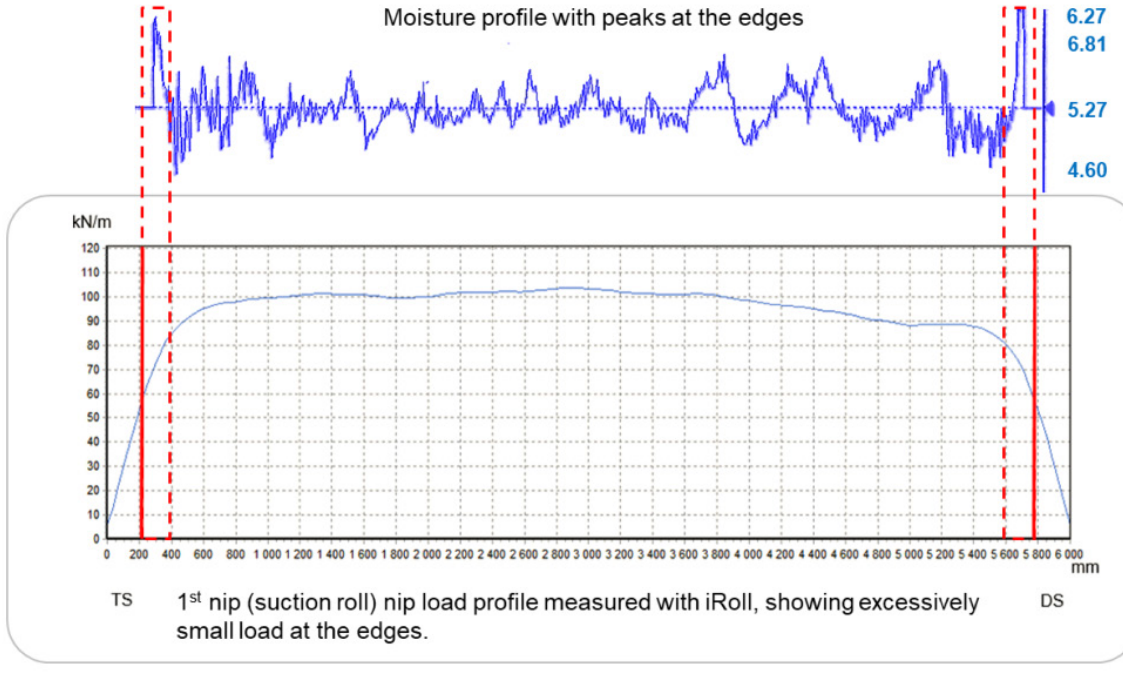
CASE EXAMPLE FOR SOVLING WRINKLING ISSUES IN CONVERTING

A customer operating a two-press nip tissue machine producing napkin paper and a converting line for finished products had a problem with sheet wrinkling at converting, causing broke and web breaks. The problem was observed to originate at the loose web edge, especially on the tissue machine's tending side.

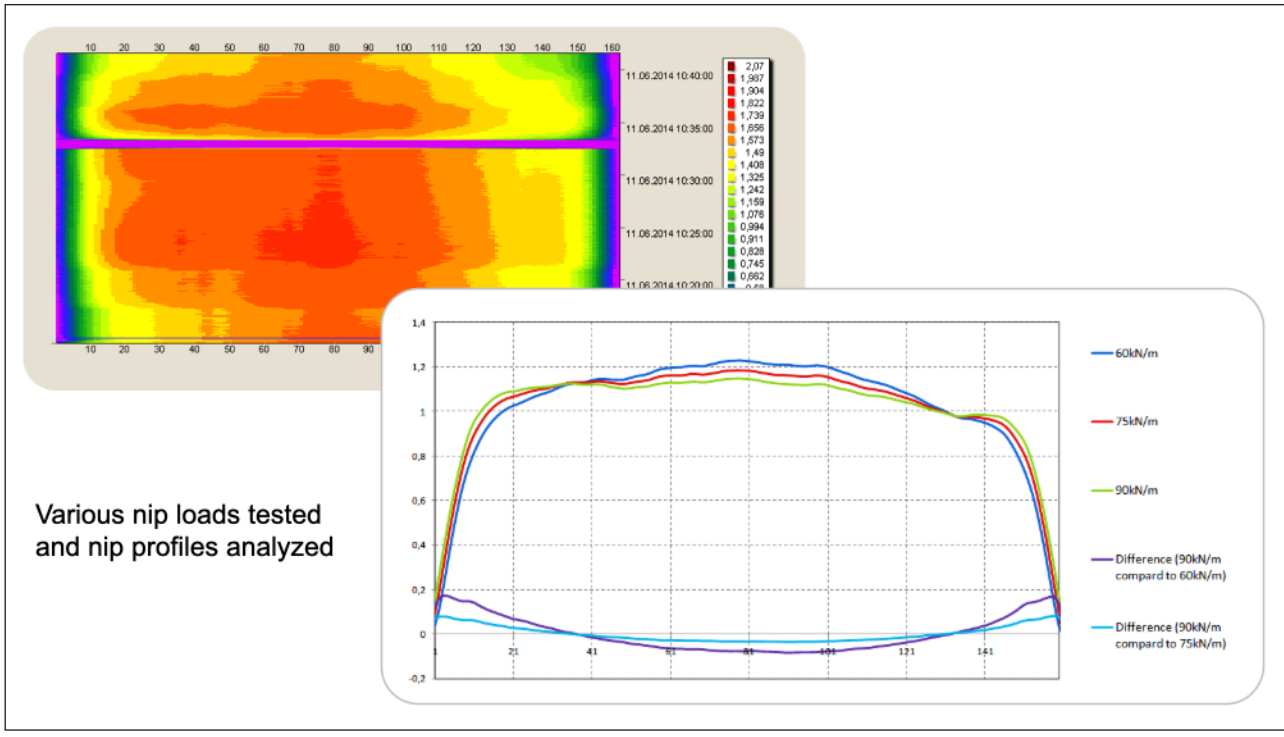
An intelligent roll portable analysis was utilized to study the problem and its root causes. Tissue web tension profile measurements were taken at the converting machine to determine the sheet's precise characteristics and to compare with the wrinkling tendency. Another measurement was taken at the tissue machine reel to see the parent roll



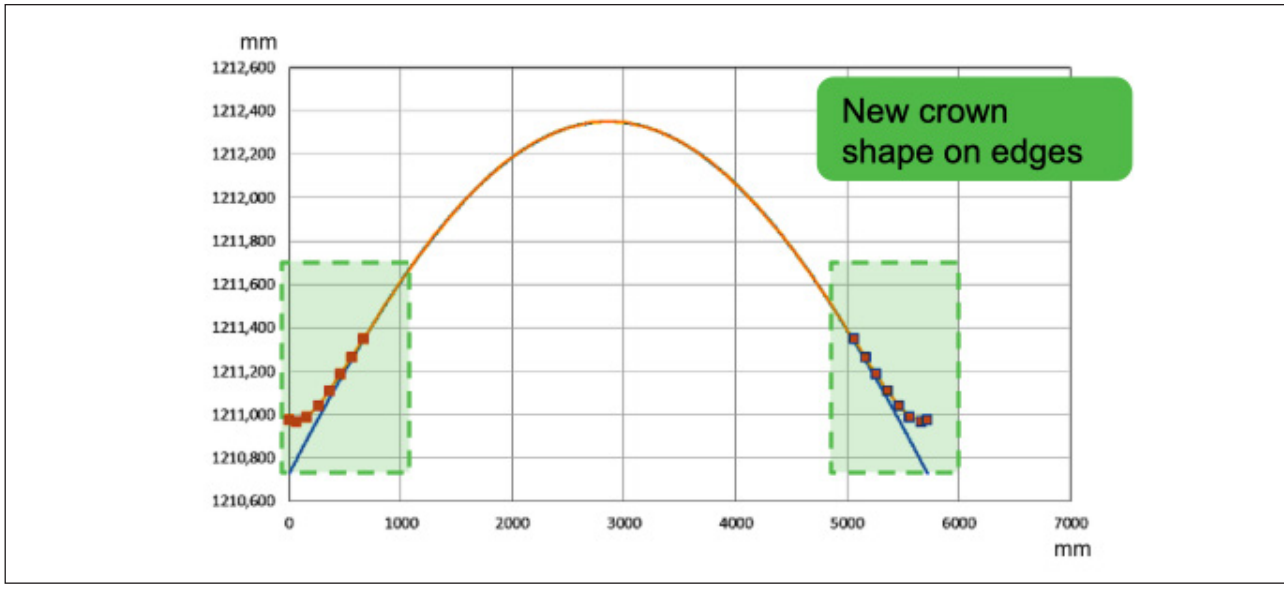
22. Portable intelligent roll systems installed on the tissue machine press section's 1st and 2nd nips to measure the nip profiles in dynamic conditions.



23. The moisture profile (upper graph) in relation to the press nip profile. The wet peaks at the edges were affected by a lower nip load and inadequate dewatering performance in edge areas.



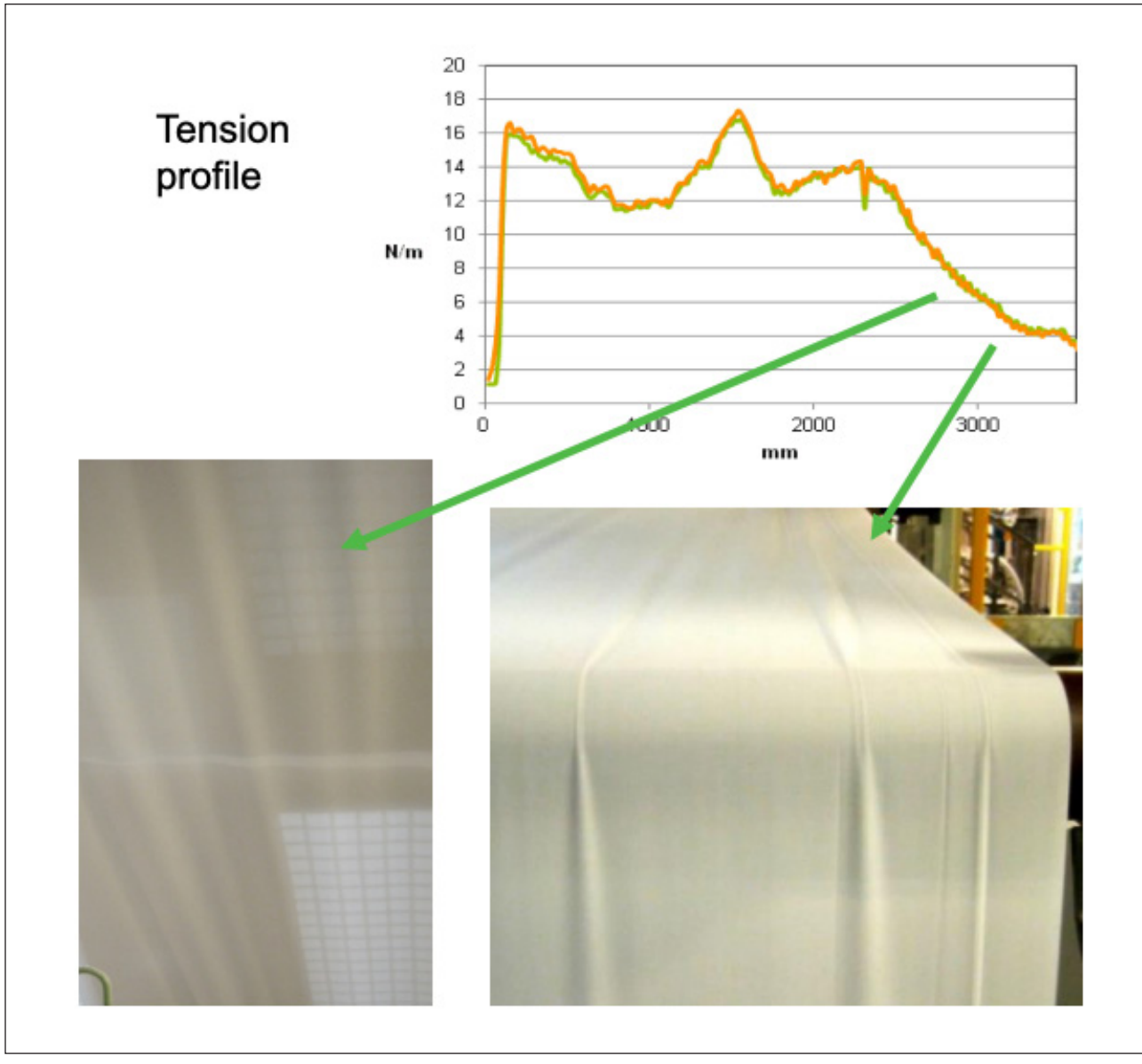
24. Examples of data gathered using intelligent roll technology during the loading tests with a press nip.



25. Optimized crowning curve determined based on intelligent roll measurements. The edge corrections with negative crowning are illustrated at both edges with a dotted square.

profile and the reeling nip function. Measurements were taken during regular production, and the parent rolls were followed up from the tissue machine to converting. The tension profile measurement system at the converting machine was installed on a guide roll. Tension profile and loose edge were found to be well correlated. **Figure 26** illustrates the relationship between the tension profile and sheet wrinkling.

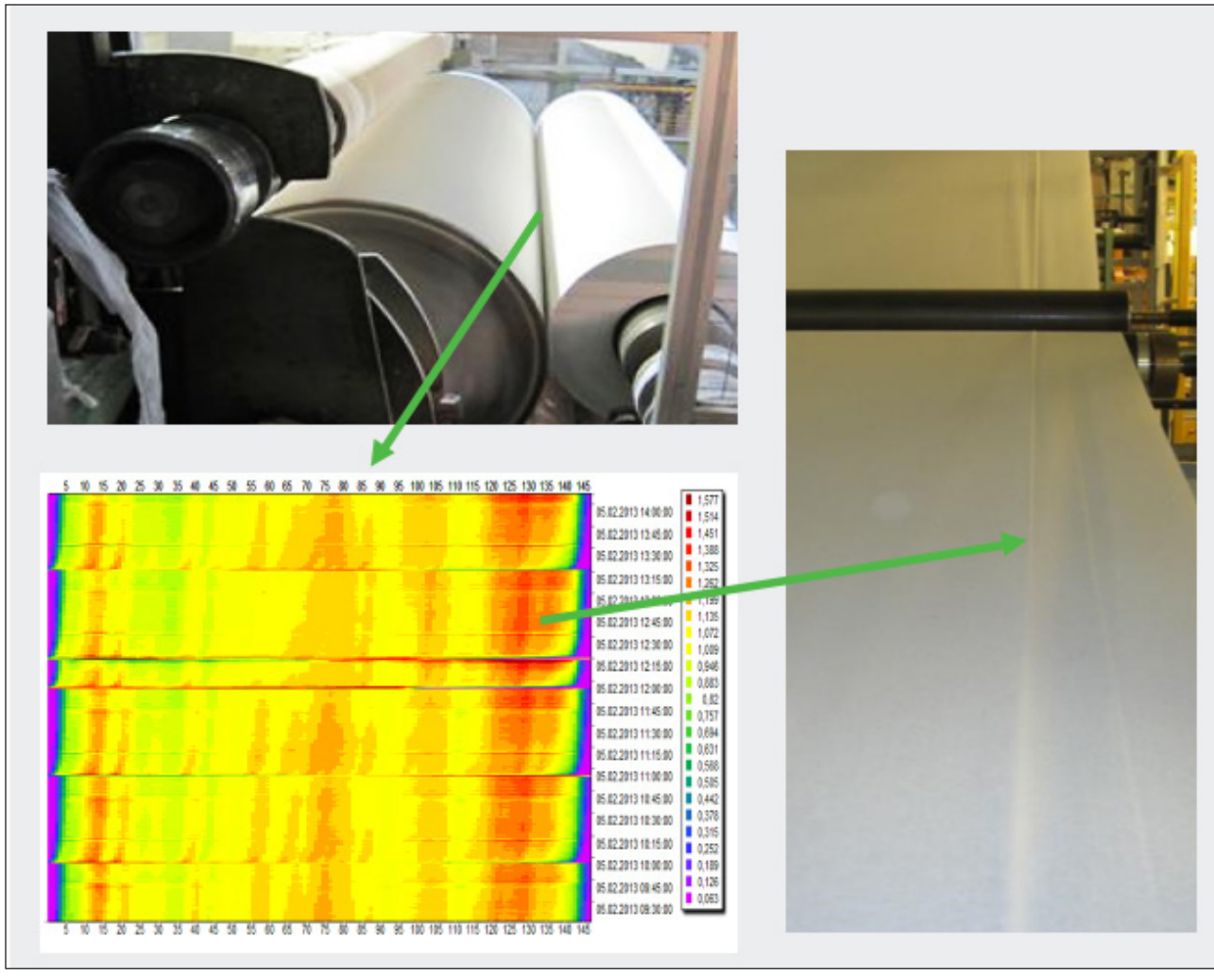
The next step was to further study the root cause of the problem by combining tension profile measurements with profile data from the tissue machine. To do this, another portable intelligent roll installation was utilized to determine if the tension profile issue was caused by the reeling process or tissue machine profiles. This system was installed with sensors on the reeling cylinder's surface. Nip load trends, reeling nip load profile, and the paper roll hardness/diameter profiles were measured online as the parent roll was built against the cylinder. Mea-



26. The profile in the top image illustrates the tissue paper tension profile measured on a web guide roll after converting line unwinding. The tension level with the tissue sheet was low, around 10–15 N/m (Newton per meter), and dropped below 5 N/m on the loose edge.

surements were taken during several parent rolls, including process response tests with press nip and reel nip loading. The hardness profile data were compared with the tension profile and other paper quality figures such as basis weight, tensile strength, tensile strain, thickness, and tear strength.

As a result of the analysis and observations, the reason for the loose edge was found. It was caused by skewed reel nip loading and a high-hardness area on drive side of the parent reel that caused overstretching of the sheet, making it loose during the next unwinding. The hardness bump origin lay in the dry weight profiles and headbox. The resulting recommendation was to reduce the basis weight in the problem area and straighten the reel nip load by reducing the drive side loading pressures. **Figure 27** shows the hardness profile measured from the reeling nip and the hardness profile error connection to the loose sheet edge, illustrated as a color map. In Fig. 27, the drive side is on the right, and several parent rolls are being measured. The hard drive side edge is shown in dark red on the color map; this area overstretches inside the parent roll and unwinds as a baggy edge in the next unwinding, resulting in wrinkling (right image). The profile color map also shows other narrow profile variations originating in other cross-dimensional profile errors in the tissue web, headbox structures, dry creping, or moisture profiles, which allow for further optimization.



27. The parent roll hardness profile data set measured from the reeling nip and illustrated as a color map (lower left image).

CONCLUSION

This paper presented a toolset for improving tissue production efficiency using intelligent roll technology. The intelligent roll measurement system converts the nip or web guide roll into a sensor that can replace a conventional roll in web handling equipment. The system can then be used for the detection of nip load, parent roll hardness, and fabric or sheet tension profiles. The sensor arrangement can also be used as a contacting sheet temperature profile measurement foil to optimize drying processes and improve moisture profiles. In addition, a portable version of the measurement system can be temporarily installed to troubleshoot press area nip load profile variations, sheet runnability characteristics, drying-induced moisture profile problems, or reel and rewinder nip load functioning.

Applications of the intelligent roll measurement system at wet pressing and drying were introduced, including a case example of improving moisture profile and energy savings through nip optimization. Reel, rewinder, and converting area applications were also introduced, including a case example of the avoidance of broke and web wrinkling issues in converting. In addition to the example cases, the paper discussed a wide selection of utilization opportunities, supported by example data sets and measurement results that showed the use of the intelligent roll in a real tissue production environment.

Utilization of intelligent rolls has mainly been concentrated on the traditional tissue machine concepts, and thus applications in new hybrid machines offer the potential for further research. With intelligent rolls, tissue makers can improve the production line's efficiency from the wet end to the rewinder and converting processes. Better material efficiency translates to bigger production volumes without additional costs. At the same time, energy consumption per ton is kept to a minimum, resulting in proportionally lower carbon dioxide emissions. These opportunities provide new expansion areas and future development targets for intelligent roll technology that focus on improved overall efficiency and cost savings in the tissue paper industry. **TJ**

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About this journal

ABOUT THE AUTHOR

The tissue paper industry needs low investment cost tools to improve overall efficiency, and development of intelligent roll applications for tissue processing equipment has given an opportunity for this improvement and other ones. This paper is a continuation of earlier intelligent roll-related research and development published in *TAPPI J.* 20(11): 695(2021).

Working with tissue machine applications differs from earlier fields of utilizing the intelligent roll advances. The demands for lower cost solutions are tight, and there are also limitations in the equipment such as space limitations, for example. Also, some areas lack rotating rolls, so the approach had to be changed to work with stationary objects like web guide foils, for instance. With developments in embedded sensor and data processing technology, these obstacles were overcome.

The embedded sensor structures provide information that has not been obtainable before in the tissue industry. Tissue applications differ from applications in printing paper, for example, and a different approach is needed. The tissue industry has a distinct culture and technology solutions. It pays to utilize these new technologies in field installations and to work with the data in a real environment, as findings from other paper industry applications may not be valid.

A particularly interesting finding was that the results gave very straightforward tools for process optimization, but advanced analysis of the data is the most difficult part in nip optimization. This is especially true when working with roll cover crowns.



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Tissue and other mills can benefit from tools like these that can be applied with relatively limited investment costs and short timeframe to bring energy savings, reduced runnability problems in converting, and improved material efficiency in the tissue production dry end. The next step is to expand this research towards new "hybrid" tissue machines, including wet creping nips or various kinds of shoe press installations.

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