



# Concept study for new Reel Spool Storage

---

Konceptstudie för nytt spindelmagasin

---

Viktoria Ekstorp

Faculty of Health, Science and Technology

---

Degree Project for Master of Science in Engineering, Mechanical Engineering

---

30 hp

---

Supervisor: Mikael Grehk

---

Examiner: Jens Bergström

---

2020-07-02

---



## Abstract

At the end of a tissue machine the tissue is wound on spools. When a roll is completed a new, empty spool should automatically be lowered into position and take over the winding process. To make this process as smooth as possible the overhead spool storage is used where the spools both are stored and transported back. The purpose of the overhead spool storage is to store empty spools, provide the primary arm with new spools and transport the spools back along the machine. There are several drawbacks with the current design of the storage. Spools get stuck and there have been some accidents where the spool got stuck at one side and tumbled down to the floor or upon machine parts located below. The purpose of this project is to improve the performance of the spool storage by reducing or eliminating above-mentioned problems. The goals of the project are to study the current design and list its pros and cons. Moreover, a requirement specification should be made. Finally, a new concept should be presented.

To get a deeper understanding of the product a pre-study of the current storage design was made. This project is built on the product development process. The pre-study together with material collected from interviews with Valmet employees, a requirement specification was made. Two concept generation sessions were performed, one with experienced Valmet employees, and one with students to increase the possibility for new perspectives on the storage. To screen out the best concept, selection charts and Pugh's relative decision chart were used.

The best alternative of the new concepts was an automated traverse system with fixed storage positions primarily in a stand between the primary arm and the Yankee frame. For increased storage capacity, storage positions could be placed anywhere along the path of the traverse as long as these positions do not interfere with the production line. This solution fulfills all requirements in the requirement specification except the wish for the cost of the new design to be lower than the cost of today's design. However, the quoted price and the cost for the current design given in the requirement specification are not completely comparable to each other. It is important to consider the increase in value that comes with the fulfillment of the wish to be able to choose which spool to use.

The new concept is a valid replacement for the current design of the spool storage. The problem with spools getting stuck due to dust and misalignment is almost eliminated and the new solution has controlled movements and will thus increase the safety significantly.

The product development process is easy to follow and applicable even for more complex products. It provides a clear documentation which for instance makes it easy to go back for more info regarding previous decisions. Thus, it can be concluded that the product development process is a useful and well-established method for generating and selecting new solutions.



## Sammanfattning

Vid slutet av en pappersmaskin rullas papret upp på spindlar. När en pappersrulle är klar ska en tom ny spindel automatiskt sänkas ned i position för att ta över upprullningsprocessen. För att göra denna process så smidig som möjligt finns det ett spindelmagasin där spindlarna både lagras och transporteras tillbaka. Syftet med spindelmagasinet är att lagra tomma spindlar, bistå primärarmen med nya spindlar och transportera tillbaka spindlarna längs maskinen. Det finns flera problem med dagens design av spindelmagasinet. Spindlar fastnar och det har skett olyckor där spindeln fastnat på ena sidan och till följd fallit till golvet eller maskindelarna nedanför. Syftet med detta projekt är att förbättra spindelmagasinets prestanda genom att kolla på ovanstående problem. Målen är att studera spindelmagasinets nuvarande design och lista dess fördelar och nackdelar. En kravspecifikation för magasinet ska tas fram, och slutligen ska ett nytt koncept presenteras.

För att få en djupare förståelse för produkten har en förstudie gjorts gällande dagens design av spindelmagasinet. Projektet bygger på produktutvecklingsprocessen. Från förstudien tillsammans med insamlat material från intervjuer med Valmetanställda gjordes en kravspecifikation. Två konceptgenereringssessioner utfördes, en med erfarna Valmetanställda, och en med studenter för att öka möjligheterna för nya perspektiv på magasinet. För att sälla fram det bästa konceptet användes elimineringsmatriser och Pughs relativa beslutsmatris.

Det bästa alternativet av de framtagna koncepten var ett automatiserat traverssystem med fasta lagringspositioner primärt placerade i ett ställ mellan primärarmen och Yankeestativet. För en ökad lagringskapacitet kan lagringspositioner placeras var som helst längs traversens bana så länge dessa inte kommer i vägen för produktionslinan. Denna lösning uppnår alla krav i kravspecifikationen utom önskemålet att den nya designen ska ha lägre kostnad än dagens design. Dock är offererat pris och kostnad given för dagens design i kravspecifikationen inte direkt jämförbara med varandra. Det är också viktigt att ta i beaktning det mervärde och den ökade kundnytta som följer med uppfyllandet av önskemålet att kunna välja spindeltyp.

Det nya konceptet är ett bra alternativ till den nuvarande varianten av spindelmagasin. Problematiken kring att spindlar fastnar på grund av damm och snedställning är i princip eliminerad och den nya lösningen har kontrollerade rörelser och ökar därmed säkerhetsaspekten markant.

Produktutvecklingsprocessen är lätt att följa och är applicerbar även på mer komplexa produkter. Den bistår med en tydlig dokumentation som exempelvis gör det lättare att gå tillbaka för mer information gällande de beslut som tagits. Därför kan även slutsatsen dras att produktutvecklingsprocessen är en användbar och väletablerad metod för att generera och sälla fram nya lösningar.



## Table of Contents

Abstract .....	3
Sammanfattning .....	5
1 Introduction .....	9
1.1 Background and problem formulation .....	9
1.2 Purpose and aim of the project .....	9
1.3 Delimitations .....	9
1.4 About Valmet .....	10
2 Current design .....	10
2.1 Standard reel spool storage .....	10
2.2 Automatic reel spool storage .....	11
2.3 Interfaces and surrounding equipment .....	12
3 The product development process .....	13
3.1 Start-up and planning .....	13
3.2 FMEA .....	14
3.3 Identification of needs and requirements .....	14
3.3.1 Step 1: Collect raw data from customers .....	14
3.3.2 Step 2: Interpret data in form of customer needs .....	14
3.3.3 Step 3: Organize the needs hierarchically .....	15
3.3.4 Step 4: Determine the relative significance of the needs .....	15
3.3.5 Step 5: Reflect on the results and the process .....	15
3.4 Requirement specification .....	15
3.5 Concept generation .....	16
3.5.1 Benchmarking .....	16
3.5.2 Brainwriting 6-3-5 .....	16
3.5.3 Morphological chart .....	16
3.6 Choice of concept .....	17
4 Method .....	18
4.1 Start-up and planning .....	18
4.2 FMEA .....	18
4.3 Identification of needs and requirements .....	18
4.4 Requirement specification .....	18
4.5 Concept generation .....	19
4.6 Choice of concept .....	19
4.7 Further development .....	20

5 Results.....	20
5.1 Start-up and planning .....	20
5.2 FMEA.....	20
5.3 Analysis of current design.....	20
5.4 Requirement specification.....	21
5.5 Concept generation .....	22
5.5.1 Benchmarking.....	22
5.5.2 Morphological charts for each concept generation session .....	22
5.5.2 Morphological charts.....	24
5.6 Choice of concept .....	24
5.6.1 Transport.....	24
5.6.2 Storage.....	29
5.6.3 Combined concepts .....	31
5.7 Further development .....	32
5.7.1 Modelling and further description of concept .....	32
5.7.2 Sequence charts.....	34
5.7.3 Quotation from supplier .....	35
6 Discussion .....	36
6.1 The final concept .....	36
6.2 The method and process.....	37
6.3 Future work .....	38
7 Conclusions .....	39
Acknowledgements .....	39
References .....	40
Appendices.....	41
Appendix A – GANTT-schedule .....	41
Appendix B – Project Risk Analysis .....	42
Appendix C – FMEA.....	43
Appendix D – Requirement specifications .....	44
Appendix E – Explanation of partial solutions .....	46



# 1 Introduction

## 1.1 Background and problem formulation

At the end of a tissue machine the tissue is wound on spools called either core shafts or reel spools. When the tissue is wound on the spools the diameter grows with time. When the diameter reaches about three meters in diameter the rolls are completed. When a roll is completed a new, empty spool should automatically be lowered into position and take over the winding process. To make this process as smooth as possible the overhead spool storage is used, marked green in Figure 1 below.



*Figure 1: Tissue machine. Spool storage marked in the green area.*

The purpose of the overhead spool storage is to store empty spools, provide the primary arm with new spools and transport the spools back along the machine.

The company currently have an ongoing project, called Soft Reel 2.0, to develop a new reel system. The function of the reel system is to thread the sheet onto the cores, continuously and controlled wind a wrinkle-free sheet and to transfer the sheet to a new spool. This thesis is a part of that project focusing on the development of a new spool storage. There are several drawbacks with the current design of the storage. Spools get stuck on the rails they roll on due to dust and misalignment, and there have been some accidents where the spool got stuck at one end and tumbled down to the floor or upon machine parts located below. This could cause critical damage to the machine and if someone is beneath, this could have fatal consequences. Moreover, the transport of the spools is time consuming.

## 1.2 Purpose and aim of the project

The purpose of the project is to improve the performance of the spool storage by looking at the above-mentioned problems.

The goals of the project are to study the current design and list its pros and cons. Moreover, a requirement specification should be made. Finally, a new concept should be presented including a cost comparison with today's design.

## 1.3 Delimitations

This is a concept study. This study includes further explanation of the final concept, event diagrams, and an overall 3D-model in CAD for visualization and further investigation and analysis of the concept. This report does not include detailed engineering work of the concepts, such as drawings, choice of material, programming or manufacturing.

The project includes the spool storage solely, however, some surrounding parts in the tissue machine are allowed to be modified. Example of such are the lifting table and the shaft puller.

Surrounding parts that cannot be modified are the winding section, the primary arm and the design of the spools. Moreover, it is assumed that the spools already are provided with new cores and thus, the process of putting these cores on the spools is out of the scope of this project. Lastly, it is also assumed that an identification system for the spools already is developed by Valmet, and ready to use in this project.

The focus of this project is to develop new concepts for the automatic reel spool storage, thus, concept generation for the standard spool storage is out of the scope of this project. However, a requirement specification should be made for both versions.

The resources of the project are limited to 800 hours, which corresponds to 30 HP.

#### 1.4 About Valmet

Valmet is a leading global developer and supplier of technologies, automation and services primarily in the pulp, paper and energy industries. The company has over 200 years in industrial history and delivered its first paper machine 1953. Valmet in Karlstad delivers complete tissue machines and associated equipment to customers worldwide. Additionally, Valmet Karlstad also provides service and aftermarket products and services [1].

## 2 Current design

Today Valmet have different versions of the spool storage depending on machine type and customer need. The standard reel spool storage and the automatic reel spool storage are presented below.

### 2.1 Standard reel spool storage

The current design of the standard spool storage is presented in Figure 2. This is the simplest design of the storage and is not fully automatic. To lift a spool from the lower rails to the storage, external equipment such as a traverse is used. There are guides (E) to help steering down the spool correctly onto the storage rails (D). The spools have special tracks to fit the rails but roll freely and are transported back to the pick-up position by a pusher (F) controlled by a pneumatic cylinder (G). The pick-up position is defined as the position where the spool must be confirmed before it can be lowered to the winding level by lowering arms (A) controlled by hydraulic cylinders (B). On the lowering arms dampers (C) are placed to absorb the impact of the moving spools. The purpose of the lowering arms is to lower the spool placing it in the primary arm. The primary arm is further explained in section 2.3.

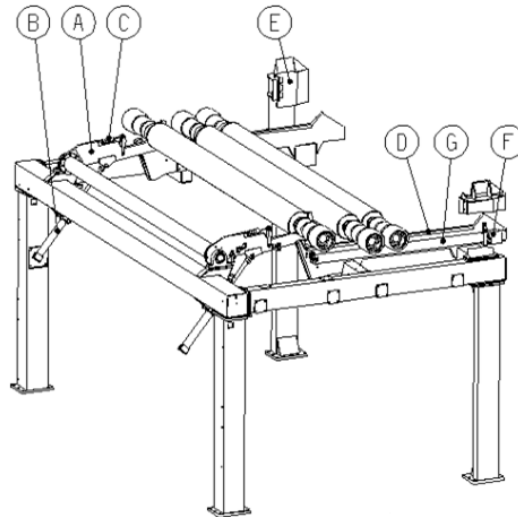


Figure 2: Standard spool storage.

## 2.2 Automatic reel spool storage

The design of the automatic spool storage is presented in Figure 3. This design is similar to the standard solution with lowering arms (A), lowering arm hydraulic cylinders (B), dampers (C) and storage rails (D). This solution has multiple pushers (E) and their corresponding pneumatic feeding cylinders (F). The spools often roll by themselves all the way to the pick-up position without help from all the pushers. Since all pushers must finish before the operators can enter the area below the storage, this process is time consuming. In addition, this model also contains lifting arms (G) controlled by hydraulic cylinders (H). The purpose of these are to return the spools from the winding level back to the spool storage without having to use external equipment. In the figure, (I) shows the pick-up position. This storage type is longer than the standard solution and contains multiple pushers to transport the spools back to the pick-up position.

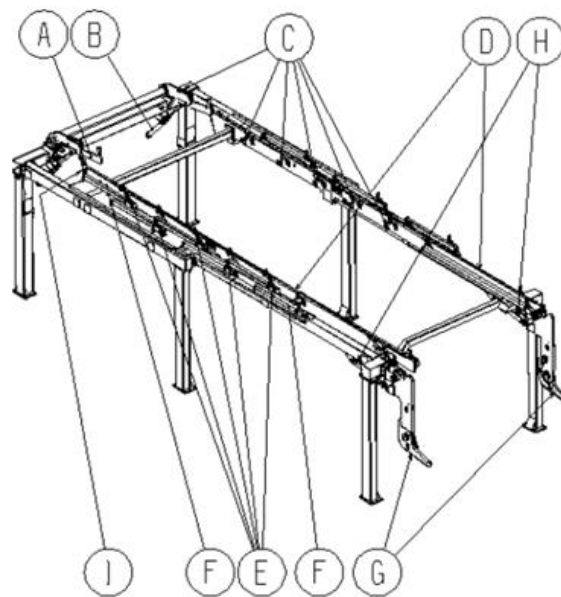


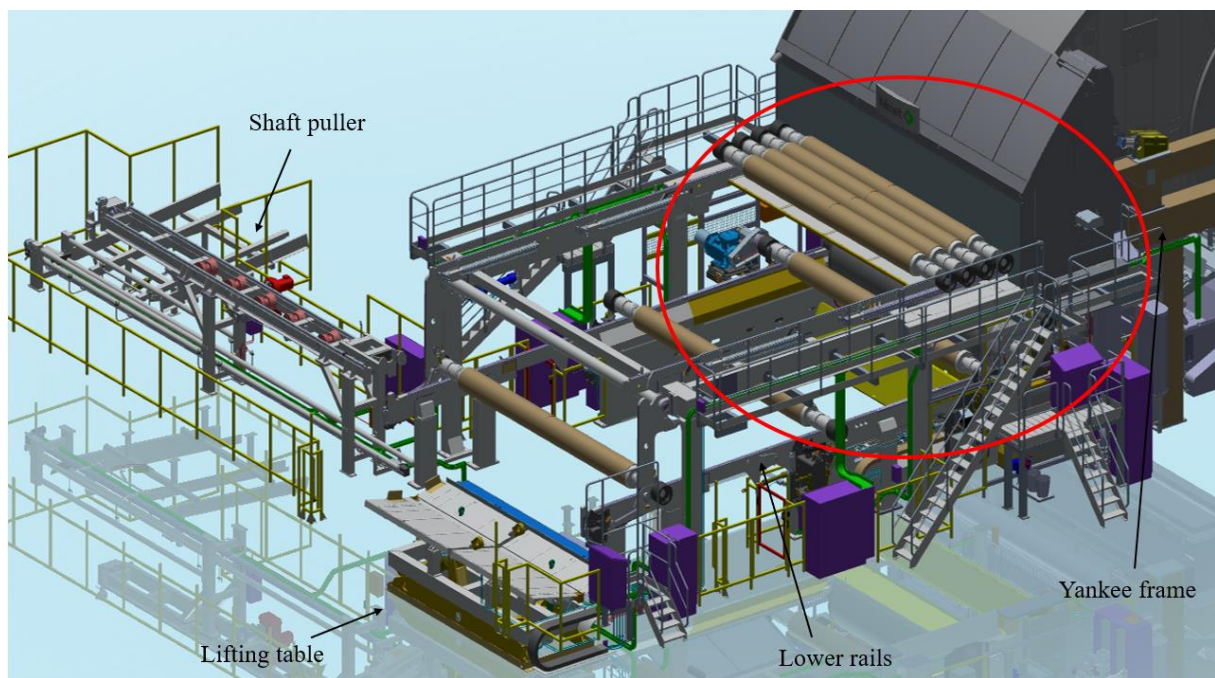
Figure 3: Automatic spool storage.

### 2.3 Interfaces and surrounding equipment

When the spool leaves the lowering arm it also leaves the spool storage. To fully understand the process and to be able to develop new concepts for the storage, it is of interest to fully understand the interfaces and the surrounding equipment. Some of these, frequently mentioned further in the report, are presented in Figure 4.

There are two different kind of spools, core shafts and reel spools. Core shafts are provided with cores for the paper to be wound onto, whereas reel spools have the paper directly wound onto the surface of the spool. Thus, core shafts can be separated from the finished paper roll, provided with new cores and directly sent to the spool storage, while reel spools go with the finished paper roll to further processing.

When a paper roll is finished it is transported along the lower rails. The shaft puller is located beside the production line. Its purpose is to extract the core shaft from the complete paper roll. The lifting table lifts the paper roll into position for the shaft puller to grab the spool, and when the spool is pulled out, the table lowers the roll to a level where it can exit the machine. Thereafter, the table is equipped with cores and raised into a position where the shaft puller can return the spool inserting it into the new cores on the table. Lastly, the table raises into a position where the lifting arms can pick it up and transport it to the spool storage.



*Figure 4: Surrounding equipment.*

Figure 5 shows a close-up of the area circled in red in Figure 4. The lowering arms transport the spool from the spool storage to the winding section and the primary arm. The primary arm presses the spool against the reel drum to start the winding of the paper. Thereafter the primary arm keeps on pressing until the spool reaches the rails where the secondary carriage takes over and keeps pressing the spool towards the reel drum. To protect the spools from debris, a dust cover is used to separate the spools from the production line.



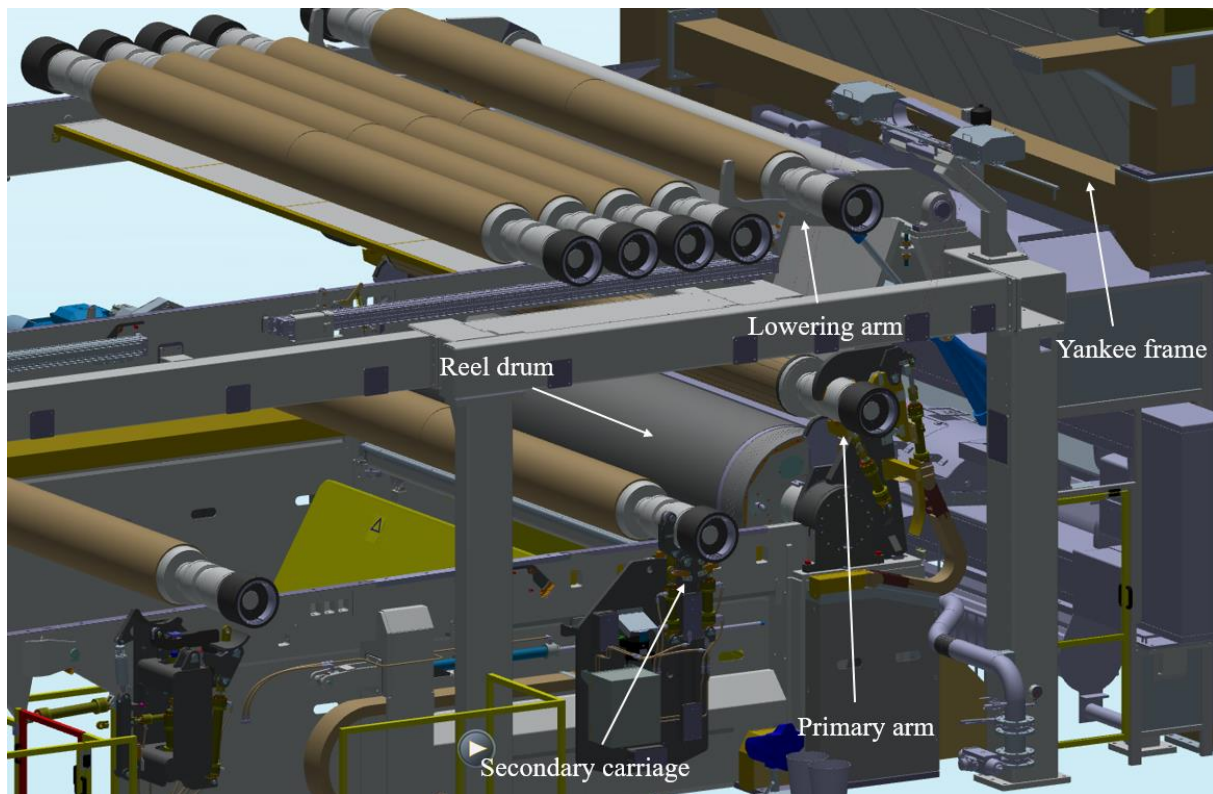


Figure 5: Close-up of circled area in Figure 4.

The dimensions and space between parts differ depending on machine type. For a so called 100-machine where the paper width is around 2700 mm, the diameter of the spools can be 270-350 mm and the weight of the spools 900-1300 kg. For a 200-machine with a paper width of 5600 mm, the diameter of the spools is 420-550 mm and it weights around 3300-4500 kg.

The space beside the reel system is limited and often occupied by external equipment. Moreover, the space between the Yankee frame and the primary arm is limited and differ depending on machine type.

### 3 The product development process

A systematic product development process is preferable for multiple reasons. It helps to focus the work on the problem and supports the generation of many alternative solutions. Furthermore, it provides checklists and a continuous documentation to make sure nothing is excluded [2]. Moreover, a detailed documentation contributes to a good foundation for future work and improvements. A well-defined development process provides a quality assurance regarding the final product [3].

#### 3.1 Start-up and planning

A project plan defines the problem to be solved, a preliminary time plan, resources and the responsible project members, and works as a contract between the project group and the customer. Some usual topics included are background, goals, project organization, time plan, project risk analysis and documentation [4].

A project risk analysis identifies the risks that affect the project. One simple way to do this is with the *mini risk method*. This method includes ranking the risks and recommending actions to minimize these risks. The *probability* that a risk will occur and the *consequence* this will

have on the project is graded from one to four respectively, where four corresponds to highest probability and worst impact on the project. The risk factor is the product of these two. When the ranking of the risks is done, the project group suggests actions to minimize these risks depending on their risk factors [4].

### 3.2 FMEA

A FMEA (Failure Mode and Effect Analysis) is a useful tool for analyzing the reliability of a product. In this method, the product development team systematically look at the different parts of the product identifying possible failures and risks, their probability, their consequences and the possibility to detect these risks. These three factors are graded from one to ten and the product of these is called the risk priority number. In this way the different risks are graded and prioritized accordingly. Thereafter, actions to lower the risks are specified and a responsible person for these actions is assigned [2, 5].

### 3.3 Identification of needs and requirements

David Dunne [6] speaks of the importance of user-centered design and to include the user in the design process. This to get a deeper understanding of the problem before attempting to generate solutions. This requires the product developers to empathize with the customers in order to fully understand their needs, referred to as *empathic design*. The first step in the product development process is to identify the customer needs and requirements. This is an important step to ensure a complete requirement specification and a result that takes several different aspects into account.

Ulrich and Eppinger [3] introduce a five-step method to detect customer needs.

1. Collect raw data from customers.
2. Interpret raw data in form of customer needs.
3. Organize the needs hierarchically in primary, secondary and (if necessary) tertiary needs.
4. Determine the relative significance of the needs.
5. Reflect on the results and the process.

#### 3.3.1 Step 1: Collect raw data from customers

The authors clearly state the importance of a direct flow of information between customer and the product development team. The information is usually collected in three different ways. Firstly, a typical way of collecting information is to have *interviews with stakeholders*. The second way is to collect information with the use of *focus groups*. Here, a moderator leads a discussion with a group of eight to twelve customers for approximately two hours. This discussion usually takes place in a room with a one-way mirror, allowing the development team to observe the discussion. However, this method is more expensive due to the costs of, for example, rental of room, participant compensation etc. Lastly, *observations of the product in use* could be done to collect information [3].

#### 3.3.2 Step 2: Interpret data in form of customer needs

Statements and data collected from the stakeholders can be rephrased into customer needs. Ulrich and Eppinger [3] gives five guidelines for the rephrasing process to ensure an effective interpretation.

- Express the needs in terms of *what* the product should do, not *how* it should do it.

- Express the needs as detailed as in the customer statements to avoid loss of information.
- Try to use positive formulations. Example: “The product can be used in wet conditions” instead of “The product should not stop working in wet conditions”.
- Express the needs as product properties.
- Avoid the expressions *must* and *will*. These expressions show the importance of the needs. It is recommended to wait with this until step 4.

### 3.3.3 Step 3: Organize the needs hierarchically

The results of step 1 and 2 can now be organized and divided into groups of primary general needs associated with secondary more detailed needs. For complex products the secondary needs could be further divided into tertiary needs. The needs should be grouped based on their similarity, and a new label or need statement should be assigned to the group. The group label are primary needs and the members of the group are secondary needs [3].

### 3.3.4 Step 4: Determine the relative significance of the needs

In this step the needs are weighted based on relative importance. This can generally be done in two different ways. The first way is to rely on the competence and experience of the product development team to do the weighting. The second way is to do further customer surveys [3].

### 3.3.5 Step 5: Reflect on the results and the process

The last step in this method is to look over the results and the process used to find the needs. Even if the process is well-structured it is not an exact science. Therefore, it is suitable to take a second look to make sure all needs are taken into consideration [3].

## 3.4 Requirement specification

The process in chapter 3.3 leads to an initial requirement specification giving the information of *what* the product should do. Later in the process, this document will be the starting point for the concept generation phase. The purpose of the product specification is to ensure that all stakeholders and aspects are taken into consideration and to give all the partakers of the project a unified goal. The document will help in the steering of the development process, in the concept generation phase and finally in the choice of concept [2].

When speaking of requirements these can originate from different sources, and thus be divided in three categories accordingly:

1. Requirements already given in the assignment from the beginning, both explicit and implicit.
2. Requirements retrieved from analysis and clarification of the assignment.
3. Requirements that emerge as a result of decisions made during the development process.

Moreover, the requirements can be divided into two main categories. The first one includes the requirements that are associated to the functions of the product, i.e. the functional properties and the expected behavior of the product. This group of requirements is the driving force for solutions. The second category includes the requirements that limit the product solutions. An example of a limiting criterion is a maximum weight or cost. This group of requirements excludes some solutions and are therefore solution limiting [2].

Another way of classifying the requirements is whether it is a demand or a wish. A demand is defined as a requirement that must be fully met whereas a wish can be more or less fulfilled depending on the solution. The wishes are usually weighted according to their importance [2].

### 3.5 Concept generation

In a product development process creativity is needed to create something new. There are several different ways to trigger creativity and gather inspiration for ideas. Some methods to help with this process is presented below.

In their article, Girotra et al. [7] investigates the significance of different group structures in the idea generation phase and their impact on the quality of the best ideas. Specifically, they study the efficiency of a team structure and a hybrid structure. Team structure is defined as a group where the members work together during the whole process whereas in the hybrid structure, the members first work individually and then come together. According to their theory, four different variables have an impact on the quality of the best idea. These are the average quality of the ideas generated, the number of ideas generated, the variance in the quality of these ideas and the ability of the group to distinguish the quality of the ideas. They conclude that groups working according to the hybrid structure have higher quality of their best ideas than the best ideas generated by groups working according to team structure. In their study the group with hybrid structure generated more ideas that were of higher quality in average. Moreover, this group were better at recognizing the best ideas. The authors also investigate the more commonly used brainstorming method and the conventional arguments that this method is beneficial due to its interactive buildup of ideas. However, they conclude that these arguments do not have experimental support. The result of their study shows that this method does not generate more ideas, and the ideas built from previous ideas are not proven better than any other random idea.

#### 3.5.1 Benchmarking

Benchmarking is a method based on comparison with other products on the market with similar functions to that of the product in question or to the subfunctions of the product [3, 8]. There are four different types of benchmarking. *Internal benchmarking* which is a comparison with internal departments, *competitor-oriented benchmarking*, a comparison with competing products and their functions, *benchmarking of functions*, which is a comparison with similar functions used in the same branch, and finally there is *general benchmarking*, a comparison with functions of processes regardless of branch [9]. However, Dörner [10] speaks of the danger of generating ideas from already existing products. He points out that experience could be of great help, but also bring conservatism, inhibiting the creation of new creative ideas.

#### 3.5.2 Brainwriting 6-3-5

This is a method developed by Bernd Rohrbach. The purpose here is to use the creativity of the whole group for each idea. Every participant gets three papers each to write their ideas on (one idea per paper). After five minutes, the participants send their ideas to the next person who will try to develop the ideas further. After another five minutes, the participants switch the paper once more. This continues until all members have had all the ideas. This process should be done in silence. If the participants do not understand an idea they should keep writing after their own interpretation. Finally, all the ideas should be presented and discussed [2, 8].

#### 3.5.3 Morphological chart

This is a method to gather ideas for partial solutions based on the identified requirements or functions of the product. This method provides many partial solutions in a short amount of time. Moreover, it deflects the focus from the intractable main problem and breaks it down to smaller problems. The session starts by listing all requirements or functions on a whiteboard so all participants can see them. All members write down partial solutions to every function on post-



it notes, one solution per note. When the team is done, all solutions are put up on the whiteboard. The different combinations of solutions, the concepts, are then discussed further within the group [8].

A morphological chart is a great way to combine partial solutions for different functions into possible complete concept for the whole system. Concepts that does not fulfill the requirements, that does not have geometrically and physically compatible solutions or that are unreasonable are discarded [2].

### 3.6 Choice of concept

Pahl and Beitz [11] present different methods for finding, evaluating and selecting the concepts. They discuss the importance of reducing the initially unattainable number of concepts at the earliest possible moment. Firstly, the partial solutions that do not fulfill the demands in the requirement specification are deselected. This step is already ongoing from the last steps of the concept generation phase where a rough screening was made.

The authors further suggest a selection chart according to Table 1 where each solution is evaluated in regard to compatibility to the overall task and to other partial solutions, the fulfillment of the demands on the requirement list, if the solution is realizable in respect of for example layout and if the solution is expected to be within the cost limit. Further aspects to consider in the selection chart are safety and ergonomic conditions and compatibility with the company. Concepts with one or more no (-) will be eliminated. All other concepts will move on to the next step of screening.

Table 1: Selection chart from Pahl and Beitz.

Selection chart for:									
Concept no.	Compatibility	Fulfills demands in req. list	Realizable	Within cost limit	Safe and ergonomic	Suits the company	Adequate information	Selection criteria: (+) Yes (-) No (?) Lack of information (!) Check req. list	
								Decision: (+) Pursue solution (-) Eliminate solution (?) Collect information (!) Check req. list for changes	
								Comment	Decision
1									
2									
3									
4									
...									

The second step is to further investigate the remaining solutions with *concept screening*, also called Pugh's method, that can be applied with a relative decision chart, Table 2. Here, the concepts are compared in how well they fulfill the demands and wishes compared with a reference solution. The reference solution is preferably a current solution within the company or a competitor solution. For every requirement the concept is marked if it is better than (+),

equal to (0), or worse (-) than the reference solution. Concepts proceeding to further development are the ones with highest net values [2].

Table 2: Pugh's relative decision chart

Criteria	Concept no.				
	Ref.	1	2	3	...
Demand A	D A T U M				
Demand B					
...					
Wish A					
Wish B					
...					
Sum +					
Sum 0					
Sum -					
Net value					
Ranking					
Further development					

## 4 Method

### 4.1 Start-up and planning

Background, problem formulation and goals are already defined in the beginning of this report. Additionally, a time plan using a GANTT-schedule and a project risk analysis according to the mini risk method was made.

### 4.2 FMEA

A general FMEA was made early in the project to identify the overall risks. This to be aware of the risks and take these into account when generating the concepts. The document was updated and renewed for the final concept when more details regarding the construction were known.

### 4.3 Identification of needs and requirements

To collect raw data from stakeholders, interviews were made. It would be ideal to interview the end customers, however it was hard to get in touch with them. Therefore, interviews were made with Valmet employees highly connected to the project in different ways. Moreover, one end-customer have been asked about the spool storage directly by a Valmet employee when visiting. The statements of the employees were organized, according to the method presented in chapter 3.3.3, in different recurrent subjects such as safety and cost. The collected data was used for an analysis of the current designs and for the requirement specification.

### 4.4 Requirement specification

From studying the current design and the material gathered during the interviews, a requirement specification was made. The requirement specification was made in Valmet's own template, however with some adjustments adding columns for function or limit, demand or wish and a column for weighting the wishes. Two separate requirement specifications were made, one for the standard spool storage and one for the automatic spool storage with just a few differences in the requirements. The documents were then approved by the dry end steering team. For the concept generation, only the requirement specification for the storage with return system was used.

## 4.5 Concept generation

In this project, a competitor-oriented benchmarking has been done. However, since it is such a complex product, there is no product data available to compare the products to each other. Although, some documents, pictures, videos of the competing products and videos of 3D-models of these products have been found. Moreover, patents from competitors have been studied.

When reading literature about product development, especially the concept generation, the methods are based on teams including more than one person. Therefore, a concept generation with experienced Valmet employees was performed. To avoid the possible outcome of only getting conservative ideas, another session was performed with students in Master of Science in Mechanical Engineering. The same method, brainwriting 6-3-5, was applied on both groups. In the session with the Valmet employees, there were nine participants (author included). For a more time efficient session, these were divided into two groups with one 4-3-5 and one 5-3-5 circle. In the session with the students there were six participants (author included) in one 6-3-5 circle. Both sessions were performed in the same way with same instructions, and the sessions were performed for one and a half hour each including instructions, execution and discussion. The problem given to the participants was based on the functional requirements regarding transport and storage, where question 1 below was the main question and 2-3 were additional questions to help with further development of the ideas:

1. How can a spool be transported from the end of the reel system to the primary arm?
2. Where can the ideas be located in relation to the reel system?
3. How and where can the spools be stored?

To activate creativity and further avoid conservatism, the participants were asked to associate one of their ideas to future technology or science fiction. The difference between the two sessions was that the students had no information regarding the current design of the spool storage, while its design is well known among the Valmet employees. This information was excluded from the students to open up for a more progressive concept generation from a wider perspective. This since the employees, as previously mentioned, hypothetically could be affected by the current design of the storage and thus might be conventional when generating ideas.

The most useful and applicable ideas from these sessions together with some new own ideas were compiled into morphological charts. Since there were many partial solutions to each function, these were divided into multiple, smaller morphological charts for better structure where every chart belongs to a sub-problem. The defined sub-problems were transport and storage. Some of the ideas were discarded directly due to limitations in space beside and below the machine and the remaining partial solutions were combined creating different concepts.

## 4.6 Choice of concept

The partial solutions for the sub-problems were combined into sub-concepts, T1-T28 for the transport and S1-S36 for the storage. These were inserted into the selection chart and scored accordingly. After this first scoring the remaining concepts were inserted into Pugh's relative decision chart with some chosen requirements specific for transport and storage respectively. However, some requirements in the specification were not directly applicable in this chart. Therefore, additional aspects connected to these requirements were added into the chart. For example, it is hard to directly compare the costs of the concepts. It is easier to divide this

requirement into aspects that affect the cost such as *number of functions needed*, and *beam material needed*. This led to a few sub-concepts, some from the T-group and some from the S-group, chosen for further development.

The sub-concepts chosen were combined into several possible total solutions where both transport and storage type were included. The combined solutions were once again inserted into a Pugh's relative decision chart compared in both requirement fulfillment from the specification and four other additional aspects. From this chart, one winning concept was chosen for further development.

#### 4.7 Further development

For the best concept, a rough sketch was made in Microsoft PowerPoint. To further visualize the concept, it was also roughly constructed in Creo Parametric. During construction, an important feature to consider is the distance between the storage positions in the stand. They must be positioned in a way so that the lifting hooks in the traverse can fit between them.

Moreover, sequence charts were made to further explain how the control system could work. To get a perception of the cost of the concept a potential supplier was contacted for a budget quotation.

### 5 Results

#### 5.1 Start-up and planning

The GANTT-schedule and project risk analysis can be found in Appendix A and Appendix B respectively. The most critical project risk was the upcoming of unexpected additional elements crucial to fulfill the project. Actions made to avoid this risk was to try to be a step ahead in the time plan. This to create space for unexpected additional elements.

#### 5.2 FMEA

Both the initial brief version and the version belonging to the final concept are presented in Appendix C. The most critical risk in the brief initial version of the FMEA, with an RPN value 200, is the risk of spools falling down during movement due to free, uncontrolled movements. The risk priority number is high since the severity if it would happen is high and it is hard to detect before it happens. Actions made to avoid this was to consider a controlled and locked movement of the spools during the concept generation phase. The final concept had much lower RPN values overall. The most critical risk here, with an RPN value 80, is failure of components due to a too weak construction. To avoid this risk an FEM-analysis of the construction can be made by the company.

#### 5.3 Analysis of current design

An analysis of the current designs was made based on interviews and research regarding the current designs and the costs of these. From the statements of the Valmet employees, the strengths and weaknesses regarding the spool storages could be listed.

The advantages with the current designs are that these are well-established and usually the spool storages do work as they should. Since the solutions have been around for a long time, the company understands it and is aware of the drawbacks of the design. Also, the hydraulic movements work well, especially the lowering arms who work well with surrounding

structures. The design of the storage is simple and similar to competitor solutions. Moreover, the design is scalable and modular with different lengths and sizes.

However, the spool storages have several problems and disadvantages. The current designs of the spool storages are expensive compared to competitor solutions. When further investigating the costs of the different parts of the spool storages it can be concluded that the most expensive parts are all the beams and pillars in the construction followed by the pneumatic and hydraulic cylinders. These are followed by the lifting and lowering arms, which are quite expensive as well. Lastly, the rails and the brackets also can be found among the expensive parts.

Moreover, both designs lack in safety. Spools get stuck due to dust and screw holes on the rails that interfere with the spool path. In order for the process to continue, spools are pushed manually, generating unnecessary risks. An even greater risk identified is that spools sometimes tumble down to the floor. These spools have a weight of several tons and if someone is beneath, a fall like this could have fatal consequences.

To prevent this from happening, it is not allowed to enter the area while the pushers are in operation, i.e. while the spools are moving. However, this safety arrangement is time consuming since all pushers go off even though the spools usually do not need all the pushers to reach their end station. Thus, the operators must wait until the pushers are done to enter the area.

According to the interviewed employees the pushers do not work as they should. They speak of leakage and failure of especially the pneumatic cylinders closest to the lifting arms. Also, there is a low serviceability, and the pushers and pneumatic cylinders are hard to reach. Moreover, the last pusher has had too high velocity leading to a high impact velocity when the spool reaches the stop, causing cracks in the stop. The last issue has been solved by limiting the last pusher to a lower maximum velocity than before.

Another drawback repeatedly mentioned by the employees is weak and misaligned lifting arms. This is believed to be due to the construction or the manufacturing, alternatively a combination of the two. The misalignment of the long lifting arms leads to a misalignment of the spools from the beginning, that might contribute to spools falling down later on.

Some other drawbacks mentioned by one or two employees was that sometimes, the rails can be misaligned in relation to the lower rails from the beginning, causing the spools to be off track from start. Also, there is wear on the lifting hooks due to the contact with the spools. One employee also mentioned that they have solved some problems regarding the spool storage with quick-fix solutions instead of looking at the main problem and sustainable solutions.

The standard reel spool storage has manual handling. Here, the operators stand on ground level when manually lifting the spool to the storage using a traverse, making it hard to see where the spool ends up. If unlucky, the traverse comes with the spool while the first pusher is running. The standard spool storage also is expensive in relation to competitor versions. However, compared to the automatic spool storage, there is a lower risk for spools falling down since the storage is shorter with fewer pushers.

## 5.4 Requirement specification

The requirement specification for the spool storage with return system and for the spool storage without return system can both be found in Appendix D.

## 5.5 Concept generation

### 5.5.1 Benchmarking

From documents, pictures, videos and patents it can be concluded that the competitors overall have similar solutions as Valmet's design. One competitor, Hergen, had lifting and lowering arms similar to Valmet's variant. However, their solution had inclined rails with pneumatic stops along the way, which will be considered during the concept generation phase.

One of the patents regarding the spool storage belonged to Andritz. It turned out that Andritz has an active patent on a plurality of upper reels in the spool storage, with the purpose to separate different kinds of spools [12]. The idea of separating spools or ways to identify and choose different spools was therefore brought up with the project commissioner and after discussion added to the requirement specification.

Another patent found, belonging to Voith, already expired. This solution, presented in Figure 6, is also based on an overhead spool storage, not significantly different from the other variants found. This variant, similar to Hergen's, has inclined rolling paths (28) which transport the spools back with the effect of gravity. The design has breaks (35) in form of bell crank levers controlled by hydraulics (36). To lift and lower the spools between the winding section and the upper rails, lift devices (24 and 29) are suspended from roller chains (25 and 33) carried by pulleys (26). To move the lift devices a cylinder (27 and 34) is used [13].

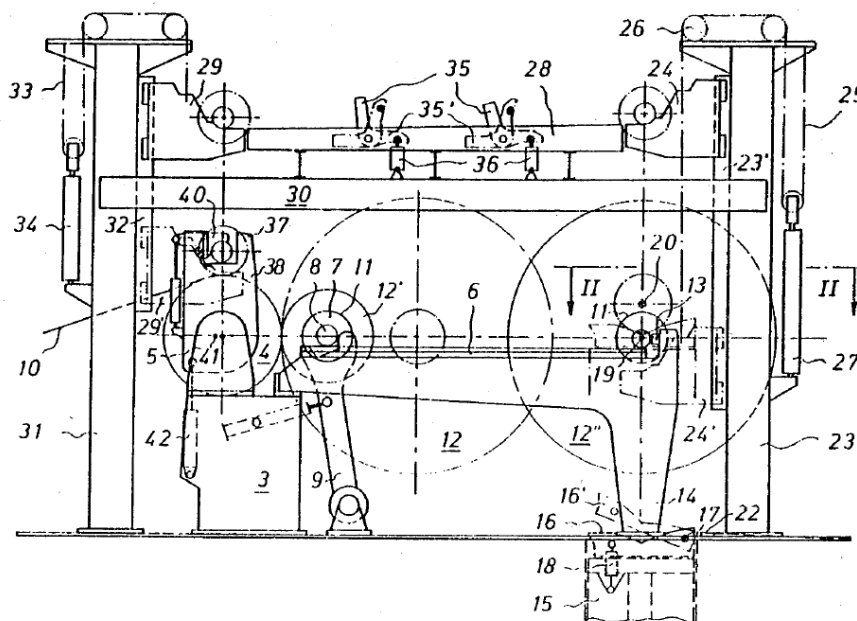


Figure 6: Voith's spool storage [13].

### 5.5.2 Morphological charts for each concept generation session

Table 3 presents the transport ideas from the concept generation session with the students on where and how the spools could be transported. Partial solutions marked with current in a parenthesis are parts of the current design of the spool storage.

Table 3: Morphological chart for transport ideas from students. \*In relation to transport section

Partial functions	Transport location*	Vertical transport	Horizontal transport
Partial solutions	Above (current)	Traverse	
	Beside	Robotic arm	
	Between rails (ground level)	Lift/elevator	Inclined rails
	Under (below ground level)		Conveyor

Table 4 presents the storage ideas from the concept generation session with the students, and the partial functions of storage type and its location.

Table 4: Morphological chart for storage ideas from students. \*In relation to transport section

Partial functions	Storage	Storage position
Partial solutions	Bit-set/revolver magazine	Beside*
	Vertical magazine	Above* (current)
	Conveyor	Between rails* (ground level)
	Stand	Under* (below ground level)

The students also had ideas regarding rotating the spool and transport it back vertically or with its axial direction along the machine. These orientations are considered in all sub-concepts during the screening process.

Table 5 presents the transport ideas from the concept generation session with the Valmet employees.

Table 5: Morphological chart for transport ideas from Valmet employees. \*In relation to transport section

Partial functions	Transport location*	Vertical transport	Horizontal transport
Partial solutions	Above (current)	Traverse	
	Beside	Crane	
	Between rails (ground level)	Robotic arm	
	Under (below ground level)	Lift/elevator	Rails (current)
		Lifting arm (current)	Inclined rails
		Lifting table	Conveyor
			Magnetic levitation
			Driving wheel
			Wave motion

Table 6 presents the storage ideas from the concept generation session with the Valmet employees.

Table 6: Morphological chart for storage ideas from Valmet employees. \*In relation to transport section

Partial functions	Storage	Storage position
Partial solutions	Indexing magazine	Beside*
	Bit-set/revolver magazine	Above* (current)
	Vertical magazine	Above primary arm
	Conveyor	Part of Yankee frame
	Rails (current)	Between rails* (ground level)
	Bin	Under* (below ground level)

The Valmet employees also had some ideas of rotating the spool with its z-direction along the machine.

Additionally, some own ideas were added. These were to have the storage by the shaft puller and after the lower rails on ground level.

### 5.5.2 Morphological charts

Table 7 presents the total morphological chart for the transport. All solutions below is meant to be automated, i.e. not driven by operators.

Table 7: Morphological chart for transport. \*In relation to transport section

Partial functions	Transport location*	Vertical transport	Horizontal transport
Partial solutions	Above (current)	Traverse	
	Beside	Crane	
	Between rails (ground level)	Robotic arm	
	Under (below ground level)	Lift/elevator	Rails (current)
		Lifting arm (current)	Inclined rails
		Lifting table	Conveyor
			Magnetic levitation
			Driving wheel
			Wave motion

Some partial solutions are deselected. Under the transport section, i.e. below ground level is not an option since Valmet cannot expect that the customers have that kind of space. Transport via magnetic levitation is a complex solution with high cost, thus this solution is excluded as well.

Explanation of partial solutions for the transport is presented in Appendix E.

Table 8 presents the total morphological chart for the storage and the partial functions of storage type and its location.

Table 8: Morphological chart for storage. \*In relation to transport section

Partial functions	Storage	Storage position
Partial solutions	Indexing magazine	Beside*
	Bit-set/revolver magazine	Above* (current)
	Vertical magazine	Above primary arm
	Conveyor	Part of Yankee frame
	Rails (current)	Between rails* (ground level)
	Stand	Beside shaft puller
	Bin	Under* (below ground level)
		After* (ground level)

A bin will provide disorder among the spools compared to the other solutions and is therefore excluded. A storage below ground level is not an option as previously mentioned due to limited space, and from the same reason there is not possible to have the storage after the lifting table.

Explanation of partial solutions for the storage is presented in Appendix E.

## 5.6 Choice of concept

### 5.6.1 Transport

The different sub-concepts for transport above the lower rails are presented in Table 9.



Table 9: Sub-concepts for transport above the lower rails

Location	Vertical	Horizontal	Concept no.
Above	Traverse		T1
	Crane		T2
	Robotic arm		T3
	Lift/elevator	Rails	T4
		Inclined rails	T5
		Conveyor	T6
		Driving wheel	T7
		Wave motion	T8
	Lifting arm	Rails	T9
		Inclined rails	T10
		Conveyor	T11
		Driving wheel	T12
		Wave motion	T13
	Lifting table	Rails	T14
		Inclined rails	T15
		Conveyor	T16
		Driving wheel	T17
		Wave motion	T18

The different sub-concepts for transport beside and between the lower rails are presented in Table 10.

Table 10: Sub-concepts for transport beside and between the lower rails

Location	Horizontal	Concept no.
Beside	Rails	T19
	Inclined rails	T20
	Conveyor	T21
	Driving wheel	T22
	Wave motion	T23
Between rails (ground level)	Rails	T24
	Inclined rails	T25
	Conveyor	T26
	Driving wheel	T27
	Wave motion	T28

Table 11 shows the selection chart for the concepts regarding transport. A crane and a robotic arm are considered to have unnecessary degrees of freedom and too high cost, there is for example no need to be able to rotate the spools when the transport is located above the lower rails. The driving wheel solution is only for transport in the spool's axial direction. This solution would only be of interest if the spool was rotated with its length along the machine. When the transport of the spool is located above the lower rails there is no need to rotate the spool, and thus these solutions can be excluded. Initially there was an idea of modifying the lifting table in a way so that it could lift the spool all the way up vertically and thus could replace the lifting arms in the current design. However, the scissor lift table cannot go as low as needed if another cross brace is added to get it all the way up. Another way to get the lifting table to lift higher is to make it wider and hence the legs longer. Due to the limited space this is not an option either. Due to unclear directions from the company regarding whether the space beside the lower rails is free or not, the decision was made to exclude these solutions as well.

To have a solution located between the lower rails some changes would be required. Firstly, the legs of the rails would have to be widened to make space for the spools. Secondly, the rails would have to be heightened to make space for both spools and their transport equipment. These two factors are feasible, however there is one more problem with these solutions. For this configuration to work, the primary arm would have to be below the reel drum and the spool pressed towards it from underneath instead of from above as in current design. This would require a redirection of the paper path to make the paper go below the reel drum instead of above. This problem is trickier to solve and requires major changes. Therefore, these solutions have been excluded as well.

Table 11: Selection chart for transport

Selection chart for: Transport									
Concept no.	Compatibility	Fulfills demands in req. list	Realizable	Within cost limit	Safe and ergonomic	Suits the company	Adequate information	<b>Selection criteria:</b> (+) Yes (-) No (?) Lack of information (!) Check req. list	
								<b>Decision:</b> (+) Pursue solution (-) Eliminate solution (?) Collect information (!) Check req. list for changes	
								Comment	Decision
T1	+	+	+	?	+	+	+	No cost calculations have been made	?
T2	-							Unnecessary movements	-
T3	+	+	+	-				Expensive	-
T4	+	+	+	+	+	+	+		+
T5	+	+	+	+	+	+	+		+
T6	+	+	+	?	+	+	+	No cost calculations have been made	?
T7	-							Only for movement in z-direction of the spool	-
T8	+	+	+	?	+	+	+	No cost calculations have been made	?
T9	+	+	+	+	+	+	+	Current design	+
T10	+	+	+	+	+	+	+		+
T11	+	+	+	?	+	+	+	No cost calculations have been made	?
T12	-							Only for movement in z-direction of the spool	-
T13	+	+	+	?	+	+	+	No cost calculations have been made	?
T14	+	+	-					Lift is too high and space to modify table to narrow	-
T15	+	+	-					Lift is too high and space to modify table to narrow	-
T16	+	+	-					Lift is too high and space to modify table to narrow	-
T17	-							Only for movement in z-direction of the spool	-
T18	+	+	-					Lift is too high and space to modify table to narrow	-
T19	+	+	-					Takes up too much space	-
T20	+	+	-					Takes up too much space	-
T21	+	+	-					Takes up too much space	-
T22	+	+	-					Takes up too much space	-
T23	+	+	-					Takes up too much space	-
T24	-							Interferes with the legs of the lower rails	-
T25	-							Interferes with the legs of the lower rails	-
T26	-							Interferes with the legs of the lower rails	-
T27	-							Interferes with the legs of the lower rails	-
T28	-							Interferes with the legs of the lower rails	-

Table 12 shows the relative decision chart for the transport sub-concepts. The reference solution is the current design of the storage. The requirements belonging to the numbers can be found in the requirement specification in Appendix D. Requirement A1 is connected to the safety requirements and compares the concepts in their amount of controlled movement. A controlled movement increases the safety, decreases the number of sensors and provides a more predictable solution.

Table 12: Relative decision chart for transport

Req. No.	Ref	Concept no.							
	T9	T1	T4	T5	T6	T8	T10	T11	T13
9 (w=1)	D	0	0	0	0	0	0	0	0
13 (w=3)	A	0	0	0	0	0	0	0	0
16 (w=5)	T	0	0	0	0	0	0	0	0
20 - vertical (w=5)	U	+	+	+	+	+	0	0	0
20 - horizontal (w=5)	M	+	0	0	+	+	0	+	+
21 (w=5)		0	0	0	0	0	0	0	0
A1 (w=5)		+	0	0	+	0	0	+	0
Sum +		15	5	5	15	10	0	10	5
Sum 0		4	6	6	4	5	7	5	6
Sum -		0	0	0	0	0	0	0	0
Net value	0	15	5	5	15	10	0	10	5
Ranking	4	1	3	3	1	2	4	2	3
Further development	No	Yes	No	No	Yes	No	No	No	No

Concept T1 and T6 got the best ranking and thus are chosen for further development. However, a conveyor in the size needed to carry spools with a weight of 4500kg would most likely be too expensive. Thus, a new concept combining T4 and T6 is created, see Figure 7. Here, the load is carried by the rails just as in the current design, but instead of pushers there are conveyors beside the rails, with fix positions for each spool, pushing the spool forward. This allows for smaller belt drives instead of one big compact conveyor requiring many big rolls.

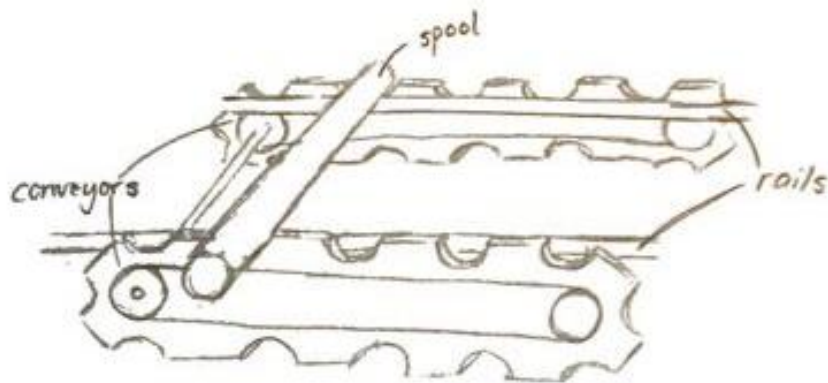


Figure 7: Sketch of new concept T4-6.

This new concept together with the winners from Table 12 are compared in a new decision chart, Table 13, where a criterion A2 regarding cost is added.

Table 13: Relative decision chart for transport including new concepts. A2 – cost

Req. No.	Ref	Concept no.		
	T9	T1	T6	T4-6
9 (w=1)	D A T U M	0	0	0
13 (w=3)		0	0	0
16 (w=5)		0	0	0
20 - vertical (w=5)		+	+	+
20 - horizontal (w=5)		+	+	+
21 (w=5)		0	0	0
A1 (w=5)		+	+	+
A2 (w=5)		0	-	0
Sum +		15	15	15
Sum 0		5	4	5
Sum -		0	-5	0
Net value		15	10	15
Ranking		1	2	1
Further development		Yes	No	Yes

### 5.6.2 Storage

The different sub-concepts for the storage are presented in Table 14.

Table 14: Sub-concepts for storage. \*In relation to transport section

Type	Position	Concept no.
Indexing magazine	Beside*	S1
	Above*	S2
	Above primary arm	S3
	Part of Yankee frame	S4
	Between rails* (ground level)	S5
	Beside shaft puller	S6
Bit-set/revolver magazine	Beside*	S7
	Above*	S8
	Above primary arm	S9
	Part of Yankee frame	S10
	Between rails* (ground level)	S11
	Beside shaft puller	S12
Vertical magazine	Beside*	S13
	Above*	S14
	Above primary arm	S15
	Part of Yankee frame	S16
	Between rails* (ground level)	S17
	Beside shaft puller	S18
Conveyor	Beside*	S19
	Above*	S20
	Above primary arm	S21
	Part of Yankee frame	S22
	Between rails* (ground level)	S23
	Beside shaft puller	S24
Rails	Beside*	S25
	Above*	S26
	Above primary arm	S27
	Part of Yankee frame	S28
	Between rails* (ground level)	S29
	Beside shaft puller	S30
Stand	Beside*	S31
	Above*	S32
	Above primary arm	S33
	Part of Yankee frame	S34
	Between rails* (ground level)	S35
	Beside shaft puller	S36

Table 15 shows the selection chart for the storage. Just as for the transport, all solutions located beside and between the lower rails are excluded due to lack of space. The sub-concepts that would cause vibrations to the Yankee frame and thus not fulfill the requirement list are also excluded. Some combinations have no clear point to them or are not compatible and are therefore deselected as well.

Table 15: Selection chart for storage

Selection chart for: Storage									
Concept no.	Compatibility	Fulfills demands in req. list	Realizable	Within cost limit	Safe and ergonomic	Suits the company	Adequate information	Selection criteria:	
								(+ ) Yes	
								(- ) No	
								( ? ) Lack of information	
								(! ) Check req. list	
								Decision:	
								(+ ) Pursue solution	
								(- ) Eliminate solution	
								( ? ) Collect information	
								(! ) Check req. list for changes	
Comment								Decision	
S1	+	+	-					Takes up too much space	-
S2	+	+	+	+	+	+	+		+
S3	+	+	+	+	+	+	+		+
S4	+	-						Will cause vibrations on Yankee frame	-
S5	+	+	-					Interferes with lower rails	-
S6	+	+	+	+	+	+	+		+
S7	+	+	-					Takes up too much space	-
S8	+	+	?	?	+	+	+	No cost calculations have been made	?
S9	+	+	?	?	+	+	+	No cost calculations have been made	?
S10	+	+	?	?	+	+	+	No cost calculations have been made	?
S11	+	+	-					Interferes with lower rails and paper roll	-
S12	+	+	+	?	+	+	+	No cost calculations have been made	?
S13	+	+	-					Takes up too much space	-
S14	-							No point to this configuration	-
S15	+	+	+	+	+	+	+		+
S16	+	-						Will cause vibrations to the Yankee frame	-
S17	-							Interferes with transport section	-
S18	+	+	+	+	+	+	+		+
S19	+	+	-					Takes up too much space	-
S20	+	+	+	?	+	+	+	No cost calculations have been made	?
S21	+	+	+	?	+	+	+	No cost calculations have been made	?
S22	+	+	+	?	+	+	+	No cost calculations have been made	?
S23	+	+	-					Interferes with lower rails	-
S24	+	+	+	?	+	+	+	No cost calculations have been made	?
S25	+	+	-					Takes up too much space	-
S26	+	+	+	+	+	+	+	Current design	+
S27	-							No point to this configuration	-
S28	+	-						Will cause vibrations on Yankee frame	-
S29	+	+	-					Interferes with lower rails	-
S30	-							No point to this configuration	-
S31	+	+	-					Takes up too much space	-
S32	-							No point to this configuration	-
S33	+	+	+	+	+	+	+		+
S34	+	+	+	+	+	+	+		+
S35	-							Interferes with transport section	-
S36	+	+	-					Would require too many extra functions	-

Table 16 presents the relative decision chart for the storage sub-concepts. The reference solution is the current design of the storage. The requirements belonging to the numbers can be found in the requirement specification in Appendix D. Requirement B1 is equal to A1 and connected to the safety requirements and compares the concepts in their amount of controlled movement. A controlled movement increases the safety, decreases the number of sensors and provides a more predictable solution. B2 and B3 are connected to the cost of the system. B2 is the amount of functions needed in the sub-concepts. Often more functions lead to higher costs. B3 compares the solutions in whether they provide possibilities to downsize the transport section (+ for yes, 0 for no). Today, the magazine and the transport are the same, causing the complete structure to be able to carry six spools. If these functions are separated, the structure of the transport section only need to have the strength to carry one spool at a time and thus have a lower cost.

Table 16: Relative decision chart for storage

Req. No.		Concept no.														
	S26	S2	S3	S6	S8	S9	S10	S12	S15	S18	S20	S21	S22	S24	S33	S34
7-8 (w=5)	D	0	0	0	-	-	-	-	0	0	0	0	0	0	0	0
11 (w=2)	A	0	0	0	+	+	+	+	0	0	0	0	0	0	+	+
13 (w=3)	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 (w=5)	U	0	0	+	-	-	-	+	0	+	0	0	0	+	+	+
B1 (w=5)	M	-	-	-	+	+	+	+	-	-	+	+	+	+	+	+
B2 (w=5)		0	+	-	-	-	-	0	+	-	0	-	-	-	-	-
B3 (w=5)		0	+	+	0	+	+	+	+	+	0	+	+	+	+	+
Sum +		0	10	10	7	12	12	17	10	10	5	10	10	15	17	17
Sum 0		6	4	3	2	1	1	2	4	3	6	4	4	3	2	2
Sum -		-5	-5	-10	-15	-15	-15	-5	-5	-5	0	-5	-5	-5	-5	-5
Net value	0	-5	5	0	-8	-3	-3	12	5	5	5	5	5	10	12	12
Ranking	4	6	3	4	7	5	5	1	3	3	3	3	3	2	1	1
Further development	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	Yes	Yes

The revolver magazine located by the shaft puller and the stands located in the area by the primary arm and the Yankee frame are the best solutions for storage.

### 5.6.3 Combined concepts

Table 17 presents the relative decision chart for transport and storage combined to total concepts. The combination of an automated traverse T1 and stands with fixed positions for the spools S33/34 adds flexibility regarding the location of the storage positions. As previously mentioned, there is limited space in the area between the primary arm and the Yankee frame, which could be a problem for this concept. However, this specific combination allows for storage positions anywhere along the path of the traverse as long as these positions do not interfere with the production line. Therefore, the combined concept T1S33/34 includes an optional combination of both stands and fixed storage positions along the path of the traverse.

The reference solution is the current design of the storage. The requirements belonging to the numbers can be found in the requirement specification in Appendix D. Requirement C1 represents the distance between possible storage positions and primary arm. This affects the time it takes to provide the primary arm with a new spool. C2 is equal to B2 and is the number of functions or complex components needed to move the spools. This condition is connected to the cost of the system. C3 is the time the spools are in movement above the dressing area. Shorter time would allow entrance of the area faster than today. Requirement C4 is the material

(beam, sheet, bulk) needed (+ for less than today, - for more than today) and is connected to the cost.

Table 17: Relative decision chart for transport and storage combined to total concepts

Req. No.		Concept no.			
	T9S26	T1S12	T1S33/34	T4-6S12	T4-6S33/34
11	D	+	+	+	0
C1	A	-	0	0	0
C2	T	0	+	-	- -
C3	U	+	+	+	+
C4	M	0	0	0	+
Sum +		2	3	2	2
Sum 0		2	2	2	2
Sum -		-1	0	-1	-2
Net value	0	1	3	1	0
Ranking	3	2	1	2	3
Further development	No	No	Yes	No	No

The results from Table 17 conclude that the best concept is an automated internal traverse system with fixed storage positions primarily in a stand between the primary arm and the Yankee frame. For increased storage capacity, storage positions could also be anywhere along the path of the traverse as long as these positions do not interfere with the production line. This concept is chosen for further development.

## 5.7 Further development

### 5.7.1 Modelling and further description of concept

A sketch of the chosen concept is shown in Figure 8 and the corresponding view of the CAD-model is presented in Figure 9. An automated internal traverse transports the spools from the end station of the reel to the storage positions, and from the storage positions to the primary arm. The concept allows for storage positions to be located anywhere along the path of the traverse, as long as they do not interfere with the production line below. Primary, the storage positions are located in a stand that is a part of the Yankee frame. However, for some machine types, the space between the primary arm and the Yankee frame is too small to fit the whole capacity of six spools (see requirement specification). In that case, some storage positions could be placed on- or between the pillars of the traverse system, see Figure 10. Here, only four storage positions could be placed in the stand by the Yankee frame. The last two positions were distributed on the pillars of the traverse system. The storage positions are marked in green in Figure 10. The number of storage positions is flexible, and another alternative to increase the number of storage positions is to put two positions on each pillar, one on each side.



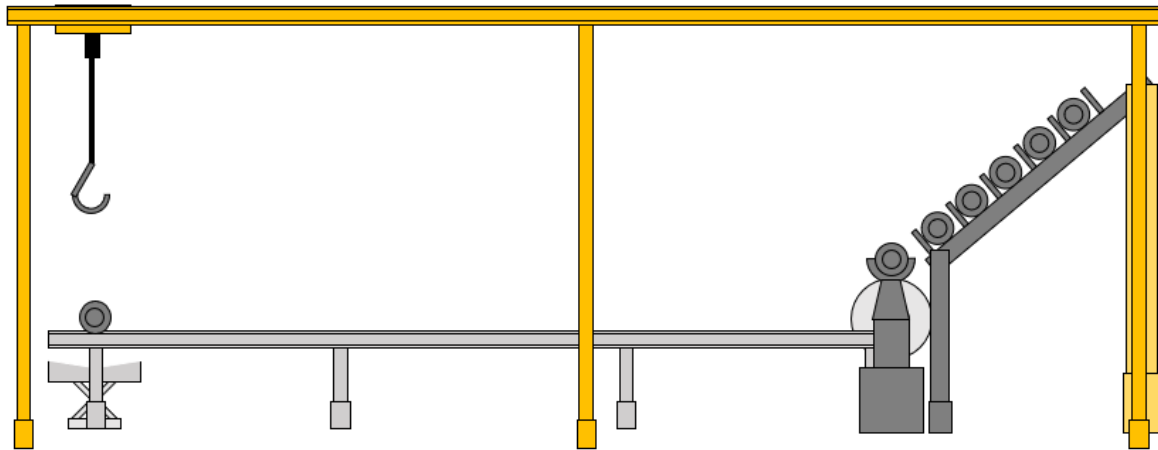


Figure 8: Sketch of concept TIS33/34.

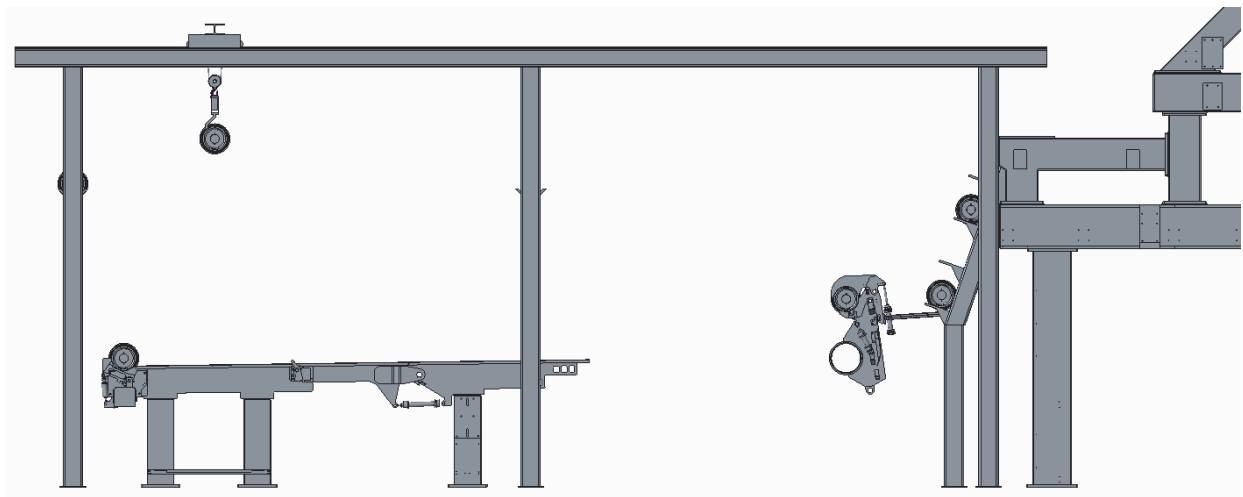
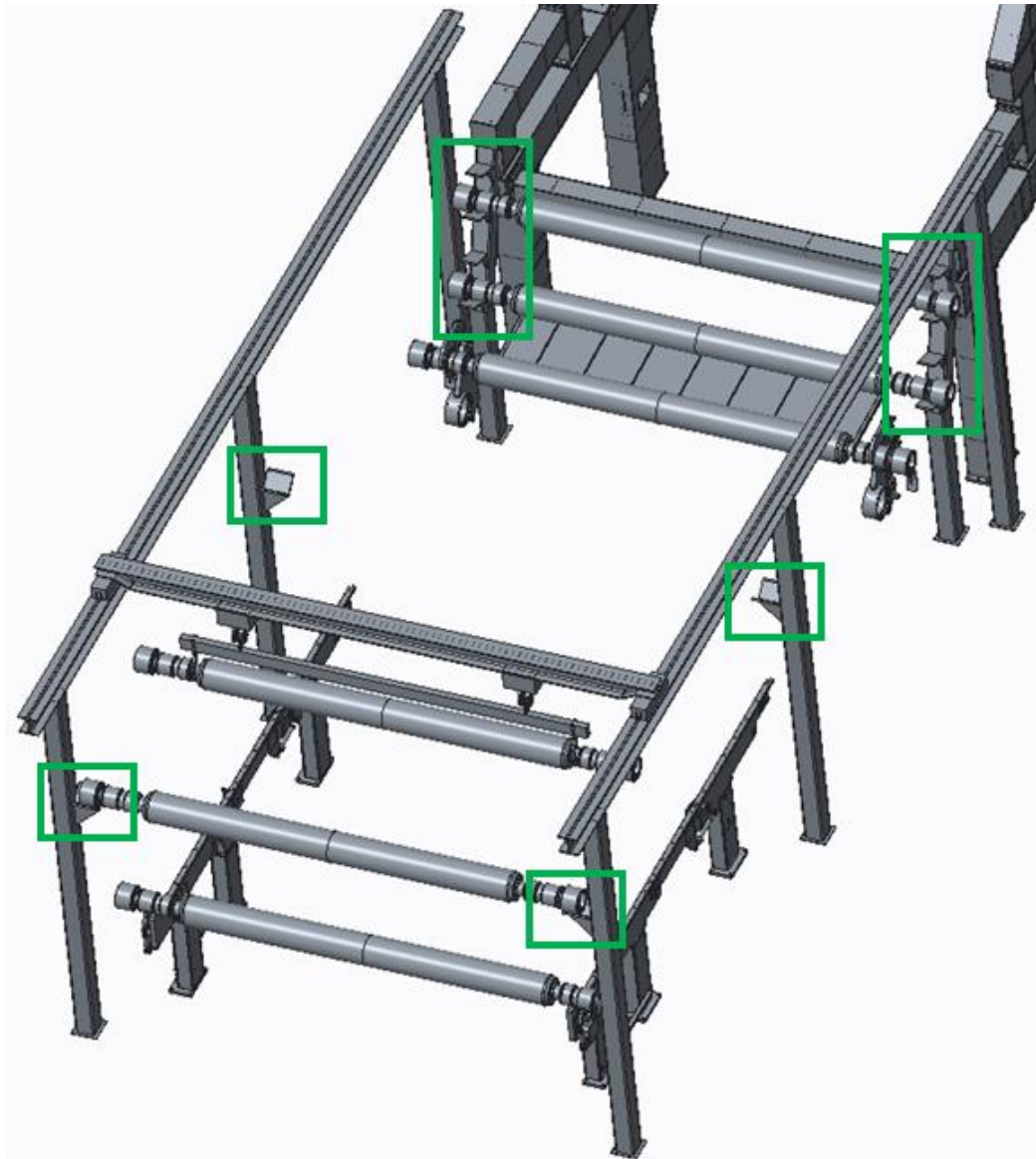


Figure 9: CAD-model.



*Figure 10: CAD-model and marked storage positions.*

### 5.7.2 Sequence charts

These propositions of sequence charts are built on the assumptions that Valmet already developed an identification system for the spools including a count on how many turns each spool have been in the production process. The operator chooses which type of spools that should be in the process, core shafts or reel spools, as an input to the control system. The system has two triggers:

1. Primary arm is empty and ready for a new spool.
2. A spool is ready for pick-up from the end station of the reel.

Moreover, every storage position has one of three states:

1. Empty
2. Core shaft (A)
3. Reel spool (B)

Presume that input is set to core shafts (A). A possible sequence chart for the input signal that the primary arm is empty and ready for a new spool is presented in Figure 11. Firstly, the system locates the storage positions containing core shafts (A). Among the identified positions, to ensure even wear of the spools, an alternative priority is to pick the spool with the fewest turns in the production line. Then the traverse picks the spool up, places it in the primary arm and then goes back to its null position.



Figure 11: Sequence chart for input that primary arm is empty and ready for a new spool.

Presume that input still is set to core shafts (A). A possible sequence chart for the input signal that a spool is ready for pick-up from the end station of the reel is presented in Figure 12. Firstly, the traverse picks the spool up from end station of the reel. The system locates empty storage positions and if the traverse picked up a core shaft (A) or a reel spool (B). If it is holding A, an alternative priority is to put the spool in a storage position close to the primary arm for an effective process. If it is holding B, an alternative priority is to put the spool down in a storage position far from the primary arm. Thereafter, the traverse goes back to its null position.

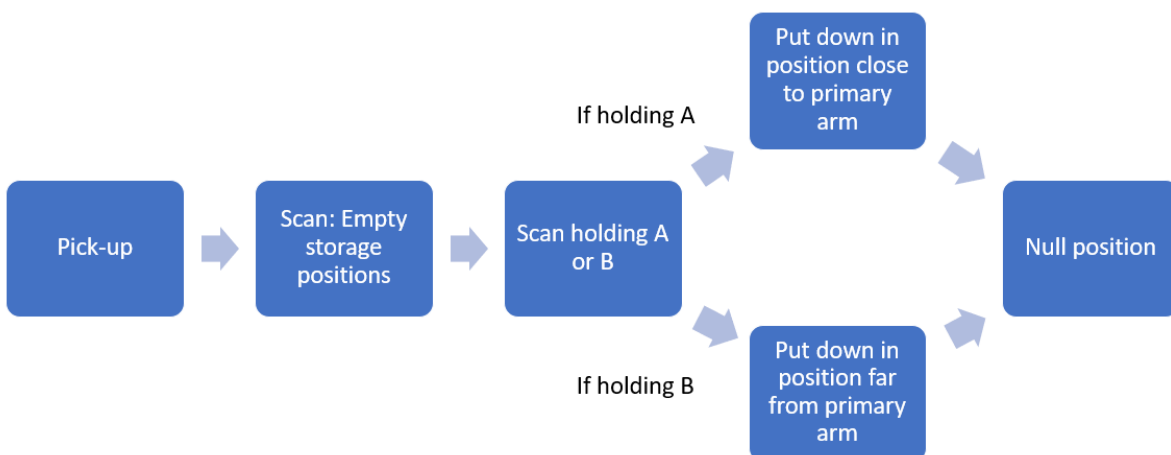


Figure 12: Sequence chart for the input that a spool is ready for pick-up from the end station of the reel.

### 5.7.3 Quotation from supplier

The budget quotation given on the traverse system is presented in Figure 13. Included in the price are preassembly of the system, overload protection with SWP, a spare radio, two lifting hooks and a lifting beam for the spools, painting of the steel construction (Epoxy 100 my), documentation, CE marking, and assembly at site.

Quotation no. P20078

Traverse prepared for semi-automatics and communication with overriding system..

Load	6.3ton (2x3.2ton)/2m(M5)
Span width	8m
Lifting height	6m
Lifting speed	0.4-4 m/min
Speed along machine	4-40 m/min
Crane group	H2B3

Included in delivery:

Preassembly  
Overload protection with SWP  
Spare radio  
2 Pce lifting hooks and a lifting beam for the spools  
Painting of the steel construction (Epoxy 100 my)  
Documentation according to Procranes Std.  
CE marking  
Assembly at site

-----  
BUDGET PRICE complete for one traverse + crane track acc. To above, 2.500.000SEK excl. moms free KARLSTAD

Figure 13: Quotation on traverse system.

The quotation also gives details such as possible velocities of the traverse. A lifting and lowering velocity of 0.4-4 meters per minute and a longitudinal velocity of 4-40 meters per minute confirms that requirement four in the requirement specification can be fulfilled.

## 6 Discussion

### 6.1 The final concept

The final concept provides opportunities to fulfill all demands and most of the wishes in the requirement specification. The solution has a fully automatized transport of the spools and stores the spools in a simple way. It can provide the primary arm with new spools in a fast and effective way. The traverse will not move the spool cross directionally. Thus, if the storage positions and lifting hooks are constructed correctly to prevent the spool from moving in that direction, the requirement regarding positioning in the primary arm also should be fulfilled. Since the spools are carefully put down in the stand, no disturbing vibrations will be initiated to the Yankee frame. The rest of the equipment is separated from the machine and will not cause disturbing vibrations. The lifting table gives opportunities to add or remove spools from external equipment. The solution provides attachment points for surrounding equipment just as previous design and has place for a dust screen and dust cover to protect the spools from debris. The wish for identification was excluded from this project and assumed to already exist. This solution in combination with the identification system fulfills the wish to be able to choose different kinds of spools. The solution is applicable in Valmet's project SoftReel 2.0, and could be applied in current tissue machine designs, however some further work on the concept must be made such as control system, identification system etc. The system can handle all dimensions and weights of the spools and it has good serviceability. The dusty environment will not be an issue any more than for today's design, and dust covers can still be provided if necessary. The movements of the spools are controlled which minimizes the risk that a spool would fall down. As long as the traverse do not move spools directly over the area and with the right safety instructions and control system, the solution allows safe entering while spools are in movement.

The wish for the concept to have lower cost than the current design is not fulfilled. However, the quoted price and the cost for the current design given in the requirement specification are

not completely comparable to each other. The budget quotation included preassembly, documentation and assembly at site, which are not included in the cost given on the current design. Moreover, the new concept would reduce the construction costs since the traverse system would replace both lifting arms and lowering arms. The steel construction is also something that can be constructed and distributed to other suppliers with lower prices. Additionally, the offer from the supplier was just a first-time budget quotation, and more suppliers should be asked for a more correct cost. The current design is well-established, and the costs have been overlooked and processed continuously over the decades.

When looking at the cost of the new concept, it is also important to consider the increase in value that comes with the fulfillment of the wish to be able to choose which spool to use. The fulfillment of this wish could increase Valmet's market position among competitors and the cost should rather be compared to the patented competitor solution with double rails and a double set of pneumatic stops/pushers.

One could argue that it is unnecessary to use an internal traverse instead of using an external one often already existing in the building. However, an automated internal traverse dedicated solely to the transport of the spools is beneficial. In this way, the traverse already existing in the building can be used for other purposes without any disturbances or bottlenecks. A negative aspect regarding this solution is that a traverse might be perceived as old-fashioned and outdated. However, with today's technology, this will be an effective and automated solution and could be viewed more as a robot solution.

The argument that the final concept would require less beam material than today is based on the fact that the current solution is designed to carry six spools, whereas the new transport section only needs to be dimensioned to carry one spool at a time. Though, additional beam structure is required for the stands. Since the already existing Yankee frame can be used for pillars to the new stand however, not as much new beam material is needed.

## 6.2 The method and process

The time plan created in the beginning of the project turned out to be accurate and could be followed throughout the whole project. The identified risks in the project risk analysis (see chapter 3.1 Start-up and planning) that the project could exceed the time plan and that unexpected additional elements needed to fulfill the project would come up did not affect the study. The GANTT-schedule was not too detailed and thus opened up for minor changes and additional elements without compromising the overall plan.

The outcomes of the two concept generation sessions had many unexpected similarities. The number of different solutions were more among the Valmet employees, however, there were more participants in that session. According to Dörner's statement that experience might bring conservatism (see chapter 3.5.1 Benchmarking), the ideas generated by the Valmet employees should be more conservative than those generated by the students. However, the concept generation sessions in this study shows otherwise. Both groups were equally creative, though it was clear that the group of Valmet employees had more experience regarding the storage. They took factors such as available space and surrounding equipment into consideration, for instance that the storage could be placed above the primary arm or as a part of the Yankee frame. To improve the session with the students, more info regarding the interfaces and the surrounding equipment could have been given. The ideas generated with association to future technology or science fiction were not useful as possible solutions since these were not realizable. Although,

the association might have helped the participants to think outside the box and initiated a wider perspective. The outcome of this idea generation method (chapter 3.5.2 Brainwriting 6-3-5) could indicate that with the right tools and methods, conservatism brought from experience can be avoided.

The study made by Girotra et al. (chapter 3.5 Concept generation) discussed the benefits of working in groups organized in hybrid structure when generating ideas. When using Brainwriting 6-3-5 the participants initially worked by themselves in silence, and then came together to discuss the ideas. Based on this, one could argue that they worked in hybrid structure. However, they also built on the ideas of others that, according to the authors, was associated with the team structure. Therefore, the 6-3-5 method could be seen as a mixture of the two structures. The original ideas from the participants had both high quality and quantity. Moreover, the new ideas associated with the ones from other participants also had high potential. However, the developed ideas, i.e. the ideas after a few rounds, were not necessarily better than the original idea on its own. Thus, this strengthens the authors' theory that ideas built from previous ideas are not better than any other random idea. Furthermore, these sessions also confirm that groups organized in hybrid structure are effective.

The combining of different partial solutions into concepts for the whole solution generated an unmanageable number of concepts that would not be able to handle in the selection chart and relative decision chart in an effective way (see chapter 3.6 Choice of concept). To make it manageable, the partial solutions were divided into sub-concepts. This made it easier to in an organized and systematic way screen out and compare the solutions. However, this approach might have excluded some solutions that could be better when combined into a total solution. For example, a stand on its own cannot provide the ability to choose spool as the revolver magazine can. However, when combined with the traverse, this solution suddenly has high potential. This might have been the case for some solutions that were deselected before given the chance to combine with a sub-concept that would increase their value and give a good candidate for a total solution.

During the process of choosing the best concept, relative decision charts were used. This is a great way of comparing the concepts, however, the comparison is subjective. Some important comparison factors might have been left out and some factors could have been misjudged. To avoid this, the empty chart could be filled in by several parties and the result an average of the collected opinions. This would give a more objective judgement of the concepts.

### 6.3 Future work

To further develop the concept and to make it ready for implementation a detailed construction must be made. This includes for example a CAD-model with associated drawings, a FEM-analysis of stands and Yankee frame and a proper cost calculation. To fulfill the wish to be able to identify and choose different spools, an identification system for the spools must be developed. Moreover, quotes would need to be collected from suppliers and a control system for the traverse must be developed.

The final concept is a great solution for the spool storage with return system, however it might not be applicable as a replacement for today's spool storage without return system. Thus, another concept should be developed, either by using the data collected from the concept generation sessions and screen according to appropriate requirements for the standard storage,

or by having a new concept generation session. To bring an optimal solution for both types would be too time consuming for this thesis and thus, this was left for future work.

## 7 Conclusions

The new concept with an automated traverse and with storage positions primarily in a stand between the primary arm and the Yankee frame is a valid replacement for the current design of the spool storage. The problem with spools getting stuck due to dust and misalignment is almost eliminated, and the lifting arms will no longer be a problem. The new solution has controlled movements and will thus increase the safety significantly.

The product development process is easy to follow and applicable even for more complex products. It provides a clear documentation which for instance makes it easy to go back for more info regarding previous decisions. Thus, it can be concluded that the product development process is a useful and well-established method for generating and selecting new solutions.

Moreover, from the idea generation, it can be concluded that with the right tools and adjustments to the idea generating group, eventual conservatism brought from experience can be avoided.

## Acknowledgements

A great thanks to Valmet and their employees for making this master thesis possible. A special thanks to Magnus Lundberg and Johanna Pihl for their support, guidance and patience throughout the whole project. I would also like to thank the Valmet employees for their participation in the interviews and the concept generation session.

Thanks to my supervisor Mikael Grehk for the continuous guidance and weekly check-ups.

I would also like to acknowledge my classmates for their participation in the concept generation session.

Lastly, I want to thank Jesper Christensson for reading my report and being my sounding board throughout the whole project.

## References

- [1] Valmet AB, "Valmet i Skandinavien - Karlstad," Valmet AB, [Online]. Available: <https://www.valmet.com/sv/om-oss/valmet-i-skandinavien/karlstad/>. [Accessed 29 January 2020].
- [2] H. Johannesson, J.-G. Persson and D. Pettersson, *Produktutveckling: Effektiva Metoder för Konstruktion och Design*, 2nd ed., Stockholm: Liber AB, 2013.
- [3] K. T. Ulrich and S. D. Eppinger, *Product Design and Development*, 5th ed., New York: McGraw-Hill, 2012.
- [4] M. Eriksson and J. Lilliesköld, *Handbok för mindre projekt*, 1st ed., Stockholm: Liber AB, 2004.
- [5] B. Bergman and B. Klefsjö, *Kvalitet: Från behov till användning*, 5th ed., Lund: Studentlitteratur AB, 2012.
- [6] D. Dunne, "User-centered Design and Design-centered Business Schools," in *The Handbook of Design Management*, R. Cooper, S. Junginger and T. Lockwood, Eds., Oxford, Berg, 2011, pp. 128-143.
- [7] K. Girotra, C. Terwiesch and K. T. Ulrich, "Idea Generation and the Quality of the Best Idea," *Management Science*, vol. 56, pp. 591-605, April 2010.
- [8] Å. Wikberg Nilsson, Å. Ericson and P. Törlind, *Design: Process och Metod*, 1st ed., Lund: Studentlitteratur AB, 2015.
- [9] A. Szatek, *Konceptstyrd Utveckling: Förnyelse av Produkter, Tjänster och Marknader*, 2nd ed., Lund: Studentlitteratur AB, 2011.
- [10] D. Dörner, "Approaching design thinking research," *Design Studies*, vol. 20, no. 5, pp. 407-415, 1999.
- [11] G. Pahl and W. Beitz, *Engineering Design: A Systematic Approach*, 2nd ed., London: Springer, 1996.
- [12] D. Bradford, J. H. Schamell, H. Schmidt-Hebbel, K. Sippel and G. J. Kramer, "Reel spool storage and loading device and method". United States Patent US7255301B2, 14 August 2007.
- [13] F. Kuhn and G. Rohde, "Reeling apparatus for a web". United States Patent US4390138A, 28 June 1983.



# Appendices

## Appendix A – GANTT-schedule

Week	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Project plan	Yellow																			
Litterature study - product developement	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow														
Study current concept		Yellow	Yellow	Yellow	Yellow	Yellow														
Checkpoint at Uni						Red														
Requirement specification					Yellow	Yellow	Yellow	Yellow												
Concept generation									Yellow	Yellow	Yellow									
Checkpoint Valmet - progress											Red									
Choice of concepts											Yellow	Yellow	Yellow							
Specification of concepts														Yellow	Yellow	Yellow				
Report	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Red				
Adjustments of report																	Yellow	Red		
Opposition																	Yellow	Yellow		
Presentation																			Yellow	Red

Yellow: Planned time

Red: Milestones

## Appendix B – Project Risk Analysis

No.	Risk	P	C	R=P*C	Action
1	The project exceeds the time plan	3	3	9	Continuously update the time plan and work toward deadlines
2	The different stakeholders have different expectations of what should be accomplished in the project	2	4	8	Keep an open conversation with supervisor on both Valmet and KAU
3	Purpose and goal are not fulfilled	1	4	4	Continuously verify purpose and goal when moving forward in the process
4	Lack of communication with supervisor from the university	3	2	6	Try to make sure I get the help I need by talking to the supervisor
5	Low response on interviews or communication with the company	2	4	8	Try to make sure I get the help I need by talking to the supervisor
6	Me or my colleagues gets the corona virus	2	3	6	Follow recommendations to prevent Corona from spreading
7	The regulations implemented due to corona virus affects the thesis, for example cancelled meetings, people working from home, etc.	3	3	9	Try to make the thesis as independent of this factor as possible
8	Unexpected additional elements need to be done to fulfill the project	4	3	12	Try to be a step ahead in the time plan so there is space for additional elements

P: Probability

C: Consequence

R: Risk factor

## Appendix C – FMEA

### C1 – First version, brief FMEA

No.	Characteristics of risk			Risk Analysis				Recommended actions	Responsible	Risk final concept			
	Risk	Reason	Consequence	P	S	D	RPN			P	S	D	RPN
1	Spool falls down during movement	Not fixed while moving	Crushing injuries	4	10	5	200	No free movement, consider during concept generation phase	Viktoria	1	10	5	50
2a	Spool get stuck	Dust	Maintenance needed	8	5	1	40	Consider during concept generation phase	Viktoria	2	5	1	10
2b		Misalignment	Manual help needed	8	5	2	80	Consider during concept generation phase	Viktoria	2	5	2	20
3	Failure of components	Too weak construction	Crushing injuries	1	10	8	80	FEM-analysis	Valmet	1	10	8	80
4	Reachable interfaces between moving components	No safety distance	Crushing injuries, pinching	2	6	3	36	Safety device/fence, consider during concept generation phase	Valmet	1	6	3	18
5	Hydraulic and pneumatic equipment	Injection of high pressure fluids	Injuries	2	5	2	20	Safety device	Valmet	0	5	2	0
6	Electrical equipment	Electricity	Electric shock	2	5	4	40	Safety device	Valmet	2	5	4	40
7	Fire	Paper, paper dust	Injuries	2	9	3	54	Fire extinguishers	Valmet	2	9	3	54
8	Falling or ejection of objects	Functional disorders	Crushing, impact injuries	1	10	4	40	Consider during concept generation phase	Viktoria, Valmet	1	10	4	40
9	Fall from height	Maintenance needed in high constructions	Impact injuries	3	9	1	27	Safety fence/walkways	Valmet	3	9	1	27

### C2 – FMEA for final concept

No.	Machine part	Characteristics of risk			Risk Analysis				Recommended actions	Responsible
		Risk	Reason	Consequence	P	S	D	RPN		
1a	Traverse	Spool falls down during lift	Spool is misplaced on the lifting hooks	Crushing injuries	1	10	5	50	Have lifting hooks fitted to the trace in the spools	Valmet
1b			Too high speed	Crushing injuries	1	10	3	30	Evaluate a maximum speed limit	Valmet
1c			Misaligned lifting hooks	Crushing injuries	1	10	2	20	Same motor for both hooks, correct instalation and control system	Valmet
2		Fall from height	Maintenance needed in high constructions	Impact injuries	3	9	1	27	Safety device/fence/walkways	Valmet
3a		Picks up wrong spool from storage	Error in control system	Error in planned production	1	6	2	12	Check when developing control system	Valmet
3b	Electric motors	Failure of components	Error in identification system	Error in planned production	1	6	2	12	Check when developing identification system	Valmet
4			Too weak construction	Crushing injuries	1	10	8	80	FEM-analysis	Valmet
5		Electricity	Failure of motor	Electric shock	2	5	4	40	Safety device/fence	Valmet
6		Fire	Paper, paper dust	Burns, injuries	2	9	3	54	Fire extinguishers, protection screen that separates equipment from dust	Valmet
7		Failure of components	Too weak construction	Crushing injuries	1	10	8	80	FEM-analysis	Valmet
8	Storage	Spool/traverse hits another spool during pick-up/drop-off	Too narrow between the storage positions	Crushing injuries	2	8	2	32	Consider during detailed construction	Valmet
9		Spool get stuck	Too narrow between the storage positions	Manual help needed, disturbance in production	1	5	2	10	Consider during detailed construction	Valmet


P: Probability

S: Severity


D: Probability of detection (Low number - high probability of detection)

RPN = P\*S\*D

Appendix D – Requirement specifications  
D1 – For spool storage with return system

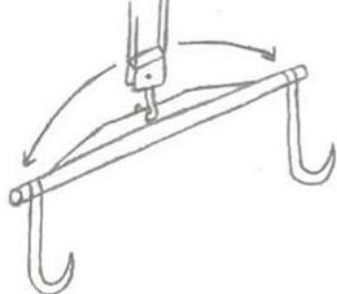
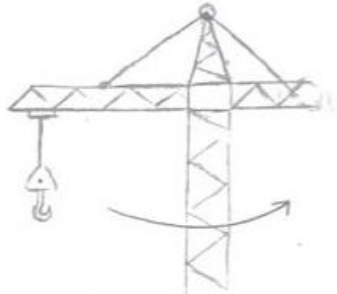
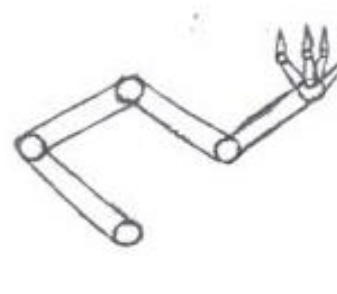
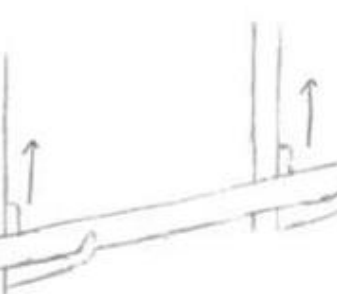
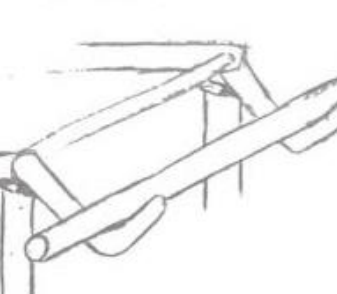
<div>  <div> <b>PRODUCT REQUIREMENT SPECIFICATION</b>  <b>Internal</b>  <b>Product: Spool storage with return system</b> </div> </div>											Issued date/by: 2020-03-26/Viktoria Ekstorp
											Rev/date: 03/2020-03-26
											Approved by: Dry End Steering Team
Category	Req. Nr.	Requirement	Function/ Limitation	Demand/ Wish	Weight (1-5)		TS/DS/ CD	Attribute	Target	Unit	Comment
FUNCTIONAL REQUIREMENTS	1	Transport spools from end of transport section (lifting table) to primary arm in top position	F	D	5						
	2	Fully automatized transport from end of transport section to primary arm in top position	L	D	5			Operator time	0 hours		
	3	Store spools	F	D	5			Quantity	6 Pieces		
	4	Maximum time to provide primary arm with new spool from end of transport section	L	D	5			Time	100 + L/0.2 seconds		L=transport length (maximum 2.5 minutes for a length of 10 meters)
	5	Position spool correctly in primary arm	F	D	5			Distance	±2 mm		Cross direction
	6	Minimize disturbing vibrations/shock loads to surrounding equipment/environment	F	D	5						
	7	Be able to handle spools delivered from external equipment (traverse or similar)	L	D	5						
	8	Create possibilities to remove damaged spools from storage	L	W	2						
	9	Provide attachment points for surrounding equipment such as dust screen, dust cover and glue system	L	W	1						
	10	Able to identify different spools	F	W	3			Quantity	2 Pieces		Two different kinds of spools
	11	Able to choose different spools	F	W	2			Quantity	2 Pieces		Two different kinds of spools
DESIGN	12	Applicable in SoftReel 2.0	L	D	5						
	13	Applicable in current tissue machine designs	L	W	3						
	14	Able to handle the maximum weight of the spools belonging to current machine	L	D	5						100-machine: 900-1300kg, 200-machine: 3300-4500kg
	15	Able to handle all dimensions of the spools belonging to current machine	L	D	5						
	16	Have good serviceability	L	D	5						
ENVIRONMENT	17	Withstand a dusty environment	L	D	5						
	18	Protect spools from surrounding debris	F	D	5						
SAFETY	19	Follow EN 1034-17 regarding safety of machinery	L	D	5						Check FMEA while choosing concepts
	20	Minimize the risk that a spool falls down	F	D	5						
	21	Allow safe entering of the area while spools are in movement	L	D	5						
COST	22	Lower cost than previous design	L	W	4			Cost	1 245 000 SEK		Excl. Documentation, installation, check-out

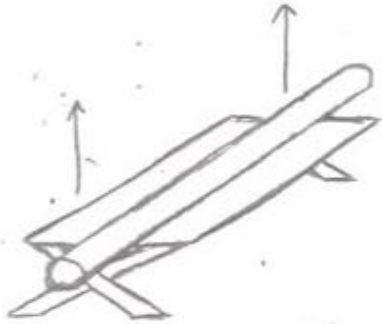
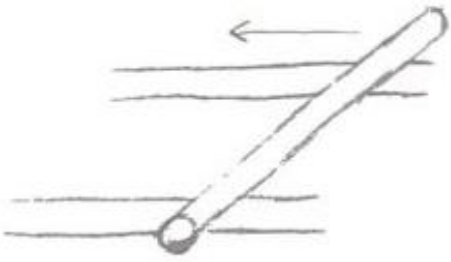
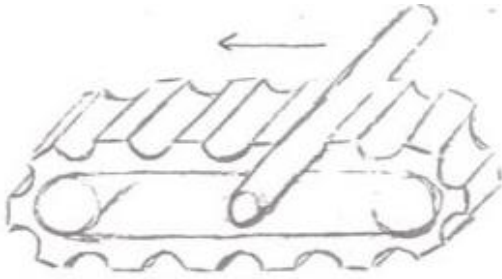
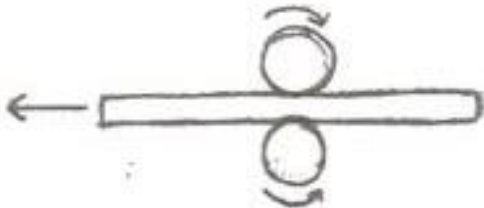

## D2 – For spool storage without return system

<div>  <div> <b>PRODUCT REQUIREMENT SPECIFICATION</b>  <b>Internal</b>  <b>Product: Spool storage without return system</b> </div> </div>											Issued date/by: 2020-03-26/Viktoria Ekstorp
											Rev/date: 02/2020-03-26
											Approved by: Dry End Steering Team
Category	Req. Nr.	Requirement	Function/ Limitation	Demand/ Wish	Weight (1-5)		TS/DS/ CD	Attribute	Target	Unit	Comment
FUNCTIONAL REQUIREMENTS	1	Transport spools from storage to primary arm in top position	F	D	5	1					
	2	Fully automatized transport from storage to primary arm in top position	L	D	5			Operator time	0	hours	
	3	Store spools	F	D	5	1		Quantity	6	Pieces	
	4	Maximum time to provide primary arm with new spool from end of transport section	L	D	5			Time	50 + L/0.2	seconds	L=transport length
	5	Position spool correctly in primary arm	F	D	5	2		Distance	±2	mm	Cross direction
	6	Minimize disturbing vibrations/shock loads to surrounding equipment/environment	F	D	5	1					
	7	Be able to handle spools delivered from external equipment (traverse or similar)	L	D	5						
	8	Create possibilities to remove damaged spools from storage	L	W	2						
	9	Provide attachment points for surrounding equipment such as dust screen, dust cover and glue system	L	W	1						
	10	Able to identify different spools	F	W	3	2		Quantity	2	Pieces	Two different kinds of spools
	11	Able to choose different spools	F	W	3	2		Quantity	2	Pieces	Two different kinds of spools
DESIGN	12	Applicable in SoftReel 2.0	L	D	5						
	13	Applicable in current tissue machine designs	L	W	3						
	14	Able to handle the maximum weight of the spools belonging to current machine	L	D	5						100-machine: 900-1300kg, 200-machine: 3300-4500kg
	15	Able to handle all dimensions of the spools belonging to current machine	L	D	5						
	16	Have good serviceability	L	D	5						
ENVIRONMENT	17	Withstand a dusty environment	L	D	5						
	18	Protect spools from surrounding debris	F	D	5	2					
SAFETY	19	Follow EN 1034-17 regarding safety of machinery	L	D	5						Check FMEA while choosing concepts
	20	Minimize the risk that a spool falls down	F	D	5	2					
	21	Allow safe entering of the area while spools are in movement	L	D	5						
COST	22	Lower cost than previous design	L	W	4			Cost	657 578	SEK	Excl. Documentation, installation, check-out

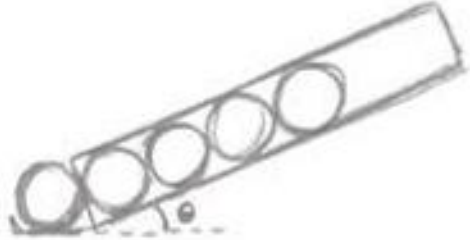
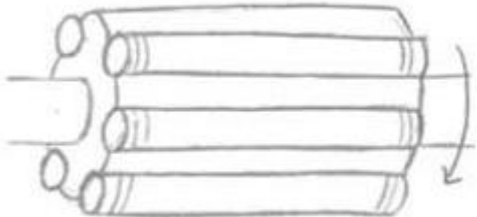

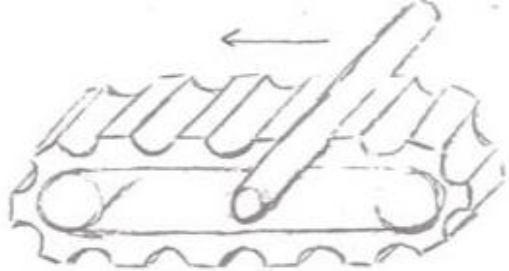
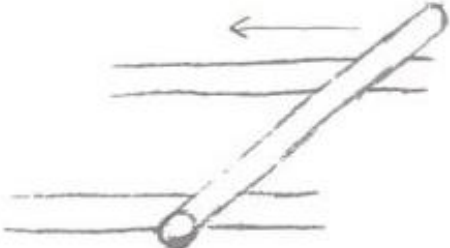
## Appendix E – Explanation of partial solutions

### E1 – For transport


<p><b>Traverse</b></p> <p>Vertical and horizontal transport with internal traverse. The pulley could be replaced by two pulleys, one at each side to prevent rotational movement.</p>	
<p><b>Crane</b></p> <p>Vertical and horizontal transport. Possible to move sideways and rotate as well.</p>	
<p><b>Robotic arm</b></p> <p>Vertical and horizontal transport. Possible to move sideways and rotate as well.</p>	
<p><b>Lift/elevator</b></p> <p>Vertical transport. No rotation.</p>	
<p><b>Lifting arm</b></p> <p>Current solution. Vertical transport, limited transport horizontally (length of arms).</p>	

<p><b>Lifting table</b></p> <p>Vertical transport. Modifying existing lifting table to transport spools all the way up to further transport above the lower rails.</p>	
<p><b>Rails/inclined rails</b></p> <p>Horizontal transport, either by external force or inclined rails driving the spool forward by gravitation only. Even possible to transport spool in a different orientation, for example with its z-direction in the machine direction.</p>	
<p><b>Conveyor</b></p> <p>Horizontal transport with fix positions for the spools. Even possible to transport spool in a different orientation, for example with its z-direction in the machine direction.</p>	
<p><b>Driving wheel</b></p> <p>Horizontal transport along the length of the spool (z-direction). Could be applied beside the transport section.</p>	
<p><b>Wave motion</b></p> <p>Horizontal transport. Pushes the spool forward with a wave motion causing the spool to roll.</p>	

## E2 – For storage

<p><b>Indexing magazine</b></p> <p>Indexed magazine where the spools get into pick-up position with gravity only. No external forces required.</p>	
<p><b>Bit-set/revolver magazine</b></p> <p>The spools are stored in a revolver magazine (bit-set magazine) in fix positions. This magazine can rotate to get the preferred spool into pick-up position.</p>	
<p><b>Vertical magazine</b></p> <p>A fix, vertical magazine where the spools move into pick-up position with gravity only. No external forces required.</p>	
<p><b>Conveyor</b></p> <p>The spools are stored in fix positions in a conveyor. The conveyor could work as transport from lifting table to primary arm, but also on its own as just a storage.</p>	
<p><b>Rails</b></p> <p>The spools are stored on multi-functional rails just as the current design, where the rails also have the purpose to transport the spools from the lifting table to the primary arm.</p>	



<p><b>Stand</b></p> <p>A fix magazine where the spools have fix positions. Require external equipment to move the spools.</p>	
---	---