LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
Faculty of Technology
New Packaging Solutions

Jyrki Mäntylä

Enhancement of water removal in the press section

Examiners: Professor Henry Lindell
Professor Juha Varis
Supervisors: Ilkka Jääskeläinen, M.Sc. (Tech.)
Riku Pihko, M.Sc. (Tech.)

ABSTRACT
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Keywords: Paper machine, board machine, press section, water removal, shoe press

The effectiveness of water removal on press section is very important for a paper and board machine's functioning, efficiency and economy. Today, the most effective method for wet pressing is shoe press technology. Metso has carried out a number of studies concerning a new type of water removal method for a press section, which has also been patented. These studies include rough sketches and some test runs. These issues form the basis of this thesis.

The objective of this work was to gather together information for a new and enhanced water removal method for a press section by studying the functioning of the device and carrying out test runs. This method is referred to here as Hydronip. The main goal was to build a functional test site which fulfills all the necessary requirements and has all the necessary information gathering devices. The design process was carried out by emphasizing the safety aspects. The goal was also to gather together information about the nip structure in running conditions, the seal function, and to carry out the nip tests with paper or board wads.

This thesis consists of a theory part, the design and construction of the test site, and carrying out test runs through information gathering. The theory part consists of the principals of water removal from a press section, Hydronip construction, and the requirements for the test place.

The safety aspects were taken into account especially in test runs, but also in the assembly stages. The design and construction of the test site includes the selection of equipment and surroundings that are needed for managing the test runs in the best possible way at certain premises. The test site included the equipment that was already on the premises. Some equipment could be used as it was but some equipment had to be manufactured or modified from existing equipment.

A functional test site with information gathering devices was accomplished as a result of the thesis. Test runs demonstrated that the Hydronip concept is, at least on a small scale, functional. Short-term tests for seal functioning showed that the seal can be lubricated sufficiently under different kinds of nip load situations. Wad tests demonstrated that the metal belt is durable against different sizes of external particles. The seal also endured wad tests even though the pressure impacts impaired the lubrication. MTS tests showing dry content increases, combined with a rough cost calculation and the basic function of the machine in test runs, show that with some further study Hydronip could be a promising new product for water removal from a paper or board machine's press section.

TIIVISTELMÄ
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Jyrki Mäntylä

Puristimen vedenpoiston parantaminen

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Professori Juha Varis

Hakusanat: Paperikone, kartonkikone, puristinosa, vedenpoisto, kenkäpuristin

Vedenpoiston tehokkuus on erittäin tärkeää paperi- ja kartonkikoneiden toiminnan, tehokkuuden ja kannattavuuden vuoksi. Kenkäpuristinteknologia on tänä päivänä tehokkain vedenpoistomekanismi puristamalla. Metso on tutkinut uudenlaista vedenpoistomenetelmää puristinosalle, mikä on myös patentoitu. Tutkimukset sisältävät karkeita luonnoksia ja joitain koeajoja. Diplomityö perustuu näihin tutkimuksiin.

Tavoitteena oli kerätä tietoa uudesta vedenpoistomenetelmästä tutkimalla laitteen toimintaa ja suorittamalla koeajoja. Vedenpoistomenetelmää kutsutaan tästä eteenpäin Hydronipiksi. Päätavoite oli rakentaa toimiva, vaatimukset täyttävä koepaikka, mikä sisältää tarvittavat tiedonkeruulaitteet. Suunnitteluprosessissa korostettiin turvallisuusnäkökohtia. Tavoittena oli myös kerätä tietoa nippirakenteesta ajo-olosuhteissa, tiivisteen toiminnasta ja suorittaa mällitestejä.

Työ koostuu teoria osuudesta, koepaikan suunnittelusta ja rakentamisesta sekä koeajojen suorittamisesta tiedonkeruineen. Teoria osuus koostuu vedenpoiston perusperiaatteista puristinosalla, Hydronipin rakenteen esittelystä ja koepaikan vaatimuksien esittelystä.

Turvallisuusnäkökulmat otettiin huomioon erityisesti kokoonpano- ja koeajovaiheissa. Koepaikan suunnittelu ja rakentaminen sisälsi tarvittavien komponenttejen ja laitteiden valinnan sekä valmistuttamisen onnistuneiden koeajojen toteutukseen ennalta määrätyllä paikalla. Koepaikka sisälsi laitteita, joita käytettiin hyödyksi joko sellaisenaan tai muokattuina tarvetta vastaaviksi.

Työn tuloksena saatiin toimiva koepaikka mittalaitteineen. Koeajojen perusteella Hydronip todettiin toimivaksi ainakin koelaiteympäristössä pienessä mittakaavassa. Testeissä tiivisteen voitelu ja toiminta todettiin lyhyissä koeajoissa vaihtelevilla nippikuormilla riittäväksi, eikä vaurioita esiintynyt. Mällitestit osoittivat, että metallihihna kestää suuriakin ulkoisia rasituksia. Myös tiiviste kesti mälleistä johtuneet häiriöt voiteluolosuhteissa, vaikka pientä kulumista esiintyikin. Näiden lisäksi MTS-testien perusteella saavutettavat kuiva-ainepitoisuuden nostot, karkean kannattavuuslaskelman tulokset sekä laitteen toiminta koeajoissa osoittavat, että Hydronipin ja sen osa-alueiden toiminnan tutkimista kannattaa jatkaa ja siitä voidaan saada uusi tuote paperi- tai kartonkikoneen puristinosan vedenpoistoon.

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1 Introduction

1.1 Background

The effectiveness of water removal from a press section is very important for a paper and board machine's functioning, efficiency, and economy. The better the wet pressing functions, the better the paper machine runnability, and the shorter the expensive drying section. Today, the most effective method for wet pressing is shoe press technology. Even though it is effective and functional, a number of alternative solutions have been studied to further improve water removal.

Metso Paper's Roll Development Department has conducted a number of studies concerning a new type of water removal method for press sections. These studies include rough sketches of the device and some test runs. The device is also patented. These studies form the basis for this thesis.

1.2 Objective of the thesis

The objective of this thesis is to gather information for a new and enhanced water removal method for press sections by studying the system and carrying out test runs. This method is referred to in this thesis as Hydronip. The main goal is to build a functional testing place for Hydronip which fulfills all the necessary requirements and has all the necessary information gathering devices. The design process is carried out by emphasizing the safety aspects aimed at safe assembly and the test runs stages. The goal is also to gather together usable information about the nip structure in running conditions, about the seal function, and to test the nip against paper or board wads.

The main research question in the study is: How will the Hydronip function in test runs? Another relevant question is: How will the sealing work? A further aim is to get answers to the following set of sub-questions:

- What should be the nip geometry?

- What should be the construction of the Hydronip?
- What loadings can the nip have?
- What are the water removal functions?
- What are the economic aspects?
- Where can it be used?
- What are the biggest challenges?
- What kinds of actuators are needed?
- What kinds of calculations should be made?
- What are the key materials?

1.3 Execution of the work

The thesis consists of a theory part, design and construction of the test place, and carrying out the test runs with information collection. The theory part consists of the principals of water removal from a press section, Hydronip construction, and the requirements for the test place.

The design and construction of the test place includes the equipment and surroundings that are needed for executing test runs in the best possible way at certain premises. The safety aspects are taken into account especially in the test runs but also during the assembly stages. The test place includes the equipment that is already on the premises and the necessary equipment that has to be purchased or modified from existing equipment. The test runs are carried out at the test site at Metso Paper Rautpohja Technology Center and the information is collected by suitable means. The results are presented in this thesis.

1.4 Paper, board and pulp drying on press section

1.4.1 Press section functions

The dry content of the web approaching from the forming section is in the range of 17 -20%. After the forming section, water is removed from the web by mechanical pressing. This reduces the web thickness and increases the interfiber contact area. The function of the press section is to remove the maximum amount of water from the web and to compress it. The goal is to achieve a sufficiently high wet strength with the press in order to ensure that the web is transferred to the drying section without any breaks. On the other hand, compressing the web enables the formation of strong interfiber bonds during web drying. (KnowPap 7.0 2005a)

Wet pressing takes place:

- between a press felt and a smooth roll
- between two press felts
- between a press felt and a transfer belt.

At first, pressing is performed carefully so as not to crush the web formed by the wire. Excessively strong or fast pressing flushes away fines from the web and, in the worst cases, crushes the fiber network. In practice, pressing performed in stages is carried out with several nips built up by rolls. When the web goes through the press nips, the nip forces can be gradually increased. (KnowPap 7.0 2005a)

Although the objective of pressing is to achieve as high a dry content as possible, the press power present in the last nip cannot be raised as high as present equipment technology allows. With excessively high press power applied, the paper sheet thickness would diminish too much, resulting in too low a level of bulk. Secondly, this would shorten the felt service life and cause potential roll or felt marks in the paper. At high press powers, the press would be sensitive to vibration. (KnowPap 7.0 2005a)

The dry content level after the press section is from 37% to 55%, depending on the paper grade and press section. A 1% increase in dry content at the press will diminish the dryer-section steam consumption by 3 -4%. At a specific web moisture level, pressing is the most economical way of drying the web. (KnowPap 7.0 2005a)

1.4.2 Effects on paper properties

Wet pressing has a strong effect on paper properties. The press geometry, rolls and their covers, felts, and linear pressure combinations must be selected to conform to the running speed and the paper grade to be produced. Wet pressing affects the following quality properties: (KnowPap 7.0, 2005a)

- paper smoothness and symmetry
- fines distribution
- surface strength
- moisture and moisture profile
- porosity
- bulk

1.4.3 Press sections: main concepts

1.4.3.1 OptiPress

The operating performance of the double-nip OptiPress, (Figure 1,) provides excellent efficiency, easy tail threading, and speed potential. The closed web run reduces web breaks and improves runnability. This solution provides very good paper and board quality with symmetrical sheet properties, good moisture profiles, excellent dry content, and high production efficiency. (Metso Paper 2010)

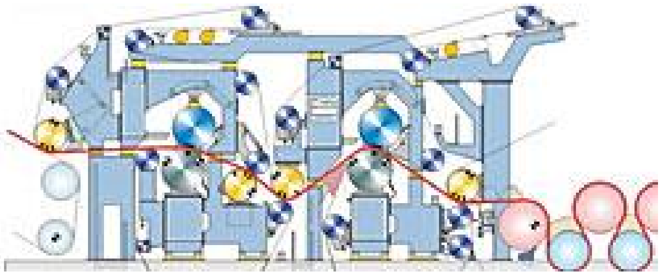


Figure 1 OptiPress (Metso Paper 2010)

OptiPress features SymBelt shoe press technology, which provides longer dwell times and higher press impulses that improve dryness after the press section. A high web dry content creates savings in drying energy. The two shoe presses produce a strong web and ensure a good moisture profile in the web after the press section. The double-shoe press section additionally offers extended felt life and lower investment cost through fewer cantilevering beams, interchangeable counter rolls, and space savings. (Metso Paper 2010)

The OptiPress press section meets the great dewatering capacity requirements of high-speed paper or containerboard machines. The concept can be applied to both new lines and rebuilds. (Metso Paper 2010)

1.4.3.2 SymPress B

A SymPress B center roll-based press, (Figure 2,) is a reliable concept with modern shoe press technology. With this solution, a shoe press replaces a roll before the first open draw. The resulting boost in dryness fully benefits web runnability in the open draw. If necessary in meeting end quality requirements, a center roll-based press can be followed by a separate roll press. (Metso Paper 2010)

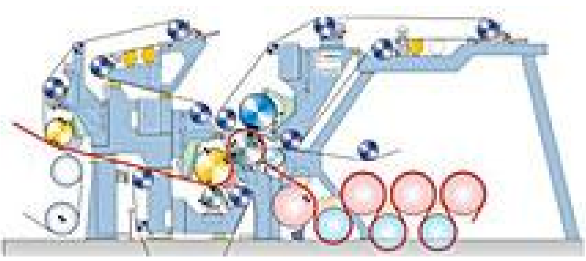


Figure 2 SymPress B (Metso Paper 2010)

Due to increased linear loads in the first and second press nips, today's center roll-based press sections are setting new world speed and production records. The most modern center roll-based press sections produce printing paper at speeds in excess of 1900 m/min, and a speed of 2000 m/min is close at hand. (Metso Paper 2010)

In the containerboard production of packaging board from recycled fiber, machines dedicated to high speeds and light basis weights can be equipped with a SymPress B pressing process. It can be applied for both new lines and rebuilds. (Metso Paper 2010)

1.4.4 Dewatering

1.4.4.1 Wet pressing mechanism

Wet pressing is usually performed with two opposing rolls that are pressed against each other. The one or two-felt assisted web is led through a nip built up by rolls. Several factors affect the water transfer from the paper into the felt and from there on to the roll. The most important of these factors are press power and the time used, felt and roll surface construction, temperature, the pulp furnish and refining stage, machine speed and linear pressure as well as the nip residence time. Web resistance to the flow will be notably increased by the use of intensely refined pulp with a high fines content. (KnowPap 7.0 2005d)

The first to investigate the wet pressing mechanism in the 1960s was Wahlstrom. His theory was later completed by Nilsson and Larsson. According to the theory, the nip process is composed of four different stages as shown in Figure 3. In reality, there is actually no such accurate limit between the various stages. (KnowPap 7.0 2005c)

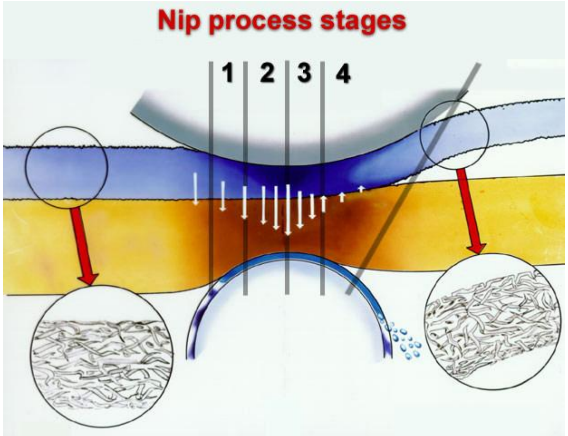


Figure 3 Nip process stages (KnowPap 7.0 2005c)

Area 1: The total pressure starts increasing in the converging nip. The force between the rolls is transferred through fiber elastic forces to not only the felt, but also to the web, and there are no hydraulic forces affected. At this point, most of the air is removed from the nip. (KnowPap 7.0 2005c)

Area 2: The web is fully saturated with water, since there is no air in the web. An increasing hydraulic pressure forces water to start flowing towards the felt with a lower hydraulic pressure. Since water can easily find its way into roll grooves or holes, the roll-side hydraulic pressure of the felt cannot increase. Furthermore, since the felt is also saturated and excess water is removed to the roll side, the nip will determine the water content of the felt. At the end of Area 2, the total pressure will reach its maximum. This stage is located before the nip's geometrical middle point. (KnowPap 7.0 2005c)

Area 3: The nip starts diverging, while the total pressure starts decreasing. Compression of the fiber structure will continue as long as the hydraulic gradient is positive, i.e. the water flow is channeled to the roll. At the end of Area 3, the web will reach its maximum dry content in the press nip. (KnowPap 7.0 2005c)

Area 4: The felt and web are no longer saturated with water. At the beginning of the area, the web has a maximum dry content, but, during nip divergence, water is again absorbed from the press felt into the paper. This is called rewetting. The rewetting level is affected by the press temperature and capillary forces transferring water from the structurally coarser felt into the denser paper. (KnowPap 7.0 2005c)

1.4.4.2 Factors affecting efficiency

Factors affecting wet pressing efficiency are indicated in the wet pressing theory. The maximum dry content achieved depends on the thickness of the pressed web in the middle of the press nip. If the web is thin, the thickness depends on the press power used, which is the most important factor affecting efficiency on thin grades. This type of nip process is called compression-limited pressing. (KnowPap 7.0 2005c)

On thick paper grades and board, the web has a significant flow resistance when water is removed from the web by pressing. The hydraulic pressure will then prevent the compression of the fiber network. This process is called flow-limited pressing. In reality, the nip process is invariably a combination of pressure and flow-limited nip processes. (KnowPap 7.0 2005c)

On flow-limited paper and board grades, pressing can be increased by allowing water to flow for a longer time. Then, when the level of the hydraulic pressure generated in pressing at a certain pressure is not be so high, the web is compressed and the amount of water removed from the web is greater. The maximum dry content of thick grades was discovered to be (approximately) proportional to the product of the pressing period and linear load, otherwise known as the pressing impulse. (KnowPap 7.0 2005c)

With thin grades, it was also discovered that pressing at a constant pressure can be boosted by extending the pressing period, although the level of water flow is small and only a few fiber plies can be expected to generate a relatively low flow resistance. Increased pressing results from the visco-elastic nature of fibers. A visco-elastic web is compressed during a continued pressing period, even when there is no water flow whatsoever. Moreover, it must be noted that water is also contained within the fibers. KnowPap 7.0 2005c)

1.4.4.3 Factors affecting pressing

1.4.4.3.1 Furnish of paper and refining

Mechanical pulp fibers are considerably stiffer than those of chemical pulp. Accordingly, it is easier for water to leave webs containing a large quantity of mechanical pulp. Pulp refining will further soften the fibers and increase the amount of fines. The web flow resistance is essentially increased by using pulp that has undergone an intense refining process. (KnowPap 7.0 2005c)

1.4.4.3.2 Fillers

The amount of fillers will vary from grade to grade. Fillers are used especially in the production of SC and LWC-papers. The most common fillers are clay and calcium carbonate. Roughly speaking, the greater the ash content of the web, the easier it is to remove water from the web by pressing. An increase of approximately 5% increase in ash content will improve the dry content level by about 1%. (KnowPap 7.0 2005c)

1.4.4.3.3 Two-sided web

There is a general trend to keep paper quality as uniform as possible for both bottom and top surfaces. The press section affects the roughness of the surface and surface absorption. These properties are affected by the water removal direction and felt roughness levels. (KnowPap 7.0 2005c)

1.4.4.3.4 Web bulk in the thickness direction

When using hot pressing, a bulk loss is often faced, resulting in excessive compression of the web. The bulk indicates web thickness and bulk loss can be reduced by decreasing linear pressures. The bulk loss is thus contradictory to the target set for dry content. (KnowPap 7.0 2005c)

1.4.4.3.5 Felt properties

There is a tendency to adjust felt properties so that a vacuum is formed in the felt in the diverging nip in order to prevent water from flowing back to the paper web, i.e. rewetting. This requires that the felt is saturated with water and the backing roll is not opened too wide. In the nip air is removed from the felt, but in diverging stage the air is coming back first from the roll side, thus preventing the formation of a vacuum. This often occurs in the last nip, where the amount of water to be removed is minor and the felt used is new. (KnowPap 7.0 2005c)

1.4.4.3.6 Rewetting

The most significant factor affecting rewetting is the breaking of the water film found at the felt and web junction, which results in water being channeled to the paper side and wetting the web. To minimize rewetting, the felt must be separated from the web as fast as possible. Another factor affecting rewetting is the felt structure. To minimize rewetting, the felt flow resistance must be as low as possible. (KnowPap 7.0 2005c)

1.4.4.4 Pressing variables

1.4.4.4.1 Temperature

Dewatering is boosted by increasing the pressing temperature. Water viscosity will drop under higher temperatures, thus diminishing the flow loss. This will also reduce the water surface tension, facilitating water removal from the fiber mat. The temperature increase results in softening of the fibers, thus compressing the web at a lower pressure. (KnowPap 7.0 2005c)

However, the paper web is weaker at an increased temperature and the improved runnability achieved by the increased dry content will often be lost, since the web becomes weaker. The use of increased temperature and linear pressure may result in the loss of bulk, thus limiting the degree of temperature increase for some fine paper grades. (KnowPap 7.0 2005c)

In the press section, the increase in the dry content level achieved by an increase in temperature is much more advantageous than drying performed in the dryer section. As a result, optimizing the press dry content level must be the objective. (KnowPap 7.0 2005c)

1.4.4.4.2 Linear pressure and time

At increasing speeds, the web remains in the nip for a shorter period of time. A normal nip length for a fast newsprint machine is in the range of 30 -40 mm at the third and fourth press. At a machine speed of, for instance, approx. 1500 m/min (25 m/s), the nip period lasts from 1.5 to 2 ms. During this period, hydraulic pressure should be built up in the nip in order to remove water from the web. Figure 4 illustrates the effect of roll diameter and linear load on achieved nip length and maximum pressure. (KnowPap 7.0 2005c)

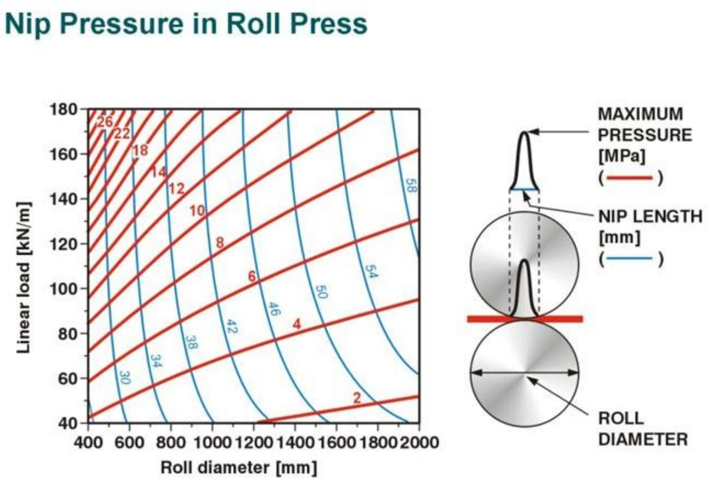


Figure 4 Nip pressure in roll press (KnowPap 7.0 2005c)

Water removal from thin paper grades depends mainly on the linear pressure level. It does not take long for the water to reach the felt. However, the first nip should be double-felted, if the machine speed exceeds 1000-1100 m/min. With a shoe press higher dryness can be reached than with roll nip due to the longer time for water removal from the web. In addition to this, the lower maximum pressure in the nip allows the usage of higher linear loads. (KnowPap 7.0 2005c)

In the production of thick grades (e.g. board), there is no time for the water to flow off the web, which means that the nip residence time should be extended. For this reason, board machines and pulp drying machines in particular will often consist of belt-assisted nips, with nips as long as 250 mm. (KnowPap 7.0 2005c)

Shoe press

The shoe press, (Figure 5,) is composed of a variable-crown counter roll withstanding high linear loads, one or two felts, and a belt or mat equipped with a hydrostatic or hydrodynamic loading system. The loading shoes applied to first presses were merely hydrodynamic, which limited the selection of pressing profile in the web's running direction. Subsequent extended nip designs were equipped with a closed, tube-like belt, which resisted dirt well and did not allow any oil to escape into the environment. These types of belt edges become more stressed, shortening its service life. (KnowPap 7.0 2005b)

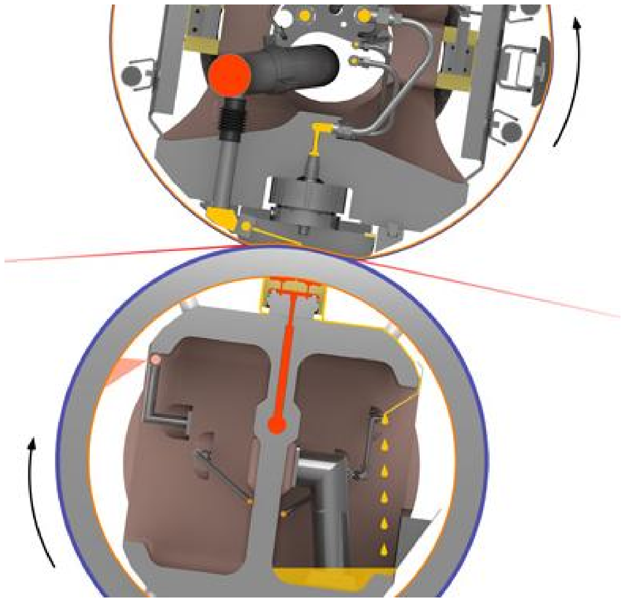


Figure 5 Shoe press nip structure (KnowPap 7.0 2005b)

Linear loads used in shoe nip presses are approximately 1000 kN/m (max 1500 kN/m), which is a multiple loading compared to roll presses. The corresponding nip length is from approximately 200 to 300 mm. By means of combining a hydrostatic and hydrodynamic loading shoe (to form a “hybrid shoe"), loading can be increased towards the end of the pressing period, leading to the formation of a pressure pulse that resembles a roll nip. Then the pressure can be rapidly decreased to reduce rewetting more than would be with a hydrodynamic loading system. (KnowPap 7.0 2005b)

Shoe nip presses can be equipped with one or two felts. The double-felted structures are used in locations where water amounts are large and the pressing process is clearly flow-controlled. Typical locations of this type are the first presses of the board machine. Single-felted presses are used in the last press position both in both board and paper machines. By using one felt, excessive rewetting is avoided and the other side of the paper is smoother. The nip lengths are the same for both types. (KnowPap 7.0 2005b)

1.4.4.4.3 Machine speed

Machine speed will affect the web's nip residence time, which is an important variable for flow-limited webs in particular. Increased speeds will reduce the dry content after the press, which is compensated for, if possible, by increasing linear pressures. The higher the dry content is after the press, the better the runnability at the drying section. Increasing machine speeds leave less time for conditioning of press felts, thus resulting in a decreasing use of lubrication water. Often the fourth press is run even without any felt conditioning (no water and suctions). The purpose is to run felts as dry as possible to facilitate water removal into the felt. (KnowPap 7.0 2005c)

1.4.4.5 Improving nip dewatering

For nip to be as efficient as possible, in addition to higher loads and longer dwelling times, some other measures should also be considered. Optimizing the entire nip system is essential for maximizing press dewatering capability.

Nip dewatering can lead to improved press solids, a reduction in vacuum and improved press fabric life. Modern machines have proven that controlled nip dewatering versus strictly vacuum dewatering is an efficient way to improve press performance. Nip dewatering has some key components that must be present in order for the total nip system to work. Doctor blades, save-all pans, moisture monitoring equipment, and proper press fabric designs need to be in place to effectively nip dewater. This equipment allows for proper control of the nip system. (Buckman 2008)

The subject of nip dewatering is taking center stage in the North American marketplace. European papermakers have been using this dewatering principle very effectively for many years. Thought only to be possible on very intense press nips on high-speed graphics machines, it is now taking place on almost every grade of paper. The benefits include:

- Higher press solids
- Reduction in steam consumption
- Cleaner press fabrics
- Reduction in chemical usage for press fabric cleaning
- Reduced dependency on a vacuum
- Less drag and wear on the press fabric surface

Vacuum studies and press water balances conducted today will almost always tell the mill they do not have enough vacuum. Therefore, the press must be optimized using something other than increased vacuum capacity. The energy requirements for a vacuum pump also make this choice prohibitive. New machines and rebuilds are being sold with minimum vacuum in all press positions. This almost ensures that press dryness figures will only be met by optimizing the nip system. (Buckman 2008)

1.4.4.5.1 Optimizing the nip system

Nip dewatering requires several essential pieces to be effective:

- Proper press fabric design
- Proper nip venting (sleeve or roll)
- Proper doctoring
- Proper save-alls
- Proper vacuum control
- Proper water measurement equipment

1.4.4.5.2 Press fabric design

There are several press design concepts using endless press fabric technology that maximize nip dewatering from a press fabric point of view. Nip dewatering is all about flow and what direction the water tries to move in the press fabric. Maximizing straight through flow into the press nip, while minimizing transversal flow in the machine direction of the press fabric, results in high press solids. Press solids in excess of 52% have produced on a single nip shoe press with these types of press fabric designs producing uncoated wood free grades. (Buckman 2008)

Seam press fabrics offer less flexibility in design because of the solid monofilament construction. There have been development in weaving techniques over the last years that lower the mid nip caliper of a seamed design. This in conjunction with non-woven materials allows for better nip dewatering than conventionally woven seam designs. It is important to remember that nip dewatering can also be achieved with a seamed design. Press solids after the press section have been above 52% on packaging machines using solid monofilament constructions. (Buckman 2008)

1.4.4.5.3 Roll and sleeve interaction

Properly designed roll covers and/or sleeves are essential to optimizing the nip. Press suction rolls on some presses exceed 40% open area with blind drilled/grooved cover designs. These kinds of roll cover designs have improved press solids in some cases by more than 1%. Sleeve designs with grooves have added water handling capacity to allow a good flow in the nip. Optimizing the roll and sleeve is essential to optimizing the nip's effectiveness to produce the highest dry content. (Buckman 2008)

1.4.4.5.4 Save-alls, wipes and doctors

After the nip is saturated and intense dewatering begins to take place, the nip must be equipped to remove this water. The roll surfaces and sleeve surfaces must be doctored effectively to prevent rewet and uneven moisture profile. The water in the grooves must be removed effectively to maintain the capacity of the grooves to accept the maximum amount of water as the sleeve or roll returns to the nip. The location of the pans is critical to collecting the water expressed on the outgoing side of the nip. Modern press concepts have pans that are placed only millimeters from the outgoing side and only millimeters above the press fabric, ensuring that no water escapes by the pan. The location of save-alls and proper doctoring have led to an increase in dry content of more than 3% on some press sections. (Buckman 2008)

1.4.4.5.5 Vacuum control

To optimize nip dewatering it is necessary to control vacuum levels. There should be valve settings that can change the vacuum levels on the uhle boxes to ensure maximum dewatering. This can also allow a faster break in the press fabric because it will allow the fabric to compact in the nip with the aid of additional water in the press fabric. This is essential to helping the press fabric reach its saturation point, which begins the nip dewatering process. Then the vacuum levels can be managed at that point to allow for maximum total water removal in the nip. It may be found that a certain level of vacuum dewatering combined with nip dewatering would lead to a higher total dewatering than simply dewatering exclusively in the nip. Also, in high water load positions such as the suction pickup roll, the water level in the nip may be too high for the size of the save-alls. The vacuum level would be critical to maintain a split of water removal that best fits the machine. (Buckman 2008)

1.4.4.5.6 Water measurement system

To truly understand the behavior in the press nip, the equation of total water removed less total water added must be known. Many applications do not have the capability to measure total nip flows. It is essential to measure, graph and optimize water management in the nip. These measurements can allow making informed decisions on the vacuum level, performance of the press fabric, startup curve of newly installed clothing and so on. A water measurement system is expensive but the payback period in production improvement, energy use, and press fabric evaluation should help justify such an expense. (Buckman 2008)

1.5 Hydronip

Hydronip is based on the patent for “PRESSING APPARATUS FOR A PAPER- OR BOARD-MAKING MACHINE FOR REMOVING FLUIDS FROM A WEB BY PRESSING, AND A METHOD FOR TREATING A WEB IN A PAPER- OR BOARD-MAKING MACHINE”. The object of the invention is to provide an improved pressing apparatus for a paper- or board-making machine and an improved method for treating a web in a paper- or board-making machine for removing fluids from a web by pressing, wherein the dewatering efficiency is improved with a simple structural constitution of the pressing apparatus and simple control thereof. (Pihko & Savela 2007)

1.5.1 Function

The general function of the Hydronip, (Figure 6,) is illustrated in as follows. The pressing apparatus comprises at least one belt which guides the web, wherein the belt is impervious to fluids and forms an endless loop. At least one nip is provided, which is formed between a press roll and a pressure means, and the guided web is arranged to pass through the nip. The pressure means comprises at least one pressure chamber containing a pressure medium and extending along the length of the nip in the web moving direction so that the pressure medium has direct contact with the belt. The pressure chamber has a pressure-operated sealing member which cooperates with the belt. The sealing operating pressure is adjusted in accordance with the pressure acting in the pressure chamber. (Pihko & Savela 2007)

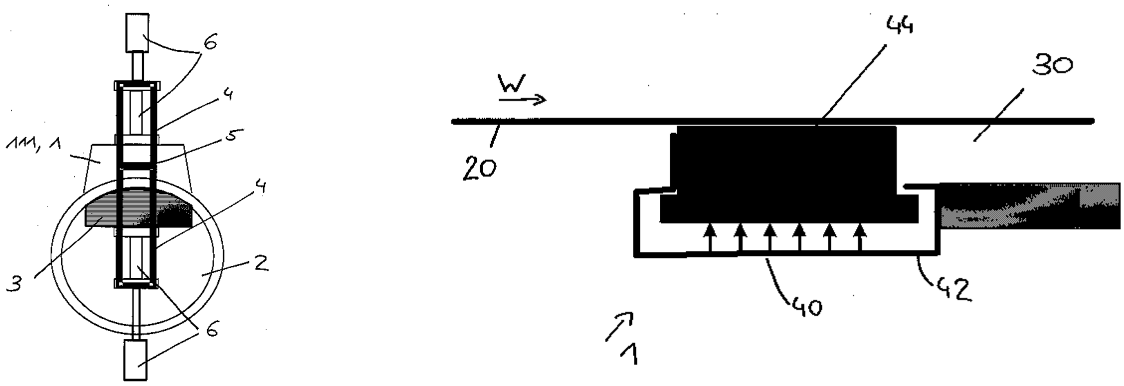


Figure 6 Hydronip general function. (Pihko & Savela 2007)

1.5.1.1 Sealing member

The sealing member is adapted to act in accordance with the rising pressure of the pressure medium in the pressure chamber in order to increase the pressure acting on the belt. Figure 7 presents an edge portion of the pressure chamber and a pressure operated sealing member.

This improves the dewatering efficiency of the pressing apparatus arrangement. The pressure medium in the pressure chamber cooperates with the belt, i.e. has direct contact with the belt. A predetermined pressing pressure is maintained only by the pressure in the chamber. As a result, the structure of the whole pressing apparatus including the pressure chamber is simplified because no further means for pressing are required. The sealing between the belt and the pressure chamber is carried out using an adjustable gap between the belt and the pressure means. This increases the range of pressure from very low pressures to high pressures in order to avoid heavy leakage of the pressure medium. The lubrication between the belt and the pressure means may be achieved by the pressure medium in order to reduce wear of the corresponding contact portions between the belt and the pressure means (particularly the pressure-operated sealing member). (Pihko & Savela 2007)

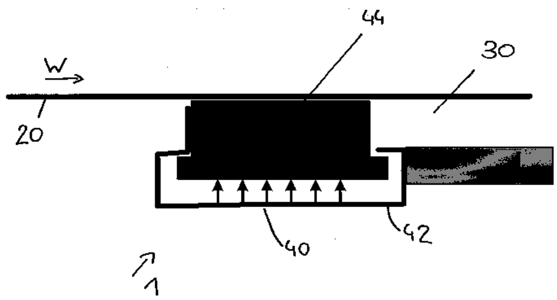


Figure 7 Edge portion of a pressure chamber of a pressure means with a pressure-operated sealing member. (Pihko & Savela 2007)

1.5.1.2 Belt

The belt of the pressing apparatus consists of one metal, synthetic, and ceramic material or various different combinations of at least two of these materials. Where the belt material is made of metals, synthetics and/or ceramics, a corresponding hardness, durability, and heat transfer capacity of the belt is achieved. Such materials exhibit only small deterioration phenomenon during the operation of the belt, so that the pressing apparatus has good performance characteristics throughout its durability. In addition, the heat transfer capacity of the belt supports the dewatering effect of the web while pressing against the belt during the passage of the web through the nip. (Pihko & Savela 2007)

The belt may have a smooth surface and/or an embossed surface. Also, the belt may be heated by an auxiliary heating means which is located upstream of the nip in the web moving direction, or is heated by the pressure medium itself, which is heated and has direct contact with the belt in the pressure means. Where the belt is used to heat the web, a lot of heat is transferred from the belt to the web. Due to the thermal conductivity of the belt, web dryness and smoothness is increased. Also due to the heated belt, the water in the web is transferred to the felt. A continuous steam pressure and vapor flow from the web to the felt prevents the occurrence of rewetting water flows from the felt to the web after the nip in the web moving direction, where the pressure caused by the nip ends and expansion of the web and felt occurs. This will increase the dryness of the web after the nip. The nip is an extended nip which extends in the moving direction of the web up to 150 cm, or more preferably up to 70 cm. (Pihko & Savela 2007)

1.5.1.3 Pressure means

The pressure means of the pressing apparatus comprises different pressure chambers which are successively arranged along the length of the nip in the web moving direction and in which different pressures and/or temperatures act as illustrated in Figure 8. The respective pressures of at least part of the pressure chambers are adjusted by controlling sealing leakage flow from one pressure chamber to another pressure chamber with a different pressure/temperature. In one pressure chamber there is a higher pressure than in another pressure chamber. With the above arrangements, in which several pressure chambers are successively arranged in the web moving direction, the respective pressure chambers may be provided with sealing elements between the chambers. These sealing elements may also be adjustable by pressure acting in the respective chamber. The sealing leakage flow from one pressure chamber to another pressure chamber may be controlled. This enables the use of a longer nip (an elongated nip) and therefore a better shape of the pressure curve over the nip. That is, the pressures in the chambers increase in the web moving direction so that a pressure impulse on the guided web may be adjusted smoothly. Further, web rewetting decreases between the chambers in which the pressures are relatively low. Higher heat transfer effects in the extended nip and higher dryness of the web after passing through the nip are achieved. Additionally or alternatively to the different pressures in the different pressing chambers, different temperatures may be provided with the pressure medium. For example, when a high temperature pressure medium is used in the end pressure chamber(s) in the web moving direction which heats the belt, the web drying rate of the belt is improved so that a higher dryness and smoothness of the web can be achieved. The sealing operating pressure is set to lock the pressure-operated sealing member in a definite position. This further reduces the control effort but allows easy access to the belt when the press section is switched off. (Pihko & Savela 2007)

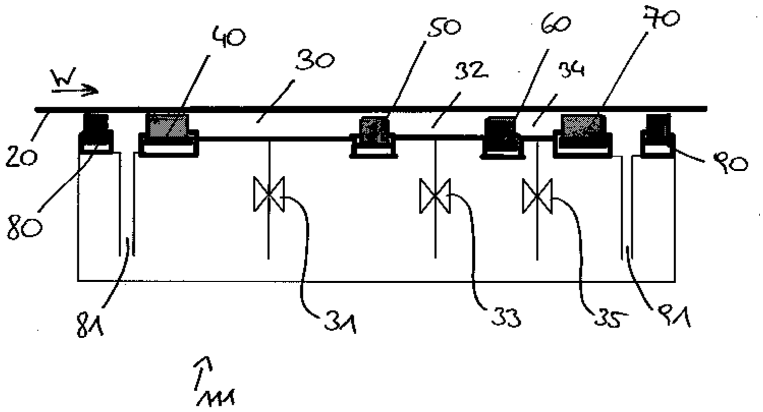


Figure 8 Pressure chamber of a pressure means with several chambers and pressure- operated sealing members. (Pihko Riku & Savela Jyrki, 2007)

The sealing member slidably contacts the belt on the rear side of the belt, on which rear side the web is not guided. This definition includes an arrangement that the pressure medium within the pressure chamber provides a finite lubrication film between the pressure-adjusted sealing member and the rear side of the belt (i.e. sliding occurs on a thin liquid film). The rear side of the belt is on the side opposite to the side on which the web is guided through the nip. This lubrication effect decreases the friction forces between the sealing and the belt, and therefore the wear resistance is increased. (Pihko & Savela 2007)

The nip is an extended nip between the press roll and the pressure means in the web moving direction. Edge seals seal the pressure means against the belt at the outer edges of the pressure means in order to avoid the escape of the pressure medium to the ambient outside pressure means. Pressure means are adapted to press against the belt towards the press roll in arbitrary radial directions. And, the pressure medium in the pressure chambers is pressed against the belt so that the fluids in the web are transferred to at least one felt and/or to the press roll. (Pihko & Savela 2007)

1.5.1.4 Nip geometry

On at least one side of the guided web, a felt is arranged to travel along the nip. The felt is detached from the web immediately after the web has passed through the nip along the web moving direction in order to avoid rewetting of the web after passing through the nip. The detached felt may be guided downwards from the belt after passing through the nip so as to quickly remove any collected water from the vicinity of the nip. According to the above preferred process, the belt is immediately detached from the felt after the belt has passed through the nip. This is to minimize web rewetting after the nip. Where the belt is underneath the felt, an opening gap (i.e. a gap after the web has passed through the nip) between the belt and felt helps to lead water flow coming from the nip away from the belt because this opening gap creates a negative pressure. This means the rewetting of the web guided on the felt is minimized. It is possible to arrange a save-all means after the nip in the web moving direction. The save-all means is able to collect the water coming from the nip through the felt. (Pihko & Savela 2007)

Figure 9 shows examples for detaching the web W (see broken line in the figures) from the felt 100 immediately after the web W has passed through the press nip so that rewetting of the web after passing through the nip can be limited or even avoided. According to the pressing arrangement with the belt 20, the felt 100 and the pressing apparatus (i.e. the loading chamber 1 or 111 and the press roll 2) along the press nip, both the felt 100 and the belt 20 are guided downwards after passing through the nip along the web moving direction. This pressing arrangement (a so-called "downwards-directed" pressing arrangement of the belt 20 and the felt 100) ensures that the belt 20 still guides the web W after the press nip, wherein the web W is smoothly detached from the felt 100. In order to further improve the water removal from the web by pressing, it is preferable to use increasing pressure and/or temperature levels towards the end of the press nip(s) formed by the pressure means having at least one pressure chamber, the belt and the press roll as mentioned in the above embodiments. The last nip(s) of a press section should have higher pressure levels compared to the previous nips in order to efficiently remove water from the web. It is also preferable to use higher temperatures towards the end of the respective press nip along the web moving direction. This provides a high dryness rate of the web towards the end of the nip. (Pihko & Savela 2007)

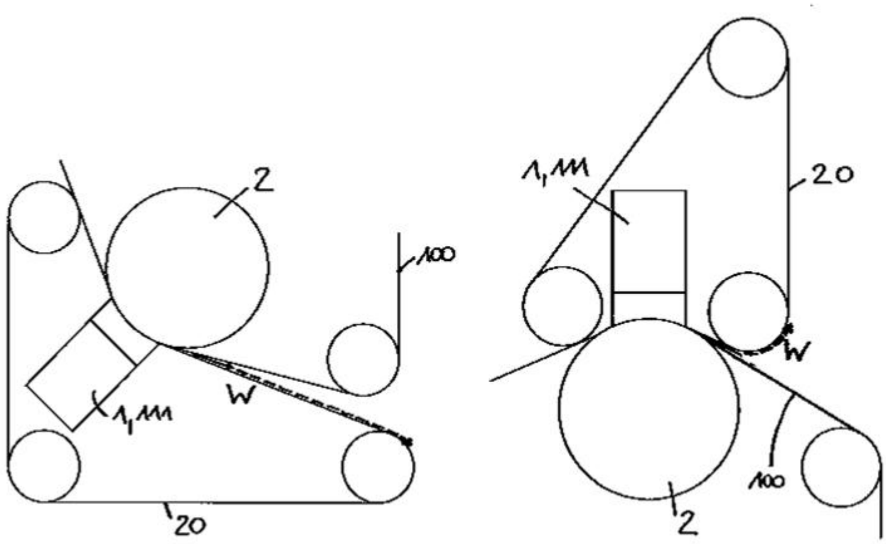


Figure 9 Detaching the web after the web has passed through the nip (Pihko & Savela 2007)

1.5.2 Comparison of different dewatering methods

In the following chapters some advantages and disadvantages are compared between different pressing methods that are or can be used in a press section. As is known, shoe press technology is the most efficient solution for dewatering by pressing. Even though it is an effective and efficient method it has some downsides that have to be taken into consideration. Another method that could be used in a press section is Condebelt. Also this method has its advantages and disadvantages. The last pressing method in the comparison is Hydronip.

1.5.2.1 SymBelt/SymBelt mini shoe

As already previously stated SymBelt shoe press technology has gained in the last few decades its position as the most efficient pressing method used in press sections. Since it has been in use already for a long time and it is proven technology that can be easily applied to new machines and rebuilds. Some other advantages and disadvantages with shoe pressing are listed in the following. (Onnela 2009a)

Shoe pressing benefits for printing and writing grades

- Higher production capacity

- Better runnability thanks to increased dry content
- Lower draw
- Possibilities for bulk preservation
- Decreased web two-sidedness and improved printability.

Additional benefits for containerboard and cartonboard grades:

- Improved density-related strength properties like burst and SCT
- Increased bulk in the final product due to gentle dewatering and low specific pressure on the fiber network
- Improved bending stiffness properties.

Even though shoe press technology is well functioning and efficient there are some disadvantages that can be developed and enhanced.

- Belt durability is a key factor. Since the belt is made of polyurethane it is vulnerable for inner and ambient impurities which can shorten its lifecycle notably and even without impurities it is a wearing part that can fail without warning.
- SymBelt construction is quite complex and there are quite many special parts.

1.5.2.2 Condebelt

Condebelt is a method to dry paper and board. Initially, the process was simply intended to improve the drying of paper and board and it was only later that the big increases in strength properties became evident. The Condebelt drying process is now used in drying sections but it could be utilized also in the press section. In the Condebelt drying process paper is dried between two steel belts, as shown in Figure 10. (Lehtinen 1998)

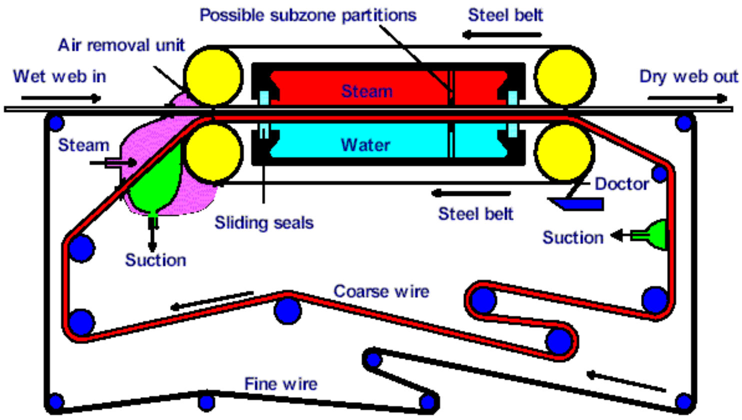


Figure 10 Condebelt drying process (Lehtinen 1998)

The web travels between a steam-heated upper and a water-cooled lower steel belt. The hot upper belt evaporates the moisture in the web and which again will condense on the cooled lower belt. Water is carried away by the steel belt and coarse wire. The fine wire between the web and the coarse wire reduces wire marking on the backside. The web surface against the hot belt becomes very smooth. (Lehtinen 1998)

If Condebelt were used in a press section, there would be some advantages and disadvantages that are listed below.

- Advantages: Long nip, high loads
- Disadvantages: Expensive and complex structure, sealing system is still challenging

1.5.2.3 Hydronip

Hydronip combines the most essential features of both SymBelt shoe pressing technology and Condebelt drying technology. Therefore it also has all the good qualities from both of these drying technologies. Compared to SymBelt and Condebelt, Hydronip has a few advantages which are listed below. (Pihko & Savela 2007)

- Compared to SymBelt, it does not have a polyurethane belt, which is the most vulnerable part in SymBelt technology. Instead it has a metal belt which is more durable and already proven technology throughout Condebelt.

- Compared to these other drying methods it is simpler.

Hydronip is still in the early stage of development so it has some unsolved issues that have to be taken into account:

- Sealing function
- Construction
- Durability against paper or board wads

1.5.3 Nipload impulse curves and comparison of existing applications

As earlier stated, what happens in the nip is the key for sufficient water removal. The pressure distribution caused by the load applied to the nip is very important and affects greatly the paper or board properties and water removal. The pressure distribution in the nip can also be described with nipload impulse curves. The most typical nip structures with nipload impulse curves, their advantages and disadvantages are discussed more precisely next.

1.5.3.1 Dynamically loaded shoe nip

Figure 11 shows the typical pressure curve of the hydrostatic press. The lubrication pockets in the shoe cause a pressure plateau acting similar to the static press. The hydrodynamic shoe allows a smaller maximum pressure in the nip with identical line force and shoe length, contributing essentially to the densification of the web. (Wasserman and Estermann 2002)

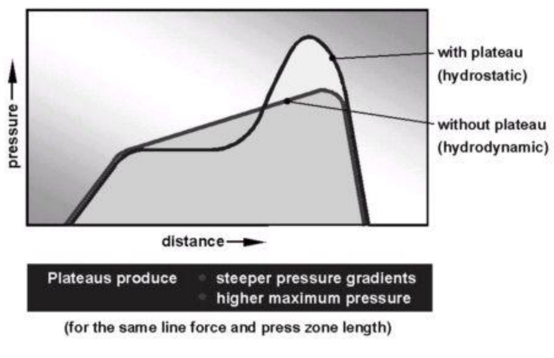


Figure 11 Hydrostatic and hydrodynamic pressure curve (Wasserman and Estermann 2002)

As the hydrodynamic shoe creates an evenly rising pressure curve, it also causes a lot of shear forces since there is no oil pocket to reduce, as Figure 12 illustrates. This produces many unwanted problems which are listed below.

- Increased power consumption
- Higher shoe and belt temperatures
- Inferior high-speed runnability
- Increased friction forces on the belt surface
- Increased sensitivity to paper wads due to impaired lubrication.

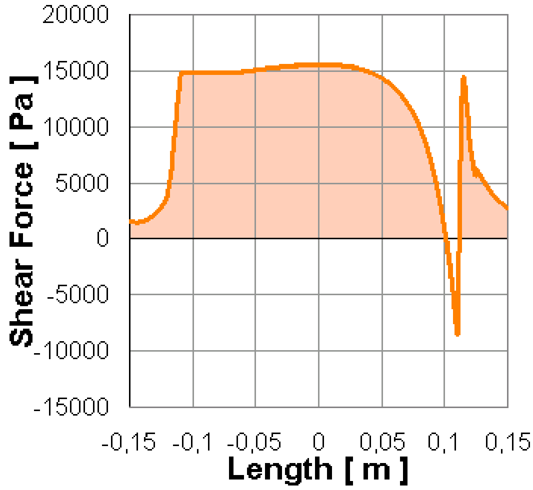


Figure 12 Shear forces in hydrodynamic shoe (Onnela 2009b)

1.5.3.2 Hybrid loaded shoe nip (SymBelt)

The shape of the hybrid loaded press shoe is designed to minimize the amount of friction generated, i.e. the amount of operating power required, and to deliver the desired nip pressure and nip profile. The press shoe employs a hybrid design that combines the best features of hydrostatic and hydrodynamic shoes. The operation is based on three machine-direction pressure zones, which are illustrated in Figure 13. (Onnela 2009b)

Dewatering stages in shoe pressing:

1. Slow pressure buildup for gentle dewatering
2. Stable dwell zone for high dewatering capacity
3. Peak pressure zone for maximum dryness.

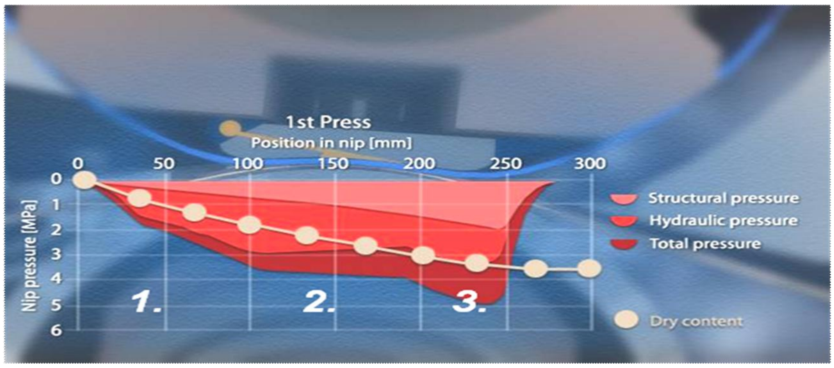


Figure 13 Pressure zones in hybrid shoe (Onnela 2009b)

The length of the press shoe, and therefore also the pressure curve, can be varied, as Figure 14 shows. Press shoe loads can be up to 1500 kN/m. (Onnela 2009b)

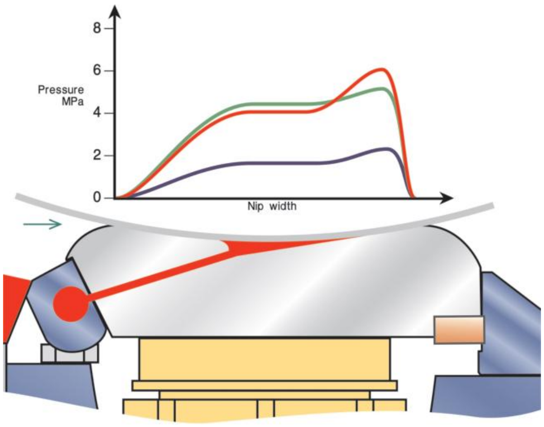


Figure 14 Shoe length and pressure curve can be varied (Onnela 2009b)

Oil is fed through the hydrostatic part, the pocket, in the center of the press shoe. The pressure curves of the nip can also be controlled with the length of the pocket as shown in Figure 15. A short oil pocket creates a long and stable pressure buildup with a short stable dwell zone compared to quite quick pressure buildup and a long stable dwell zone with long oil pocket. (Onnela 2009b)

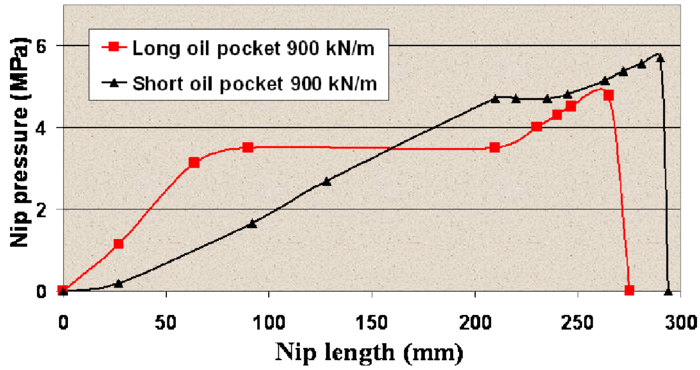


Figure 15 Comparison of short and long pocket (Onnela 2009b)

With optimal pocket length many benefits can be achieved:

- Reduced power consumption
- Lower shoe and belt temperatures
- Improved high-speed runnability
- Reduced friction forces on the belt surface
- Reduced sensitivity to paper wads due to improved lubrication.

The pocket results in very low shear stress due to the thick oil film and that leads to a minimized power loss. In Figure 16, a hydrodynamic and hybrid shoe shear stress distributions have been compared. This shows the advantage of having an oil pocket and the effect of reduced shear forces. (Onnela 2009b)

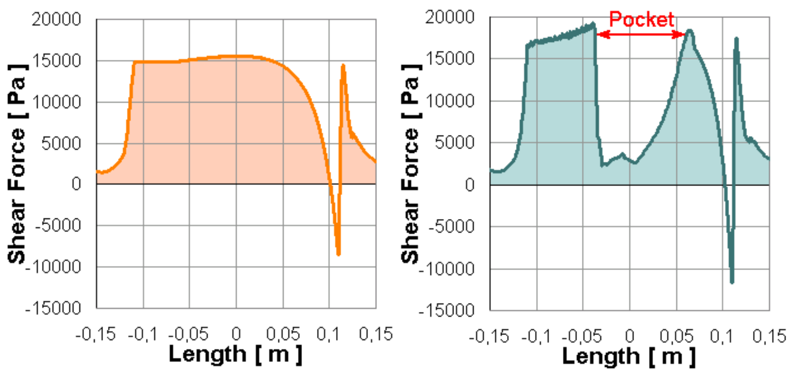


Figure 16 Hydrodynamic and hybrid shoe (Onnela 2009b)

The same issue can be seen from the relative power consumption. The Figure 17 illustrates the relative power consumption at 1500 m/min machine speed for a hydrodynamic and hybrid shoe. The hydrostatic oil pocket will decrease the total shear forces, which is beneficial for power consumption, shoe temperature, and belt life. (Onnela 2009b)

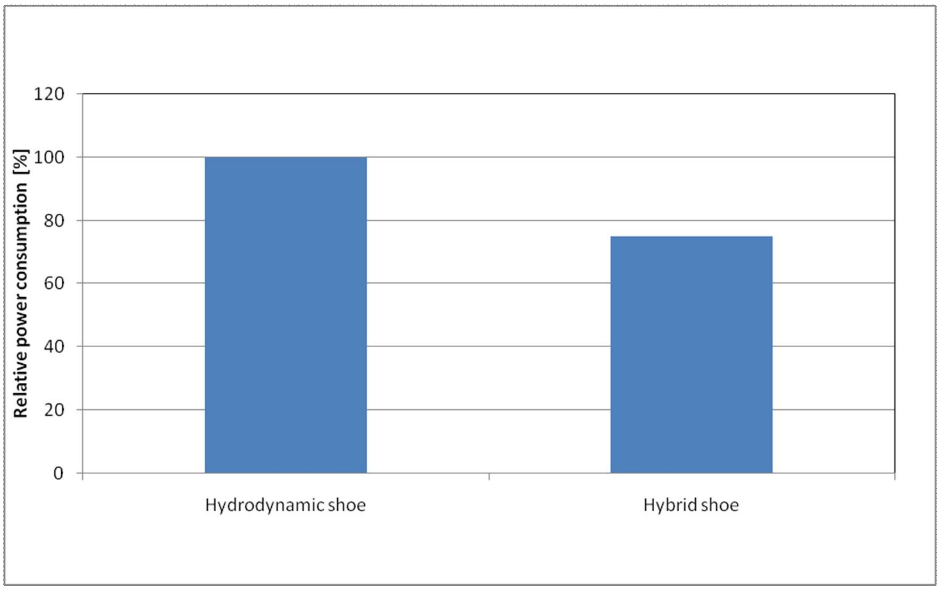


Figure 17 Relative power consumption for hydrodynamic and hybrid shoe (Onnela 2009b)

1.5.3.3 Hybrid loaded shoe nip with multiple pressure levels (Hydronip)

Hydronip emphasizes the best properties of SymBelt shoe press technology. Therefore the previously described features with the SymBelt shoe can also be applied to Hydronip. Hydronip also has some other benefits compared to SymBelt shoe nips. The maximum loads can be increased from the typical shoe press loads. According to Korolainen's study, with today's load joint technology, maximum loads can be up to 1600 kN/m with wide paper and board machines. With narrow paper and board machines the load can be 3200 kN/m. (Korolainen 2011)

The other limiting factor is the counter roll. The maximum diameter of the Sym roll with today's technology is 1700 mm. The maximum load with this kind of roll could be as much as 1500 kN/m with wide paper and board machines. With narrow paper and board machines the load can be 3000 kN/m. (Korolainen 2011)

Another benefit is that the Hydronip shoe nip length can be increased many times compared to the SymBelt shoe nip width, which can be over 300 mm. The construction of Hydronip is still not totally finished, which has to be taken into consideration when comparing different technologies.

1.5.3.3.1 Hydronip test runs with MTS

Hydronip test runs were carried out with MTS (Material Test System) testing equipment. It is universal test equipment for testing different materials. In this case it was modified to correspond with paper and board machine surroundings. In addition, the samples were made especially to correspond to paper and board samples. For analysis, precision scales and laboratory measuring were used. (Pihko 2011)

The target for the tests was to study the dryness content of relatively thick carton samples after different pressing dewatering measures. Samples were taken at a dryness level of 45% and they were moistened to a dryness level of about 35%. The root length of the press shoe pulse was about 38 ms. This corresponds to a shoe length of 500 mm at a speed of 800 m/min. The samples were heated with a metal belt at temperatures of 40°C, 80°C, 90°C, and 100°C. (Pihko 2011)

Samples were kept 0.5 to 1 seconds against the metal belt before detaching. 0.5 seconds corresponds to the web being in contact with metal belt at 4 meters with a speed of 500 m/min and 1 second corresponds with the web in contact for 8 meters with a speed of 1000 m/min. The dry content of samples was determined after nip pulses. A Tamfelt Ecostar felt and a smooth warmed metal pressure mean were used as contact surfaces. The results are presented in Figure 18. (Pihko 2011)

- A basic pressure impulse with a 250 mm long shoe with nip pressure (6MPa) produces a dry content of 46% with one felt and 44% with two felted constructions. When one felted construction is impacted with a 100°C metal belt, it produces a dry content of 49%.
- A Hydronip pressure impulse with a 500 mm long shoe with nip pressure (6MPa) produces a dry content of 49% with one felt and 48% with two felted constructions. When

one felted construction is impacted with a 100°C metal belt, it produces a dry content of 51%.

- A Hydronip pressure impulse with a 1000 mm long shoe with nip pressure (6MPa) produces a dry content of 51% with one felt and 49% with two felted constructions. When one felted construction is impacted with a 100°C metal belt, it produces a dry content of 57%.
- A Hydronip pressure impulse with a 2000 mm long shoe with nip pressure (6MPa) produces a dry content of 53% with one felt and 51% with two felted constructions. When one felted construction is impacted with a 100°C metal belt it produces a dry content of 59%.

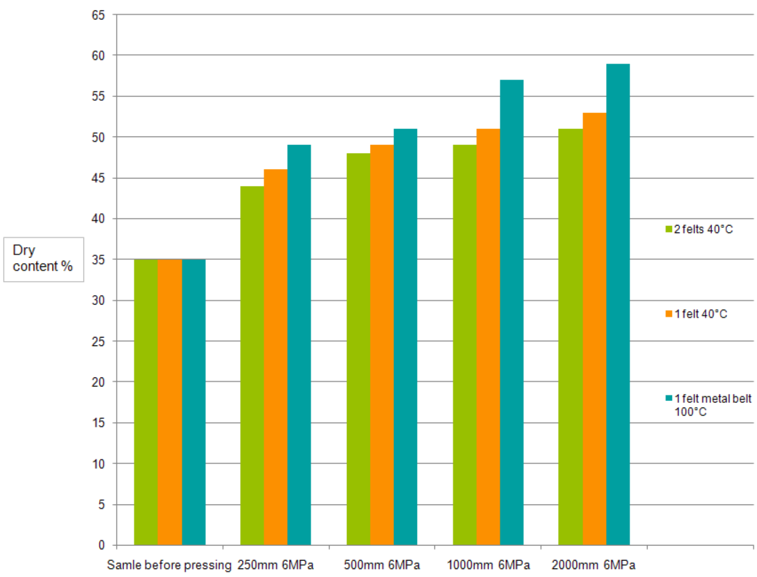


Figure 18 MTS test run results (Pihko 2011)

1.5.4 Comparison of nip structure effects on dryness development

As the SymBelt shoe nip and Hydronip have almost same types of nip profiles they can be observed as a shoe press in the following demonstrations. Figure 19 shows the principle graph for different nip profiles. The roll nip dwell zone is very short and the maximum pressure in the nip rises as the load is increased from 70 kN/m to 130 kN/m. During drainage, steep pressure gradients result in high flow velocities, possibly causing fiber displacements in the form of crushing. When compared to shoe nip, the maximum pressure stays at a relatively low level, and the dwell zone lengthens notably, which gives the water more time to move from the web and provides a gentle pressing maintaining bulk. Also with a gradually ascending pressure profile, the web structure in the z-direction shows more uniform densification over the web thickness. (Pirinen 2010)

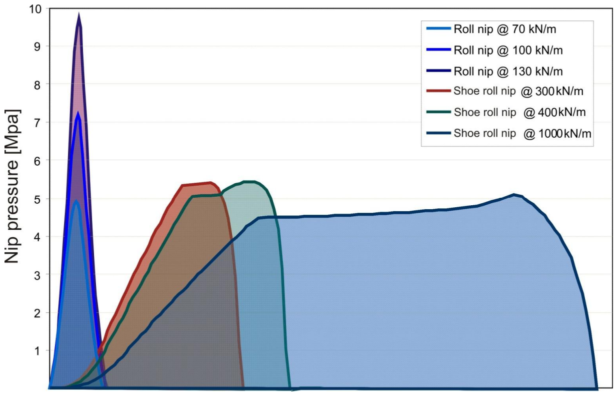


Figure 19 Principle graph of nip pressure profiles (Pirinen 2010)

Figure 20 illustrates the dryness development through a press section. As can be seen the dryness level increases by the end of the press section, which means that the first nips merely affect the paper or board web properties and the dewatering becomes more effective in the following nips. (Pirinen 2010)

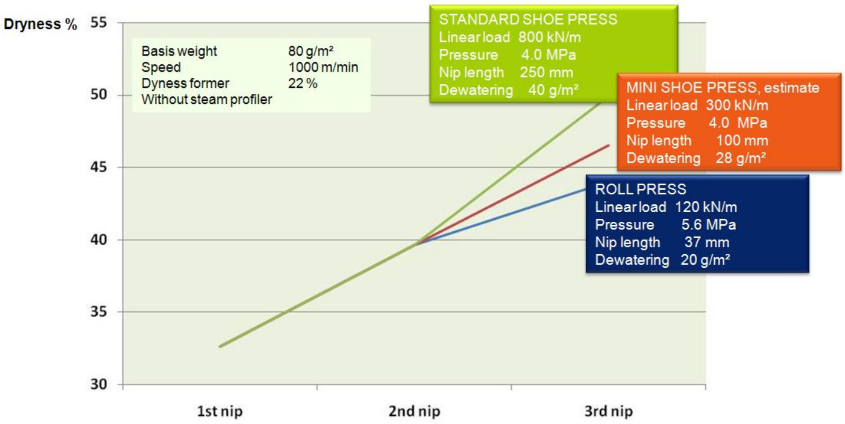


Figure 20 Dryness development through press (Pirinen 2010)

Press runnability is improved via a dryness increase with the shoe press compared to the roll press, as Figure 21 illustrates. Depending on the machine speed, the dryness improvement can be from 5% to approximately 8%. Also, the higher dryness leads to higher production capacity, possibilities for bulk preservation, lower draw, decreased web two-sidedness, and improved printability. It also provides improved density-related strength properties such as burst and SCT as well as improved bending stiffness properties. (Onnela 2009b)

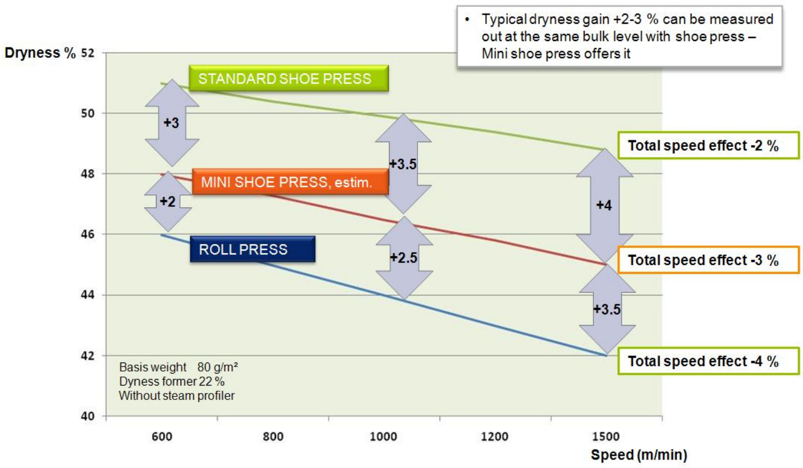


Figure 21 Dryness after press section (Onnela 2009b)

1.5.5 Comparison of the cost effects of roll and shoe press rebuilds

The cost effects of different press section solutions are compared next. Figure 22 illustrates the break even points for shoe presses compared to roll presses. The rebuild for a standard shoe press requires a shutdown of approximately 10 days. As machine speed can be increased by 20%, the added production covers the shutdown costs so that the cumulative profit loss because of the shutdown will be covered in about six months. (Pirinen 2010)

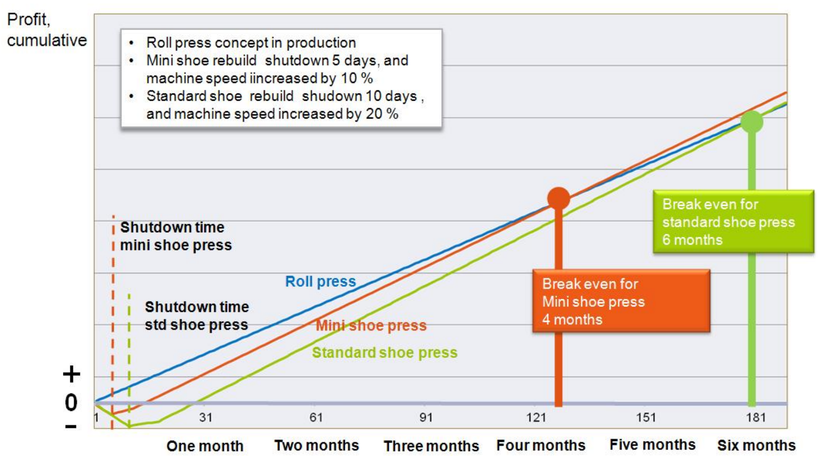


Figure 22 Break even comparison (Pirinen 2010)

The payback on the investment due to the increased production is illustrated in Figure 23. (Pirinen 2010)

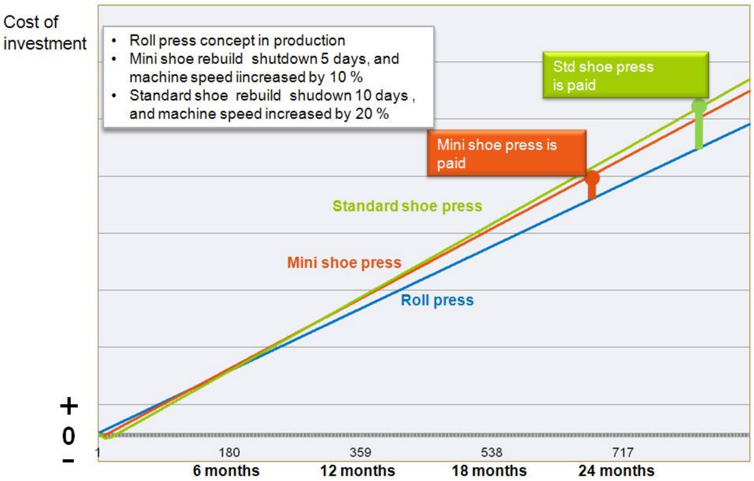


Figure 23 Payback on the investment (Pirinen 2010)

In the overall view of different kinds of press section alternatives presented in Figure 24, the solutions are compared according to some key facts. In this case a paper machine for fine paper is used as the reference. The linear load in roll a press is approximately 120 -130 kN/m, whereas in a shoe press it can be from 600 -1500 kN/m. The dry content can be increased by 3 -6% in a shoe press. A production increase can be even 12 -24% in a shoe press compared to a roll press. The cost estimation for shoe press investment is approximately EUR 5.5 -7 million, and if a Mini shoe press is considered, the costs can be from EUR 2 -5 million. (Pirinen 2010)

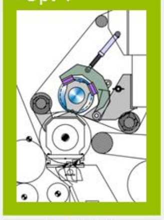
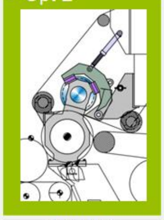
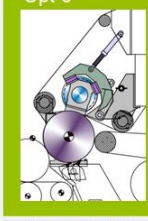
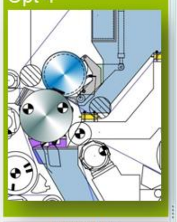
Case fine paper machine, Width 5,500 mm, 1,100 m/min	Roll press	Mini shoe press – Opt 1 	Mini shoe press – Opt 2 	Mini shoe press – Opt 3 	Std shoe press – Opt 4 
Linear load (kN/m)	120-130	200 kN/m	350 kN/m	Up to 600 kN/m	600-1500
Dry content increase	Ref.	Approx. 1 – 1.5 %	Approx 2 %	Approx. 2 – 3 %	Approx. 3 - 6 %
Production increase or steam cons decrease		4 – 6 %	6 – 8 %	8 – 12 %	12 – 24 %
Press / Shoe press roll diameter	700-900	1095	1095	1095	1250-1595
Counter roll	Solid roll	Existing (new drive)	Existing (new bearing housing, new drive)	New SolidL roll	New SymZLC roll package
Estimated total budget Investment cost	.	2 – 2.5 MEUR	2.5 – 3.5 MEUR	4 – 5 MEUR	5,.5 – 7 MEUR

Figure 24 Shoe press alternatives (Pirinen 2010)

1.5.6 Profitability comparison of a shoe press and Hydronip rebuild

The comparison of a shoe press against Hydronip is relatively difficult since there are no acute rebuild specifications and cost estimations yet. Even then it can be achieved with some simplifications and estimations.

Since shoe press deliveries have been part of Metso Paper's product scope for a long time the rebuild specification and cost estimation can be done exactly. In the following, a rebuild delivery has been taken as the reference when compared to an estimated Hydronip rebuild. The press section rebuild concerns the third nip in a SymPress B type of press section. New parts included in the rebuild are shown in Figure 25 in blue. The existing machine was started up in 1995. The machine produces uncoated wood-free paper and the wire width is approximately 7000 mm. The machine speed is 1400 m/min. (Kairus 2009)

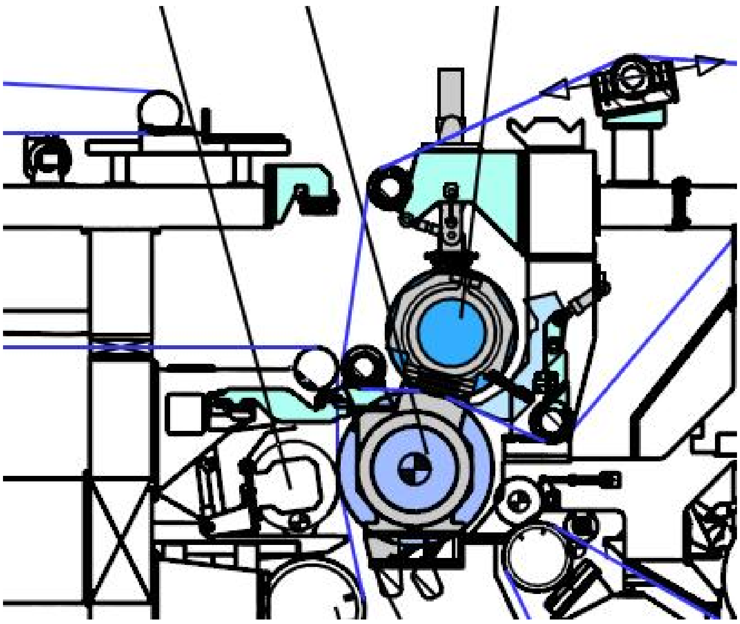


Figure 25 Shoe nip rebuild scope (Kairus 2009)

Delivery scope for SymBelt shoe press rebuild in this case includes:

- SymBelt roll, spare shoe and inside support
- SymZLC center roll with spare roll and drive for center roll
- Frame parts, moving devices, roll doctor and save-all for SymBelt roll

- Hydraulic center for SymBelt and SymZLC roll, Lubrication and controls
- Supervising, start up and spare parts

The total costs of this kind of rebuild would be from EUR 5 -7 million, as presented earlier. A SymBelt roll requires polyurethane belts that have a lifetime from a few months to a few years, depending on the paper or board grade involved. Belts are vulnerable to inner and ambient impurities and those may notably affect the belt life time. The total estimation for one year's use could be two to three belts. (Pirinen 2010)

The Hydronip structure is not yet fully developed and when it is compared to a typical shoe press investment some simplifications and estimations have to be made. If it is assumed that the rebuild for Hydronip would be similar to the previously described shoe press, the rebuild scope would include the following items:

- Hydronip and possible spare shoe
- SymZLC center roll with spare roll and drive for center roll
- Frame parts, moving devices, roll doctor and save-all for Hydronip roll
- Hydraulic center for Hydronip and SymZLC roll, Lubrication and controls
- Supervising, start up and spare parts

Hydronip metal belt total estimation for one year's use is one piece. Hydronip metal belts, on the other hand, may endure better against the inner and ambient impurities which may lead to much longer belt lifetimes. The endurance against paper/board wads can be higher because of the nonflexible structure compared to a polyurethane belt.

According to these estimations and simplifications, differences between component costs would be SymBelt roll costs compared to Hydronip costs and polyurethane belt costs compared to metal belt costs. Compared to a SymBelt roll, the Hydronip cost could be approximately the same. The metal belt costs would be approximately half of the polyurethane belt costs.

The dry content increase with SymBelt would be from 3% to 6% and, as earlier presented, the production increase or steam consumption decrease would be from 12% to 24%. According to Pihko's earlier research with Hydronip in this kind of position, the dry content increase could be approximately 5% more than when compared to SymBelt (Pihko 2011). If the metal belt is heated, the difference can be even more. Roughly estimated the production increase could be broadly twice as much as with SymBelt. (Pirinen 2010)

If it is presupposed, according to Pirinen's research, the shutdown for a Hydronip rebuild lasts the same 10 days as it does with a SymBelt rebuild, the break even for Hydronip would be under five months compared to six months with SymBelt. The payback on the investment in SymBelt is approximately 30 months. With the same estimations for Hydronip the payback on the investment would be approximately 24 months. (Pirinen 2010)

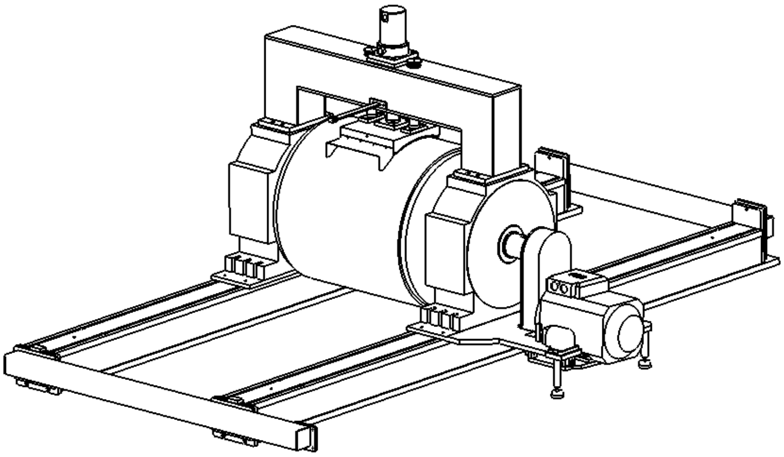
2 Test site requirements, design, implementation, and use

2.1 Objective for test site arrangement

As already stated earlier in the introduction, the main goal for this thesis is to build a functional test site for Hydronip which fulfills all the needed requirements and has all the needed information gathering devices. The goal is also to gather usable information about the nip structure in running conditions, about the seal function, and to test nip loading against paper or board wads.

2.2 Starting point and existing facilities

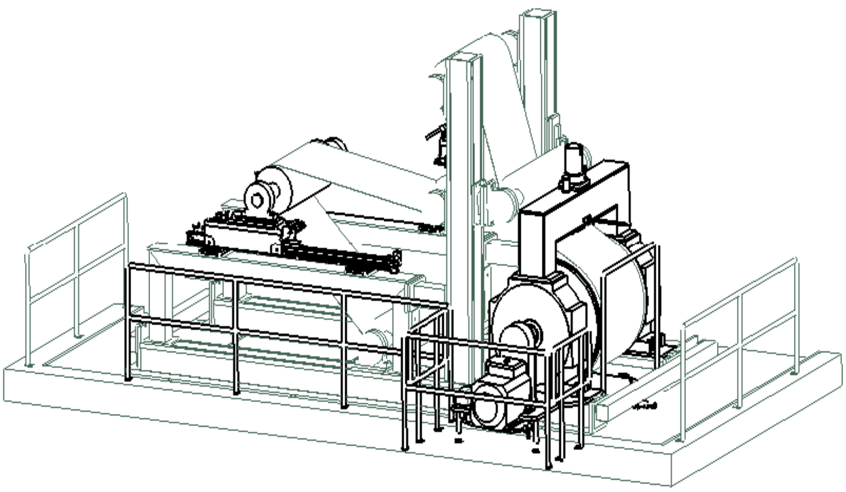
Test runs are carried out at the separate test site at the Technology Center Rautpohja. Test runs had been conducted already for Superhydronip at these facilities. Figure 26 introduces the Superhydronip assembly with its components. The aim then was to study press shoe lubrication with water and the sealing system of the shoe. The test arrangement and equipment included:



- Superhydronip assembly
- Hydrostatic shoe
- Hydrodynamic shoe
- Press roll D1200
- Press shoe
- Motor M3BP225 SMA B3 4P 37 kW, with vee belt gearing

Figure 26 Superhydronip assembly

Test runs for wire stretching and guide devices were also conducted at the same location. The test arrangement and equipment included the following components and the assembly is illustrated in Figure 27:



- Stretcher and guide test arrangement
- Lead rolls, five pieces D450
- Edge position sensor
  - Mounting tools
- Hydraulic stretcher

Figure 27 Stretcher and guide test arrangement

Both of these arrangements can be utilized for Hydronip. All the essential components can be utilized but some additional equipment and systems are needed to achieve all the required properties from the machine and to be able to collect all the necessary information.

2.3 Basic requirements for the design

Metso Paper's products are designed to be safe. This also includes test site arrangements and certain procedures have to be followed. Primarily known hazards are eliminated at the design stage. Whenever this is not possible, guards are placed around hazards or they are pointed out using warning signs. Operating and maintenance instructions provide further guidance with respect to hazard areas. (Hakala 2002)

The risk assessment is a base in all design processes. In this case the risk assessment and risk factor listing are combined to evaluate and indicate the risks and hazards that may occur during the Hydronip assembly and use.

Risk analysis

Risk analysis was performed as part of the risk management process for this project. The data was based on risk discussion workshops where potential issues and risks were identified.

The risk workshop was chaired by a small group of individuals from the various departmental functions. The participants were: project manager, safety manager, development manager, supervisors, and pilot plant manager, and the participants were collected together so as to cover every risk element from different perspectives. (Hakala 2002)

The outcome of the risk analysis was the creation or review of the risk register to identify and quantify risk elements for the project and their potential impacts. Given that risk management is a continuous and iterative process, the risk workshop members would regroup at regular intervals and at project milestones to review the risk register mitigation plans, make changes to it as appropriate, and, following those changes, re-run the risk model. By constantly monitoring risks these can be successfully mitigated, resulting in cost and schedule savings with a positive impact on the project. (Hakala 2002)

During the assembly and modification phase the following risks may occur:

- Dropping and tilting of objects while changing the metal belt
- Incision danger while working with the metal belt
- Sparks
- Tripping, slipping, and crashing
- Falling
- Unexpected starting
- Hand-operated machines

Risks that are originating from the machine or from test runs

- Crushing / trapping in
- Shearing
- Clinging in moving / rotating part / nip
- High-pressure liquid / gas jet, or the risk of ingress
- Contact with energized parts
- Eye damage
- Loss of hearing
- Flying of felt or metal belt pieces
- Control of the machine
- Electricity
- Hydraulics
- Pneumatics

The majority of the risks are taken into account by preparing extensive instructions and manuals for assembly, implementation, use, and service. People working with the machine have to become acquainted with the essential instructions and manuals. The main risks are minimized through the construction and safety equipment of the machine. Some risks are reduced by personal safety equipment that has to be used. Other risks can be managed with general cleanliness, good order, and correct working methods.

Risk factor listing

The risk factor listing was prepared according to the SFS-EN 1050 standard. The outcome of the risk factor listing includes risk elements and the explanation of those. It also includes examples and footnotes concerning those mentioned earlier. The risk factor listing consists of different categories that are presented below:

1. Mechanical risk factors
2. Risk factors due to electricity
3. Temperature related risks
4. Noise (due to work stage or surroundings)
5. Vibration (due to machine, device or working environment)
6. Radiation
7. Materials
8. Risks due to ignoring ergonomic principles
9. Risks due to machines used
10. Risks, hazards, and dangerous situations due to movement
11. Risks due to working place
12. Risks due to lifting
13. Risks due to lifting individuals

14. Mental risk factors

The risk factor listing presents risks more accurately. The risks are taken into account as described in risk analysis.

2.4 Basic functionality and layout of the Hydronip pilot machine

To be able to create an efficient and functioning test site a preliminary layout had to be created to outline what kinds of components, devices, and measuring equipment was needed. The basis for the layout design was the Hydronip patent and some rough sketches that were done earlier. Existing facilities also determined some limits because they were meant to be utilized as effectively as possible.

As the earlier test runs with Superhydronip were carried out by loading a press shoe lubricated with water against the mating roll, some additional equipment was needed to create the test scene for Hydronip. This was discussed in meetings to be sure that all the necessary functions and properties needed were covered.

In the Hydronip press solution the press shoe is pressed against the press roll which acts as a counter roll. A metal belt loop is located around the press shoe which acts as a shell for Hydronip. The metal belt loop consists of two corner guide rolls and a stretching guide roll. The guiding and stretching of the belt is managed by crowned guide rolls and a stretching guide roll. For the belt change a lifting beam was needed to cantilever the frame beam. By cantilevering the frame, the metal belt is possible to install to the machine as a whole.

The press shoe is lubricated with water which is fed through the press shoe. Because of that the existing water removal system had to be improved so as to prevent water misting around the test place. For this purpose a doctor was also needed on the guide roll after the nip to clean the metal belt and prevent the water from misting around. The doctor was also needed for the wad test to collect the wads for the water removal system.

A press felt is located around the press roll which removes the water from the paper or board. The felt has to be seamed felt because it cannot be installed to the machine as a whole. The felt guiding and stretching is carried out with guide rolls, pneumatic guide, and hydraulic stretcher. The Hydronip shoe with metal belt, felt and the press roll creates the nip.

Since the designed machine speed was 1500 m/min, the gearing had to be changed. The existing gearing was a vee belt which was modified to a cogged belt. Because the machine speeds can become quite high an efficient safety system was also required. The metal belt was surrounded with safety nets and mechanical stops. The felt was surrounded with a safety net.

The measuring equipment plays a key role in the information gathering and that had to cover all the necessary variables that had to be monitored.

The additional equipment needed for Hydronip is presented in the list below:

- Seamed felt for shoe press application. The felt has to be seemed because there is no possibility for cantilevering and that would be the prerequisite for having seamless felt.
- Metal belt for Hydronip shoe loop.
- Crowned felt rolls for metal belt loop
- Crowned felt stretching roll for metal belt
- Security limit switch for metal belt
- Motor/drive
- Measuring points and computer for analyzing
- Doctor for metal belt

- Water removal system
- Safety net
- Lifting beam for cantilevering the frame

2.4.1 Metal belt loop with guiding and stretching

Because the press shoe was already positioned for Superhydronip test runs, the metal belt loops had to be located around it. Another issue was how to arrange guiding and stretching for the metal belt so that it would maintain its position in the machine cross direction and keep the desired belt tension. The experience from a freshly introduced metal belt calender demonstrated that metal belt guiding should be arranged by crowned guide rolls which would also take care of metal belt stretching. According to that, the metal belt loop was designed as shown in Figure 28. The press shoe is in its original place. Crowned and coated guide roll was positioned on both sides of the press shoe for position 81 in the figure below. The rolls were received from pilot machine spare rolls and they were coated with rubber and balanced suitably for this position and machine speed. Position 71 is a crowned and grooved guide roll that can also be moved in the vertical direction. The roll was designed and manufactured for this position. This roll carries out the metal belt stretching. All the guide rolls also needed bearing houses and pedestals that were designed and manufactured for this. All the drawings are provided as a part of this thesis.

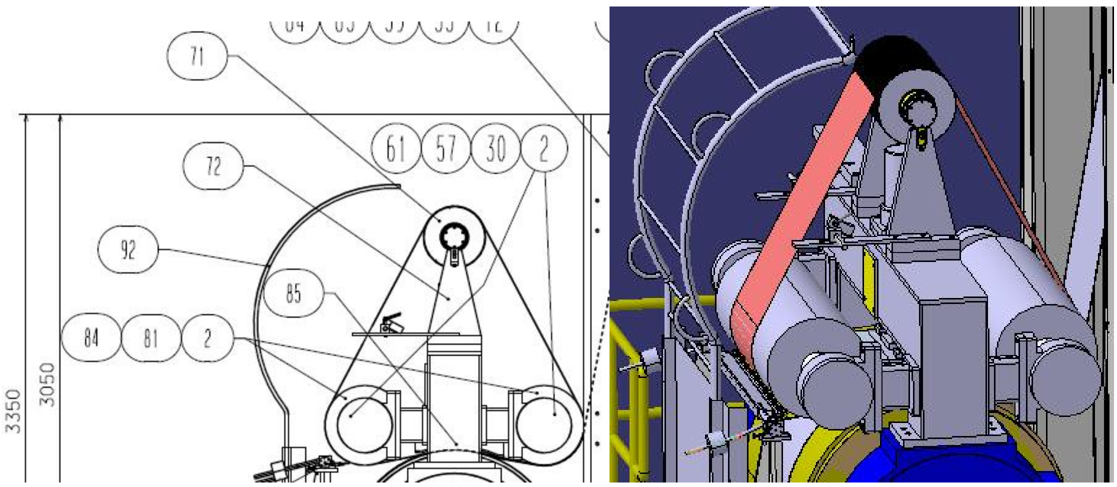


Figure 28 Metal belt loop with guide rolls

The metal belt material is an accurate steel belt which is laser cut and welded to the whole loop. The dimensions are:

- Thickness 0.6 mm
- Width 500 mm
- Length 4678 mm

2.4.2 Felt loop with guiding and stretching

As the stretching and guiding tests were carried out earlier at the same location, the devices could be utilized for Hydronip. Some modifications had to be made though, and these are shown in Figure 29. The hydraulic stretcher was in its position and it could not be changed, so the felt stretching was carried out as it was earlier. The guide roll with pneumatic guide was previously positioned on the vertical beam beside the metal belt loop in the Hydronip arrangement, so it had to be relocated. Since the guide roll location towards felt geometry is essential for efficient felt guiding, the guide roll with pneumatic guide had to be moved between the press roll and stretching roll for optimal felt guidance. A felt edge position sensor with fabric guide valve was also moved on the frame beside the guide roll.

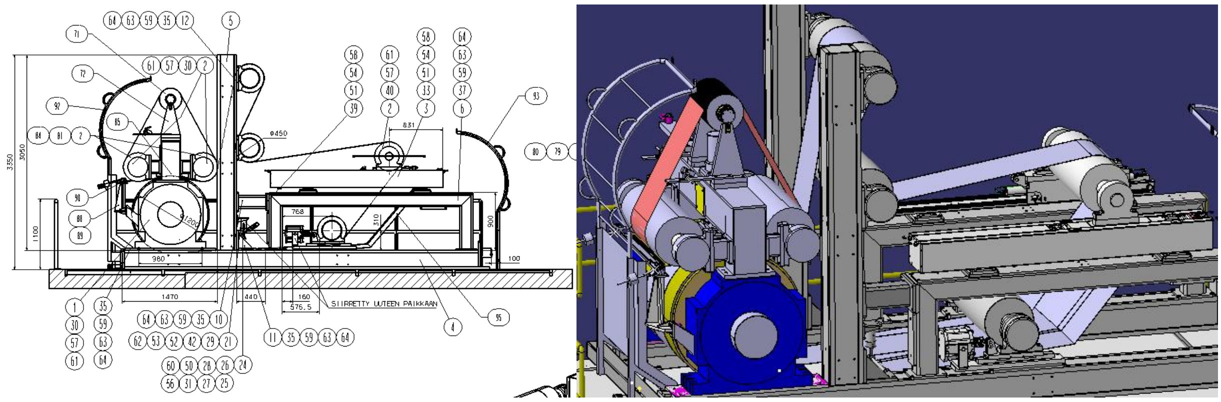


Figure 29 Felt loop in Hydronip

The felt is seamed felt Ecoseam 9504 form Tamfelt. The felt is typically used in SymPress B shoe press positions. The specification is shown in Figure 30.

Figure 30 Felt specification

The specification is as follows:

- Thickness 3-4 mm
- Length 13000 mm
- Width 550 mm
- Base weight 510 g/m²
- Gross weight 1360 g/m²
- Roving amount in the felt is 800 g/m²
- Surface rovings are fine 6.7 dtex and bottom and reverse side roving fine 17 dtex.

2.4.3 Drive and gearing

The existing drive had a 37 kW driving output. Since it was used only for rotating the wire, and in the Hydronip application it would need to rotate felt while loaded with the shoe, it had to be checked that the drive had enough power output. Since there are not very good calculations for the required power, measurements made in the pilot machine were used to determine if the output was sufficient. The machine speed target for Hydronip is 1500 m/min. The maximum loading power is 400 kN/m and the nip length is 270 mm. Some trials were carried out in the in pilot machine, where only the 3rd press was rotated with the felt and transfer belt in the SymBelt nip. This corresponds quite well to the Hydronip application, which is press roll rotated with felt and a metal belt in the nip. As can be seen from Figure 31, the power consumption with SymBelt is approximately 120 kW with a speed of 1500 m/min. The SymBelt shoe nip is 700 mm and if it is assumed that the Hydronip power consumption will be the same towards the width meter, the required power need would be approximately 43 kW. Since it is quite near the existing drive capacity it was decided to proceed with that.

Figure 31 Pilot machine power consumptions (Snellman 2008)

Since the speed was increased from the earlier test with Superhydronip, the gearing had to be changed. The existing gearing was a vee belt, but it was modified to a cogged belt gearing with 40 teeth on the drive and 140 on the roll shaft leading to a gear ratio of 3.5. Modified parts for the drive and gearing are shown in Figure 32. All the drawings are provided as a part of this thesis.

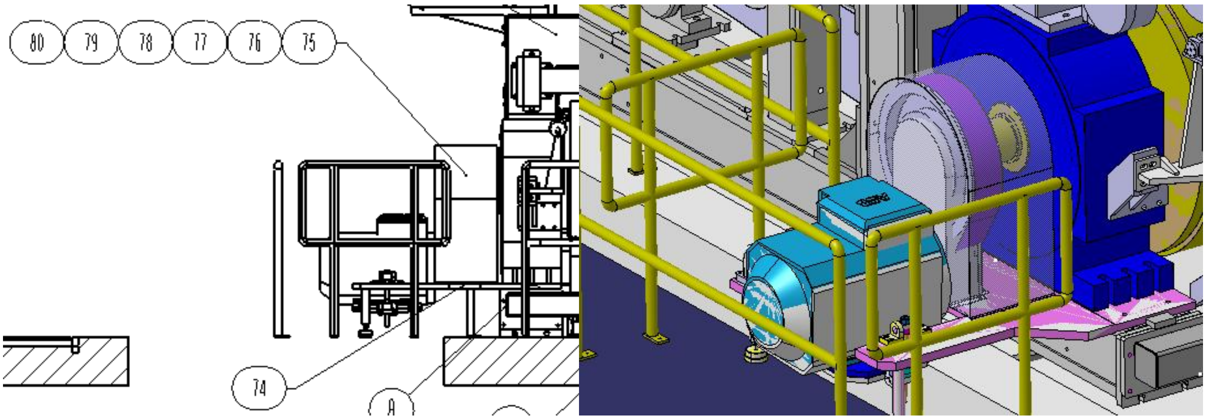


Figure 32 Modified parts for drive and gearing

2.4.4 Lifting beam for metal belt installation and change

Because the metal belt must be installed in the machine as a continuous loop, some additional equipment was needed to cantilever the frame beam including the guiding rolls. The lifting beam, shown in Figure 33, is installed on the drive side of the frame beam. The cantilevering can be done by lifting the frame beam with guide rolls from the lifting beam with a crane. When installing the metal belt, it can be laid over the lifting beam before starting the lift so the installation is easier.

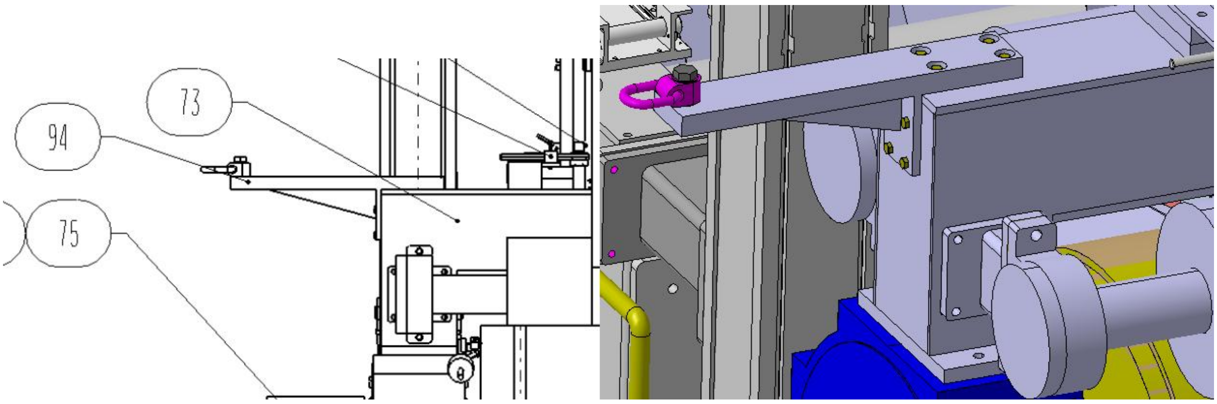


Figure 33 Lifting beam

The lifting beam is a lifting accessory and it requires certain maneuvers to fulfill the aspects set by law and safety regulations according to the Machinery Decision. At first the strength calculation and loading test were carried out according to regulations with suitable safety factors. Each lifting accessory should be included with the following details, which were attached on the lifting beam sign: (Occupational Safety and Health Administration 2007)

- manufacturer's details
- raw material information, if required
- compatibility purposes
- working load limit
- CE marking.

In addition, each lifting accessory or lifting accessory must include an instruction manual containing at least the following information: (Occupational Safety and Health Administration 2007)

- standard operating conditions
- use, assembly, and maintenance instructions
- restrictions on use.

All the required documents are provided for Metso as a part of this thesis.

2.4.5 Frame beam modification

Because of new guide rolls attachments and lifting beam attachment, the frame beam needed to be modified for these changes. The changes are illustrated in Figure 34. All the drawings are provided as a part of this thesis.

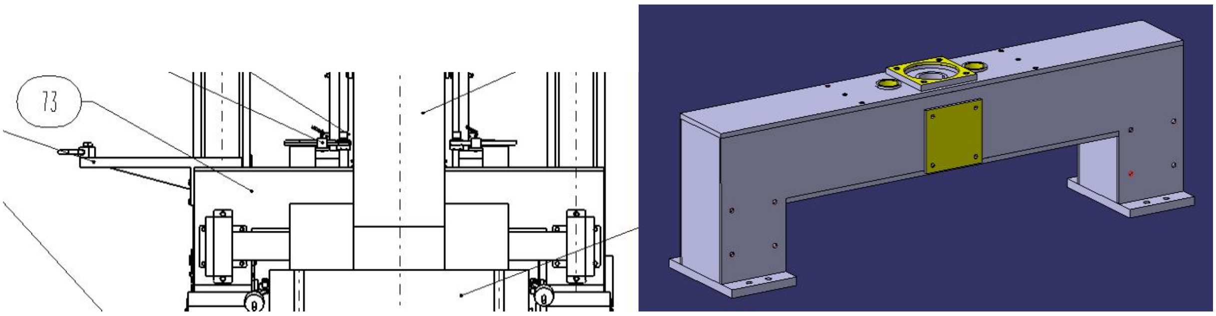


Figure 34 Frame beam modification

2.4.6 Doctoring

To keep the metal belt loop clean of water and to prevent the wads spreading around the doctor is located beside the corner guide roll on the nip outgoing side. The doctor, Figure 35, is weight loaded with a carbon-fiber blade. It was acquired from the pilot plant surplus stock.

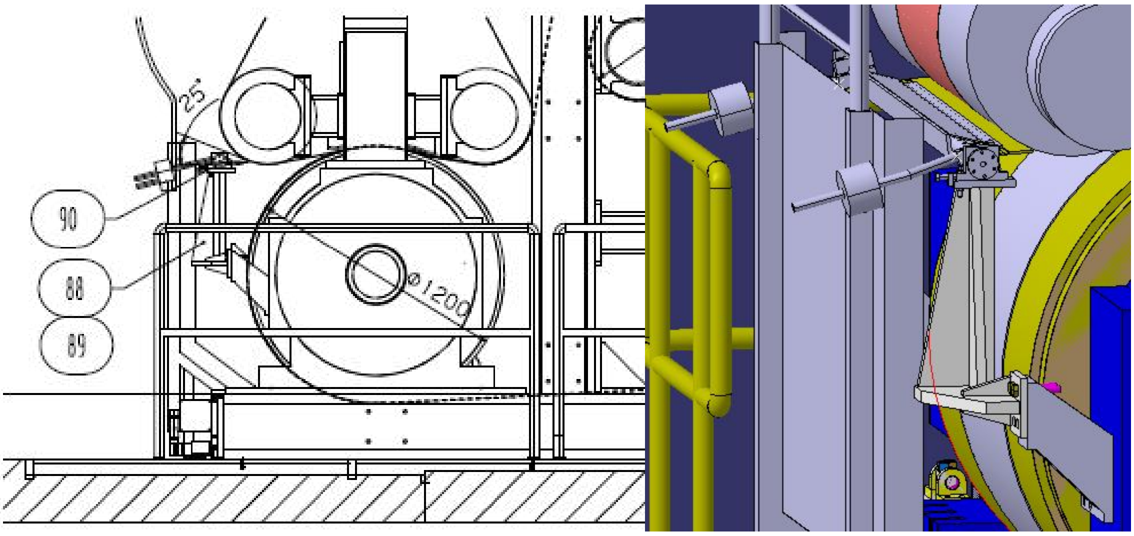


Figure 35 Doctor for metal belt

2.4.7 Save-alls

Because the press shoe seal is lubricated with water and there is water leakage coming from the nip, a water collecting system had to be constructed around the nip. One save-all, Figure 36, is located on the outgoing side of the nip to collect the water coming from the nip. This guides the water flow to the save-all located below the nip. From the save-all below the nip the water is drained to the canal.

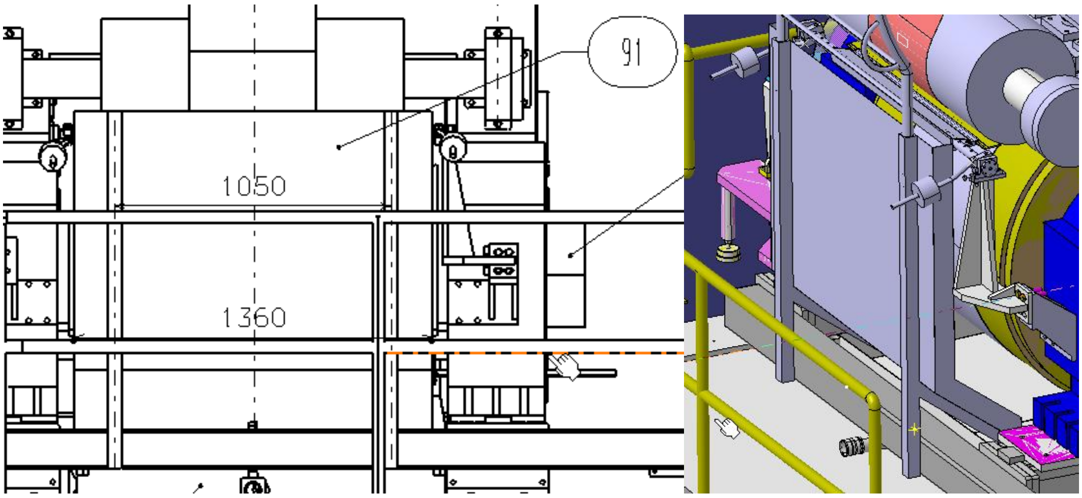
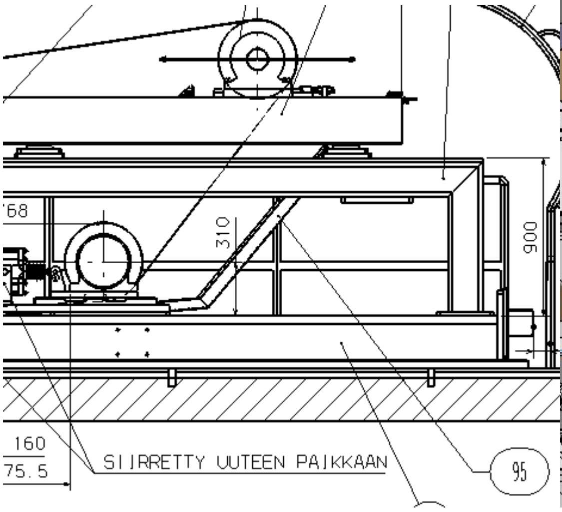


Figure 36 Outgoing side save-all

The press shoe is pressed against the press roll and with high water lubrication pressures the water mists around the nip. In order to see the nip action, the mist protection is built of plexiglass around the nip.

The felt is saturated during the machine run and with higher speeds the water spatters before the stretching roll. Therefore another save-all, Figure 37, is located beside the felt near the stretching roll which guides the excess water to the save-all below the nip. All the drawings for save-alls are provided as a part of this thesis.



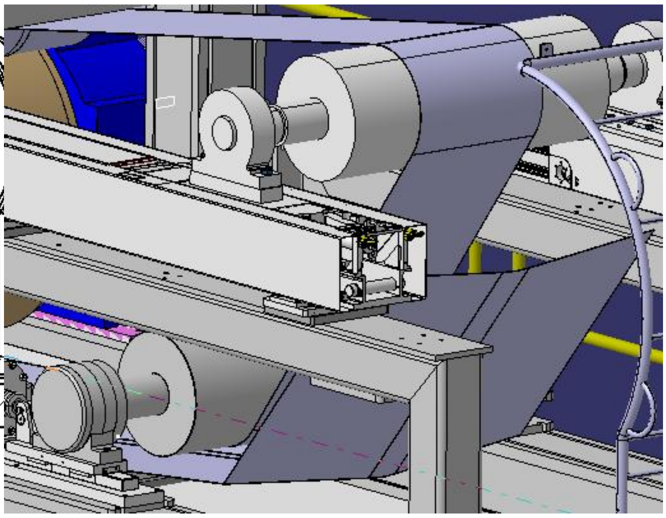


Figure 37 Save-all beside the stretching roll

2.4.8 Safety equipment

There are several safety issues that have to be conducted with Hydronip. The one critical location is metal belt loop. With high machine speeds breakage of the metal belt could lead to a severe danger situation due to high velocity metal pieces. The metal belt had to be surrounded with protective gratings. In the machine cross direction there are two rigid metal bars that provide mechanical stoppers which will restrain the metal belt sliding out of the machine. There are also two pieces of inductive proximity switches that will monitor the metal belt and stop the machine if the belt slides out of the monitoring range. Mechanical stoppers and inductive proximity switches are presented in Figure 38. Inductive proximity switches were received from the Technology Center and the drawings for holders are provided as a part of this thesis.

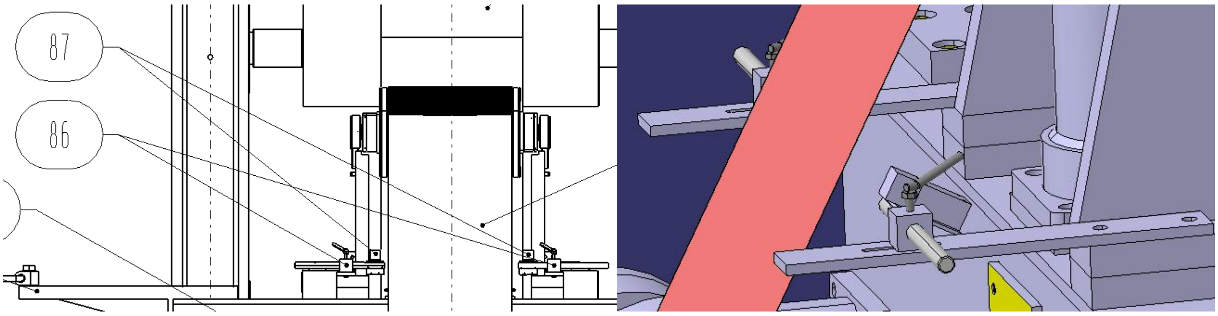


Figure 38 Mechanical stoppers and inductive proximity switches

In the machine direction the outgoing side of the nip had to be protected in case of metal belt breakage. For this purpose a protective grating, Figure 39, is located beside the nip on the outgoing side.

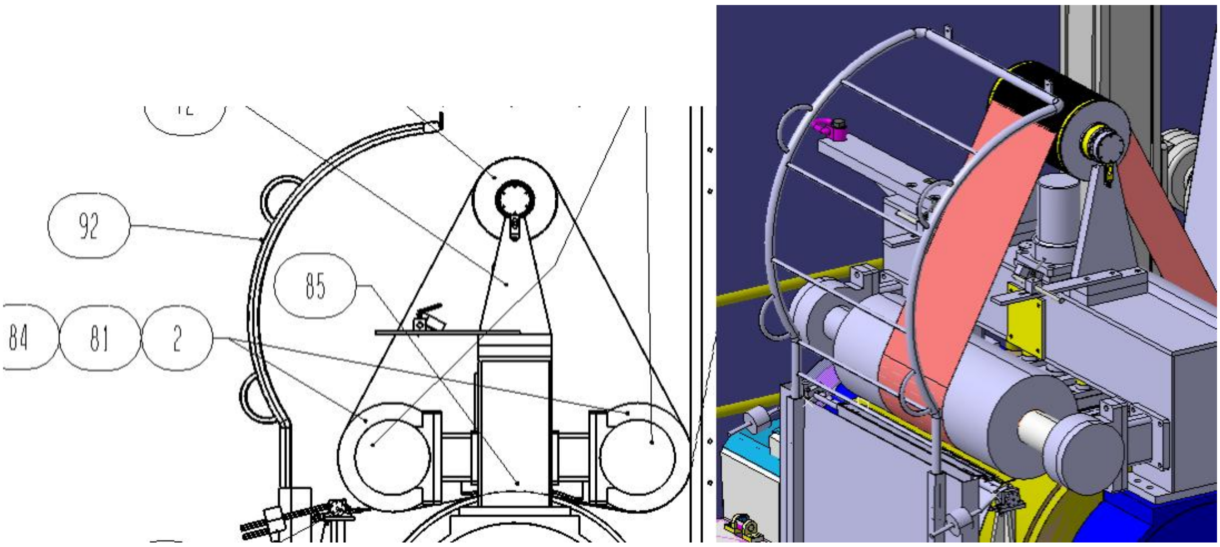


Figure 39 Protective grating for metal belt

Another protective grating is located beside the felt stretching roll to eliminate any loose felt pieces coming from the machine in case of felt damage. The protective grating is illustrated in Figure 40. Protective gratings were acquired from the pilot plant surplus stock.

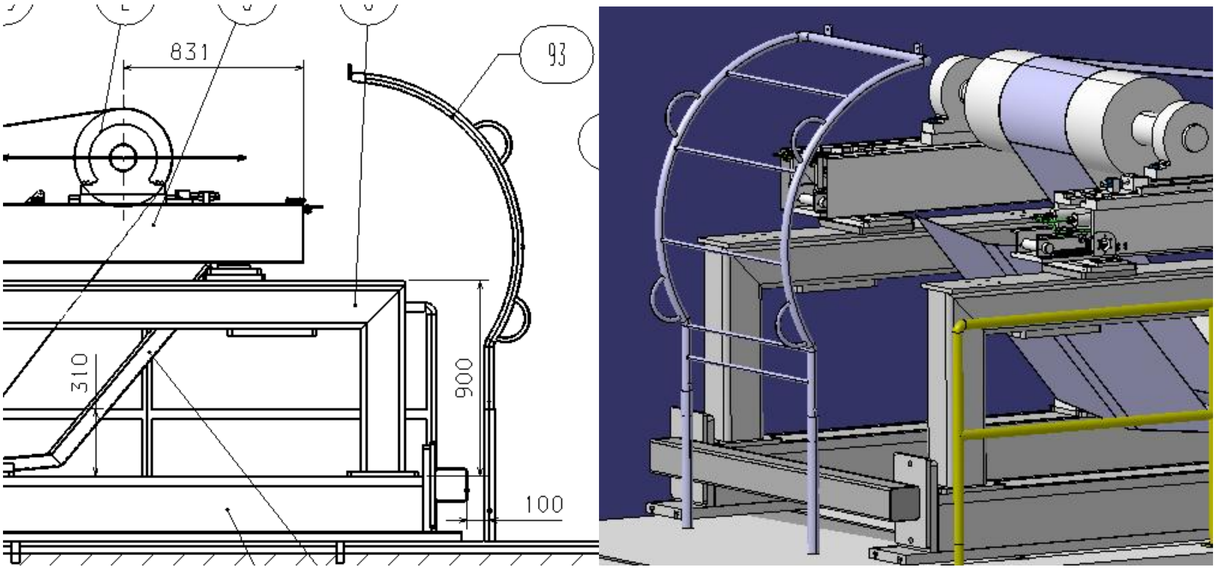


Figure 40 Protective grating for felt

The press roll has a rotating shaft on the back side which had to be covered with screen as Figure 41 shows. The whole back side of the machine is protected with movable separating walls to prevent access to the machine from that direction.

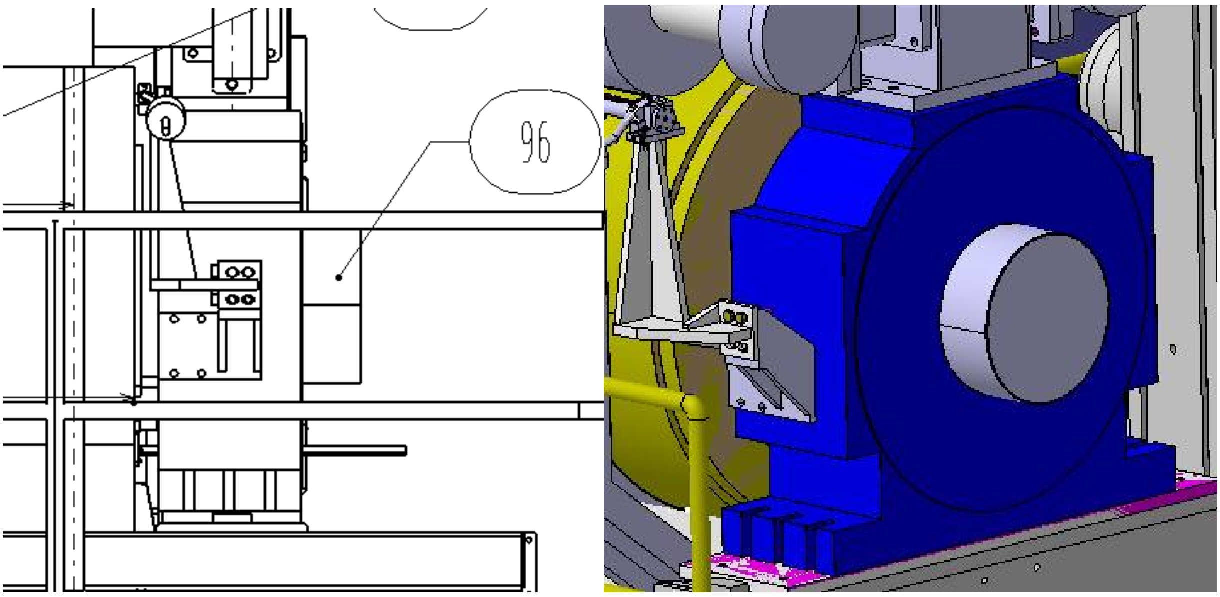


Figure 41 Protective screen

2.4.9 Measuring equipment

The measurement arrangement is an important part of the system to be able to analyze the results of the test runs. The following sensors are used in Hydronip arrangement:

- Shoe loading pressure 0...100 bar/4...20 mA
- Shoe lubrication pressure 0...400 bar/4...20 mA
- Shoe water flow 0...5 lpm/4...20 mA
- Water temperature after the pump 0...100 C°/4...20 mA
- Operation speed 0...1500 m/min/4...20m A
- Driving output 0...37 kW/4...20 mA

A description of the measurement system and devices used can be seen in Figure 42.

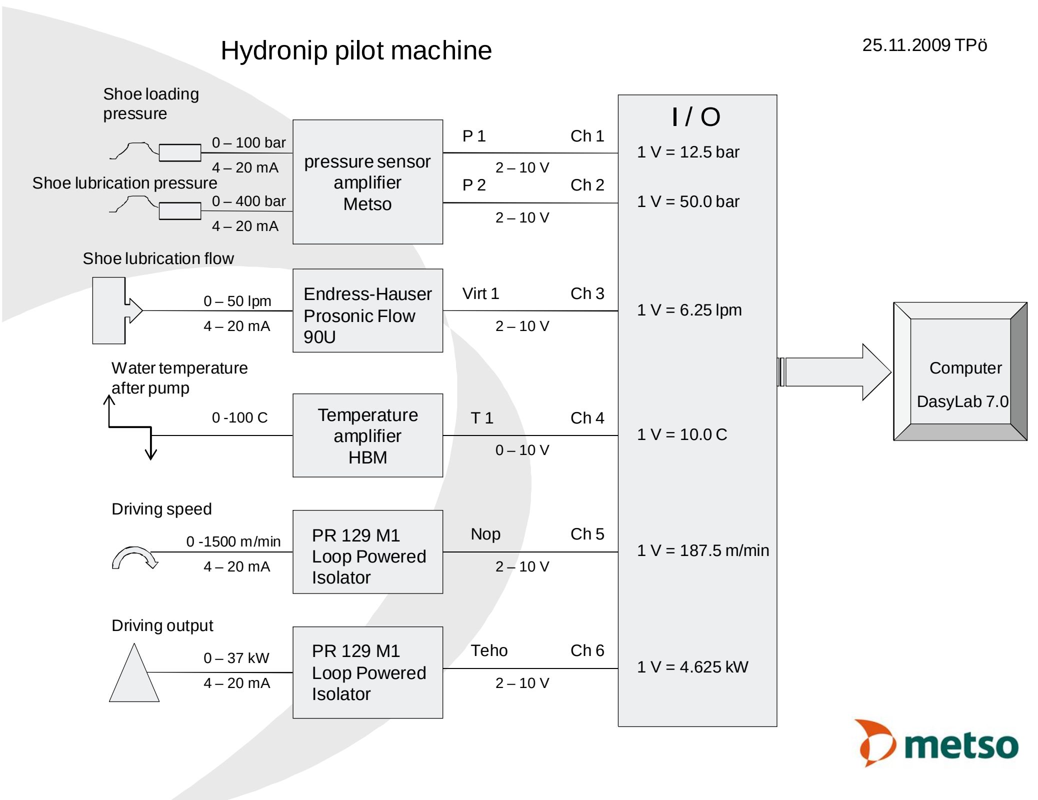


Figure 42 Measurement system

2.5 Hydronip arrangement and installation

The Hydronip arrangement is presented in Figure 43. All the required drawings, manuals, and instructions according to the Machine Decision are provided as a part of this thesis. The content of those are briefly presented in the following chapters.

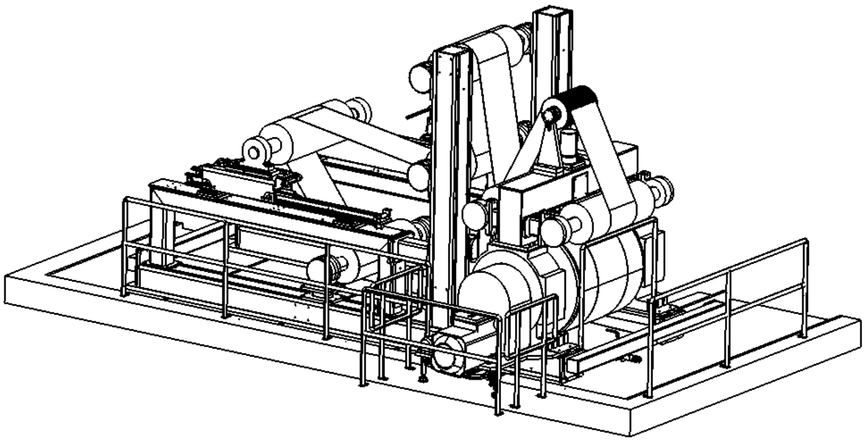


Figure 43 Hydronip arrangement

2.5.1 Installation instruction

An installation instruction was prepared according to the machine safety instructions. The following sections were handled:

- Mechanical assembly instruction
- Instrumentation assembly instruction
- Measuring equipment assembly instruction
- Testing equipment systems adjustment instruction
- Felt and metal belt changing instruction
- Pressure shoe seal change instruction

2.5.1.1 Mechanical installation

Mechanical installation is done according to the installation instruction. It includes illustrative and detailed installation instructions for each component. It also provides the essential information about layout and individual part drawing numbers.

2.5.1.2 Instrumentation installation

Instrumentation installation is done according to the installation instruction. It includes illustrative and detailed installation instructions for each component and the bill of materials. It also provides the essential information about the layout.

2.5.1.3 Lifting beam installation and use

Lifting beam installation is done according to the installation instruction manual for the lifting beam. It includes all the required information according to the Machine Decision lifting accessory guidelines presented earlier:

- Safety instructions
- Technical introduction and purpose of use
- User manual
- Service and inspection.

2.5.2 Felt and metal belt installation

The felt installation is done according to Tamfelt's instruction. It includes illustrative and detailed installation instructions for felt seaming.

The metal belt installation is done according to the felt and metal belt changing instruction. It includes illustrative and detailed installation and safety instructions.

2.5.3 Pressure shoe seal change

The shoe seal installation and change is done according to the press shoe seal change instructions. It includes illustrative and detailed installation and safety instructions.

2.5.4 Hydronip user manual

All the essential information for using the Hydronip safely and efficiently is gathered in the user manual. It includes:

- Safety instructions
- Safety instructions during shutdowns
- Safety instructions during running
- Environmental aspects
- Technical data
- Construction
- Function
- Machine operating instructions
- Measuring equipment operating instructions

2.5.5 Start-up and use

After the Hydronip assembly is completed and the security review has been done, the adjustments before start-up can be done. Devices are presented in the instrumentation graph, Figure 44.

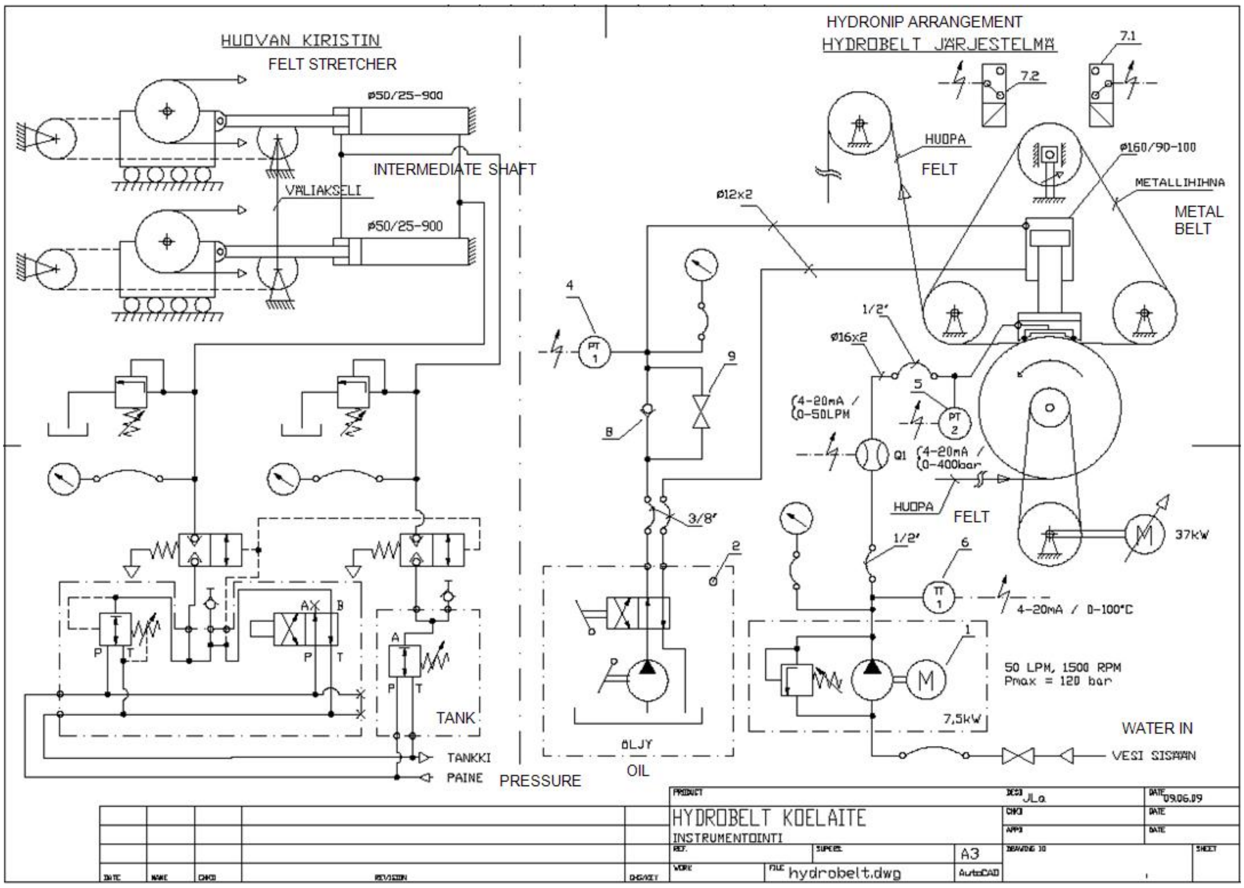


Figure 44 Instrumentation graph

Before start-up there are also some mandatory adjustments that have to be done. The Hydronip test equipment contains the following systems that have to be adjusted:

- Control of the main driving motor
- Metal belt tensioning and guiding
- Felt tensioning and guiding
- Hydronip nip load control
- Hydronip shoe lubrication flow (water) control
- Measurement system.

1) Control of the main driving motor

The main driving motor for the counter roll of Hydronip is controlled from the local control panel switches (start, rotation direction, speed setting). Before starting the main driving motor, the metal belt and felt have to be tensioned. When the main driving motor is started, the metal belt must not be loaded.

2) Metal belt tensioning and guiding

The belt is tightened manually with tightening screws in the tending side and back side. While rotating the metal belt, it is set parallel to the center of the guiding roll with adjusting screws. Tension is determined by experience. When the belt is rotating in the middle, the edge controlling inductive limit switches are set to stop the main driving motor as activated by the belt when it moves outside the guiding roll edges.

3) Felt tensioning and guiding

Felt tensioning is done by the hydraulic stretcher, and it is powered by the hydraulic unit. Starting the hydraulic unit is the first step while starting-up the stretcher. At the same time, the hand valve for the feeding pressure line has to be opened and it has to be ensured that it is closed for the other equipment that uses the same unit.

The stretcher is controlled by a separate local control panel with three position switch “loose-stop-move ". The local control panel has a separate supply voltage source (24 VDC), which has to be energized. The felt tension is adjusted manually by means of pressure-reducing valves. The cylinders’ minus-chamber (the piston rod side) has a constant pressure of 10 bar, which does not need to be changed. Tension is adjusted only by changing the pressure of the plus-chambers (piston side). The tension control valve is located under the directional valve which controls the stretcher stages (loose-stop-tightening. Tension is set to the desired constant value, and usually it does not need to be changed often. The valve panel in the middle of the test equipment includes two pressure gauges from where the pressure can be checked. The relation of pressure to tightness force is illustrated in the form located in the local control panel beside the machine.

The felt guide is pneumatic. When starting up the Hydronip, the hand valve for the input air line of the guide has to be opened. The pneumatic cylinder turns the guiding roll of the felt. The pressure of the cylinders' piston side is controlled with a flap valve. The pressure on the piston rod side is constant: the flap follows the felt edge. The spot where the felt is moving in the center is located by moving the valve mounting position. Usually, a single adjustment is adequate (the start-up adjustment).

4) Hydronip nip load control

The water lubrication for the shoe has to be switched on, if the nip loading is done while rotating the metal belt. The load cylinder is pressurized with the hand pump (Part 2 in the Figure 44). By the hand Pump is the directional valve that controls the pump flow to either the opening or nip loading direction. The pressure will be monitored from the load pressure gauge. While loading the nip, the ball valve (Part 9) beside the check valve (part 8) in the pressure line has to be closed. While reducing the loading the ball valve has to be opened and the flow direction of the hand pump has to be changed with the directional valve.

5) Hydronip shoe lubrication flow (water) control

Lubrication-flow pump is started from a separate safety switch. Before starting the pump, the water input line that is connected to the suction connection must be opened. The pump is rotating at a constant rotation speed and a flow moves to the loading shoe of the belt, presupposing that the pump pressure limit is set to sufficiently high value. If the pressure falls below the loading value of the shoe, the water flows back to the pump suction side and the pipe leading to the shoe is pressurized, but the flow does not start because the pressure is not high enough to open a gap between the belt and shoe. The pressure limit should be set to largest value possible (approximately 100 bar) to ensure that the flow does not escape through the pressure relief valve to the pump suction, but moves fully to the shoe. Lubrication flow pressure can be followed from the gauge locating in the line.

6) Measurement system

Measurement system captures the power output of the main driving motor, machine speed, shoe lubrication pressure, load, shoe water flow volume, and water temperature (from pressure line). There is a separate instruction for using the measurement system.

After the adjustments the start-up can be done. For the correct and secure utilization of the Hydronip pilot machine, the operating and safety instructions has to be viewed.

2.6 Trial runs

2.6.1 Objective

The object for the trial and test runs was to perform them with the loading press shoe against the counter roll with water lubrication together with felt and metal belt loops to test the sealing operation and overall function of Hydronip. Another object was to study the required amount of seal lubrication flow. Trial runs are done before final test runs to ensure that all components and data gathering devices are functioning.

The object for wad tests was to review what happens in the nip in web break situations. More precisely, the target was to study the impacts on the seal and the metal belt.

2.6.2 Preliminary runs

At first some preliminary runs were carried out in different phases to check all the necessary equipment and device adjustments that were executed. These were done in the following order.

2.6.2.1 Metal belt loop guiding and stretching adjustment

In the first preliminary runs, the metal loop was positioned to travel on the guiding rolls center line. The metal belt was installed on the machine after all the rolls were aligned. Initially the metal belt was positioned without a felt loop. While running, the metal belt tried to move towards the front side. The metal belt tension was adjusted with the stretching and guiding roll's adjusting screws. Next the corner guide roll was lifted from the front side. Simultaneously, the stretching and guiding roll was lifted from the back side. In addition, the spacers underneath the stretching and guiding roll bearing houses were made thinner to achieve more allowance for metal belt tightening and adjustment. After these measures the metal belt was travelling in the middle of the rolls as planned.

At first the measurement of the rotational speed of the machine was problematic. Eventually, it became clear that the measurement scaling factor doubled the correct speed. The speed on the screen and measurement results was verified with a hand speed meter.

The metal belt surface roughness was also measured using a hand meter. The surface roughness varied quite a lot, but it was outside the flat area of about Ra 0.1 - 0.3, and the welding seam of about 3.5 Ra. Inside, the surface was rougher, and on the back side it was a little smoother, about 1.3 Ra and on the front side it was approximately 2.2 to 3 Ra. The thickness of the coating could not be measured because the meter does not work with austenitic materials.

2.6.2.2 Press shoe alignment and adjustment

The press shoe was aligned as well as possible. The test load was done loading the press shoe lubricated with water against the counter roll without rotation. The press shoe's incoming edge squirted water a lot, which indicated that the shoe was not quite straight. At first the shoe was moved to the incoming side as much as the bolt attachment clearance allowed. The bolts were machined thinner to get more room for adjustment. In addition, the press shoe was removed and the spacer plate between it and the shoe attachment was machined straight. Extra spacers were also put on the outgoing side to turn the shoe to a better position against the counter roll.

2.6.2.3 Metal belt loop rotating, shoe loading, and lubrication

Next the metal belt rotation with press shoe loading and water lubrication was tested. The running speed was 700 m/min and the power consumption was 16 kW. The press shoe loaded at different pressure levels with the water lubrication at full (50 lpm). When the metal belt and counter roll got wet, the friction between them lowered so much that slipping occurred. Some solutions for this were considered and which included:

- Use of a separate drive for the metal belt's stretching and guiding roll. This would rotate the metal belt, even if the friction between the belt and the counter roll would decrease considerably.
- Use of a doctor at the outgoing side of the counter roll, which would reduce the water going to the corner guide roll and thus improve the grip.
- Use of a grooved or coated guide roll, which would increase the friction between the corner guide roll and the metal belt.
- Use of a rubber list or seal (e.g. the spring loaded lock seal used in suction rolls), which would prevent water from entering between the metal belt and the corner guide roll.

For the following tests, however, the effect of the felt installed on the machine was examined. A long felt loop on the counter roll creates a lot more friction in the nip and thus also helps the metal belt to rotate.

2.6.2.4 Hydraulic stretcher and pneumatic guide adjustment

The hydraulic stretcher and the pneumatic guide functioning to guide the press felt was tested next. The felt tension was adjusted to approximately 3 kN/m. During the experimentation a suitable place was sought for the fabric guide flap valve, which keeps the felt running in the machine center line. Also, the response time of the guide was adjusted a little faster to guide the felt smoothly. The felt tension and the control were managed to operate as planned.

2.6.3 Trial runs with metal belt and felt

The first trials were carried out with the entire lineup. Immediately a problem was discovered with the shoe lubrication flow measurements, which did not give any result at all. The lubrication flow valve was removed completely from the line, but this did not help. At that moment the metal belt's welded seam broke and the trials had to be stopped.

The metal belt was changed and the flow sensor was repaired. The metal belt was adjusted to rotate in the center of the machine line and the flow sensor and other equipment operations were tested to be functioning. The belt was rotating in the middle after just one adjustment and the flow sensor functioned as well. Some short demonstration runs were done to be sure that everything was functioning. The outcome from the three runs is presented below.

1st run:

- Machine speed: 158 m/min
- Pressure shoe loading: 35 bar
- Pressure shoe lubrication pressure: 7 -28 bar
- Pressure shoe lubrication flow: 15 lpm
- Driving output: 1.49 kW

2nd run:

- Machine speed: 15 m/min
- Pressure shoe loading: 30 bar
- Pressure shoe lubrication pressure: 7 -28 bar
- Pressure shoe lubrication flow: 12 lpm
- Driving output: 1.49 kW

3rd run:

- Machine speed: 200 m/min
- Pressure shoe loading: 20 bar
- Pressure shoe lubrication pressure: 2 -20 bar

- Pressure shoe lubrication flow: 12 lpm
- Driving output: 1.93 kW

All equipment was functioning well and the measuring devices worked well. The press shoe lubrication flow was restricted by controlling most of the water to drains. Shoe lubrication pressure fluctuated a lot, and this was due to the fact that the shoe was not quite uniformly loaded against the counter roll and the water escaped from all sides of the shoe seal. The shoe lubrication pressure and flow should be balanced and the lubrication pressure should be steady.

The shoe was then taken out of the machine and the seal was inspected. The seal is shown in Figure 45. The corner of the seal was well worn on the incoming side at the back side; there was also some minor polishing on the outgoing side. The center of the incoming side seal had some minor scratches and wear. Occasional minor traces of wear were also found in the other parts of the seal. The seal was replaced with a new one and the shoe was installed back to the machine.

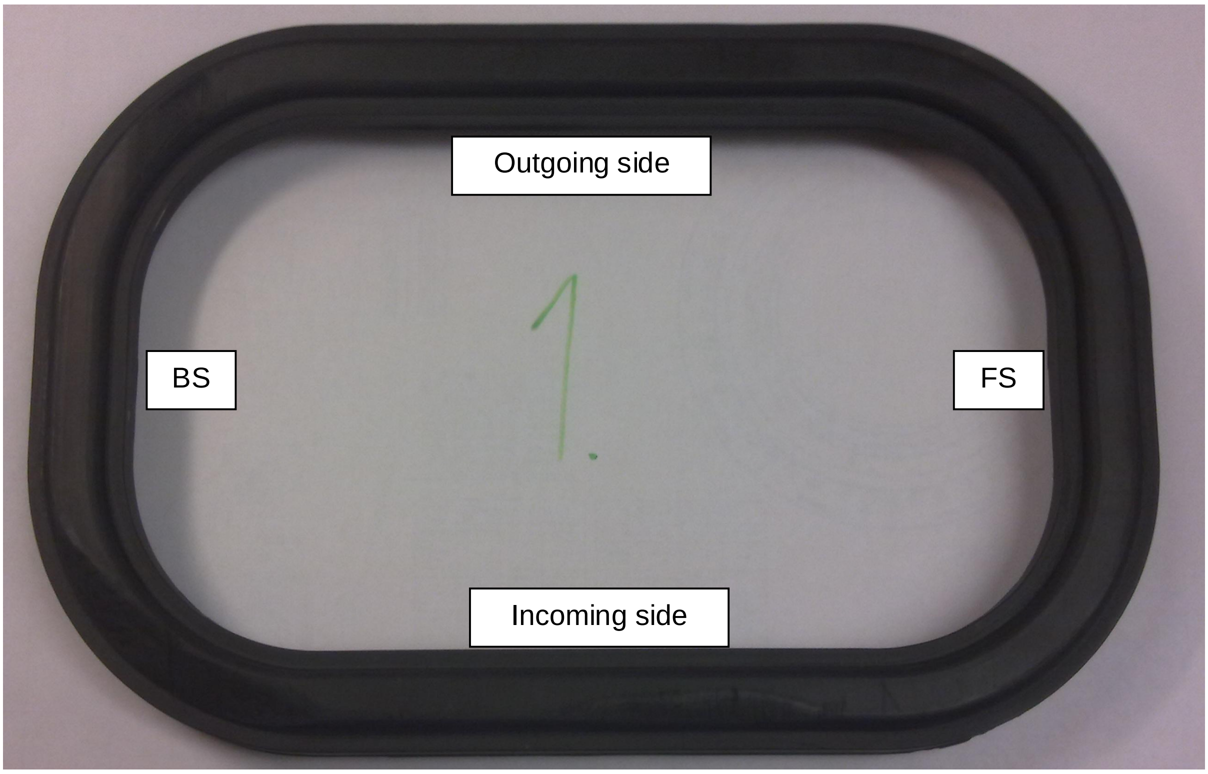


Figure 45 Pressure shoe seal after adjustments and first tests

After this the shoe was positioned again by loading the shoe against the counter roll lubricated with the water supply network pressure in the chamber to see how the shoe should be balanced. 0.5 mm spacers were added on the outgoing side of the shoe and the fastening bolts from the side guides were loosened to settle the shoe better against the counter roll.

With the shoe positioned some trials with different machine speeds, different press shoe loads, and different lubrication flows were carried out. The essence of the problem is still that the water film between the seal and the metal belt is not smooth and the water escapes more than will come back, which causes the pressure variation. When the water chamber pressure drops to compress the seal and the leakage is reduced again until the seal opens and the pressure from the edge collapses. A very small shoe misalignment can cause a pressure drop. The film of water should be even throughout the whole seal or there should be a steadily tapering gap towards the belt running direction.

To make the shoe alignment against the counter roll even better a 10 mm thick rubber plate was assembled between the shoe and the loading cylinder and the guides. This enhanced the shoe alignment. At the same time, some additional problems occurred. The shoe lubrication pressure transmitter and the flow transmitter did not function properly. In addition, the power output measurement had to be repaired.

These deficiencies were corrected. There were also problems with the main drive. When the protective cover was taken away, it could be seen that in the acceleration and deceleration the tooth of the belt tried to jump over the tooth of the gearwheel. The engine was aligned, but it did not help. The adjustment was found to be incorrect. The drive did not control the inertial mass. The current of the drive also varied so much that the drive was not able to calculate the operating power output. It was also found that the trial run has been left undone. It has to be done with only the motor without a load.

After that the adjustment parameters of the motor were changed, which were much too brisk and the current varied exceedingly. After the changes the screen display was working. When driving a steady speed, the power consumption is very low, approximately 2.5 kW, without a shoe load.

The measurements were collected next. The trials were done with different loads, different shoe lubrication flows, and at different machine speeds. All the equipment functioned well. The first trial was done with the following parameters:

- Machine speed: 190 m/min
- Pressure shoe lubrication flow: 50 lpm
- Pressure shoe lubrication pressure, increased in the following phases: 10, 20, 30, 40, 50, 60, 70 bar.

The data collected by means of the measuring equipment was translated to an Excel graph and it is presented in Figure 46. The horizontal axis represents the time line. The light blue line represents the driving speed. It varies slightly for the whole measuring time, but rises at the end when the load is released. The blue line represents the shoe loading pressure, which was gradually increased in phases from 10 bar until 70 bar. The orange line represents the driving output, values on the right vertical axis, and that follows quite accurately the amount of load applied through the press shoe. The green line represents the shoe lubrication flow. The flow remained quite stable but caused a little vibration with higher loads on the graph. The red color represents the shoe lubrication pressure, which followed accurately the shoe loading pressure. As also can be seen, it varied exceedingly and was not stable. The violet line represents the water temperature, and it remained constant for the whole test.

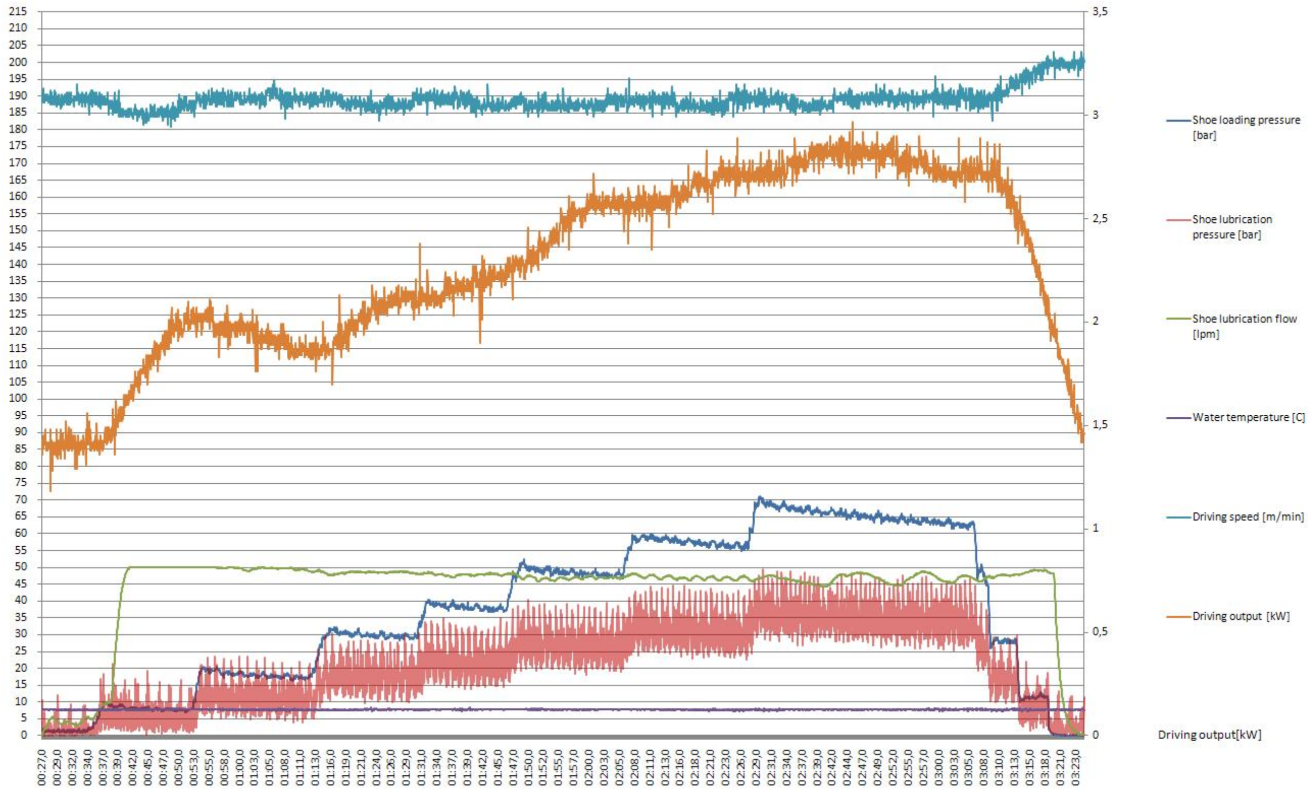


Figure 46 Trial 1; speed: 190 m/min, lubrication flow: 50 lpm, loading pressure: 10 -70 bar

The second trial was done with the same parameters as in first test to check that the results were comparable. The results are totally comparable to the first trial.

In the third trial the machine speed was increased to 400 m/min. All the graphs follow the same pattern compared to test with the machine speed 190 m/min, which can be seen in Figure 47. The speed varies during the different loads and quite heavily rises after the load is released.

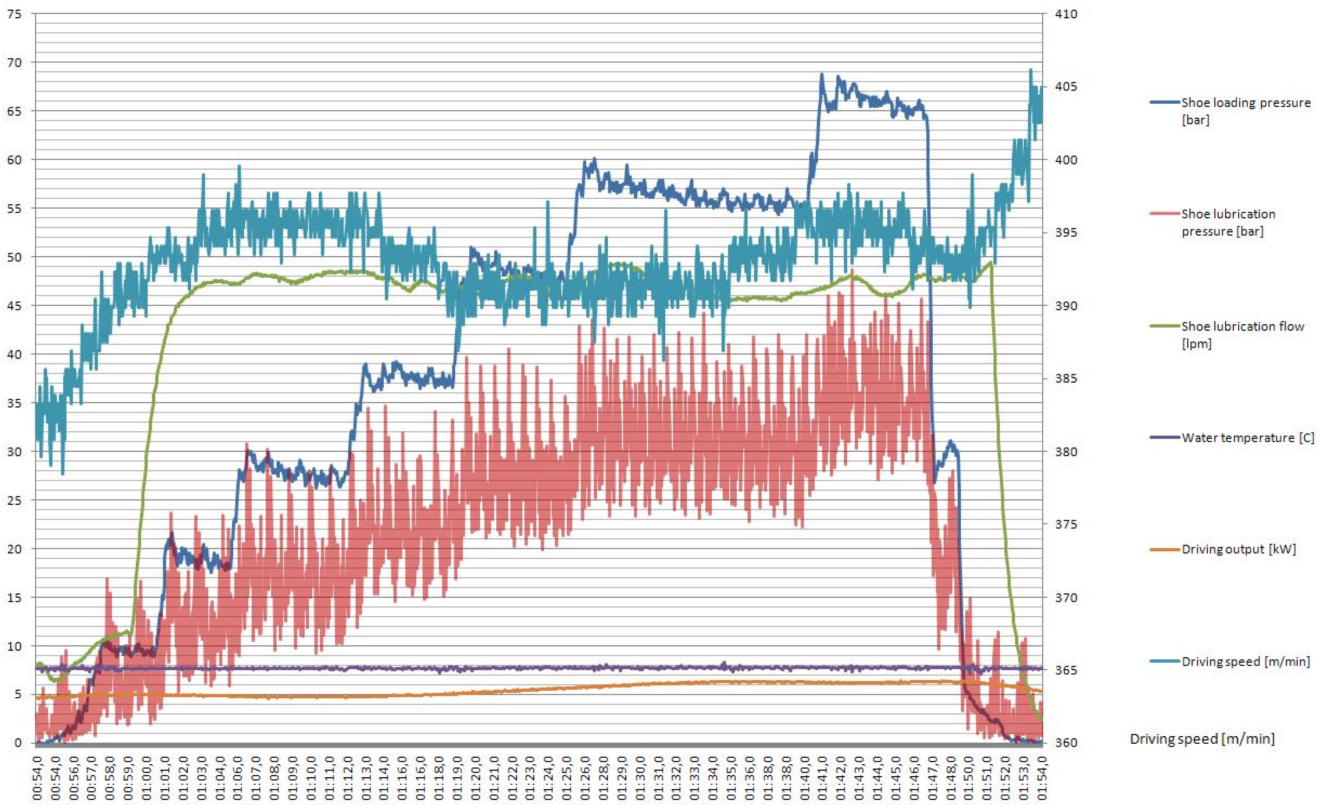


Figure 47 Trial 2; speed: 400 m/min, lubrication flow: 50 lpm, loading pressure: 10 -70 bar

The metal belt moves towards the front side or the back side when the machine speed is changed. At a constant speed it can be kept in place well, but when the speed is changed, the stretching and guiding roll adjustments have to be reset. When the speed increases, the felt guide response should also be accelerated.

Upon reflection it was noticed that the water pump is a piston pump, causing water supply pressure to be uneven, which causes variations in pressure shoe lubrication pressure. As a result, it was decided to move the lubricating pressure measurement to the pressure shoe chamber and to assemble a pressure accumulator to the pump. This results in the pressure measurement becoming more stable and reliable.

2.6.4 Preliminary board wad tests

Because some adjustments on the machine were planned, which would have an implication for the test results, some preliminary wad tests were carried out before starting the modifications. The target for the board wad tests was to study what happens when board wads go through the nip with different machine speeds and nip loads. This illustrates the case of web brake or other comparable situation where different shapes of particles go through the nip. The metal belt and seal durability against wads is important because, as stated previously, with SymBelt technology the polyurethane belt is vulnerable to these kinds of particles, which may lead to severe belt and felt damage.

Preliminary board wad tests were performed using 200 g/m² carton sheets as wads. Wads were dropped in the incoming side of the nip between the felt and metal belt. The distance from the dropping point to the nip is approximately 500 mm, as illustrated in Figure 48. At first the test was done with a 20 bar nip load, initially with one sheet and then adding more layers. The doctor worked well, and the wads going through the nip did not cause any remarkable phenomena. Thereafter, the machine speed was doubled, and the test was repeated. Again, everything worked well and the wads going through the nip were barely noticeable.

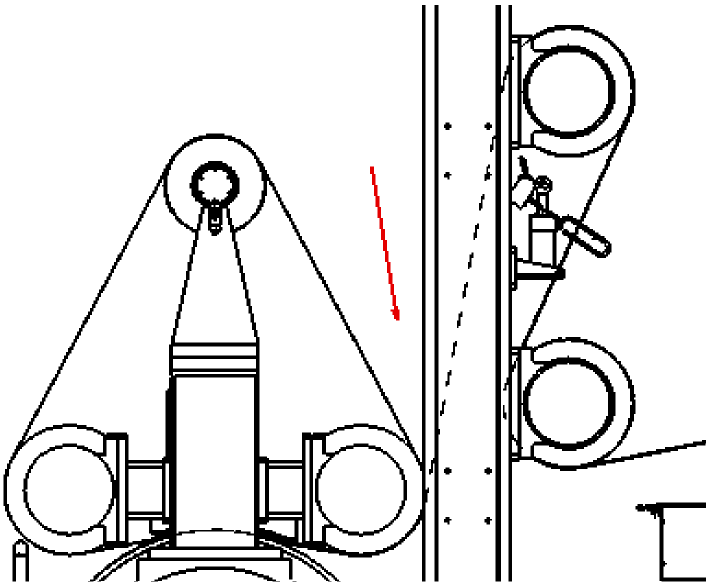


Figure 48 Board wad dropping location

2.6.5 Changes before final tests

According to observations made in the first trial runs, some adjustments on the Hydronip arrangement were made. Since the incoming side of the pressure shoe seal wore heavily it was decided to add a shower pipe to get adequate lubrication to the seal.

For managing the shoe lubrication pressure variation caused by the piston pump, the pressure transmitter was moved from the pressure line straight to the pressure chamber of the shoe. Also a pressure accumulator was assembled for the water pump to reduce the variation of the lubrication pressure.

3 Final test runs and results

The changes made after the trial runs were found to be working. Somehow the pressure shoe seal did not wear that much even though the shower pipe on the incoming side was not in operation. The shower pipe could still be used for moisturizing the felt before starting the test runs. The seal lubrication pressure variations reduced notably after the changes, as can be observed from the following results. All the other equipment functioned well.

The tests were carried out with different loads, different shoe lubrication flows, and at different machine speeds. The trial runs carried out earlier showed that there are limits with machine speeds and pressure shoe loads for the metal belt guiding to function as desired. As observed the metal belt guiding loses its functionality after machine speed exceeds 150 m/min, while the pressure shoe seal lubrication is on. This is due to the fact that the water coming out of the nip outgoing side goes between the corner guide roll and the metal belt, which causes slipping and the metal belt loses its controllability. The same phenomenon occurs when the pressure shoe load is increased over 20 bar with pressure shoe seal lubrication. Therefore the machine speed in the following tests was chosen below the limiting speed, which is approximately 150 m/min.

The plan with test runs was at first to start with full lubrication flow for the seal and gradually increase the pressure shoe load. This was to study the correlation between different loads and full lubrication flow to the seal wear. Between the runs the condition of the seal was monitored to observe the possible wear and failure.

The first test was carried out with the following parameters:

- Machine speed: 110 m/min
- Pressure shoe lubrication flow: 45 lpm
- Pressure shoe loading pressure, increased in the following phases: 10, 20, 30, 40 bar.

The data collected is presented in Figure 49. As can be seen, the shoe lubrication pressure (pink line) is much more stable compared to trials presented earlier due to the change of measuring point and the added pressure accumulator. The pressure variation stays within a few bar when earlier it vibrated within 20 bar. Driving output is relatively low and it reaches approximately 1.5 kW with a load of 40 bar. The shoe lubrication pressure followed the increased load on a slightly smaller scale.

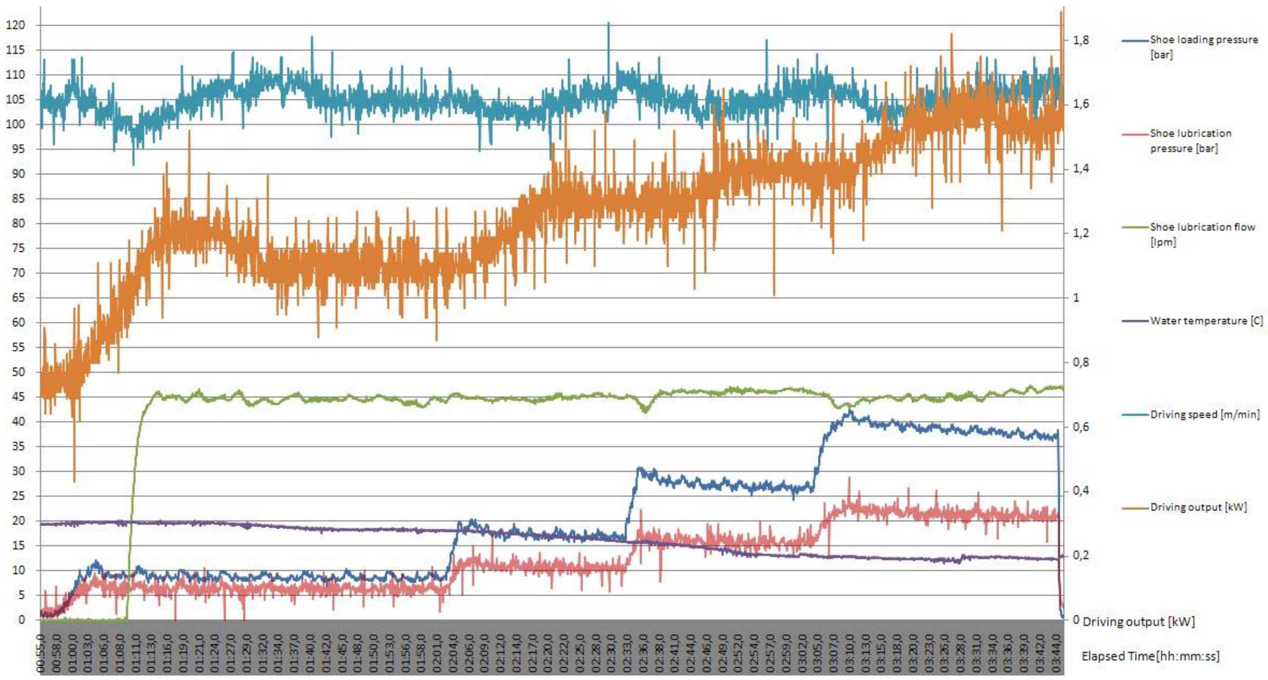


Figure 49 Test 1; speed: 110 m/min, lubrication flow: 45 lpm, loading pressure: 10 -40 bar

After the test the seal was inspected visually and the following was found:

- Incoming side: Minor polishing on the back side
- Outgoing side: Minor polishing throughout the whole length
- Front side edge: Minor scratches and polishing
- Back side edge: Slightly more scratches and polishing.

The second test was done with the following parameters:

- Machine speed: 110 m/min
- Pressure shoe lubrication flow: 50 lpm
- Pressure shoe loading pressure, increased in the following phases: 10, 20, 30, 40, 50, 60, 70, 80 bar.

As can be seen from Figure 50, with the full lubrication flow of 50 lpm and 80 bar load the driving output is approximately 2 -2.3 kW.

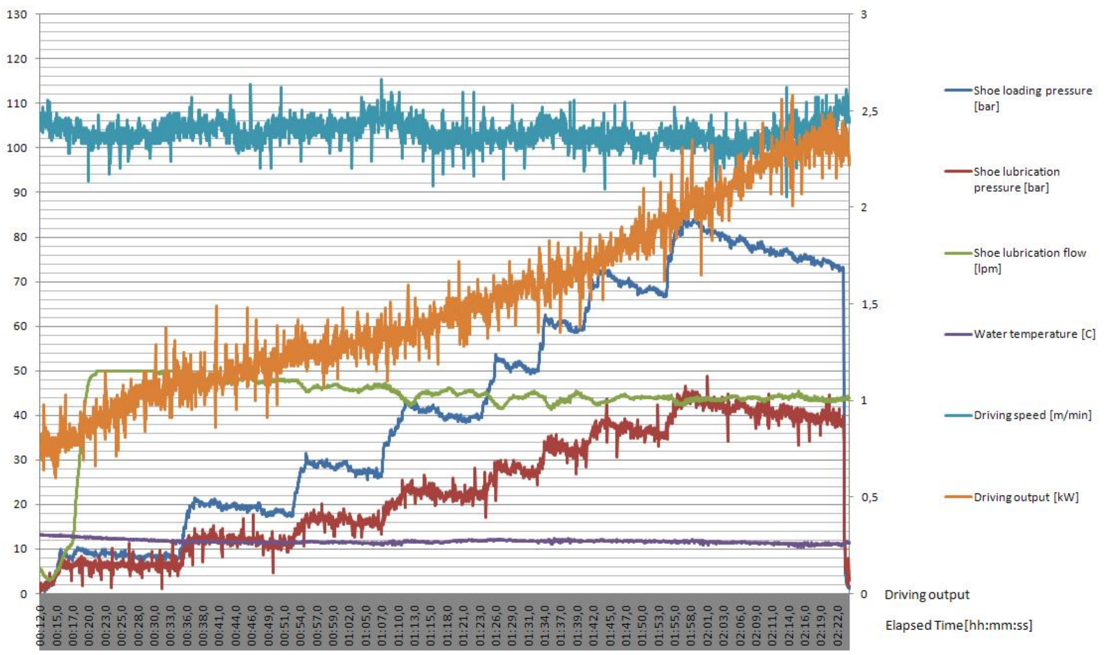


Figure 50 Test 2; speed: 110 m/min, lubrication flow: 50 lpm, loading pressure: 10 -80 bar

After the test the seal was inspected visually and there was not that much difference compared to traces after the earlier test. It was slightly more polished on the front side edge compared to the earlier inspection.

After the tests with different loads and full lubrication flow the effect of reducing the flow with increased pressure loads was studied. The third test was carried out with the following parameters:

- Machine speed: 110 m/min
- Pressure shoe lubrication flow: 30 lpm
- Pressure shoe loading pressure, increased in the following phases: 10, 20, 30, 40, 50, 60, 70, 80 bar.

Figure 51 shows that with reduced lubrication flow, the driving output with the 80 bar load exceeds 3 kW. The shoe lubrication pressure remains at the same levels as with the full shoe lubrication flow.

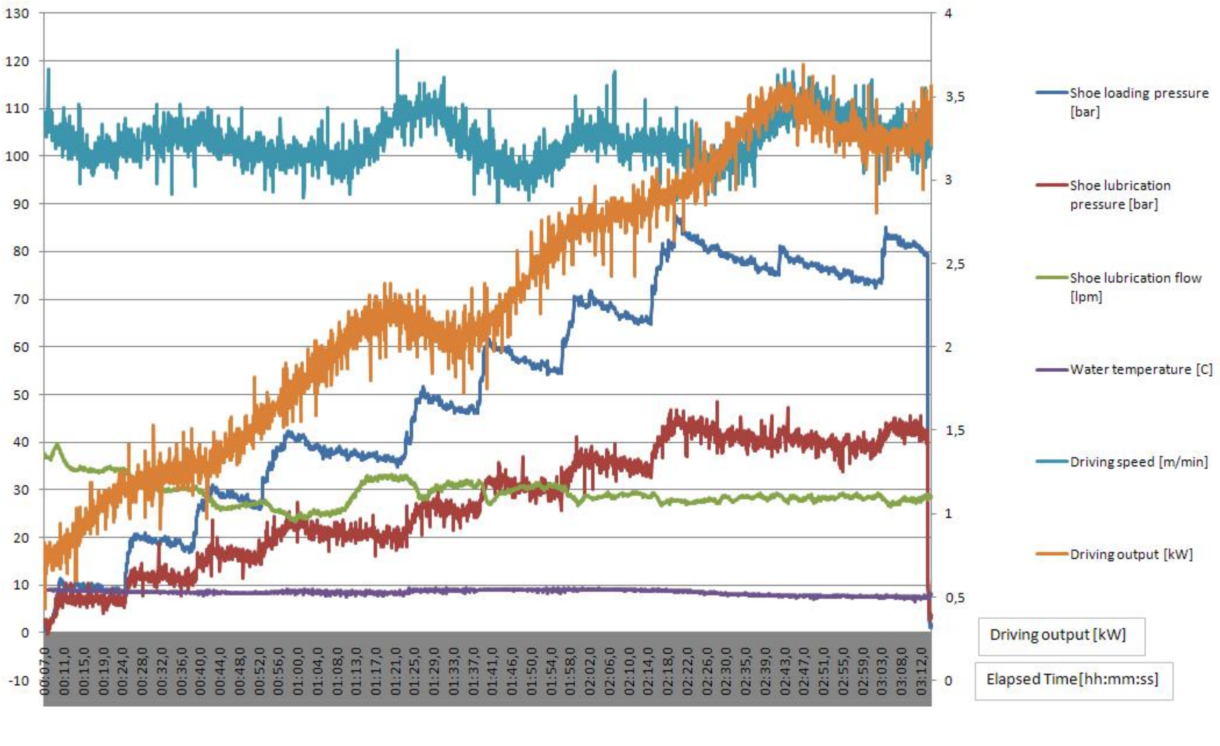


Figure 51 Test 3; speed: 110 m/min, lubrication flow: 30 lpm, loading pressure: 10 -80 bar

After the test the seal was inspected visually and there was not that much difference compared to traces after the earlier test.

In the fourth test the lubrication flow was reduced more and the test was carried out with the following parameters:

- Machine speed: 110 m/min
- Pressure shoe lubrication flow: 15 lpm
- Pressure shoe loading pressure, increased in the following phases: 10, 20, 30, 40, 50, 60, 70, 80 bar.

Figure 52 illustrates that the driving output exceeds 3 kW already with the 40 bar load. The shoe lubrication pressure remains at the same levels as with the full shoe lubrication flow.

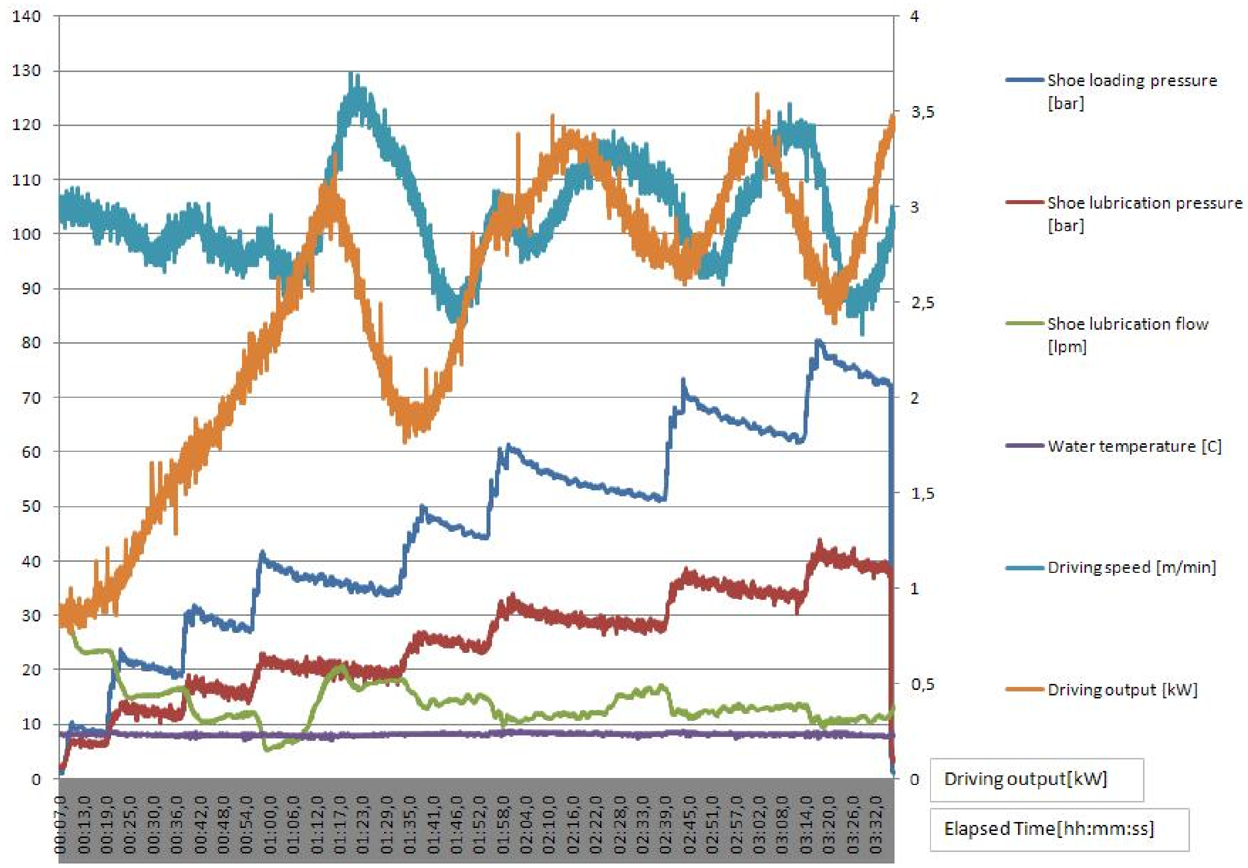


Figure 52 Test 4; speed: 110 m/min, lubrication flow: 15 lpm, loading pressure: 10 -80 bar

After the test the seal was inspected visually. It was slightly more polished from the back side corners from the incoming and outgoing side compared to the earlier inspection. Also, some rubber particles were found in the pressure chamber.

The next test run was carried out with a constant pressure shoe loading and decreasing the lubrication flow from 50 lpm to 10 lpm. This was to observe the correlation between diminishing the lubrication flow and a certain load to the seal wear. The fifth test was carried out with the following parameters:

- Machine speed: 120 m/min
- Pressure shoe lubrication flow: decreased from 50 to 10 lpm
- Pressure shoe loading pressure: 20 bar.

As can be seen from Figure 53, when the amount of lubrication flow descends, the driving power required increases. The change of lubrication flow does not affect noticeably the lubrication pressure.

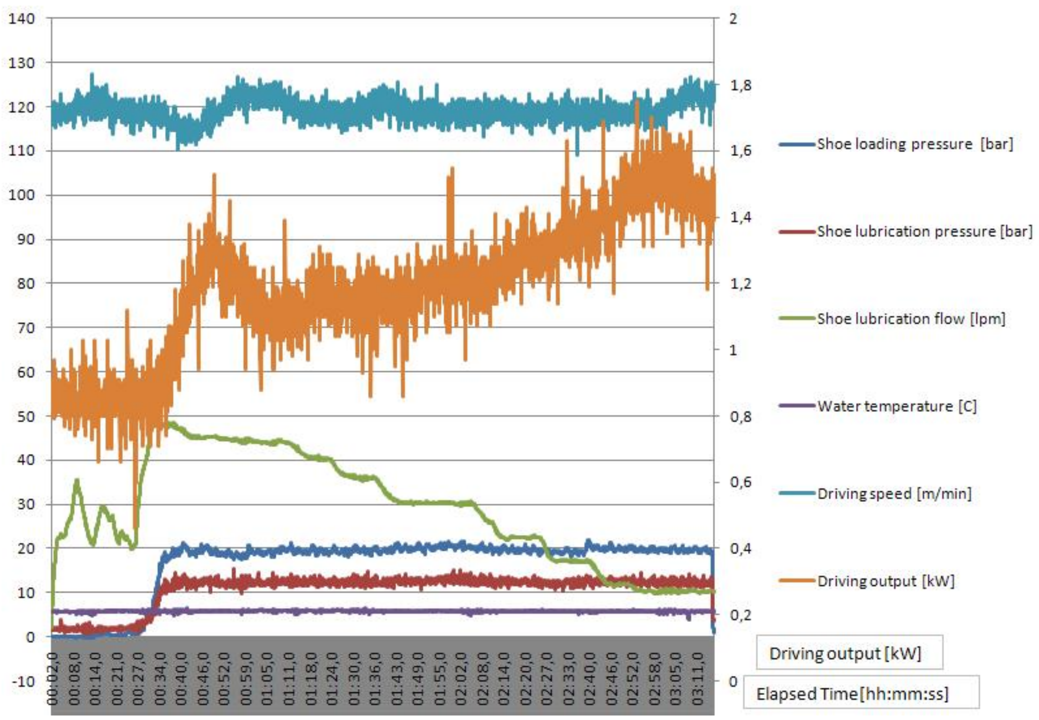


Figure 53 Test 5; speed: 120 m/min, lubrication flow: 50 -10 lpm, loading pressure: 20 bar

After the tests the seal was taken off the shoe and inspected. As can be seen in Figure 54 the seal is in reasonable good condition.

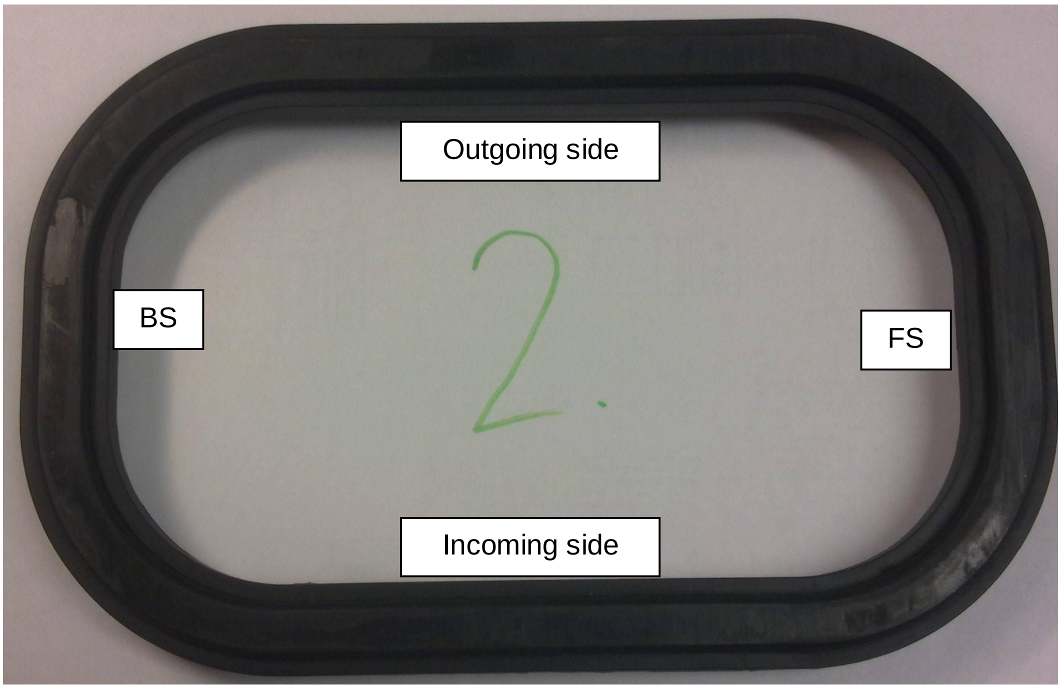


Figure 54 Pressure shoe seal after test runs

There is some minor polishing and wearing mainly on edge area on the front side and back side, as can be seen from Figure 55; however, overall it is in good condition.

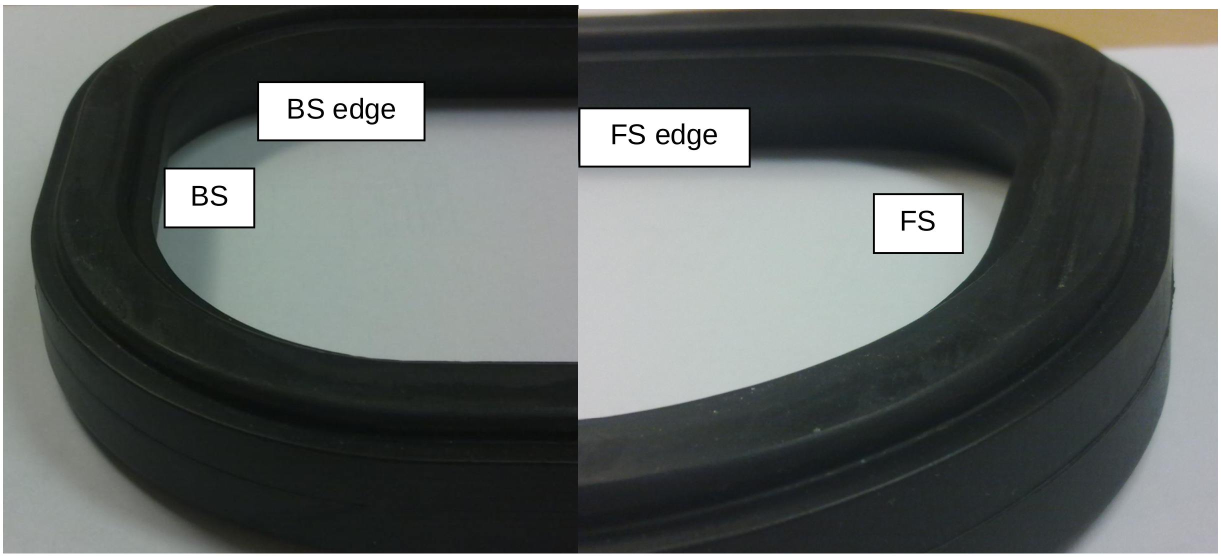


Figure 55 Press shoe seal edges after test runs

Before wad tests the seal was changed so any possible wear and damage could be observed from the new seal. Wad tests were carried out with different loads. Starting with 13 bar and gradually increasing the press shoe load to 80 bar. 80 g/m² carton strips were used as wads and the samples were put in the nip in four stages, piled up as follows. The insertion time of each wad was marked up in order to locate the impacts from the great amount of data collected.

1. 2 layers* 80 g/m² =160 g/m²
2. 8 layers * 80 g/m²= 640 g/m²
3. 20 layers * 80 g/m²= 1600 g/m²
4. 40 layers * 80 g/m²= 3200 g/m²

Tests were carried out at first with the following parameters:

- Machine speed: 105 m/min
- Pressure shoe lubrication flow: 28 lpm
- Pressure shoe loading pressure: 13 bar.

Carton was fed into the nip in the stages mentioned earlier. The insertion times were as follows: The first wad set with two layers after 10 seconds, the second set with eight layers after 48 seconds, and the third with twenty layers after 85 seconds. Figures 56, 57, and 58 illustrate the shoe loading pressure variation in the time lines from 10 to 13 seconds, from 48 to 51 seconds, and from 85 to 87 seconds.

Figure 56 Shoe loading pressure 13 bar, 160 g/m² wad in the time line from 10 to 13 seconds

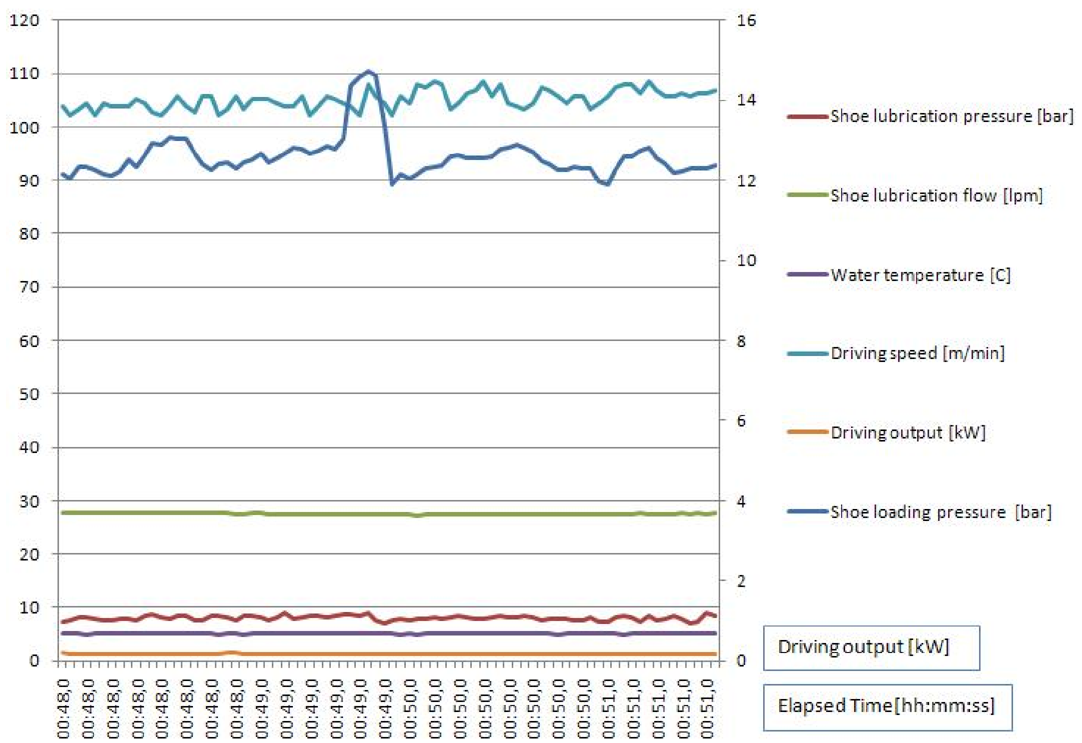


Figure 57 Shoe loading pressure 13 bar, 640 g/m² wad in the time line from 48 to 51 seconds

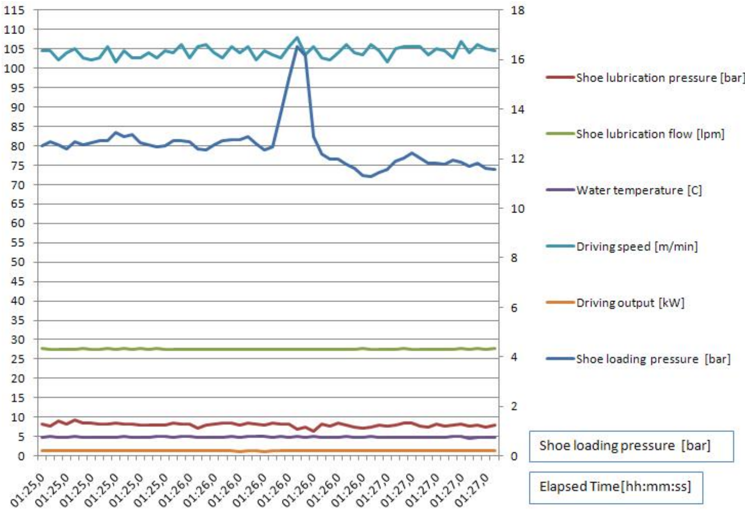


Figure 58 Shoe loading pressure 13 bar, 1600 g/m² wad in the time line from 85 to 87 seconds

The first wad of 160 g/m² did not have a significant effect on the shoe loading pressure. The loading pressure fluctuated from a little less than 12 bar to a little over 13 bar. The second wad of 640 g/m² caused an approximately 3 bar peak on the pressure loading curve. The third wad of 1600 g/m² caused an approximately 5 bar peak on the pressure loading curve.

Figures 59, 60, and 61 illustrate the shoe lubrication pressure variation in the time lines from 10 to 13 seconds, from 48 to 51 seconds, and from 85 to 87 seconds.

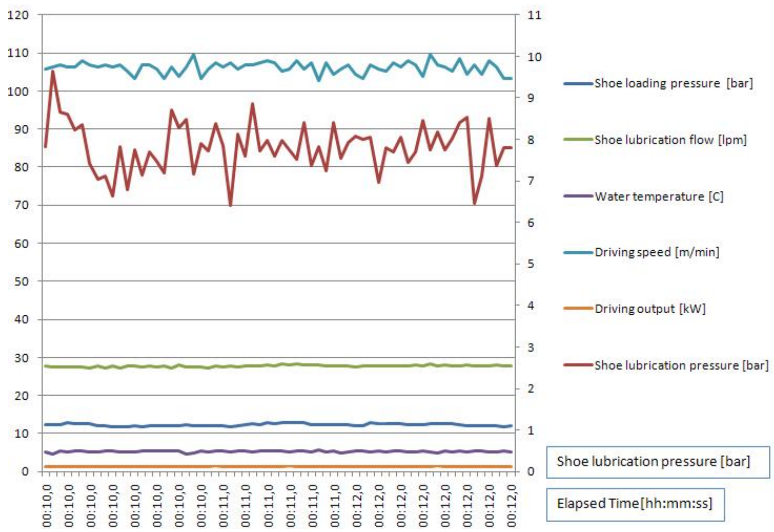


Figure 59 Shoe lubrication pressure; load 13 bar, 160 g/m² wad in the time line from 10 to 13 seconds

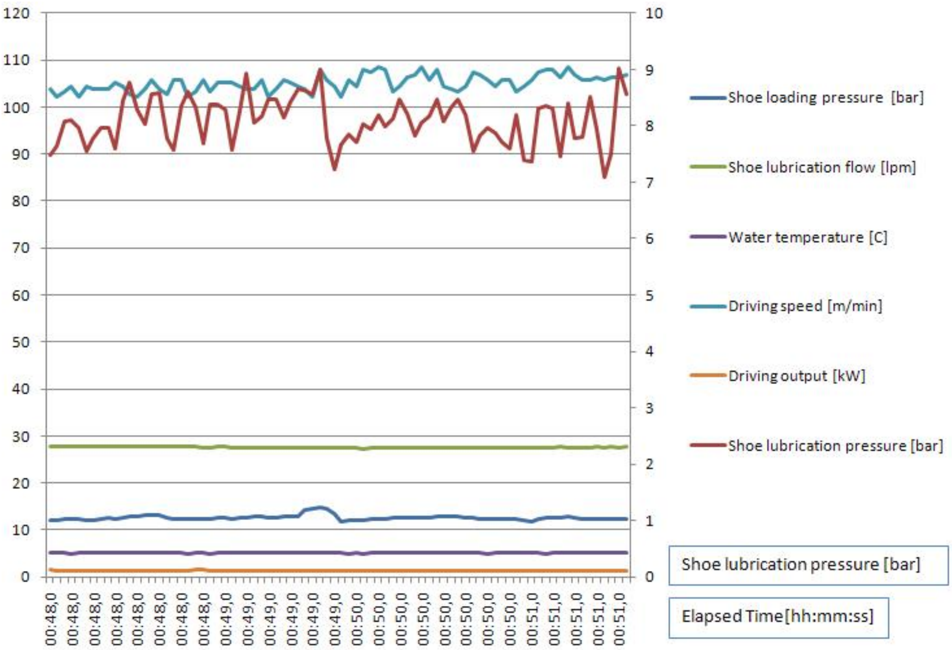


Figure 60 Shoe lubrication pressure; load 13 bar, 640 g/m² wad in the time line from 48 to 51 seconds

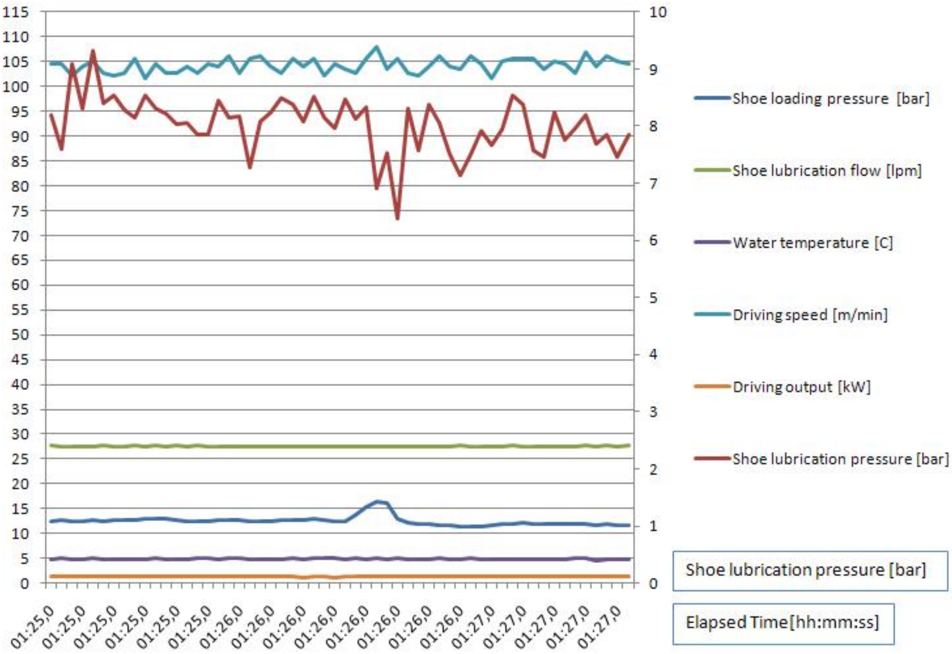


Figure 61 Shoe lubrication pressure; load 13 bar, 1600 g/m² wad in the time line from 85 to 87 seconds

The first wad of 160 g/m² did not have a significant effect on the shoe lubrication pressure. The lubrication pressure fluctuated between 6 and 9 bar. The second wad of 640 g/m² caused a minor drop on the pressure lubrication curve. The third wad of 1600 g/m² caused approximately a few bar drop on the pressure lubrication curve. After the test the seal was inspected visually and only some minor polishing was discovered.

The second wad test was carried out with the following parameters:

- Machine speed: 105 m/min
- Pressure shoe lubrication flow: 22 lpm
- Pressure shoe loading pressure: 38 bar.

Carton was fed into the nip in the stages mentioned earlier. The insertion times were as follows: the first wad after 7 seconds, the second after 34 seconds, and the third after 73 seconds. Since the third wad made the largest impact, the Figure 62 illustrates the shoe loading pressure variation in the time line from 73 seconds until 75 seconds.

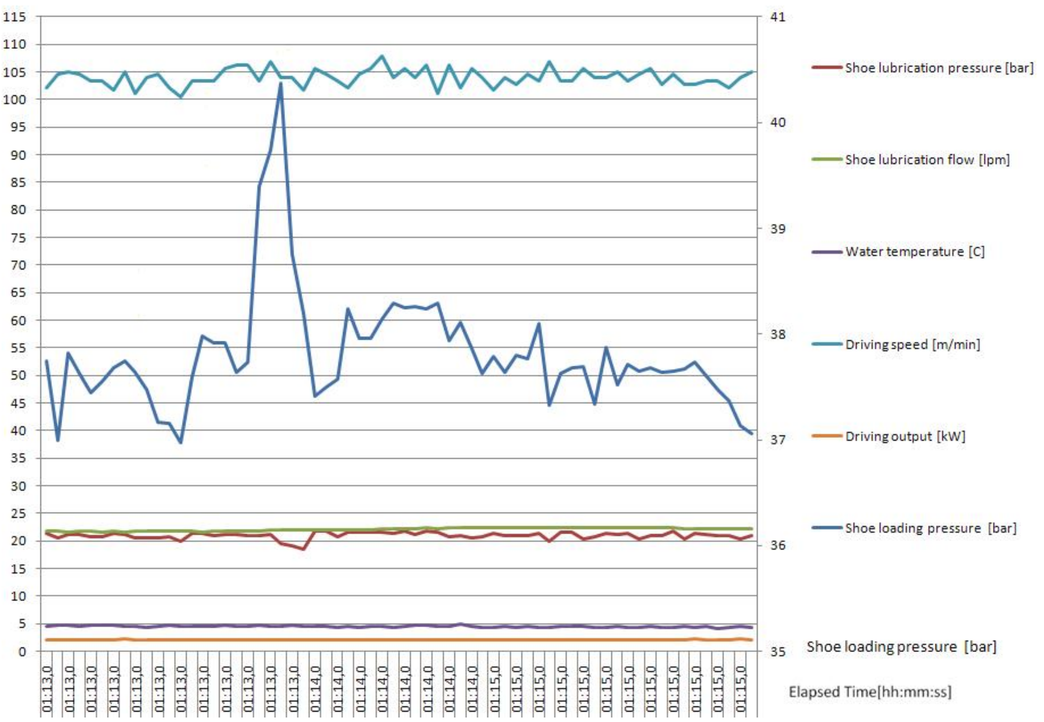


Figure 62 Shoe loading pressure 38 bar, 1600 g/m² wad in the time line from 73 to 75 seconds

Figure 63 illustrates the shoe lubrication pressure variation in the time line from 73 seconds until 75 seconds.

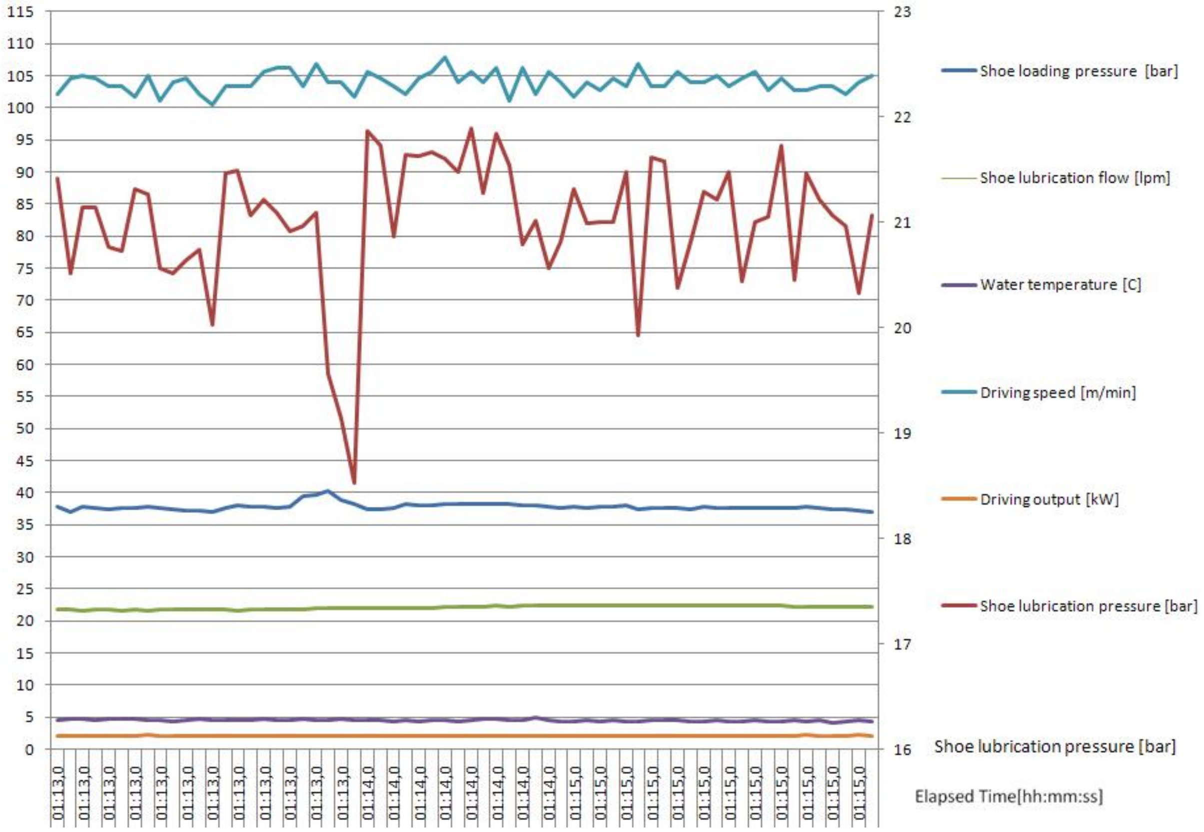


Figure 63 Shoe lubrication pressure; load 38 bar, 1600 g/m² wad in the time line from 73 to 75 seconds

The third wad of 1600 g/m² caused an approximately 5 bar peak on the pressure loading curve and approximately a few bar drop on the pressure lubrication curve. After the test the seal was inspected visually and there was some more minor polishing.

The third wad test was carried out with the following parameters:

- Machine speed: 105 m/min
- Pressure shoe lubrication flow: 18 lpm
- Pressure shoe loading pressure: 60 bar.

Carton was fed into the nip in three stages. The insertion times were as follows: the first wad after 23 seconds, the second wad after 44 seconds, and the third wad after 63 seconds. Figure 64 illustrates the shoe loading pressure variation in the time line from 44 seconds until 46 seconds.

Figure 64 Shoe loading pressure 60 bar, 1600 g/m² wad in the time line from 44 to 46 seconds

Figure 65 illustrates the shoe lubrication pressure variation in the time line from 44 seconds until 46 seconds.

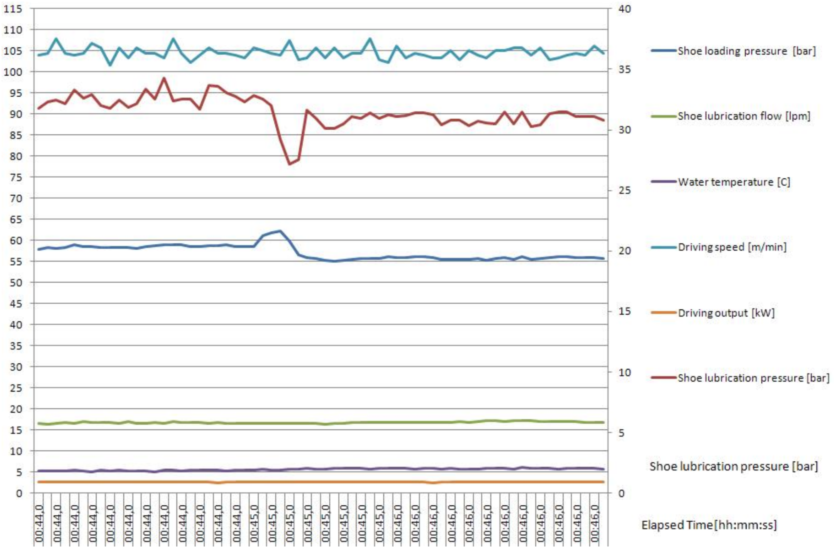


Figure 65 Shoe lubrication pressure; load 60 bar, 1600 g/m² wad in the time line from 44 to 46 seconds

The third wad of 1600 g/m² caused an approximately 6 bar peak on the pressure loading curve and an approximately 5 bar drop on the pressure lubrication curve. After the test the seal was inspected visually and there was again some more polishing.

The fourth wad test was carried out with the following parameters:

- Machine speed: 105 m/min
- Pressure shoe lubrication flow: 42 lpm
- Pressure shoe loading pressure: 80 bar.

Carton was fed into the nip in the stages mentioned earlier. The insertion times were as follows: the first wad after 25 seconds, the second wad after 36 seconds, the third wad after 45 seconds, and the fourth wad after 86 seconds. Figure 66 illustrates the shoe loading pressure variation in the time line from 86 seconds until 88 seconds.

Figure 66 Shoe loading pressure 80 bar, 1600 g/m² wad in the time line from 86 to 88 seconds

Figure 67 illustrates the shoe lubrication pressure variation in the time line from 86 seconds until 88 seconds.

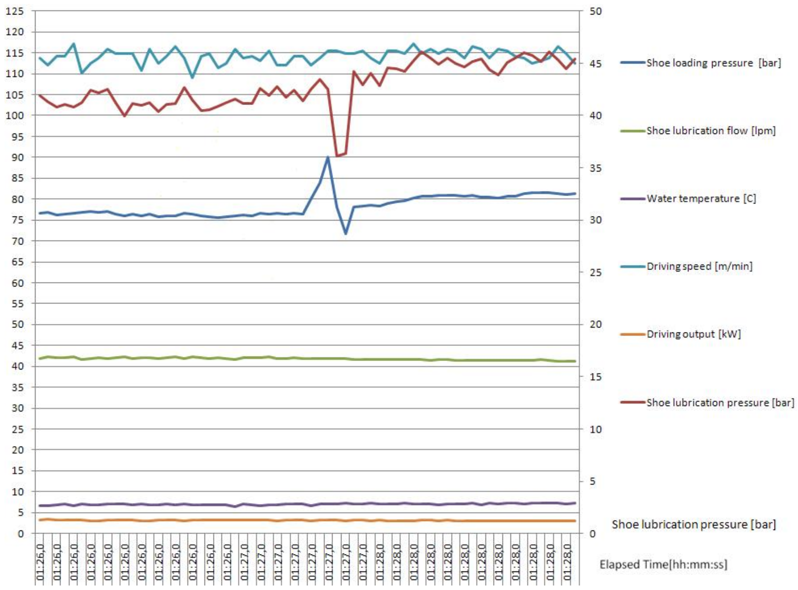


Figure 67 Shoe lubrication pressure; load 60 bar, 1600 g/m² wad in the time line from 44 to 46 seconds

The third wad of 1600 g/m² caused an approximately 15 bar peak on the pressure loading curve and an approximately 10 bar drop on the pressure lubrication curve. After the wad tests the seal was taken out of the shoe and inspected. As Figure 68 illustrates, there was some wear on the incoming side. Also, both edge areas on the front side and the back side were worn. The outgoing side was almost intact. Overall, the condition of the seal was relatively good.

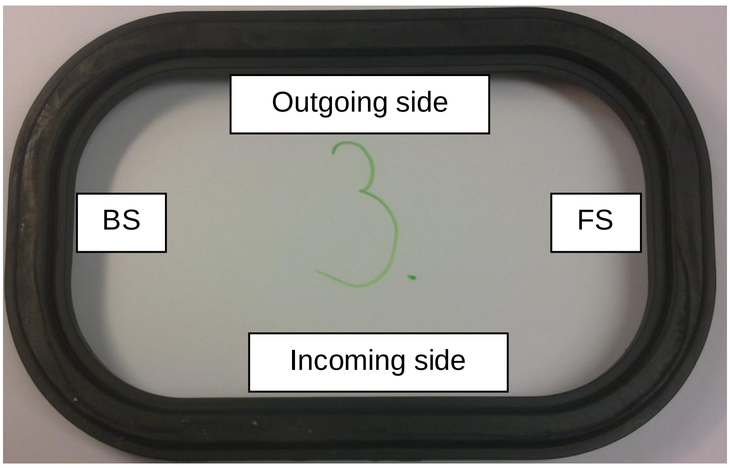


Figure 68 Press shoe seal after wad tests

4 Analysis and discussion

The first test runs were carried out with full lubrication flow for the seal. At the same time the pressure shoe load was gradually increased. The target was to study the correlation between different loads and full lubrication flow to the seal wear.

Tests were carried out in relative short-term runs with relatively low running speeds. The reason for this was, as mentioned earlier, that the guiding of the metal belt was not functioning anymore with higher speeds and loads due to slippage between metal belt and guiding roll. Because of the short duration of the runs the results do not correspond with the actual production circumstances as well as was desired. Despite this, some valuable observations were made.

As can be seen from the graphs of the first and second test the required drive power increases smoothly according to the increase of the pressure shoe load applied. Both graphs show that with a 40 bar load the power output is approximately 1.5vkW. This indicates that the nip behavior is stable and the results can be used as a reference in the following test. For tests to be more reliable, they should be repeated many times. In this case, due to the lack of time, the tests were performed only once. The second test shows that with an 80 bar load the power output is approximately 2 kW. This can be used as a reference value while comparing results with different lubrication flows. An efficient amount of lubrication medium between the seal and the counterpart reduces friction and that can be viewed from the lower power consumption. Inadequate lubrication increases the friction which leads to higher power consumption and causes wearing to the seal.

After the tests the seal was checked and only some minor polishing was found. This would suggest that with a full lubrication flow in different loads, the seal would have enough lubrication and actual wear would not occur. It has to be pointed out that the seal was inspected while attached to the shoe and, because of the location, the visual inspection is not very accurate. Another point is that the test runs lasted only two to four minutes. This is a relatively short period of time to examine wear as a phenomenon.

In the next tests the lubrication flow was gradually reduced together with gradually increased pressure shoe loads. The target was to study the effect of these parameters on the required power output and seal wear. As can be seen from the graphs, if the lubrication flow is reduced to 30 lpm with 40 bar shoe press load, the driving output is approximately 1.7 kW. Compared to results found in the first tests the required power output is only slightly more. This would indicate that the amount of lubrication between the seal and counterpart would diminish only a little. With a pressure shoe load of 80 bar the power output rises to 3 kW compared to power output of 2 kW with full lubrication flow. This would indicate that the seal would slide substantially dryer, which increases the friction between the seal and the counterpart. After the test the seal was inspected again but there were no signs of further wear, even though the seal was not lubricated as comprehensively as with full lubrication flow. Some more minor polishing was found on the seal surfaces. This would indicate that the lubrication flow still decreases the friction and lubricated the seal. Again it has to be pointed out that the test run lasted only three minutes and was performed only once.

With a lubrication flow of 15 lpm the power output was approximately 2.7 kW with a press shoe load of 40 bar. It is almost twice as much as with a full lubrication flow. The driving speed fluctuates quite heavily, which affects the power output. The mean value of the power output remains at the level of approximately 3 kW, even though the pressure shoe load increased to 80 bar. It is approximately at the same level compared to lubrication flow of 30 lpm. This would indicate that the amount of lubrication between the seal and counterpart would correspond to the situation with a lubrication flow of 30 lpm. After the test the seal was inspected again. Some small rubber parts were found from the pressure chamber of the shoe but, except for minor polishing, no more severe signs of further wear were observed.

The next test run was carried out with a constant pressure shoe loading and decreasing the lubrication flow from 50 lpm to 10 lpm. The target was to study the correlation between diminishing lubrication flow and a constant load on seal wear. When the amount of lubrication flow decreases, the driving power required increases. The graph corresponds to the tests performed earlier. After the test the seal was taken out of the machine and it could be investigated thoroughly. As in Figure 54 and 55, it can be seen that the seal was in good condition. There was only some minor polishing on the seal surfaces. The edge areas on both the front and back side had polished slightly more, but the incoming and outgoing sides were in relatively good condition. This indicates that the seal had enough lubrication during the whole testing period.

Wad tests were carried out with moderate lubrication flow for the seal. At the same time, the pressure shoe load was gradually increased. The target was to study what happens in the nip when a wad goes through it with a shoe pressure load on. At first this was done with a relatively small load of 13 bar. As can be seen from the graphs, the first wad of 160 g/m² did not have a remarkable effect on the shoe loading or shoe lubrication pressure. The second wad of 640 g/m² caused a pressure peak of 3 bar to the loading pressure curve and a small drop on the shoe lubrication pressure curve. The third wad of 1600 g/m² caused a pressure peak of 5 bar to the loading pressure curve and a remarkable drop on the shoe lubrication pressure curve. When the wad goes through the nip, it causes a pressure impact on the incoming side of the press shoe and also to the seal. This can be seen as a peak on the press shoe loading graph. This indicates that if the wad is large enough, it has an effect even with smaller pressure shoe loads. Even though it caused a pressure peak, and probably had some negative effects on the seal lubrication, the seal was only slightly polished when checked. As discussed earlier, this is a challenging situation for shoe nip rolls with polyurethane belt, which is vulnerable for external impurities. During these tests there was no effect on the metal belt, and even the largest wads did not cause any damage.

The second wad test was carried out with a 40 bar press shoe load. The third wad of 1600 g/m² caused an approximately 5 bar peak on the pressure loading curve and approximately a few bar drop on the pressure lubrication curve. The third wad test was carried out with a 60 bar press shoe load. The third wad of 1600 g/m² caused an almost similar effect compared to the second test, an approximately 6 bar peak on the pressure loading curve and an approximately 5 bar drop on the pressure lubrication curve. After both of these tests the seal was inspected and some more polishing had occurred.

The fourth wad test was carried out with an 80 bar press shoe load. The shoe lubrication flow was 42 lpm. The third wad of 1600 g/m² caused an approximately 15 bar peak on the pressure loading curve and an approximately 10 bar drop on the pressure lubrication curve. Even though the pressure peak was very remarkable the metal belt remained intact. After the test the seal was taken out of the shoe and inspected. Some more polishing and wear were found on the incoming side of the seal. This is the challenging area in the case of wads. The high pressure impact on the incoming side of the shoe inflicts some breakage on the lubrication of the seal and then the seal will run dry, which causes wearing. Also, both edges on the front and back side were worn. It is challenging to get sufficient lubrication to a relatively long part of the seal on the machine direction due to metal belt contact on the long range. The outgoing side of the seal was intact.

As an overview for test runs, a few things have to be pointed out. Since the function of the metal belt guiding restricted the duration of each test run, it has to be taken into consideration that the test runs were relatively short. As a consequence, studying the wear of the seal in short-term does not give a result that would be comparable to a real production environment where the running periods are much longer. Each test run was carried out only once. To achieve more extensive results the test runs should be repeated multiple times.

5 Summary and conclusions

Hydronip test site lay-out and detail design was fairly demanding because the existing facilities, equipment, and available components restricted the process. The timetable was challenging with component and equipment planning and procurement, as well as implementing all the changes that occurred during the project in practice. This was due to labor shortage, as well as many of the changes that were not taken into account during the design process. Also, many things had to be changed and adjusted in practice on the site in the installation stage, which was also very time-consuming.

The installation phase itself went by reasonably quickly, although some challenges caused by the availability of manpower as well as some delays outside the actual project.

The start-up phase of Hydronip and its components and equipment adjustments caused a lot of challenges. Despite these, the end result was a functional test site with all the essential measuring equipment and data collection means. Diverse and comprehensive instructions for installation, use, and data collection were also produced. Also, from the safety point of view, instructions for design and use were gathered.

Safety issues were the basis for the whole design, manufacture, assembly, and test stages. These were carefully thought through in every step of the process and, as a result, the project was managed safely and systematically. Consequently, versatile and illustrative instructions and manuals were gathered, and they can be used for following projects or modifications relating to Hydronip or some other machines. In particular, various documents for lifting accessories were compiled and, based on those, some instruction material for Metso was prepared. Those official documents can also be used as a basis for similar cases in the future.

As a conclusion for the first tests, it can be stated that when the lubrication flow decreases, it also increases the required power output. To identify the exact amount of lubrication needed for a seal to function properly is difficult. It could be calculated from the pressure balances between the seal and the pressure chamber. Because the shoe is not floating it is challenging to align it totally against the counter roll. During test runs the shoe was not entirely aligned and that caused some pressure unbalance in the pressure chamber. With these studies the right amount of lubrication can only be concluded from the visual inspection of the seal. If the seal is not fully taken out of the machine, it can only be estimated roughly because of the location of the seal. Also, the duration of test runs is quite short for studying the wear of the seal. When the seal was taken out of the shoe after the first tests, it was in relatively good condition. From that it can be concluded that a shoe lubrication flow of 15 lpm is enough even with high loads in short-term test runs.

With modern carton machines the board can be up to 200 -300 g/m². In the case of web brake the carton tail may end up in the nip folded in many layers, and that could build up to 400 to 600 g/m² thick carton wads. Wad tests were carried out even with 1600g/m² wads, which are many times thicker than compared to maximum ones in the production environment. After the tests there was only some minor polishing on the seal surfaces. The edge areas on both the front and back side had polished slightly more, but the incoming and outgoing sides were in relatively good condition. As a conclusion, it can be stated that the metal belt was remarkably durable against the wads and no damage or wear occurred. Also, the seal lubrication seemed to be sufficient enough because there was no severe damage on the seal.

MTS tests showed that with a heavy basis weight felt for cartonboard is required to have enough water space. One felted dewatering seemed efficient, especially in combination with a heated metal belt. A press nip with a 1000 mm long shoe is enough, and it is not worth making it much longer. After the nip the felt should be detached and further dried with metal felt or a belt. An overly long shoe leads to an intense felt marking. In addition to this, excessively high press power applied reduces the felt service life and cause also potential roll or felt marks in the paper. At high press powers, the press would also be sensitive to vibration. As discussed earlier, when using hot pressing, it often leads to a bulk loss, resulting in excessive compression of the web. The bulk indicates web thickness and bulk loss can be reduced by decreasing linear pressures. However, the paper web is weaker at an increased temperature and the improved runnability achieved by the increased dry content will often be lost, since the web becomes weaker. Since the bulk loss is contradictory to the target set for dry content, it should be studied more in case of Hydronip with a long shoe, high loads, and a warmed metal belt.

As discussed earlier, Hydronip costs could be at the same level with SymBelt costs in a similar type of machine rebuild. The metal belt costs could be approximately half of the polyurethane belt costs mainly because of the better durability. The dry content increase with Hydronip could be approximately twice as much as with SymBelt and the same thing with the production increase or steam consumption decrease. As also presented earlier, the break even for Hydronip could be approximately one month less compared to SymBelt. The payback on the investment for Hydronip could be six months shorter compared to SymBelt. Of course, it has to be taken into account that these are only rough estimations and presumptions because the Hydronip construction and process is still under development. But, overall, it seems that with the information gathered within this thesis, the Hydronip could be a profitable investment in rebuilds and also in new machines.

During the thesis some issues came up that should be examined more. The Hydronip pilot machine, or some components of it, could be utilized for these purposes.

To be able to execute long-term test runs some adjustments for the Hydronip have to be made. When accelerating the speed of the Hydronip without pressure shoe seal lubrication, the metal belt guiding functions correctly and keeps the belt at the center of the machine. As observed in the test runs, the metal belt guiding loses its functionality after the machine speed exceeds 150 m/min when pressure shoe seal lubrication is on. This is due to the fact that the water coming out of the nip goes between the corner guide roll and metal belt, which causes slipping and the metal belt loses its controllability. The same phenomenon occurs when the pressure shoe load is raised over 20 bar with the shoe seal lubrication.

The metal belt loop could be arranged more suitably for guiding. When a guiding principle is decided, the arrangement could be changed according to that and accordingly so that it could be studied which parameters most affect the guiding of a stiff metal belt. The guiding of a metal belt could also be examined by arranging the guide roll moving in the machine direction. This would offer versatile adjustment possibilities for guide roll movement. For better metal belt guiding the nip outgoing side could be covered or doctored so that the surface of the corner guide roll would remain dry and no slippage would occur. Relating to that the effect of the friction coefficient between the metal belt and guide roll could be studied with this Hydronip pilot machine. This would enable longer test runs with larger loads.

Metal belt tension could be studied more. By setting up a tension measurement for a metal belt, it could be seen what kinds of variables affect it (stretching the metal belt, warming the metal belt, et cetera).

A pressure shoe seal wearing test should be carried out separately with a smaller scale test machine where the condition of the seal can be monitored easily. With Hydronip it is too difficult and time consuming to take the seal out of the machine to be evaluated. On the other hand, the

Hydronip could be used for a seal wearing test with a new type of pressure means so that the seal can be fastened and removed easily.

The seal material used in Hydronip is the same as that is used in Condebelt. As the tests demonstrated the seal material was good and it has good duration against wear in the Hydronip circumstance. There are still some other good materials that could be used for this purpose. For example, graphite rubber, which is used in demanding suction roll positions, could be an option for this application.

As earlier stated with the MTS test, a heated metal belt itself can improve dewatering and thus raise the dry content of the web. The Hydronip arrangement could be utilized for this purpose. The heating could be managed, for example, with electricity, gas or some other means.

As described in the Hydronip theory, a use of multiple pressure chambers in the machine direction could provide an optimal pressure curve and thus enhance nip dewatering. Different pressure chambers could be arranged with water or steam as a medium and simultaneously the sealing system between the chambers and shoe edges could be examined. The Hydronip pilot machine could be utilized for this purpose with only minor changes to the arrangement.

As an outer seal, a spring loaded seal could be used in this application. This could be added relatively easily to the present arrangement.

The pressure shoe attachment in Hydronip is quite rigid even though it was made slightly floating with rubber plate. Therefore it does not settle completely evenly against the counter roll. With some adjustments the shoe could be made more floating, such as the SymBelt roll shoe design. This would reflect the real shoe nip construction and give more reliable information about the nip and possible shoe sealing and pressure chamber solutions.

If the press shoe is made more floating, it would also allow studies for determining the connection between the lubrication flow and lubrication pressure. This means the efficient lubrication the seal requires with minimum lubrication flow could be determined. The needed amount of lubrication for the seal is quite challenging to estimate but with easy access to seal change it could be observed from the wear of the seal. It could also be observed from the required drive output, but in this case it is very difficult since the driving output is relatively small.

The wear of the seal and the circumstances inside the press shoe could be studied more by adding a temperature measurement into the shoe. This might give more information about what is happening inside the shoe during nip process.

During the first tests that were done, the metal belt welding ruptured. The second metal belt had a much better weld and it lasted well in the following test runs. The Hydronip pilot machine would be an efficient place to study more the metal belt structure, welding, different coatings, etc. The tests could be done on the small scale, and the results could be revalued easily due to easy access and relatively fast metal belt change.

In the first tests the pressure shoe seal was wearing notably on the incoming side. A shower pipe was assembled on the incoming side of the shoe to enhance the lubrication. In the following tests the extra lubrication was not needed because there was not that significant wear occurring on the incoming side. The reason for this is still an open question. Even though the incoming side of the seal remained quite intact, both sides of the seal in the machine direction wore quite heavily. Managing the lubrication on the seal edges could be one thing to study more in the future and the Hydronip pilot machine could be utilized for that.

As an overall evaluation for the whole Hydronip arrangement, a little too much was implemented based on earlier designs and components for Superhydronip and the wire guiding test place. With some larger-scale modifications Hydronip could have been more versatile, and especially easy to access the test arrangement, which could have been used for some other applications as well. Even then the Hydronip was safely designed, assembled, and it could be used to illustrate the function of a press shoe loaded nip surrounded with a metal belt and felt.

This thesis also demonstrated that even though there are still a considerable number of details unsolved, the concept of Hydronip, at least on the small scale, is functioning. Short-term tests for seal functioning showed that the seal can be lubricated sufficiently under different kinds of nip load situations. Also, the wad tests demonstrated that the metal belt is durable against different sizes of external particles going through the nip. The MTS tests showing remarkable dry content increases combined with rough cost calculation and the basic function of the machine in test runs show that with some more studying Hydronip could be a promising new product for water removal from a press section. At least some parts or components of it can be shortly exploited in the distinct production environment.

The sealing system of the pressure chamber was functioning well with the test site surrounding. When moving to the larger scale production machines, some challenges will be met in arranging the seal system for wide machines. Also, when using multiple pressure chambers, the function of the sealing system will be crucial.

There are many things that have to be considered before implementing these kinds of solutions in a real production environment. With the large scale of machines the correct function of a metal belt guiding is challenging. The precise guiding requires very high accuracy from the guiding devices. Also the water or some other medium between the metal belt and guiding rolls causes serious challenges with guiding due to slippage, as observed also during test runs. With a stiff metal belt guiding rolls should be very rigid or even deflection compensated with large machines. If some irregularity occurs on the metal belt, it can damage the welded seam.

The counter roll plays an important role while implementing a Hydronip type of solution with heavy linear loads. The counter roll has to be stiff or large enough to withstand heavy loads. If the loads are increased, it also requires development of the counter rolls.

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