CHALMERS

Shaker Screen Cleaning System

Degree project in the Bachelor of Science in Engineering Programme

Mechanical Engineering

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Cover:
A dirty shaker screen, see chapter 5.1.

PREFACE

We, Frans Isaksson and Anton Östebo, have developed a product concept that cleans shaker screens. These are used in shale shakers, on oil rigs. The project is a bachelor thesis for the mechanical engineering education at Chalmers University of Technology in Gothenburg, Sweden. The three-year mechanical engineering program at the bachelor level, 180 Swedish credits, includes a ten-week bachelor thesis, 15 Swedish credits.

The bachelor thesis has been done in collaboration with Step Offshore AS in Hvalstad, Norway, during the spring term 2013. The mentor at Chalmers University of Technology has been Gert Persson and the mentor during the first six weeks at Step Offshore AS has been Halvor Kvifte, development manager for the project. During the last four weeks of the project Ivar Holshagen has been the mentor at Step Offshore AS.

Thanks to:

Per Øystein Pedersen, Egil Dilkestad, Kjell Petter Skjønneberg, Ulf Ellingsen, Pål Eriksen, Endre Ahmer, Arild Grasdal, John Dubland, Vidar Vik, Lars Erik Halvorsen, Peter Davies, Knut A. Bakke, Lars Kristian Breivik Askgaard, Anton Larsson, Anton Marinovic, Kurt Schünemann, Sven Ekered, Anders Rosell, Lars Larsson and Peter Hammersberg,

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DICTIONARY

Annulus - space between the drill string and the wellbore where cuttings and used drilling fluid flow on their way back to the platform

CE - mandatory marking for all products sold in the European Economic Area (2.2.2)

Cuttings - particles that are removed when the drill bit penetrates the sea floor and consists primarily of rock (shale, clay, claystone, sand, salt, etc.)

DFM - Design For Manufacturing. While considering the manufacturing of the product early in the development process the product is more likely to actually be easy to manufacture later on.

DNV - Den Norske Veritas (2.2.4).

Drill bit - the unit that penetrates the sea floor creating the wellbore

Drill string - a series of pipes that transfers drilling fluid to the drill bit and making it rotate by transferring torque

HSE - Health, Safety and Environment. This is core values in Aker Solutions.

Mud - drilling fluid that facilitates the drilling and helps removing the cuttings

NORSOK - standards developed by the Norwegian petroleum industry (2.2.3)

Shaker screen - fine metal mesh (single, dual or triple layered) used for filtering and separating cuttings from mud (drilling fluid)

Shale shaker - machine used for cleaning drilling fluid by separating the fluid from the cuttings through a set of vibrating shaker screens. Through a vibrating motion the liquid falls through and the cuttings are removed.

Wellbore - the drilled hole between the sea floor and the well

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SUMMARY

At oil rigs there are filters, shaker screens, which clean the recycled drilling fluid when drilling. Occasionally these shaker screens need to be cleaned and this is done by an operator with a pressure washer. This is not good according to HSE, Health Safety and Environment, because the operators expose themselves for injury risk when using a pressure washer. There is also a risk that the operators, during cleaning, inhale the solid mist and drilling fluids vapours, which contain chemicals. This is why there is a need for a product that washes shaker screens, without putting the operators at risk. There are products on the market that clean the shaker screens, but they are not effective enough and are therefore not used as intended.

During ten weeks a development process in a shaker screen cleaner has been made at Step Offshore AS in Hvalstad, Norway. The new product concept is presented in a computer model. The later processes of drawings and prototyping are not a part of this project.

The work resulted in a computer model of a robust machine that washes two shaker screens simultaneously. The shaker screens are leaning towards the middle-wall, which separates the two shaker screens inside of the enclosure. The dirty side of the shaker screen is facing outwards. The model of the machine has two doors on each short side for inserting the shaker screens. The operator closes the doors and starts the machine by pushing two buttons, which are positioned on the long side of the machine. It has a cleaning mechanism that is flushing the dirt from above with pressurized water. The cleaning mechanism starts to spray at the top of the shaker screen and then moves downwards until it reaches the bottom. When the cleaning cycle is finished, the doors open automatically.

The product concept has reached the goals of not putting the operators at unnecessary risk. The machine is effective and easy to use, which means that the operators will prefer this machine instead of using a manual pressure washer.

Keywords: shaker screen, drilling fluid, HSE, shale shaker, cleaning

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Background

When drilling for oil in the sea, a drilling fluid is used both to make the drilling more effective and to remove cuttings and material from the wellbore. This liquid, commonly referred to as “mud”, is water- or oil based containing different chemicals. The composition depends of the kind of formation that the drillbit penetrates. Since the mud is both environmentally harmful and costly it is continuously circulated in a closed loop system and stored on the rig/ship after the drill operation for future use. Cuttings consist of rock (shale, clay, claystone, sand, salt, etc.). These cuttings follow the mud flow to the rig where it is cleaned by a shale shaker machine and recirculated through the wellbore. The shale shaker is a vibrating machine using a very fine mesh that separates the cuttings from the fluid. The mesh is often divided into six or eight sections, each mounted on a frame, called shaker screens.

After a while the mesh is plugged with particles and its ability to let liquid pass is reduced. When a too large area of the shaker screen is plugged it needs to be cleaned. Occasionally the composition of the mud changes and the shaker screens necessarily has to be exchanged by other types of shaker screens. The removed shaker screens also have to be cleaned, before storage. This is often done manually by an operator. The shaker screens are then extracted from the shale shaker, positioned vertically nearby, and washed with a manual pressure washer.

1.2 Purpose

Step Offshore AS needs to develop a shaker screen cleaner that could be used in a global market. This unit needs to be efficient and easy to use so that the operators actually use them. This will improve the working environment and conditions for the operators by the reductions of harmful gases in the air and overall risks. It would also mean reduced water waste and time for cleaning.

1.3 Delimitations

The project aims to develop a realistic concept for a shaker screen cleaner, considering the shaker screen cleaner only and not the shale shaker in which the shaker screens are located.

The shaker screen cleaner is assumed to be placed within walking distance from the shale shakers. The project will result in a detailed product concept that should be possible by the end of 2013. The product concept will be presented through a 3D computer model. Prototype or drawings will not be made in this project.

1.4 Clarification of the problem

Cleaning shaker screens manually includes a severe risk of injury from the manual pressure washer and creates a harmful fog of water, particles and chemicals.

There are shaker screen cleaners that clean shaker screens in a closed compartment today. Unfortunately none of them are efficient and easy to use; therefore the operators on the drilling platforms still often clean the shaker screens manually.

1.5 Company information

Step Offshore AS is based in Hvalstad outside Oslo, Norway, and has approximately 100 employees. They are a supplier of drilling fluid (mud) management solutions and will hereby be named as “the company”. This includes equipment for mixing, pumping, storing and also cleaning the drilling fluid. This equipment is often delivered as a package when a new rig or drillship is built. The company is a part of the subdivision “Drilling technologies” under Aker Solutions which is one of the largest providers of drilling equipment in Norway with over 25,000 employees worldwide. They deliver all necessary parts for drilling for oil and gas in a subsea environment.

2 THEORETICAL FRAMEWORK

This chapter is an explanation of the product development process, the laws and regulations and experiment methodology.

2.1 Product development process

To create a competitive product an important step is to identify customer and user needs and establish a product specification from that. When that is clarified, the process continues with a concept generation. A good concept generation can lead to many concepts. Only a fraction of them will be chosen for further development during the concept selection phase. (Ulrich & Eppinger, 2003)

2.1.1 Concept generation

Advantageously is to have a lot of information within the product field early in the development process. This will increase the chance to find a product that suits the user in his or her context. It will reduce the risk to come up with a better idea later or that a competitor will invent a better product.

A good first move in a concept generation is to clarify and understand the problem. Then the problem can be divided into sub problems called problem decomposition. That can be made by describing a sequence of user actions, in a flow chart, and then focus on the “critical” sub problems.

By an overlaying exploration, searching externally is a good start. When searching externally, interviewing users and experts is an excellent way to find relevant information. Searching patents is also useful and necessary, (see chapter 2.2.1 for more information). There is also published literature, such as books, journals, trade magazines and product information, both printed and online versions. If there are any related products, this information should be collected to find out the strengths and weaknesses of the competitors. (Ulrich & Eppinger, 2003)

With this solid description of the factors affecting the product, new ideas is to be created. There are many methods for this idea generation and one of these is the 6-3-5 brainwriting.

6-3-5 brainwriting is an idea generation technique that focuses on creating a large quantity of ideas. The method name stands for six people, three ideas each five minutes. This is often done by six people where each person sketch or write down three ideas in three separate areas on the paper. After five minutes, the paper is passed to the right and each person writes down three new ideas based on or inspired by the ideas noted by the previous person. (Wodehouse & Ion, 2011)

2.1.2 Concept selection

In this sub process the concepts, from the concept generation phase, is evaluated. This can be made in a two-stage concept methodology. The two stages are concept screening and concept scoring.

The concept screening stage is set up with a selection matrix, this analysis tool is based on the specification, and each concept is analysed in how well they meet each requirement. If the requirement is completely met, that concept is given for example a score of three. If the requirement is partly met, the concept is given a score of two and if the requirement is not met at all the concept is given one point on that row. When all concepts have been weighted to all relevant requirements the points can be summarized. Finally choices are taken of which of the concepts that should be continued to the concept scoring stage.

In the concept scoring stage a selection matrix is set up. The concepts are rated to one criterion at a time. The criteria are weighted to their importance. When ranked, the rating of each concept's criteria is multiplied with its criteria weights. The sum of the weighted score is the concepts total rank.

It is important to understand the customer and the user needs. One opportunity is to ask the customer, for example in a questionnaire, what they prefer and which of the concept they would choose. Some concepts could then be combined or improved. In some cases more than one concept is continued in the development process. (Ulrich & Eppinger, 2003)

2.1.3 Design for manufacturing, DFM

"DFM leads to low manufacturing costs without sacrificing product quality" (Ulrich & Eppinger, 2003). During the whole process by choosing a product concept, cost is taken into account. In the design process a determination of the costs in components, assembling and production support is made (Ulrich & Eppinger, 2003).

2.1.4 FMEA – Failure Mode and Effects Analysis

This is a method commonly used to find the risks the operator using the product is exposed to. To get a product CE certified a FMEA in accordance with ISO standard 12100 has to be made (British Standards Institution, 2011).

2.2 Laws, regulations and standards

When developing a new product on the market there are certain requirements, laws and regulations that must be considered. Searching for patents is also necessary to avoid infringement of other concepts already patented.

2.2.1 Patent

Intellectual property can be categorized into four areas during a development process. These areas are patent, trademark, trade secret and copyright. A patent can be valid for 20 years after the day that the patent application has been submitted (SFS1967:837, 1967). The patent is only valid in the country where the application is made, however it is able to make an international patent application. The law of patents varies in different countries (Patent- och registreringverket, 2013).

2.2.2 CE marking

This is a conformity marking mandatory for all products to be used within the European Economic Area (EEA). By putting the CE mark on a product the manufacturer guarantees that the product meets the essential requirements basically stating that the product is safe to use.

2.2.3 NORSOK

The Norwegian petroleum industry has developed a standard called the NORSOK standards. The standard is mainly to “ensure adequate safety, value adding and cost effectiveness for petroleum industry developments and operations” (Standards Norway, The Norwegian Electrotechnical Committee and Standard Online AS, 2013).

2.2.4 DNV –Den Norske Veritas

DNV is an independent foundation with the purpose of safeguarding life, property, and the environment.” (DNV, 2013). They have published a set of standards that are not mandatory to follow in order to sell a product but often used by manufacturers of offshore equipment and are comparable to ISO standards.

2.3 Factorial experiment

When factors affecting a method or case are unknown an experiment can be made to study those factors. A factorial experiment is one method that is commonly used. In a factorial experiment the factors that change the situation are carefully controlled. The result can be studied by a response variable. The factors are independent from each other. Before a factorial experiment is made it is important to clarify what factors that could affect the result significantly. If this is done correctly it could show the result of which of the factors that are significant. (Dahlbom, 2003)

3 METHOD

The product development process chosen in this project follows the company's internal development process model. This follows the same overall principles as described in (Ulrich & Eppinger, 2003). This methodology has been proven successful in many of Aker Solutions' projects.

3.1 Research

As explained in chapter 2.1.1 a product development process starts in a broad research and information is gathered. The information is collected mainly from people with field experience, the internet and published books. The research also includes a factorial experiment (chapter 6.1.4), which is described in chapter 2.3. The research is further explained in chapter 4 and summarized in chapter 5.

3.2 Product development process

After the research, the product development process starts with a concept generation, as explained in chapter 2.1.1. The generated concepts are screened and evaluated, as explained in chapter 2.1.2. The final concept is a result based on the concept evaluation. That concept is developed further in chapter 7.

4 RESEARCH

As explained in chapter 3.1 a research in the product field was made, which is explained further in this chapter.

4.1 Collect information

A collection of information about competitors' products and a patent (US 7,740,021 B2) of one of the competitor's product were provided by the company. So was a compilation of regulations (chapter 2.2.2 - 2.2.4).

4.2 Patent research

Through the databases "Google Patent Search" and "Espacenet" several patents were studied (chapter 2.2). This is made by studying their characteristics in the patent's independent claims (Schünemann, 2013). No other patents than the one provided by the company were found relevant. The text in the independent claims in this patent (as shown in the next paragraph) was studied carefully to avoid infringing.

"What is claimed is:

1. An apparatus comprising:
   (a) a washing enclosure comprising a box-like component dimensioned to receive a screen of size used in drilling wells and in well workovers, the washing enclosure having a single screen entry and exit;

- (b) a screen carriage inside of and supported by the washing enclosure;
- (c) a plurality of spray nozzles mounted inside of the washing enclosure arranged to spray a cleaning composition toward a screen carried by the screen carriage; and
- (d) one or more carriage vibrators mounted on the screen carriage.

…

- 11. An apparatus comprising:

- (a) a washing enclosure comprising a box-like component dimensioned to receive a screen of size used in drilling wells and in well workovers, the washing enclosure having separate screen entry and exits on opposite ends of the enclosure;
- (b) a screen carriage inside of and supported by the washing enclosure;
- (c) a plurality of spray nozzles mounted inside of the washing enclosure arranged to spray a cleaning composition toward a screen carried by the screen carriage;
- (d) one or more carriage vibrators mounted on the screen carriage; and
- (e) one or more automated rollers for moving the screen through the enclosure."

(RNG Oilfield Sales & Service, 2010)

4.3 CE marking

From the research of CE marking, many factors which involve risks concerning machines were studied. For example dynamical testing, lifting components and safety components has to be kept in mind during the development process. This is important for avoiding problems that may emerge later in the process.

4.4 NORSOK standard

In this standard information is held about the standards that are used in the North Sea, where this product will be used. In one of these standards NORSOK S-002, limits for dust emission and acoustic noise is set. These standards are relevant for all product development concerning the North Sea and the requirement specification required that the product concept must follow these.

4.5 Benchmarking competitors

There are several products that clean shaker screens today. All available product information was studied carefully. Since none of the competitive products were physically available for studying, opinions and experience from personnel that have been or are working in the field were used. This made it easy to find out the product's pros and cons.

4.6 Private communication

People that have personal experience in the area are perfect sources of information. By talking to operators, customers, sellers and product developers the product and its context has been mapped. These conclusions can be viewed in chapter 5.

5 CONCLUSION OF RESEARCH

The research resulted in knowledge about the drilling procedure and the functionality of the shaker screens. Understanding of the operators view was crucial in this case.

5.1 The drilling procedure

Oil and gas are found in large fields all around the globe and in many places far below sea level. This is the case in for example Norway. To move the oil from the well to the surface, where it can be processed and transported, a drill bit makes a hole through the sea floor to the well. The drill bit penetrates the sea floor and can then be steered in three dimensions to reach the final target. When the well is completed and secured the work is handed over to production which extracts the oil. The drill bit is mounted and operated from a vessel such as a drill ship, semi-submersible or an oil platform (*Figure 5.1*, page 12).

A drill bit is used for the actual drilling and is powered by the circulating fluid and the top-drive rotating the drill string. A drill string consists of long steel tubes connecting the drill bit to the drill ship or oil platform. The drilling fluid or “mud” is pumped down through the drill string and drill bit to facilitate the drilling and remove cuttings. The diameter of the drill bit is larger than the diameter of the drill string creating an area outside of the drill string (annulus). Here the mixture of drilling fluid and cuttings flows upwards along the drill string. The drilling fluid prevents the hole from collapsing and ensures that the wellbore pressure is contained by adjusting the drilling fluid density.

When the drilling fluid reaches the drilling vessel it is divided onto a number of shale shakers (typically 4–8 units, mounted in parallel), separating the cuttings from the fluid. There are usually between six to eight shaker screens per shale shaker. The drilling fluid is then reused. The shale shakers are stacked closely together in one room, and if there are any shaker screen cleaners there is one or two located nearby. There is often just enough room for an operator to pass between the shale shakers and the wall. The operators spend as little time as possible in the shaker room due to high noise levels and exposure to hazardous gases and vapors (Onsøyen, 2013).

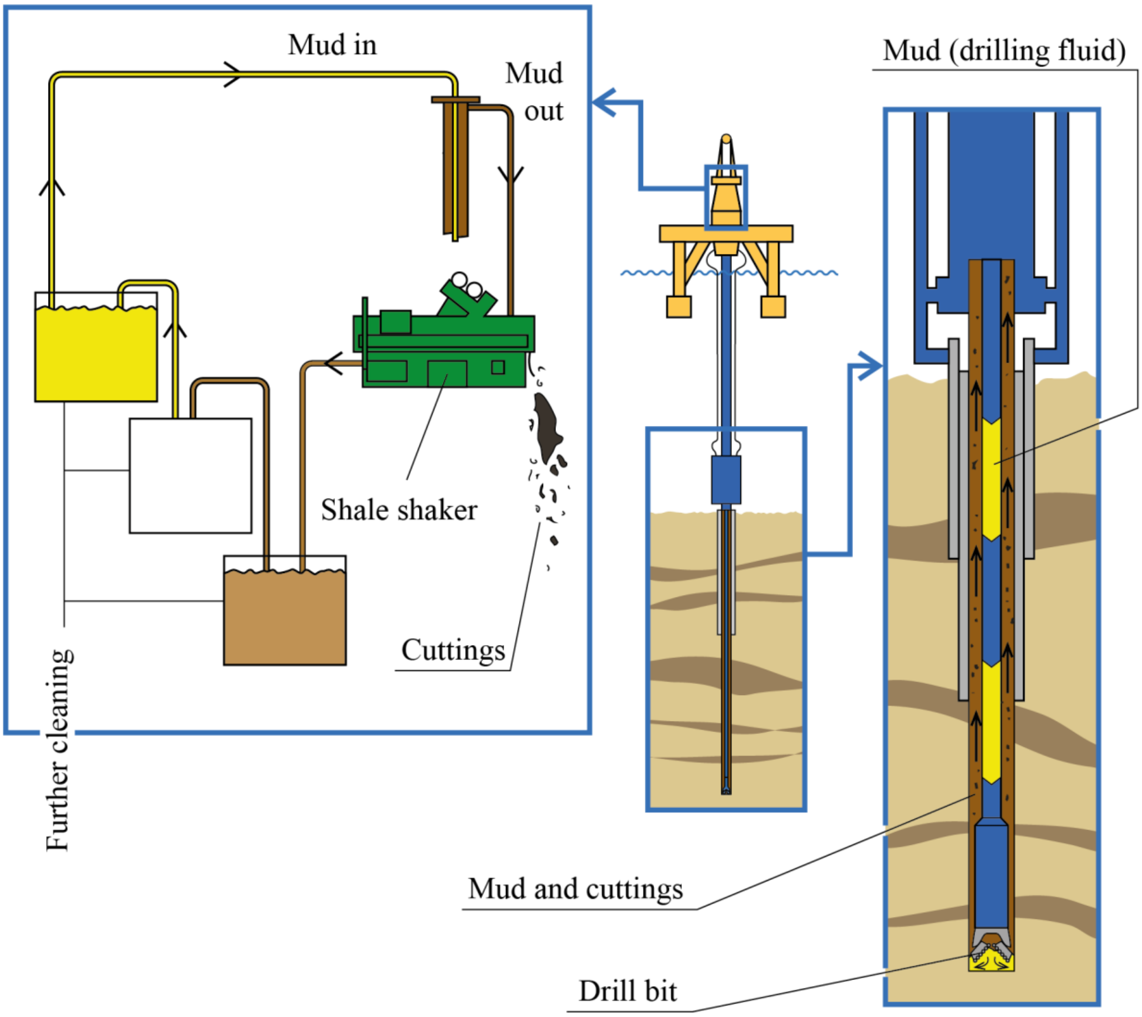


Figure 5.1. The drilling procedure.

5.2 General cleaning

Cleaning is a broad concept. It depends on what kind of dirt you want to remove from what kind of surface. Shaker screens can be compared to a coarse fabric and methods for removing dirt from fabric today usually include fluids. There are also alternative ways such as vacuuming, brushing and adhesive material. Except for these traditional ways other cleaning methods were studied such as dish washers, car washers, floor cleaners, ultrasonic cleaners and etcetera.

5.3 Shale shaker operators

The operators that take care of the maintenance of the shale shakers are therefore responsible for the shaker screens. They keep an eye on the shaker screens and when they have reached a certain level of dirtiness, the operator removes the shaker screens from the shale shaker and cleans them. Today, this is usually done by putting the shaker screens along a wall nearby the shale shaker and clean them with a manual pressure washer. A shaker screen is clean within 10-15 seconds and is then put back in the shale shaker.

The people in charge of purchasing and/or planning the drilling fluid equipment needed are not likely to use the equipment themselves. However, the primary concern for both operators and customers are that the machine cleans shaker screens in an efficient way. Secondarily the size of the machine should be as small as possible. One operator mentioned the need of a cleaning process that minimizes waste as this needs to be handled afterwards. The set up time for plugging the machine into power and fluid systems is also of interest. The investment cost of the machine is not a primary concern as long as it does its job well. (Dubland, 2013) (Grasdal, 2013) (Larsson, 2013) (Marinovic, 2013) (Salte, 2013)

5.4 Product

As described in chapter 5.1 the shale shaker is a machine that separates the drilling fluid from cuttings. It does so by letting a bed consisting of a fine metal mesh vibrate while the fluid flows through. The shale shakers come in a variety of sizes from several different brands and therefore there is a great variety of the shape and size of the shaker screens. Except for the outer size there is also different shaker screen mesh with different thread thickness, size of holes and shape. It is important to have the correct hole size to minimize the fluid waste. If the mesh holes are too big, particles will not be removed from the fluid resulting in increased wear on hoses and tools. If the mesh holes on the other hand are too small, the mesh risks of being clogged quickly making the valuable fluid stick to the cuttings and being thrown away. There are also shaker screens that are flat and those with a three dimensional pattern such as pyramid shapes going along the full length of the shaker screen. The pyramid shape increases the mesh area without affecting the outer dimensions of the shaker screen why these are becoming more and more popular. (Dubland, 2013) (Grasdal, 2013) (Onsøyen, 2013)

5.5 Existing products

The most commonly available products that clean shaker screens today have been analysed and evaluated together with John Dubland and Arild Grasdal. They have personal experience from a variety of products through their role as sales managers and John also knows the cleaning process from his time as a shale shaker operator.

- *RNG Screen Machine model SM 36*, (*Figure 5.2*), is basically a closed container with a numbers of pressure nozzles stacked vertically that the operator moves manually with a knob. There is room for one shaker screen at the time and this is inserted from the left through a slot and the hinged door is closed manually. The water is pressurized by an air driven pump and ejects from the nozzles and hits the shaker screen causing the dirt and particles to fall off. The outlet is connected to the rig's drainage system.

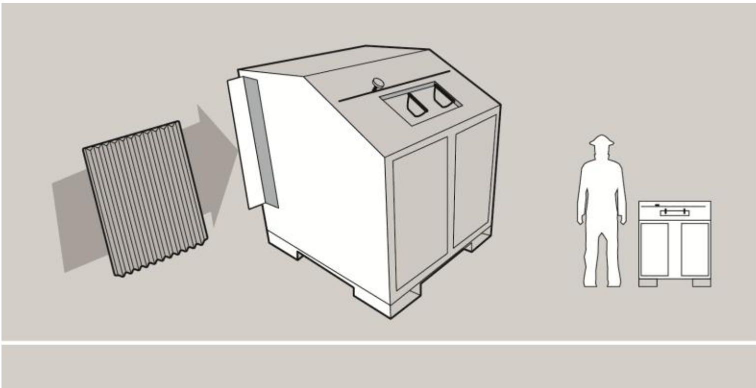


Figure 5.2. RNG Screen Machine

- *Rigtools - Shaker Screen Clean Machine* (*Figure 5.3*) is a box like shaped housing mounted on a frame lifting it approximately 500 mm above the floor. Like the machine from RNG this also has a hatch where the operator inserts the shaker screen though this is a lot bigger. Pressurized water is used to remove the dirt from the shaker screen. How potential nozzles look like or how they move over the shaker screen is not clear. The outlet is connected to the rig’s drainage system.

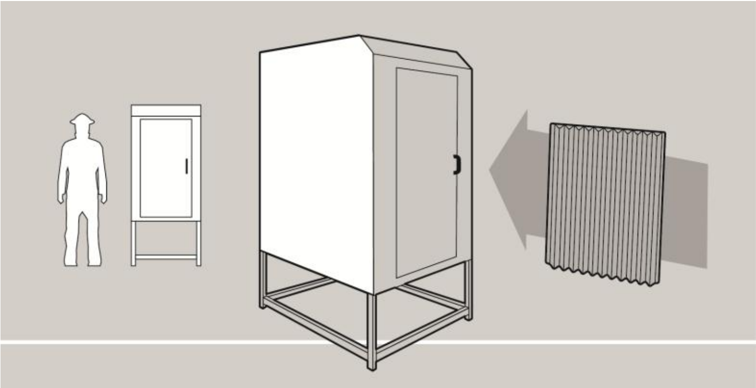


Figure 5.3. Screen cleaning machine from Rigtools

- *Fluid Systems Inc. (FSI) SCREEN MACHINE Model SM 101* (*Figure 5.4*) is a tower like shape with a vertical opening where the shaker screen is inserted. The shaker screen is pushed through the vertical opening manually resting on a conveyor belt and there is a number of pressure nozzles vertically aligned in the cleaner.

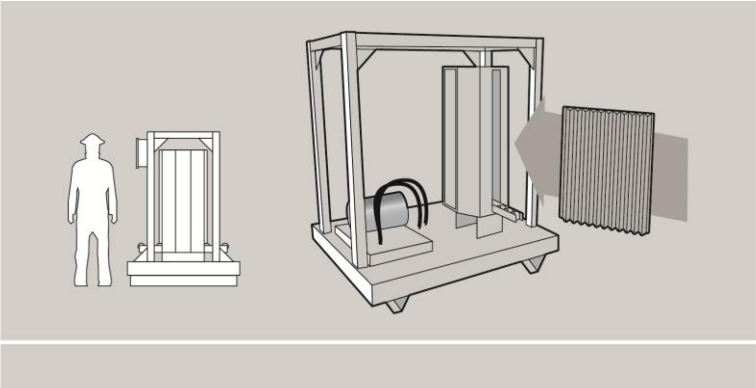
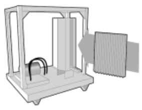
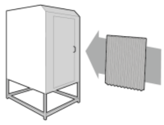
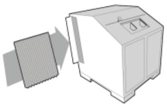


Figure 5.4. FSI screen cleaning machine

There are three properties that of these product that are compared in *Table 5.1*.

Table 5.1. Specifications of the different screen cleaners.

	 **FSI**	 **Rigtools**	 **RNG**
Time consumption per screen	10-25s	60/30s	60s
Operator needed in cleaning process?	Yes	No	Yes
Water consumption per screen	3-15 l	15 l	15 l

5.6 Requirements

A list of requirements was given in the beginning of the project. This includes general project information and also a series of requirements that the final product has to satisfy:

- The machine should clean two shaker screens at the time from the most commonly available shale shakers which are described in the requirement specification. The shaker screen sizes used in these shakers vary from the smallest, 625x710mm (Figure 5.5), to the largest, 711x910mm (Onsøyen, 2013) (Dubland, 2013). The thickness varies from around 10 mm for the flat screens to approximately 40 mm for pyramid screens.

Figure 5.5. A small shaker screen with pyramid shaped mesh.

- The maximum dimensions for the product's base is 1000 x 1200 mm and the height should not exceed 1500 mm so the base dimensions are slightly larger than a standard EUR-pallet.
- The product can use air, water and electrical power which are available on all rigs. The air is pressurized to 6-10 bars while the water flow is not and can be compared to the pressure found in a garden hose. The electrical is connected with three phases but both voltage and frequency can vary depending on where in the world the platform is located.
- There are also two sets of guidelines listed in the requirement specification regarding health and safety (NORSOK S-002) and also regarding the conditions on oil related vessels (DNV-RP-C205) that all equipment on board those vessels should satisfy. The product must for example be operational even if the rig or ship tilts up to 10°.
- The product should also allow the operators to work under ergonomically acceptable conditions.

6 PRODUCT DEVELOPMENT PROCESS

As in chapter 2.1, the development process will begin by generating as many concepts as possible. Then a concept screening is an early step in the concept selection phase (2.1.2), where the final concept is chosen and developed further.

6.1 Concept generation

As in chapter 2.1.1, generating as many ideas as possible is preferred, and brainwriting is a very useful method to achieve that. The ideas generated ranged from both general cleaning methods to specific concept ideas.

6.1.1 Brainwriting

Four students with different technical and mathematical background were invited to participate in the brainwriting session. This brainwriting started with a warm-up where all participants were asked to write or sketch different ways of cleaning. A variety of ideas from biological cleaning using bacteria to ultrasonic vibration cleaning and brushes were noted. During the following intense hour approximately 50 different ideas were generated and then evaluated and categorized into four groups. The groups describe different ways of solving the problem on a conceptual level:

- Integrate a cleaning procedure into the shale shaker
- Have a separate cleaning unit
    - Automatic
    - Semi-automatic
    - Manual

6.1.2 General concepts

These different directions were evaluated using an evaluation matrix (*Table 6.1*), which is similar to a selection matrix as described in chapter 2.1.2. The requirements are ones that customers have listed as important, through interviews (chapter 5.2). Since none of the concepts exist this evaluation is based on estimations.

Table 6.1. Evaluation of four general concept directions. Higher score is better.

			Separate unit		
	Importance (%)	**Integrated into shale shaker**	**Automatic unit**	**Semi-automatic unit**	**Manual unit**
Time consumption	45	5	4	3	1
Product size	20	3	3	3	3
Waste creation	15	5	5	5	2
Set up time	10	5	3	3	3
Investment cost	5	1	3	4	5
Energy consumption	5	3	3	3	5
Sum	100	**4,30**	**3,75**	**3,35**	**2,15**

The table shows that an integrated automatic cleaning unit in the shale shaker is preferable. This is however outside the project limits and such unit is also less modular than a separate unit, because of vast variety of shale shakers on the market. The requirement specifications (see APPENDIX 5) also clearly clarify that the product should be separate and moveable. A completely automated product is not an alternative either because creating an automated extraction of the shaker screens is a too extensive task. Therefore the semi-automatic unit is the general concept that is chosen for further development.

6.1.3 Cleaning method

Next important question is how to clean the shaker screens and what method is most suitable for this application. In the brainwriting session many interesting ideas came up and those are presented in a mind map (*Figure 6.1*).

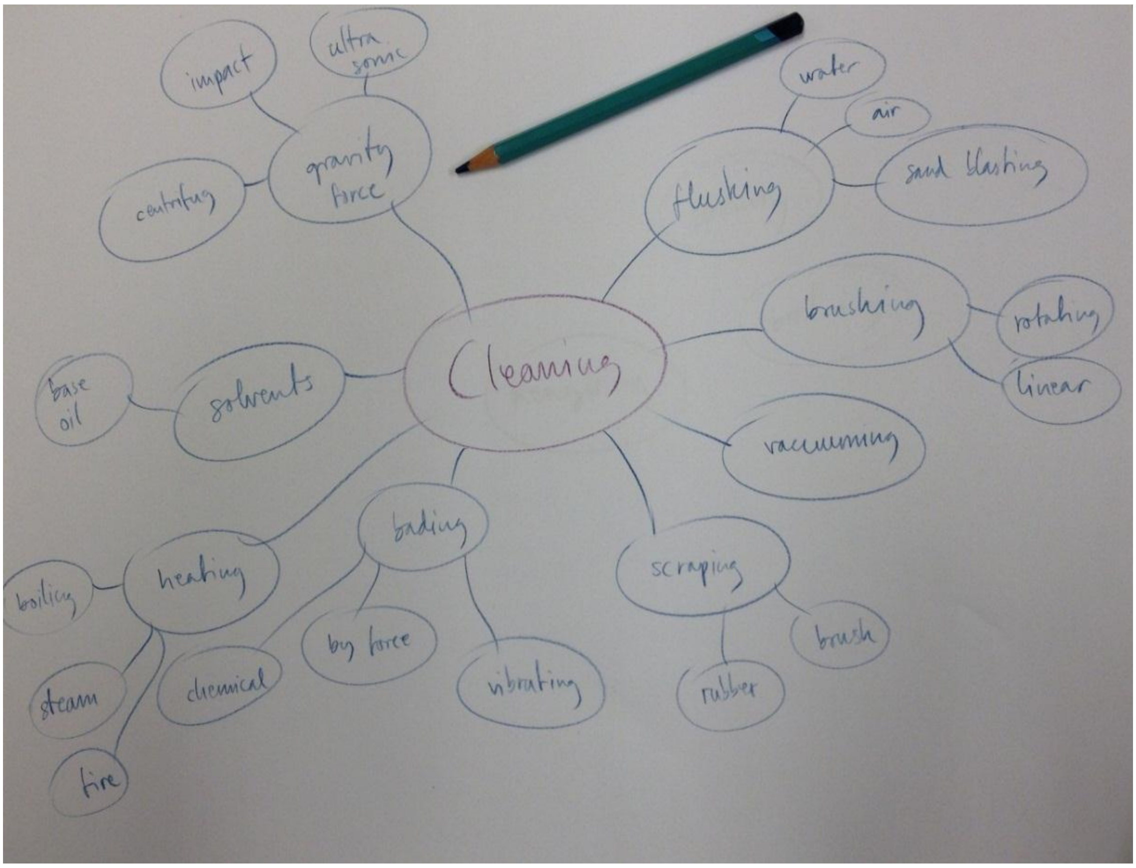


Figure 6.1. Mindmap of different cleaning methods.

The different methods of cleaning were evaluated (*Table 6.2*) against requirements and wishes from those interviewed to find the best method of cleaning (Dubland, 2013) (Larsson, 2013) (Grasdal, 2013). The different aspects have different importance where "Effectiveness" has the greatest importance and covers 60% of the total score. During the experimental test previously conducted both pressurized water and air were tested together with a brush.

Table 6.2. Evaluation of methods to clean shaker screens. Higher score is better.

	Importance (%)	Flushing water	Flushing air	Brushing	Vacuuming	Scraping	Bading	Heating	Solving	Shocking
Effectiveness	60	3	1	1	2	1	1	1	1	1
Maintenance intensive	5	3	3	1	2	1	1	1	1	3
Waste creating	15	1	3	3	3	3	1	2	1	3
Screen gentleness	5	2	2	1	2	1	3	1	1	1
Energy efficiency	5	1	1	2	1	2	2	1	1	2
Simplicity	10	3	3	2	1	2	1	1	1	1
Sum	**100**	**2,55**	**1,65**	**1,45**	**2**	**1,45**	**1,15**	**1,15**	**1**	**1,45**

The matrix clearly shows that water is estimated to be the most effective way to remove dirt from a shaker screen followed by vacuuming and pressurized air. Vacuuming reached a high score based on estimation from a sales representative at Norclean (Karlsson, 2013), a company delivering industrial vacuuming systems in Sweden.

6.1.4 Experiments

When cleaning shaker screens today all methods include high pressure water. This is mainly because water is always available on the rigs and that it is a proven way to clean shaker screens etcetera. The water is normally pressurized by a pump driven by either air or electrical power.

To get a better grip of how water affects a clogged shaker screen a full scale experiment was made. The reason to do this was both to get a better grip of how water and air interacts with dirt on a shaker screen, and to find out what the physical relation between a spray nozzle and a shaker screen look like. A full factorial experiment was done in order to be able to make a statistical conclusion from the test. Vacuuming was not tested further both because of the difficulty in finding powerful and robust equipment. It was also considered to be an untested method which would be time consuming to investigate.

The statistical conclusion showed that water was many times more efficient than air in removing dirt from a shaker screen. It was also clear that the pyramid orientation relative to the angled nozzle was of great importance (*Figure 6.2-Figure 6.3*). If the shaker screens have a pyramid shaped mesh, the water must flow along these pyramids to maximize the cleaning effectiveness and reduce turbulence and splash.

See APPENDIX 3 to see how the experiment was made.

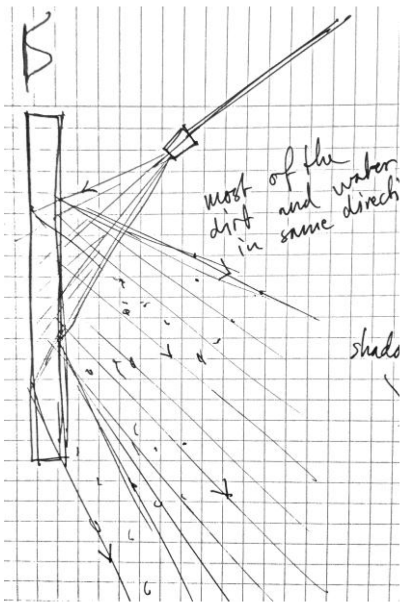


Figure 6.2. Sketch of how the water reflects on a shaker screen with pyramids aligned with the water flow.

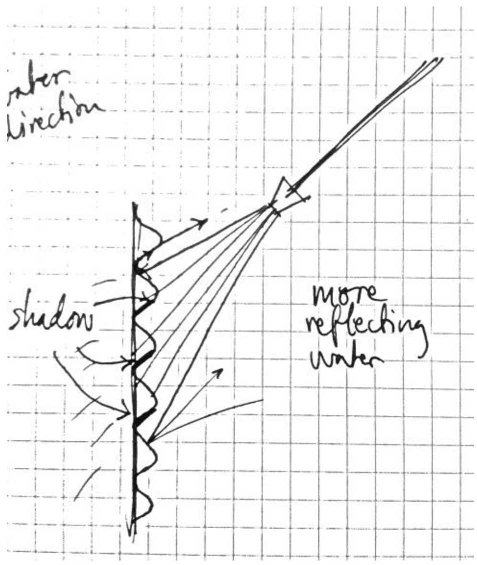


Figure 6.3. Sketch of how the water reflects on a shaker screen with pyramids aligned perpendicularly.

During the experimental testing it was also concluded that if water was to be used, the pressure needs to be high. This can be achieved by spraying a thin beam of water that covers the entire width or length of the shaker screen.

6.2 Concept selection

From the concept generation only one or a few has to be chosen. By a concept screening the concepts that are not meeting the requirements are removed. Those concepts that still are relevant to become a good product are ranked in a scoring selections matrix. The ranking do not decide which of the concepts that are chosen but is a basis for further discussion of which of the concepts that should be continued.

6.2.1 Concept screening

By using the ideas from the concept generation (chapter 6.1.1) eight different concepts were created. These were reduced to six, (see pages 24-25, *Figure 6.4-Figure 6.9*), in a concept screening because of their similarities with other concepts and estimated functionality (Rosell & Larsson, 2013).

6.2.2 Concept scoring

All the concepts require enough space for the shaker screens to pass through the machine. If no such space is available, the machine can easily be modified to receive and eject shaker screens from the same side.

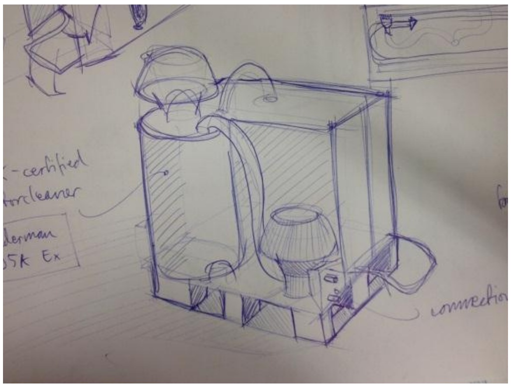


Figure 6.4. Sketch of concept A.

- Concept A

A vacuum cleaner that covers the entire width of the shaker screen moves in a horizontal track inside a closed housing. Two shaker screens can be inserted each time. A foot pedal makes the front and back doors open. The cleaned shaker screens are pushed out by the new contaminated shaker screens and are then collected in a rack on the back side of the product.

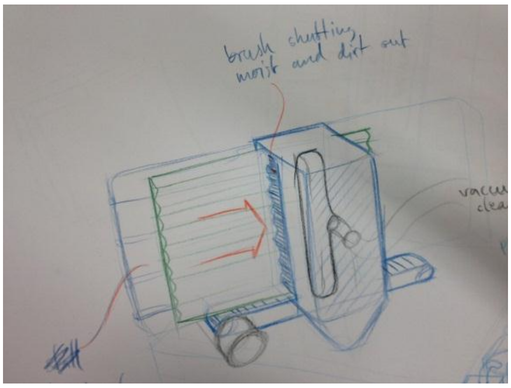


Figure 6.5. Sketch of concept B.

- Concept B

A vacuum cleaner is fixed inside a small housing where contaminated shaker screens roll by. The translational movement is controlled by tilting the conveyor belt causing the shaker screens to move through gravitational force. The moist and dirt tumbling around inside the housing is prevented from getting out through the fine brushes that covers the entry and exit.

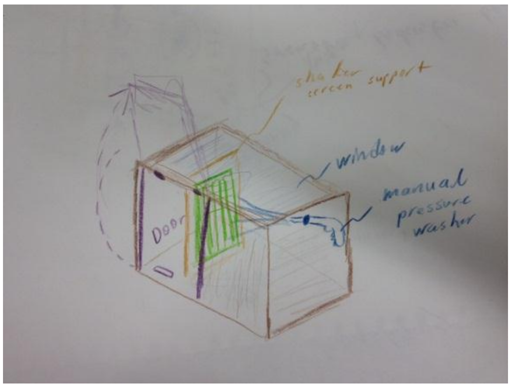


Figure 6.6. Sketch of concept C.

- Concept C

This concept is primarily a fixture so that the shaker screen and an ordinary pressure nozzle are placed the same way every time. The shaker screen is inserted into the back of the machine. The operator then uses the pressure washer handle to activate and control the cleaning of the shaker screen and the result can be viewed through the transparent top of the machine.

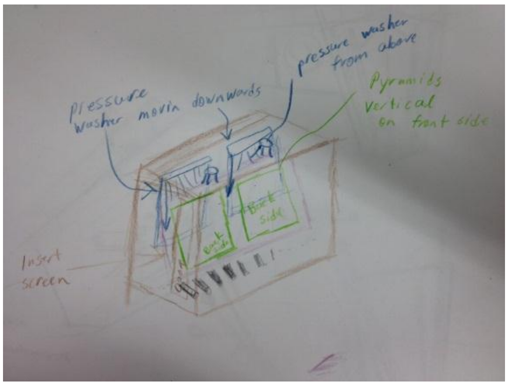


Figure 6.7. Sketch of concept D.

- Concept D

Two shaker screens are inserted after each other and a horizontal bar with nozzles cleans the shaker screens simultaneously with pressurized water. The nozzle bar movement can be controlled by a pneumatic or hydraulic motor. It can also use a weight raised by the operator that slowly falls down causing the nozzle bar to move slowly downwards.

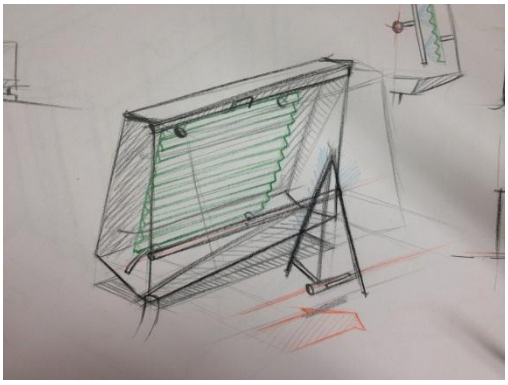


Figure 6.8. A section view of concept E.

- Concept E

The shaker screens are tilted towards the middle. The tilting allows the water to rinse more easily and also keeps the shaker screens in place without additional fastening mechanisms. The nozzle bar is mounted on a sleigh that makes a linear movement in the center of the machine, spraying the left shaker screen on the first move and then the second shaker screen on its way back. The dirt and water is collected in one end of the housing and could then be connected to the rig's drainage system.

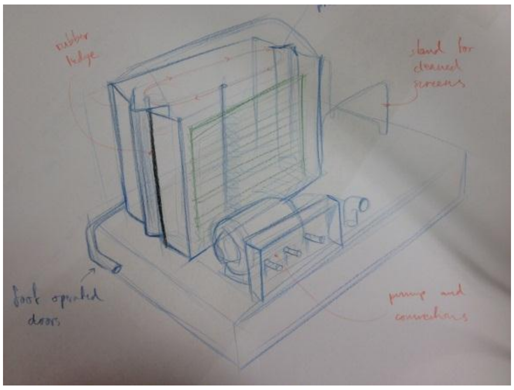


Figure 6.9. Sketch of concept F.

- Concept F

By pressing the foot pedal the front and rear door open and two shaker screens can be inserted. These are positioned vertically along the wall and one bar with pressurized water slowly passes the shaker screens. When the shaker screens are clean the operator again press down the foot pedal opening both front and back doors and two new dirty shaker screens can be inserted, causing the clean ones to slide out of the machine.

The concepts were evaluated against those requirements resulting in concept E and F reaching high scores (*Table 6.3*). Concept B also reached a high score but the vacuuming method was not considered to be interesting for the company at this point, because of the time consumption by testing this method. The requirements were those found when talking to the operators and the customers (chapter 5.2). Beginning with the most important those were:

- ☐ Time consumption for cleaning a shaker screen
- ☐ Product size
- ☐ Waste creation
- ☐ Set up time
- ☐ Investment cost
- ☐ Energy consumption

Table 6.3. Concept selection matrix.

	Importance (%)	**A**	**B**	**C**	**D**	**E**	**F**
Time consumption	45	3	4	3	5	5	5
Product size	20	3	2	3	2	3	3
Waste creation	15	5	5	1	1	1	1
Set up time	10	4	4	3	3	3	3
Investment cost	5	2	2	5	4	3	3
Energy consumption	5	3	3	3	3	3	3
Sum	100	**3,35**	**3,60**	**2,80**	**3,45**	**3,60**	**3,60**

These concepts were also evaluated during two separate sessions with different personnel from the company in a presentation and discussion. (Kvifte, 2013) (Holshagen, 2013) (Halvorsen, 2013) (Onsøyen, 2013) (Eriksen, 2013) (Dubland, 2013) (Grasdal, 2013) (Persson, 2013) The general opinion from these sessions was to continue developing concept E and F.

6.2.3 Conclusion

In a discussion with a former shale shaker operator it was clear that many operators actually carry the shaker screens upended due to the small spaces on board. The dirty side of the shaker screen is also carried away from the body (Dubland, 2013). This knowledge changed the orientation of how the shaker screens should be inserted into the machine.

Before developing the concepts further, the different sub problems were isolated. Decisions have been made from the concept generation process that the shaker screens shall lean vertically with the dirty side outwards in two separated spaces. The shaker screens should be inserted through the front face of the machine. Particles, water and noise should be prevented from exiting the machine area by doors. The washing cycle is performed by pressurized water that sprays from the above the shaker screens through nozzles that are moving downwards until it reaches the bottom. The dirty water is running to the drain system by a leaning machine floor. The machine could also have a rack on the backside, where the cleaned shaker screens will be placed.

From a mind-map the solutions from the chosen concept's sub problems were listed as in *Figure 6.10*.

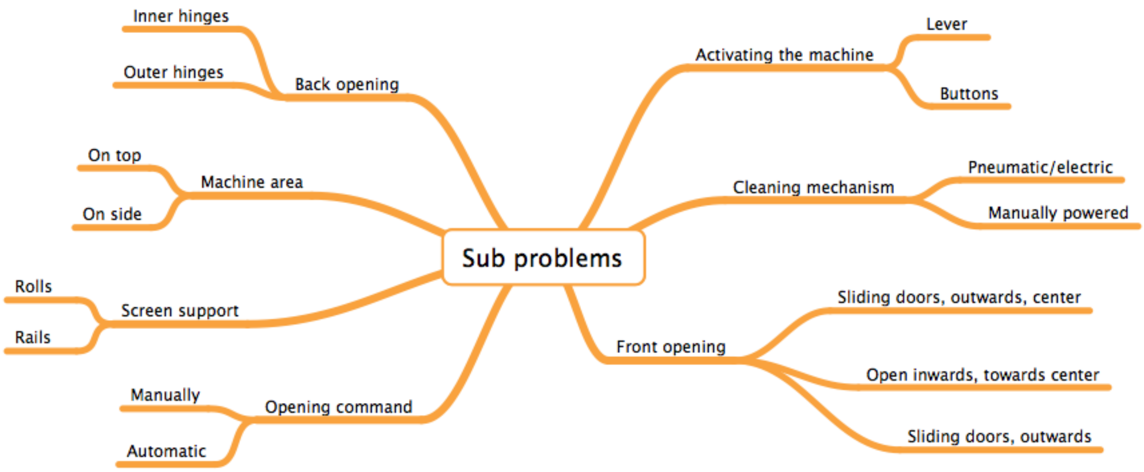


Figure 6.10. A mind-map over the concept's sub problems.

By combining different types of solutions to the sub problems three new concepts were generated as shown in *Figure 6.11-Figure 6.13*.

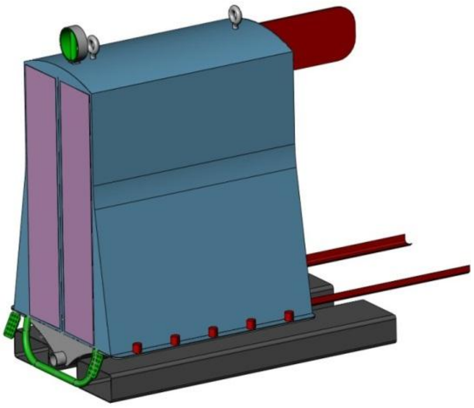


Figure 6.11. Concept mechanical version

- Mechanical version

Front and back doors open outwards by a pressure on a foot pedal, which also is used as a support when inserting the shaker screens. The shaker screens are placed on rails. The cleaning mechanism is activated mechanically. A ring on the top of machine gives a visual signal when the cleaning is finished.

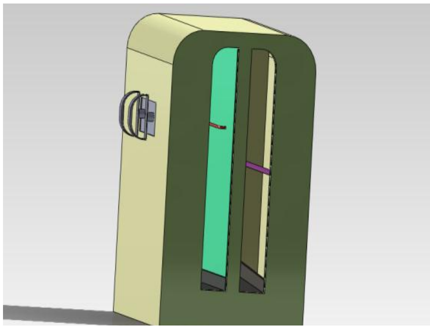


Figure 6.12. Concept partly mechanical version

- Partly Mechanical Version

Front doors are sliding doors and the back doors open outwards. The shaker screens are places on rails, which are twisted and make the shaker screens tilt inwards. The machine is activated by two handles on the left side of the machine. The cleaning mechanism is operated by pneumatic power. The doors open automatically when the cleaning cycle is finished.

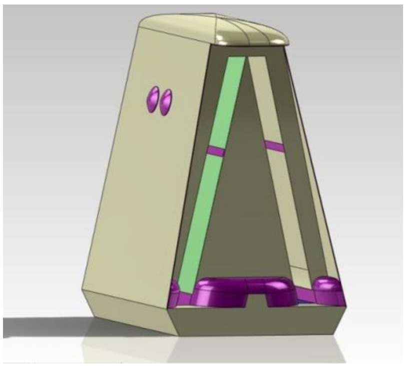


Figure 6.13. Concept automatic version

- Automatic version

Front doors open inwards and back doors outwards. There is a support for the shaker screens in the front of the doors. The shaker screens are moving on rolls in the machine. The operator pushes two buttons at the same time to activate the machine, which close the doors and start the cleaning cycle pneumatically.

6.3 Conclusion of the concepts

A summary of a group of engineers' opinions were made of the three concepts, (*Figure 6.11-Figure 6.13*), which are explained in chapter 6.2.3 (page 28). A pneumatic version was considered not to be reliable enough, which meant that the affected components were to be powered by electricity instead. Electricity is reliable, easy to control and can easily be modified afterwards. When continuing the development of the final concept the robustness was highly prioritized, due to the humid and dirty environment. (Pedersen, 2013) (Vik, 2013) (Halvorsen, 2013) (Skjønneberg, 2013) (Dilkestad, 2013)

7 DEVELOPMENT OF THE FINAL CONCEPT

In this chapter the final concept was developed further during two separate reconstruction phases using both FMEA and reviewing the concept by experienced personel on the company.

7.1 Detail design of the first draft

When working with the design, minimizing the “dead space” were kept in the mind to reduce the size of the machine and that it should also be easy to maintain. The decisions made referred to the gathered information. Every sub problem was reviewed carefully, and the best solutions were chosen. A compilation of the essential features in the final concept was made (APPENDIX 1). From this compilation the concept was rebuilt and presented to a reference group at the company (*Figure 7.1*). (Holshagen, 2013) (Pedersen, 2013) (Skjønneberg, 2013) (Onsøyen, 2013)

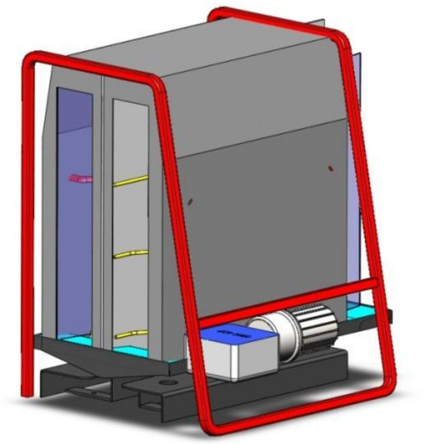


Figure 7.1. The first draft of the final concept

7.2 FMEA

A risk analysis, as described in chapter 2.1.4 was made in order to make sure that the machine does not expose humans to any serious risk, see APPENDIX 2. This led to a number of changes that were implemented into model. The most important was to include a safety stop on the machine and to create inspection windows. This way the operator or service technician does not have to get in to the machine to see that everything is in order.

7.3 Reconstruction #1

After the presentation, the feedback was reviewed and led to the following changes:

- The model should be moveable with crane so eyebolt have been mounted
- A new support inside of the machine that helps the shaker screen to slide out easily
- The doors have pneumatic motors
- The motors have been placed outside the machine
- Rolls help the shaker screen to be correctly positioned
- The back doors open inwards - Longer machine
- The doors are made higher, making it easier to insert the shaker screens
- New type of doors, with broken edges, which will help the sealing
- Transparent windows, to see what is happening inside of the machine
- The pallet dimensions have been adjusted to fit EUR pallets

The result after updating the model can be viewed in *Figure 7.2*.

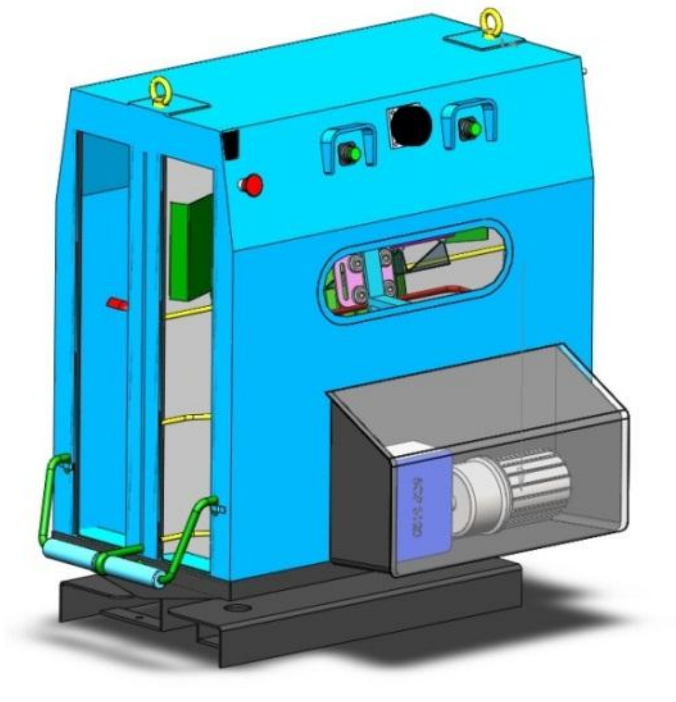


Figure 7.2. Revised draft of the final concept.

This concept was again reviewed on the company and further research in how to produce the model was requested. (Dilkestad, 2013) (Onsøyen, 2013) (Ellingsen, 2013) (Skjønneberg, 2013).

7.4 Reconstruction #2

With the focus on manufacturing the model was reviewed by Sven Ekered. The feedback concerned:

- Supportive frame to secure the lift eye bolts and reduce the complexity of the housing
- Reduce the complexity of the nozzle bar movement. See parallel moving rulers on drawing boards.
- Allow easier inspection and maintenance

After reviewing the feedback and making changes the concept was considered to be finished for presentation.

8 RESULT

The product concept is a machine for cleaning shaker screens in an efficient way. The operator inserts two shaker screens into the machine and then activates the machine by simultaneously pressing two start buttons on the side. The machine then closes the doors and cleans the shaker screens and the machine itself in approximately 30 seconds. The operator can in the meantime go and get the next two shaker screens in need of cleaning while the machine is running. When the machine is ready, the doors will open and allow the operator to extract the shaker screens.

See *Figure 8.1-Figure 8.4* for a product overview.

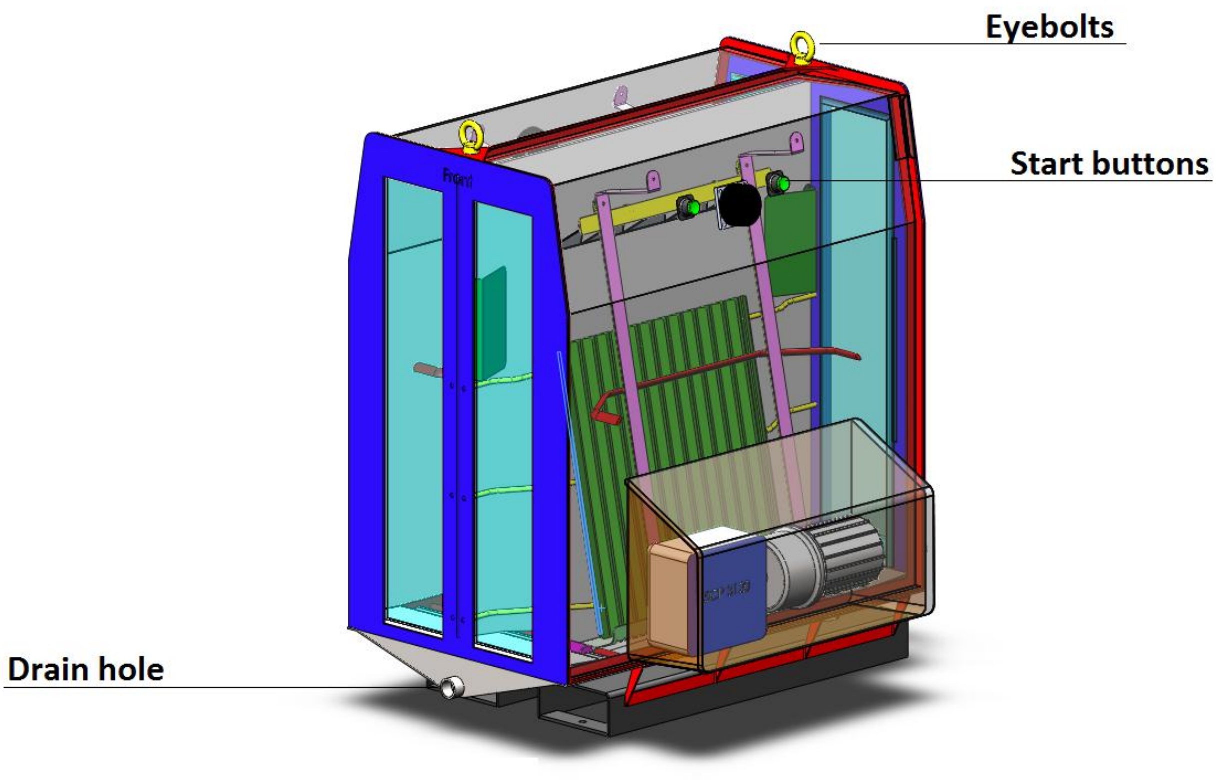


Figure 8.1. A perspective view of the final concept.

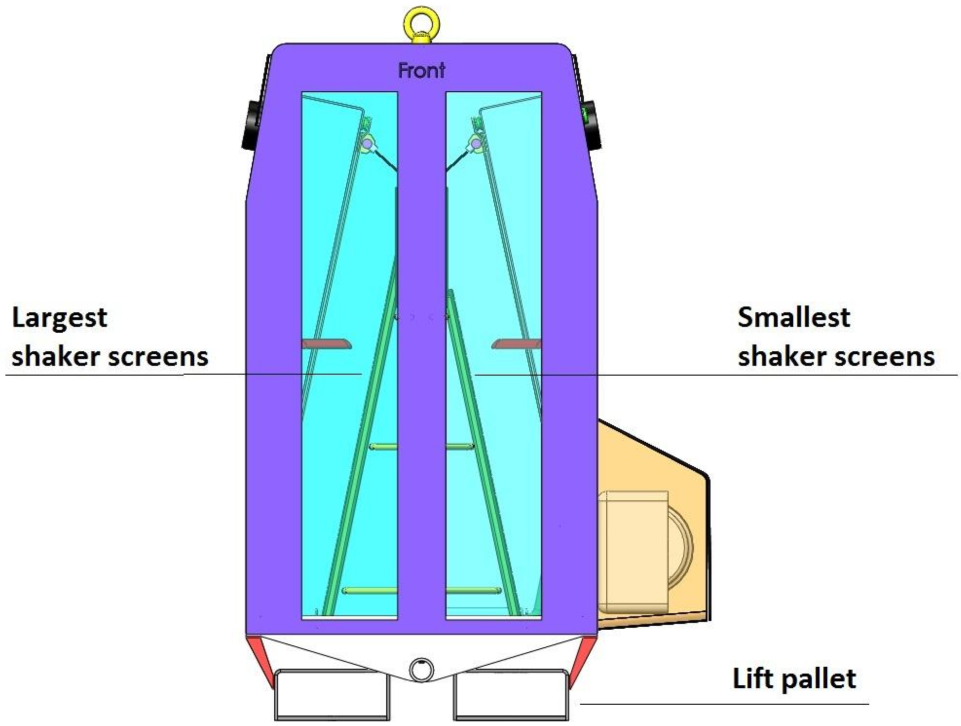


Figure 8.2. Front view of the final concept.

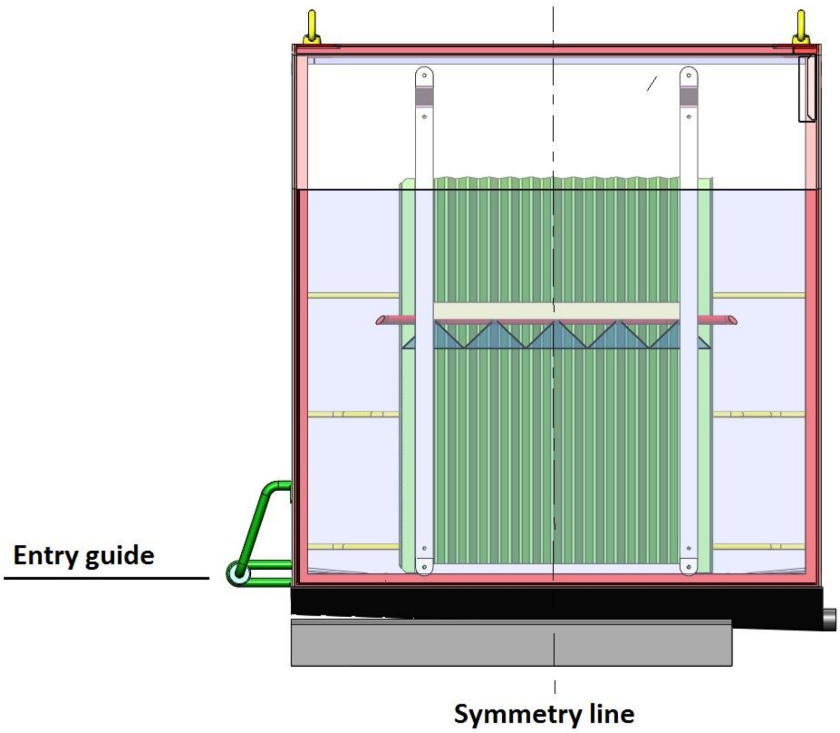


Figure 8.3 Side view of the final concept.

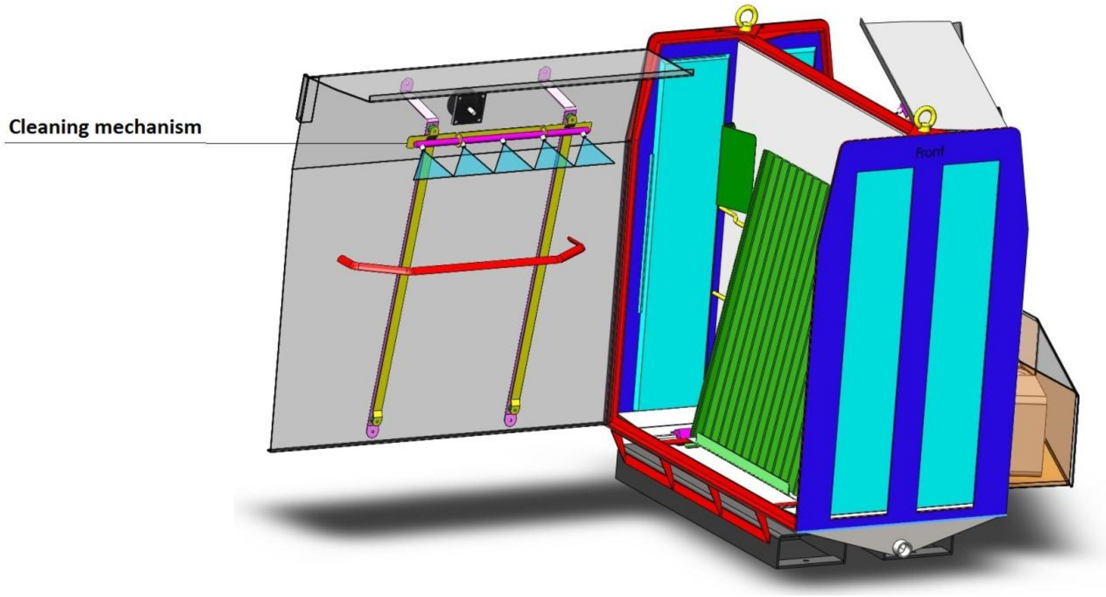


Figure 8.4. The cleaning mechanism and the inside of the machine is easily accessed by opening the hinged sides. This also simplifies the assembly of the machine.

8.1 Detail specification

1. The shaker screens are cleaned using water that is pressurized and sprayed onto the shaker screen in a thin stream. The water ejects from five high pressure nozzles that is mounted on a bar that divides the pressure equally between the nozzles.
2. The bar is mounted on a carriage that makes a translational movement starting at the top of the shaker screen.
3. This movement is controlled by an electric motor.
4. There are two sets of moving nozzle mechanisms. One for each shaker screen.
5. The shaker screens rest in a tilted position and do not need any additional fastening inside of the machine.
6. Two doors on each side prevent water, particles and moist from exiting the machine. These doors open inwards to minimize spill outside the machine.
7. The inside is symmetric. This way the machine could be placed next to a wall or in a narrow space allowing the shaker screens to be inserted from the same side.

8. The entry guide consisting on stainless steel rolls can be moved from one side to the other depending on how the machine is oriented.
9. If there is a lot of available space around the machine, it can be adjusted to receive shaker screens from one direction and eject them on the opposite side. The shaker screens are ejected when the operator pushes them through the machine using the next set of shaker screens in need of cleaning.
10. The machine is built on an outer frame that supports the sides and makes it rigid enough to be lifted in the lift eye bolts.
11. The sides can be folded outwards around a vertical hinge for maintenance or inspection. The sides also hold the mechanism for the nozzle movement allowing easy maintenance.
12. The Delta Cleaner's body is made from high grade stainless steel sheets to withstand the corrosive environment in which it will be placed. The two rectangular tubes at the bottom allow it to be moved with a fork lift truck or a EUR-pallet lifter.
13. The lifting eye bolts are certified so that the machine could be lifted over sea in an offshore environment.

If the power to the machine should fail all pressurized water will eject and there is no place high pressurized fluid or air could be accumulated.

9 CONCLUSION

From the continuous dialogue, with the shale shaker operators and engineers, feedback was constantly received during the development process. This resulted in a realistic product concept that is effective and easy to use. The increased efficiency comes from the angled high pressure nozzles removing the dirt in an efficient way and in the same time reducing the airborne moist and the water consumption. The product also allows a continuous flow through the machine instead of being a dead end.

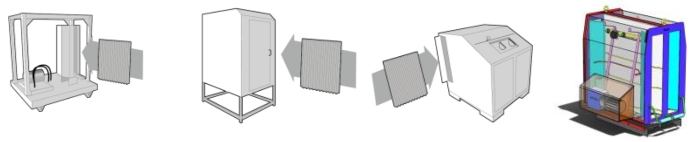
Since the machine has doors in both ends, the shaker screens can be inserted in either end and therefore the machine can be placed in any direction relative to a wall. The rolls in the front of the machine can easily be moved to the other side.

It will also improve the operators working conditions by protecting them from harmful gases and the risks associated with the use of a manual pressure washer.

The product concept has also been developed with the company’s role as both vendor and lessor in mind. This can be seen in the ease of maintenance and inspection.

The final product concept is compared to the existing competitors in *Table 9.1*.

Table 9.1. Comparing the final product concept with the existing products.



	FSI	Rigtools	RNG	New
Time consumption per shaker screen	10-25s	60/30s	60s	**15 s**
Operator needed in cleaning process?	Yes	No	Yes	**No**
Water consumption per shaker screen	3-15 l	15 l	15 l	**4 l**
Allowing ergonomic working conditions	Partly	No (high lifting)	No (low insertion)	**Yes**
Minimize manual handling of screens	No	No	No	**Yes**
Simplified service and maintenance	Yes	-	Yes	Yes

9.1 Ergonomy

How users actually clean shaker screens has been a focus throughout the project. The goal has been to allow operators to have the shaker screens cleaned as convenient as possible. Since the operator can insert the screens into the machine from the position he or she carries them, no extra manipulation of the shaker screens are needed. Keeping the lifting height to only 200 mm (*Figure 9.1*) the risk of injury caused by repetitive lifting and insertion is low. No other product on the market comes close to this.

According to Swedish Work Environment Authority's the risk of carrying and inserting shaker screens into the machine is low. APPENDIX 4 (written in Swedish).

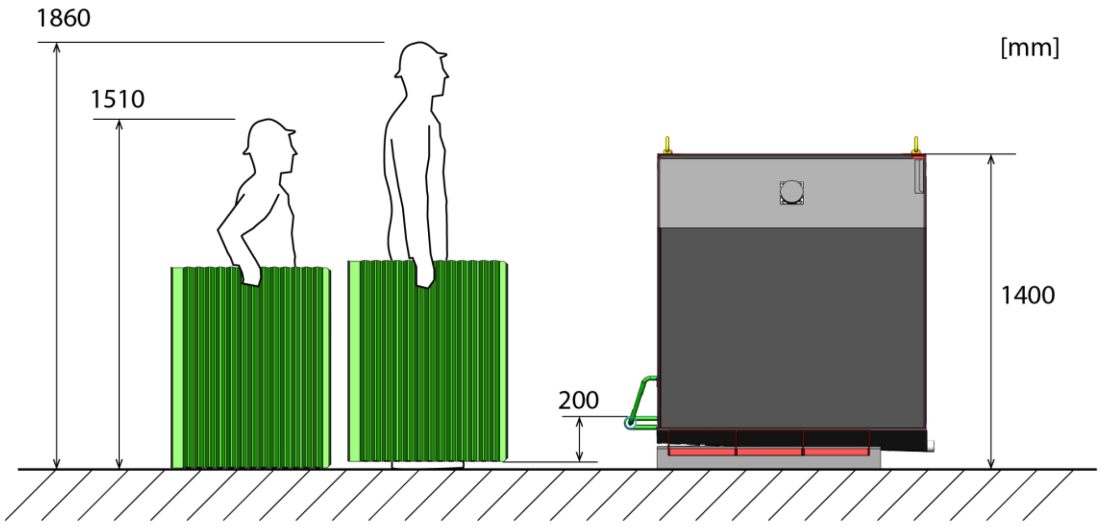


Figure 9.1. Side view of the tallest and shortest operator that should be able to operate the machine according to the company's requirements. The screens shown are the largest that the machine will clean.

9.2 Reflection

The project has generally followed the initial plan. People at the company have been very helpful and encouraging and there seem to be an actual need for the product. Certainly it has been some difficulties as listed.

- Finding people outside of the company to provide feedback and thoughts has been hard. Many of the questionnaires and issues sent out have not been answered.
- A more detailed plan, day-by-day, would probably increase the efficiency since a lot of time were spent on planning what to do next.
- It has been hard to present the concepts in an equivalent way, without revealing your own opinion.

The product concept has by the company and mentor been considered to be realistic. The product functionality very much relies on finding a robust solution for the automated movements. This development needs external competence and several working hours before a prototype can be made.

The concept is still only a theoretical concept that needs to be tested in a full scale field study.

Recommended continuation of the project before making a prototype the major challenges that remains are:

- Designing the system for controlling doors, pumps and movement
- Simplifying the overall design including finding more standard components
- Reduce the number of surfaces where dirt can be accumulated
- See that the stability is not affected when the sides are opened

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All images and illustrations in this document are produced by Anton Östebo and Frans Isaksson.

APPENDIX 1 - COMPILATION OF THE FINAL CONCEPT

HOUSING

OUTSIDE

- The design is a box-like with flat sides
- Frame that supports the rest of the components
- Eyebolts on the top – for lifting/transportation
- Possibility to lift by a pallet truck

INSIDE

- Minimizing of “dead space”.
- Shaker screens position: Two shaker screens at the time – leaning vertically, 12°– dirty side out
- Supports that leads the shaker screens to a leaning position
- A separation wall – that prevents water and dirt from getting from one screen to the other.
- As rounded edges as possible on the inside – considering water flow
- Machine floor is leaning, for a better water flow towards the drain system
- A support for shaker screens to stand on
- A support for shaker screens to lean on
- Safety support – that prevents the shaker screens from leaning to the other side and cause damage to the cleaning system
- Doors should be wide enough so that maintaining the machine could be done through these

CLEANING SYSTEM

- Water based
- Flushes away dirt
- Possibility to switch over to base oil
- Water get pressurized by an air or electric driven compressor
- The fluid is led to the high pressure nozzles from the compressor
- The high pressure nozzles moves downwards and are angled downwards
- The pressure nozzles are connected to a platform with wheels and slides along a guiding rail
- The rail is mounted on a support that fix the rail in three dimensions
- A chain transfers movement and power to the platform causing it to move
- The platform moves from the top to the bottom of the rail in 15 seconds
- There are two platforms, one at each side of the machine and they are moving and spraying fluid one at the time to maintain the high fluid pressure
- The chain is connected to an electric engine

DOORS

- Front and back doors open inwards approximately 80° towards the machine’s outer walls, guiding the shaker screens to the correct position in the machine.
- Minimize water spill
- Both pair of doors can be locked in the closed position if the machine stands next to for example a wall
- By pressing the two buttons on the side simultaneously the doors will close and the cleaning cycle begins. These are electronically wired to a main circuit.
- Doors open automatically when the cleaning cycle is finished

ENGINE COMPARTMENTS

- The engines opening the doors will be places outside of the housing to allow easy maintenance and to protect the motors from the water and moist on the inside
- The engine that makes the platform with the pressure nozzles move is also places outside of the housing
- Some sort of service hatch that give access to the engine room is required

SCAFFOLDINGS

- On the edges of the machine
- On the backside

DRAINAGE SYSTEM

- The drainage system connects to a hole in the machine floor
- There could be a need for a drainage pump to facilitate the flow of the water but this is outside the project range

SWITCHES

- Two switches on the side of the machine need to be pressed simultaneously to start the machine
- Safety stop that has to be reachable from both sides of the machine

APPENDIX 2 – FAILURE MODE AND EFFECTS ANALYSIS

Product	TA02	Revision	01
Model	Shaker screen cleaning system	Participants	KPS, PED
Document No.	1	Date Completed	2013-03-28

IDENTIFICATION ACCODING TO EN ISO 12100:2010 — QUANTIFICATION

No.	Lifecycle step	Task	Hazard group	Origin	Hazardous event	otential consequence	Seriousness of injury K		Frequency of hazardous f		Probability of hazardous s		Possibility to avoid injury m	
10	Transport	Unloading	Mechanical	Gravity	Can cause damage to person, by falling.	Crushing	Death, loosing an eye or arm	4	Never/almost never less 1 year	1	Very small	1	Possible	3
20	Transport	Lifting	Mechanical	Gravity	Use of under rated lifting equipment can lead to an uncontroleed fall of the machine.	Crushing	Death, loosing an eye or arm	4	Never/almost never less 1 year	1	Very small	1	Possible	3
20	Transport	Lifting	Mechanical	Stability	The machine can be rotate uncontrollably when being lifted from the transport vehicle. Incompetent personnel can present a risk during lifting operations.	Crushing	Death, loosing an eye or arm	4	Never/almost never less 1 year	1	Possible	3	Possible	3
30	Transport	Lifting	Mechanical	Cutting parts	Sharp edges after production can present a cutting hazard.	Cutting or severing	Permanant, loose finger etc.	3	Never/almost never less 1 year	1	Very small	1	Possible	3
150	Assembly_installation	Assembly of machine	Electrical	Parts live under fault conditions	Misconnection may arise during electrical installation is required.	Electrocution	Death, loosing an eye or arm	4	Never/almost never less 1 year	1	Very small	1	Very likely	1
160	Commissioning_setting	Adjustment, setting and verification of paramenter	Electrical	Parts live under fault conditions	Misconnection may arise during electrical settings.	Electrocution	Death, loosing an eye or arm	4	Never/almost never less 1 year	1	Very small	1	Very likely	1
200	Operation_training	Feeding/filling raw material	Mechanical	High pressure	When the screens are inserted or removed from the machine, the pressurized fluid could be released.	Injection	Permanant, loose finger etc.	3	Seldom >6month >=1 year	1	Possible	3	Very likely	1
210	Operation_training	Operating the machine	Mechanical	High pressure	If the doors should open when the cleaning cycle is running pressurized fluid and mud particles could be released to the surroundings.	Injection	Permanant, loose finger etc.	3	Seldom >6month >=1 year	1	Possible	3	Very likely	1
230	Operation_training	Inspection	Material	Mist	Drilling fluid and cleaning fluid mist can be released into the surrounding environment when opening the machine.	Breathing difficulties, suffocation	Reversible, first aid	1	Regularly >1hr >=2 wks	1	Possible	3	Very likely	1

Probability of harm	Probability category.	Risk profile	Acceptable risk level?	Risk reduction	Risk reduction classification	Seriousness of injury		Frequency of hazardous		Probability of hazardous		Possibility to avoid injury		Probability of harm	Probability category.	Risk profile	Acceptable risk level?	Implemented	
N=f+s+m	N1; (A-E)	P	P<=3			K		f		s		m		N=f+s+m	N1; (A-E)	P	P<=3	Sign	Date
5	D	5	Reavaluate	Ensure that the unloading area is level with ample space for optimal lifting by crane/s.	Assembly check	Reversible, first aid	1	Never/almost never less 1 year	1	Very small	1	Very likely	1	3	E	1	Yes		
5	D	5	Reavaluate	Total weight of the machine has to be shown on the data plate. Weight is to be verified via the use of the weight certificated. Ensure that trained operators conduct the lifting and are aware of the risks present. Lifting points are to be marked with lifting procedure outlined in the user manual.	Combination	Reversible, first aid	1	Never/almost never less 1 year	1	Very small	1	Very likely	1	3	E	1	Yes		
7	C	6	No	Ensure that the personnel are properly trained in lifting equipment and have read an understood the lifting procedure. Ensure that the lifting equipment is of sufficient capacity and certified. Ensure that the machine is lifted on level stable ground. Do not work under a hanging load as an extra precaution. Ensure the area of the lift is secured to prevent unauthorised personnel entering during the lift. Include this is the user manual. Use of suitable Personal Protection Equipment is required that includes gloves, hard capped boots.	Documentation	Reversible, first aid	1	Never/almost never less 1 year	1	Unlikely	2	Very likely	1	4	E	1	Yes		
5	D	4	Reavaluate	Ensure that sharp edges are removed and corners are rounded. Include in the detail drawings and add as a check item on the assembly checklist.	Assembly check	Reversible, first aid	1	Never/almost never less 1 year	1	Unlikely	2	Very likely	1	4	E	1	Yes		
3	E	4	Reavaluate	Ability for switching off during normal operation and/or in an emergency. Measure the voltage to confirm that the electrical supply is isolated before commencing. Include this in the manual.	Documentation	Reversible, first aid	1	Never/almost never less 1 year	1	Very small	1	Very likely	1	3	E	1	Yes		
3	E	4	Reavaluate	Ability for switching off during normal operation and/or in an emergency Measure the voltage to confirm that the electrical supply is isolated before commencing. Include this in the manual.	Documentation	Reversible, first aid	1	Never/almost never less 1 year	1	Very small	1	Very likely	1	3	E	1	Yes		
5	D	4	Reavaluate	Make sure that the cleaning cycle could not be initiated when the doors are opened or not sufficiently closed. (When installing or maintaining the machine, this function could be override.)	Mechanical	Reversible, first aid	1	Seldom >6month h >=1 year	1	Possible	3	Very likely	1	5	D	2	Yes		
5	D	4	Reavaluate	Make sure that the doors remain tightly closed when the cleaning cycle is running. (When installing or maintaining the machine, this function could be override.)	Mechanical	Reversible, first aid	1	Seldom >6month h >=1 year	1	Unlikely	2	Very likely	1	4	E	1	Yes		
5	D	2	Yes		Mechanical	Reversible, first aid	1	Regularly >1hr >=2 wks	1	Very small	1	Very likely	1	3	E	1	Yes		

No.	Lifecycle step	Task	Hazard group	Origin	Hazardous event	otential consequence	Seriousness of injury		Frequency of hazardous		Probability of hazardous		Possibility to avoid injury	
							K		f		s		m	
240	Operation_training	Inspection	Mechanical	Height from ground	By the oil or the water mist the floor can became slippery	Slipping, tripping and falling	Reversible, medical attention	2	Regularly >1hr >=2 wks	4	Possible	3	Possible	3
250	Maintenance_troubleshooting	Inspection	Mechanical	High pressure	Opening something in the pressurized fluid or air area can release pressurized fluid or air.	Injection	Permanant, loose finger etc.	3	Seldom >6month >=1 year	1	Very small	1	Very likely	1
260	Maintenance_troubleshooting	Inspection	Electrical	Live parts	The motors elecical connections are inspected to check for tightness. The junction box must be opened exposing potentially live parts.	Electrocution	Death, loosing an eye or arm	4	Seldom >6month >=1 year	1	Very small	1	Very likely	1
271	Maintenance_troubleshooting	Reparing	Mechanical	High pressure	Opening something in the pressurized fluid or air area can release pressurized fluid.	Injection	Permanant, loose finger etc.	3	Seldom >6month >=1 year	1	Possible	3	Very likely	1
280	Maintenance_troubleshooting	Reparing	Electrical	Live parts	Inspection, repair and replacementment of components of the electric motors can give risk of electrical hazards.	Electrocution	Death, loosing an eye or arm	4	Seldom >6month >=1 year	1	Possible	3	Very likely	1
300	Decommissioning_dismantling	Isolation and energy dissipation	Electrical	Live parts	Inspection, repair and replacementment of components of the electric motors can give risk of electrical hazards.	Electrocution	Death, loosing an eye or arm	4	Never/almost never less 1 year	1	Possible	3	Very likely	1
310	Decommissioning_dismantling	Dismantling	Material	Fluid	Prior to decommisioning the screen washer can be covered with remains of drilling fluids.	Sensitization	Reversible, medical attention	2	Seldom >6month >=1 year	1	Very probable	5	Small	4

Probability of harm	Probability category.	Risk profile	Acceptable risk level?	Risk reduction	Risk reduction classification	Seriousness of injury		Frequency of hazardous		Probability of hazardous		Possibility to avoid injury		Probability of harm	Probability category.	Risk profile	Acceptable risk level?	Implemented	
N=f+s+m	N1; (A-E)	P	P<=3			K		f		s		m		N=f+s+m	N1; (A-E)	P	P<=3	Sign	Date
10	B	5	Reavaluate	Doors open inwards, the mist from the doors will drop on the inside. Minimize space inside the machine. Minimize amount of fluid usage. Fluid flow is aimed downwards towards the drainsystem.	Combination	Reversible, medical attention	2	Seldom >6month >=1 year	2	Very small	1	Likely	2	5	D	3	Yes		
3	E	3	Yes	Allow visual inspection through windows so that the personal does not need to get into the machine. Include in the manual.	Documentation	Reversible, first aid	1	Seldom >6month >=1 year	1	Unlikely	2	Very likely	1	4	E	1	Yes		
3	E	4	Reavaluate	Ensure that the motors are electrically isolated before commencing inspection. Hang a suitable notice on the starting device stating the following; MACHINE UNDER REPAIR, DO NOT START. Ensure that competant personel conducts inspection. Include in the manual.	Documentation	Reversible, first aid	1	Sometimes >2wks >=6 month	1	Unlikely	2	Very likely	1	4	E	1	Yes		
5	D	4	Reavaluate	Make sure that all pressure can be released manually without risking personal safety. Ensure that pressure in the fluid and/or air system is released before repairing anything. Include in the manual.	Mechanical	Reversible, first aid	1	Seldom >6month >=1 year	1	Unlikely	2	Very likely	1	4	E	1	Yes		
5	D	5	Reavaluate	All inspection, repair and replacement of components of the electric motor to be carried out by skilled specialists for motor supplier. Refer to the motor manufactureres manual for all relevent infomation. Include in the manual.	Documentation	Reversible, first aid	1	Seldom >6month >=1 year	1	Unlikely	2	Very likely	1	4	E	1	Yes		
5	D	5	Reavaluate	Ensure that the motors are electrically isolated before commencing inspection. Hang a suitable notice on the starting device stating the following; MACHINE UNDER REPAIR, DO NOT START. Ensure that competant personel conducts inspection. Have a main power switch before the machine that cuts all power. Include in the manual.	Mechanical	Reversible, first aid	1	Seldom >6month >=1 year	1	Unlikely	2	Very likely	1	4	E	1	Yes		
10	B	5	Reavaluate	Machine decomissioning must always begin by running a cleaning cycle without any screen in the machine to clean the insides. Make sure that hazardous substances are disposed of safely and that the correct personal protective equipment is used. The safety specifications must be in accordance with the current regulations at all times.	Documentation	Reversible, first aid	1	Seldom >6month >=1 year	1	Unlikely	2	Very likely	1	4	E	1	Yes		

APPENDIX 3 - FACTORIAL EXPERIMENT

A. Preface

When conducting a test the most important question to answer is: what will we measure and why? This test aimed at investigating how a fast flowing stream of water or air should be oriented relative to a shaker screen and a horizontal ground plane.

Water and air are commonly available on oil rigs and the test was therefore limited to these two fluids. The fluids were pressurized and applied to the contaminated shaker screens in a stream.

The equipment consisted of one Kärcher K 3.150 pressure washer, a consumer product delivering a maximum water pressure of 120 bar at a flow rate of 6 l/min. A “turbo” nozzle was used claiming to increase the maximum pressure by 50%. This nozzle delivered one thin stream of water circulating fast and creating a thin cone of water that was applied to the area in need of cleaning.
A compressor delivering a maximum pressure of 8 bar was used when studying air. A blow gun was connected through a hose to the compressor. This compressor had a rather small tank to contain the built up pressure leading to a quick pressure drop after air was released through the blow gun.

The shaker screen used was a commonly used model from Derrick called DX-A100 where the mesh hole size is 175 micrometers. This shaker screen pyramid shaped grooves stretch from side to side. See *Figure A 10.1* and *Figure A10.2*.

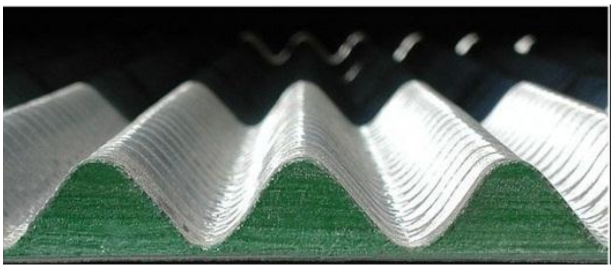


Figure A 10.1. Pyramid shaped screen.

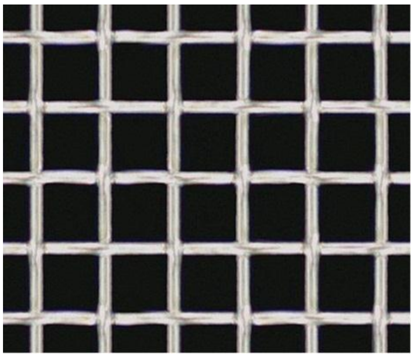


Figure A10.2. Enlarged view of the screen mesh.

To simulate a shaker screen in need of cleaning, clay for flower mud was mixed with sand and water. The clay mixture was applied to the shaker screens by hand. See figure *Figure A10.3*.

Figure A10.3. The clay added to a shaker screen to simulate a screen contaminated by mud and cuttings.

B. Screening experiment

The test was initiated by rigging the equipment and investigating how to perform the test practically. The test was a factorial experiment where a number of factors are chosen and varied through a specific number of trials. To determine what factors that have a large impact on the cleaning result, a “screening” was done. This is a quick version of a factorial experiment where more factors are tested. No conclusion regarding how these factors affect each other can be made, but the factors that are important to the result can easily be distinguished.

The shaker screens were first polluted with the mud mixture and then cleaned with a combination of following factors:

A. Air or water
B. The angle of the nozzle. Either parallel to the ground, normal to the shaker screen or with a 45° degree angle relative to the ground
C. Back or front of shaker screen
D. The orientation of the pyramid shaped grooves, either vertical or horizontal
E. The tilting of the shaker screen relative to vertical plane. Either parallel to the vertical plane or angled 45° relative to the vertical plane.
F. The angle of the nozzle. Either normal to the shaker screen or 45° angled in the horizontal plane

Then the time it took to get half of the screen clean was timed and documented.

C. Conclusion of screening experiment

The following conclusion was made.

- The air pressure from the compressor dropped quickly as soon as a couple of seconds after initiation. Apart from this, the air source had to be very close to the polluted area to have any cleaning affect. Also, the air almost “peeled” the dirt off the surface and pushed it aside instead of removing it. With a greater constant pressure and several nozzles, air might have cleaned the shaker screens faster and with a better result. Even though, it was decided that air should not be the primary cleaning liquid.
- The cleaning fluid should be applied from the front. If applied from the back, the areas of supporting frame gave a too large “shadow” under which the fluid caused little or no cleaning effect.

When the important factors (BDEF) had been isolated a reduced factorial experiment was conducted. By “reducing” the experiment half of the experiments are erased and by ignoring the interaction between all of the four factors at the same time. By doing so, time is saved and still with a good result.

D. Full factorial experiment

The experiment was conducted in the same way as before and the results were noted. Unfortunately the mathematical analysis of the experiment showed that no certain conclusion can be made from the experiment. The effects shown were too close to each other to be significant. This was probably a result of a several factors where difficulty in maintaining the given angles and positions and different levels of dirtiness and cleanliness were among the most important. Measuring the time when the shaker screen was clean enough was also subjective and was made by Anton who held the pressure washer.

Despite this, some interesting observations were made:

- When water has been applied from the front to clean the shaker screen, the back of the shaker screen collects some of the dirt. When the front appears to be clean, the back needs to be cleaned as well.
- As the figures below shows shadows appears if the nozzle is angled as in *Figure A10.4*. This leaves the shades areas unaffected by the water and it also creates more reflecting water and dirt particles back towards the nozzle.
- It was also observed that when aiming the nozzle normal to the shaker screen, as *Figure A10.6*, there was more reflecting water and dirt. If the nozzle was held at an angle relative to the shaker screen, spraying it along the pyramids, the reflecting water and dirt seemed to move more controlled in the same direction as you would expect from light hitting a surface at the same angle. See *Figure A10.5*.
- By the nozzle spray the shaker screen from an angle along the pyramids, the dirt also seemed to fall off more easily than when sprayed normal to the shaker screen.

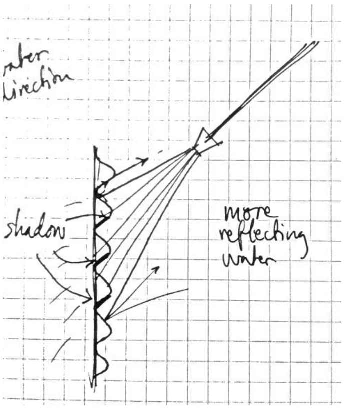


Figure A10.4. Sketch of how the angle of the water affects a shaker screen with horizontally oriented pyramids

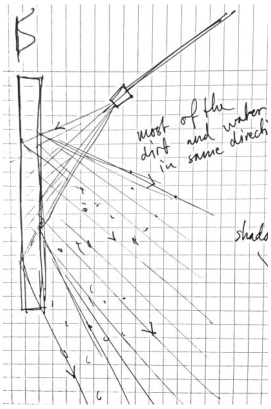


Figure A10.5. Sketch of how the angle of the water affects a shaker screen with vertically oriented pyramids

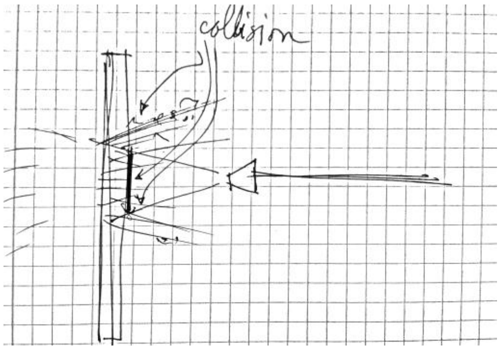


Figure A10.6. Sketch of how water affects a shaker screen when sprayed perpendicular towards the shaker screen.

The factors, which is named above, where only a few of many factors that is able to affect the cleaning. Test experiments could continue for a much longer time, but is limited. A new test will probably be made later during the concept phase of the project.

Two different types of nozzles that where tested, as shown in *Figure A10.7* and *Figure A10.8*.

Figure A10.7. Pressurized water from the pressure washer's original spray gun penetrates and reflects when hitting the shaker screen mesh.

Figure A10.8. A rotating pressure nozzle unit was also tested.

This original spray gun did not remove the clay as good as the turbo nozzle.

This double rotating nozzle did remove clay from a large area, but did not remove all the clay. The clean effectiveness did also decrease very fast while the distance increased.

These two types where not included during the factorial experiment.

APPENDIX 4 – ERGONOMIC LIFTING SHAKER SCREEN

Bedömning av manuell hantering med stöd av nyckelindikatorer

Version 2008

Om det finns ett antal individuella aktiviteter som innebär stor fysisk ansträngning måste de bedömas separat.

Arbetsmoment / aktivitet: Bära och sätta in shaker screens i screen cleaner

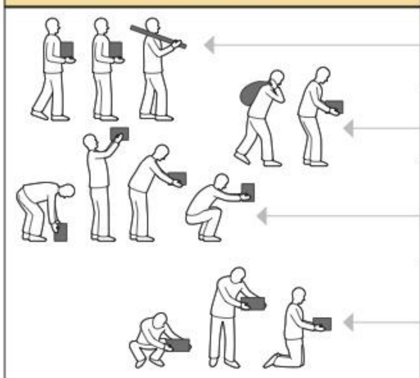
Datum för bedömning: 2013-03-28 Bedömd av: Frans Isaksson, Anton Östebo

Steg 1: Bestämning av tidspoäng (Välj endast en kolumn!)

Att lyfta eller flytta laster (< 5 s)		**Hålla** (> 5 s)		**Bära** (> 5 m)	
Antal gånger per arbetsdag	*Tidspoäng*	*Totalt tid under arbetsdagen*	*Tidspoäng*	*Totalt avstånd under arbetsdagen*	*Tidspoäng*
< 10	1	< 5 min	1	< 300 m	1
10 till < 40	2	5 till 15 min	2	300 m till < 1km	2
40 till < 200	4	15 min till < 1 h	4	1 km till < 4 km	4
200 till < 500	6	1 h till < 2 h	6	4 till < 8 km	6
500 till < 1000	8	2 h till < 4 h	8	8 till < 16 km	8
≥ 1000	10	≥ 4 h	10	≥ 16 km	10
Exempel: • mura, • placering av arbetsstycken i en maskin, • ta lådor ur en container och placera dem på ett transportband		**Exempel:** • hålla och styra ett stycke gjutjärn vid arbete med en slipmaskin, • användning av en handslipmaskin, • användning av en ogräsrensare		**Exempel:** • bärande av möbler, • leverans av byggnadsställnings-komponenter till en bygg-arbetsplats	

Steg 2: Bestämning av bedömnings-poäng för belastning, arbetsställning och arbets-förhållanden

Lastens vikt	**Lastpoäng**
< 5 kg	1
5 till < 10 kg	2
10 till < 15 kg	4
15 till < 25 kg	7
≥ 25 kg	25

Vanlig arbetsställning, lastens position	**Arbetsställning, lastens position**	**Bedömningspoäng arbetsställning**
	• Upprätt överkropp, ej vriden • När lasten lyfts, hålls, bärs och sänks är den nära kroppen	1
	• Lätt framåtböjd eller vriden överkropp • När lasten lyfts, hålls, bärs och sänks är den nära kroppens mitt	2
	• Låg böjd kroppsställning eller långt framåtböjd • Lätt framåtböjd samtidigt som överkroppen är vriden • Lasten är långt från kroppen eller över axelhöjd	4
	• Långt framåtböjd samtidigt som överkroppen är vriden • Lasten är långt från kroppen • Begränsad stabilitet när arbetaren står upprätt • Hukande eller på knä	8

För att bestämma bedömningspoängen för arbetsställningen ska den arbetsställning som är vanligast användas. Om arbetaren intar olika arbetsställningar med lasten måste en sammanvägning göras, använd inte tillfälliga extrema värden.

Arbetsförhållanden	Bedömningspoäng arbetsförhållanden
Goda ergonomiska förhållanden, d.v.s. gott om utrymme, inga fysiska hinder i arbetsområdet, jämnt och fast underlag, tillräcklig belysning, låg halkrisk	0
Utrymmet för rörelser är begränsat och ogynnsamma ergonomiska förhållanden förekommer (t.ex. 1: utrymmet begränsat på grund av för låg takhöjd eller ett arbetsutrymme som är mindre än 1,5 m^2, eller 2: arbetsställningen är instabil på grund av ojämnt golv eller mjukt underlag)	1
Mycket begränsat rörelseutrymme och/eller instabil tyngdpunkt hos lasten (t.ex. flytt av patienter)	2

Steg 3: Utvärdering – Fyll i poängen och beräkna

	Lastpoäng: 4					
+	Bedömningspoäng arbetsställning: 1					
+	Bedömningspoäng arbetsförhållanden: 0					
=	Totalt: 5	x	Tidspoäng: 2	=	Riskpoäng: 10	

Med stöd av beräknad poäng och tabellen nedan är det möjligt att göra en grov bedömning. Allt eftersom antalet bedömningspoäng stiger, så ökar även risken för överbelastning av muskler och benstomme. Gränserna mellan riskområdena är flytande på grund av individuell arbetsteknik och prestationsförmåga

Riskområde	Riskpoäng	Beskrivning
1	< 10	Låg belastningssituation, fysisk överbelastning är osannolik.
2	10 till < 25	Ökad belastningssituation, fysisk överbelastning är möjlig för personer med lägre fysisk kapacitet. För denna grupp är det fördelaktigt att ändra arbetsplatsens utformning.
3	25 till < 50	Kraftigt ökad belastningssituation, fysisk överbelastning möjlig. En ny utformning av arbetsplatsen rekommenderas.
4	≥ 50	Hög belastningssituation, fysisk överbelastning är sannolik. Arbetsplatsens utformning måste ändras.

Kontroll av arbetsplatsen är nödvändig av andra skäl:

Orsaker: Utanför projektets ramar.

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APPENDIX 5 - ADDITIONAL REQUIREMENTS FOR SHAKER SCREEN CLEANING SYSTEM

MF - main function
NF - necessary function
DF - desirable function

	Function	Comments
MF	Clean shaker screens	
NF	Should be easy to use	
NF	Allow ergonomic working conditions	no awkward lifting heights or positions or other potentially harmful procedures.
NF	Clean most screen sizes	from the most commonly available shale shakers. Dimensions from 710x625 to 910x711mm. Both flat and pyramid shaped mesh.
NF	Use available resources	on board drilling platforms: water, electricity, air (6-10 Bar), base-oil
NF	Must be more convenient	than cleaning the screens using a manual pressure washer
NF	Should fit inside a volume	with the dimensions (LxWxH) 1200x1000x1500mm
NF	Be a separate unit	from the shale shaker
NF	Minimize airborne dirt	
DF	Minimize waste	resulting in less waste handling and a cheaper running cost
NF	Allow multiple screens	to be cleaned at the same time or after one another without additional interaction from the operator. At least two screens at the time.
NF	Maintain constant cleaning	The cleaning process should give the same result every time
DF	Minimize start up time	to make the SSCS easy to move and initiate cleaning process
NF	Minimize maintenance	The machine should have a low complexity level, few moving parts and a robust design.
DF	Operation speed	The time too clean should not exceed 30 seconds/screen.
DF	Minimize noise	
NF	Mobility	The machine should be movable with a pallet truck or fork lift. Should also be possible to move with a traverse or crane.