Development of New Lifting Equipment for VPA plates

Bolormaa Batchuluun
Abstract

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This thesis explores how to develop new lifting equipment for the membrane and filter plates of the VPA (Metso) machine satisfying all the safety requirements. The VPA is a heavy duty machine with a number of plates, developed for filtration of minerals. The plates must be replaced or removed immediately once the wear has reached a given value or an error has been detected.

The new lifting system differs to a great extent from conventional system in which a fiber strap was used; the designed lifting equipment comprises of a variety of parts resulting in a higher capacity to be used in different situations safer and satisfies the vital requirements such as being a secure and cost-effective method, issued by the customers.

Several solution proposals have been developed to offer better proposals before the final candidate has been selected and theoretically motivated with FEM analysis as well as analytical calculations.

Keywords – VPA, membrane and filter plate, lifting equipment, pivot support hinge, safety, cost effective

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Ämnesgranskare: Henrik Hermansson
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Sammanfattning

Denna examensrapport handlar om utveckling av en ny lyftutrustning för filterplattor i VPA, (Pressfilter tillverkat av Metso), som uppfyller säkerhetskraven. VPA är en kraftig filterpress med ett antal plattor och dukar, som utvecklats för att filtrera vatten ur mineralkoncentrat. Plattorna måste tas bort och bytas ut omedelbart då slitaget har nått ett visst värde eller då en skada upptäcks.

Det nya lyftsystemet skiljer sig i stor utsträckning från den konventionella lösningen där ett fiberband används. Den nya lyftutrustningen består av en mängd olika delar som resulterar i en högre kapacitet som kan användas i olika situationer säkrare och uppfyller de krav ställts av kunden.

Flera lösningsförslag har tagits fram för att erbjuda bättre förslag innan den slutliga kandidaten har valts.
Acknowledgement

I would like to express my deepest appreciation to my supervisors Henrik Hermansson from Uppsala University and Patrik Djurfeldt from Metso Minerals (Sweden AB) for their invaluable advices and academic supports during the course of my work. Without their assistance, this work would not be completed.

The writer is equally indebted to Mr. Peter Bäckström, Process Engineering Manager, who provided me with an opportunity to complete this work at Metso in Sala and many other colleagues who have been tolerant and supportive throughout the course of my research.

Last but not least, I would like to thank my family – my husband Nandinbaatar Tsog and my son Ananda Nandinbaatar who have been patient and supportive.

Sala in March 2016

Bolormaa Batchuluun
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## Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basket lift/ Basket hitch</td>
<td>The sling cradles the load while both eyes are attached overhead (see Figure 49 in Appendix E)</td>
</tr>
<tr>
<td>Cake</td>
<td>A filter cake is formed by the substances that are retained in a filter</td>
</tr>
<tr>
<td>Chamber</td>
<td>Space in which filter cake is formed</td>
</tr>
<tr>
<td>Choke lift/ choke hitch</td>
<td>Sling passes through one end around the load, while the other end is placed on the hook (see Figure 50 in Appendix E)</td>
</tr>
<tr>
<td>Chute</td>
<td>Container in which falling materials are guided</td>
</tr>
<tr>
<td>ETO</td>
<td>Engineering to order</td>
</tr>
<tr>
<td>FEM</td>
<td>Finite Element Method</td>
</tr>
<tr>
<td>Filter</td>
<td>Shortened traditional name for VPA</td>
</tr>
<tr>
<td>Ramshorn hook/ double hook</td>
<td>Twin hook</td>
</tr>
<tr>
<td>Sling eye</td>
<td>Sling end for the load to be inserted in</td>
</tr>
<tr>
<td>Slurry feed</td>
<td>A semi-liquid mixture, typically of fine particles of manure, cement, or coal suspended in water</td>
</tr>
<tr>
<td>Spreader beam/ lifting beam</td>
<td>Below-the-hook lifting device</td>
</tr>
<tr>
<td>VPA</td>
<td>Vertical Plate Airblow</td>
</tr>
</tbody>
</table>
1. **Introduction**

Metso is one of the world’s leading industrial companies in the mining and aggregates industries and in the flow control business. Metso employs approximately 13,000 industry experts in more than 50 countries.

Metso was created on July 1, 1999 through the merger of Valmet, a paper and board machine supplier, and Rauma, which focused on fiber technology, rock crushing and flow control solutions. Metso Paper, Metso Minerals and Metso Automation were three main business areas of Metso until the corporation announces its demerging into two companies on 1 October, 2013.

Metso Minerals in Sala is responsible for providing minerals processing solutions for mining customers.

1.1. **Background**

The Metso Vertical Plate Airblow (VPA) is a heavy duty machine, developed for filtration of industrial minerals when gravity dewatering can no longer be used. VPA basically consists of fixed and moving head, joined by two side beams, which support the movable head and the membrane and filter plates, which are fitted between the fixed and movable heads. A multi-level elevated work platform is built around the VPA for works at height.

Metso offers a wide range of VPA machines adapted to every application in terms of a desired capacity. Filtration capacity partly depends on a number of the plates used in the VPA, thus for instance, VPA2040-50 can filter a greater amount of materials than VPA2040-20 because the former has 50 filtering plates whilst the latter has only 20 plates.

Membrane and filter plates are important parts of the VPA filter used to filter material in the chambers between the plates. Membrane plate is made from machined polypropylene with membrane (natural rubber) on each side of it. The two pivots are attached to support it on the side beams when the plate is vertically installed on the machine. Filter plate differs from membrane plate mainly by not having membranes on it. However, there are a couple of critical differences between them which should be addressed when it comes to be hoisted up and it will be discussed later in more detail (Sections 3.1 & 3.2).

The plates must be replaced and removed immediately once the wear has reached a given value or an error has been detected either on the plate or its components such as lock ring, membrane or gasket. However, it’s a challenging task to remove and transport them as there is no fixed permanent point attached to the plate to be lifted up. Moreover,

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the physical presences of different objects around the plates, contribute greatly to a limitation of access to the plates.

1.2. Problem Formulation

A fiber strap is used as a conventional method of hoisting or transporting the plates. The strap is threaded through an inlet hole on the plate forming a choked lift (Fig 29 in Appendix A). However, an incident has revealed that lifting the plate with the strap is not a completely safe method. A membrane plate fell down when the strap snapped during the lifting operation at the Australian mineral site where Metso VPA is used.

Eventually it became clear that the sharp edge of the metal lock ring which sits inside the inlet hole caused the incident. From economic point of view, it’s apparently cheaper to develop a new lifting tool rather than modifying the plane by adding some radius on the lock ring edge (making less sharp edge). In addition, the method with fiber strap exposes the operators to danger because it often forces them to work in forbidden areas like inside the filter where many dangerous and hazardous objects exist.

1.3. Goal

The goal of the project is to develop a safe and cost effective lifting mechanism for hoisting, lowering and transporting the membrane and filter plates of the VPA in different situations. The designed lifting equipment must meet the following demands:

• Safety requirement: A new method should meet all the safety requirement specifications issued by the customer side (i.e. Australia).

It’s forbidden to climb over the handrail (Fig 28 in Appendix A) and work on top of the plates at Australian sites although it’s allowed to do so at some other sites. It means that one must always operate from inside of the handrail.

• Economical requirement: As mentioned earlier, the fiber strap was used to lift up the plates when the incident happened. It means that the lifting tool did cost Metso nothing since the fiber strap at site was used as a lifting tool.

It’s essential to modify the lifting equipment completely or partly because safety requirement such as “inside handrail” has been added to the requirement list. Besides it, as written above, it’s too expensive to modify the plate as adding radius on the lock ring edge.

Consequently, the new equipment for material and fabrication cost should not exceed more than a several thousand Swedish krona (approx. 3000-5000 Swedish krona).

• Technical requirement: It should be ensured that the new equipment arrangement must work properly in all of the following situations:
  - Plates vertically positioned in VPA filter
  - Plates horizontally placed on the ground or inside box
Both membrane and filter plates

Furthermore, the design should not be too complex so that the lifting and/or lowering operation could be performed in as much time as what it needed for the fiber strap method.

1.4. Delimitation

The project scope will be narrowed in the following ways:

- New lifting gear is developed for the plates of the VPA2040-54. This is the VPA machine used at the Australian Mineral Site. The same lifting equipment cannot be used for the other types of the VPA because not only the machine itself but also the working platform surrounding it can differ from VPA2040-54.

- Manual calculation is going to be performed in order to comparing it to the FEM analysis result mainly for the designed components, because other components such as lifting beam, sling and shackle are designed according to the standards.

- The lifting equipment will not be constructed during the project but the design will be developed after which FEM simulation will be performed on the 3D-models. An actual construction of designed components will start once the project is approved by both sides.

1.5. Method

A number of methods have been used in this study of developing lifting equipment.

*Literature Study:* A literature study of press filter and general lifting equipments (Google Scholar, ASME) has been conducted. There are many useful lifting equipment websites available online which provide readers with information of classifications, standards and prices of lifting equipments.

*Academic papers:* A number of papers related to the hook, lifting beam and sling theories and the course books have been used throughout the work.

*A study through the VPA drawings:* A process of generating different lifting equipment ideas (brainstorming) is based on studying a part, assembly, general arrangement drawings of VPA, membrane and filter plate, lock ring, pivot as well as top and middle plane of platform by accessing Metso Database System.

*Interview:* Since it is impossible to be present at the site where the incident had occurred, most of the information on “actual situation” was collected through the interview with Metso ETO engineers who have a direct contact with the Australian side.

*Workshop Visit and Field Trip:* A clear picture of how VPA looks in real life is obtained by visiting Boliden Mineral AB in Garpenberg, Sweden where Metso VPA machines are used, although they are different models than that of Australia. Besides field trip, the
writer has visited the workshop several times in Metso (Sala) to check webbing sling thickness, crane hook dimension and lock ring of the membrane filter.

### 1.6. Related work

Despite a number of articles on the Plate Filter Press and its components such as membrane plate have been published so far, no public article specifically related to the lifting equipment for the VPA plates was found.

Considerable reason for absence of the lifting equipment paper for the VPA plates can be that lifting equipment for the plates is a very practical issue that hugely depends on what kind of VPA we are talking about. Each and every VPA model differs more or less from each other and that difference makes the design of general lifting tool difficult. This means that for each application one needs to find the solution that applies the best in that particular environment.

As no paper of lifting arrangement for the VPA plates is found, the study starts from the most general lifting equipment for industrial and construction areas.
2. **Theory**

This chapter serves as a theoretical basis of general lifting arrangement such as spreader beam and sling. Bearing stress for pin as well as tensile and compressive stress in any given material is introduced also. Emphasis is placed on the determination of stress distribution in spreader beam.

2.1. **Definition of Lifting Operation and Lifting Gear**

*Lifting Equipment for construction work*

Lifting equipment is defined as any working equipment for lifting and lowering loads including necessary accessories used in lifting applications. Examples of lifting equipment include tower and mobile cranes with their supporting runways, construction hoists for transportation, motor vehicle lifts and forklifts and so on.

Lifting accessories are pieces of equipment used to attach the load to lifting equipment providing a connection link between the two. Slings, shackles, chains, hooks, clamps, eyebolts, spreader beams, magnetic, hydraulic and vacuum devices and tongs are typical lifting accessories used for construction work.

*Lifting Operation*

The term lifting operation is used to designate the process of suspending, raising or lowering loads and moving them from one position to another while suspended or supported. Before any lifting operation is conducted, the risks involved in the work must be identified clearly. Risk factors that affect the operation include environment, visibility, location, overload, positioning and stability etc.

*Lifting Load*

A load is the item or items being lifted, suspended, transported and lowered by the lifting equipment. In most cases, loads are attached with fixed permanent points which are considered to be a part of the load, in order to be lifted and transported.

2.2. **Lifting Gear Theory**

2.2.1. **Shear Stress in Lifting Beam**

Lifting beams (spreader beams) are below-the-hook lifting devices used to lift large loads with single or multiple attachment points in the hoisting process. Some common profiles are depicted in Fig 1.

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4 Ibid.

5 Ibid.
The most basic arrangement illustrated in Fig. 1. A provides two points of attachment to the load being lifted and allows a straight pull on the object rather than an oblique pull, thus avoiding the possibility of overstressing if a single attachment were used.

When a beam of any cross-section is subjected to non-uniform bending, both bending moments, \( M \), and shear forces, \( V \), act on the cross section\(^6\). The distribution of shear stresses \( \tau \) associated with shear force \( V \) can be obtained with following formula:

\[
\tau = \frac{VQ}{IB}
\]  \( (2.1) \)^7

Where:

\( V \) = Transverse shear force
\( Q \) = First moment of area
\( I \) = Moment of inertia
\( B \) = Width of section

For cross section of I-beam, first moment of area \( Q \) and moment of inertia \( I \) are calculated as follows:

\[
Q = \sum A \cdot a = A_1 \cdot a_1 + A_2 \cdot a_2
\]  \( (2.2) \)^8

Where,

\( A_i \) = Individual segment’s area
\( a_i \) = Individual segment’s centroid distance from a reference line

---


\(^7\) Ibid.

The moment of inertia of a rectangular area about its centroid axis is:

\[ I = \frac{bh^3}{12} \]

Where
\[ b = \text{the base of width of the rectangle} \]
\[ h = \text{the height of the rectangle} \]

As depicted in Fig 2, the moment of inertia of I-beam is equal to

\[ I_{\text{beam}} = I_{\text{orange}} - 2 \cdot I_{\text{green}} \]

\[ I = \frac{bh^3}{12} - 2 \left( \frac{fd^3}{12} \right) \]  \hspace{1cm} (2.3)

The shear force \( V \) occurs when a perpendicular force is applied to static material and it’s calculated from the shear force diagram (see Section 6.1 in detail).

2.2.2. Maximum Allowable Stress

Stress represents the internal resistance due to the continuous exertion of neighboring particles of a structural member. The pulling force results the member in a tensile stress whilst the pushing force results in compressive stress. Uniaxial stress is defined as force (\( P \)) divided by area (\( A \)):

\[ \tau = \frac{P}{A} \]  \hspace{1cm} (2.4)

The state of stress at any point within the member can be calculated with a complete description of the loading applied to it and the geometry of the member\(^9\). Once the state

\(^9\) Ibid., p. 6.
of stress is known, the strength of the member will be compared to ultimate strength in order to identify whether the member with a specific material is able to withstand the applied force and it called as maximum allowable stress:

$$\text{maximum allowable stress} = \frac{\text{ultimate tensile strength}}{\text{factor of safety}} \quad (2.5)$$

ANSI/ASME Standard requires that lifting beams be designed using a minimum design factor of 3 based on yield strength, for load bearing structural components\(^{11}\). However, safety factor is established as 5 not 3 in our case.

If the stress at any given point within the member due to the applied force exceeds the maximum allowable force, the member will fail and the structure should be reconsidered. Therefore, the maximum allowable stress should be less than stresses identified within the members.

### 2.2.3. Shearing Stress on Pin

Shearing stress \(\tau\) is commonly found in bolts, pins and rivets and is computed according to:

$$\tau = \frac{P}{A}$$

where \(P\) is the load applied on area \(A\).

![Free Body Diagram of Pin](image)

Figure 3 Free Body Diagram of Pin

Free body diagram of pin in Fig 3 depicts how force \(V\) results in shearing stress. The average shear stress on pin with diameter \(d\) is expressed:

$$\tau = \frac{P}{\pi r^2} = \frac{P}{\pi d^2} = \frac{4P}{\pi d^2} \quad (2.6)$$

### 2.2.4. Tension in Sling

More advanced and complex calculation is required when the slings are placed not equidistantly from the center of gravity. As the load (plate) is symmetrically placed between the slings, a simple sling calculation is sufficient to compute the tension imposed on slings or individual legs of a multi-part sling system.

---


\(^{11}\) Ibid., p. 6.
This simple tension calculation is based upon\textsuperscript{12}:

- Sling attachment points being equidistant from the center of gravity
- Sling attachment points being equidistant to each other
- Sling attachment points being on the same horizontal plane
- Equal sling leg lengths

\begin{center}
\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{headroom.png}
\caption{Headroom}
\end{figure}
\end{center}

In order to select slings with adequate Work Load Limits (WLL), the following steps should be performed:

1. Determine the Load Angle Factor (LAF): Divide the leg Length (L) by the Headroom (H) illustrated in Fig 4:

\[ LAF = \frac{L}{H} \] (2.7)

2. Determine the Share of the Load (SOL) for the individual sling legs: Divide the load weight by the number of sling legs

\[ SOL = \frac{\text{load weight}}{\text{number of legs}} \] (2.8)

3. Determine Sling Tension: Multiplying LAF by the SOL

\[ Tension = LAF \cdot SOL \] (2.9)

\subsection*{2.2.5. Welding}

Welded assemblies represent a large group of fabricated steel components and it’s a very complex process involving heat and liquid-metal transfer, chemical reactions as well as the gradual formation of the welded joint through liquid-metal deposition and subsequent cooling into the solid state\textsuperscript{13}. The material in this section will provide the


\textsuperscript{13} Marks*, *Standard Handbook for Mechanical Engineers*, 10th edn, McGRAW-HILL, 1996.
readers mainly with different formulas which describe relationship of the load and the weld that can sustain it.

There are various types of welds that can be made in each of the basic joints\textsuperscript{14}. Each type of welds and corresponding images are illustrated in Table 9 and Figure 51\textsuperscript{15}(Appendix F).

As seen in Fig 51: right, various T-joint welds are used to join members at an angle to each other. The joint can be classified as a single fillet, double fillet or combination of a groove and fillet weld depending on the intended use of the weldment.

A lifting lug on the spreader beam is welded with double T-joint in general (Fig 5: left).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{lifting_lug_welding.png}
\caption{Lifting lug welding}
\end{figure}

The weld stresses due to the load are depicted in Fig 5 (middle):

$\sigma_\perp =$ direct stress on weld throat plane

$\sigma_\parallel =$ direct stress on weld throat section

$\tau_\perp =$ shear stress on weld throat plane

$\tau_\parallel =$ shear stress on weld throat section

$a =$ weld throat

$W =$ efficient weld length

Normal stress ($\sigma_N$) can be calculated according to:

$$\sigma_N = \frac{P}{A} = \frac{P}{aw} \quad (2.10)$$

Where:

$P =$ load on the weld throat plane


\textsuperscript{15} Ibid.
$A = \text{area of weld throat plane}$

With help of equation (2.10), $\sigma_\perp$ and $\tau_\perp$ will be computed as below (Fig 5: right):

$$\sigma_\perp^2 + \tau_\perp^2 = \sigma_N^2 \quad (2.11)$$

$$\sigma_\perp = \tau_\perp = \frac{\sigma_N}{\sqrt{2}} = \frac{P}{aW\sqrt{2}} \quad (2.12)$$

The design of the weld is sufficient if both the following are satisfied$^{16}$:

$$\sqrt{\sigma_\perp^2 + 3(\tau_\perp^2 + \tau_{\parallel}^2)} \leq \frac{f_u}{\beta_{w}\gamma_{M_2}} \quad (2.13)$$

$$\sigma_\perp \leq \frac{f_u}{\gamma_{M_2}} \quad (2.14)$$

Where:

$$\frac{f_u}{\beta_{w}\gamma_{M_2}} = \text{design strength}$$

$\beta_{w} = \text{correlation factor}$

The research suggested that fillet welds under combined stresses could be represented by an ellipsoid consisting of $\tau_{\parallel}$, $\tau_\perp$ and $\sigma_\perp$. However, direct stress along the length of the fillet weld $\sigma_{\parallel}$ didn’t appear to make any contribution to failure$^{17}$. Due to this reason, $\sigma_{\parallel}$ is not involved in either of the above equations.

Design (material) strengths and correlation factors for some steel grades are shown in Tables 10 and 11 in Appendix F.


3. Review of Metso VPA Filter

The aim in this chapter is to introduce what Metso VPA filter is and in which ways the membrane and filter plates differ from each other. In addition, physical environment around the plates plays a crucial role in an appropriate handling of the vertical plates.

3.1. Membrane and Filter Plate

As pointed out earlier, the membrane and filter plates are the most important parts regarding filtration process and in order to be able to operate as they’re designed and/or to deliver the high standards of performance, the plates should be equipped together with other components such as hydraulic cylinders, filter cloth and spray pipes and so on. Operating pressure is approximately 7-10 bar and filtration (dewatering) process can be performed by both compression and air blowing. The plates are placed in such a manner that every two membrane plates should have the filter plate between them, i.e. there are always two membrane plates on each side of the filter plate (Fig 6). A certain depth is removed away from each surface of the plate forming biconcave so that slurry feed can be held and contained between two plates. Thus, every plate builds a room called chamber with its neighboring plate on both sides where dewatering process will be able to be taken place. Surfaces of both plates are carved with distinctive patterns to drain/run out liquid through.

Dewatering (filtration) process occurring inside the chambers which made from each type of the plate is divided in the following stages:\(^{18}\).

---

**Filtration:** The pressure filter plate pack is locked thus allowing slurry feed to enter the filter chambers (consists of two closely spaced polypropylene plates) when the hydraulic cylinders move towards the fixed head side. The water runs out due to gravity through the ports of each chamber (Fig 7: Filtration).

**Compression:** The cake inside the chamber is compressed further by inflating the rubber membrane on one side of each cake. Membrane inflation is accomplished by compressed air or pressure water (Fig 7: Compression).

**Air-Dewatering:** The filter cake is exposed to compressed air in order to displace the free water in it. The membrane is usually kept inflated as described in compression state to maintain good cake stability (Fig 7: Air-blowing).

![Filtration](image1.png) ![Compression](image2.png) ![Air-blowing](image3.png)

**Figure 7 Filtration Stages**

**Cake Discharge:** When the cakes become dry and ready for discharge, the filter opens by moving the hydraulic cylinders towards the opposite side of the fixed head. The cakes are dropped one by one into the chute which locates under the filter.

**Cloth Washing:** The filter cloths are rinsed by the spray nozzles and get rid of the remains to process the next cycle before the filter is closed again.

Membrane plate is made from machined polypropylene with membrane (natural rubber) on each side of it. The two pivots are attached to support it on the side beams when the plate is installed on the machine. An outlet corner with hole for air blowing is attached at four corners after the plate is placed on the rail beams which run entire way along the length of the plates (Fig 8).

**Table 1 Comparison of Membrane Plate and Filter Plate**

<table>
<thead>
<tr>
<th></th>
<th>Membrane Plate</th>
<th>Filter Plate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (Plate together with all of the parts assembled at site)</td>
<td>575kg</td>
<td>502kg</td>
</tr>
<tr>
<td>Height</td>
<td>3200mm</td>
<td>3200mm</td>
</tr>
<tr>
<td>Width (Including outlet corners)</td>
<td>2800mm</td>
<td>2800mm</td>
</tr>
<tr>
<td>Depth (Thickness)</td>
<td>104mm</td>
<td>96mm</td>
</tr>
<tr>
<td>Object inside Inlet Hole</td>
<td>Lock Ring (Metal)</td>
<td>Gasket (Rubber)</td>
</tr>
<tr>
<td>Method to fasten Object to Inlet Hole</td>
<td>Screw</td>
<td>-</td>
</tr>
</tbody>
</table>
Examensarbete: DEVELOPMENT OF NEW LIFTING EQUIPMENT FOR VPA PLATES

Filter plate differs from membrane plate mainly by not having membranes on it. Accordingly, they have different weight and thickness because of presence and absence of the membranes.

The distinctive characteristics of each type can be summed up in Table 1.

**Table 1**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Membrane Plate</th>
<th>Filter Plate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Plate</td>
<td></td>
<td>1. Plate</td>
</tr>
<tr>
<td>2. Membrane</td>
<td></td>
<td>2. Rubber Gasket</td>
</tr>
<tr>
<td>3. Metal Lock ring</td>
<td></td>
<td>3. Inlet Hole Notch</td>
</tr>
<tr>
<td>4. Screw</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 8 General Arrangement of Membrane and Filter Plates**

**Figure 9 Cut Sections of Lock Ring and Rubber Gasket**
Here requires a brief explanation regarding the method of attaching rubber gasket inside the inlet hole of filter plate. A metal lock ring sits inside the inlet hole tightened on the membranes with screw in case of the membrane plate while a rubber gasket rests on the notch of the inlet hole in case of filter plate.

The notch emerged from inside of the inlet hole fits perfectly into the hollow made on the gasket rubber. As a result, gasket on the filter plate is sensitive to any force which it exposed to since it’s not fastened as stable as lock ring on the membrane plate and it’s considered as a disadvantage compared to the membrane plate.

Section drawings of the inlet holes with respective rings are depicted in Fig 9. As mentioned previously, the rubber gasket rests on the notch while the lock ring fastened with screws. The actual notch on the filter plate can be seen in Fig 30 in Appendix A.

3.2. Physical Environment

In the previous section, the physical qualities (weight, material) and dimensions (length, width, depth) are taken in detail to describe for what item new lifting equipment is going to be used. In this section, the physical environment around the plates is going to be described to clarify in which way/how new lifting equipment is going to be used.

The plates hang on the support rail beams which link the fixed and moving heads, with help of the pivots. With slide block attached to the pivot bottom, the plate can move together with other plates on the rail beams when hydraulic cylinders run forward or backward to open or close the plates.

There are four hydraulic cylinders used in total; the upper two cylinders are placed under the upper outlet corners and the lower two cylinders are placed above the lower outlet corners. A cylinder supporter is attached to middle of the rail beams in order to support the long hydraulic cylinders. Therefore, a distance between the plate next to the cylinder supporter and handrail of the middle plan is greater than what it is for the rest of the plates and handrail (the handrail of middle plan that is placed precisely under the top plan handrail will be closer to the rest of the plates).

Filter cloths are suspended from the bars which serve as spray pipes placed over the range of the plates. When one (dewatering) cycle is completed, the chambers open and release the cakes into the chute located under the filter. The distance between the two plates is around 84 mm when the filter is in an open state. This is the maximum distance allowed between the two vertical plates in the filter.

A multi-level (top, middle and bottom) elevated working platform is built around the filter for temporary access for inaccessible areas of the filter (see Fig 32-35 in Appendix A). The handrails along the stairs and walkways prevent the operators to fall down and from other possible accidents. Currently, it’s forbidden to work outside the handrail at Australian plant although it’s allowed at some sites in Sweden.

The VPA filter with its working platform is depicted in Fig 10 below.
When the plates are arrived at site in horizontal position, five of them are packed together in a wooden box without outlet corners and pivots (See Figure 31 in Appendix A).

*Figure 10 VPA with Working Platform*

1 Membrane / Filter Plate 2 Hydraulic cylinder (x4) 3 Cylinder supporter (x2) 4 Support rail beam (x2) 5 Pivot (x2) 6 Chute 7 Handrail 8 Top, middle and bottom plan
4. Industrial Lifting Equipment

Following the Chapter 3, this chapter provides a review and discussion of various standard industrial equipments such as magnetic and vacuum lifter, in heavy lifting. The discussion covers both advantages and disadvantages of the equipments if they will be applied for the VPA plate handling.

4.1. Magnetic Lifter

Magnetic lifter can be used in industrial areas because of its improved productivity as well as increased efficiency compared to other conventional lifting devices. When a fiber strap is used to lift up the VPA plate from horizontal position, one end of the plate is required to be lifted so that the strap could be passed underneath. Operators often face challenges finding out a proper way of lifting one end of the plate when the load is heavy as 600 kg. On the other hand, a lifting magnet could be attached to ferrous parts of the plate from above with minimal effort.

However, there are several issues relating to the magnetic lifter if it’s going to be used for the VPA plates. Firstly, the only available ferrous surface to be attached to the magnet is the metal lock ring inside the inlet hole of the membrane plate (see Fig 9, Lock Ring). However, there is no metal lock ring on the filter plate as it uses a rubber gasket as described in Section 3.1. The pivots are made of metal but they have restricted surface areas to be attached, therefore not the entire magnet makes contact with the load. If the entire magnet doesn’t make contact with the load surface, the lifting capacity of a magnet is reduced dramatically because the magnet is not used at its full capacity.

Secondly, it’s a top priority not to harm any component on the plate. If the magnetic lifter presses hard against the lock ring, there is no guarantee it won’t cause any damage on the ring when the large breakaway force is required. Therefore, in order to prevent premature wear, metal-against-metal method should be avoided by any means.

Thirdly, permanent magnetic lifters require an operator to pull the lever in order to activate/deactivate the magnet (Fig 36 in Appendix B). In order to attach the magnet lifter to the plate and to activate magnet force, operator must be inside the VPA machine which is against safety rule (Section 1.3). Unlike the permanent magnetic ones, electromagnet lifters can be activated remotely. If the latter is going to be used for the VPA plates, a power failure can be catastrophic. Although universal power supplies and battery backup systems are available in today’s market to prevent failures, these extra devices would lead to higher costs.

Lastly, to be lifted up with the magnetic lifter, the load surface plays an important role during the operation. The lifting capacity of the magnetic lifter decreases dramatically if the work piece surface is not clean and smooth as it should be. Unfortunately, it’s next to impossible to ensure the plates are clean in the mining industries in order to keep the performance of the magnetic lifter higher. Besides it, there is not sufficient room for this
type of the lifter when it’s used for the VPA plates because of the existence of the various items around them (Fig 10).

4.2. Vacuum Lifter

As magnetic lifter, vacuum lifter can be applied best to horizontal VPA plates without lifting up one end of the plate. Even better than former, vacuum lifter can be used generally for any type of material allowing a load with restricted ferrous surfaces like VPA plate can be lifted easily.

However the vacuum lifter is relatively expensive device comparing to the other devices. Vacuum lifters can be integrated into the manipulators or can be supplied as independent operating equipment that can be attached to hoists and cranes. Neither type is considered to be cost effective due to the accessories such as vacuum generator and operating unit etc.

The issues related with the load surface dirt and dust as well as insufficient room for the equipment which mentioned in the previous section should be considered carefully in this case also. Additionally, most of the vacuum lifters are designed for non-porous and smooth workpieces due to safety purposes. Vacuum lifters with higher capacity are for porous objects requiring more air-flow to compensate for air loss. Apparently the higher capacity devices would result in higher cost which is beyond the estimated budget.

An example of vacuum lifter is presented in Fig 37 in Appendix B.

4.3. Scissors Clamps

Scissors clamps/ tongs equipped with simple technologies are cheaper than the magnetic and vacuum lifter. Thanks to high frictional rubber pads, not only does the lifting operation work safely but also the material surfaces are kept out of scratch and damage.

![Figure 11 Scissors Clamps Gripping from Different Faces of the Load](image)

---

Even though it looks like an ideal lifting device for the VPA plates both in horizontal and vertical positions, a list of pitfalls would be found during the lifting operation.

To grip and lift up an object with device shown in Fig 11: left, the object should not be fully lowered to the ground otherwise there is no space underneath for one of the arm ends. As stated earlier, the plates are packed horizontally next to each other in the box when they arrive at the site (Fig 31 in Appendix A). Despite the fact that this device can work properly when the plates stay vertically in the VPA machine, it’s impossible to use for the horizontal plates when they are piled up because there is no space/ distance between them along the outside edges.

Let’s see what happens with the device in Fig 11: right. This type of device works properly for the plates in both horizontal and vertical positions as long as there is a sufficient width for the arm ends. One may wonder why outlet corners can’t be gripped as illustrated in the above Fig 11: right. As a matter of fact, those four outlet corners are not intended to support the plate in the first place. Each corner is fastened with two screws, one of which has tightening torque 80Nm. That’s why it’s not recommended to insert the sling/ strap through the corner holes in order to lift up the plate.

There are spaces just under the outlet corners to be clamped, but the upper hydraulic cylinders prevent the clamp arms to reach the open spaces under the corners (see Fig 10).

4.4. **Tongs**

Except the gripping clamps as described in the previous section, for example, Bushman Equipment Inc\(^\text{20}\) designs a tong-type clamp for the special conditions in particular applications. Differing from the gripping and pressing clamps, this tong-type clamp needs a hole to be inserted.

The advantage of using this type is that it can be used for both vertically and horizontally placed plates if some adjustments are made on the holder (the holder apparently does not work properly if the holder is placed as illustrated in Fig 12: left, it should be modified somehow in order to function for the vertical plates like Fig 12: right).

On the contrary, this device cannot be successfully applied to the filter plate equipped with rubber gasket which is unlike metal lock ring of the membrane plate.

As pointed out in Section 3.1, the rubber gasket is placed inside the inlet hole without any screws or any other fasteners. Only a small notch prevents the rubber gasket from popping out of the hole. Unfortunately this tiny notch cannot prevent the gasket from popping out when a force acts on the gasket. The gasket is a very sensitive to any force which acts on it. It’s therefore considered inappropriate to use this tong-type clamp for the filter plate either.
5. Lifting Equipment Design Procedure

In the previous sections, it was concluded why the different lifting equipments such as magnetic and vacuum lifter, clamps and tongs are inappropriate solutions for this special situation.

Section 5.1 provides an overview of the various design concepts developed during the brainstorming. In Section 5.2, Pugh Matrix is established/carry out to select the most appropriate design concept among the proposed concepts by evaluating against weighted criteria. The chapter will end introducing the different parts included in the selected design in Section 5.3.

5.1. Brainstorming Process

Brainstorming process had started at a very early stage of the project. Some of the design concepts had started developing before all the relevant factors were actually being known to the author. Therefore, the reader should be aware of the fact that the author had no full knowledge of the VPA and its components at the moment of brainstorming stage.

5.1.1. Concept 1

Working principle of this concept is similar to that of the Bushman lifting tong which described in Section 4.4.

![Figure 13 Concept 1](image-url)
A cylinder formed object (item 1) with levers at the bottom (item 5) should be inserted into the inlet hole of the plate with help of the rotatable main body (item 2). The main body has long arms (item 3) which allow the operator to stay inside the handrail. The arms have a controller (item 4) allowing the levers expand under the inlet hole once the cylinder formed object fully inserted into the hole.

What makes this concept attractive is that it’s capable of being applied to both horizontal and vertical plates in addition to safe “inside handrail” operation thanks to the long arms. Regardless of it, the concept has the following disadvantages:

- It cannot be applied to the filter plate because of the reason explained in the previous section. The rubber gasket pops out easily if the levers act force on it from underside when the plate is located in horizontal position.

- As mentioned before (Section 3.2), the maximum open space between the two plates is 84mm. In order to insert cylinder formed object (item 1) into the inlet hole, the length of it must not be greater than 84 mm otherwise it wouldn’t fit between the plates. The problem is that length of the inserted part of item 1 for the membrane plate already exceeds 80mm (= metal lock ring height 60mm plus the open space/ cavity from the lock ring to the plate surface is 22mm (see Fig 9, Lock Ring)). The question is how realistic it is for the main body (item 2) to lift up the plate with its 2mm thickness. This length is a bit smaller for the filter plate (70.5mm) which in turn contributes to slightly thicker main body.

5.1.2. Concept 2

This concept is inspired by an idea of self-locking latch used for the crane hooks. During the interview with ETO engineers, it became known that it’s possible to attach the pivots to the load/ plates as fixing points prior to installation. Pivots are the parts designed to support the plate from the sides. Accordingly, there is no concern for issues of falling off or failure under normal usage (see how the pivots support the plates on the support rail beam Fig 6 & 10).

When the latches (items 1 & 2) meet the object (pivot), they turn by 90 degrees up allowing the pivot to enter inside. Once the pivot passes fully, the latches will be lowered as they were before and the device is self-locked now (See Fig 14).

One can win relatively large room/ space by effectively using the both sides of the plate compared to the Concept1. However how much thickness the latch will have depends directly on the distance between the two pivots of the filter plates in horizontal place. The distance between the two pivots on the filter plates is 16 mm while it’s slightly larger for the membrane plate pivots due to the greater thickness. Consequently, the latch thickness must not exceed 16 mm in order to be inserted between the pivots.

This efficient working thickness (16mm) will be reduced further because of the protection material attached around the latches in order to not to harm the pivots. If all of the latch sides that would be in contact with pivot were equipped with protection materials, its thickness will be greater than/ beyond the allowed 16 mm (Fig 15).
Secondly, the latch can’t be removed/taken away from the plate once the lifting operation is completed. The self-locking mechanism allows the latch gates solely to be raised up not to be hung down or else the device is unable to support the load. It’s apparently meaningless to have such a lifting device that can’t be taken away from the load after the operation.

![Diagram of Concept 2](image1)

**Figure 14 Concept 2 (Vertical Plate)**

![Diagram of Concept 2](image2)

**Figure 15 Concept 2 (Horizontal Plate)**

### 5.1.3. Concept 3

Concept 3 (Fig 16) has in common with Concept 2 in terms of using pivots as fixing points whilst it has relatively a simple design. The pivots will be supported by the slings which in turn supported by the lifting beam.

The biggest benefits of having the slings around the pivots are:
- The slings are obviously thinner and more flexible than any other materials used in, for example, the latch because they are made of usually nylon or polyester. Consequently, they can easily get in between the pivots where the latch of Concept 2 has difficulty to be inserted.

- The slings don’t need extra protective rubber materials because they are made of textiles although they need to be overlapped in a several layers.

However, there are also disadvantages of sling method, such as the following:

- In order to perform the lifting operation of the plates in a safe way, the slings have to completely wrap around the pivots, called “choke hitch” (see Fig 50 in Appendix E). In the choke hitch, one eye of the sling is attached to the lifting hook, while the sling itself is drawn through the other eye. The load is placed inside the “choke” that is created while the sling is drawn tight over the load through the eye.

![Diagram of Choke Hitch](image)

**Figure 16 Concept 3**

This process requires a presence of an operator who wraps the sling around the pivots so that it can form a proper choker hitch, i.e. choke hitch can’t be configured automatically. An operator can fix it simply and handily for the horizontal plates since he/ she can reach plates in the box or on the ground. The situation is different for the vertical plates in VPA machine as the pivots on the plates are beyond the reach of the operator when he is inside the handrail. In addition, there are numerous other obstacles/ hinders such as hydraulic cylinders preventing the operator from reaching the pivots.

As a result, the operator needs an extra device to reach the pivot where the sling will be wrapped around by some means.

- At least two operators are necessary to manage the slings through the pivots, each standing at each side of the plate.

---

5.2. Pugh Matrix for Concept Selection

In this section, Pugh matrix is used to select the most appropriate candidate from the previously discussed different design concepts by establishing a set of criteria essential for determining important characteristics for the product.

The process for constructing Pugh Matrix comprises the following steps:

Step 1: Identify and clearly define the criteria for selection. These criteria reflect the customer’s including Metso’s requirements on the considered lifting device and consist of safety, design complexity, harmful effects on the load, cost efficiency and capability of being used in different conditions like vertical or horizontal plates. The criteria are weighted with 1-5 scale to give better differentiation.

Step 2: Candidates for design concept used in matrix consist of Concept 1, Concept 2 and Concept 3. The conventional fiber strap method through the inlet hole is established as reference/baseline design.

Step 3: Compare each candidate against the reference, criteria by criteria and decide a “pair-wise” score with:

0 = same  
+ = better  
- = worse

If necessary, extra levels of discrimination (“++” = much better, “--” = much worse) can be used during the evaluation process. Record also the reasons behind decisions for each candidate design concept.

Step 4: For each alternative the total score can be calculated by summing the number of “+”s and “-”s after multiplied by a given scale for the criteria weights. Make clear which alternative got the highest ranked score.

Step 5: No matter how much high score the selected design obtains, there is always room for improvement since at least one “-“ is included within the score. Those “-“s can be improved by combining where possible the best from each alternative.

Table 2 Pugh’s Diagram

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Concepts</th>
<th>Weight</th>
<th>Reference</th>
<th>Concept 1</th>
<th>Concept 2</th>
<th>Concept 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>Working area : inside the handrail</td>
<td>5</td>
<td>0</td>
<td>++</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Stability</td>
<td>5</td>
<td>0</td>
<td>+</td>
<td>5</td>
<td>+</td>
</tr>
</tbody>
</table>

As a result, Concept 3 has adopted as new lifting equipment for the VPA plates since this alternative got higher scores than the rest (Table 2). As pointed out in Step 5, Concept 3 can’t be applied as it’s designed, therefore some improvements should be implemented on the selected design. The specific improvements made on the concept will be discussed in detail in next section.

### 5.3. New Lifting Equipment Components

The finalized design concept after implementing some improvements will be introduced in below figure and what kind of modifications are developed in which ways are described in detail afterwards.

The adopted/modified design concept comprises a double-hinge typed pivot supporter (x2), a lifting beam with double hook at both ends (x1), webbing slings (x4), shackle and crane hook (Fig 17).
Pivot supporter
This double-hinge type pivot supporter consists of mainly three parts: a base part which supports the pivot (x1), a side part which encloses the pivot (x2) and a sling connector part which link the pivot supporter with slings (x2). In addition, it has a rubber (EPDM) metal protection (x5) attached not to harm the pivot. Rubber materials can be either glued or nailed to the bodies although the former is preferred than the latter because the nail heads might cause scratches on the pivot surface. These three main parts are connected with each other with four clevis pins as shown in the Fig 18 (middle).

Pivot supporter is going to support the pivot as illustrated in Fig 18 (left). Together with slings, the pivot supporters lift up the plate from both sides. Thanks to the hinge design, all the three parts can move around its pins. When the slings grow weary, they can be easily changed by separating sling connector from side parts.

Figure 17 Design of New Lifting Equipment
Either stainless or carbon steel can be a potential option although a variety of materials are available for the pivot. Excellent resistance to corrosion makes stainless steels very versatile in their applicability while carbon steels are known for their outstanding ductility and toughness. As a consequence, both materials should be regarded as best alternatives. The mechanical properties are presented in Table 3 below.

<table>
<thead>
<tr>
<th></th>
<th>Stainless Steel</th>
<th>Carbon Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s Modulus (psi)</td>
<td>2.799E+07</td>
<td>2.901E+07</td>
</tr>
<tr>
<td>Poisson’s Ratio (ul)</td>
<td>0.30</td>
<td>0.29</td>
</tr>
<tr>
<td>Shear Modulus (psi)</td>
<td>1.247E+07</td>
<td>1.156E+07</td>
</tr>
<tr>
<td>Density (pound/ inch^3)</td>
<td>0.292</td>
<td>0.284</td>
</tr>
<tr>
<td>Yield Strength (psi)</td>
<td>3.626E+04</td>
<td>5.076E+04</td>
</tr>
<tr>
<td>Tensile Strength (psi)</td>
<td>7.832E+04</td>
<td>6.092E+04</td>
</tr>
</tbody>
</table>

The edges of the upper part of sling connector are recommended to be rounded in order to reduce stress come from the slings so that cracks in the body can be avoided.

**Working Principle**

The working principles for the vertical and horizontal plates vary from one another because physical environments around the plate are totally different from each other when the plate is in any of these situations.

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Vertical Plate

The sling connector part is designed based on combination of Concept 2 and 3. As explained in Subsection 5.1.3, it’s important that the sling must form “choke hitch” around the pivot so that the plate can stay as stable as it’s handled by latches (Concept 2) during the lifting operation.

However, it’s next to impossible to attach the sling around the pivot and form choke hitch from the top plane or the middle plane when the plate is in vertical position (i.e. inside VPA machine) because of a number of obstacles like hydraulic cylinders, outlet corners and support rail beams etc that neighbored around the pivot (Fig 10).

Therefore, we need a device that satisfies the following conditions:

- To keep the plate stable throughout lifting operation, pivots must be held tightly with devices like latch (Concept 2) or wrapped in choker hitch if the device is sling.
- To avoid working inside the machine, operator must reach the pivots from the top plane (or the middle plane) behind the handrails.

Both conditions will never be satisfied with Concept 2 alone neither with Concept 3 as we know. However, a pair of slings with pivot supporter can satisfy both of them: the pivot supporter can hold the pivot tighter than sling as they are made of metal like latch and slings work as an extended arm for operators. Even rubber protection material helps the pivot not to glide away or being loose thanks to its sticky feature due to the frictions.

In order to attach the pivot supporter to the pivot (to hold the pivot), only one sling with pivot supporter will be hanging down from lifting beam between the plates (Fig 19 step 1). Next, the operator will pick up the other hanging sling with extra device so that the pivot supporter will be placed under the pivot (Fig 19 step 2). From perspective of stability, it would be better if the pivot supporter didn’t consist of different parts but of one whole/ solid entire body.

To attach the pivot supporter around the pivot, it should pass between pivot and rail beam (Fig 20) where a very limited room is allowed to pass by; length from bracket (on the plate) to shaft of slide block (connected to pivot) is 121mm and height from pivot to top of the rail beam is 132 mm. As seen in Fig 18, a flexible device made of a several pieces which are rotatable around their axes relative to each other can pass through easier than a device built as one solid body. That’s why a double-hinge type pivot supporter is chosen as a most appropriate device for this condition.

In next step, the operator will put the other sling over the lifting beam hook (Fig 19 step 3). Step 1-4 will be repeated at the other side of the plate if there is only one operator or these steps can be performed at the same time when more than one operator are available (Fig 19 step 4).
Horizontal Plate

Process of attaching the pivot supporter to the pivot is a simple for the horizontal plates but at a sacrifice of complicated raising process. Unlike the vertical plate, no obstacle prevents the operator to reach the pivot when the plate is in horizontal position. As a consequence, there is no need of an extra device which was used in case of a vertical plate.

On one hand, raising the plate from horizontal position upward is not as simple as it seems due to the smaller distance between the pivots. The pivot supporter has a thickness of 48mm against a distance of 16mm between the pivots, so it can’t pass through between them. Therefore, we need a different lifting procedure here.
Figure 21 Pivot Supporter for the Horizontal Filter Plates

Having less thickness than 16mm, the sling is able to be placed between the pivots first (Fig 21 A). It’s considered that the other ends of the slings are already placed over the hooks of the lifting beam (which is not seen in the figure above). Once the lifting beam starts to pull up the slings, the plate rises upward and as a result, a sufficient room will be provided for the sling connector to pass fully the pivot. Now the plate is ready to be lifted up with lifting beam which in turn hangs from the crane as/ since the pivot supporter is in right place where it should be (Fig 21 B).

More detailed drawings of the pivot supporter with clevis pins are found in Fig 38 and Fig 39 of Appendix C.

Sling

The four webbing slings, a couple of a pair of slings at each side of the plate, are used to connect the pivot supporter to the hooks of the lifting beam in total. The webbing slings are made of usually high-strength synthetic fibers such as nylon, polypropylene or polyester.

The sling has two eyes at both ends; the lower one is threaded through the pivot supporter (sling connector) while the upper one is hung over the lifting beam hook. The upper eye is rotated 90° to the plane of the main body so that the sling body needn’t to be twisted during the lifting operation (Fig 22). When the sling with eye terminations is in use, consideration must be taken to ensure that the length of eye is not too short in regard to diameter of the object within it so that the internal angle of the sling eye
doesn’t exceed 20°; the eye length(s), designed after the standard, is 3-5 times greater than the diameter of the object within it (sling connector and lifting beam hook are the objects inside the sling eyes).

The standard thickness of the webbing sling for <500kg load is considered to be around 7mm. However, extra layers which have same thickness as the sling are recommended to be sewn to the sling at wear points on either or both sides of the sling body. Due to the lowering or tilting applications where friction between sling and plate is of importance, the sling body should be protected with extra layers throughout its length and breadth in the same manner as sling eyes are done.

It’s recommended to use approximately 3m sling from lower sling eye to upper sling eye. This dimension can be referred to as distance between the pivot where the lower eye is attached and lifting beam hook where upper eye is attached. The lifting beam and operator on the top plane must be on same level so that the latter can reach the former without (great) suffering. (This level is the most appropriate height for an operator to hang the sling over the lifting beam hook from inside handrail on the top plane (see Fig 19 Step 3)). Therefore, sling with excessively long or short length will result in greater level difference between operator and lifting beam possibly causing a possible fall of operator from the top plane.

The webbing sling provides all the above mentioned conditions (length, sling eye type & length etc) will be purchased.

Figure 22 Sling eyes face different directions
Sling eye dimension can be found in Fig 40 from Appendix C.

Lifting Beam with double hooks
The lifting beam with double hooks (Fig 23) can be purchased and manufactured locally considering shipping/transportation cost from Sweden to Australia.

It comprises three parts: a standard stainless steel W/I beam, double hook (sometimes called ramshorn hook) at both ends of lifting beam where slings will hang down and bail which is positioned over the beam center and will be lifted up with crane hook.

A stainless steel spreader beam is available in the market, but double hook will be manufactured/ designed in a manner that webbing sling hangs down from double hook can be as straight as possible and distance between the two slings on the same hook can be as little as possible in order to maintain stability of the plate being lifted up. In other words, double hook must be welded on the lifting beam exactly above the pivot otherwise operator on the top plane is unable to reach the hook if the hook is welded towards the center of lifting beam. Besides it, width/ thickness of hook should be kept as little as possible so that a pair of slings on the same hook can stay close to each other allowing for the pivot supporter holds the pivots tightly (Fig 23: right).

Dimensions for double hook and bail will be designed based on standard dimensions taken from a homepage where standard spreader beams are being developed and introduced27.

Crane hook and shackle
Both crane hook and shackle can be purchased on site. Crane hook should be capable of being locked so as to prevent any accidental uncoupling, that’s why it’s preferred to be equipped with latch to prevent the load disengagement. D-shackle with bolt and nut will connect the lifting beam to the crane hook. Shackle body should be large enough to insert the bail hole. Each device is capable of lifting 1.5ton load (Fig 24).

Hooks are available in different cross section of area like circular, rectangular, triangular and trapezoidal. The crane hook with trapezoidal cross section of area is used in FEM analysis because this type of hook has a higher ability to withstand stress

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developed at critical areas than that of other types of hooks according to the several studies\textsuperscript{28}.

\textit{Figure 24 Crane Hook with Shackle}

See detailed dimensions on the crane hook as well as shackle in Fig 41-42 in Appendix C.

\textbf{Grabber}

The grabber is not a lifting device itself but a supporting item which is designed to help new lifting equipment to lift up the plates in vertical position. The operator from the top plane will use this device to pick up the other side of the pivot supporter with sling from underside of the pivot so that the pivot supporter is around the pivot (Fig 19 Step 2), i.e. the grabber functions as an extended arm for the operator. The grabber can be either purchased (selected from available items) or manufactured or ordered from suppliers. The arm should be a long enough to reach from the top plane to the pivot. The protection rubber material is necessary for the hook part because it often meets the pivot and pivot supporter which made of metals. The grabber can possibly be used for different purposes as the operator has a limited access to the plates inside VPA machine; for instance, to utilize it in Step 3 (Fig 19) in case the lifting beam hook is beyond the reach for the operator. See some examples of the grabber in Fig 25.

\textit{Figure 25 Grabber and Sticker}

6. Analytical and Numerical Analysis for Lifting Equipment

The objective of this chapter is to investigate whether the designed components of the lifting device act in accordance with the theoretical knowledge described in Chapter 2. Even FEM structural analysis is performed on the both whole package of the load and the pivot solely in the end of the Chapter partly to discover the critical points on the latter and partly to support the result of the analytical calculations.

6.1. Shear Stress in Lifting Beam

6.1.1. To compute shear force in lifting beam

Load diagram

Lifting beam length $L = 2240mm$
Length between two attachments $l = 2190mm$
$P = $ crane hook pulls the lifting beam upwards
$R_a, R_b = $ slings around the pivots pull the lifting beam downwards

↑: $R_a + R_b - P = 0$
$P = R_a + R_b$

The plate is symmetrically lifted with lifting beam, so $R_a = R_b$. This leads to:

$P = 2R_a = 2R_b$  \hspace{1cm} (6.1)

The membrane plate mass can be rounded to 600kg (actual mass is 575kg). In order to simplify the calculation, acceleration of gravity is rounded to 10 m/s$^2$ as well:

$F = mg = 600kg \cdot 10 \frac{m}{s^2} = 6000N$
$P = F = 6kN$

From equation (6.1):

$R_a = R_b = \frac{P}{2} = 3kN$
Shear and Moment Diagram

Shear and moment diagrams help to determine the value of shear force and bending moment at a given point in the lifting beam. The lifting beam should be broken in several segments so that shear and moment values will be specified at all change of loading positions.

\[ \uparrow: \text{shear force at cross section along the } y\text{-axis} \]
\[ \rightarrow: \text{normal stress at cross section along the } x\text{-axis} \]
\[ \circ: \text{bending moment at cross section} \]

Break1: \[ 0 < X < (L - l)/2 \]

\[ \begin{align*}
\uparrow: & \quad V = 0 \\
\rightarrow: & \quad N = 0 \\
\circ: & \quad M = 0
\end{align*} \]

Break2: \[ (L - l)/2 < X < L/2 \]

\[ \begin{align*}
\uparrow: & \quad V - R_a = 0 \iff V = R_a \\
\rightarrow: & \quad N = 0 \\
\circ: & \quad -R_a \left( X - \frac{L-l}{2} \right) + M = 0 \iff M = R_a \left( X - \frac{L-l}{2} \right)
\end{align*} \]

When \( X \) is \( (L - l)/2 \), the moment will be:

\[ M = R_a \left( X - \frac{L-l}{2} \right) = R_a \left( \frac{L-l}{2} - \frac{L-l}{2} \right) = 0 \]

When \( X \) is \( L/2 \), the moment will be:

\[ M = R_a \left( X - \frac{L-l}{2} \right) = R_a \left( \frac{L}{2} - \frac{L-l}{2} \right) = R_a \frac{l}{2} \]

Break3: \[ L/2 < X < L/2 + l/2 \]
When $X$ is $L/2$, the moment will be:

$$M = R_a \left( X - \frac{L - l}{2} \right) - P \left( X - \frac{L}{2} \right) = R_a \frac{l}{2}$$

When $X$ is $(L + l)/2$, the moment will be:

$$M = R_a \left( X - \frac{L - l}{2} \right) - P \left( X - \frac{L}{2} \right) = R_a l - P \left( \frac{l}{2} \right) = R_a l - 2R_a \left( \frac{l}{2} \right) = 0$$

Shear and moment diagram will be plotted according to the values obtained above:
As seen from shear and moment diagram, the maximal bending moment is obtained at middle of the lifting beam at which the maximal shear force is $V = R_a = 3kN$.

6.1.2. To compute First Moment of Area
Using equation (2.2), first moment of area on the I-shape beam is calculated as below:

$A_1 = 128 \cdot 11 = 1408mm^2$
$a_1 = 52.5 + 5.5 = 58mm$
$A_2 = 52.5 \cdot 8 = 420mm^2$
$a_2 = 52.5/2 = 26.25mm$

$Q = A_1 \cdot a_1 + A_2 \cdot a_2 = 1408 \cdot 58 + 420 \cdot 26.25 = 92689mm^2 \approx 0.93 \cdot 10^{-4}m^3$

6.1.3. To compute Moment of Inertia
Equation (2.3) gives:

$I_x = \frac{bh^3}{12} - 2\frac{fd^3}{12} = \frac{128 \cdot 127^3}{12} - 2 \frac{60 \cdot 105^3}{12} = 10273168.67mm^4 \approx 0.1 \cdot 10^{-4}m^4$

Width of Section

$B = 8mm = 8 \cdot 10^{-3}m$
Shear stress can be computed according to Equation (2.1) since all the variables are known now:

\[ \tau = \frac{VQ}{IB} = \frac{3000N \cdot 0.93 \cdot 10^{-4}m^3}{8 \cdot 10^{-4}m \cdot 0.1 \cdot 10^{-4}m^4} = 3487.5 \cdot 10^2 \frac{N}{m^2} = 3.5 \frac{N}{mm^2} \]

On the other hand, maximum allowable stress in the steel material (1.0038) is calculated with Equation (2.5):

\[ \text{maximum allowable stress} = \frac{\text{ultimate tensile strength}}{\text{factor of safety}} = \frac{320 N}{5} = 64 \frac{N}{mm^2} \]

Result: shear stress in the lifting beam \( \left( \tau = 3.5 \frac{N}{mm^2} \right) \) is sufficiently less than maximum allowable stress \( \left( 64 \frac{N}{mm^2} \right) \) → Safe to use!

6.2. Shear Stress in Pin

Tension in one sling connector is expressed as \( T = \frac{W}{4} = \frac{6000N}{4} = 1500N \).

The pin fits snugly in the hole of the pivot supporter, so the pin diameter is identical to the diameter of the hole in the pivot supporter, \( d = 24mm \). If we define \( P \) as a force applied on each sling, then \( P \) is equal to \( T/2 \):

\[ \text{According to the equation (2.6), } \tau = \frac{4P}{\pi d^2} = \frac{4 \cdot 750N}{\pi (0.024m)^2} = 1.66 MPa \]

When the plate is being raised from or lowered to the horizontal position, only one sling connector member with its other pair will support the plate which suppress with its full
weight on it. Consequently, shear stress for the pin will be doubled followed by doubled applied force on it in this case:

\[ \tau_{\text{pin in horizontal plate}} = 1.66 \text{MPa} \cdot 2 = 3.32 \text{MPa} \]

If the pin is considered to be steel as the pivot supporter, the maximum allowable stress of \( 64 \text{N/mm}^2 \) can be used in estimating the maximum safe load on it.

Result: \( 1.66 \text{MPa} < 64 \text{MPa} \rightarrow \text{Safe to use!} \)

\( 3.32 \text{MPa} < 64 \text{MPa} \rightarrow \text{Safe to use!} \)

6.3. Tensile and Bending Stresses in Different Pivot Supporter Parts

To compute tensile strength applied at either sling connector with Equation (2.4):

\[
\begin{align*}
\text{Area} &= 48 \text{mm} \cdot 20 \text{mm} = 960 \text{mm}^2 \\
P &= T = 1500 \text{N} \quad \text{(see shear stress in pin)} \\
\tau &= P/A = 1500 \text{N}/960 \text{mm}^2 = 1.5625 \text{N/mm}^2 = 1.56 \text{MPa}
\end{align*}
\]

Figure 26 Sling Connector and Section

\[ \tau_{\text{pin in horizontal plate}} = 1.56 \text{MPa} \cdot 2 = 3.12 \text{MPa} \]

Result: \( 1.56 \text{MPa} < 64 \text{MPa} \rightarrow \text{Safe to use!} \)

\( 3.12 \text{MPa} < 64 \text{MPa} \rightarrow \text{Safe to use!} \)

Thus, as stated previously, tensile strength occurred at side part due to the load is ensured to be less than the maximum allowable stress.

To compute compressive stress at base part from Equation (2.4):

Effective area which subjected to force due to the pivot is
\[ A = 40mm \cdot 90mm = 3600mm^2 \]
\[ P = 3000N \]
\[ \tau = \frac{P}{A} = \frac{3000N}{3600mm^2} = 0.83\, MPa < 64\, MPa \quad \rightarrow \text{Safe to use!} \]

**Calculation**

The Equations (2.7)-(2.9) used to identify the adequate WLL can be applied to our case. The plate is symmetrically lifted up with four slings of the same length.

Using (2.7), \( LAF = \frac{L}{H} = 1 \) (Note: Headroom and sling length are established at approximately same length)

Using (2.8), \( SOL = \frac{600\, kg}{4} = 150\, kg \)

Using (2.9), \( Tension = LAF \cdot SOL = 1 \cdot 150\, kg = 150\, kg \)

The number of sling legs will be halved when the plate is either lowered to the horizontal plane or raised up from the horizontal plane:

\[ SOL = \frac{600\, kg}{2} = 300\, kg \]

\[ Tension = LAF \cdot SOL = 1 \cdot 300\, kg = 300\, kg \]

As shown in Table 4, the minimum working capacity for a single webbing sling is \( 0.5t = 500\, kg \) (> 300 kg OK)

*Table 4 Sling Chart*\(^{29}\)

![Table 4 Sling Chart](image)

### 6.4. Welding Calculation

The welding theory described in subsection 2.2.5 will be applied in computing of sufficient weld throat which is necessary to sustain the whole load (plate) with spreader beam.

Total load of the plate, lifting beam, slings and other accessories hanging from the lifting lug is (each mass of the items are obtained from Table 8):

\[ P = Mg = (m_{\text{plate}} + m_{\text{beam}} + m_{\text{slings}} + m_{\text{pivot.supporter}} + m_{\text{rubber.protectors}})g = (600 + 110 + 32 + 0.2) \text{kg} \cdot 9.81 \text{m/s}^2 = 7400\text{N} \]

\[ W = 610\text{mm} \] if the fillet weldment is executed along the whole length of the lifting lug (Fig 52 in Appendix F).

Combining equations (2.12) and (2.13), the following expression will be obtained:

\[ 2\sigma_\perp = \frac{2P}{\sqrt{2}aw} = \frac{\sqrt{2}P}{aw} = \leq \frac{f_u}{\beta_w \gamma_{M2}} \]

According to the Table 10 (Appendix F), design strength of carbon steel 1.0038 (S235) is equal to 360MPa \( (\frac{f_u}{\beta_w \gamma_{M2}}) \).

The weld throat a must be:

\[ \frac{\sqrt{2}P}{aw} \leq \frac{f_u}{\beta_w \gamma_{M2}} \iff a \geq \frac{\sqrt{2}P}{360\text{MPa} \cdot W} = \frac{\sqrt{2} \cdot 7400\text{N}}{360\text{N/m}^2 \cdot 610\text{mm}} = 0.05\text{mm} \]

A small weld throat \( (a \geq 0.05\text{mm}) \) results in the reasonable cost followed by the little weld amount.

We will check if the second condition (2.14) is satisfied with the specified weld throat below. First, it’s necessary to compute \( \frac{f_u}{\gamma_{M2}} \) using correlation factor obtained from Table 11:

\[ \frac{f_u}{\beta_w \gamma_{M2}} = 360\text{MPa} \iff \frac{f_u}{\gamma_{M2}} = 360\text{MPa} \cdot \beta_w = 360\text{MPa} \cdot 0.8 = 288\text{MPa} \cdot \]

\[ \sigma_\perp = \frac{P}{\sqrt{2}aw} = \frac{7400\text{N}}{\sqrt{2} \cdot 0.05\text{mm} \cdot 610\text{mm}} = 172\text{MPa} \leq 288\text{MPa} \]

Since the both conditions satisfied, welding with weld throat \( \geq 0.05\text{mm} \) and length of 610mm is sufficient to hold the plate including the spreader beam and other accessories.

### 6.5. Finite Element Analysis (FEM)

Finite Element Analysis is widely accepted in all engineering disciplines as finite model can be represented in a detailed structure with greater precision than conventional simplified hand calculations. Since actual shape, constraints, as well as material properties can be specified with greater accuracy than that used in hand calculation, the numerical analysis should be regarded as more reliable than analytical analysis.
The objective of this section is to perform a simulation on the configuration of designed system and to determine its real world behavior under identical environment where it’s going to be used. Once the analysis is completed, the feasibility of the new design will be evaluated focusing on the pivot supporter and identify the critical stress and fail points. In addition, displacement and safety factor information will be obtained.

The lifting analysis is performed using the Autodesk Inventor Simulation Software.

**Structural and Material Details**

The plate used in the simulation has a simplified design than the actual one at the plant. Due to design modification, the weight increases up to around 600 kg which is heavier than the actual plate. The rest of the structural dimensions such as height, length, width and depth are kept same.

The desired material EPDM for the rubber protection was not on the list. Therefore, a butyl rubber instead of EPDM is selected for it under simulation running. Both materials have similar mechanical properties (Table 5), so simulation results wouldn’t differ in a great extent in case EPDM was selected. For same reason, a nylon 6.6 is defined for the webbing sling (Table 6). Material for lifting beam as well as pivot supporter will be high strength steel with yielding stress of 320MPa.

**Table 5 Comparison of EPDM and Butyl Rubber**

<table>
<thead>
<tr>
<th></th>
<th>EPDM</th>
<th>Rubber Butyl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s Modulus</td>
<td>1.45E+03</td>
<td>2.901E+02</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>0.50</td>
<td>0.44</td>
</tr>
<tr>
<td>Yield Strength (MPa)</td>
<td>21.99</td>
<td>15.002</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>27.5997</td>
<td>15.002</td>
</tr>
</tbody>
</table>

**Table 6 Comparison of Polyester and Nylon 6.6**

<table>
<thead>
<tr>
<th></th>
<th>Polyester</th>
<th>Nylon 6.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus of Elasticity (GPa)</td>
<td>2.06 – 4.41</td>
<td>1.59 – 3.79</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>0.37 – 0.44</td>
<td>0.39</td>
</tr>
<tr>
<td>Yield Strength (MPa)</td>
<td>59 – 100</td>
<td>55.1 – 82.8</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>41.4 – 89.7</td>
<td>94.5</td>
</tr>
<tr>
<td>Density (g/cm$^3$)</td>
<td>1.04 – 1.46</td>
<td>1.14</td>
</tr>
</tbody>
</table>

6.5.1. **Lifting Equipment Arrangement Simulation**

**Von Mises Stress**

Von Mises stress is used to check whether the design is able to withstand a given load. The lifting equipment is subjected to none other than the gravity load due to the plate.

No critical stress was recognized on the lifting beam or pivot supporter except at the following points of shackle and crane hook.

---

30 Ibid., p. 28.  
31 Ibid., p. 28.
The max critical stress found on the shackle is 88.1MPa out of 234.2MPa which is approx. 38% of maximum stress. On the other hand, 199MPa stress is found on the tip of the crane hook where the latch sits (see Fig 43 in Appendix D).

**Displacement**

The plate is displaced down with 0.44mm at maximum due to the stretch/elongation of the nylon slings caused by the load. This very small displacement assumes that there is no significant deformation followed by changed stiffness occurs at any of the individual components during loading (see Fig 44 in Appendix D).

**Safety Factor**

Generally, it’s considered to be safe if a safety factor is larger than 1 at a location in the material and failed if it’s less than 1. The safety factor of 5 is our goal while 4 is common for many applications.

As one can see for a blue color in Fig 45 in Appendix D, this new arrangement of lifting system has exceeded our target of having a safety factor 5.

**6.5.2. Pivot Supporter Simulation**

Except the pivot supporter, all of the equipment components including lifting beam with hook, sling, crane hook and shackle are designed according to the standards. Consequently, there is no need of running FEM analysis on those different members separately. On the other hand, in order to have a closer look at what really happens with pivot supporter when it’s subjected to the load, it’s effective to carry out FEM simulation solely on the pivot supporter.

**FEM Result**

Applied force used during the simulation on each pivot supporter is established as follows:

\[
F = \frac{\text{Plate Mass}}{2} \cdot \text{Safety Factor} \cdot \text{Acceleration of Gravity} = \frac{600}{2} \cdot 5 \cdot 9.81 \cdot \frac{m}{s^2} = 14715N
\]

The critical stress points identified at the different parts of pivot supporter is summarized in Table 7:

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Sling connector</th>
<th>Side</th>
<th>Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Inner corners of upper side where webbing sling threads through (Fig 46 in Appendix D)</td>
<td>Lower edges of the pin hole (Fig 46 in Appendix D)</td>
<td>-</td>
</tr>
<tr>
<td>Marked Stress</td>
<td>27.98MPa</td>
<td>18MPa</td>
<td>Below</td>
</tr>
</tbody>
</table>

The relatively sharp corners and presence of holes has acted as stress concentrators in the side and sling connector parts. It’s assumed that reductions in area due to the hole for the sling or clevis pins contribute to the localized increase in stress. On the other hand, there is no critical stress is recognized on the base part regardless of several holes in its structure (Fig 46 in Appendix D).

As regarding to displacement and safety factor, the rubber protection material (rather than the members of the arrangement) is severely subjected to the applied force. The minimum safety factor identified on the pivot supporter is marked with 7.5 out of 15 which exceeds the required safety factor issued by customer (7.5 > 5). These minimum safety factors are discovered on the base rubber protection and corners of sling connector (Fig 47-48 in Appendix D).
7. Cost Analysis

Cost Analysis consists of two parts: manufactured and purchased.

Manufactured: The former includes the designed products which will be manufactured/constructed in China eventually. According to cost contract, the manufacturing and labor cost including material price per 1kg is estimated as 2.67 US dollar (2015). The only component that will be manufactured in China by Metso is a pivot supporter with rubber protections.

Purchased: The rest of the lifting arrangements are either purchased locally or ordered at suppliers in Australia mainly to save transportation cost. Therefore, webbing slings, crane hook and shackles will be purchased in the customer’s country. Generally, it’s considered to be a cost-beneficial to contact local suppliers instead of delivering heavy products such as lifting beam to long destination. However, it could be opposite in some cases where sum of the manufacturing and delivery cost falls below the amount of purchase price.

Accordingly, the lifting beam can be either purchased or manufactured:

- To order the lifting beam at local supplier in Australia
- To manufacture it in China and ship to Australia

Alternative A: The lifting/spreading beam price varies depending on a number of factors such as how many items are being purchased, what kind of material is used and what loading capacity it has and so on. In addition, it varies a lot geographically also.

However, an average price for the spreader beam can be estimated according to the criteria established by W.W.Grainger which offers industrial supplies on and offline. Estimated price will be calculated once the desired working load limit, spreader maximum length and headroom are filled in.

![Figure 27 Lifting Beam Price](source)

The search result shows that the lifting beam that’s the most appropriate for our application will cost 1,474.00 USD per each (Fig 27).

---

As described previously, it’s difficult to know the exact price for other components since the price differ greatly from website to website.

The total price:

- Web sling\(^{35}\) = 23.30USD (WLL x Length: 1T x 3M)
- Shackle\(^{36}\) = 15.00USD (WLL: 800kg)
- Crane Hook\(^{37}\) = 113.85USD (WLL: 5T)
- Lifting beam = 1474.00USD

Total = 1626.15USD = 13009.20SEK (> 5000SEK)

Note: total price calculated here can be less or more than the actual price since there is no way of defining the actual total price for the components included in the arrangement.

*Alternative B*: If the lifting beam is decided to be manufactured in China, it will cost less than buying locally regardless of the shipping cost. Here illustrates total price for the whole arrangement if they would be manufactured in China.

Table 8 Price Chart

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
<th>Piece</th>
<th>Total mass (kg)</th>
<th>Price per kg (USD/kg)</th>
<th>Total price (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubber protection</td>
<td>Rubber</td>
<td>side x2 sling connector x2 base x1</td>
<td>0.2</td>
<td>2.67</td>
<td>0.534</td>
</tr>
<tr>
<td>Pivot Supporter</td>
<td>1,0038</td>
<td>side x2 sling connector x2 base x1</td>
<td>32</td>
<td>2.67</td>
<td>85.44</td>
</tr>
<tr>
<td>Lifting beam including hooks</td>
<td>Steel 1.0038</td>
<td>x1</td>
<td>110</td>
<td>2.67</td>
<td>293.7</td>
</tr>
<tr>
<td>Shackle</td>
<td>Steel 1.0038</td>
<td>x1</td>
<td>0.4</td>
<td>2.67</td>
<td>1.068</td>
</tr>
<tr>
<td>Hook(crane)</td>
<td>Steel 1.0038</td>
<td>x1</td>
<td>0.37</td>
<td>2.67</td>
<td>0.9879</td>
</tr>
<tr>
<td>Slings</td>
<td>Nylon</td>
<td>x4</td>
<td>4.4</td>
<td>2.67</td>
<td>11.748</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>393.4779</strong></td>
</tr>
</tbody>
</table>


\(^{36}\) eBay, 2 x 7 Ton D Link Towing Lifting Shackle, *eBay* [website], <http://www.ebay.co.uk/itm/2-x-7-Ton-D-Link-Towing-Lifting-Shackle-/262284642650>, accessed 14 Dec. 2015.

As presented in Table 8, total price would be 393.4779USD = 3147.8232SEK (<5000SEK).
8. Conclusions and Recommendations for Future Work

8.1. Conclusions

The designed lifting equipment comprises conventional lifting devices like lifting beam, sling, shackle, crane hook in addition to the “pivot supporter”.

Thanks to the long slings from the spreader beam, the operator was allowed to work outside the filter machine. In addition, all the four slings help the plate to stay stable during the lifting operation by enclosing it from both sides. In order to avoid the sling wear due to the friction with outlet corners and hooks, the slings were equipped with extra layers so that they won’t be broken easily.

Since the sling can’t be formed in choker hitch around the pivot without the operator’s closer presence to the pivot, something that holds the pivot tightly was necessary to be designed. As a result, a lifting device called pivot supporter was designed in order to ensure the compliance with requirements described in Section 5.3 (Page 29). The pivot supporter around the pivot holds it tight so that the plate can be handled in a safer way and allows the operator to operate in work zones. It consists of the three parts which can move freely with respect to each other. This hinge design helps the pivot supporter to pass through the limited space between the pivot and rail beam (Fig 20). The pivot supporter was equipped with rubber protection materials not to harm the pivot since it directly attached to the pivot.

The lifting beam with ramshorn hook at both ends was used to lift up the plate with help of the slings. The positions of the double hooks on the lifting beam should be considered carefully so that the slings hang down from the hooks will not be tilted to the sides. Besides it, thickness of the ramshorn hook should be kept as little as possible otherwise unnecessary thicker design put the pivot supporters at risk of opening wide followed by the slings (remember that the pivot supporters around the pivot should be held tight).

As for the crane hook and shackle, they will be purchased at the site. Shackle should be chosen in a manner that the lifting lug can be fitted into the shackle body.

Although the new lifting equipment has fulfilled the safety requirements, there is still room for improvements regarding the design. As mentioned in Horizontal Plate of Section 5.3, an issue related to the operation of lowering the plate to the ground was left unsolved. When the plate is lowered onto the ground, the two of the slings are happened to be laid under the plate (more correctly, under the upper outlet corners) and the slings are forced to be dragged from the underside of the plate.

Each individual component is described in separate subsections in order to have a closer look at the members. Furthermore, manual calculations were made on the lifting beam, sling, pivot supporters and the lifting lug (bail) to investigate to what degree the
designed parts can be feasible or reliable for the specific application. According to the calculation results, all of the lifting equipment parts are feasible for handling of the VPA plates and all the stresses occurred in each component are far lower than the maximum allowable stresses (Chapter 6). Welding calculation made on the lifting lug indicates that a very small amount of the welding is sufficient to lift up the whole load including the plate and lifting beam.

Besides it, FEM analysis was performed to compare an analytical analysis with numerical one. It has reached a conclusion that FEM result supports the manual calculation in large extent. However, some critical points are discovered on the pivot supporter around its corners. As those critical points are impossible to be discovered with simple manual calculations, the results of FEM analysis should to be taken seriously in the later manufacturing stage of the pivot supporter.

Lastly, a cost analysis is carried out to examine if the economical requirement has been fulfilled. Pivot supporter is going to be manufactured in China according to the special contract with Metso whereas the rest of the components are going to be ordered locally. As for the lifting beam, it can be either manufactured in China or purchased in Australia depending on which alternative is cost-beneficial. Alternative B cost less than Alternative A as far as we believe the price suggestions described in Chapter 7 are close to the actual prices.

8.2. Recommendations for Future Work

Although the new lifting system presented in the thesis have demonstrated safer and relatively robust mechanism compared to the conventional fiber method, it could be further developed in a various ways:

- Adjustable Lifting Beam: In the new lifting model, double-hook is attached firmly to the beam ends. However, if the beam has the adjustable attachments, it can be applied for the other plants and sites where the different types of the VPA plates are in use.
- To find a better solution for taking off the webbing slings from under the plate. As described in Section 5.3, the slings are trapped under the load after lowering it on the ground. It’s important to avoid situations where slings must be dragged from a load resting on it.
- According to the manual calculation, the pivot supporter is many times stronger than it need to be. Since there is a very limited space for the pivot supporter under pivot in the VPA filter, a modification of geometry is strongly recommended on the structure so that it would have less volume.
- Cost Analysis should be recorded in a more accurate and detailed way. Market price for the lifting components such as shackle and crane hook must be calculated after comparing a several prices at different suppliers. Even the current costs for the raw material as steel, nylon or rubber should be examined carefully.
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Appendix A

VPA Filter and Plate

Figure 28 VPA Top Plane View

Figure 29 Fiber strap (A) through the inlet hole (B)
Figure 30 Filter Plates with Notch

Figure 31 Plates in the wooden box
Platform Proposal

Figure 32 Platforms around three VPA filters

Figure 33 Platform front view
Figure 34 Platform side view

Figure 35 VPA filters
Appendix B

Industrial Lifting Equipment

Figure 36 Examples of Magnetic Lifter

Figure 37 Example of Vacuum Lifter
Appendix C

New Lifting Design

Figure 38 Pivot supporter parts

Figure 39 Clevis pin
Figure 40 Webbing Sling
Examensarbete: DEVELOPMENT OF NEW LIFTING EQUIPMENT FOR VPA PLATES

Figure 41 Crane Hook

<table>
<thead>
<tr>
<th>Kad</th>
<th>ZN01128</th>
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<tbody>
<tr>
<td>Kostning</td>
<td>604-8-10</td>
</tr>
<tr>
<td>L</td>
<td>64 mm</td>
</tr>
<tr>
<td>R</td>
<td>24 mm</td>
</tr>
<tr>
<td>Max last ton</td>
<td>1.5</td>
</tr>
<tr>
<td>G</td>
<td>17 mm</td>
</tr>
<tr>
<td>E</td>
<td>22 mm</td>
</tr>
<tr>
<td>F</td>
<td>10 mm</td>
</tr>
<tr>
<td>H</td>
<td>20 mm</td>
</tr>
<tr>
<td>kg/kl (Weight, kgs)</td>
<td>6.34 kg</td>
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</table>


Figure 42 Shackle

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<tr>
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<td>Kostning</td>
<td>Standard Shackle No 835</td>
</tr>
<tr>
<td>d</td>
<td>13 mm</td>
</tr>
<tr>
<td>d1</td>
<td>16 mm</td>
</tr>
<tr>
<td>a</td>
<td>21 mm</td>
</tr>
<tr>
<td>e</td>
<td>41 mm</td>
</tr>
<tr>
<td>d2</td>
<td>33 mm</td>
</tr>
<tr>
<td>d1 inch</td>
<td>0.5 inch</td>
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<tr>
<td>WLL</td>
<td>2.01</td>
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Appendix D
FEM Simulations

Lifting Assembly FEM Result

Von Mises Stress

Figure 43 Lifting Equipment Arrangement - Von Mises
Displacement

![Displacement Diagram]

*Figure 44 Lifting Equipment Arrangement - Displacement*

Safety Factor

![Safety Factor Diagram]

*Figure 45 Lifting Equipment Arrangement - Safety Factor*
Pivot supporter

Von Mises

Figure 46 Pivot Supporter - Von Mises

Displacement

Figure 47 Pivot Supporter - Displacement
Safety Factor

*Figure 48 Pivot Supporter - Safety Factor*
Appendix E

Figure 49 Basket Hitch

Figure 50 Choke Hitch
Appendix F

Table 9 Butt and T-joint welds

<table>
<thead>
<tr>
<th>Butt-joint (Fig 51: left)</th>
<th>T-joint (Fig 51: right)</th>
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<tbody>
<tr>
<td>Square-groove butt weld</td>
<td>Fillet weld</td>
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<tr>
<td>Bevel-groove butt weld</td>
<td>Plug weld</td>
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<tr>
<td>V-groove butt weld</td>
<td>Slot weld</td>
</tr>
<tr>
<td>J-groove butt weld</td>
<td>Bevel-groove weld</td>
</tr>
<tr>
<td>U-groove butt weld</td>
<td>J-groove weld</td>
</tr>
<tr>
<td>Flare-V-groove butt weld</td>
<td>Melt – through weld</td>
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<tr>
<td>Flare-bevel-groove butt weld</td>
<td>Flare-bevel-groove weld</td>
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Figure 51 Types of Butt and T-joint welds

Table 10 Design Strength for Various Materials

<table>
<thead>
<tr>
<th>EN10025 steel grade</th>
<th>Yield strength $f_y$ (N/mm²)</th>
<th>Ultimate tensile strength $f_u$ (N/mm²)</th>
<th>Correlation factor $\beta_W$</th>
<th>Design Strength $f_{u1} / \beta_W$ Y50</th>
<th>Design shear strength $N_{V,W} = f_u / \beta_W$ [N/mm²]</th>
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<tbody>
<tr>
<td>S235</td>
<td>235</td>
<td>580</td>
<td>0.8</td>
<td>520/0.8</td>
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<tr>
<td>S275</td>
<td>275</td>
<td>530</td>
<td>0.65</td>
<td>484/0.65</td>
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<tr>
<td>S355</td>
<td>355</td>
<td>610</td>
<td>0.9</td>
<td>463/0.9</td>
<td>261</td>
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<tr>
<td>S460</td>
<td>460</td>
<td>660</td>
<td>1.0</td>
<td>432/1.0</td>
<td>266</td>
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<tr>
<td>S560</td>
<td>560</td>
<td>770</td>
<td>1.0</td>
<td>418/1.0</td>
<td>356</td>
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</tbody>
</table>

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40 Ibid., p. 10.
41 Ibid., p. 11.
Table 11 Correlation Factors for various materials^\textsuperscript{42}

<table>
<thead>
<tr>
<th>Standard and steel grade</th>
<th>Correlation factor ($\beta_{in}$)</th>
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<tr>
<td>BS EN 10025</td>
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<tr>
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<td>S235H</td>
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<td>S235W</td>
<td>S235H</td>
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<td>S275</td>
<td>S275H</td>
</tr>
<tr>
<td>S355</td>
<td>S355H</td>
</tr>
<tr>
<td>S420 NNL</td>
<td>S420 NH/MLH</td>
</tr>
<tr>
<td>S460 NNL</td>
<td>S460 NH/MLH</td>
</tr>
</tbody>
</table>

Figure 52 Lifting Lug Length

^\textsuperscript{42} Ibid., p. 11.