Innovative reclaim technology
Medium size bulk storage solution

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Sammanfattning

Detta examensarbete gjordes åt BRUKS, ett företag aktivt inom trä process, bioenergi och bulkmaterial hantering industrin. Idén för examensarbetet var att ta fram ett nytt utmatningssystem för silolösningar där träflis lagras. Ett mellansegment på 1000 – 5000 m³ togs fram som det segment med störst försäljningspotential. Två olika koncept togs fram, ett för nybyggen och ett för ombyggnad av existerande silos.


Dessa koncept utvecklades med hjälp av ett CAD-program (Solid Edge), beräkningsprogram (ANSYS Workbench 10.0) samt med hjälp av BRUKS och olika personer inom industrin. När koncepten börjat ta form utvärderades dessa av BRUKS. I denna utvärdering upptäcktes vissa problem som erfarna medarbetare påpekade. Efter detta omarbetades koncepten för att ta hänsyn till deras synpunkter, vilket ledde till bättre funktionalitet. Detta gav examensarbetarna en unik inblick i vilka problem som kan uppstå där bara erfarenhet är till hjälp, eftersom träflis som material är väldigt oberäkneligt och svårt att göra korrekta antaganden på.

Koncepten blev aldrig detaljutvecklade eftersom BRUKS ansåg att det var viktigare att fokusera på nya idéer då de behövde hjälp med att ta fram nya systemlösningar där de fick färska ögon som såg problem och möjligheter från en annan synvinkel. Därför avslutades utvecklingen då en systemöverblick och de funktionella problemen lösts.

Problem som dök upp under utvecklingen hänförde främst från att examensarbetarna hade en begränsad erfarenhet inom industrin och hade svårigheter att uppskatta kraftor och materialbeteenden. Information visades vara svår att få tag på då arbetet skedde på distans och det tog ibland tid att få svar från medarbetare på BRUKS då de ofta var upptagna med sitt eget arbete.
Abstract

This master thesis was done for a company called BRUKS which is active in wood-processing, bio-energy and bulk material handling industry. The idea for the master thesis was to develop a new reclaiming method for silos where wood chips are being stored. A medium segment of between 1000 – 5000 m$^3$ was defined as the segment with the most sales potential. Two different concepts were produced, one for new constructions and one for rebuilding already existing silos.

In the beginning of the master thesis a lot of time was spent on visiting different BRUKS offices and customers to get an overview of the industry and the product. This information was the basis when the idea generating phase began. Of 50 ideas the result after the selection process was two concepts. The first idea combined a stoker and a rotating screw to create a cost efficient and robust solution. The second idea was a new development of a stoker where the rate of reclaim and load bearing capabilities were improved.

These concepts were developed with a CAD-program (Solid Edge), a calculations program (ANSYS Workbench 10.0) and with the help of BRUKS and different persons in the industry. When the concepts started to take shape they were evaluated by BRUKS. In this evaluation different problems were discovered by more experienced personal. After the evaluation the concepts were remade with respect to the highlighted problems which led to increased functionality. This gave the participants a unique insight into the different problems that can occur where only experience can help, wood chips is a very unpredictable material and a hard material to make assumptions on.

The concepts were never constructed in detail because BRUKS deemed it more important to develop a systematic view over the concepts with fresh eyes would help them see the problems and opportunities from new angles. That is why the development ended with functional problems being solved.

Problems that occurred during the development originated often from the lack of experience of the participants which made it hard to estimate forces and material behaviour. Because the master thesis was done by distance it proved hard to get a hold of information and answers were sometimes delayed because personal at BRUKS often were occupied with their own work.
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1. Introduction
This master thesis lasted from 2nd of June to 14th of November 2008. The master thesis was done as collaboration between the company BRUKS and the department of Machine Design at the Royal Institute of Technology, KTH.

The assignment given by BRUKS was for the students to help BRUKS develop two new bulk handling systems for silos in the medium sized segment where BRUKS felt they were lacking a competitive edge. BRUKS also needed help compiling their products and to see what additional cost that are associated with their products.

To make BRUKS competitive in the medium sized market is the main reason for the master thesis work being issued.

1.1. Background
BRUKS is a company active in the Pulp & Paper industry. This industry has very high demands regarding quality and durability because the paper industry has very small margins. For a paper mill to go with profit it has to run constantly for an entire year. Every year a five day stop is allowed for maintenance of the entire paper line. This means that paper mills are willing to pay more for products with higher quality\textsuperscript{1}.

BRUKS has identified new markets where they would like to see an increase in market shares, such as medium sized storage for wood chips. Many of the players on these markets do not come from a background with as high demands as the Pulp & Paper industry has, which means that they are offering solutions with lower standards regarding durability and quality but the products are cheaper.

The following questions are important to answer for the thesis work to be able to produce the best result possible:

- Which solutions are applied in the medium size segment and which requirements must the new solution fulfil?
- Which viable techniques exists for handling wood chips and what factors must be considered for an efficient reclaiming method?
- In which size intervals are the different storage systems within the group used?
- What is the customers demand on the storage system?

It is important to BRUKS that these aspects are investigated to enable them to make a decision on how to best approach and stay competitive in the smaller segments. It is also of practical importance to BRUKS to collect their information about the different kinds of products and spread it within the group.

\textsuperscript{1} Forsberg, R. (080917 – 081023).
1.2. Problem description
BRUKS has a problem that they are not competitive when it comes to storage of bulk materials for the lower segments. This partly depends on that their products are customized for every customer, which pushes up the price and the time-to-market increases. They also do a large part of their new development within each new project which increases the workload and time to market since they need to “re-develop” machines for all their different customers. BRUKS does not have a large scale production of smaller bulk storage solutions which means that it is difficult for BRUKS to maintain competitive pricing. This means that other companies can come in to the market and offer virtually the same product as BRUKS but faster and to a lower price. Because BRUKS is in a stage of rapid growth and corporate acquisitions there is an overlap in their product catalogue. They are currently in a process of evaluating what kind of storage systems that works the best with different materials and applications depending on different markets and segments.

1.3. Purpose and goal
The purpose of this master thesis was to develop new solutions for medium sized storage for bulk materials for different customer segments in BRUKS main market.

Tasks that have been done to achieve the purpose are as follows:

1. A market- and competitor analysis was done to investigate BRUKS standing in the different customer segments that was of interest.

2. An analysis of existing products within the group and clarification of the capabilities and limitations.

3. A simple cost analysis for customers with different storage solutions.

4. Concept development of storage solutions.

The concept development was focused on small and medium sized storage solutions. The idea was to develop different concepts, one new and one for existing costumers. BRUKS want to be more competitive in the smaller segments with these concepts by increasing the value for the customer or supplying a cheaper solution. There is a market potential for this segment in Europe but the biggest market potential is in North America.

The main goal of the thesis work had to be prioritized, i.e. the development of concept solutions, the preparatory work such as market and cost analysis was done to that extent that there was time left for the development of concept solutions. The amount of time spent on preparatory work was regulated by a schedule which was formed during the planning phase of the thesis.

Course goals
The master thesis is an independent work that shall be done with scientific and engineering methods and link back to a specific problem with relevant theory.

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2 Forsberg, R. (080917 – 081023).
The students doing this master thesis shall:

− Be able to apply relevant knowledge and skills within a certain area of technology for a given problem.
− With limited information independently analyze and discuss a complex formulation of a question and handle an intricate problem on an advanced level of engineering.
− Reflect over, evaluate and critically review own and others scientific results.
− Be able to document and present ones work, for a given target audience, with high demands on structure, formalities and language.
− Be able to identify need of more knowledge and continuously develop their competence.

2. Delimitations

To make sure that the thesis work would not get excessively large and time consuming a number of delimitations were necessary. These delimitations acted as guidelines after which the thesis work was defined and amount of time spent on different parts were regulated.

2.1. Handled material

BRUKS has a lot of different possible materials that can be handled by their equipment. All materials have different properties and behaviors. This means that different materials will react differently to the same equipment. Some materials are free-flowing which means that they avalanche easily, which results in a set of specifications for the reclaimers that makes it possible to maintain a controlled flow. Because of the large variety of materials that can be handled it was deemed best to focus on BRUKS core competence which is wood chips.

2.2. Storage volume

The volume of the stored material in a silo has a big impact on how a reclaimer is designed. Reclaimers have to be designed to withstand the weight of the material being placed on them. According to Ken Upchurch and Johan Johansson\(^3\) a large potential market gain in the North America is in closed silo storage between 1000 – 5000 m\(^3\). This is a market segment where BRUKS has problems being competitive and is losing business. Even in the European market this segment is a potential market gain for BRUKS.

2.3. Closed storage

Closed storage was chosen as the main focus for storing bulk material instead of open-air storage because closed storage is viewed as a better solution for smaller storage volumes and wood chips. Another factor was that all the competence within BRUKS for closed storage is in Sweden instead of open-air storage where all the competence is in the United States.

2.4. Focus on reclaiming devices

Early on it was decided that the reclaiming device was the main focus of the thesis work. The construction of the silo is something that the customer themselves hire contractors to do. The

intake into the silo was also deemed not important enough to be included in the thesis work. The intake is often very simple, a transporter which dumps everything through a chute down into the silo.

2.5. Market

The market focus was decided to only include the North American and the European markets, because of the similarities between the markets. The Chinese market was considered but discarded because this market is considerably different from the North American and the European markets. Potentially the Chinese market is a very large market for BRUKS but because of their small market presence in China, they have recently started a sales office in Beijing, it was believed not to be possible to get a good enough view over the market.

3. The company

BRUKS is an international mechanical-engineering company which develops, manufactures and markets machines and systems for the wood-processing, bio-energy and bulk material handling industry. Their customers are sawmills, board and pulp mills as well as energy suppliers all over the world. Their head office is located in Arbrå, Sweden, and they also have an office in Germany and two in the US. BRUKS has representatives in over 50 countries and their annual sales volume is about 75 million EUR and exports around 80% of its production. The company has had a period of rapid expansion with many new acquisitions which has taken a strain on the internal structure and they are now trying to integrate the new affiliations so that the cooperation between the new offices runs smoothly.

3.1. Ownership

BRUKS is a part of the JCE group since 2006 which is a Swedish based investment company. The JCE group is owned by Christer Eriksson and started off in the oil and gas offshore industry. The company has over the years diversified their operation and is now present in many different areas of industry such as forestry, bio energy and technical engineering. The JCE group has it’s headquarter in Gothenburg, Sweden and employs about 8000 people operating in many different places around the world.

3.2. History

BRUKS was founded in 1959 and began with developing and selling chippers, later on they continued on to manufacturing butt-end reducers. In 2000 BRUKS acquired Klöckner which is a German company that is a leading supplier of drum chippers. In 2006 Celltec engineering joins the BRUKS Group within JCE to fill a gap in the Pulp & Paper area. Two new companies joined the BRUKS Group in 2007, first Swedish Rotom which has a strong trademark in size reduction with their extremely sturdy hogs. The second company was Rockwood which is a USA based company who are a leading supplier of logistics systems for bulk handling. The latest acquisition is the Swedish engineering company GVC which supplies conveying equipment that is going to increase the cost-efficiency of their total solutions.

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3.3. Future goals

BRUKS is expanding their operation rapidly and are trying to become a major supplier of complete system solutions for bulk handling. Their main market is for handling wood chips but the company is also looking into many new areas of bulk handling. They are now trying to get a better hold on the market for smaller and medium sized storage of bulk material, which is an area where they have stiff competition from cheaper suppliers. They are also extending their global coverage and are planning to set up new offices at strategic locations.

4. Method

The purpose of the master thesis is to develop storage solutions for BRUKS different customer segments. To create a storage solution that appeals to customers it was necessary at an early stage of the product development process to do a market analysis to see what was already available for the customer. It was also important for BRUKS that their different types of storage reclaiming devices were structured to make an overview of their existing technology possible. This was done by extracting a lot of information from BRUKS themselves early in the market analysis to enable a view of the capacities and prices of the different storage and reclaiming types.

It is important to know what the customers want and are willing to spend money on. To make the new storage solution as good as possible it is important to have a big variety of concepts to enable different ideas to take form. A crucial step of the master thesis is the brainstorming and concept development.

The methods used to achieve the thesis main goals were a market analysis, an analysis phase to structure the different storage and reclaiming alternatives BRUKS has and a brainstorming phase where ideas were produced. After the brainstorming the ideas had to be developed, at a systems level, and evaluated to ensure that the ideas most suited became the final concepts. After the final concepts were chosen design at a systems level began. This phase enabled the concepts to work properly on a functional level.

4.1. Methods used

The methods used to complete this master thesis have been chosen after what was needed to complete the main goal and how to better understand the problem at hand.

Interviews

Semi-structured interviews were conducted with two persons on different BRUKS offices. 18 telephone interviews were done with different paper- and pellet mills and also thermal power stations to get a deeper understanding about how the end-users thinks and what they demand from their storage solutions.

Semi-structured interviews are interviews where the people being interviewed have the opportunity to talk freely about the subject. The one interviewing has the control by asking the questions and keeping a focus on the subject being discussed. If the interview starts to stray from the subject it is the responsibility of the person conducting the interview to steer the interview back to the subject. This was preferable because of the thesis participant’s lack
of knowledge. These interviews were used mainly to collect information about BRUKS and the end-users.

**Visits**

Visits to different BRUKS offices and study visits to different mills were done to get a more practical view of the problem and the different solutions that are implemented today. The BRUKS office in Atlanta, Georgia, and Örnsköldsvik were visited to get a better understanding of BRUKS and the products they make. During these visits interviews were conducted with key persons in the offices. In connection with the visit in Örnsköldsvik a field study took place in “Ö-vik Energi” which is a thermal power station under construction where a storage system from BRUKS has been bought. Another visit was done to the Hallsta paper mill in Hallstavik. Hallsta paper mill is a large customer of BRUKS and the visit made it possible to see the different solutions that BRUKS had supplied.

**SWOT-analysis**

SWOT is an acronym for “Strengths”, “Weaknesses”, “Opportunities” and “Threats” and a frequently used aid especially in planning. In a SWOT-analysis the goal is to come up with all possible strengths, weaknesses, opportunities and threats that might affect the company. This will help to form an overview over the surrounding world, see chapter 6.2.

**Function-means tree**

The process, storing bulk material, is divided into different functions and to each function every available means of fulfilling this function is listed. This makes it easier to take different means from different functions and combine these into a new solution and identifying new means of solving the problem, see appendix 6.

**Internet**

Internet is a good source of information when it comes to looking up different competitors and technologies. Internet has been widely used for searching literature, patents, new and existing technology and information about different companies.

**Requirement specification**

To define the area and the requirements for the solution it has been important to create a requirement specification. It is a valuable tool when you design a solution to know the target capacity of the solution you want to achieve. These requirements have been taken from interviews and experiences from different persons in BRUKS and outside of BRUKS, see appendix 3.

**Literature**

Literature is important not only for the theoretical frame of reference but for the understanding of how bulk material handles and what to think about when you design a solution. It is an important step towards understanding and defining the problem.
Brainstorming
To be able to create a new solution it was important to generate as many ideas as possible. Many ideas meant that a lot of different solutions were explored. Brainstorming is a form of forum where it is not allowed to criticise or otherwise talk negatively about an idea. The purpose of brainstorming is to generate as many ideas as possible that can be selected from in a later phase during the product development process.

Concept scoring & screening
It is important to have a systematic way to screen different concepts so only the ones with the best chance of success gets picked as a final choice for a concept. When the concepts were screened a screening matrix were used. This matrix had a number of properties that the different concepts were evaluated on, for the different matrixes used see appendix 4 and 5.

Computer programs
To visualize and to create drawings of the concepts a CAD - program (Computer Aided Design) was used called “Solid Edge”. FEM - analysis was conducted on different parts that were of structural importance. The FEM - analysis (Finite Element Method) was done by “ANSYS Workbench 10.0”, the simulations in ANSYS are approximations of actual working conditions. Silo Stress Tool is a program created to calculate an approximate pressure in silos of different shapes and sizes.

5. Theoretical frame of reference
The theoretical background that the thesis work is based upon is focused on the bulk handling of wood chips. Several books on the subject of bulk solids handling have been studied to determine the crucial factors that needs to be considered when developing a new storage system for wood chips. The books have also been studied to determine which techniques are being used today and how well they perform. Much material has also been received from BRUKS regarding their machinery and its performance.

An extensive breakdown of current technologies were performed to identify different methods for storing wood chips and to analyze their strengths and weaknesses. This has been partly gathered from the interviews made with people from different facilities, information from BRUKS and also by books on the subject of bulk handling. The behaviour of wood chips in bulk storage has been studied to determine which types of techniques would be viable for handling.
5.1. Current Technologies
Here current technologies for reclaiming and discharge aids are discussed. How they work, what kinds variations there are and what benefits or drawbacks they may have.

Screw reclaimer
Screw reclaimers are a very common mechanical solution for extracting bulk material ranging from fine-grained powders to lumpy materials.\(^6\) They consist of a central shaft to which helical flights are mounted. When extracting material with a screw it is subjected to shear deformation and internal friction which makes it less suitable for friable material.\(^7\) An advantage with most screw reclaimers is that they can be made completely dust-, gas- and pressure tight which can be desirable for some applications like feeding a pneumatic conveying line. Very free flowing materials will cause a problem for screws since they can flood through it making the flow uncontrollable. Sticky materials will also be difficult to extract with a screw since they may stick to it and clog, this can be avoided by using special flights and smooth surfaces for the screw helix. An important aspect for the screw reclaimer is to make sure that it is getting a uniform removal of material throughout its length. This may otherwise cause “dead zones” where the material is standing without extraction.\(^8\) The cause of this is due to the fact that the screw flights fill up to early so that it is unable to remove material all over the its length. To achieve this uniform removal the screw is usually made with an increasing pitch and diameter from one end to the other so it doesn’t fill up to soon, an illustrated example of a screw reclaimer can be seen in figure 5.1.1. Screws are used in many different configurations for extracting material depending on how material is stored, below are the most common ways.

\[\text{Figure 5.1.1: Screw reclaimer}\]

Parascrew
This type of configuration works with a pair of screws and is used for linear storage facilities such as A-frame storage where the screw is covered with material that is fed from the top. It moves linearly through the pile reclaiming the material from the bottom to one side where it is extracted. Since the screw covers the bottom of the pile it cuts through the different layers of material that builds up depending on the time it was feed onto the pile, see figure 5.1.2. This means that each feed produces a blend of material that has been fed at different times.

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reclaiming from the bottom also ensures first in is first out that minimizes material degradation⁹.

![Figure 5.1.2: Extraction of the different layers in A-frame storage.](image)

**Circular screw reclaimer**
This configuration consists of a central hub to which a screw is mounted, see figure 5.1.3, the screw then rotates in a circle from the hub which is covered in material from above¹⁰. As the screw rotates it feeds material in to the hub at the centre of the pile, beneath the hub there is usually a type of conveyor belt for extraction. This configuration can be used both for open piles and covered silo storage. Depending on the length and toughness of the screw it can sometimes require a support at the perimeter.

![Figure 5.1.3: Circular screw reclaimer](image)

**Rotoscrew**
The rotoscrew is a variation of the circular screw reclaimer; it is used for covered silo storage. The difference between the rotoscrew and the circular screw is that the rotoscrew is angled up

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⁹ Consilium

¹⁰ Consilium
to about 35 degrees so that it travels in a conical plane\textsuperscript{11}. It’s an economical solution but it has a lower max capacity than the circular screw.

**Tubefeeder**

This is a variation of the circular screw where the screw has been encapsulated in an outer shell, the material to be reclaimed enter through openings in the shell to the screw\textsuperscript{12}. The shell around the screw is supposed to carry most of the load from the material that covers the machinery; this in turn will reduce the forces on the screw and lower the energy consumption. The drawback to the solution is the risk of having material getting stuck in openings and getting lodged between the screw and shell.

**Stoker**

The stoker is BRUKS version of a walking floor which is a discharge system often used in smaller loading bins and hoppers. It consists of two “ladders” which are mounted horizontal to the floor of the storage. Each ladder step is shaped to promote horizontal movement in the bulk material in one direction towards the outlet. The side facing the outlet is planar perpendicular to the floor while the other side is sloped. The two ladders are driven by two hydraulic pistons each which moves the ladders back and forth towards the outlet\textsuperscript{13}.

**VibraFloor**

This technique is based on vibrations to create a motion in the bulk material to make it easy to handle and slide down for extraction. The construction is made up of special steel membranes that are mounted on resilient supports on which the material rests\textsuperscript{14}. The membranes are set in motion by vibrators that are installed sheltered from the material that is stored. This technique works on a wide range of particle sizes without emitting any dust. The construction has very low maintenance requirement and low power consumption. It can handle vertical loads up to 200 ton/m\textsuperscript{2} and can be made to handle abrasive material, corrosive material and also watertight.

**Rotating table**

This construction consists of a container that is open in the bottom and below there is a circular disc with a diameter around 50% greater than the containers outlet\textsuperscript{15}. The disc rotates with a certain gap between the silo and disc at a relatively low RPM allowing the material to flow out from the bottom of the container. As the disc rotates material is being feed from the container and out on the perimeter of the disc. The material is then pushed off the disc with a plough and extracted, an illustration can be seen in figure 5.1.4. This method of discharge gives a good control of the outflow from the storage which is decided by the gap between the disc and the silos bottom. There is however some shearing stress exerted on the rotating disc which is caused by a zone of “dead” conical mass which emerge in the centre of the outlet.

\textsuperscript{11} Wennberg
\textsuperscript{12} Rader, (2008-10-29, 15:00).
\textsuperscript{13} Forsberg, R. (080917 – 081023).
\textsuperscript{14} Silexport, (2008-10-29, 15:00).
Belt feeder
This is a similar construction to the rotating table in that it uses a container that is open in the bottom but the rotating disc is replaced by a rubber or polymer belt. The container usually has a rectangular outlet that is tapered to provide a uniform feed across the length of the belt, an illustration can be seen in figure 5.1.5. The capacity of the belt feeder’s discharge can vary greatly depending on its width and speed of the belt.\(^{16}\)

Rotary feeder
The rotary feeder comes in several different designs depending on the bulk material handled. The extreme version is simply a rotating drum over which the material flows; they are usually fitted with vanes which gives more control over the discharge rate\(^{17}\). There are also open and closed varieties where the closed ones are preferred if the material is very free flowing and risks flooding\(^{18}\). This solution is cheap and easy to maintain when used for free flowing materials.

Moving Hole
This is a technique which relies solely on gravity to remove the material. The construction consists of a slot that is able to traverse back and forth across the bottom of the container.

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without friction against the material. Since the material is not subjected to any force from the reclaim there is also no risk of compaction. Beneath the moving hole there is usually a conveyor belt or other means of extraction.  

**Drag arms**

The drag arms are made to drag along the bottom of a silo keeping the flow continuous and feeding screws or other means of extraction. They are made of specially alloyed spring steel customized according to the bulk material. The arms are attached to a rotor drum which creates the rotating motion across the silos bottom.

**Airflow**

This is a discharge aid that as the name implies uses air that is injected into the bulk material to initiate flow. It is important to achieve a uniform distribution of airflow within the container for a desired effect. The air can be applied with different types of flow patterns either a small constant flow or short bursts of air, an example can be seen in figure 5.1.6. What kind of flow that is appropriate depends on the type of material that is being stored and the nature of the problem. The constant airflow is to keep the material from consolidating which can occur when it is stored for greater periods of time. The burst of airflow is used when the material is being extracted to make it more free flowing. When an airburst is injected into a closed storage it causes a local overpressure causing a flow of air towards lower pressure zones such as the ambient pressure at the outlet. The airflow created can destroy rat-holes and arches (see chapter 5.2: “Typical flow problems”) that may have formed by exerting a force on the bulk material in the direction of the outlet. The injection of air is most effective for free flowing bulk material with small particles, for larger particles the increase in required airflow may make the technique uneconomical. For cohesive bulk material other problems may arise such as the air creating channels in the material while the most of it remains stationary. The airflow may also cause dust generation and increase the stress on the walls of the container if the material is resistant to move and the pressure keeps building up.

![Figure 5.1.6: Airflow](image)

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19 Kamengo, (2008-11-17, 14:00).
20 SHW engineering
Air pads
This is another method of using airflow to promote extraction of bulk material. It uses inflatable pads that are mounted on the inside of the container at areas where problems may occur such as arching\textsuperscript{23}. The pads that are made of an elastic material can be inflated to exert a mechanical force on the material and hopefully disrupt any arching. There is a risk the material will be compacted by the expanded pad making the situation worse if a strong arch has been formed.

5.2. Bulk solid material
A bulk solid consists of many particles or granules of different sizes randomly grouped together to form a bulk. The way such a material behaves in various circumstances depends on many different factors, but principally on size, shape, density of the constituent particles and the friction between particles\textsuperscript{24}. A lot also depends on the equipment that interacts with the bulk solid, wood chip behavior can vary depending on the design of the equipment. Flow patterns from the storage are very dependent on the design of the storage. Faulty design often results in major flow problems that can cause entire feed lines to a paper mill to stop or breakdown.

Flow patterns
This segment explains the different flow patterns that can occur when material is being discharged. When the different patterns are discussed discharge aids of any sort are not considered. The discharge from the storage is only relying on gravity. A lot of the flow problems can be avoided with different discharge aids or reclaimers, but to get a picture of potential problems they are not considered in this chapter.

Core flow is a flow pattern where some of the material is in motion while some is stationary\textsuperscript{25}. Core flow happens if the silo walls of the converging section are not steep enough, i.e. flat bottom\textsuperscript{26}, see figure 5.2.1. A channel is formed in the center of the silo where material is being discharged. Because the flow is in a channel material is being discharged by the first in-last out which is not good when a material like wood chips is handled. The stationary material will start to deteriorate because that material is never being discharged from the silo. The flow from a core flow silo tends to be erratic due to parts of the stationary zones collapsing into the core\textsuperscript{27}. When the stationary material have gained enough strength to remain stable after the core has emptied out and the stationary material has reached the roof then a rat-hole has been formed, see chapter 5.2: “Typical flow problems”.

\textsuperscript{27} Kulwiec, R.A. (1985), pp 902-905.
Mass flow is a flow pattern where all the material sets in motion when a discharge begins\textsuperscript{28}. Mass flow requires steep walls of the converging section and low friction on the walls\textsuperscript{29}, see figure 5.2.2. For wood chips this pattern is ideal because the first in-first out can be obtained and no stationary zones will form which minimizes degradation. The flow from a mass flow silo is uniform and steady. No rat-holes can be formed because all the material is moving but cohesive arches can form if the material is cohesive enough\textsuperscript{30}. Mechanical arches can also form if the design of the outlet is improperly designed, see chapter 5.2: “Typical flow problems”. Because mass flow requires steeper walls the silo where mass flow is obtained is usually larger than a core flow silo which can be a problem if space is of concern.

There is a third and more unusual flow pattern and that is the expanded flow. The expanded flow combines a mass flow section below a core flow section\textsuperscript{31}. The mass flow section ensures a uniform discharge from the silo while the core flow section makes the total silo smaller than a mass flow silo would be. Because of the mass flow section rat-holing can be avoided in the core flow section.

**Typical flow problems**

Different obstructions can occur during discharge from a silo. These obstructions can render an entire silo useless. Therefore it is important to understand the obstructions that can occur and how to avoid that these occurs. There are basically two types of obstructions that can occur when a silo is discharging, arching and rat-holing.

**Arching:**
An important practical consequence of the cohesiveness of a bulk solid is that the material can develop enough strength to form an “arch” over an opening. Therefore it is important with knowledge about a material’s flow behavior before designing storage for the material.

There are two different forms of stable arches that can occur across an opening\textsuperscript{32}, see figure 5.2.3.

1. **Mechanical arch:** A mechanical arch develops as a direct result of large particles being wedged together. This is the simplest form of arch to avoid. It is usually avoided by designing the storage outlet to be at least ten times the largest particle.

2. **Cohesive arch:** A cohesive arch is the more difficult arch to predict and avoid. The cohesive arch is formed as a result of the consolidation and strength of a cohesive material and can therefore occur even with fine particles size. Cohesive arches generally occur during mass flow. A lot of the research done has been aimed at understanding what is needed for a stable cohesive arch to occur so that later on technology can be developed to avoid these arches.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{arches.png}
\caption{Figure 5.2.3: Left: Mechanical arch, Right: Cohesive arch.}
\end{figure}

**Rat-holing:**
Rat-holes are characteristic of cohesive material and only known to occur during core flow\textsuperscript{33}. Rat-holes occur when the stationary zones in a core flow silo gain sufficient strength to become stable even after the core part of the silo has been emptied out, see figure 5.2.4. Then there is still material left in the silo but no material is flowing out. If the stationary material remains stable, the silo cannot be emptied. Rat-holes can be avoided by careful design of the storage outlet and preventative measures.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{rat_holes.png}
\caption{Figure 5.2.4: Rat-holes in a core flow silo.}
\end{figure}

---


has built up to the silo roof no material can enter or leave, depending of the silo design. The live storage, the actual storage capacity of a silo, will be drastically reduced.

Figure 5.2.4: Rat holing illustrated in a silo.

Segregation:
Many bulk solids segregate when they are handled. A bulk solid usually consists of a range of particle sizes. The fines are usually concentrated under the filling point while coarser particles concentrate at the periphery. This means that with a center filled and center discharged silo the fines is located in the middle while the larger particles are located along the wall of the silo. Often a homogenized blend is preferred when a silo is about to discharge. If core flow occurs and the material is segregated then there won’t be a homogenized blend that is discharged but just the fines that will fall out. This is why mass flow is a more desirable flow pattern then core flow. When mass flow is obtained the material will blend homogenized and the output will be the desired blend.

Angle of repose:
When a bulk solid, like wood chips, is allowed to form a heap or when slippage occurs and a sloping surface is created, then the angle between the surface of the material and the horizontal plane is determined by the properties of the bulk solid. The way the sloping surface was created also has an impact on the angle. There are standardized tests that have found reasonably consistent results for the angle of repose for different bulk solids, see table 5.2.1.

Table 5.2.1: The effects of angle of repose on bulk solid behavior.

<table>
<thead>
<tr>
<th>Angle of Repose:</th>
<th>Type of bulk solid:</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-30°</td>
<td>Very free-flowing</td>
</tr>
<tr>
<td>30-38°</td>
<td>Free-flowing</td>
</tr>
<tr>
<td>38-45°</td>
<td>Fair flowing</td>
</tr>
<tr>
<td>45-55°</td>
<td>Cohesive</td>
</tr>
<tr>
<td>&gt;55°</td>
<td>Very cohesive</td>
</tr>
</tbody>
</table>

Wood chips have an angle of repose\textsuperscript{36} of 43° which means that wood chips are fairly flowing, lower end of a cohesive material. These values are no absolute truth and should be regarded as a guideline for when designing different products that come in contact with the material.

Knowing the angle of repose is important when designing storage for bulk solids, because when the storage silo is being filled with wood chips there will be an angle from the top part of the material touching the walls to the center of 43°, this affects the size of the silo and the design of the reclaim equipment which will be discussed later on.

6. Market analysis

To develop a solution that satisfies the market demands and appeals to the customers it is important to make a market analysis. A market analysis was deemed necessary to get an overview over the market and their demands and expectations. Information was sought through interviews with personnel within the company to accumulate information from the different affiliates to get a good view of their operation. People working at different facilities such as paper mills and thermal power stations with wood chip storage within the medium size segment has also been interviewed, to find out what solutions are being used and if there are any problems or improvements that can be made. Also a SWOT-analysis was done to enable a strategic overview of BRUKS standing in the market.

6.1. The market

The market that is considered for this thesis is only wood chips. This means a lot of customers like the pulp and paper industry, thermal power station, pellets mills and saw mills. This means that there is a large variety of demands and expectations. The pulp and paper industry has high demands on durability and are willing to pay higher prices for this while others are more cost-conscious and can take a breakdown if the price is better\textsuperscript{37}. The delimitation is medium sized storage between 1000 - 5000 m\textsuperscript{3} with a solution that is either cheaper or has a unique property or function which makes it more appealing than today’s solutions.

\textsuperscript{36} Smith, D. (080623 – 081105).

\textsuperscript{37} Johansson, J., Upchurch, K. (2008-06-11)
### 6.2. SWOT-analysis

The SWOT-analysis was made to determine BRUKS standing in the market, which advantages they had against the competition and what they needed to improve in order to strengthen their market presence.

#### Strengths
- High quality standards
- Competence
- Offer complete system solutions
- Independent sellers
- Wide spread market representation

#### Weaknesses

<table>
<thead>
<tr>
<th>Weakness</th>
<th>Action proposals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expensive</td>
<td>New development of products with lower standards adapted for easier applications</td>
</tr>
<tr>
<td>Limited resources</td>
<td>More organic growth, not just increasing revenue by acquiring new companies</td>
</tr>
<tr>
<td>Lack of product overview within the group</td>
<td>Compilation of common information and uniting affiliated companies in a shared corporate culture</td>
</tr>
<tr>
<td>Lack of internal structure</td>
<td>Creating an internal network, common organisation</td>
</tr>
<tr>
<td>Bad communications with representatives on different continents</td>
<td>Developing a network that connects the whole group, a common calendar where everyone’s availability is clearly visualized</td>
</tr>
<tr>
<td>Lack of complete cost analysis for customers</td>
<td>Documentation of complete facility costs for a ballpark figure</td>
</tr>
</tbody>
</table>

#### Opportunities
- Great market potential for medium sized storage
- Development of creative solutions
- Greater potential to sell the groups product globally
- Many unexplored sectors of application for the current products

#### Threats

<table>
<thead>
<tr>
<th>Threat</th>
<th>Action proposals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing lead time because materials get scarce because increasing demand (large bearings etc.)</td>
<td>Try to develop new products that don't use the same measurements as other industries, minimize storage time for manufacturing details</td>
</tr>
<tr>
<td>Difficulty getting a hold of new markets because of the lack of references</td>
<td>Discounts on the first facilities to get references</td>
</tr>
<tr>
<td>Agreeing to too much work which takes a toll on the quality of the products</td>
<td>Increase resources, chose projects wisely</td>
</tr>
<tr>
<td>Work is repeated between different offices</td>
<td>Quick dissemination of information concerning new developments</td>
</tr>
<tr>
<td>Difficulties finding qualified people when the company expands</td>
<td>Improve premises and place them centrally for ease of transportation</td>
</tr>
<tr>
<td>Hard to find available manufacturing</td>
<td>Start searching early, get good contacts with workshops to get priority</td>
</tr>
<tr>
<td>New market requires new knowledge</td>
<td>Strategic acquisition of personnel with competence and thorough market research</td>
</tr>
<tr>
<td>Segregation within the group</td>
<td>Common culture, integrating affiliated businesses early</td>
</tr>
</tbody>
</table>
6.3. Market shares

BRUKS has acquired companies that have a lot of references and contacts with the pulp and paper industry where the demands are high. BRUKS has sold products to almost every paper mill in the Scandinavian region. BRUKS are considered as one of the best there. When other industries are considered BRUKS does not have the same reputation. Because of the high durability in the products, foremost the storage equipment like screw reclaimers, they are expensive especially for the medium sized segment for storing bulk material. This has resulted in a decreasing market share in this segment. BRUKS is almost twice as expensive as their competitors. This is a trend they want to stop by introducing a new solution to the market.\(^\text{38}\).

6.4. Market demands

The customer demands can vary greatly from little requirements to highly elaborate requirements on the equipment. In the first case this leaves the entire design of machinery to the manufacturer as long as the output demands are met. This means that the customer do not always know what they want and has to rely on the manufacturer to guarantee that the solution works. This is very difficult because customers are often only willing to buy a solution if it has a reference which shows that it works. This is a problem when a new product has been introduced; no one wants to be the first one to buy it. Manufacturers can be forced to give away the first product so they can show a reference; the products are also often very expensive.

This is the case with the European and North American market. If the Asian market is considered then an entirely different picture is painted. Asian customers want to be the one with the latest technology and are therefore very eager to buy a new product even if it does not have any references. This means that a product can get Asian references fairly easy but have great problems getting a reference in the European and North American market. The European and North American market does not accept Asian references because the Asian customers and the European and North American customers have a very different way of working. North American customers do not always even accept European references. Customers, especially North American ones, want to see that a plant or mill very similar to theirs have done the same thing that they want to do and succeeded with it before they are willing to buy the solution.

The North American market is the hardest market to introduce a new solution in and the Asian is the easiest. The European market is somewhere in between.\(^\text{39}\).

6.5. Market development

BRUKS has been focused on mostly handling wood chips because it is their core competence. Now they are seeing a lot of market possibilities in other fields than wood chips. Bio energy, like pellets, is a market that BRUKS has started to look into because of its proximity to wood chips. This market can be explored without major modifications to the products and the solution itself.

BRUKS has a lot of market potential when it comes to totally different markets. Probably the largest market gain for the moment is in medium sized bulk storage. When BRUKS can

supply a competitive storage solution for 1000 – 5000 m$^3$ then BRUKS has all the components to deliver a total and competitive system solution to customers. This makes BRUKS more attractive to customers and through these new customers will follow.

6.6. **End-user interviews**

Interviews were conducted to see what opinions the end-user had about bulk storage systems in Sweden. 11 paper mills, 2 pellets mills and 5 thermal power stations were contacted and interviewed. The interviews were done over the telephone and the length ranged from 5 minutes to 15 minutes. The interviews were foremost used to collect additional information and see if there were any discrepancies between BRUKS and the end-user. The information received from the interviews showed that silo storage systems were not the most commonly used storage. Instead it was open storage systems with manual labour that was mostly used. Open storage is cheaper and have almost unlimited storage capacity, the only restricting factor is the size of the open space. Because of the often very big price tag that comes with a new storage the mills that were interviewed often had old equipment and manual labour instead of fully automatic silo solutions. A lot of the people interviewed saw potential and wanted to buy but the price and the insecurity of the industry were factors that kept them from investing. Another factor that discouraged facilities from investing was that it is difficult to see when an investment has paid off. The personnel available for an interview at the different facilities varied and thus their knowledge of the storage solution was not always reliable.

7. **Competitors**

There are a lot of companies that all are active in the same area as BRUKS. Because the technology behind the products is relatively easy companies have little problems moving between markets with similar premise. This means that competitor can surface quickly and take market share from more established companies.

7.1. **Market leaders**

To date there are a few larger groups that are dominating the market. These players have become big competitors by acquisitions and mergers with other companies. Companies have problems keeping a competitive edge and if they have one it will not take long before other players have adopted that same edge, since this is an industry which has been active for a long time and where most possible solutions have been tried. BRUKS is one of those players who are big and very influential on the market$^{40}$. Vecoplan, Raumaster, Metso and Andritz are the main competitors to BRUKS, see appendix 1.

7.2. **Competitive edge**

BRUKS has increased their competitiveness by making smart recruitments which have resulted in their core competence being strengthened and expanded. BRUKS has through acquisitions made it possible for them to provide turnkey installations to their customers which not all players can. Because of the large amount of acquisitions that BRUKS has made there is not a sense of a common BRUKS environment. BRUKS has solved this by having independent sellers that can take products from all the different offices. BRUKS also has a

$^{40}$ Forsberg, R. (080917 – 081023).
good market representation, BRUKS has offices on every continent and the number of offices are about to increase. This means that BRUKS has key personnel on every market which is beneficial because it makes it easier to follow market trends and to be there for the customers.

8. Concept development
This chapter will explain the creation and selection process of the concepts.

8.1. The creation of ideas
The concept development was initiated with a brainstorming session to get an opportunity to document the initial ideas and thoughts on how to discharge wood chips from a storage container. The ideas in the beginning were not restrained to the already existing technology because of the participant’s limited knowledge in the field of reclaiming devices. There were no restrictions other than that the ideas had to deal with the problem of reclaiming material from a silo; the silo did not need to be circular. These ideas where first independently developed and later discussed to get a different approach on the subject and any new ideas were documented. This allowed new and different ideas to be vented and evaluated. To get a good foundation of ideas a target of 50 ideas was set. A list was made to get an understanding of what methods were being employed and would work for discharge of wood chips. It was composed of the information that was gathered from literature, internet and interviews. These methods were analyzed and systematically categorised according to the principles that were used such as hydraulics, pneumatics or mechanical. This list gave a background to the continued development of concepts and worked as a database from which relevant solutions were easily accessible, see appendix 6. Apart from identifying current technologies new methods of discharging bulk material were also sought, this was done by applying other means of material transportation and adapting them to bulk material. This was done for example by identifying means of transportation which is used in household appliances.

Another method of producing new solutions for bulk handling was to combine existing technologies, this was in many cases a difficult task but it worked well to force out new ways of addressing the problem. When the process of creating new concepts started to stagnate and the effort required to making new concepts became too demanding it was time to start screening the ideas.

8.2. The selection process
This chapter describes the work that was done to evaluate the concepts and later choose two winners. The process that has been the foundation of the creation of the concepts can easily be described as a funnel were a lot of ideas are being poured down and only the best made it all the way through, see figure 8.1.1. You want to keep as many ideas as possible for as long as possible to reduce the chance of missing out on a good and viable ideas.

41 Forsberg, R. (080917 – 081023).
The screening process

The first cut in the screening process was done by removing the least promising ideas through discussion, among the thesis participants, and common sense. After the first and crude evaluation of the concept there were 24 concepts left. These concepts were further developed to be able to make a more accurate assessment of the concepts potential. To evaluate these concepts a screening matrix was created to make a fair judgment of the concepts potential down the line. The screening matrix is based on a set of different criteria that all the concepts were evaluated as better, worse or the same as a reference, which in this case was a basic screw reclaimer, see appendix 4. The criteria used were based on the information gathered from the market- and competitor analysis, interviews and suitable theory on bulk handling.

The different criteria for the selection process were:

**Discharge capacity** – The amount of bulk material that can be reclaimed from a silo.

**Price** – Price of manufacturing, engineering and ground work.

**Risk for blockage** – If the concept ran the risk of being clogged up during operation.

**Complexity** – The complexity of the concept, a lot of moving parts etc.

**Operating cost** – The energy consumption during operations.

**Process control** – If the rate of reclaim could be controlled in a satisfying manner.

**Durability** – If the concept can withstand a year of wear and tear.

**Blending/Mixing** – If material is reclaimed over the entire surface of the silo, no dead spaces.

**Even output flow** – If the material output is even.

The result of the screening matrix was a ranking of the different concepts. The ranking system was used to see which concept was best and which was worst. All the concepts with the same or higher ranking as the reference were automatically put through to the next evaluation step. Four concepts had a score of -1, one criteria less than the reference. These concepts were put to something named the “second chance”. The four concepts were evaluated and developed to see if the concept could be salvaged or remade. From the “second chance” two concepts were put through to the next evaluation step based on that the concepts had potential that would benefit from being put through.

After the concepts had been evaluated in the screening matrix it became clear what kind of weaknesses and strengths the different concepts had. This made it easier in the next step,

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where the concepts needed to be further developed before the next evaluation step. A total of 9 concepts scored high enough to be put through to the next step of evaluation.  

After the screening process external input was received in the form of feedback from the school supervisor. This feedback was used when developing the concepts and to see the functional problems more clearly.

The scoring process

Before the scoring matrix the concepts were developed even more. Now the concepts started to take their final form. The development became more based on solving functional problems so that the concepts would work if constructed. Before the scoring matrix was applied external input was received in the form of feedback from the BRUKS supervisor. This input was used when weighing the criteria and in the selection of the final concepts.

The scoring matrix is basically the same as the screening matrix with the difference that the criteria are weighed to reflect their importance, see appendix 5. Table 8.1.1 shows the different criteria and their weight factor.

<table>
<thead>
<tr>
<th>Selection Criteria</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge capacity</td>
<td>10%</td>
</tr>
<tr>
<td>Price</td>
<td>17%</td>
</tr>
<tr>
<td>Risk for blockage</td>
<td>8%</td>
</tr>
<tr>
<td>Complexity</td>
<td>13%</td>
</tr>
<tr>
<td>Operating cost</td>
<td>10%</td>
</tr>
<tr>
<td>Process control</td>
<td>10%</td>
</tr>
<tr>
<td>Durability</td>
<td>20%</td>
</tr>
<tr>
<td>Blending/Mixing</td>
<td>6%</td>
</tr>
<tr>
<td>Even output flow</td>
<td>6%</td>
</tr>
</tbody>
</table>

Each criteria was scored 1 - 5, where 5 is best, this was then multiplied with the weighing to give a weighted rating for the criteria in a specific concept. Then the score for each criteria was added together to give a total score for the concept.

The chosen concepts

The result of the scoring was table 8.1.2. After the scoring matrix the four concepts with a score higher than three were still in consideration of becoming one of the two chosen concepts.

Table 8.1.2: The score after the scoring matrix

<table>
<thead>
<tr>
<th>Rank</th>
<th>Concept</th>
<th>Score</th>
<th>Continue</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Stoker 2.0</td>
<td>3.68</td>
<td>YES</td>
</tr>
<tr>
<td>2.</td>
<td>The Plow</td>
<td>3.6</td>
<td>YES</td>
</tr>
<tr>
<td>3.</td>
<td>The Bend</td>
<td>3.4</td>
<td>YES</td>
</tr>
<tr>
<td>4.</td>
<td>Dual Rotofeed</td>
<td>3.27</td>
<td>YES</td>
</tr>
<tr>
<td>5.</td>
<td>Shell</td>
<td>2.95</td>
<td>NO</td>
</tr>
<tr>
<td>6.</td>
<td>Chainscraper</td>
<td>2.75</td>
<td>NO</td>
</tr>
<tr>
<td>7.</td>
<td>Birds nest</td>
<td>2.73</td>
<td>NO</td>
</tr>
<tr>
<td>8.</td>
<td>Hoover</td>
<td>2.63</td>
<td>NO</td>
</tr>
<tr>
<td>9.</td>
<td>Tubescraper</td>
<td>2.58</td>
<td>NO</td>
</tr>
</tbody>
</table>

It is not given that the concept with the highest score is automatically the best concept. There are other things that need to be considered before choosing a concept. Things that were considered were manufacturability, functionality, adaptability and basic potential.

It was viewed by BRUKS to be important to see if the concepts were adaptable for different types of silo configurations, see table 8.1.3. This is important because depending on what the customer wants and what silo configuration that is most economical for the customer the silo configuration can vary. This matrix was made to see if the concepts were adaptable to different types of silo configurations to get a better overview.

Table 8.1.3: Adaptability matrix (Green = OK, Red = NO, Yellow = N/A)

<table>
<thead>
<tr>
<th>Concepts</th>
<th>Silo (round)</th>
<th>Silo (square)</th>
<th>A-frame</th>
<th>Open stack</th>
<th>Scalability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birds nest</td>
<td>Green</td>
<td>Red</td>
<td>Green</td>
<td>Green</td>
<td>Green</td>
</tr>
<tr>
<td>Chainscraper</td>
<td>Green</td>
<td>Red</td>
<td>Green</td>
<td>Green</td>
<td>Red</td>
</tr>
<tr>
<td>Stoker 2.0</td>
<td>Green</td>
<td>Red</td>
<td>Green</td>
<td>Green</td>
<td>Red</td>
</tr>
<tr>
<td>Tubescraper</td>
<td>Red</td>
<td>Green</td>
<td>Green</td>
<td>Red</td>
<td>Green</td>
</tr>
<tr>
<td>Shell</td>
<td>Green</td>
<td>Red</td>
<td>Green</td>
<td>Green</td>
<td>Red</td>
</tr>
<tr>
<td>Hoover</td>
<td>Green</td>
<td>Red</td>
<td>Green</td>
<td>Green</td>
<td>Yellow</td>
</tr>
<tr>
<td>The Bend</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Green</td>
</tr>
<tr>
<td>The Plow</td>
<td>Green</td>
<td>Red</td>
<td>Green</td>
<td>Red</td>
<td>Green</td>
</tr>
<tr>
<td>Dual Rotofeed</td>
<td>Red</td>
<td>Green</td>
<td>Red</td>
<td>Green</td>
<td>Green</td>
</tr>
</tbody>
</table>

This matrix shows the different concepts and what configuration they are appliable in. It became clear that “The Plow” was a concept that could be adapted to a lot of different silo configurations. The “Dual Rotofeed” is a concept that was not adaptable at all which did not improve its chances. “The Bend” and “Stoker 2.0” had similar amounts of adaptability with the difference that “The Bend” could not be evaluated for the open stack.

With all of these different things in consideration the concepts that were chosen were Stoker 2.0 and The Plow, see figure 8.1.2. The Plow was chosen as the rebuild concept because it has a high grade of adaptability and can be fitted to circular silos which were a requirement for the rebuild concept. The Stoker 2.0 concept was chosen as a new development since it has a square shape that is less common.
9. Applied techniques

In this chapter the techniques which have inspired the concepts will be analyzed and explained in further detail.

9.1. Stoker

The stoker method of generating motion in the bulk material is used in both of the concepts which were developed. The stroke length of a stoker is between 700 - 1000 mm depending on the material, where more springy material requires a longer stroke to achieve a sufficient compaction to initiate motion\(^45\). The time it takes for a forward and return stroke is usually between 30-40 seconds but for special applications that time can be lowered to 10 seconds at the cost of increased wear. The pushing surface of the ladder steps of the stoker is at most 2,5 m in width and between 30-50 mm in height. Stokers are usually used for smaller storage applications such as loading bins but they have in some cases been applied as a reclaiming device for square silos. When used for silo discharge several stokers are placed alongside two walls of the silo, in the middle of the silo between the rows of stokers a screw reclaimer is placed in a groove across the floor. To keep the screw from being flooded with material a ridge is placed about two meters above it so that the flow of material onto the screw is regulated by the stokers. The stoker concept and the reason how it can move such large amounts of material with a small motion at the floor of the storage is a difficult matter to grasp. The reason why such a small pressure surface is required on the ladder steps of the stoker is because of the angle of friction. In wood chips it is about the same as the angle of repose, this means that the amount of material being pushed by the stoker is expanded in roughly a 43° angle from the pressure surface. This effect has in some instances been observed to cause material at a height of as much as 5-6 meters to be affected by the stoker’s motion\(^46\).

9.2. Keith Walking Floor

This is a discharge system that in some respects are similar to the regular stoker; it is built up of many long slats that extend along the bottom of the container. These slats cover the entire floor of the storage. The slats reciprocates while remaining horizontal, there are three pairs of slats that first move one at a time and then together to convey the material\(^47\). The slats motion

\(^45\) Hörnquist, G. (080623 – 081015).
\(^46\) Nilsson, B. (2008-09-26).
\(^47\) Keith Walking Floor, (2008-10-29, 15:00).
is driven by hydraulic pistons which have relatively low power consumption and the construction requires little maintenance. The slats can be made of many different materials to withstand high loads and abrasive substances. The system can be constructed for high durability so maintenance is focused on the hydraulic system. This conveying system is used for a wide variety of material from ice to scrap metal.

**9.3. Circular screw reclamer**

The circular screw reclamer is one of the most common methods of extracting material from a silo. The screw is driven by two separate motors one for the screws rotating motion and another to rotate the hub to which the screw is connected. The screw usually make a full rotation across the silo floor in a day or two depending on the installation, the hubs rotation is often driven by a constant torque motor so that horizontal force on the screw is controlled. Apart from keeping the forces on the screw within reasonable limits it is also important to configure the pitch and diameter of the screw, inappropriate values can cause the screw to compact the wood chips before they are discharged. This has in some extreme instances caused screws to get clogged with compacted wood chips with a density close to solid wood where the use of chainsaws was necessary to remove the material. The friction between the screw (steel) and wood chips is estimated to 0.1–0.3 in motion and about the double when static. The vertical pressure exerted on a screw covered with material is reduced because of the material beneath the screw strengthens it.

**10. Circular Stoker**

This chapter is going to explain the design details and the calculations used for the concept Circular Stoker. Circular stoker was previously named The Plow.

**10.1. Operating principle**

The principle on which the circular stoker operates is like a stoker that is being pushed round a circular silo. The hub in the middle of the silo is rotating with about 360° in 1-2 days depending on the application. As the hub rotates the stoker reciprocates with a velocity of 0.1 m/s to discharge material from the silo. The stoker takes material from the edge of the silo to the middle of the silo and the hubs rotating motion guarantees that material in the entire silo will become discharged. This means that the dead zones will be minimized where material never gets discharged. The stroke length of the hydraulic pistons is 1000 mm which ensures that the material will be compacted enough to initiate motion.

**10.2. The road to the final design**

In the beginning of the design phase the circular stoker concept looked a lot different from the current version. The first version consisted of only a big plow that moved back and forth to discharge material, see figure 10.2.1. To get an even output flow from the silo there was two plows one on either side of the hub whose motion was opposite each other. This meant that when one plow went in towards the hub the other one went out from the hub. This gave it a constant flow of material from the silo. To achieve high rates of reclaim the plow needed to be quite large, about 2.5 m wide and 0.7 m tall. The plow was controlled by a series of cables.

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48 Hörnquist, G. (080623 – 081015).
When the concept had been under development for a while a senior manager at BRUKS highlighted a few problems with the concept.

The first problem was the internal friction angle of the wood chips which is 43°, this was discussed in chapter 9.1 this effect would greatly increase the required force. This means that with the current shape even very oversized motors are likely to struggle to discharge the material. The second problem was the flat bottom plate; it was not rigid enough to withstand the torque that the pressure from the wood chips would generate. Another concern was that the cables pushing and pulling the plow would wear down before a year of operation could be completed because of the abrasive nature of wood chips.

![Figure 10.2.1: The old version of the concept](image1.png)

After the feedback the concept was remade with the new problems in mind. The bottom plate was made more rigid to withstand torque forces. The plow was replaced with a custom made stoker to fit with the bottom plate, see figure 10.2.2. The cables were replaced with hydraulics that was mounted directly in the hub and connected directly to the stoker.

![Figure 10.2.2: The new version of the concept](image2.png)
10.3. Design details

In this chapter the different design details will be explained and shown.

**Bottom plate**

The bottom plate is the most exposed part of the concept. The bottom plate has a total length of 8 m; a profile of the bottom plate can be seen in figure 10.3.1. This means that the pressure of the wood chips and the bottom plates own weight will cause the bottom plate to bend. This is not a big problem because the bottom plate will glide on a bed of wood chips that will help to strengthen the plate. The internal structure of the bottom plate will first be welded together and then the sheets of HARDOX 400\(^{49}\), which is very hard and resilient steel, will be welded on to the internal structure.

![Figure 10.3.1: Drawing of the profile for the bottom plate, Grey: Internal structure, Red: HARDOX 400](image)

The carriers that travels on top of the bottom plate are made from steel as is the bottom plate. This means that there will be steel – steel friction. The wear and tear due to the high pressures will cause the material to be slowly shaved away. To avoid having to replace a large part like the bottom plate the steel around the bottom plate, not the internal structure, will be made from HARDOX 400, see figure 10.3.2.

![Figure 10.3.2: The red area shows where the HARDOX 400 should be applied](image)

There are eight holes in the in the bottom part of the bottom plate, see figure 10.3.3. These holes are used for securing the bottom plate to the hub. These holes are made for M24 type screw which will be enough to support the bottom plate and all the forces applied, see chapter 10.4: “Deformation of the bottom plate”.

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\(^{49}\) SSAB, (2008-10-29, 15:00).
Carriers

The carriers are essential for the discharge of material. They are the ones affecting the material and forcing the material to move into the hub. The carriers are made from a weaker material to allow some flexibility. The flexibility is important because if the bottom plate twists or bends it should not be able to lock the carriers from moving. If the carriers can flex they will not be locked down if the bottom plates starts to bend or twist. The front carrier is connected to the hydraulic piston rods and the rest of the carriers are connected via braces, see figure 10.3.4. All the carriers have a chamfer on the backside of 25° to ease the backwards motion.

The carriers can not leave the bottom plate since they are fitted with a hook on each side. These hooks act as a guideline so even if the carriers are exposed to lifting forces they will stay mounted to the bottom plate, see figure 10.3.5.

To be able to move all the carriers at the same time fastenings are used to connect all the carriers with one another. The carriers are connected with each other through braces on each side of the carrier, two on the front side and two on the back side, these braces are made out of steel and have diameter of 3 cm. The front carrier, the carrier closest to the hub, will be
directly mounted to the hydraulic pistons. These require special fittings to be able to transfer the transversal movement, see figure 10.3.6.

Figure 10.3.6: Left: Brace fastenings, Right: Hydraulic fastenings

**Hydraulics**

To move the carriers back and forth hydraulics has been implemented. Industrial cylinders from “CA Verken” were chosen because they are sturdy with a high tolerance against forces and shocks. They are also able to generate a lot of force which is necessary in this application, the calculations which the cylinder dimensions is based on can be seen in chapter 10.4: “Hydraulic force and Euler breaking model”. The cylinders have a diameter of 160 mm and the piston rod a diameter of 90 mm. The nominal working pressure is 16 MPa but the maximum working pressure is 25 MPa with limited life time. The hydraulic cylinders will need to generate a speed of max 0.1 m/s. One of the biggest benefits with hydraulics has been the placement of the cylinders, see figure 10.3.7. They are mounted directly to the hub with 8 M22 with a front flange and fastened directly to the carriers which eliminate components like chains which are prone to break.

Figure 10.3.7: Exploded view over the mounting of the hydraulics

To protect the hydraulic cylinder from foreign particles an inset was constructed. Because of the size of the cylinder it is necessary to mount the cylinder in the outside of the hub. To protect the protruding part the inset is mounted on top of that. In the inset two seals are applied which gives a total protection against the material, see figure 10.3.8.

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50 CA-verken, (2008-10-29, 15:00).
The first seal is a scraper which will remove most of the particles that might have got stuck on the piston rod. The second seal will help support the piston rod and remove the last of the particles. The hydraulic cylinder also has its own scrapers and seals, the extra scraper and seal in the inset is more for extra support and to make sure that no foreign particles will get into the hydraulic oil. As shown in figure 10.3.8 the piston rod will be longer than the actual cylinder. The length of the stroke will be 1000 mm and the piston rod has to be 1520 mm to be long enough to reach the fastenings of the first carrier in the withdrawn position of the cylinder. The abrasive nature of wood chips and the presence of moisture will have an impact on the piston rod because it will go back and forth through the material about four times per minute. The piston rod will be made of stainless chrome – plate to withstand the abrasion and the moisture.

To supply the cylinders with the pressure needed a few things is necessary like a motor, a pump, a tank, cooling, vents, filters and a control system. These are often supplied as a whole from a hydraulic supplier. For this reason there has been no further investigation towards the dimensions needed on the pump, tank, cooling, vents, filters and the control system. What has been investigated is how the hydraulic system should be connected to the cylinders. The hydraulic system is often supplied in one piece which makes it easier to handle. One idea was that the hydraulic system could be placed on the floor below the rotating hub and connected to the cylinders through a swivel. This idea was quickly dismissed on the basis that a swivel working under constant high pressure would not have a significant life time, which is an important factor. The new idea is based on that the hydraulic system for two cylinders will not be especially big which means that the entire hydraulic system can be mounted in a basket underneath the rotating hub. This means that the hydraulic system will rotate with the hub. Because the hub rotates at a very slow pace, one 360° turn in 1-2 days, it is possible to maintain the hydraulic system without any problems.
The hub

The hub is the connection between the reclaiming device, stoker, the transport and the rest of the silo. In the hub is where all the motors for both the transversal and rotating motion are stored. Because this is a rebuild concept it was deemed necessary to use the same dimensions on the hub as a regular screw reclaimer uses. In the hub there are walls dividing the different sections from each other, these walls will be welded on to the hub. Several different parts are attached to the hub. These parts are the chute, the bottom plate and the hydraulics. How the hub is attached to the silo has not been investigated because it was deemed best to use the BRUKS current equipment, like the hub and the grooves in which the hub rotates in.

The chute is where the wood chips fall down to a transporter that will transport the wood chips away from the silo and into the mill. The chute is attached by 14 M22 all around the chute, see figure 10.3.9.

![Figure 10.3.9: Bottom view over the attachment points for the chute](image)

The bottom plate is attached with 8 M24 type screws which give a security factor of about 4, see figure 10.3.10 and chapter 10.4. “Deformation of the bottom plate”. If these fastenings would break everything that has anything to do with the reclaiming would fail or in a worst case scenario break, which is why a decent security factor is important.
The dimension of the opening is not an easy task to design. If the opening is too small then the hydraulic cylinders will have to work extra hard to push the material out of the silo and into the opening. If the opening is too big it will be hard to regulate the amount of material being discharged due to avalanching. This has to do with the internal friction of the wood chips, $43^\circ$. If you have an angle of $43^\circ$ or higher from the top of the opening to the chute the material could avalanche. If the angle is lower the reclaim device will have to work harder to reclaim the material, see figure 10.3.11. This is not something that should be designed without the customer specifications. A customer might want a big opening because they have a transport system that can handle avalanching or they might be willing to let the hydraulics work harder to reclaim the material because they have a weaker transport system.

Seals
The seals are used to ensure that no particles from the material get into the hydraulic oil. The scraper is meant to remove all the particles while the seal is meant more to support the hydraulic piston rod, see figure 10.3.12. Even if particles get past the scraper they will be removed by the seal. The hydraulic cylinder has its own seal which according to the
manufacturer is good enough to keep everything out. This means that with the total number of seals there will be little chance of any foreign particles to get into the hydraulic fluid.

![Figure 10.3.12: Left: Scraper, Right: Seal](image)

**Rotating motors and hub groove**
The motor to rotate the hub and the groove where the hub is secured in is taken straight from the current screw reclaimer. This was deemed easier and because the circular stoker is a rebuild concept it will be things that the customer already have in their possession.

**10.4. Calculations**
In this chapter the different calculations and simulations will be presented and explained.

**Deformation of the bottom plate**
The bottom plate is 8 m long which means that it is quite heavy. When the silo is full the bend of the bottom plate is not a problem because it will glide on a bed of wood chips that will help to strengthen it up. The only problem is the self-weight which can be an issue when the silo is empty and is being filled up with wood chips. The CAD – model of the bottom plate was put in ANSYS Workbench 10.0 which is a calculations program for solid mechanics. As seen in figure 10.4.1 the self-weight will only cause the bottom plate to bend approximately 6 cm.
Because of the hubs rotating motion the bottom plate will be pushed into the wood chips. This will create a torque force on the bottom plate; this has to be tested to get an accurate picture over the torque forces. The plate is going to be subjected to a pressure of 32 kPa in a silo of 5000 m$^3$ that will try to push the plate down, which was calculated using the Silo stress tool, a computer program which aids silo design. This pressure was then used to derive an approximate value of the torque, which amounted to 32 kNm; this is the equivalent of the force from the pressure on a 7 m long strip with a width of 20 cm on the edge of the plate, 75 cm from the center of the plate. When the torque was applied to the bottom plate it only twisted 2,4 mm, see figure 10.4.2, 32 kNm is just a test value, but it is a linear relationship between the torque and the amount of twist. If the torque is doubled then the torsion will be doubled too.
When this was simulated the torque was applied to the edge of the bottom plate furthest from the hub. In real life the torque would affect the bottom plate over its entire length. It is the pressure that will create the torque on the bottom plate; this pressure will act on both sides of the symmetry line of the bottom plate which means that the pressure will try to twist the bottom plate in opposite directions.

The bottom plate will be fasted to the hub with 8 M24. M24 screws can withstand a force of 226 kN before deformation. A rough calculation gives:

The weight of the bottom plate and carriers combined are 7200 kg, approximate 72 kN. The pressure exercised by the wood chips on the bottom plate is 32000 Pa which gives:

\[
(7 \text{ m} \cdot 1,5 \text{ m}) \cdot 32000 \text{ Pa} = 336 \text{ kN}
\]

\[
\text{Security factor} = \frac{8 \cdot 226 \text{ kN}}{336 \text{ kN} + 72 \text{ kN}} = 4,43
\]

This means that the load will be four times smaller than what the screws can handle without deforming. This shows that the fastening of the bottom plate should hold for a long time under constant pressure.

Deformation of the carriers

The carriers are 1,5 m wide and 0,05 m in height, there are seven carriers in total. This results in a combined push surface of 0,52 m² which can be compared with the original stoker ladder (with eight steps), if the steps have are 2,5 m wide and have a height of 0,05 m it will have a pushing surface of 1 m². This means that the circular stoker will only experience 52% of the force that the original stoker experiences. The normal working pressure for the hydraulic cylinders is assumed to be 160 bar and the given the cylinder diameter is 160 mm. This gives the force that the carriers are subjected to when pushing through the wood chips for a regular stoker. Then the solid mechanics calculations were done to assess if the carriers could withstand the forces, 340 kN was used since it is 52% of 650 kN. The maximum stretch that the carriers experienced was 2 mm, see figure 10.4.3.

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52 Hörnquist, G. (080623 – 081015).
The braces that the carriers are connected with have a diameter of 3 cm and are made of steel. The braces can withstand about 340 kN force and only stretch 0.12 mm which means that they can withstand a lot more force without breaking, see figure 10.4.4.

Hydraulic force and Euler breaking model

Calculations were made to ensure that the right cylinder was chosen. As previously stated it is known that a stoker should be able to generate 650 kN and the circular stoker requires approximately 340 kN to move the carriers. Cylinders are placed on each side of the hub to reduce the chance of the carriers skewing. This means that each cylinder had to generate about 170 kN. Because the cylinders need to generate the same amount of force on both strokes the smallest area $A_2$ was the critical and the area which decided if the cylinder was big enough, see figure 10.4.5.
The following condition had to be met:

\[ 170 \text{ kN} \leq \left( P_1 \cdot A_1 \right) - \left( P_2 \cdot A_2 \right) \]

If all the pressure is applied on \( P_2 \Rightarrow P_2 \cdot A_2 \geq 170 \text{ kN} \Rightarrow 16 \text{ MPa} \cdot 0.0137 \text{ m}^2 \approx 220 \text{ kN} \]

If a smaller cylinder is used, 140 mm diameter, the force generated is 145 kN which is not enough.

The cylinder with a diameter of 160 mm is strong enough to be able to operate the stoker. The extra power that the hydraulic cylinder has can be used when wood chips get stuck or extra power is needed for different reasons. This means that the extra power will not limit the cylinders lifetime because it is not often that the cylinder will need to operate above its nominal max pressure, 16 MPa.

Because the piston rod is longer than the actual cylinder it is important to consider if the piston rod will break. Euler breaking case number 5 was applied to approximate the breaking force, see figure 10.4.6.

\[
P_k = \frac{\pi^2 \cdot E \cdot I}{l^2} = 6.68 \text{ MN}
\]

Where:
\[
E = 210 \text{ GPa}, \quad I = 3.22 \cdot 10^{-6} \text{ m}^4, \quad l = 1520 \text{ mm}
\]

The breaking force needed is 6.68 MN and the maximum force that the piston rod can experience is approximately 500 kN. The breaking of the piston is not a problem that is likely to occur if the piston rod is 90 mm in diameter.

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Seals
Because the seal, figure 10.3.12 right part, should support the piston rod and all the forces it is important that the seal is strong enough to handle the force. The piston rod is 90 mm in diameter and if you assume that the seal is 50 mm long then it will have an area of 14137 mm$^2$. 32 kPa of pressure that will push down on the seal gives 0.032 N/mm$^2$ that the seal have to absorb. The weakest seal at Super seal$^{55}$ can absorb 15 N/mm$^2$ which means that the pressure the seal will experience is far from critical.

11. Stoker 2.0
In this chapter the design details and the calculations will be explained for the concept Stoker 2.0. This stoker is supposed to be placed in a square silo with a similar configuration as a regular stoker that was discussed in chapter 9.1: “Stoker”.

11.1. First design
The first version of the stoker 2.0 can be seen in figure 11.1.1. The principle of this new take on the original stoker concept is partially derived from the operation of Keith Walking Floor$^{56}$. A similar design using plates that are driven by hydraulic pistons are used. The difference is that there are only two different sets of plates and they move continuously back and forth in opposite direction to each other. On top of the moving plates there are added scrapes which are connected to the plates. The scrapes are connected to the plates that are beside the plate which the scrape is over, this means that the scrape will be moving in the opposite direction of the plate which is below. The idea behind this motion pattern was to create a constant push of material towards the outlet, seeing as the scrape is either pushing material to the sides (where the other pair of scrapes is pushing forward) when going back and moving it towards the outlet on the forward stroke.

![Figure 11.1.1: Stoker 2.0](image)

$^{55}$ Super seal, (2008-10-29, 15:00).
$^{56}$ Keith Walking Floor, (2008-10-29, 15:00).
This initial concept was evaluated in a session with a senior manager from BRUKS who voiced some concerns about the design and feasibility of the concept. The problem with this concept was the fact the motion of the scrapes was likely not enough to get it to flow towards the outlet, the wood chips require a sufficient degree of compaction before the mass begin to move. This motion pattern would probably push the material back and forth and it was also likely that the material would get stuck between the scrapes.

### 11.2. Second Design

With this input in mind the concept was configured to address the concerns that were discussed previously. The scrapes were replaced with carriers working like the ladder steps on a regular stoker, shaped to promote motion in one direction. These carriers were attached to the plates in a similar fashion as the scrapes where every other carrier was attached to one set of moving plates. The plates and their motion remained the same as before. This configuration of plates and carriers created a new motion pattern similar to that of a regular stoker with the exception that the different sets of carriers move in opposite direction. The two sets of plates and carriers which the concept consists off can be seen in figure 11.2.1.

![Figure 11.2.1: The two different sets of the stoker 2.0](image)

This motion is supposed to increase the efficiency of the reclaim of the stoker, this is because when the carrier which is closest to the dividing wall start compacting and eventually moving the material towards the outlet it will push it over to another carrier before turning back. The new carrier will not have to compact the material at the beginning of its stroke and it will move the material more efficiently. Material will move in a wave pattern with sections of compacted material being pushed towards the outlet, this motion pattern is illustrated in figure 11.2.2.
This concept will be using the same stroke length and movement speed as a regular stoker which is 700 mm stroke and a speed between 0.1 m/s – 0.4 m/s\(^5\). This is a modular concept where several instances of the stoker plates are combined to form the complete solution, one module of the new design can be seen in figure 11.2.3.

There will be two different versions of the stoker 2.0 to cover the entire range of silo dimensions. The smaller version is used in the range of 1000 – 3500 m\(^3\) the bigger is used for the remaining 4000 – 5000 m\(^3\). Both of the versions use the same number and width of plates the difference is that the bigger has 9 m long plates and the smaller has 6 m long. The concept will also be using a different number of stoker 2.0 modules depending on the silo; there are three different base plates from which the silo dimensions are derived by altering the height. The smallest base plate is 10x14 m and will be using 4 modules, the second is 14x15 m and will be using 6 modules and the last is 20x15 m and will be using 6 of the larger modules, see figure 11.2.4 for an example of how the modules will be placed for the smallest base plate. The complete list of silo dimensions can be seen in appendix 2. The following explanations of the design of the stoker 2.0 and the calculations will be based on the smaller version with 6 m long plates. This is because it is the most common version used for the different base plates.

\(^5\) Hörnquist, G. (080623 – 081015).
11.3. Design details

Here the individual parts of the stoker 2.0 will be explained in greater detail, what materials that are going to be used and how the parts will be constructed.

Plates

The stoker consist of nine plates, two end plates with a width of 20 cm and seven plates with a width of 65 cm, they are 6 m long with an 1 m extension which will extend below the dividing wall. The plates are 1 cm thick which is sufficient to handle the pressure of the wood chips, see chapter 11.4: “Deformation of the plates”, and are made of HARDOX 550\textsuperscript{58} wear plate to promote a long lifetime. HARDOX 550 was chosen to assure that the material would have hardness higher than 500 Brinell, since they can only guarantee the hardness within a spread of ± 25 Brinell, the hardness requirement will be explained later on in chapter 11.3: “Slide bearings”. There are several elevations on the plates which are supposed to create additional friction against the wood chips in the outlets direction, they have a triangular shape and are phased to minimise the friction in the opposite direction. The elevations have a maximum height of 10 mm; they will be welded onto the plates. The plates also have several pins on which the carriers are attached; the pins have a wider diameter in the bottom which suspend the carriers 15 mm above the plates. The carriers are suspended above the plates to reduce the resistance when pulling them back on the return stroke, considering the elevations they will always have at least a 5 mm gap to the plates. The pins have a diameter of 20 mm at the top and 25 mm at the bottom, this is to keep the stress at a reasonable level to reduce the risk of pins breaking, see chapter 11.4: “Stress levels in the pins”. Below the extended part of the plates there will be a recess for the slide bearings which will be further explained later on. The plates come in two versions for each set which depend on the set of carriers that are attached to it, there is also an added pair of pins to one of the plates to give the rubber plate seal an additional attachment point, this plate can be seen in figure 11.3.1.

\textsuperscript{58} SSAB, (2008-10-29, 15:00).
Plate seals
There will be a gap of 3 mm between each plate and to prevent wood chips and dust from falling down between them a simple rubber seal will cover the gap. The rubber seal will be 6 m long to cover the entire length of the plates and it will be threaded through the thicker section of the pins to which the carriers are attached. The plate seal is attached to both sides of the plate which has an extra pair of pins. This means that the seal will follow the plate’s movement, see figure 11.3.2. The end plates will have a seal against the wall beside them; this seal is going to be fitted in a groove which is made in the side of the end plate. An example of the seal and how it will be fitted can be seen in figure 11.3.2.

Carrier
There are six carriers attached across the stoker plates, they are 4974 mm in length and 50 mm in height. The profile can be seen in figure 11.3.3. The carriers are attached to the plates by being placed onto the pins and locked with a nut.
There are eight holes on each carrier and it is at most about 0,7 m between them, the amount of attachment spots is to stiffen the carriers to reduce the deformation, see chapter 11.4: “Deformation of the carrier”. In comparison a regular stoker can have up to 2 m between attachment points. The sloped part of the carrier (part 2 and 3 in figure 11.3.3) is made of steel plates with a thickness of 5 mm which is welded to the base of the carrier (part 1 in figure 11.3.3).

Slide bearing

The plate’s motion was selected to be supported by rails covered with a layer of PDE Rubber\textsuperscript{59} which will act as a sliding bearing against the plates. The rails are 4,85 m long and 0,09 m in width and each plate will be supported by two rails and the endplates will be supported by one each. Below the extended part of the plates shorter rails will be mounted which are 0,2 m long. The bottom of the plates are fitted with linear guidance racks that are fitted to the far side of each rail to assure a straight linear motion of the plate as can be seen in figure 11.3.1, therefore a small strip of rubber will be placed on the side of the rails. The shorter rails however will be sliding in a recess; this is because guidance racks would collide with the crossbeams which are mounted close by. The rubber covering the rails will extend 5 mm to each side thus the rubber layer will have a width of 0,1 m which will support the plates.

This solution was selected since the motion is relatively slow, there is no need for precise motion and it was required to have a very low need of maintenance. This solution was also well suited for environments where contaminants such as dust occur since the material absorbs minor particles. The static and dynamic friction is almost equal which makes the material ideal for applications such as this where the direction of movement is constantly switching. The PDE Rubber can handle pressures of up to 4 N/mm\textsuperscript{2} (4 MPa) at the max operating speed of 0,1 m/s, load capacity increases to 70 N/mm\textsuperscript{2} with static loads. When operating at 0,1 m/s with a full silo there is a good safety margin since the sliding bearing is only subjected to a fraction of its max load, about 30 times lower, see chapter 11.4: “Pressure on the sliding bearings”.

To minimise the wear on the PDE Rubber it is recommended to use a material with a hardness of 50 HRC (Rockwell) which converts to roughly 500 Brinell\textsuperscript{60} to run against. It is also recommended to have a general surface roughness $R_a = 0,2 – 1,6 \ \mu$m and a average roughness

\textsuperscript{59} D&E Trading, (2008-10-29, 15:00).
\textsuperscript{60} Woodco USA, (2008-10-29, 15:00).
$R_z = 1.25 – 8 \mu m$, these are general guidelines and may differ for this application, this would mean that additional processing would be required. The slide bearings can be seen in 11.3.4.

Crossbeam

Two crossbeams are attached on the underside of the plates each to one set of plates. The crossbeams are made of steel with a thickness of 30 mm and are attached to pins on the underside, it is also advisable to weld the crossbeams by the edges to the plate to increase their stiffness, see chapter 11.4: “Deformation of the attachment points”. The crossbeams are fitted with attachment points for the hydraulic pistons as seen in figure 11.3.5. The attachments are constructed from steel plates with a thickness of 20 mm which is welded to the underside of the plate.

Hydraulics

Each set of plates are driven by a pair of hydraulic cylinders with pistons that are connected to crossbeams that are attached to each set of plates. This new stoker concept requires about 14% more force, see chapter 11.4: “Hydraulic forces”, compared to the regular stoker, this is mostly due to friction between the plates and wood chips. The extra force needed to move the stoker 2.0 is within the limits of the dimensions used for the pistons in the regular stoker. The cylinders selected have a diameter of 160 mm and piston rods with a diameter of 90 mm\textsuperscript{61}, as previously stated in chapter 10.3: “Hydraulics” no further investigations were made in to the hydraulic system. The fitting of the hydraulic pistons can be seen in figure 11.3.5.

\textsuperscript{61} Hörnquist, G. (080623 – 081015).
CA-Verken, (2008-10-29, 15:00).
Wall sealing

There will be a dividing wall which the end of the plates will slide below, behind the wall the hydraulics are connected to the crossbeams. This wall requires a seal against the sliding plates to minimise the amount of wood chips that come through. A rubber seal\textsuperscript{62} was chosen that is glued to the bottom of the sealing wall and is clamped between the wall and plates. A rubber seal was chosen because it can adjust itself when the sliding bearing gets worn and the plates consequently lowers creating a wider gap. The seal will be made in neoprene rubber which is very resistant to wear and aging. The shape of the seal and an example of how it can be fitted on the dividing wall can be seen in figure 11.3.6. Depending on the forces which the seal will be subjected to a series of several seals maybe used.

\textsuperscript{62}Kuntze, (2008-10-29, 15:00).
11.4. Calculations

In this chapter the different calculations and simulations will be presented and explained.

Deformation of the plates

The plates are subjected to a pressure of 30 kPa which is pushing down on the plate, this was calculated using the Silo stress tool when the silo is full (3500 m$^3$). The plates are supported by rails which have five carrying points the, furthest distance between these points is 1,1 m. The rails have a thickness of 20 mm and 90 mm in width, the rails cross section was merged with the plates to determine how much the construction would bend down. This case was simulated in ANSYS; the result can be seen in figure 11.4.1.

![Figure 11.4.1: ANSYS simulation of plate and rail](image)

This simulation was done for a plate with a thickness of 10 mm which is the thinnest supplied from HARDOX, the maximal deformation was then about 0,47 mm (4,7% of the plate thickness) which was deemed acceptable. This gives a decent safety margin given this simulation was a simplification of the actual working case where the plate is going to slide across the rails.

Stress levels in the pins

The pins that the carriers are attached to will be subjected to heavy forces (650 kN per set) and to achieve a decent safety margin against unforeseen circumstances the pins where designed so that two of them would be able to withstand the load on their own. This comes down to a force $F_p = 650 \cdot 10^3 / 3 / 2 \approx 108 \text{kN}$ which each of the pins require to withstand. Two different designs were tested to determine how much difference the thickness of the pins had on the deformation and stress level. First a pin with a base width of 20 mm and a top
width of 15 mm was tested and a second thicker version with a base width of 25 mm and a top width of 20 mm. The results of the stress analysis in ANSYS can be seen in figure 11.4.2.

These results showed a significant reduction on the stress levels which made it obvious that increasing the diameter greatly lowered the risks of pins snapping off and the thicker version was used to attach the carriers.

**Deformation of the carriers**

Three carriers are attached to each set of plates; the pressure the pushing surface is subjected to is $P_c = 650 \cdot 10^3 / (3 \cdot 4.974 \cdot 0.05) \approx 870$ kPa. This case was simulated in ANSYS with the maximum distance between the attachment points which can be seen in figure 11.4.3.
Pressure on the sliding bearings

The force subjected upon the plates is \( F_{\mu} = 5 \cdot 6 \cdot 30000 = 900 \text{kN} \), this amount to a pressure of \( P_{y} = 900 \cdot 10^3 / (4.85 \cdot 0.1 \cdot 16) \approx 116 \text{kPa} \) which the rubber is subjected to. Given that the rubber can withstand pressures of 4 MPa; this gives a safety margin of \( 4 \cdot 10^6 / 116 \cdot 10^3 \approx 34.5 \) times.

Deformation of the attachment points

The attachment points for the hydraulic pistons are each subjected to a force of 325 kN. There where two different cases which were simulated using ANSYS to determine how the crossbeams should be attached to the plates. The first case is when the crossbeams are merely attached to the pins and in the second case the crossbeam is welded by the sides to the plate; the results can be seen in figure 11.4.4.

![Figure 11.4.4: Left: First case Right: Second case](image)

As shown in the results there is a much smaller deformation when the crossbeam is fixed against the plate, this is however not a perfect simulation of the different cases. In the second case the entire underside of the crossbeam is fixed but in reality it would bend a bit so the results will probably not be as favourable.

Hydraulic force

Comparing the new stoker concept with the old stoker in terms of the force required to move it. At first it is assumed that both require the same amount of force per pushing face. As previously stated in chapter 10.4: “Deformation of the carrier” the regular stoker has a pushing surface of 1 m\(^2\), the new stoker is then assumed to exert a force of 650 kN/m\(^2\). The pushing surface of stoker 2.0 is \( 6 \cdot 5 \cdot 0.05 = 1.5 \text{ m}\(^2\) for the carriers and \( 0.44 \cdot 0.01 \cdot 7 \cdot 5 = 0.154 \text{ m}\(^2\) for the elevations which adds up to a total pushing surface of 1,654 m\(^2\). The stoker 2.0 is also going to have to work against the friction of the plates against he wood chips and the
slide bearings. The friction of the steel against wood chips is assumed to 0,3 and the friction against the rubber is 0,15. These two frictional forces amount to \( (0.15 + 0.3) \cdot 30000 \cdot 6 \cdot 5 = 405 \) kN. Given that the stoker 2.0 is the equivalent of two regular stoker ladders which have a pushing surface of 2 \( \text{m}^2 \) which equals a pushing force of 1,3 MN. This compared to the stoker 2.0 which have a pushing surface of 1,654 \( \text{m}^2 \) which equals a pushing force of 1,075 MN and frictional forces of 0,405 MN. Compared \( (1,075 + 0,405)/1,3 \approx 1,14 \) shows that the new stoker requires 14% extra force compared to the regular and this is disregarding the frictional forces which the regular is subjected to.

12. Discussion
In this chapter the different parts of the master thesis is discussed such as problems that occurred, how the selection process affected the result, why the different concepts were chosen and how this task developed the participants.

12.1. The assignment
The assignment for this thesis started out from a very brief explanation of a development project based around bulk material handling. The first interview with the supervisor from BRUKS gave a better understanding of the products they were working on and how their organisation was built up. The problem which was going to be addressed was still kept very open-ended to give the opportunity to define what would be the most interesting to work with. There was however a discussion about several different directions in which the thesis could be focused. The first couple of weeks into the project were spent getting to know the company and to lay out a basic schedule of the upcoming work. The project started to take shape as to what was going to be focus of the thesis after discussions at the BRUKS office in Atlanta. It was then decided that there was going to be developed two different concepts for medium sized bulk storage, one designed to be used when rebuilding old silos and another with less restrictions which would be incorporated when designing a new silo from scratch. This process was beneficial to the result of the thesis because of the favourable opportunity to get to know the company and its products before specifying the assignment, this made it possible to both weigh what BRUKS was interested in achieving and if there were other areas which could be interesting to explore when selecting the problem.

12.2. Market – and competitor
The results of the market- and competitor analysis were of varying importance to the project. A lot of the input which was received from the interviews at BRUKS and the end-users helped with the understanding of the problems related to bulk handling. The 18 interviews which were done with the different facilities were in many cases not very relevant to the subject at hand because they were using open storage, which led to a brief description of the results. The market- and competitor analysis did not significantly contribute to the end result of the concepts but it did provide the thesis participants with background knowledge and a common understanding of the problem.

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63 Hörnquist, G. (080623 – 081015).
12.3. Selection

The most important decision to do during a development project such as this is to decide which final concepts to develop. There were several different stages in the selection process which gradually narrowed it down to the most promising ideas. It was easier in the beginning to discern which concepts that would not fit the demands and the first cut was made based on common sense. As the selection process progressed and the difficulty rose and there was a need to use more refined methods of determining the concepts worth, for this purpose a matrix was used to evaluate the different concepts in several categories against a reference. What is important to understand is that even if there has been a structured method behind choosing the concepts both the screening- and scoring matrix are subjective. If someone else were to do the same thing they would almost certainly come up with a different answer. The screening- and scoring matrix are tools used to give an indication on concepts strengths and weaknesses.

The adaptability of the concepts was also evaluated to account for if they can be used in different silo configurations and sizes. The results of these evaluation methods were discussed and were not used as definitive decision when choosing which concepts to put through. When the final decision was made and the development of the final concepts began there were still many directions which could be followed. When dealing with new technology in an area which is unfamiliar it is hard to anticipate all the different problems and ramifications of the design. It is during these circumstances important to view the product development process as iterative since it is very likely that the first concept is going to have its flaws, which gradually emerge as the design is becoming more precise. The opportunity to have a discussion with a senior developer at BRUKS regarding the concepts gave a lot of input which led to an iteration of the concepts which greatly increased their functionality. There were however not enough time for a second iteration of the concepts but the rule of thumb is that the gains diminish with each iteration and hopefully the major pitfalls were avoided with the first iteration.

12.4. The result

A combination of different reclaiming methods were used in the final concepts, this was partly to have some reference of their ability to extract wood chips. Using completely new technologies for the extraction of wood chips would be very difficult to design, since most of the know-how within the industry is based upon years of experience. It is not uncommon to experience difficulties even when applying well established methods since the conditions and material behaviour vary between every installation. Trying to apply new untested technologies during these circumstances would make it very difficult to anticipate how the material would behave and to determine the concepts viability. The two concepts that were developed both utilized the stoker method of moving material.

The first concept was made to use a stoker reclamer in a circular silo for rebuilds, the second used a modified stoker in a square silo. The circular stoker is an attempt at combining the cost effective storage area of a circular silo with the cost efficient construction of a stoker. The design is only using one stoker ladder which rotates around the silo floor; this should keep the operating costs to a minimum. The whole reason behind the circular stoker is to be able to rebuild an old silo with a new reclaiming system which is simpler and more reliable, which will probably reduce the cost. The price was often a deciding factor when rebuilding or modifying existing plants which was mentioned in customer interviews.
The second concept stoker 2.0 is an attempt at improving the regular stoker; this was done by combining the regular stoker with Keith Walking Floor which is similar to the stoker. The resulting combination is a stoker which is made to withstand heavier loads up to 5000 m$^3$, and it is also designed to increase the efficiency of each stroke by reducing the requisite to compact the material at the beginning of each stroke. This is because the carriers are divided into two sets which move individually to constantly push the compacted material over to one another before returning. The major selling points with the stoker 2.0 are that it is made to reclaim material more efficiently than the regular stoker, reducing the operating costs. Also the rugged construction is made to withstand heavy loads enabling it to be used for higher storage volumes then the regular stoker and its minimal maintenance requirements.

It should be noted that the FEM – analysis which many of the design choices are based upon are idealized cases made to reflect the actual working conditions. The results validity varies depending of the cases complexity and the thesis participant’s knowledge of the case and the program. Fatigue analysis has not been considered because the uncertainty of the number of cycle during normal operating conditions.

12.5. The obstacles
One important issue that one needs to consider when working with a tight schedule is to be quick to request information seeing as it may often be hard to get a hold of the appropriate person. This was experienced a number of times during the project and in many cases it may have depended on the fact that work was done away from the company which meant that much of the communication was done by e-mail. Another problem which emerged was the difficulty when trying to evaluate the first versions of the concepts and to determine how the material would behave and how big the forces would be. This was mostly because the engineering decisions in this industry often were based of many years of experience with wood chips which required consulting. The magnitude of the thesis work was a factor which limited the depth of the analysis in the projects different stages, this effect was more explicit in the beginning.

12.6. Retrospect
This project has been a traditional product development assignment which has given a lot more practice in how to organize projects and how to apply previous understandings of product development to a new unknown industry. The task has been challenging from many aspects, at first trying to develop a new method to reclaim wood chips in an industry where most have been tried. Evaluating the concepts has also been a challenging task since the environment in which they would operate have been difficult to define and what problems that may occur.

13. Future development
In this chapter it will be discussed on what is needed to be further developed before an installment is done. It is important to realize that these concepts are still in the development phase, manufacturing material or prototypes has not been produced.
13.1. General
This chapter will present some general development that needs to be considered in the future to get a good product to the customer.

Cost analysis
A full cost analysis is required before anyone can answer if the concepts are cheaper than the current technologies. A shorter cost analysis was performed for the thesis and only discussed the construction and material of a silo. A more extensive cost analysis is necessary, this cost analysis need to consider location of the customer, groundwork, construction and assembly of silo, the price for raw material (concrete, steel and plastics etc.), manufacturing cost of the product, transport of product to site, assembly of product, engineering time and operating cost for the customer.

Detailed design
A detailed design has not been done because BRUKS has a lot more experience in the exact nuts and bolts that is needed. Before any of the concepts are sold to an end-user it is important that a thorough design overhaul is conducted. In this thesis work little consideration has been taken to manufacturing and suchlike. This thesis has focused on the overview and solving the functional problems with the concept as a whole.

13.2. Specific areas of improvement and consideration
Here are specific areas in both of the concepts that require more attention and improvement discussed.

Circular stoker
A specific area that has not been considered is how that hub shall be fitted to the silo itself. The idea is that the hub is exactly the same as the hub for a circular screw reclaimer with a couple of adjustments to fit the circular stoker concept. The hub should be connected to the same flange as the hub for the screw reclaimer is. It is of interest to see if the altered design of the hub impedes the design of the flange.

Another specific area of interest is the design of the basket for the hydraulic system. This has not been considered because BRUKS has no record of hydraulic systems that small. A subcontractor needs to be contacted to get an accurate picture of the size and weight of the system.

Something that needs to be further investigated is if there will be any dust accumulation in the gap between the inset and the cylinder. If there is any dust accumulation it can be wise to allow the dust to escape via holes in the bottom of the gap between the inset and the cylinder. This has to be tested to see if there is any dust accumulation, otherwise there is no need for venting holes.

If the silo will be empty for a longer while it might be necessary to consider making a support for the bottom plate to rest on. The bottom plate will bend 6 cm of its own weight which might cause problems if it is in a bent state for a longer while.
Stoker 2.0
An area which has not been explored yet in the concept of stoker 2.0 is the fitting to the floor of the silo will be placed directly on the floor or with some kind of feet. Different customer might want different fittings which might alter the performance of stoker 2.0. The stoker 2.0 has been drawn to date with feet on which the plates rest on; these are mostly to visualize where on the plates the fitting shall be placed. Instead of feet, beams across the entire width of the silo can be used to get a cheaper and easier installation. Further investigations as to how the dividing wall and hydraulics are going to be constructed and fitted in the silo is also required.

It would be advantageous if the fittings for the hydraulic pistons on the plates were moved to fall in line with the plate’s centreline to prevent unnecessary torque causing the plates to bend.

The price of square silos within the given volume segment should be further investigated to determine the cost efficiency of the concept. The silo contractors which were contacted in the price comparison had no definitive answers but suggested the price would increase compared to round silos.

14. Reference

Literature
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Wennberg, Company Documents.

**Interviews and conversations**
Forsberg, R. Mail conversation, (080917 – 081023).
Hörnquist, G. Mail conversation, (080623 – 081015).
Smith, D. Mail conversation, (080623 – 081105).

**Internet**
BRUKS Group: Supplier of reclaiming products.
Rader: Supplier of reclaiming products.
http://www.rader.com/, (2008-10-29, 15:00)
Keith Walking Floor: Supplier of reclaiming products.
http://www.keithwalkingfloor.com/, (2008-10-29, 15:00)
Silexport: Supplier of reclaiming products.
http://www.silexport.com/, (2008-10-29, 15:00)
Kuntze: Supplier of rubber and plastics.
http://www.kuntze.se/, (2008-10-29, 15:00)
CA-Verken: Supplier of hydraulics.
http://www.caverken.se/, (2008-10-29, 15:00)
D&E Trading: Supplier of sliding bearings.
http://www.detading.se/, (2008-10-29, 15:00)
Woodco USA: Conversion table from Brinell to HRC.
http://www.woodcousa.com/, (2008-10-29, 15:00)
SSAB: Supplier of wear plates.
http://www.hardox.com/, (2008-10-29, 15:00)
Super seal: Supplier of seals.
http://www.superseal.hu/, (2008-10-29, 15:00)
Kamengo: Supplier of reclaiming products.
http://www.kamengo.com/, (2008-11-17, 14:00)
## Appendix 1 - Competitors

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Solution</th>
<th>Competitiveness</th>
<th>Turnover (Millions)</th>
<th>Employees (Approx.)</th>
<th>Web address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vecoplan</td>
<td>A German competitor that specializes in wood and recycling.</td>
<td>System</td>
<td>Big</td>
<td>€ 70,8</td>
<td>365</td>
<td><a href="http://www.vecoplan.com">http://www.vecoplan.com</a></td>
</tr>
<tr>
<td>Raumaster</td>
<td>A Finnish competitor that specializes in pulp &amp; paper and energy industries.</td>
<td>System</td>
<td>Big</td>
<td>€ 60</td>
<td>230</td>
<td><a href="http://www.raumaster.fi">http://www.raumaster.fi</a></td>
</tr>
<tr>
<td>Metso</td>
<td>A Finnish competitor with a lot of specialties like bulk material handling.</td>
<td>System</td>
<td>Big</td>
<td>€ 362,6</td>
<td>27 000 Metso Inc.</td>
<td><a href="http://www.metso.com">http://www.metso.com</a></td>
</tr>
<tr>
<td>Rader</td>
<td>An American competitor who is active in the same segments as BRUKS.</td>
<td>System</td>
<td>Medium</td>
<td>€ 25</td>
<td>-</td>
<td><a href="http://www.rader.com/">http://www.rader.com/</a></td>
</tr>
<tr>
<td>SHW Engineering</td>
<td>A German competitor in the wood industry. Innovative reclaim solutions.</td>
<td>System</td>
<td>Medium</td>
<td>€ 16</td>
<td>60</td>
<td><a href="http://www.shw-shs.de">http://www.shw-shs.de</a></td>
</tr>
<tr>
<td>Kellve</td>
<td>A Swedish competitor in bulk material handling.</td>
<td>System</td>
<td>Medium</td>
<td>209,5 SEK</td>
<td>70</td>
<td><a href="http://www.kellve.com">http://www.kellve.com</a></td>
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<tr>
<td>Saxlund</td>
<td>A Swedish competitor in bulk material handling. Manufactures in Germany, Sweden, UK and US.</td>
<td>System</td>
<td>Medium</td>
<td>€ 6,5</td>
<td>14</td>
<td><a href="http://www.saxlund.se">http://www.saxlund.se</a></td>
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<tr>
<td>FMW</td>
<td>An Austrian competitor who makes stacker-reclaimers and Tubulators.</td>
<td>System</td>
<td>Medium</td>
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<td>110</td>
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<tr>
<td><strong>Laidig</strong></td>
<td>An American competitor who is taking market shares from BRUKS.</td>
<td>Storage</td>
<td>Medium</td>
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<td>-</td>
<td><a href="http://www.laidig.com">http://www.laidig.com</a></td>
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<tr>
<td><strong>Laitex</strong></td>
<td>A Finnish competitor who does discharge systems for storage solutions.</td>
<td>Storage</td>
<td>Medium</td>
<td>-</td>
<td>-</td>
<td><a href="http://www.laitex.fi/eng/index">http://www.laitex.fi/eng/index</a></td>
</tr>
</tbody>
</table>
| **Tank Connection** | A competitor, who bought Starvrc, can supply storage solutions. | Storage | Medium | - | 225 | [http://www.actionunloaders.com](http://www.actionunloaders.com)  
[http://www.tankconnection.com](http://www.tankconnection.com) |
| **Schade Lagertechnik** | A German competitor who makes stacker-reclaimers and who is a part of the AUMUND Group. | Storage | Medium | - | - | [http://www.schade-lagertechnik.com/](http://www.schade-lagertechnik.com/) |

N.B.  
- Only competitors in the wood chip segment are considered.
Appendix 2 - Silo dimensions

Square Silo
Includes flat roof. Dimensions include heap height. Angle of repose 45°.

<table>
<thead>
<tr>
<th>Volume [m³]</th>
<th>Dimensions [m]</th>
<th>Actual volume [m³]</th>
<th>Floor Pressure [Pa]</th>
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</thead>
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<td>1050</td>
<td>24 971</td>
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<tr>
<td>1500</td>
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<td>1610</td>
<td>24 971</td>
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<td>21 x 14 x 15</td>
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<td>18 x 15 x 20</td>
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<td>4500</td>
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Round Silo
Includes flat roof. Dimensions include heap height. Angle of repose 45°.

<table>
<thead>
<tr>
<th>Volume [m³]</th>
<th>Dimensions [m]</th>
<th>Heap height [m]</th>
<th>Actual volume [m³]</th>
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<tr>
<td>5000</td>
<td>18 x 25</td>
<td>9</td>
<td>5217</td>
</tr>
</tbody>
</table>
Appendix 3 - Requirement specification

- Size segments should be between 1 000m$^3$ – 5 000m$^3$.
- The solutions should be dimensioned for intervals of 500m$^3$.
- Only wood chips shall be considered for the solution.
- For increased competitiveness should at least one of the following should be satisfied:
  1. The price should be competitive.
  2. Unique functions/properties that increases the value for the customer.
- The concept solution for the existing clientele should be within the borders of already existing construction, as groundwork and suchlike, this means a round silo and centre discharge hole.
- The solutions should foremost focus on the European and North American market.
- The solutions should be robust and be able to withstand a whole year of constant operation without breakdown.
- The solutions have to have good accessibility for maintenance and inspections.
- Possibilities for manufacturing should be regarded in the choice of material and design.
- The process (rate of reclaim) shall be controllable.
- The rate of reclaim should be constant and 300 - 1000m$^3$/h for larger storage (2000m$^3$ – 5000m$^3$) and 100 - 500m$^3$/h for smaller storage (1000m$^3$ - 2000m$^3$).
## Appendix 4 - Screening matrix

<table>
<thead>
<tr>
<th>Selection Criteria</th>
<th>Reference</th>
<th>Concept 1</th>
<th>Concept 2</th>
<th>Concept 3</th>
<th>Concept 4</th>
<th>Concept 5</th>
<th>Concept 6</th>
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<th>Concept 15</th>
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<td>-</td>
<td>-</td>
<td>-</td>
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## Appendix 5 - Scoring matrix

### Concept Scoring

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### Continue? Yes/No
Appendix 6 - Function-means tree
Appendix 7 – Price compilation

Price Compilation

![Price Compilation Graph]

- Company 1
- Company 2
- Company 3
## Appendix 8 – Size segments

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**N.B.**

- All values are approximated and require to be recalculated from case to case.
- The rate of reclaim for OCR, COSR, Air- Max and LSR are calculated for wood chips weighing 350 kg/m³.
No fittings for braces on backside of carrier
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**SOLID EDGE**

UGS - The PLM Company

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**CHECKED**

**ENG APPR**

**MGR APPR**

**TITLE**

Front Carrier

**SIZE**

A4

**DWG NO**

**FILE NAME:** medbringare_fram.dft

**SCALE:**

**WEIGHT:**

SHEET 1 OF 1

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS

ANGLES ±XX°

2 PL ±XXX 3 PL ±XXXX

DRAWN CHECKED ENG APPR APPR UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN MILLIMETERS ANGLES ±X.X° 2 PL ±X.XX 3 PL ±X.XXX
Circular Stoker

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN MILLIMETERS
ANGLES ±XX°
2 PL ±XXX 3 PL ±XXXX

DATE: 11/03/08

SOLID EDGE
UGS - The PLM Company

FILE NAME: utmatning.dft

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**Dimensions are in millimeters**

**Angles** ±X.X°

- 2 PL ±X.XX
- 3 PL ±X.XXX

**NAME**

**DATE**

11/03/08

**SOLID EDGE**

**UGS - The PLM Company**

**Title**: Carrier_set_1

**Size**: A4

**Dwg No**

FILE NAME: Carrier_set_1_em.dft

**Scale**: SHEET 1 OF 1

**Revision History**

- REV 5
- DESCRIPTION
- DATE
- APPROVED
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN MILLIMETERS
ANGLES ±XX°
2 PL ±XXX 3 PL ±XXXX