STUDY ON THE RELIABILITY OF TURN-UP DEVICES

Lappeenranta–Lahti University of Technology LUT

Master’s Programme in mechanical engineering, Master's thesis

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ABSTRACT

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Study on the reliability of turn-up devices

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79 pages, 29 figures, 4 tables and 4 appendices

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This thesis is made for Valmet Technologies Järvenpää Reels&Winders-department. The aim of this thesis is to study the existing turn-up combinations on the reel and to come up with ideas that increase their reliability and success rate. This thesis consists of theory, interview, and practical part that is implemented in the test facilities of Valmet Technologies Järvenpää. Theory section consists of presentation of the present reel- and turn-up combinations, a short description of the main competitors in the field of papermaking and a more thorough study on waterjet turn-up device and the arrangement for the practical tests.

The aim of the interviews is to gather all the existing problems that reduces the reliability of the turn-up process and to come up with solutions to fix these problems. The interviewing is made for the reel product manager, superintendent, and development manager of Valmet Technologies Järvenpää. The aim of the practical tests is to study the properties of the current adhesives in different temperatures to be able to place them in order of precedence, and to understand what adhesive should be used on a certain project. The actual process has been copied by standardizing some values and variables. The results of this study are used as a preliminary information in the product development project in 2022.

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Tämä diplomityö on tehty Valmet Technologies Järvenpään Rullaimet&Pituusleikkurit-osastolle. Työn tarkoituksena on tutkia olemassa olevia vaihtolaitemahdollisuuksia rullaimella ja listata ideoita, jotka parantavat niiden luotettavuutta ja toimintavarmuutta. Työ sisältää teoriaosuuden, haastattelun, sekä kokeellisen osuuden Valmet Technologiesin tutkimuslaitoksella. Teoriaosuus pitää sisällään esittelyn nykyisistä rullain- sekä vaihtolaitekombinaatioista, lyhyen esittelyn kilpailijoista tällä saralla, sekä tarkemman tutkimuksen vesivaihtolaitteesta ja koejärjestelyistä.

Haastattelun tarkoituksena on kerätä yhteen ja luetteloida kaikki olemassa olevat ongelmat, jotka vaikuttavat heikentävästi vaihtoprosessin luotettavuuteen, sekä keksiä mahdollisia keinoja näiden ongelmien korjaamiseksi. Haastattelu on tehty Valmet Technologies Järvenpään rullainten tuotepäällikölle, tutkijalle laboratoriossa sekä kehityspäällikölle. Käytännön kokeissa pyritään selvittämään nykyisten käytössä olevien liimojen ominaisuuksia eri lämpötiloissa, jotta ne pystytään laittamaan paremmuusjärjestykseen, ja nähdään mitä liimaa tulisi käyttää missäkin projektissa. Oikeaa prosessia pyritään kopioimaan mahdollisimman hyvin vakioimalla eri arvoja. Tästä työstä saatuja tuloksia on määrä käyttää esitietona tuotekehitysprojektissa, joka käynnistyy vuonna 2022.

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SYMBOLS AND ABBREVIATIONS

CD-direction	Cross-machine direction	
DFA	Design for assembly	
DFM	Design for manufacturing	
DFR	Design for reliability	
DS	Drive side	
MD-direction	Machine-direction	
TS	Tending side	
Viscosity	Centipoise	[cP]
Ø	Diameter	[mm]

Table of contents

Appendices

1. Introduction

Turn-up device is a device that is used to replace the full parent roll with an empty reel spool by transferring the ongoing paper web to the new reel spool in the middle of paper or paperboard making process without having to stop the whole process. There are several different turn-up devices on the markets that uses either nip contact, pressured air, or pressured water to implement the change. The most modern of these all methods is the waterjet turn-up device, which consists of waterjet beam, pick-up glue unit and surface binding arms.

Paper machine can be divided to different sections, which together enables the production of paper and paperboard. Reeling, also called wind up-section, is used to roll the full-width paper web around reel spool, to make a parent roll. After the parent roll achieves either desired length, mass, or diameter, it needs to be replaced with a new empty reel spool. This process is made by using the turn-up process. Figure 1 below shows the parent roll in reeling section, which is then transported to unwinder. After reeling, the parent roll is transferred to unwinder, to make customer rolls by cutting them in longitudinal direction on the width that customers desire. Figure 2 shows an example of customer roll. After unwinding, the empty reel spool is cleaned and transferred back to reeling section to wait for a new sequence. Reeling section is a vital part of process, since it enables the paper machine to produce paper at constant speed and store the full parent rolls.

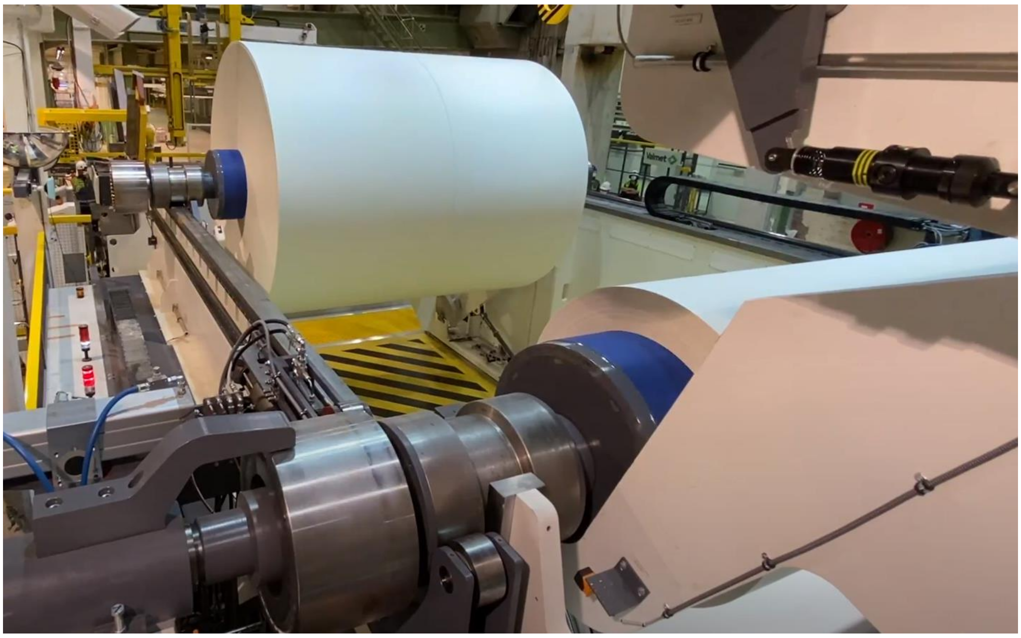

Figure 1. Full parent roll located in one paperboard mill in Finland.

Figure 2. Finished product of paperboard manufacturing, a customer roll.

The turn-up process has gone through many changes during past years. Nowadays, the two most usual turn-up devices that are used are waterjet- and tape turn-up devices. Still, the process can be made by using some alternative way, such as goose neck, side blow or edge nozzle, bubble blow or full width-knife method. All these processes have their pros and cons and the turn-up process to be used depends mostly on the paper grade that is produced and the desire of a customer. (Rautiainen 2010, pp. 210-211.) Depending on the desire of the customer, reeling section can have multiple turn-up devices, so that if one turn-up equipment fails, the other is in reserve. This can be seen by looking at the 3D-models of reeling sections that Valmet provides. Figure 3 introduces one of Valmet's reeling concepts, which is called OptiReel Center Plus.

Figure 3. One of Valmet's many reeling concepts, OptiReel Center Plus (OptiReel Primary, Center and Linear 2021).

The end-products in the papermaking industry can be divided into three main groups, which are paper, paperboard and cardboard. Paper usually has one layer but can also be multilayered depending on the construction of headbox of the machine. The basis weight of paper is between 6 and 150 g/m^2. Paperboard is a bit heavier since its basis weight is between 125 and 600 g/m^2 and it is always made from multiple layers. Lastly the heaviest, cardboard, which is produced by layering multiple paper- or paperboard together. Its basis weight is over 400 g/m^2. Roughly it can be said that paper is used for printed publication, paper- and cardboard for packages (KnowPap 2021a).

1.1 Research problem and questions

Depending on the web speed of the paper machine and the size of the reel spool and parent roll, the turn-up process approximately happens once in 45 minutes. In an ideal case, the turn-up process happens over 720 times in a month, which can be calculated with Valmet's internal sequence-excel, so every failure on turn-up causes either high loss of production or parent rolls with poor quality. Poor reliability also causes unnecessary work for Valmet since the warranty repairs need to be handled worldwide. Not to mention that the low reliability might lead to customers to order their machines from somewhere else. The research problem is the reason for insufficient reliability on turn-up section. Thesis answers to the following research questions:

- Why is the reliability of current waterjet turn-up devices insufficient?

-How can the turn-up process be intensified, can the current turn-up method be updated, or is it necessary to come up with a new solution to improve the reliability?

- What are all the parts that has effect on the reliability of the waterjet turn-up process.

1.2 Objective and defining

This thesis studies and takes a stand on the problems and fault points on the turn-up process now, finds out and compares the similar solutions from other industries, and comes up with a bunch of ideas that will improve the efficiency and reliability of the turn-up process. This thesis is used as preliminary study for a product development project that takes a place in year 2022. The aim of this thesis is to gather all the existing information about the faults and problems of the existing turn-up processes and to come up with some new ideas that will decrease the amount of turn-up breaks and thus increases the reliability of this mentioned process. Thesis also studies, tests, and compares the adhesives that are used on turn-up section. Thesis introduces other turn-up processes on Valmet's and its competitor catalogue, but mainly concentrates on the waterjet turn-up process and the ways to improve its reliability. Since waterjet turn-up beam always comes equipped with pick-up- and surface binding equipment, this thesis also studies and takes a stand on possible methods on how to improve their reliability.

1.3 Research methods

The research for this thesis is implemented by studying the literature in the field of papermaking, attending a paperboard startup in one paperboard mill located in Finland, interviewing the experts of Valmet, and executing practical tests in the facilities of Valmet Järvenpää. The interview is implemented by gathering a list of questions, which is then filled by the experts. All the information is gathered and organized in tables, which shows all the answers categorized. The reliability of the interviews is strived to maintain high by gathering the information from reliable sources. The interviews are made with Valmet’s reel product manager, the superintendent in the test facilities and a development manager, from which all these above-mentioned people have made a long career among reels. The actual outcome of this thesis is the preliminary information considering the available problems and solution in the waterjet turn-up process and the classification and comparison between the available adhesive. The gained results are then utilized during the product development project to be able to improve the reliability of the turn-up process in practice. The comparison of the available adhesive is implemented by planning and building a test equipment that can be used to measure the pick-up force of different adhesive in different temperatures and under the influence of different variables.

2. Study on the reeling section and practical tests

Paper and paperboard manufacturing is one of the world's largest industries. In 2020 the biggest export product in Finland by over 5,7 billion euros was paper and paperboard (Metsäteollisuus ry 2021). This leads to huge production volumes worldwide, since Metsä Board itself produces over 2 million tons of paperboard with eight machines every year (Metsä Board 2021). As every paper and paperboard machines has one reel, the demand for its reliability is highlighted. Thesis studies the field of papermaking and concentrates on the reeling section of the paper machine. The subject of this thesis is the turn-up device, which is in the finishing room and more specifically, reeling section. This chapter briefly introduces the finishing room of a paper machine but still concentrating mainly on the reeling section and the machinery in that specific area. Main competitors in the field of papermaking are also introduced to gain reference base for this study.

The reliability of the paper and paperboard machines can be increased by many operations, but this thesis concentrates on the turn-up process. The reliability of the turn-up process can be generally increased by either making modifications on the existing methods or coming up with a whole new idea. The increase of the reliability is measured by making practical tests, which will show whether the some components needs to be re-designed.

Like in any other industry, safety and efficiency are considered valuable, especially in the field of papermaking. In the manufacturing of paper machines, the efficiency partially comes from efficient designing. Designing needs to be manufacturing- and reliability oriented and modular solutions are highly recommended. Manufacturing- and reliability-oriented aspects can be viewed by DFM (Design for manufacturing) and DFR (Design for reliability), which are introduced below. Multi-objective conceptual design approach is used as a guideline on how to come up with an end-product by maximizing the reliability and minimizing the costs from the designing to the manufacturing phase. The modularity in the designing process means combining different modules to come up with a functional and cost-effective outcome. (Baldwin et al. 2000, p. 63.) The waterjet turn-up process consists of a turn-up-, pick-up- and surface binding devices. All these are complex entities with multiple modular solutions, which are viewed more specifically on the next chapter.

DFM is a traditional engineering methodology, which is used to maximize the efficiency and decrease the downsides of the manufacturing process. It combines the designing and manufacturing processes to decrease the time and costs during the designing process, speeds up the designing process, allows the product to be tested with as fast and with as low costs as possible. It is also used to accomplish a certain level of quality and reliability and to satisfy the needs and demands of customer. DFM is highly recommended tool for machine design since it has a great effect on the total costs of the product. The importance of DFM comes from the fact, that up 70 % of the product total costs comes from the designing process (Shebab et al. 2002, p. 999). DFR is a tool which is used to make sure that the designed and manufactured components can perform their tasks with a certain level of reliability. It helps recognize the possible problems and to avoid them happening before the manufacturing (Wang et al. 2012, p. 34).

The designing of turn-up devices needs to be made by considering the reliability-oriented- and manufacturing friendly aspects. These two aspects can be viewed from multiple perspectives. The reliability of the product is dependent on the single machine parts and their reliability. Multi-objective conceptual design approach is a flow chart that is used to come up with a product with maximized reliability with minimized lifecycle costs. Figure 4 below illustrates a multi-objective conceptual design approach.

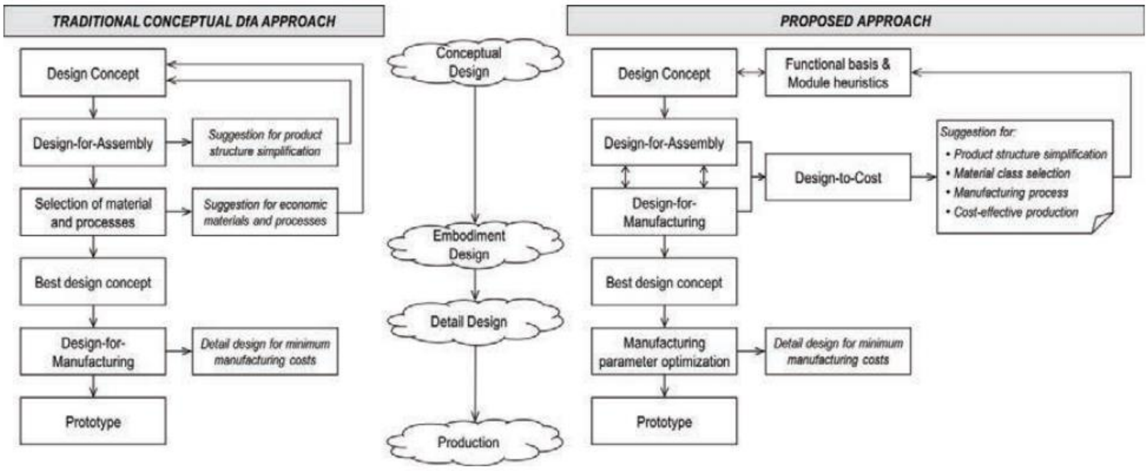

Figure 4. Multi-objective conceptual design approach. Traditional conceptual DFA (Design for assembly) approach is shown on left side and the proposed approach on the right side (Favi et al. 2016, p. 277).

As seen on the figure 4 the lifecycle of a product is wide. Traditionally the process starts by designing the product, which is followed by the DFA-inspection. DFA gives suggestions for improvement that are used to increase the quality and reliability of the product. The idea goes through the designing process again and again as many times as needed. After the fine graining of the idea, the next subject is the selection of materials and processes. DFM is used to minimize the overall costs of the product, which is followed by making of the prototype. The proposed approach starts by designing process as well. The first difference compared to the traditional method is cooperation between DFA and DFM methodology, which produces the DFR. By combining these three methodologies, many improvements can be achieved, such as structure simplification, material selection, manufacturing process and lowering of the total costs. The original idea is then modified in the terms of these improvements and this is the cycle that is repeated as many times as needed. After the desired result, the best design concept is chosen, and the manufacturing is started to consider minimizing the manufacturing costs, from which follows the prototype.

2.1 Finishing room in paper machine

The finishing room of a paper machine consists of pre-treatment of the paper web, reeling, winding, sheeting, and handling of the roll. All the paper machines don’t necessarily have to include all the same aggregates, since surface sizing, coating and calandering are only made if the product requires it, meanwhile all machines have reeling-, winding-, and roll handling sections. The biggest change inside the finishing room is the transition from reeling section to winder, since the mean of reeling section is to produce uniform paper with continuous feed, while winder is the first periodic process, so the reeling can be said to be the key factor on the process (Häggblom-Ahnger et al. 2001, s. 220).

Surface sizing is invented for paper grades such as fine paper, raw paper and paperboard. It is used to increase the strength properties by adding starch between the fibers of a dry paper. Surface sizing method depends on the paper produced. Normally surface sizing is made by using a film size press on paper grades and by pond sizing on paper- and cardboard. Both methods have liquid which is applied on the surface of the web by guiding the paper web through a nip contact of two spools (KnowPap 2021f).

Pigmenting is used to decrease the air permeability, printing properties and the looks of different paper grades by mixing filler material to the surface sizing liquid. Pigmenting and coating increases the lightness, gloss and opacity of paper. By opacity is measured the transparency of a material. The greater the opacity, the less the material lets light through (KnowPap 2021e).

Calandering is used to increase the printing- and processing properties, adjusting the thickness of the paper, and stabilizing the thickness profile by pressing the web between two or more cylinders. Calandering is also used on gloss controlling of the paper. Some paper lines can also have a pre-calander, which is located before the actual calander. Calanders can be divided to on-machine calander and off-machine calander. On-machine calandering happens before the finishing room, meanwhile the off-machine calandering happens in the finishing room (KnowPap 2021g).

Reeling section is the turn point where the continuous process turns into periodic process. Reeling is used to transform the web into a product that can be stored, used and moved more easily. The other important task of reel is also to make sure that the material efficiency stays high enough. The size of a parent roll also has a huge effect on the efficiency of the reeling process. The size of the parent roll depends on many factors, such as the width and the grade of the paper produced. While making larger paperboard parent rolls (Ø 3800 mm), there will be roughly 67 % less turn-ups and roll handling compared to the smaller rolls (Ø 2300 mm), which reduces the risks of the failure of the process (KnowPap 2021b).

After the reeling, the parent roll is guided to winding section, where the full-width parent roll is cut to desired width customer roll by using rotating cutting blades. Since the quality of the edge of the web does not meet the customer’s demands, it is removed by using edge trimming equipment. Since the parent roll have exact amount of paper, which is then rolled around the smaller customer rolls, there will be a little left-over paper around the parent roll, which is then pulped. The empty parent roll is now a reel spool, which is then cleaned and transferred back to the reeling section to wait for a new sequence to begin. Final step in the finishing room is the roll handling section, which includes all the work that is done to the finished customer roll such as storage and packing (KnowPap 2021d).

2.1.1 Reeling section

Valmet is the biggest paper machine producer in the world, which reflects on the reeling equipment and machinery. Valmet has a brand for reels, which is called OptiReel. Nowadays Valmet’s catalogue consists of multiple different OptiReeling concepts such as OptiReel Linear, OptiReel Center and OptiReel Pope. Some of these are old products with a new name. All these mentioned OptiReels have their own unique design and functions (Reel_SMM_Portfolio.pptx 2021). The oldest concept was the ValReel-series, which included ValReel, ValReel Plus and ValReel Pro. After the brand change the basic model ValReel was renamed as OptiReel Pope, ValReel Plus as OptiReel Primary and the ValReel Pro as OptiReel Linear. (Reel technology, spare parts academy 2021.)

OptiReel Pope is the most traditional reeling device. The reel spool is lowered down with the primary arms on top of the rotating reel drum. Reel spool starter attaches the reel spool and starts to accelerate it to the web speed. After the web speed is achieved, reel spool starter pulls away and the primary nip is closed by using the primary arms. The most important factor in this reel type is the primary arms, which transport the reel spool all the way from the beginning to reeling rails, until the secondary arms attach to the reel spool and provides a decent nip load in the secondary nip. (Rautiainen 2010, p. 208.)

OptiReel Center is an updated version of the OptiReel Pope. Empty reel spool is lowered down with the lowering arms on to the primary reeling device. The primary reeling device then locks the reel spool and starts to lower on a small angle towards the reel drum until the nip closes. After the turn-up the primary reeling device starts to rotate then reel spool over the reel drum while simultaneously keeping the nip closed. Secondary center drive then attaches to the fulfilling reel spool to maintain the torque and slow down the finished parent roll while still moving it ahead. (Reel technology, spare parts academy 2021.)

OptiReel Linear normally has long reeling rails which hold the reel spools. Reel spool is attached to the primary center drive, which accelerates the spool to the web speed. Reel drum rises with hydraulic cylinder, the primary nip closes and turn-up happens. After the turn-up the reel drum starts to lower, secondary reeling device attaches the reel spool, and the primary center drive comes off. The secondary carriages start to move the reel spool ahead to pass the reel drum. (Reel technology, spare parts academy 2021.)

Although all these reels have their own specialities and unique designs, they can be combined depending on the needs of a customer and the installing location for the machine. For example, the factory that was visited during this thesis was equipped with an OptiReel

Linear with overhead reel spool storage and OptiReel Cart to transport the full parent reel to the transfer rails because of the separate rooms for the reeling and winding.

Three tail threading ropes travel all the way from predryer- to reeling section, defining the route for the paper web. The tail of the paper web travels from calander to reeling section under the guide roll and counter-clockwise over the reel drum down to the pulper. The web is then expanded to its full width by using the desired variation of tail cutter. Depending on the grade of paper, the tail can be cut by double jet tail cutter or double blade tail cutter. The paper web now needs to be picked-up around the reel spool, which is made by using the turn-up process. Empty reel spools are stored in the reel spool storage, which changes its shape and location depending on the used reeling device (Pope, linear etc.) After the tail threading on Optireel Linear, the empty reel spool is picked from reel spool storage. The mill that was visited during this thesis had an elevated reel spool storage from where the reel spools were lowered on top of the rails by using lowering arms. This construction was made since there was very little space. Primary center drive on the TS (tending side) of the machine and the secondary drive on the DS (drive side) of the machine then attaches on the ends of the reel spool, and the primary center drive starts to accelerate the reel spool to the web speed. (Rautiainen 2010, pp. 210-212.)

Once the web speed is achieved, the turn-up process begins. The reel drum starts to lift near the reel spool. The nip contact between reel drum and reel spool closes and the turn-up happens. The order and movements of the machine depends on the used turn-up method. After winding section, the empty reel spools are cleaned are transported back to the reel spool storage by using a crane. (Rautiainen 2010, pp. 213-214.) Figure 5 illustrates the reeling section on OptiReel Linear, showing the most vital components, such as the crane, reel spool storage, primary- and secondary center drive, reel drum and pulper.

Figure 5. OptiReel Linear photographed from the frontside, across the paper direction.

2.1.2 Different variations of turn-up methods

Turn-up and pick-up are used to transfer the full-width web to an empty reel spool by cutting the web and attaching it to a new reel spool while simultaneously keeping the other processes running. The turn-up takes place when the desired mass, diameter or length of the parent roll is achieved. There are many methods of implementing the turn-up, such as sideblow, bubble blow, gooseneck, tape turn-up and waterjet. Out of these processes the waterjet is the most recent and offers the highest reliability, success rate and quality of the parent rolls, but many reels are still equipped with several turn-up devices, for example waterjet and tape turn-up device combination. (Rautiainen 2010, pp. 210-211.)

One of the most common turn-up methods is **waterjet turn-up**. Waterjet unit is quite a complex structure, which consists of multiple parts, which are introduced on the figure 6 below. As the name implies, this method uses high pressured water to cut the web and steer it to the reel spool. When the turn-up process takes place, reel drum rises to the nip contact with the empty reel spool and the surface binding arms turns near the parent roll. The pick-up glue unit behind the reel drum prepares and the waterjet cutting nozzles moves from the sides of the web to the center so that they go across the defined amount. The amount of crossing can be adjusted by the user. (APPENDIX 2) introduces the waterjet turn-up process from two different perspectives.

Pick-up glue unit shoots either cold- or hot glue through its glue nozzles on the web near the nip, which forces the glue to attach on the surface of the new reel spool. The timing of the pick-up glue and the beginning of the cut is adjusted by the user, one combination for example is that after the glue has reached a full round around the reel spool, the waterjet nozzles start to cut the web by using highly pressured water with pressure up to 1500 bar. (Waterjet turn-up device, REEL 2019.) As the cutting nozzles move from the center towards the edge of the web as fast as 10 m/s, the tail of the web attaches to the new reel spool by the force of the pick-up glue and the nip contact. (Rautiainen 2010, p. 214.) After the cut, the surface binding arms on the sides of the parent roll bind the surface of the full parent roll by spraying a small amount of adhesive between the last few layers.

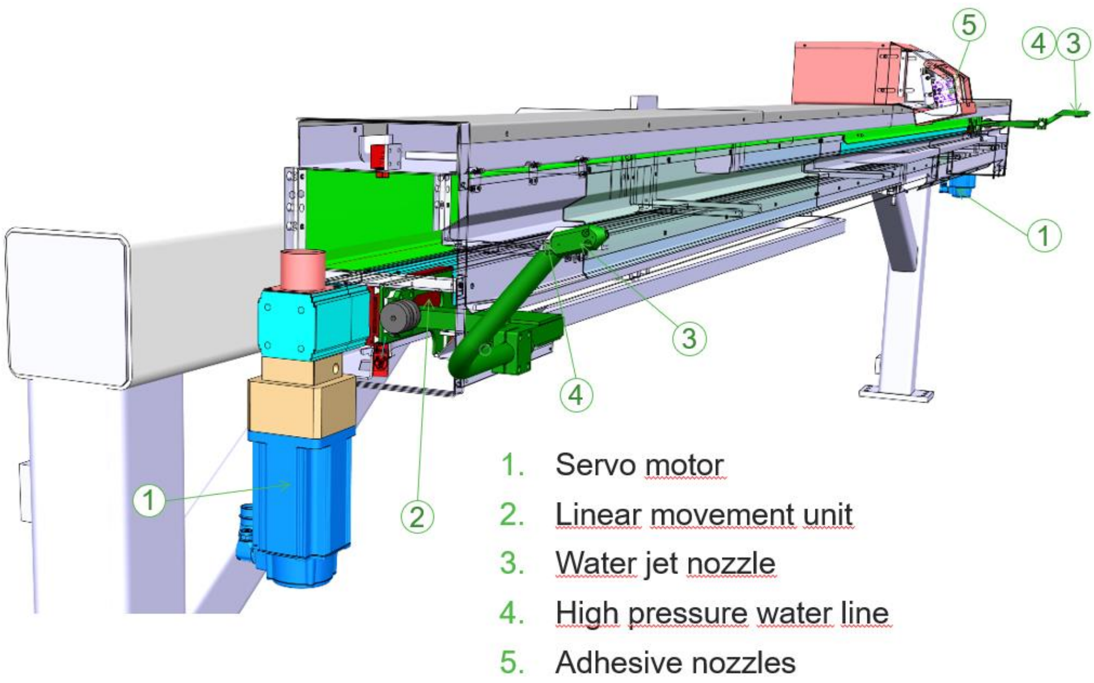

Figure 6. Components of waterjet turn-up device. (Waterjet turn-up device, REEL 2019.)

The principle of the waterjet device is quite simple. The two servo motors have pulleys, which are in contact with a belt that moves the water jet nozzles on CD (cross-machine direction). To maintain the high-pressure water hoses unbroken, there needs to be an energy transmission chain which absorbs the external forces and allows the hoses to move freely on the desired direction. Figure 7 below illustrates the energy transmission chain that is located inside the waterjet beam. High pressure inside the water hoses forces them to yield which leads to the fact that the energy transmission chain will not stay on its location. This problem has been solved by making a small bend on the edge of the beam. The nozzle arms are on different levels and work with their own servo motors, which allows them to cross in the center. Depending on the design of the reel, the length of the waterjet beam can be from 3000 mm to 11 000 mm, which is assembled by using modules. (ReelReferences18 2021.)

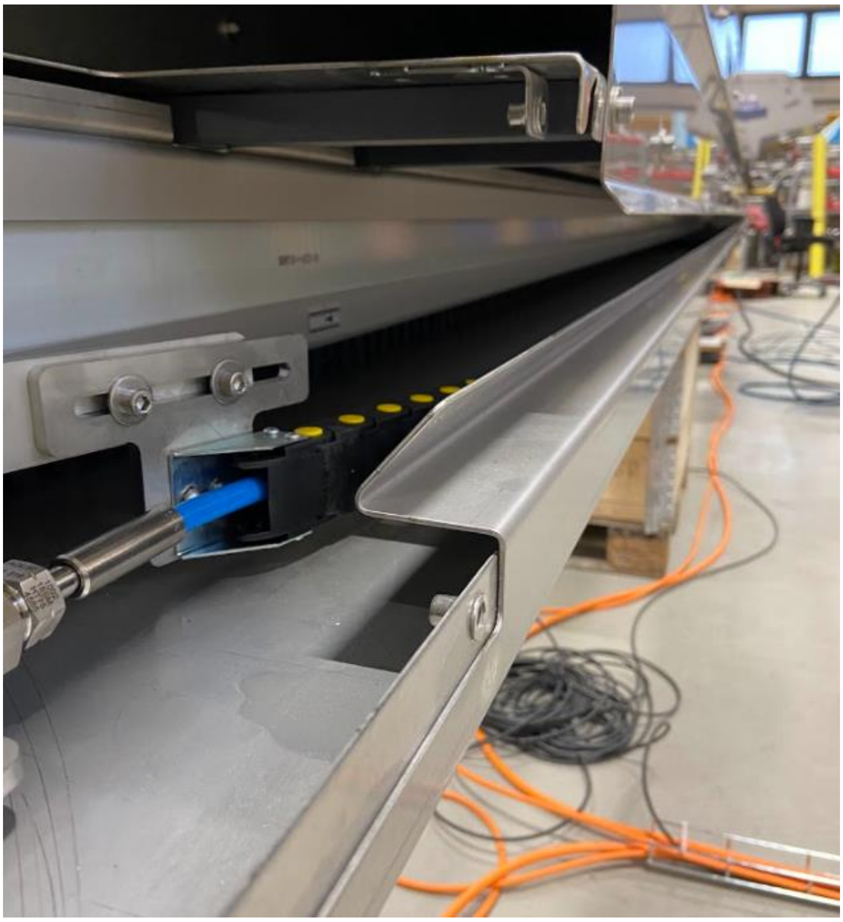

Figure 7. Waterjet beam and the two mentioned components, which are the energy transfer chain and the bend on the edge of the panel.

The waterjet nozzles can be either 0.15 mm or 0.20 mm size, which depends on the grade of the produced paper or paperboard. Roughly it can be said that that paper grades use 0.15 mm and paperboard 0.20 mm nozzles. The distance between the nozzle and the nip is defined during the designing. It needs to be accurate since the timing of turn up is calculated through the distance that the water needs to travel along the surface of reel drum from the nozzle to the nip. The distance from the nozzle to the paper web also needs to be right, about 20-30 mm, because if the nozzle is too close, the paper web won't fit between the reel drum and the cutting nozzles, meanwhile if the nozzle is too far from the reeling drum, the water beam will not be sharp enough, which can be seen on figure 8. (Waterjet turn-up device, REEL 2019.) Figure 7 also shows the difference between a working nozzle and the faulty one. Table 1 introduces some general information considering the waterjet turn-up equipment.

Figure 8. Working and faulty water nozzles that were discovered during a test. The nozzle on the top is the working and the lower nozzle is broken.

Table 1. General information about the waterjet turn-up device. (Valmet Water Jet Turn-up Adhesive and HotMelt 2016.)

Used source	Information	Consumption
Water	Distilled water	0.5 – 1.0 dl / turn-up
Air	Compressed air, 5 – 8 bar	220 l / turn up
Surface binding glue	Starch based cold glue	< 10 g / turn-up
Pick-up glue	Starch based cold glue or water-soluble hot melt glue	< 10 g / turn-up

Valmet has also developed more cutting techniques to be used with the waterjet. Valmet soft start and W-cut offers new innovations for turn-up process. The main benefit of the soft start cutting is its ability to prolong the lifetime of the reel drum. When using the soft start, the cutting nozzles are pressured while they travel to the starting position in the middle. This leads to the fact that the nozzles will not cut on the same spot on the reeling drum every time, since the reel drum rotates. This is mostly used with soft reel drums. (Valmet Water Jet Turn-up Adhesive and HotMelt 2016.)

Name W-cut comes from the cutting trail which the waterjet nozzles leave on the paper web. The principle of W-cut can be best understood by looking the figure 9 below. When the desired size of the parent roll is achieved, the waterjet nozzles move to their home position in both edges of the web. The cutting starts and the nozzles travels in the middle of paper web across each other, and the cutting stops for 0.05 – 3 seconds, which is defined by the user itself. While the nozzles make the cut, pick-up unit dispenses the glue on the web. Waterjet nozzles starts to cut again and at the same time the pick unit dispenses the glue again. Then the cutting nozzles travels back to the home position. This allows the surface binding device to be left out since the pick-up glue has two jobs. It picks the web on the new reel spool and binds the surface of the full parent roll (Pat. IPC B65H19/26 2019, p. 13). The development and testing of w-cut is in early stage since it has only been tested on two different reels and with two different paper grades, so a few targets of development has occurred.

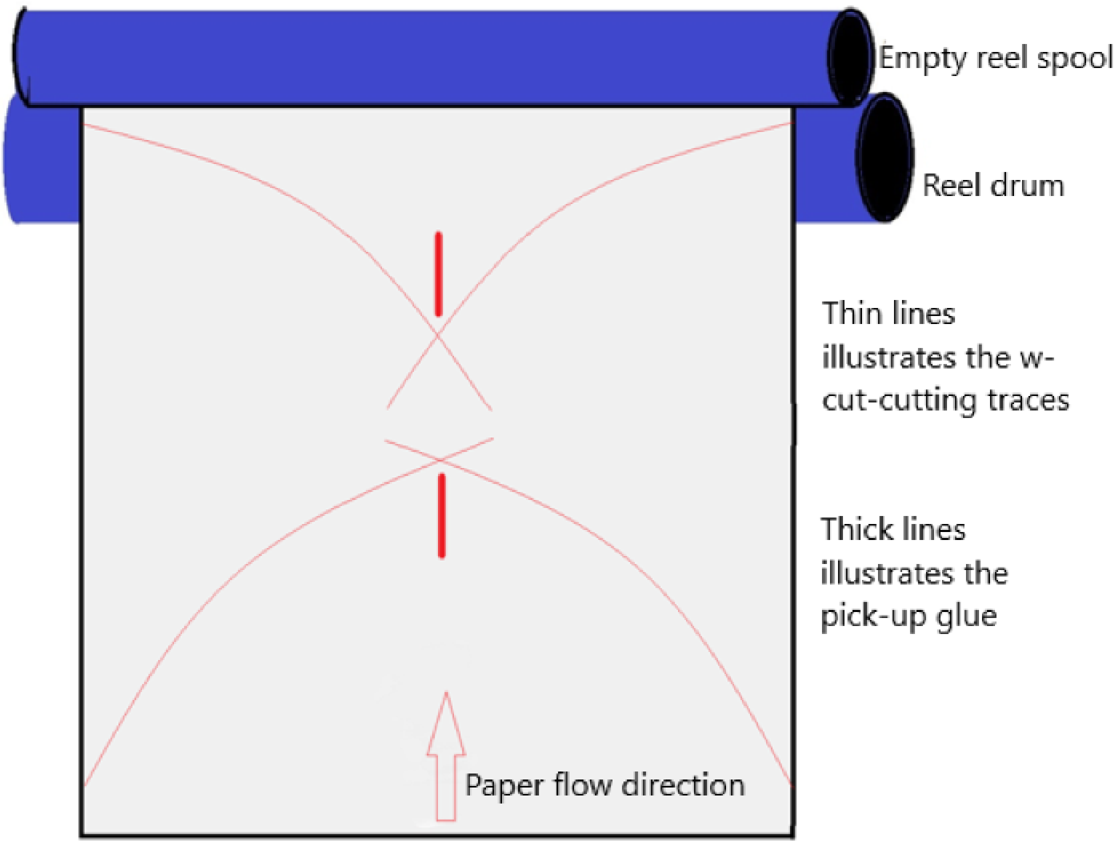

Figure 9. Principle of Valmet W-cut waterjet cutting method. Red thin lines illustrate the waterjet cutting traces. The arrow on the bottom shows the paper flow direction. The two thick red lines illustrate the pick-up glue.

The other possible area of development is the pick-up during turn-up. If the nozzle speed is too high, the tail of the paper web can hit the reel spool, which can cause the turn-up process to fail. This problem can be solved by using lower accelerations of the cutting nozzles. (Hyötynen 2021.) The slower the cutting nozzles travels from the edges to the center, the narrower the tail of the paper web will be, and the narrower the tail, the easier it is to control its direction of travel. By cutting with lower acceleration, the shape of the paper tail can be adjusted, which reduces the risk of downtime when doing the turn-up with the W-cut. (Hyötynen 2021.) Since the W-cut is not in use yet, the edges of the full parent roll are sealed by surface binding equipment so that the parent roll stays on shape during the transportation to the next process, which is the winder. This whole turn-up process happens within seconds, so timing is an asset to maintain sufficient quality and efficiency (Reliability 2021).

The **side blow**, also called edge nozzle method, uses one air nozzle, which is located on either side of the reel drum. The air nozzle is used to blow high-pressured air against the web between the primary- and secondary nip to cut and steer the web through the nip and around the reel spool. This method works on slow- and narrow lines, since it is starting to lose strength, accuracy and blowing distance on higher speeds. (Rautiainen 2010, p. 212.)

Bubble blow method is used for slow speeds and light paper species. The parent roll is transferred further away from the secondary nip contact to slow down by using brakes. While the web begins to loosen up, it will start to fold around the new reel spool through the primary nip which is made between the reel spool and reel drum. The paper web snaps in the effect of the nip contact. The process can also be intensified by using blow pipes which guide the paper web in the nip more efficiently by blowing a pouch into the paper web. (Rautiainen 2010, p. 212.)

Gooseneck turn-up method uses a web slasher to slice the web in longitudinal direction before the nip, which allows the air flow to come through the web. The air flow is brought through gooseneck-shaped blow pipes, which are shown in the figure 10. The air helps the web to split horizontally. The web is rolled around the reel spool by the primary nip contact. (Rautiainen 2010, pp. 212-213.)

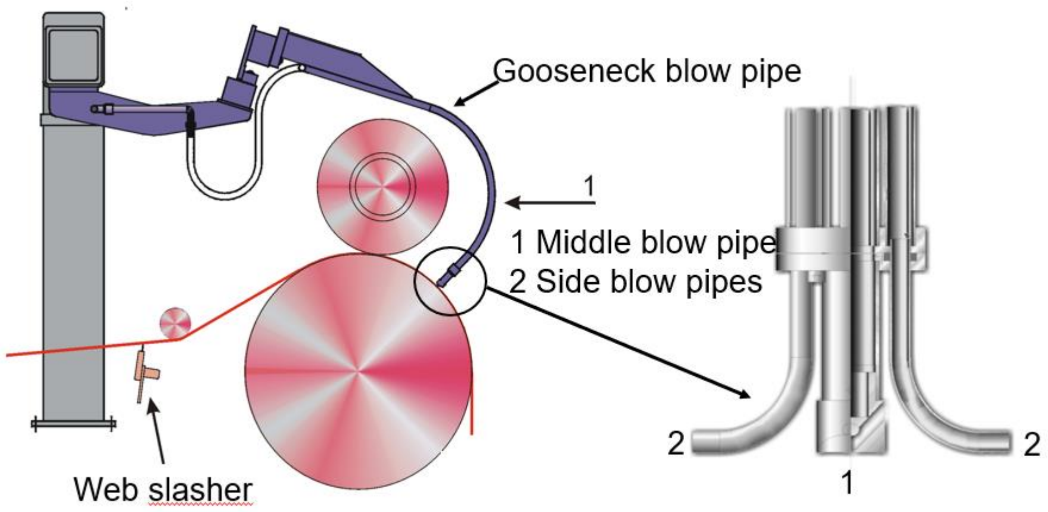

Figure 10. Gooseneck turn-up method and its most vital parts. (Reel technology, Spare parts academy 2021.)

Tape turn-up is the second most common turn-up method that is used. It uses a tape drive which moves on CD direction from the tending side to the drive side of the machine below the reel spool. The tape is fed between the nip during turn-up. Tape starts to wrap around the reel spool, and it is started to brake which causes the web to break and attach to the reel spool. (Rautiainen 2010, p. 213.) Tape turn-up unit has a "loop-box" which is used to make a tape loop long enough, which can be fed quickly. Figure 11 represents the whole assembly of an RCS 5000 tape turn-up device. As like gooseneck, side blow and bubble blow methods, surface binding cannot be made with this method since the accurate timing would be impossible to achieve. (Hyötynen 2021.)

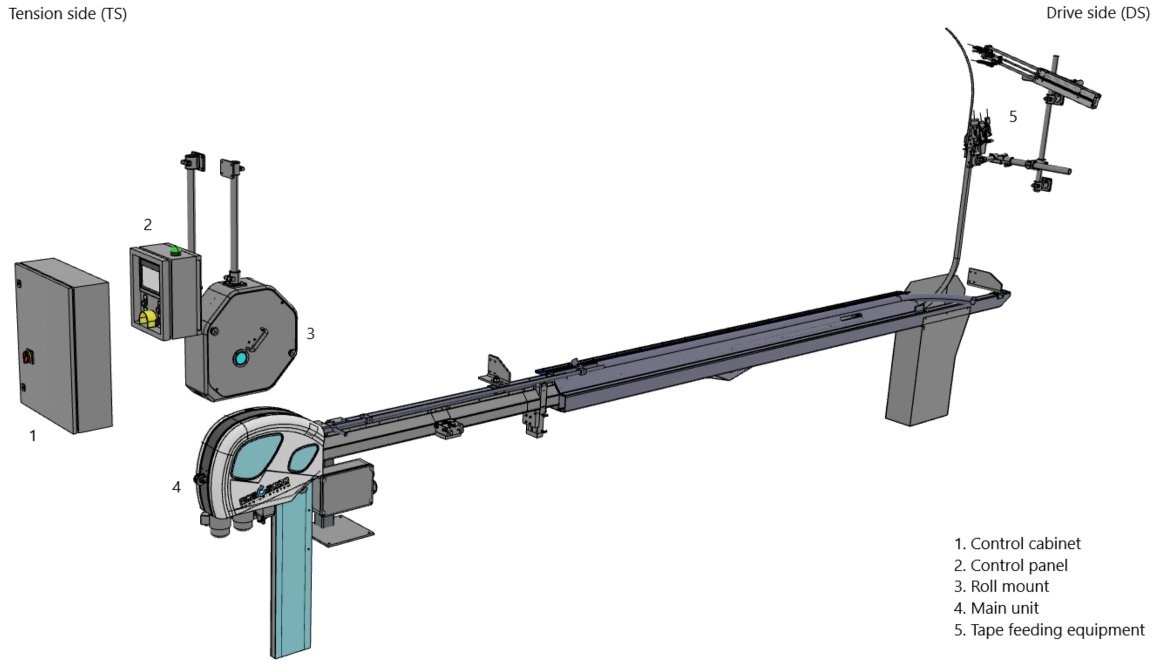

Figure 11. RCS 5000 tape turn-up device and its components.

2.1.3 High pressure water unit- and tank

Waterjet turn-up device always needs the high-pressure water unit- and tank, which are located near the servo cabinet on the drive side of the machine. These needs to be located so that the maintenance can be made easily, and the water tank can be filled regularly. Depending on the used pick-up method, the design of the high-pressure water unit can vary. The high-pressure unit has pneumatic components to transfer the water from the water tank and pressurize it up to 1900 bar. The water used for waterjet needs to be distilled or deionized to ensure that there are no particles that could harm the components (Kasula 2020, p. 1). The actions of the high-pressure unit are controlled through the servo cabinet and the control panel on it.

2.1.4 Reel spool and parent roll

The only purpose of reel spool is to be the foundation for parent roll. It needs to withstand all the external forces that will occur during reeling, transportation, and winding processes.

Masses of parent rolls can be from 3100 kg to 160 000 kg, and they can be up to 12 meters wide, which will generate bending forces on the reel spool. It also needs to be made from a material that will allow the pick-up glue to attach on it, yet the glue needs to be able to be removed from it. (ReelReferences18 2021.)

Parent roll is structured by multiple layers of paper rolled over a reel spool. Different layers of the parent roll have a unique name and purpose, as seen on figure 12. The thickness of the first layer is about 10 – 20 mm and it is the most vital for the durability of a roll. The first layer needs to be tight and even to begin the rolling properly. Bottom layer, which is about 100 – 300 mm layer after the first layer, is the most vital since it is the foundation of the whole roll. The bottom layer needs to be tight enough to avoid waste-paper, but in the other hand, too tight layer will cause stress on the inner nip and in the worst case, the paper web can snap. (KnowPap 2021c.)

The middle section is the thickest part of the parent roll. One specific task of middle section is to make sure that the hardness of the parent roll decreases layer by layer towards the surface. After the middle section comes the last, surface layer. As the first layer, surface layer is also 10 – 20 mm thick. The most important task of this layer is to protect the whole roll and look welcoming and representative, since it is the only layer that can be seen properly when looking at the finished product. The surface layer is bind during the turn-up process by using the surface binding equipment. The binding is made to maintain the roll unbroken during the storage and transportation.

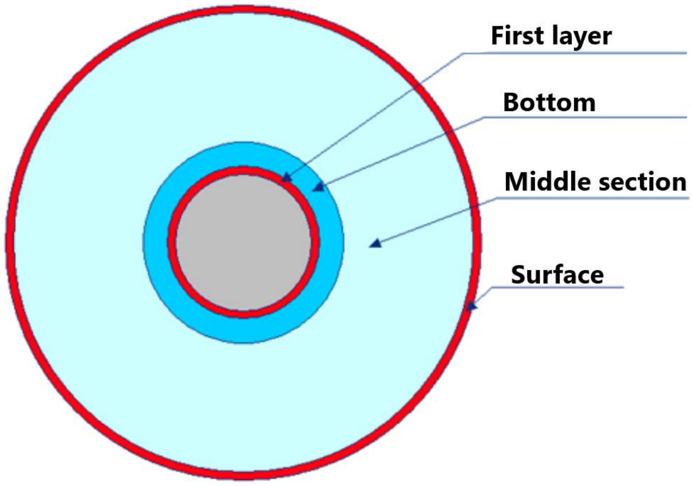

Figure 12. Structure of a parent roll. (KnowPap 2021c.)

Since the biggest goal of paper and paperboard machine lines is to produce satisfying customer rolls with certain efficiency, these following seven reeling factors and parameters needs to be considered carefully. (Rautiainen 2010, p. 220.)

1. Tension of the paper web
2. Pressure on the primary- and secondary nip
3. Torque on reeling drum and on center drives
4. The profile of the web
5. Paper to paper friction
6. Size of the parent roll
7. Size of the reel spool

Some of these factors and parameters can be adjusted automatically or manually by the process operator. Web tension, nip pressure and torque can be adjusted remotely from the control room. These parameters have a great effect on the outcome of the parent roll. By driving the web with right tension, the process operator can be sure that the bottom and all the other layers are tight enough, meanwhile too high tension will break the web. By adjusting the nip pressure and torque, the bottom waste can be reduced and by that the quality of the parent roll can be increased. Valmet has also developed an intelligent reeling drum called iRoll, which is equipped with sensors to automatically adjust the nip-, hardness- and tension profiles by drawing colour maps. All these parameters can be adjusted in real time, which helps producing better parent rolls. Simple illustration of the construction of the iRoll is introduced in the figure 13. (iRoll - intelligent roll solutions for board and paper making 2021.) Greatest benefit of using iRoll is the fact that it is studied that iRoll helps reducing 50 % of the web breaks by adjusting the reeling parameters. (Significant results achieved with Valmet iRoll 2021.)

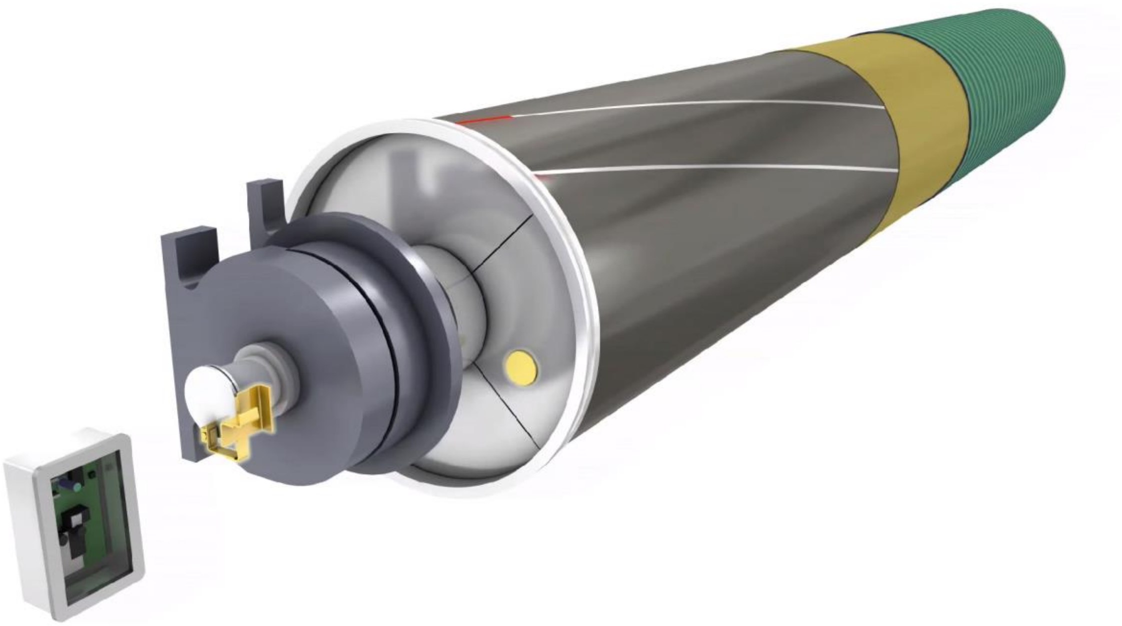

Figure 13. Illustrative picture of Valmet iRoll reeling drum technology. (Significant results achieved with Valmet iRoll 2021.)

Paper to paper friction defines the friction between the paper layers on the parent roll and it has a significant effect on the quality of the parent roll. The smaller the paper-to-paper friction, the more slippery the paper layers are together, which can cause the layers to “slide” on top of each other which will lead to the unwinding of the roll or bad quality of bottom layers, which will generate problems (Enomae et al. 2006. p. 509).

Size of the reel spool and parent roll also have their own effect on making the production efficient. The size of the reel spool is defined on the designing stage since the width of the web and the mass of the parent roll effect on the choice. Since the inner nip and reel spool bending are limiting factors, within the limits of the size of the parent roll should be as large as possible. The larger the parent roll, the less turn-ups need to be made, which of course reduces the risks of web break. There are many ordinary reeling problems that can be seen on reel spool and parent roll. Although all these problems have their own unique name, the cause of them can be very similar. Also, all these problems generate broke, which reduces the efficiency of the paper machine.

One big issue on reel spools is the contamination of the bottom. The contamination proceeds from the pick-up glue. After unwinding the parent roll there will be a thin layer of bottom broke, which cannot be used. This bottom broke is attached tight on the surface of the reel spool and will harm the reeling process if not removed. One solution for preventing the bottom broke is to roll one or more full circles of Teflon tape on the surface of the reel spool. The Teflon tape is designed so that its slippery surface prevents the pick-up glue and paper to attach to it too strictly. Reel spool with Teflon tape is introduced in figure 14.

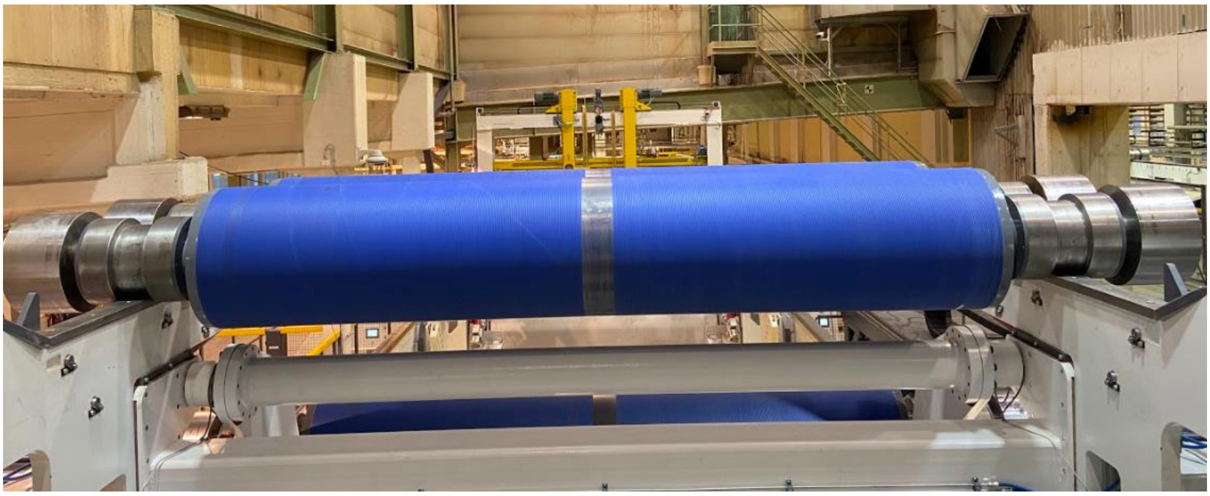

Figure 14. Reel spool with Teflon tape around its center.

2.1.5 Pick-up unit

The speed of paper machine depends on multiple matters, such as the designed speed of the machine, the width and diameter of the reeling drum, paper grade to be produced and the basis weight of it. (Valmet Water Jet Turn-up Adhesive and HotMelt 2016.) Valmet has its own internal concept selection guide which allows the designers to decide which pick-up method is used on which projects.

The pick-up glue is used to attach the paper web to the empty reel spool during the waterjet turn-up process. Nowadays the pick-up can be made using hot- or cold glue, which is dispensed on the paper web through a nozzle. Valmet had a tape pick-up equipment before the glue technology. Tape pick-up method is functional but laborious. This method is based on two-sided tape that is manually inserted on the surface of a reel spool, which then picks the paper web during the turn-up. Cold glue pick-up can be used on paper grades up to 275 g/m^2, but it is common that even lower grades are picked with a hot glue. Cold glue pick-up equipment consists of pneumatic- and hydraulic components to transfer and pressurize the glue. The pressure on the cold glue is much higher than in hot glue, up to 150 bars (Kasula 2021). Figure 15 illustrates a cold glue pick-up unit in the test facilities.

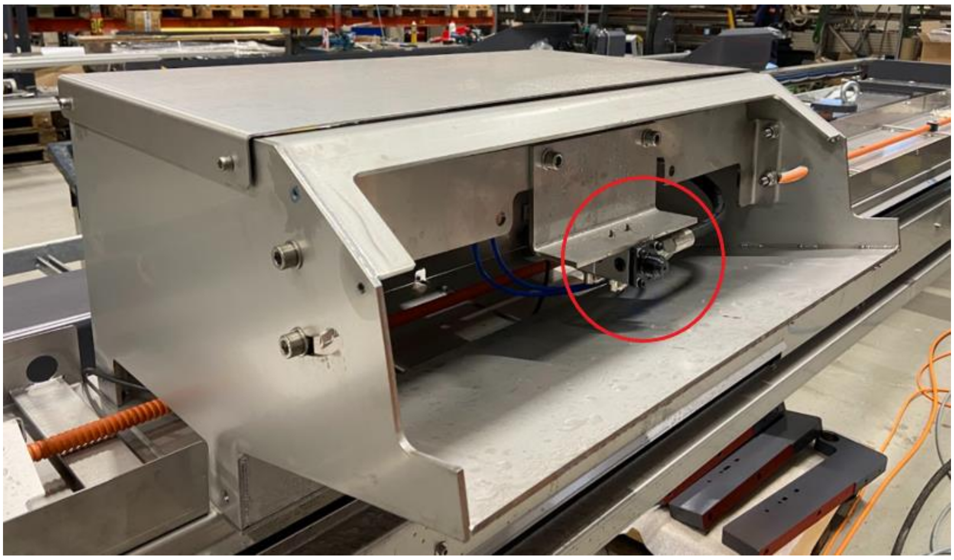

Figure 15. Construction of a cold glue pick-up unit. It contains the pressure valve with the pressure hoses and the actual glue nozzle. Glue nozzle is circled with the red colour.

As told, hot glue is theoretically used on grades up to 275 g/m^2 but can be used on even lighter grades due to its ability to generate glue that solidifies quickly enabling a successful pick-up. Robatech offers an equipment to pressurize the hot glue up to 96 bars, which is applied on the paper web through a pistol. Hot glue pistol has nozzles which spreads the glue better on the paper web. Due to the long distance between the nozzle and the pressurizing equipment the pressure of the glue drops dramatically between the pulses. This problem can be solved by changing the glue pistol. Figure 16 introduces the pick-up unit for hot glue, which keeps inside the glue pistol and pressure hoses. Development of hot glue pick-up has brought four glue nozzles to the hot glue pistol, which enables wider pick-up trace and higher amount of glue. The problem with lower pressure can also be solved by making the pick-up unit mobile, which moves on MD (machine direction) during the turn-up.

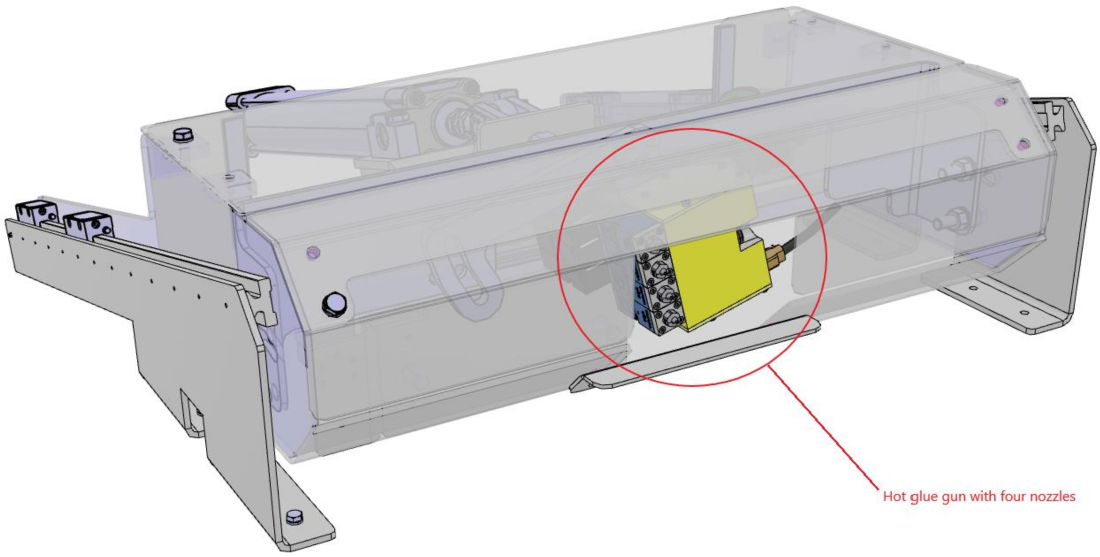

Figure 16. Construction of a hot glue pick-up unit.

The hot glue unit needs to be located somewhere so that it can be easily reached. The hot glue needs to be added to the unit manually and it needs regular maintenance. The location also needs to be considered carefully so that the heat won’t harm any other devices. The most usual location for the unit is near the high-pressure water unit on the drive side of the machine. Since the velocity of paper web can be up to 2500 m/min, the pick-up glue needs to be dispensed within milliseconds. This leads to the fact that the timing of gluing needs to be very accurate, and the amount of glue used is also very important, since too much glue will splatter around and harm other processes, meanwhile too little glue will not attach the paper web properly. Even though the hot glue is recommended for heavier grades, in some situations the cold glue could be the better alternative, since the hot glue can bring many risks and problems that are discussed more on the chapter 3. (ReelReferences18 2021.)

The paper grade has a great effect on the success of the pick-up process. The taber-density of the paperboard defines the density of the paperboard. The higher the taber-density, the harder the paperboard is to pick-up, since thicker paperboard needs much higher picking force from the glue. Paperboard grades with high taber-density tend to stay straight and not bend around the reel spool after the primary nip, which can cause problems. (Hyötynen 2021.) Taber-density is not the only parameter affecting the pick-up, since the dimension of reel spool, web speed, the surface of the paperboard and scott bond-value are affecting much. In a worst-case scenario, there is a paperboard machine with high web speed, surface sizing and a reel spool with small diameter, which most likely will cause the failure of the pick-up. In the best case the web speed is lower, and the reel spool diameter is bigger, so the paper web does not need to bend in so small radius after the primary nip.

Scott-bond value measures the Z-direction strength of the paperboard, which is the direction vertically from bottom to surface layer. The thicker the paperboard, the lower the scott-bond, which leads to delaminating. Delaminating means a situation where one or more of the layers of the paperboard comes off during turn-up process, which leads to a situation where one layer of the paper web is around the empty reel spool and one around the full parent roll. Depending on the headbox of the paper machine, the paperboard can have over three layers. Delaminating can be prevented by narrowing the tail of the paper web by increasing the acceleration of the waterjet cutting nozzles. (Hyötynen 2021.)

2.1.6 Surface binding device

Surface binding is a vital part of the paper and paperboard making process. It ensures that the freshly reeled parent roll won’t start to unfold during storage or transportation to winding section. After the waterjet nozzles cut the web, the surface binding arms on the sides of the parent roll sprays a small amount, which is less than 10 grams of adhesive or water between the last layers to bind the surface of the parent roll. Depending on the grade of the paper or paperboard, the surface binding can be made with adhesive or water. If the paperboard has coating which repels water, the surface can be bind without adhesive, meanwhile if the paperboard absorbs the liquid, adhesive must be used to bind the surface. As Valmet has multiple OptiReels which all have their own, unique design, it is understandable that there is no “one and only” solution to implement the surface binding. Some surface binding devices have found their places in a certain reeling device.

Surface binding on OptiReel Linear can usually be implemented two ways. The first version is illustrated in figure 17. The principle of this construction is simple. While in the home position the nozzle arm rests in the same direction as the paper web. When the turn-up process is about to begin, the surface binding arm turns 90 degrees to reach the surface of the parent roll. After binding, they just turn back. The biggest problem on this design is the maintenance aspect. Since the glue nozzles and hoses needs to be replaceable, the location is difficult. (Riihelä 2021.)

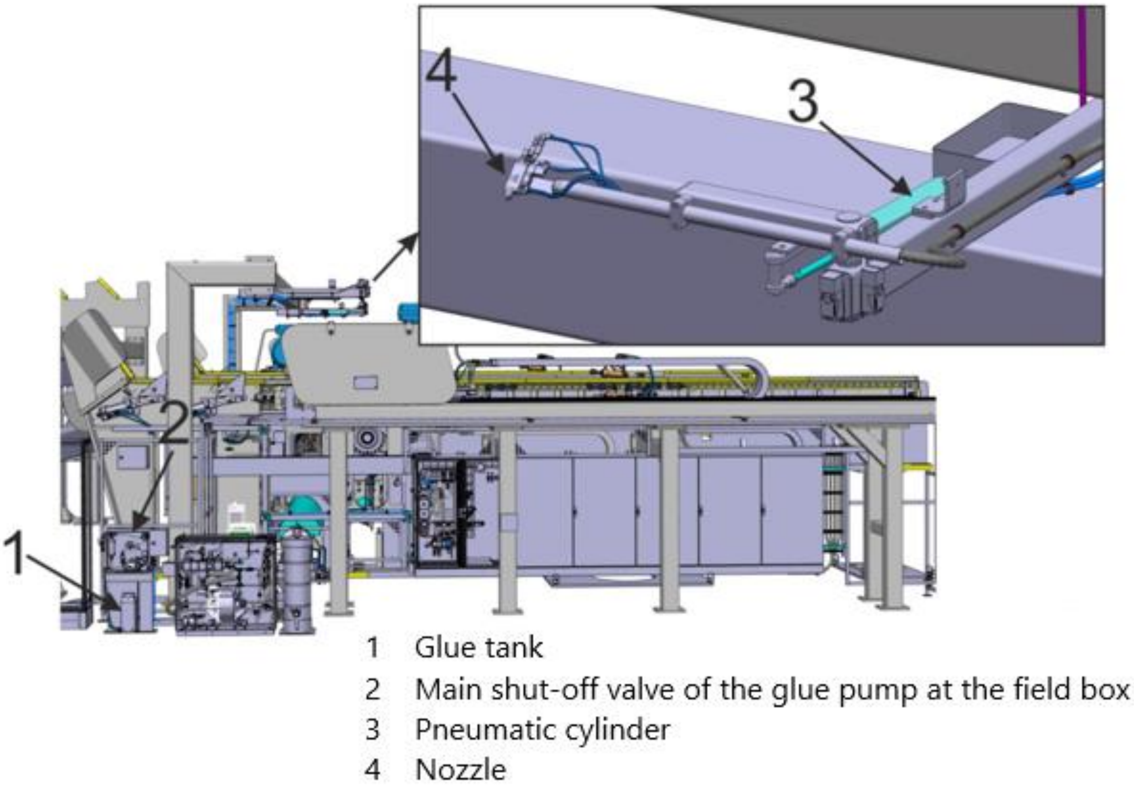

Figure 17. Illustration of the old version of surface binding device on OptiReel Linear (Valmet Oy 2019a).

On the later version this maintenance aspect has been taken into consideration. While in the home position the surface binding arms rotate vertically over the edge of the web. This idea can be best seen on figure 18.

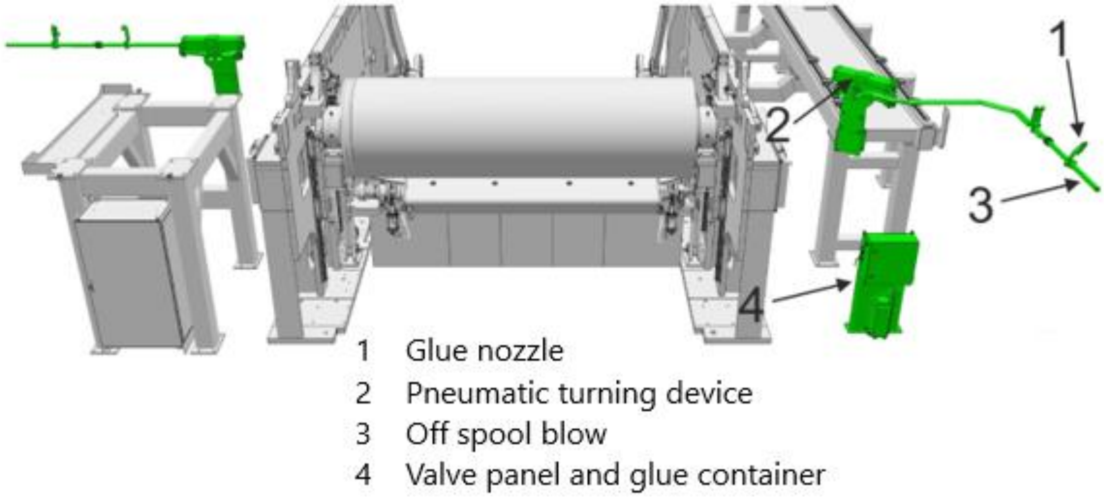

Figure 18. Illustration of the updated version of surface binding device on OptiReel Linear (Valmet Oy 2021).

OptiReel Primary and Pope offers new difficulties due to their different structure. Surface binding on OptiReel Primary is mainly executed by vertically turning nozzle arms which brings back the difficulty of maintenance, since the home position of the nozzles is upwards as seen on figure 19. Surface binding in OptiReel Pope is implemented by using a pneumatic cylinder and two joints which allows the nozzle arms to move horizontally from outside of the edge of paper web to over the paper web, as seen on figure 20.

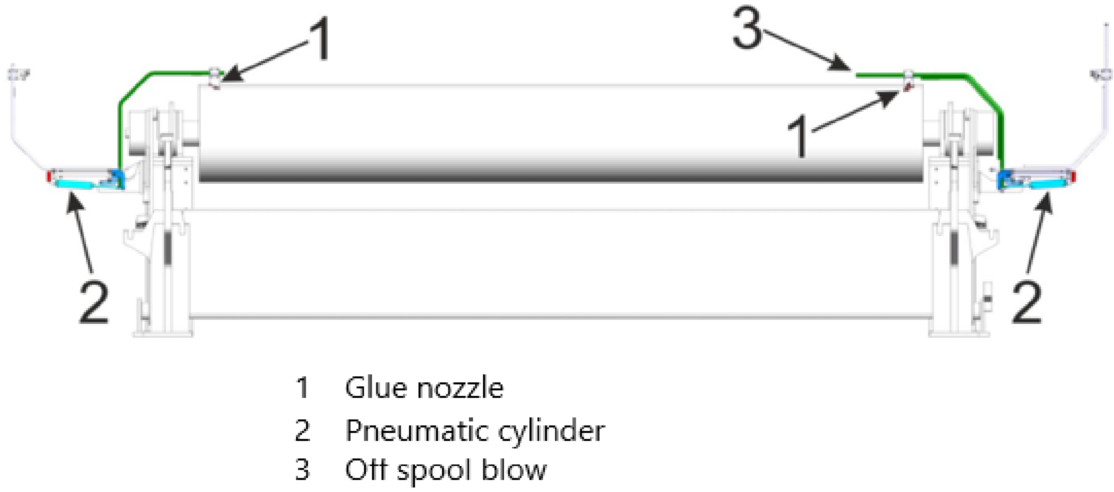

Figure 19. Surface binding system on OptiReel Primary (Valmet Oy 2020).

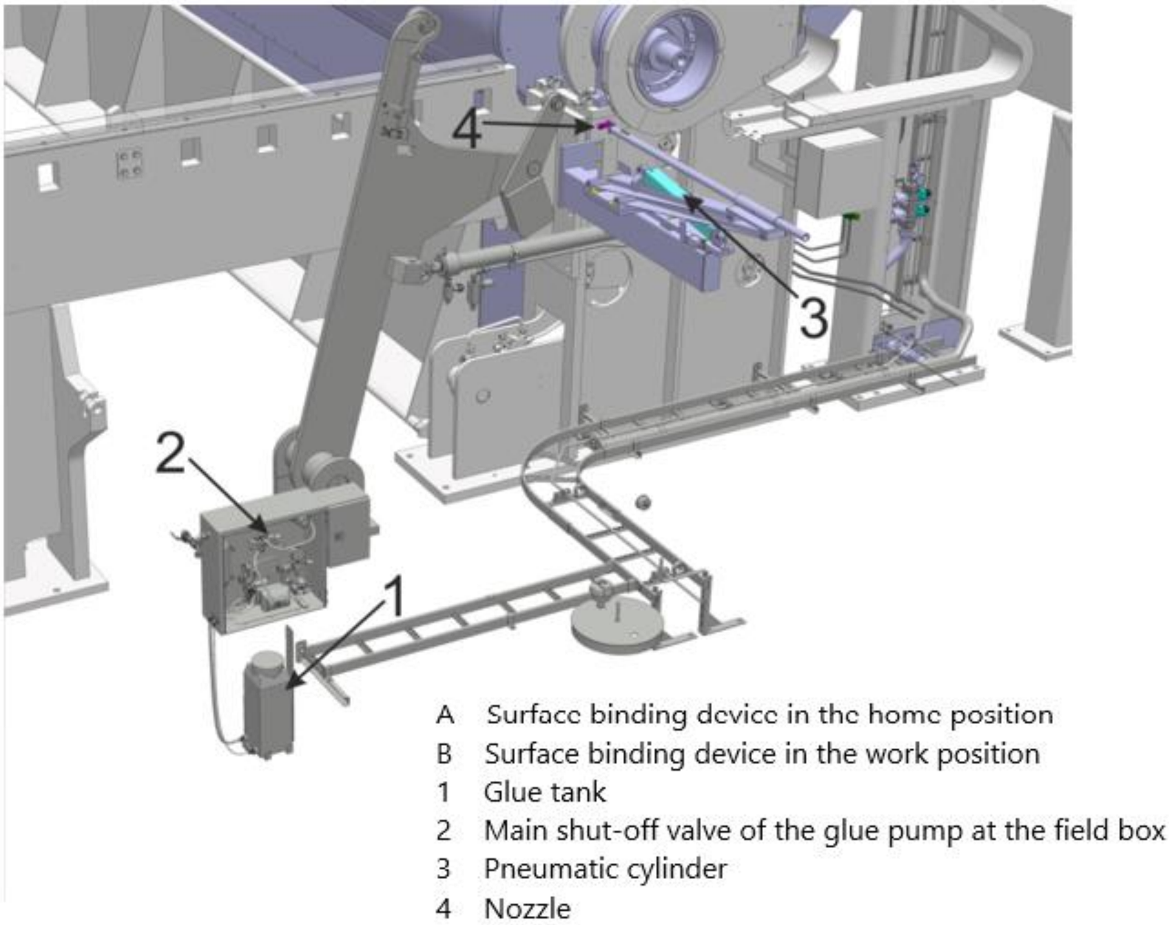

Figure 20. Surface binding technique on OptiReel Pope (Valmet Oy 2019b).

As like any other parameters in the reeling section, the values for surface binding can also be adjusted by the user. The normal adjustment of surface binding is so that as the waterjet starts to cut, the surface binding starts at the same time. As the cutting nozzles are 300 to 500 millimetres away from the edge of the paper web, the surface binding shuts off. It is also vital to adjust the CD-location of the surface binding nozzles so that the glue hits the right spot. If the glue nozzles are located too near the edge of the web as in the number 1’s in the figure 21, the glue will bind the side of the parent roll, which will make the winding of it impossible, meanwhile if the glue nozzles are too far from the edge, as like the number 3’s, the glue won’t attach the tails of the paper web properly, so they might start to come off as the parent roll rotates at high speed. Number 2’s are the most optimal CD locations for the surface binding glue to be attached. (Riihelä 2021.)

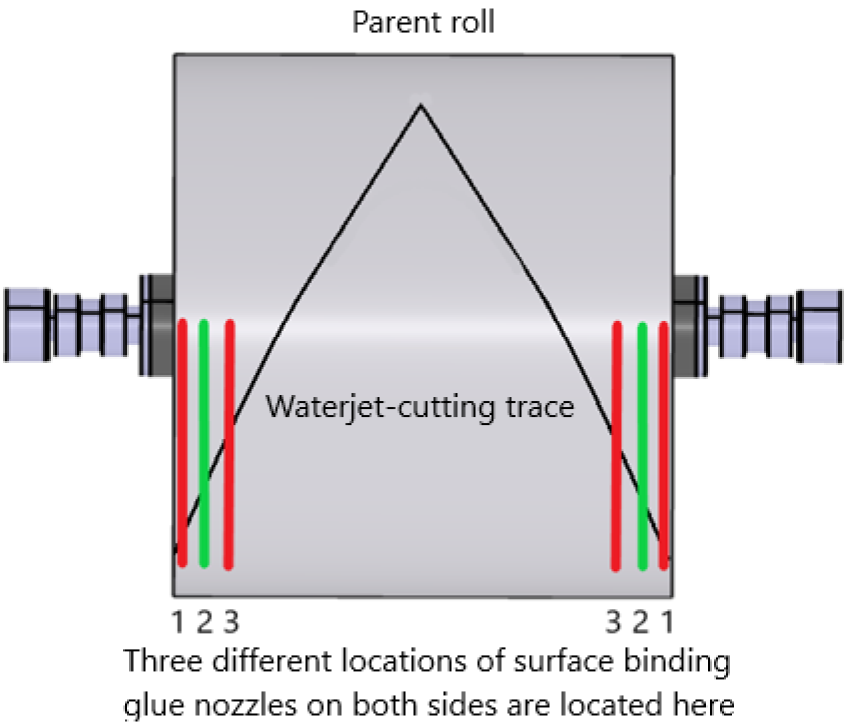

Figure 21. Parent roll and the locations of the surface binding glue nozzles. Trails number 1 and 3 shows the bad and number 2 shows the good locations. The upwards V-letter illustrates the cutting trail of waterjet.

2.2 Competitors in papermaking industry

Since the paper making is such a big industry, it can be guessed that Valmet is not the only service- and machine provider in the field. This chapter highlights some of the biggest competitors and discusses a bit about their products and technical ideas to gain some perspective and possible ways to implement turn-up process.

Paprima is the Valmet's biggest competitor on turn-up devices. Paprima is a Canadian company which is specialized on all kinds of papermaking devices, such as turn-up devices, edge trimmers, fabric cleaners and tail cutters. (ENGINEERED WATER-JET SOLUTIONS 2021.) Since Paprima's specialty is waterjet devices, a further study on their turn-up solutions could be wise considering this thesis.

Similarities between Valmet's waterjet turn-up device and the Paprima's Reel-jet™ is the versatility. Both can be flexibly used with other turn-up methods, such as gooseneck or tape turn-up, which increases the overall reliability and makes them more versatile, since there can be back-up turn-up method if the prime method fails. (ENGINEERED TURN UP SOLUTIONS FOR ALL APPLICATIONS 2021.) The cutting trace that Paprima has developed is called X-cut, which allows them to get rid of surface binding equipment by cutting the paper web from side to side cross while simultaneously applying the pick-up glue in the middle, which picks the tail to the empty reel spool and at the same time binds the surface of the finished parent roll (Pat. EP2812268 B1 2014).

Bellmer is a German company which is mainly specialized in headboxes, formers and pulpers, although it also competes against Valmet on the field of reeling, since Bellmer has launched its own reeling concept called TurboReeler and TurboReeler Pro. Bellmer claims that they can reel parent rolls up to 4 meters diameter. Like Paprima and Valmet, Bellmer also offers variety of turn-up devices to be used with the TurboReeler. Air type, belt type and water cut turn-up devices are the ones that mentioned on their home pages (BELLMER FINLAND OY 2021).

When it comes to reeling line deliveries, **Voith** is one of the biggest competitors. Voith produces paper machines and provides service and maintenance to their customers, working towards more efficient and smoother production process (Papermaking Vision 2021). Valmet, like other suppliers, promises up to 99 % turn-up efficiency on reeling section. This percentage would mean that 1 out 100 turn-ups can fail (Reeling concepts 2021).

2.3 Demands for turn-up devices

Modularity is one demand for modern products. Modular entirety is an assembly which is divided into different smaller entities, which are called modules. (Baldwin et al. 2000, p. 63). Modularity allows making multiple changes to machine, when necessary. For example, reeling section is modular since the width of the web can be either decreased or increased by changing standard sized modules. Modular designing decreases the amount of hours used on designing and that way lowers the total costs and increases the profit of the machine provider.

Safety is one of the most important factors in the paper and papermaking industries. In rural term, the word “safety” can be defined to be a situation in where no accidents, injuries or harms happens to a person (Hollnagel 2014, p. 22). Standard EN ISO 1034-1 and EN ISO 1034-16 defines the overall safety and the possible safety hazards that can occur in the paper and papermaking industry. The overall safety can also be decreased through some exceptional situations such as turn-up failures, hardware failure or breakage of some mechanical component. The overall safety of the papermaking process is increased by automating the process so that as little as possible needs to be made by the process operators. The processes that process operators needs to handle, such as the troubleshooting and web breaks are secured by using security gates, light curtains, and fences. The security gates and light curtains are both equipped with an acknowledge-pushbutton to ensure that nobody is in the danger zone while executing the process. In addition of these, Lean-tools are also very common in the factory condition due to the simplicity, informativeness and efficiency of them. Safety is also being improved by using internal software and forms to be completed with security observations that are discovered during work (Vorne Industries 2021).

As a term, reliability of the study means the reliability and accuracy of the used method of studying the subject. It measures how accurately the used measuring method measures the wanted phenomenon (Tilastokeskus 2021a). Validity in the other hand measures how accurately the used study method measures the feature of the studied phenomenon (Tilastokeskus 2021b). When completing the research-part of the study, validity is the first aspect to be studied to define if the right phenomenon is studied. Only after that comes the reliability review.

2.4 Planning of the practical tests

The need and idea for practical tests came up when the certainty and reliability of the pick-up was discussed. What are the elements that affect the success rate of the pick-up? These elements were used to make a mind map, which is shown below in the figure 22.

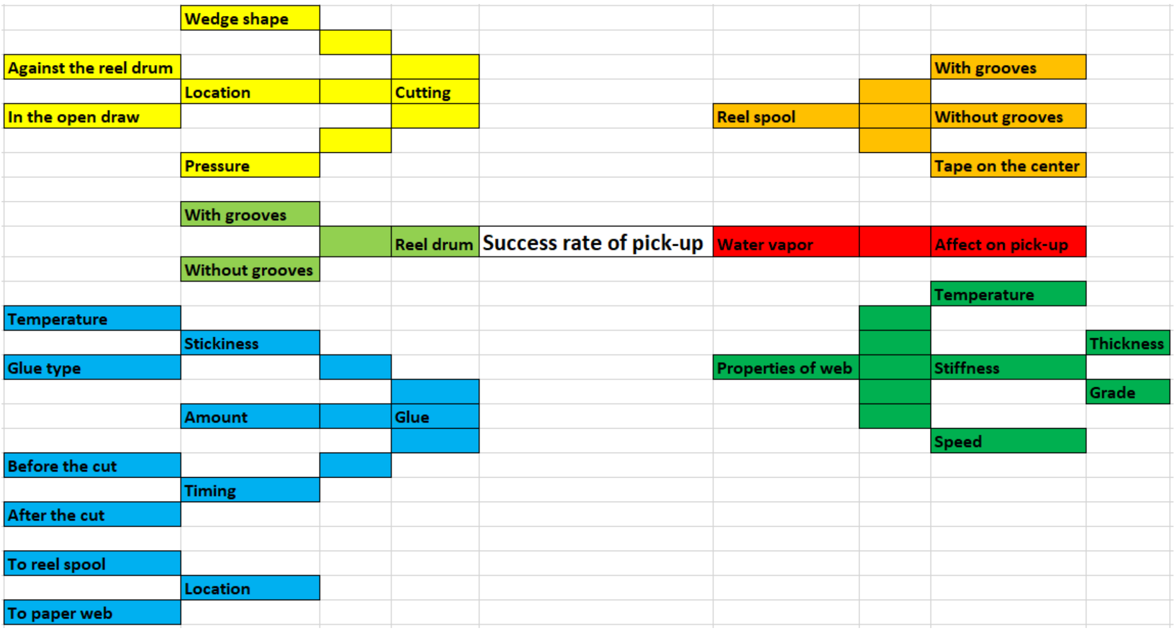

Figure 22. Mind map that gathers up all the elements that affect the success rate of the pick-up process. Colour-codes are only for visualization, they have no further meaning.

Several parameters affect the reliability and success rate of the pick-up. The parameters with the highest affect can be said to be the cutting, reel drum, web properties, water vapour, reel spool and glue. The cutting-section can be divided into wedge shape, pressure, and location, from which the location means whether the cutting is made against the reel drum near the nip or further away in the open draw. There are two main types of reel drums, either with- or without grooves, which effects on many parts of the process. On the aim of reliability of pick-up, the reel drum with grooves can cause the pick-up to fail, since the nip won't close entirely because of the grooves. Reel spools can also have grooves, which can cause the glue to be applied on the bottom of the groove, which can cause bad pick-up. Reel spools can be also equipped with Teflon tape on the center, which helps the cleaning after unwinding.

Although Teflon tape can cause the pick-up to fail since its main task is to be slippery. Properties of the web, such as temperature, stiffness, and speed effects the process in many ways, not to mention the water vapour that is caused by the waterjet cutting nozzles. Lastly the effect of the glue. It can be divided into stickiness, amount, location, and timing. The stickiness of the glue is affected by the process temperature and type of glue. Amount of the glue needs to be on point, since too little glue will not pick, meanwhile too much glue will splatter and eventually cause problems. Timing is a valuable parameter to be considered. Is the pick-up glue applied before or after the cut? Location is the last parameter to be considered, since it makes a difference whether the glue is applied on the surface of the reel spool or on the paper web.

The aim of the practical tests was to come up with test equipment that can be used to measure the pick-up force of different adhesives in a certain temperature to be able to put the adhesives in order of precedence. The adhesives that were tested are the ones that Valmet has used or is currently using on customer projects worldwide. The names of all adhesives are renamed with capital letters so that the information remains hidden, and the names of adhesives can be seen clearly in the text. In addition of these, some extra adhesives were tested, such as four different syrups, COLD GLUE and HOT GLUE 5. There were several parameters that affected the pick-up force and the measuring of it, so they needed to be standardized for anyone to carry out these specific tests. Tests were made using a Heraeus industry oven which was set on specific temperatures which was then verified using a digital thermometer. There was a hole on top of the oven, from where the force measurement stamp was placed against the glue. The force was measured with a Alluris-force meter. All the steps of implementing this specific test are described on the next chapter.

The basis weight of the paper samples that were used on these pick-up force tests were between 252 and 255 g/m^2 and the amount of the tests per adhesive per temperature was defined so that the average force was evened out. The test equipment was developed several times during the tests to come up with the best and most reliable method to accurately measure the pick-up force. All the variations of the test equipment can be viewed from the (Appendix 3).

Third test included testing three different adhesives under the influence of a water vapour that is caused by the waterjet cutting nozzles. The first adhesive was HOT GLUE 2, which is older version of the second tested adhesive which was HOT GLUE 4. Third test was made just out of pure curiosity for the new HOT GLUE 5 to see how the water vapour affects its features.

2.5 Implementation of the practical tests

The implementation of all the practical tests is described below accurately enough for anyone to carry out the tests with sufficient accuracy. The first list describes the implementation of the pick-up force tests on temperatures below 80 degrees Celsius.

1. Open the oven door.
2. Pull back the base plate.
3. Loosen the two screws to insert the paper sample on the frame and then tighten them up.
4. Push back the base plate.
5. Close the oven door.
6. Set the temperature of the oven on the desired value. (20…79 °C.)
7. Use the digital thermometer to make sure that the temperature is right.
8. Turn on the Alluris-force meter.
9. Open the oven door.
10. Pull back the base plate.
11. Apply the hot adhesive (120…140 °C) on the paper with the glue gun.
12. Push back the base plate.

13. Close the oven door.
14. Pull the pneumatic lever towards you which lowers the stamp.
15. Press button number “2” to set the force to 0 newtons.
16. Push the pneumatic lever away from you which lifts the stamp.
17. Read the results from the Alluris-force meter.

On the temperatures over 80 °C the system varies a bit. This system allows the adhesive to be set on a certain temperature to accurately study how the temperature affects the properties of the specific adhesive.

1. Open the oven door.
2. Pull back the base plate.
3. Loosen the two screws to insert the paper sample on the frame and then tighten them up.
4. Close the oven door.
5. Set the desired temperature (80…160 °C.)
6. Use the digital thermometer to make sure that the temperature is right.
7. Turn on the Alluris-force meter.
8. Open the oven door.
9. Pull back the base plate.
10. Apply the hot adhesive (120…140 °C) on the paper.
11. Push back the base plate.
12. Close the oven door.
13. Wait until the temperature evens out on the desired temperature (80…160 °C.)
14. Pull the pneumatic lever towards you which lowers the stamp.

15. Press button number “2” in order to set the force to 0 newtons.
16. Push the pneumatic lever away from you which lifts the stamp.
17. Read the results from the Alluris-force meter.

Third list consists of instructions on how to implement the pick-up force tests with the artificial water vapour affecting.

1. Open the oven door.
2. Pull back the base plate.
3. Loosen the two screws in order to insert the paper sample on the frame and then tighten them up.
4. Set the desired temperature.
5. Use the digital thermometer to make sure that the temperature is right.
6. Turn on the Alluris-force meter.
7. Open the oven door.
8. Pull back the base plate.
9. Apply the hot adhesive (120…140 °C) on the paper.
10. Push back the base plate.
11. Close the oven door.
12. Wait until the temperature evens out on the desired temperature (80…160 °C.)
13. Open the oven door.
14. Apply water with a spray bottle on the adhesive (2 pumps).
15. Close the oven door.
16. Pull the pneumatic lever towards you which lowers the stamp.

17. Press button number “2” to set the force to 0 newtons.
18. Push the pneumatic lever away from you which lifts the stamp.
19. Read the results from the Alluris-force meter.

By following these given instructions all users can perform the pick-up force tests with the equipment that is built for this thesis. Even though the instructions are accurate and specific, they might need to be adjusted during more thorough tests.

3. Demands in designing and presentation of results

While considering the turn-up section, its reliability, and ways to improve it, there are many demands and criteria, that needs to be considered while designing. The demands can be divided by the area. These criteria are collected by interviewing experts in Valmet and gathering up information through general ISO standards according to paper machine safety. In addition to demands, this chapter also lists all the problems and solution that affect the overall reliability. The results of the practical pick-up force tests are also included in the end of this chapter.

3.1 Modularity and safety aspects

Turn-up- and pick-up devices must be designed to be modular to be able to use the same frame for all reeling sections, apart from the width of the web. Waterjet-unit has its standard linear unit widths, which are 4000 mm, 5400 mm, and 6600 mm (Sjöblom 2021). The waterjet beam is assembled by combining desired amount of these units. This allows the designers to use the standard frame of waterjet-unit on each project, by only changing the modules. The same fact applies on the pick-up device as well. The pick-up device always has the same outer casing which holds either the hot- or cold glue equipment.

Another important factor that needs to be considered while designing machine parts is the safety aspect. By looking the statistics that Accident Insurance Center TVK offers, between the year 2013 to 2017 approximately 600 accidents happened during 30 million labour hours only in the paper industry (Työturvallisuuskeskus ry 2021). Standard EN ISO 1034-1 and EN ISO 1034-16 introduces the possible safety hazards to consider, when designing paper machines, and reeling section more specifically (ISO 1034-1 2021, pp. 9-19). (Appendix 1) introduces all the possible safety hazards that can occur nearby reeling section and what needs to be taken into consideration (ISO 1034-16 2012, pp. 14-16). Turn-up section keeps inside many safety factors that needs to be considered. In some constructions the empty reel spool is lowered by lowering arms from the reel spool storage down to the rails. This creates a risk of crushing since there are cylinders and multiple moving parts. When the reel is equipped with the waterjet turn-up device, the high-pressured waterjet nozzles need to be warned, since the waterjet uses pressure up to 1900 bars to cut the paper web. Depending on the paper grade, the pick-up may be executed by using hot glue, so thermal hazards are present, since the glue temperature is up to 160 °C. (Water jet turn-up device, REEL 2019.) The reeling section has multiple spools and cylinders, which while spinning will generate a risk of entanglement or crushing between the nips.

3.2 Design for reliability

As discussed in the chapter 2, DFR is a vital methodology to maintain the efficiency and competitiveness of the product. DFR consists of a few facts that are listed below. (Favi et al. 2016, p. 277.)

1. Designing leads to manufacturing fast.
2. Manufacturing is made as cheap as possible.
3. Manufacturing is made as easy as possible.
4. The end-product reaches its desired quality.

All these facts are taken into consideration during the design phase of all Valmet’s products. Designing of a new delivery project always begins by finding an existing model that is used as a base for the designing, which speeds up the process and decreases the amount of labour hours used in the designing. Depending on the type of the reel and the width of the paper web, the waterjet unit is constructed by using modular solutions and surface binding type is defined. To make sure that the solutions can be made in the 3D- and real life, designer usually visits the assembly phase of the product and the start-up of the new paper line.

The importance of the reliability of reeling section can be viewed by looking at figure 23 below, which is a straight reference from Rautiainen 2010, p. 221. The chart introduces the annual production loss percentages on one super calandered, uncoated magazine paper line. Figure 23 states that the greatest annual loss was generated by cracks and puckers, which are a consequence for bottom waste, which can be partly affected by adjusting the reeling- and turn-up parameters. The production loss percentage is a straight consequence that occurs from the low reliability.

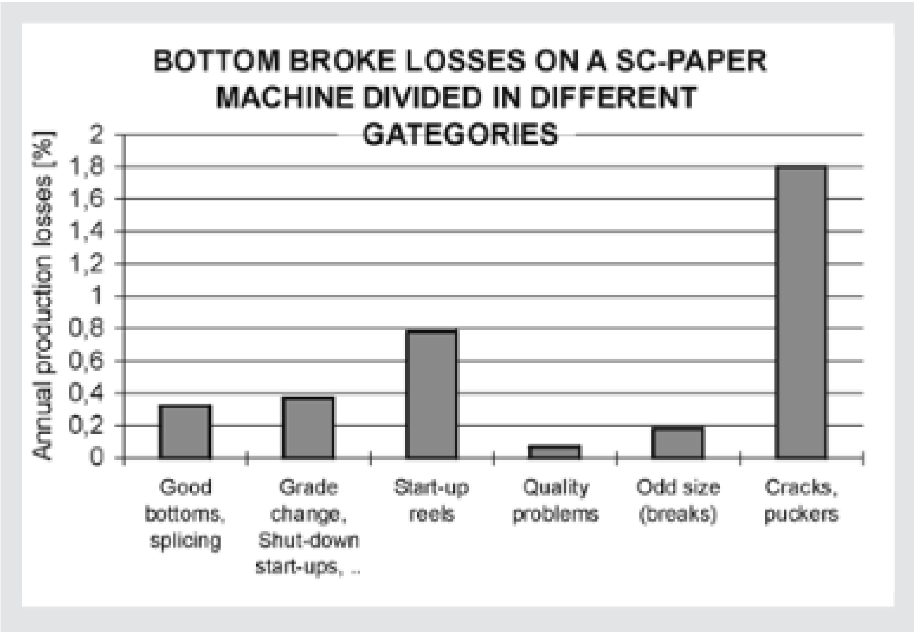

Figure 23. Annual production losses on super calandered magazine paper categorized. (Rautiainen 2010, p. 221.)

3.3 Existing problems and ways to improve the reliability of a turn-up process

The easiest way to start the development of the reliability is to list down all the identified problems and defects of the already existing processes. The interview data can be found from the (Appendix 4). The discovered faults and problems are then fixed and developed by the means of modularity, safety, and reliability- and manufacturing oriented methods and ISO-standards.

It is most sensible method to organize the problems identified by the process, so the areas of development can be viewed separately for the turn-up-, pick-up-, and surface binding device. Some problems occurred in everyone’s answers, so they can be assumed to be the most known ones. To clarify the data, all the information is gathered to three different tables, 2, 3 and 4 below by the device. The criticality of the problem is colour coded so that the red text shows critical problem that can be fixed by some mechanical solution, blue shows critical problem that can be fixed with some change in a way of working and green colour shows a problem that exists but does not affect the reliability of the process, so it is not critical enough to be concentrated on. All these problems are the ones that have occurred during the years, and they are critical in the terms of reliability. The criticality is defined by the severity the fault causes to the process.

Table 2. Identified problems occurring in the waterjet turn-up equipment.

Waterjet turn-up	**Fault**	**Criticality**	**Correction method**
Cutting nozzle	Location control of cutting nozzles and inaccuracy in MD-direction, understanding the cutting pattern and CD-direction adjustment.	Critical and can be affected by some mechanical solution	Adjustment of the cutting angle so that the water goes under the paper web.
Cutting nozzle	Replacement of nozzle can be difficult depending on the design	Critical and can be affected by some mechanical solution	Poor location of maintenance hatch. Designers needs to be informed and trained.
Cutting nozzle	Tail of the paper web won’t go correctly in the nip	Critical and can be affected by some mechanical solution	CD-direction angle adjustment of nozzle

Table 2 continues. Identified problems occurring in the waterjet turn-up equipment.

Waterjet turn-up	**Fault**	**Criticality**	**Correction method**
Cutting nozzle	Difficulty on cutting heavier grades	Critical and can be affected by some mechanical solution	Bigger nozzles, more high-pressure pumps
Reel spool	Cleaning the paper mess out of the centre of a reel spool	Critical and can be affected by some mechanical solution	Better alternatives for Teflon tape are under investigation
Labour	Multiple geometries for different type of reels	Critical and can be affected by some mechanical solution	Needs to be considered while designing
Technique	How to execute the grade change to pulper	Critical and can be affected by some mechanical solution	Development of the W-cut technique
High-pressure hose	Tightening of the high-pressure water hoses / "Pearl" can prevent the tightening	Critical and can be affected by some change in a way of working	Installation instructions within the shipment/QR-code with language translating
High-pressure hose	Clogging of the high-pressure nozzles	Critical and can be affected by some change in a way of working	Importance of flushing / Trying out solvent flushing
High-pressure hose	Low shrinkage capacity on long high-pressure hoses	Critical and can be affected by some change in a way of working	Installation instructions within the shipment/QR-code with language translating
Waterjet turn-up device	Too complex for customer to make "troubleshooting"	Critical and can be affected by some change in a way of working	Typical challenges-training video.

Table 2 continues. Identified problems occurring in the waterjet turn-up equipment.

Waterjet turn-up	**Fault**	**Criticality**	**Correction method**
Waterjet turn-up device	Difficulties on executing maintenance	Critical and can be affected by some change in a way of working	Typical challenges-training video.
Control system	Problems that occur due to tightness problems	Critical and can be affected by some change in a way of working	Valmet needs more power on controlling
	Surface of the reel drum can get harmed due to pressure nozzles	Critical and can be affected by some change in a way of working	Some mechanism that allows the cutting start only after the reel drum is rotating
Labour	Paper pieces that occur from web breaks	Critical and can be affected by some change in a way of working	Process operators need to clean the area after web break
Reel spool	Broken surface of reel spool	Critical and can be affected by some change in a way of working	Different type of coating is under investigation
Cutting nozzle	Service life of cutting nozzle	Not so critical	Distillation of the water
Cutting nozzle	Cutting won’t be efficient if made too far away from the paper web	Not so critical	CD-direction angle adjustment of nozzle

Table 2 continues. Identified problems occurring in the waterjet turn-up equipment.

Waterjet turn-up	**Fault**	**Criticality**	**Correction method**
Adhesives	Poor follow-up on consumables history	Not so critical	Information from the Sales-team. How often, what and to who?
Control system	Parameter adjustment between tail threading and normal drive	Not so critical	
Linear motor	Contamination and jamming of the linear movement unit	Not so critical	Process operators needs to be trained.
	Customer wants the access to the "black box"	Not so critical	
Pressured air	The level of compressed air in the factory can vary	Not so critical	Size of the booster and container can be increased

Table 3. Identified problems occurring in the pick-up equipment.

Pick-up device	**Fault**	**Criticality**	**Correction method**
Pick-up unit	Glue pistol too far away from the nip	Critical and can be affected by some mechanical solution	MD-adjustment on the pick-up unit. Regular cleaning. Blowpipes?
Pick-up unit	Glue can get to reel drum	Critical and can be affected by some mechanical solution	Mechanical doctor. Regular cleaning?

Table 3 continues. Identified problems occurring in the pick-up equipment.

Pick-up device	Fault	Criticality	Correction method
Glue	Poor infection with the glue	Critical and can be affected by some mechanical solution	What glue is used? Could cold glue solve these problems?
Glue	Splattering of the glue	Critical and can be affected by some mechanical solution	Better glue -> less glue needed. The accuracy of application. Application of pick-up glue long before the nip?
Glue pistol	Leakages on the hot- and cold glue pistol	Critical and can be affected by some mechanical solution	New type pistol, physical guards, regular cleaning
Glue pistol	The width of the glue tray differs between hot- and cold glue	Critical and can be affected by some mechanical solution	2 glue pistols. Risk of getting too much glue
Glue pistol	How to get enough glue on higher web speeds	Critical and can be affected by some mechanical solution	Can be fixed with the new glue pistol
Glue	The availability of glues on different continentals	Critical and can be affected by some change in a way of working	Could the pick-up adhesive be applied as a tape or powder?
Glue / Glue unit	Burning of the hot glue	Critical and can be affected by some change in a way of working	Place the hot glue unit on inclined position. Guiding the customer. New Robatech-hot glue unit uses the glue more wisely. Trying out new adhesive?

Table 3 continues. Identified problems occurring in the pick-up equipment.

Pick-up device	**Fault**	**Criticality**	**Correction method**
Waterjet turn-up device	Too complex for customer to make "troubleshooting"	Critical and can be affected by some change in a way of working	Valmet installs a camera on the right spot. Valmet keeps training sessions for customer.
	The "paper war" of glues that comes from the chemical legal requirements	Critical and can be affected by some change in a way of working	
Glue	The materials of adhesives: They need to pulpable and need to fulfil the food grades	Not so critical	Tape pick-up?
Glue	Off-coater tail threading vs the turn-up	Not so critical	
Glue pistol	CD-direction adjustment	Not so critical	CD-angle adjustment on the glue nozzle.
Labour	Clogging of the nozzles	Not so critical	Guidance of customer
Labour	Replacement of nozzle can be difficult depending on the design	Not so critical	Needs to be considered while designing
	Customer wants the access to the "black box"	Not so critical	
Adhesives	Poor follow-up on consumables history	Not so critical	Information gathering from sales-team

Table 4. Identified problems occurring in the surface binding equipment.

Surface binding	**Fault**	**Criticality**	**Correction method**
Nozzle arms	Replacement of glue nozzles can be hard	Critical and can be affected by some mechanical solution	Rotating arms enables them to be maintained during process.
Glue pistol	Surface binding won't work on all grades	Critical and can be affected by some mechanical solution	Static experiment: Powder glue applied with 2-component pistol
Nozzles, pump, hoses	Problems that are caused because of the paper pieces	Critical and can be affected by some mechanical solution	Replacement of the pump and hoses to increase the amount of glue. Angle adjustment on glue nozzles?
Reel spool	Bad nip profile	Critical and can be affected by some mechanical solution	iROLL Technology
Labour, nozzle arms, glue	Clogging of nozzles and the drying of the glue	Critical and can be affected by some change in a way of working	Regular cleaning. Rotating nozzle arms. The equal quality of the glue.
Glue	Dilution of the surface binding glue / Transportation of the water globally	Not so critical	Different kind of glue, maybe a powder glue?
Glue	Difficulty in obtaining adhesives between different continentals	Not so critical	

Table 4 continues. Identified problems occurring in the surface binding equipment.

Surface binding	Fault	Criticality	Correction method
Glue	The materials of adhesives: They need to be repulpable and need to fulfil the indirect food contact (FDA)	Not so critical	
Glue	Sufficient amount of glue between the layers	Not so critical	Trying out different glues?
Nozzle arms	Difficulty of maintenance	Not so critical	Rotating arms enables them to be maintained during process.
Labour	Poor follow-up on consumables history	Not so critical	Information from the sales-team
	The bureaucracy of different glues	Not so critical	
Labour	Glue can get to the reel drum	Not so critical	Cleaning and maintenance of the surface binding equipment

Tables 2, 3 and 4 shows that there are multiple different problems occurring in the waterjet turn-up process, more specifically there are total of 54 problems from which 32 are defined as critical by the means of reliability. Based on these tables, and conversations with the personnel of Valmet, the practical tests were implemented to study the properties of the used adhesives in different temperatures. Pick-up can be said to be one of the weak links during the turn-up process and it was the easiest to start development with.

3.4 Results of the practical tests

Practical tests for this thesis were implemented between January 13th and 28th. The results from the tests are divided so that every tested adhesive and its properties in different temperatures can be viewed in a same figure. Figure 24 below illustrates the pick-up force in different temperatures of multiple different adhesives that Valmet uses on its customer projects. Out of these adhesives listed on the chart, HOT GLUE 1, HOT GLUE 2, HOT GLUE 3, HOT GLUE 4 and the new HOT GLUE 5 are hot glues and COLD GLUE is cold glue. Figure 25 compares HOT GLUE 2 with- and without water vapour and figure 26 compares HOT GLUE 4 with- and without water vapour. Figure 27 compares the two most recent adhesives which are the older version, HOT GLUE 3 and the new updated version HOT GLUE 4. Figure 28 is a compilation figure which uses the test results and the manufacturers' information to introduce the two adhesives, HOT GLUE 2 and HOT GLUE 3 and their viscosity curves in a one figure. The HOT GLUE 5 that was used on the tests was supra glue. It was tested in temperatures 80 to 160 °C with- and without the artificial water vapour. Figure 29 illustrates the pick-up force to temperature curves of this specific HOT GLUE 5.

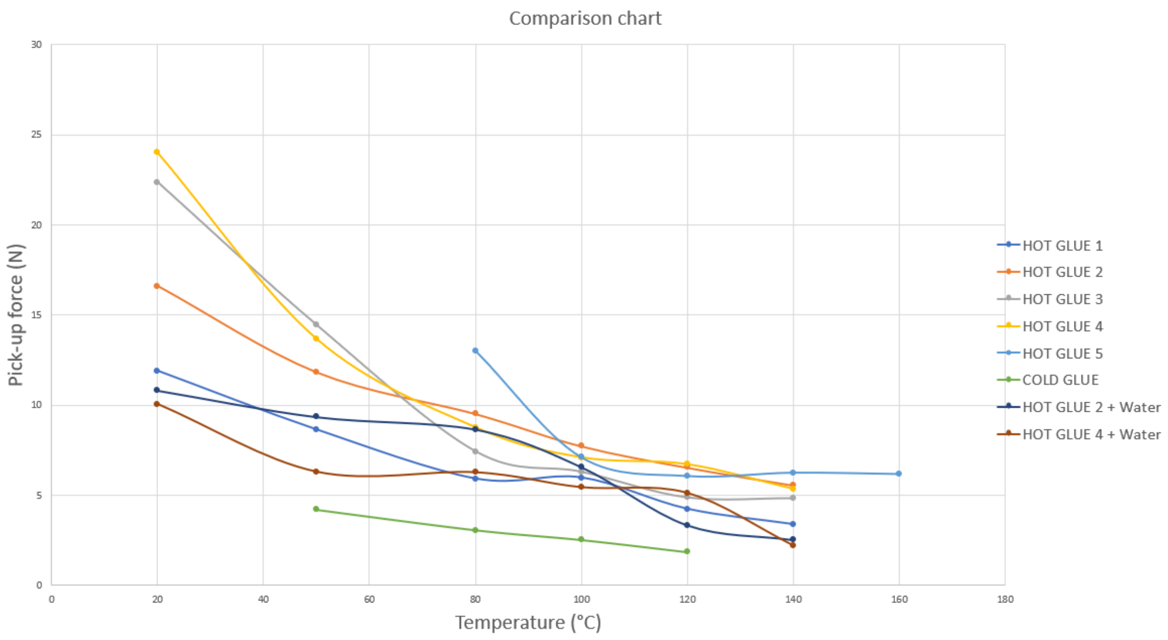

Figure 24. Comparison chart of different adhesives that Valmet uses. Axis x introduces the test temperatures in Celsius degrees and axis y is the pick-up force on newtons. HOT GLUE

1, HOT GLUE 2, HOT GLUE 3, HOT GLUE 4 and the HOT GLUE 5 are hot glues and COLD GLUE is cold glue. HOT GLUE 2 + Water and HOT GLUE 4 + Water are the test results that were gained by applying water vapour on the adhesive during the tests.

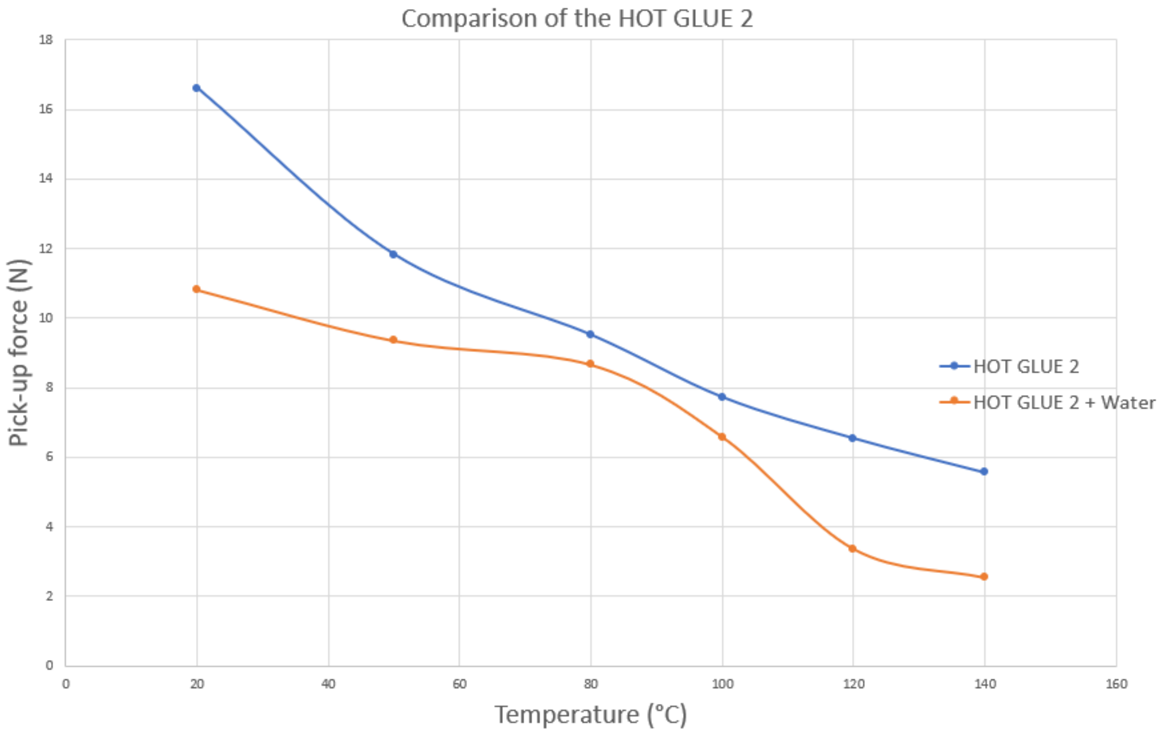

Figure 25. Comparison of the adhesive HOT GLUE 2. The blue curve illustrates the pick-up force in different temperatures. Orange curve illustrates the pick-up force in different temperatures, but it is influenced with artificial water vapour which copy the actual process the best.

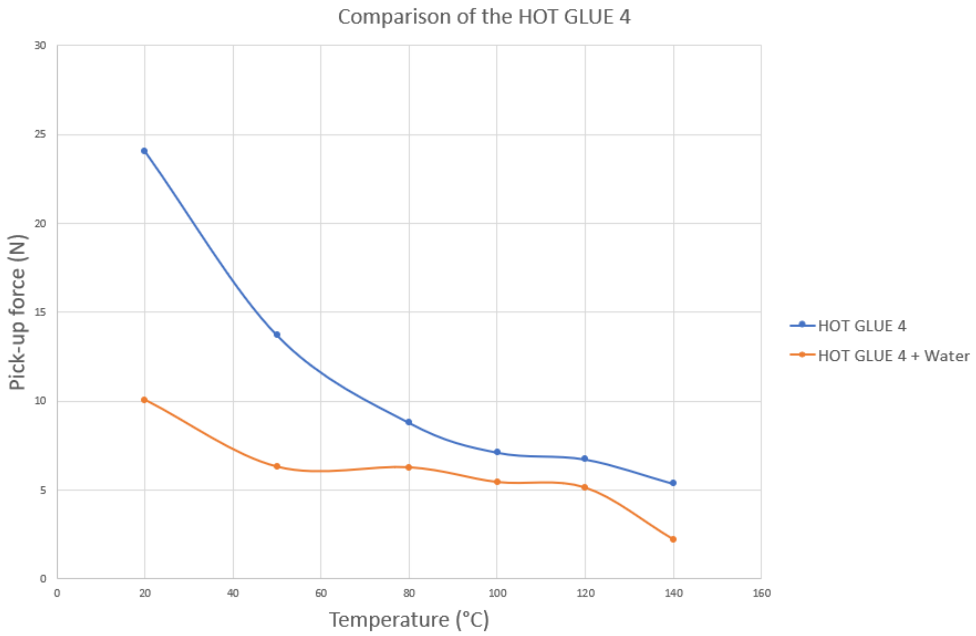

Figure 26. Comparison of the adhesive HOT GLUE 4. The blue curve illustrates the pick-up force in different temperatures. Orange curve illustrates the pick-up force in different temperatures, but it is influenced with artificial water vapour which copy the actual process the best.

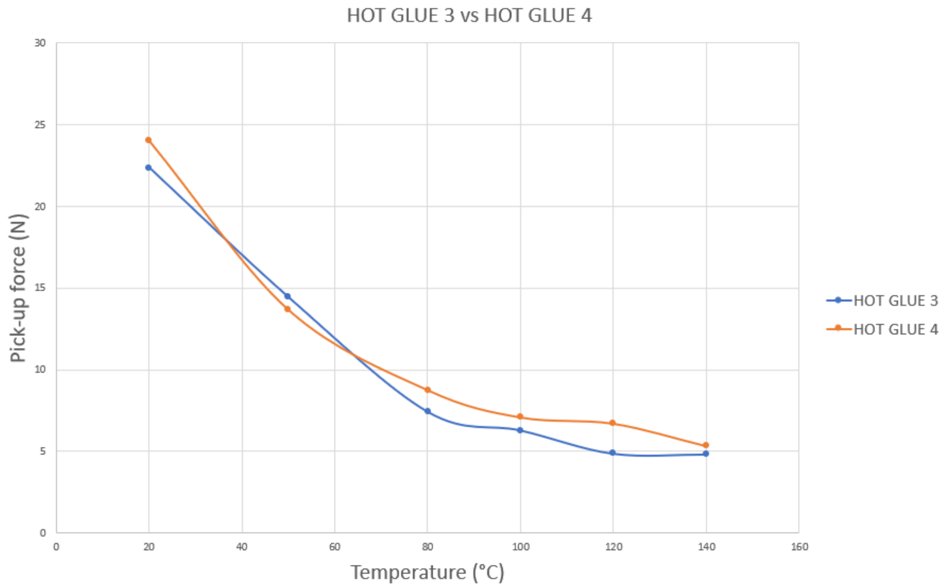

Figure 27. Comparison between the old HOT GLUE 3 and the new updated version, HOT GLUE 4. X-axis marks the temperature of the process and y-axis shows the pick-up force. Blue curve illustrates the pick-up force of the adhesive HOT GLUE 3 and orange curve illustrates the pick-up force of the adhesive HOT GLUE 4.

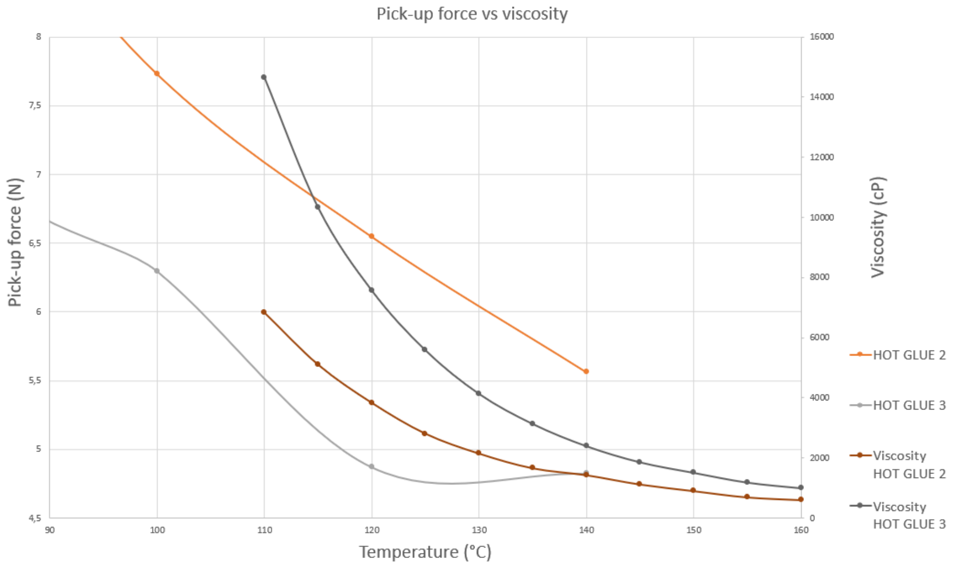

Figure 28. Comparison between HOT GLUE 2 and HOT GLUE 3 and their viscosity curves in a one figure. X-axis marks the temperature of the process and the left side y-axis shows the pick-up force. Right side y-axis shows the viscosity.

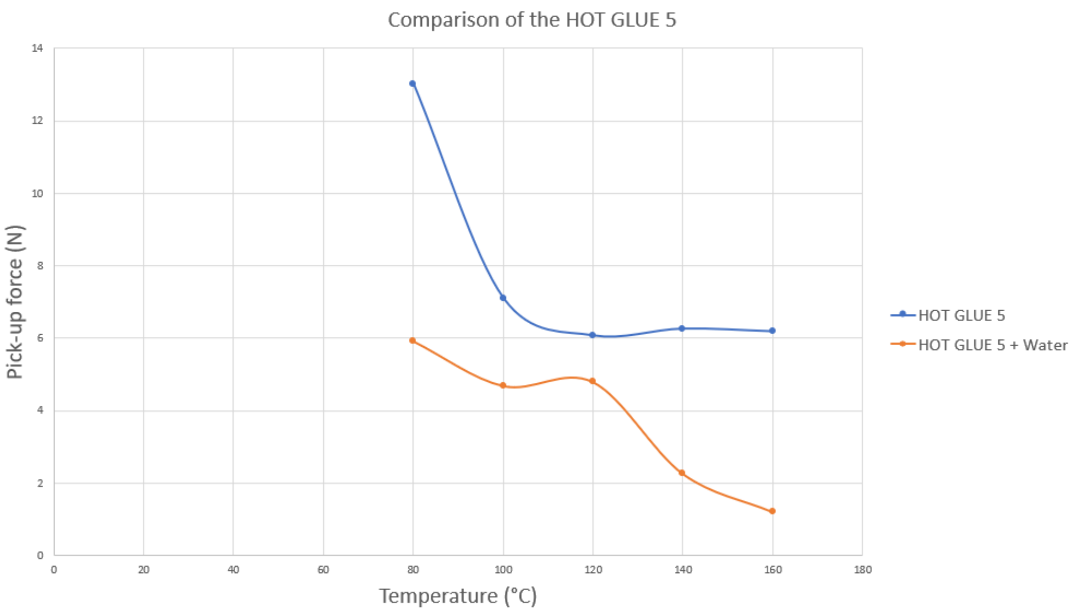

Figure 29. Comparison of the HOT GLUE 5. The blue curve illustrates the pick-up force in different temperatures. Orange curve illustrates the pick-up force in different temperatures, but it is influenced with artificial water vapour which copy the actual process the best.

Practical tests gave many tables and figures as a result, but only the most necessary ones are gathered in this thesis. These results are analysed more thoroughly in the next chapter. Next chapter studies deeply all these aforementioned figures, analyses the properties of each adhesive and places them in order.

4. Evaluation

There are plenty of critical problems occurring in the waterjet turn-up process that causes the poor reliability of the process. All these problems and solutions for them are obtained by having multiple meetings with the same personnel as with the interviews were gathered earlier. Practical tests also study the current pick-up glue and its properties. All this gathered information is used more thoroughly in the product development project later in the year 2022.

4.1 Analysis of the pick-up test results

The practical tests were implemented by using the equipment described in the chapter 2.4 and on the described timeslot. The gained results are tabulated to Microsoft Excel during the tests and graphs were drawn based on the results. Even though the test equipment did take into consideration most of the parameters occurring the actual papermaking process, some factors are still affecting the reliability of the results.

The amount of adhesive was informed in the test instructions, but since the adhesive was applied by test user itself, the amount of the glue is not necessarily accurate every time. Other factor is the temperature. Even though the oven is heated to desired temperature, which is then double-checked with the digital thermometer, the temperature will drop dramatically when the oven door is open. So, the speed of the test author influences the results. Speed also effects on multiple different parameters, such as the solidification of the adhesive. Third observation is the artificial water vapour which is applied by using a spray bottle filled with cold water. The temperature and aiming of the water vapour influence the results. The conductor of the Alluris-force meter also started to get a bit loose, which very likely started affecting the Newton-results by adding extra friction. These tests were implemented only using paper samples with basis weight of 252 and 255 g/m^2 which both produced similar results, but the results might vary when using different grades of paper. Some tests were also implemented by using a Teflon tape on the stamp, since many mills have Teflon tape on their reel spool which helps to clean it up, but the tests didn’t show almost any variation between the tests made with- and without Teflon tape. Lastly, the size of the stamp on the Alluris-force meter. These tests were implemented by using a self-made 12 mm diameter stamp, but a few tests were also made by using a stamp with twice the area, with diameter of 17 mm. Tests with this stamp gave results that were approximately twice as big as with the 12 mm stamp, so it can be said that the area of the stamp directly affects the received results.

The practical tests gave useful information considering the pick-up adhesives and possible faults on the process. As it can be seen on figure 24, there are huge differences between the adhesives that are currently used. By analysing the received results, it can be said that based on these studies the two best alternatives for pick-up are the HOT GLUE 2 and HOT GLUE 4, since they offer the best pick-up force between the temperatures 70 and 140 °C. The viewing interval of the temperature is 70 - 140 °C in this case, since the temperature of the paper web is between 60 and 80 °C and the hot glue is applied on a temperature of 110 - 140 °C, so it can be assumed that the right temperature will hit that scale. On lower temperatures, under 70 °C, the HOT GLUE 3 and HOT GLUE 4 are the best option, but rarely the temperature of the process decreases that low. The actual waterjet turn-up process was tried to be copied by applying the water vapour generated by the cutting nozzles artificially by using a water spray bottle. Results show that between the temperatures 80 – 115 °C the HOT GLUE 2 is the better choice, meanwhile at the temperatures 115 °C and over, HOT GLUE 4 offers similar pick-up force.

These gained results give guidelines on what adhesives are proceeded with, but it must be remembered that even though these tests are implemented by a technique that can be repeated easily there are still some variables that affect the total outcome, such as the amount of adhesive applied, nip time, burning of the glue and the heat of the oven during the tests with artificial water vapour. These tests can be used as a preliminary information on the product development project. As the results show, the water vapour has huge effect on the pick-up force. Figure 25 states that the pick-up force drops dramatically after 80 °C by the influence of the water vapour while using the HOT GLUE 2 adhesive. Same fact can be seen by looking the figure 26 which introduces the same tests on the adhesive HOT GLUE 4. On these tests the pick-up force drops on lower temperatures, between 20 and 80 °C.

These results can be compared with the viscosity curves that the manufacturer of the adhesive provides. Figure 28 introduces the viscosity curves for adhesives HOT GLUE 2 and HOT GLUE 3. Curves show that the viscosity of the adhesive drops dramatically after the temperature hits 110 °C, which leads to the fact that the adhesive turns more fluid. Figure 28 also shows that the gained pick-up force correlates with the viscosity curves, which is a good sign, since it shows that the tests gave reliable results.

One important thing to achieve on this test method was also to be able to compare the old HOT GLUE 3 and the updated and modified version, HOT GLUE 4. Tests which can be seen on figure 27 show that HOT GLUE 4 is approximately a bit better alternative, since between the temperatures of 65 to 140 °C the pick-up force of HOT GLUE 4 is about 2 newtons higher, which is a lot as a percentage.

The HOT GLUE 5 was only tested on an experimental basis since its features with- and without the influence of water vapour was a question mark. This glue needed to be applied on higher temperature, 145 °C because of its higher melting point. The test results for this glue can be seen on figure 29. Without the water vapour the pick-up force seems to be high on the temperature of 80 °C, but dramatically drops all the way to the temperature of 100 °C. From the temperature 120 to 160 °C the curve is quite even, which is interesting. With the influence of water vapour the pick-up force is immediately smaller in the 80 °C, from where it keeps dropping. After the even curve between 100 and 120 °C the pick-up force drops a lot, all the way to 1.5 Newtons.

As the results of the practical tests show, the adhesives can now be set in the order of precedence. All these adhesives have their own specific temperature in which they offer the best properties, but by talking about the actual process temperature, the HOT GLUE 2 and 4 can be said to be the best alternative.

First research question did consider why is the reliability of current waterjet turn-up devices insufficient? Based on the interviews and practical tests it can be said that the reliability is insufficient because of multiple matters – Water vapour affects the pick-up process negatively, pick-up adhesive might not have enough time to solidify, the pick-up adhesive may be applied too far away from the nip. Next research question was about intensifying the turn-up process. How can it be made? The current turn-up process can be intensified with modifying the existing equipment. The waterjet cutting nozzles could be tilted towards the edge of the paper, which will reduce the amount of the water vapour and may help lift the paper web. The hot glue adhesive could also be applied closer to the paper web and nip by replacing the pneumatic cylinders which move the pick-up unit. Third research question is a bit tricky, since the interviews did show that many parts affect the reliability of the waterjet turn-up process, such as the level of compressed air, the high-pressure hoses, cutting nozzles, linear motors, pick-up gun, Robatech hot glue-unit, surface binding arms- and nozzles etc.

4.2 Reliability and validity

The validity in this thesis remains high, since the used research methods give accurate results considering different adhesive types and it also answers fully to the research questions. The aim of this thesis through the research questions was to define a method to increase the reliability of the turn-up process by either coming up with a new solution or by modifying one of the existing ones. All the answers were gathered through interviews and the discussion after that. The aim of the practical tests was to measure the pick-up force of different adhesives in different temperatures to be able to compare them together and place them in order of precedence. The developed measuring system did consider most of the factors that occur during the real process, so it can be said that test was success.

Even though reliability also remains high considering these tests, it won’t be as accurate as the validity. The reliability of this study was strived to keep high by making enough repeats for every adhesive in all desired temperatures. Some adhesive only required 5 tests in a certain temperature, meanwhile some adhesives required 10 to 15 repeats to set the average force even. This can be partly explained by the properties of the adhesive since some adhesives were so sensitive to temperature variations and the pick-up time. The validity of the tests was confirmed by counting the average number for the pick-up force through several tests.

4.3 Further development

As can be seen on the tables 2, 3 and 4 and based on the practical tests, the most urgent problems that should be paid attention during the product development project are in the waterjet cutting- and pick-up section. Practical tests show that the water vapour has a huge effect on the pick-up force which is a thing to be considered. The amount of water vapour can be reduced by running tests to find out what is the minimal amount of water that is required to be able to cut the paper web. After the optimization of the amount of the water, the water nozzles could be tilted so that the bouncing water would go under the paper web during the cut. This will reduce the amount of water vapour during pick-up and could potentially also help lift the paper web on the reel spool. The pick-up adhesive could also be applied in the surface of the reel spool instead of the paper web, which could help the glue tray to always be on the right place. This could also help reduce the effect of the water vapour during the pick-up process. The distance from the pick-up glue gun to paper web is a bit too long now, which reduces the pick-up force of the adhesive and causes splattering of the glue. The pick-up adhesive needs to be applied closer to the paper web to come up with higher reliability rate. Last correction proposal is the chance of applying the pick-up adhesive in as far the nip as possible. This would give the adhesive some extra time to solidify, which will increase the pick-up force as the practical tests stated. On the other hand, applying the pick-up adhesive before the waterjet cutting could influence the pick-up force negatively.

5. Summary

The aim of this thesis was to either come up with a new turn-up method or develop the existing waterjet turn-up equipment so that the reliability of the turn-up process could be increased from the current. The other aim was to gather a list of problems occurring with the existing turn-up process and its equipment for a base of the product development project. This was implemented by making interviews and then having multiple meetings with the experts working in Valmet to decide which of the ideas were critical and which were not, in the name of reliability.

Thesis consists of a literature review which introduces the reeling section and the most vital components that affect the reliability of the turn-up process. All the existing turn-up methods were introduced but this thesis mainly focuses on the most modern one, waterjet turn-up device. The reliability of the waterjet turn-up device was studied by categorizing the problems in turn-up-, pick-up-, or surface binding device.

The problems and solutions were gathered by making an interview template that was sent to every expert individually, which prevents the other people opinions to effect on one or another. After gathering all the interviews, the meetings were arranged together to get as many solutions as possible and to share opinions together.

Practical tests were implemented in the test facilities of Valmet Järvenpää to be able to set the current adhesives in order of precedence. The practical tests did show that the turn-up process is widely affected by the water vapour generated from the high-pressured waterjet cutting nozzles, so one major target of development is how to reduce the water vapour during the pick-up.

Based on the results achieved it can be said that the aim of this thesis was achieved. All the existing problems are listed with an idea for a solution. A comprehensive preliminary study was made, which can be used as a base for a product development project. The outcome of this thesis was also a working prototype of equipment that can be used to measure the features of different adhesives with sufficient accuracy. By making a little product developing, this equipment can be utilized on deciding what adhesive to be used on a certain project.

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Appendix 1. Possible safety hazards on reeling section (ISO 1034-1 p. 14)

Table 1. Possible safety hazards on reeling section. (ISO 1034-1 p. 14)

No	Hazards		subclause of this European Standard	EN 1034-1: 2000 +A1:2009
	Origin (source)	Potential consequences		
	Mechanical hazards			
1	Inadequate design of workplaces, means of access, walkways, passageways	Slipping, tripping and falling	5.2.1; 5.2.2; 5.2.5; 5.2.7; 5.2.8; 5.11.1; 5.11.3; 5.11.4; 5.12.4; 5.12.9; 5.25.6; 5.26.4; 5.27.7; 5.28.7; 5.28.8; 5.32.1; 5.34.14; 5.36.1; 5.36.2; 5.36.3; 5.37.1	5.5
2	Obstacles in the area of workplaces, means of access, walkways, passageways	Impact hazards for the head	5.2.3; 5.8.4	5.5.9
3	Inrunning nips on rotating rolls, reels, cylinders; Wrapping points of fabrics, wires, ropes, power transmissions elements	Drawing-in or trapping, amputation, death	5.2.6; 5.2.7; 5.2.8; 5.3; 5.4; 5.6.1; 5.6.2; 5.11.2; 5.11.3; 5.12.1, 5.12.3; 5.12.9; 5.19.2; 5.19.3; 5.19.4; 5.22.4; 5.24.1; 5.24.2; 5.24.3; 5.24.8; 5.25.5; 5.25.6; 5.26.6; 5.26.7; 5.26.8; 5.27.1; 5.27.2; 5.27.3; 5.27.4; 5.28.1, 5.28.2; 5.28.4; 5.29.1; 5.29.2; 5.29.3; 5.29.4; 5.30.1, 5.30.2; 5.30.3; 5.32.1; 5.32.2; 5.34.1; 5.34.2; 5.34.6; 5.34.7; 5.34.8; 5.34.12; 5.37.1; 5.37.2	5.1; 5.4; 5.7
4	Outer rolls	Drawing-in or trapping, amputation, death	5.19.3	

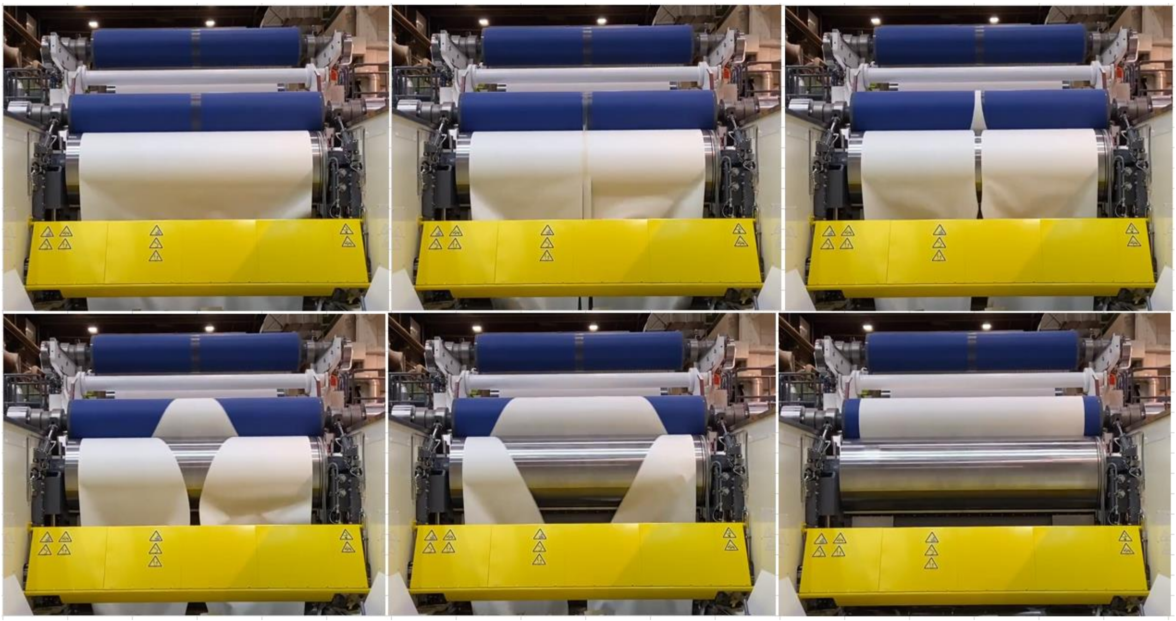
Table 2. Possible safety hazards on reeling section. (ISO 1034-1 p. 14)

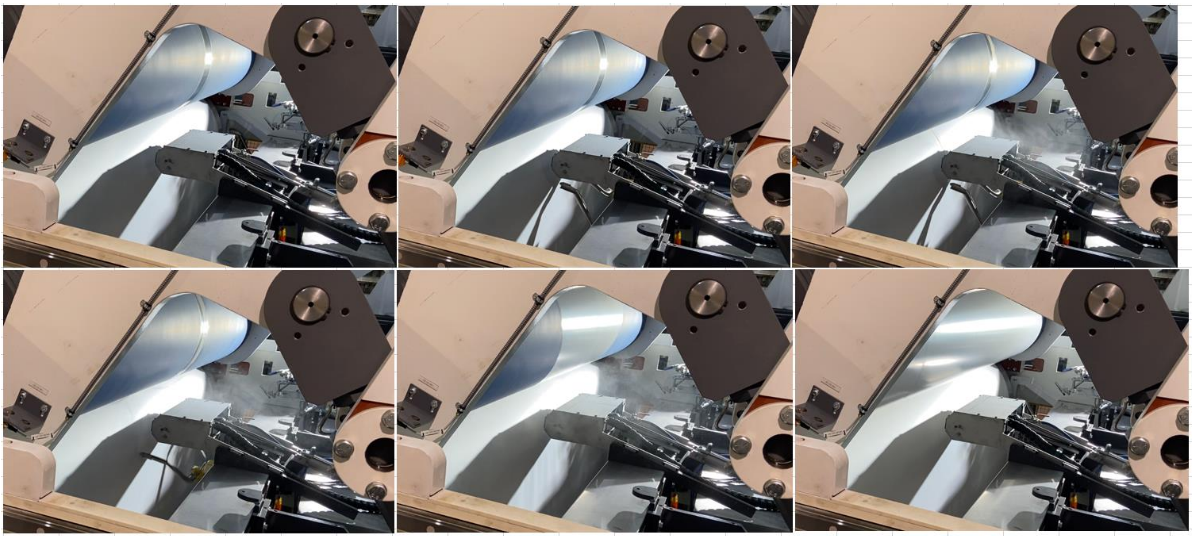
5	Linear and swivelling movements of machinery parts	Crushing injuries	5.2.6; 5.2.7; 5.4; 5.11.4; 5.12.6; 5.12.7; 5.24.7; 5.24.9; 5.25.2; 5.26.1; 5.26.2; 5.26.3; 5.26.5; 5.26.11; 5.27.5; 5.28.8.7; 5.29.5; 5.30.4; 5.31.5; 5.32.3; 5.33.1; 5.34.9; 5.34.13; 5.34.15; 5.35	5.1; 5.3; 5.7
6	Linear and swivelling movements of machinery parts	Shearing injuries	5.4; 5.26.9; 5.26.10; 5.26.11; 5.26.12; 5.33.1; 5.34.3	5.1; 5.7
7	Knives, edges of wires, sharp edges of machinery frame	Cutting injuries	5.1; 5.12.5; 5.20.1; 5.20.2; 5.25.3; 5.25.4; 5.37.1	5.1; 5.11; 5.12
8	Movement of crane, reels	Impact, Crushing injuries	5.11.4; 5.19.1; 5.28.4; 5.28.8.9; 5.34.13; 5.35	5.1; 5.7
9	Rotating bolts on rolls and cylinders	Impact injuries	5.19.1; 5.27.6	
10	Hydraulic and pneumatic equipment	Injuries by ejection of high-pressure fluids	5.9; 5.10; 5.12.8; 5.20.1; 5.34.4	5.24
11	Ejection and falling of machinery parts	Crushing, impact of persons	5.24.5; 5.24.6; 5.25.1; 5.26.2; 5.28.8.4; 5.28.8.6; 5.30.4; 5.34.5; 5.34.10; 5.34.11	5.2
	Electrical hazards			
12	Electrical equipment	Electric shock	5.6.1; 5.8.1; 5.8.2	5.23
13	Electrical equipment	Outside effects on electrical equipment	5.6.1; 5.8.3	5.23
	Thermal hazards :			
14	Hot surfaces of machinery parts	Burning and scalds by contact of persons	5.14; 5.22.2; 5.28.9.1; 5.28.8.5; 5.30.6; 5.31.1; 5.31.4; 5.31.8	5.13; 5.17
	Noise hazards			
15	Running machine, drives, power transmission elements, hydraulic aggregate, ventilation system	hearing loss or other physical disorders, interference with speech communication and acoustic signals	5.6.1; 5.13; 5.28.8.1	5.15
	Radiation hazards			
16	Measuring unit with radioactive source	Ionising radiation, cancer causing	5.33.2; 5.33.3	5.20
17	Infrared dryer	Irritating or burning to the skin by infrared radiation	5.31.2	
	Hazards generated by material and substances			
18	Chemical substances	Loss of health, injuries of the skin or eyes	5.17	5.16
19	Paper, drying section, flotation dryer, infrared dryer, hydraulic oil	Fire	5.8; 5.18; 5.28.5; 5.28.6; 5.28.8.2; 5.28.8.3; 5.30.6; 5.30.8; 5.31.2; 5.31.3; 5.31.6; 5.31.7; 5.31.9	5.13; 5.18; 5.19; 5.23

Table 3. Possible safety hazards on reeling section. (ISO 1034-1 p. 14)

20	Neglect of ergonomic principles	Discomfort, fatigue, stress, overload	5.2.4; 5.2.8; 5.12.2; 5.16; 5.21; 5.26.11; 5.26.12; 5.27.7; 5.34.11; 5.34.14	5.22
21	Inadequate lighting of the workplace	Blinding, falling, stress	5.15	5.18
	Hazards caused by failure of energy supply, control system and other functional disorders			
22	Unexpected start-up	Crushing, shearing, impact, drawing-in or trapping	5.3; 5.5; 5.9; 5.10; 5.22.3	5.6; 5.8
23	Malfunction in the control system	Crushing, shearing, impact, drawing-in or trapping, overturn, falling or ejection of objects	5.2.6; 5.3.5; 5.4.3; 5.5.2; 5.6.3; 5.6.4; 5.7; 5.12.6; 5.19.2; 5.20.1; 5.24.8; 5.26.1; 5.27.5; 5.28.2; 5.28.3; 5.28.8.7; 5.29.2; 5.29.5; 5.30; 5.31.4; 5.32.2; 5.32.3; 5.33.1; 5.34.2; 5.34.3; 5.34.4; 5.34.10; 5.34.15; 5.35; 5.36.2	5.14
	Combination of hazards			
24	Work in confined spaces	Asphyxiate, inhalation of chemical substances, crushing, shearing, impact, electric shock, stress	5.22.1; 5.23	

Appendix 2. Waterjet turn-up process illustrated from the front- and back side of the web.





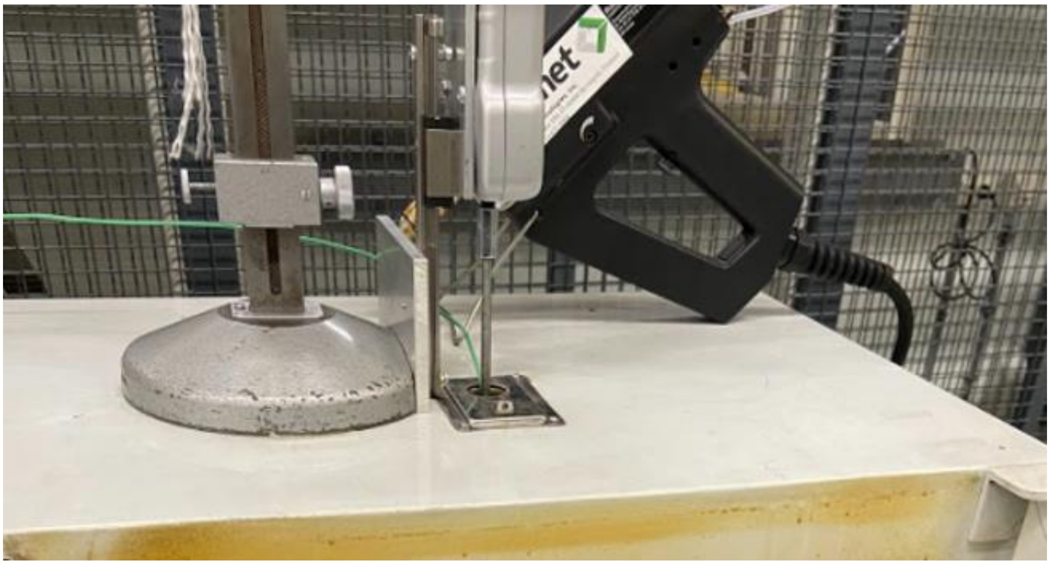
Appendix 3. The development of the pick-up glue force tests.

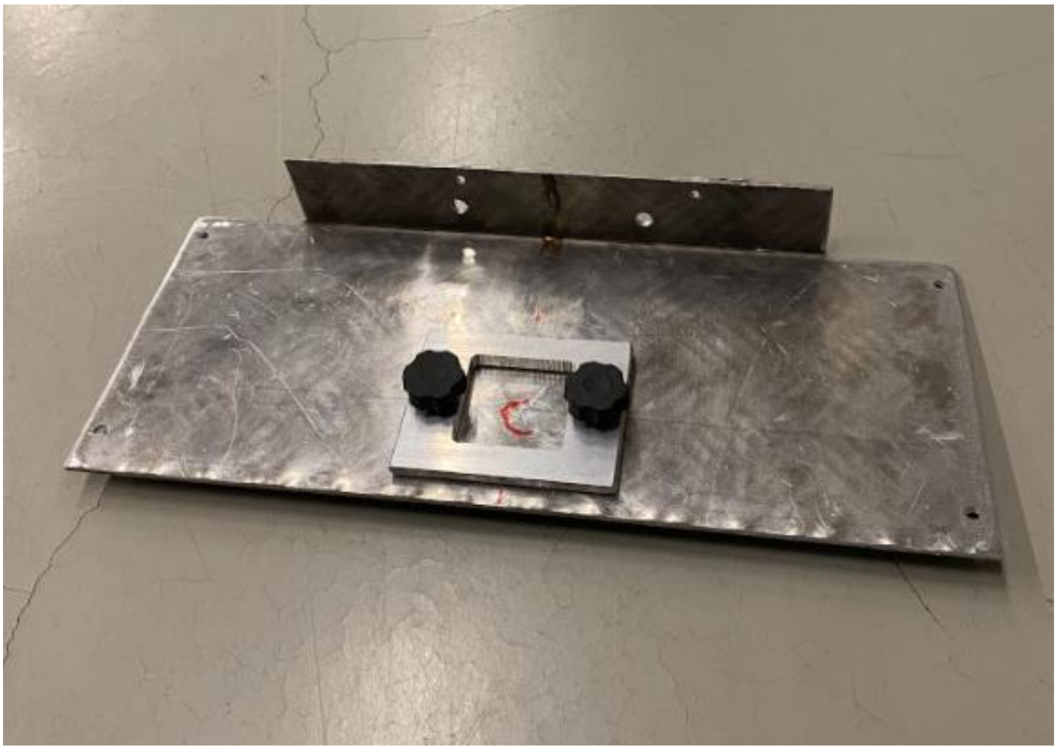
Test equipment 1.

Test equipment 2.

Test equipment 3.

Test equipment 4.





Test equipment 5.

Appendix 4. Interview form for experts

Haastattelu Diplomityötä varten

Diplomityön aihe on rullaimen vaihtoprosessin luotettavuuden tarkastelu. Tarkoituksena on parantaa luotettavuutta vaihtoprosessissa, pikkauksessa ja pintaliimauksessa. Alla on listattu kysymyksiä, joihin toivon vastausta. Kiitos!

1. **Nykyisissä vaihtolaitteissa ilmenevät ongelmat?**

2. **Missä tilanteissa ongelmat esiintyvät ja pystytkö nimeämään projektia, jossa ongelmia on esiintynyt enemmän kuin muissa?**

3. **Mistä ongelmat johtuvat?**

4. **Mahdollisia ideoita vaihtoprosessin kehittämiseen?**

5. **Miten nykyisiä ongelmia on hoidettu?**

6. **Miten paperilaatu vaikuttaa vaihtoprosessin luotettavuuteen?**

7. **Mitkä ulkoiset tekijät paperilaadun lisäksi vaikuttaa vaihtoprosessin luotettavuuteen?**

8. **Muuta mahdollista huomioitavaa, jos tulee mieleen?**