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Project Pinnacle

Spring term report

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Abstract

The current process of manual mounting and removal of twistlocks of shipping containers is labour-intensive and unsafe. This project aims to design and create an automated pinning station for shipping containers that can securely and efficiently mount and remove twistlocks in every corner of the container. The stakeholder for this project is LOX Container Technology, a company specialising in automatic, electric, and digitally controlled twistlocks used in the container shipping industry. They aim to automate and improve the safety of container handling operations. The project is conducted as part of the MF2058/MF2059 Mechatronics Advanced Course at KTH in collaboration with LOX Container Technology. The project is divided into two phases; the first phase is presented in this report. The first phase involves comprehensive research into the current state-of-the-art automated pinning solutions for container transportation. Based on this research, innovative concepts and ideas for the pinning station will be designed. The project has researched various existing automated pinning solutions, including systems from KALP, RAM Spreaders (Pinsmart and Pinsmart II), UCLS (Universal Container Locking System), and autonomous vehicles developed by research institutions. These solutions utilise different mechanisms, such as hydraulic systems, electric systems, robotic arms, and autonomous vehicles, to handle twistlocks. The research and requirements were then used to generate design concepts of possible solutions, that were evaluated and iterated in turns until one final concept was decided on. During the second phase, the concept will be constructed into a fully functioning full-scale prototype of one corner with a reduced-size magazine, as stated by the stakeholder.

Acknowledgements

We would like to express our gratitude to LOX Technology for offering us this project and providing us with continuous feedback and support. Their assistance in supplying the necessary resources has been incredibly valuable to our progress. We also extend our appreciation to our project supervisor, Daniel Frede, for his guidance and insightful input throughout the duration of our work. Additionally, we want to thank Björn Möller for connecting us with industry professionals outside of our immediate network, enhancing our project experience.

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List of Acronyms and Abbreviations

HMI Human machine interface

ISO International Organization for Standardization

PM Pinning machine

RORO Roll-on/Roll-off

SOTA State of the art

SWOT Strengths-Weaknesses-Opportunities-Threats

1 Introduction

This chapter provides an overview of the project, covering its background, detailed aspects, scope, and relevant requirements that will serve as guiding principles for its success.

1.1 Background

When shipping containers are transported, they are secured together and to the transport vehicle using twistlocks in each corner. However, this process currently requires manual mounting (pinning) and removal (depinning) of the twistlocks before and after each transport. Workers must manually insert heavy metal twistlocks into the bottom corners of the container while it is suspended from a crane, making this process both labour-intensive and unsafe. This project aims to create an automated pinning station that can securely and efficiently mount and remove twistlocks, eliminating the need for manual labour and creating a safer working environment.

1.2 Project description

This research and development project aims to design and create an automated pinning station capable of securely and efficiently mounting and removing twistlocks. This project is conducted as part of the MF2058/MF2059 Mechatronics Advanced Course at KTH in collaboration with LOX Container Technology, spanning the spring and autumn terms of 2023.

The project is divided into two distinct phases. The first phase involves comprehensive research into the current state-of-the-art automated pinning solutions developed for container transportation. This research will identify existing concepts, technologies, and best practices. Based on this knowledge, we will then proceed to design different innovative concepts and ideas for the pinning station.

The project's second phase is focused on developing and delivering a functional prototype for the pinning station and magazine, explicitly targeting one corner of the container. The prototype will be designed to meet the specified requirements identified during the research phase.

1.3 Scope

This project's scope includes creating a complete design of the pinning machine prototype, including all the required pinning stations and a full-scale magazine. On the other hand, due to resource limitations within the project scope, the implementation will be limited to constructing the full-scale prototype of one corner, including a reduced-size magazine. This approach will allow an evaluation of the prototype's functionality and its feasibility within the constraints of the project.

1.4 Organisation

For the spring, the team was organised to have one team manager and all members to work in sub-teams of 3, having weekly meetings with the whole team and meetings with the stakeholders and the coach when necessary. The work began with the complete team working on the State of the art (SOTA) for two weeks; the aim was that every member understood the existing solutions that would benefit the proceeding preliminary design phase. For the mentioned design phase, the team of 9 was split into sub-teams of 3, and the goal was to develop a complete solution with three different points of view. The best aspects of each design were selected after detailed meetings with the stakeholders. The team was further split into a reshuffled group of 3 to focus on the design of the three essential systems; the pinning station, the transfer bot and the magazine. In such a manner, the final concept for the spring term was established.

1.5 Stakeholders

The stakeholder for this project is LOX Container Technology, located in Stockholm, Sweden. The company specialises in automatic, electric and digitally controlled twistlocks used in the container shipping industry. Their twistlocks are used to improve the speed and safety of container handling operations. The ability to be digitally controlled from a remote distance eliminates the need for manual labour and reduces accidents. Their technology greatly speeds up the loading and unloading procedures, saving a lot of time, which is critical in the supply chain industry.

Founded by Magnus Carlmeister (CEO), the student team receives continuous and great support from Erik Leonton (Research and Development) and Patrik Tiainen (Application and Embedded Software Engineer). With one stellar product in the market, LOX aims to step up the container shipping industry by bringing in more automation and safety.

1.6 Requirements

This section presents an overview of the requirements obtained by the stakeholders and extensive research. The requirements will serve as a guiding principle throughout the project, ensuring the final product meets the expectations.

1.6.1 Stakeholder Requirements

- Pinning machine (PM) shall be able to use for Roll-on/Roll-off (RORO) and Train segments.
- The PM shall work with LOX RCL twistlocks.
- The PM shall be able to handle 20ft and 40ft standard shipping containers.
- The PM should be able to handle 45ft standard shipping containers.
- The PM shall handle a pinning/de-pinning twist motion in less than or equal to 30 seconds.
- The PM shall handle a full pinning/de-pinning cycle in less than or equal to 90 seconds.
- The PM shall contain a magazine that holds a minimum of 160 twistlocks when full
- The PM shall be able to withstand 200G of impact forces when containers land on it.
- The PM shall be able to be moved with at least reach stacker or forklift.
- The PM will only be connected to external power.
- The PM shall have exception handling for when an error arise.
- The PM shall work without any human interaction, except for exception handling or change of magazine.
- The PM shall be implemented as either one placement and one removal machine or as a combined placement and removal machine.
- The PM main functionalities shall be evaluated with a prototype of at least one corner of the container

1.6.2 Technical Requirements

- The PM shall have minimum dimension of 12.192 x 2.438 m (40 ft container).
- The PM shall handle a weight of at least 36 000 kg.
- The PM shall provide a minimum of one emergency stop button.
- The PM will provide a Human machine interface (HMI) for the operators.
- The PM will be further evaluated, beyond the prototype, with computer simulations.

2 State of the art

In order to avoid the pitfalls encountered by previous attempts at designing a twistlock pinning and depinning machine, solutions made by other teams have been thoroughly investigated and evaluated. Their respective strengths and weaknesses have been analysed to establish the groundwork for a prototype that may be robust, fast, and reproducible. Furthermore, the intended prototype's somewhat differing prerequisites regarding lock type specificity and working conditions have been explored.

2.1 Container design

Freight containers are highly standardized by the International Organization for Standardization (ISO) standard 668 *ISO 668:2020* [6]. This includes, among other things, the containers width, length, height, empty weight, and max loaded weight. Furthermore, the standard describes the dimensions and placement of the corner castings. There exist several different types of ISO containers with different dimensions. Common for all types are that they have the same width, 8 ft, and that they all have four corner castings, one in each corner used for connecting containers together. The 45 ft ISO container has 4 extra corner casting placed at the same positions as for the 40 ft container. The ISO standard can be seen in appendix A

2.1.1 Corner castings

Shipping container corners consist of two corner castings, one on the top and one on the bottom, made of high-strength steel that are welded to the container's frame at each corner, see figure 2.1. They distribute the load of the container evenly across the frame, allowing for safe stacking, transportation, and handling. The corner castings also include holes for lifting lugs and interlocking mechanisms to prevent shifting during transportation. It is these corners that are interfaced with interlocking mechanisms, one solution being the container twistlock.

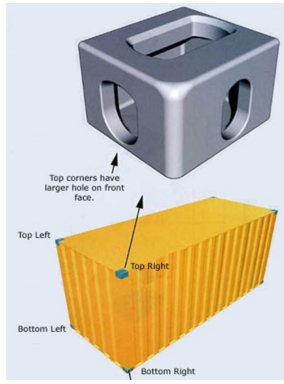
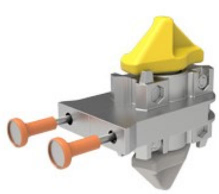


Figure 2.1: Corner castings, [2]

2.1.2 Twistlock

Twistlocks are components located on the corner castings of shipping containers that twist into place and lock containers together during transportation. They prevent containers from moving or shifting while in transit and are made of high-strength steel. Twistlocks are easy to connect and disconnect, and can withstand the forces generated during transportation. They are most commonly applied manually by an operator, which is both time-consuming and labor-intensive.



(a) Conventional Twistlock [1]

(b) LOX Twistlock [4]

Figure 2.2: Twistlocks

LOX Technology twistlocks are a smarter, more modern version of the conventionally used twist lock. LOX has built tracking tags and identities into their twistlocks. This makes them traceable and permits large scale data collection on transports and their lock locations. Additionally, the lower hooks can be electronically engaged and disengaged, saving valuable time and ensuring safety in the loading and unloading processes. Furthermore, they can provide status messages on their state, saving workers time on manual observation.

2.2 Harbour / Container terminals

RORO ships carry trucks loaded with containers; see figure 2.3. These containers are loaded onto the trucks in harbours and container terminals using forklifts, reachstackers, movable cranes etc. To better understand the process of loading and unloading the containers at these harbours and container terminals, a dock worker was interviewed, see Appendix B. Some important information collected from the interview was that stacking a container upon another one was fully dependent on vision, there were no other guidance used.

Figure 2.3: RORO container handling, [5]

2.2.1 Pinning and Depinning

In order to secure the twistlocks to the underside of the container, an operation called pinning is performed. The twistlocks are inserted into corner castings on the underside of the containers, as mentioned in section 2.1.2. After being inserted into the corner castings, the whole lock assembly is turned 45°, thus securing the locks in place. Similarly, the depinning is done in reverse: by first turning the twistlock inside the corner castings, the lock is released. The lock can then be lowered and removed from the container. A container generally has 4 corner castings; therefore, the pinning or depinning operation needs to be done 4 times per container. Many attempts to automate this process have been attempted, as described in section 2.3. However, it still remains predominantly reliant on manual labour even to this day.

2.3 Current Solutions / Previous attempts

This subsections goes through some of the current solutions and previous attempts for twistlock handling in containers.

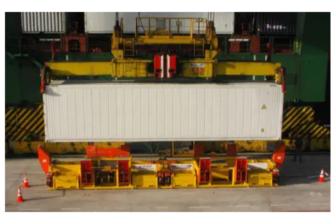
2.3.1 Pinsmart

A solution developed by the company RAM Spreaders is the automatic twistlock handling machine, also called Pinsmart. The solution utilizes a bed with eight fixed pinning stations. The task of the pinning station is the provide the linear and twisting motion needed for pinning and depinning of twistlocks. The bed also utilizes gather guides that guides the container to the right position. The actuators used in the machine are powered with hydraulics. The machine can be seen in figure 2.4a

The machine can handle several kinds of twistlocks although requires manual reloading of the pinning stations. According to RAM Spreaders the reloading of the machine compared with manual pinning results in a 75% reduction in work [8]. The discharging of the pinning station after depinning is fully automatic. Furthermore the machine can handle 20 ft, 40ft and 45ft containers or two 20 ft containers simultaneously.

2.3.2 Pinsmart II

Pinsmart II is a further development of the original Pinsmart discussed in section 2.3.1. It is a stationary solution with 7-axis robotic arms that performs the pinning and de-pinning of twistlocks, see figure 2.4b. Similarly to the original Pinsmart it uses gather guides that guide the container to the correct position. The robotic arms will then perform the pinning or de-pinning operation. The robotic arms can also memorize the exact twistlocks used and their exact positions. The time it takes for Pinsmart II to cone/decode a twistlock is within 10 seconds, and the magazine can hold up to 2000 twistlocks. It is also designed to handle 20 ft, 40 ft and 45 ft containers.



(a) Pinsmart [7]

(b) Pinsmart II [9]

Figure 2.4: Pinsmart 1 and 2

2.3.3 Autonomous vehicle

In cooperation with Siemens, a research project from the Technical University of Delft has created an autonomous vehicle able to do the pinning and de-pinning of twistlocks [10]. The project utilized a four-wheeled vehicle able to navigate to the corner castings. The vehicle formed a platform for a linear actuator, able to insert the twist lock into the corner casting. How the final twisting motion is achieved is not clearly stated. However the linear actuator used was a TL3 industrial column. The TL3 is a rectangular lifting column a with a maximum load of 4000 N and a speed of 13.7mm/s at the max load [11]. The TL3 was deemed suitable as it can handle high loads and operate in a rough environment such as ports. The project was considered a success and an working concept was presented to Siemens. A picture of the autonomous vehicle can be seen in figure 2.5a.

A similar project was developed at Singapore Polytechnic [3]. The vehicle used was a KUKA youBot which uses a similar four wheeled platform with an actuator placed on top. The actuator was in this case is a 6-axis robot. A figure of the used KUKA youBot can be seen in figure 2.5b.

(a) Autonomous vehicle from the University of Delft [11]

(b) KUKA youBot [3]

Figure 2.5: Autonomous vehicle

A key feature of the system is that it features a 3D scanning system that can estimate the pose of the twistlocks. The 3D scanning system is not mounted on the vehicle but in connection to the storage of the locks. The information can then be fed to the vehicle from the 3D scanning system. The vehicle can then use the robot arm to pick up a lock. Finally, the vehicle can locate a corner casting with the help of RFID-based autonomous localisation. When the corner casting has been found, the robot arm can perform the pinning motion.

3 Concept development

At first glance, the task appeared to be challenging in its complexity. The design of an automatic container twistlock applicator had to meet several requirements and constraints, from reliability to error handling. However, the problem was managed effectively by breaking it down into smaller, more manageable pieces. The most critical components of the product were identified and evaluated individually using a Pugh matrix; refer to C. This allowed for an objective assessment of the pros and cons of different design options and data-driven decisions were made. By breaking the task down into smaller parts and evaluating each individually, the project was tackled confidently.

3.1 Design concepts

The design of the PM was divided into three main parts: the magazine's development, the pinning mechanism and the transfer between those parts.

3.1.1 Lock Magazine

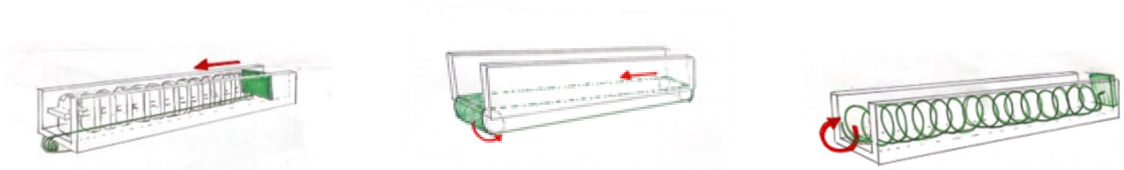
One of the stakeholder requirements was to have a magazine holding at least 160 locks. To achieve this, and to keep the loading process of the locks automated, four different concepts were generated.

Push Magazine The first concept made was the push magazine. The idea behind this concept was that along each long side of the container bed, there would be six chutes for each pinning station holding 40 locks each, see figures 3.1a, 3.1b and 3.1c. The chutes would have traces for keeping the locks in place and in the proper orientation. For pushing the locks to the pinning station, three alternatives were discussed.

The first alternative for pushing the locks was to have a support at the end of the chute connected to a motor by a wire. To load the pinning station, the motor would then roll in the wire, pushing the locks towards the pinning station, see figure 3.1a.

The second alternative for pushing the locks was to have the locks on a belt, see figure 3.1b. This way jamming of the locks could be avoided and the needed force for pushing the locks would be reduced. Having a belt would also allow for depinning by switching the direction of the belt.

The third alternative for pushing the locks was to have a motor connected to a rotating spiral in the chute, see figure 3.1c.



(a) Push magazine alt. 1 (b) Push magazine alt.2 (c) Push magazine alt.3

Figure 3.1: Push Magazine

Conveyor magazine with indexed positions Exception handling is one of the most important features of the machine, for example, rejecting a faulty lock; and it was challenging to incorporate such handling methods in the 'Push Magazine' due to its linear queue-type nature of dispensing locks. To counter this problem, a conveyor magazine concept was introduced. It was essentially a conveyor belt carrying 160 locks indexed into appropriate positions that ran in the middle of the chassis, refer figure 3.2.

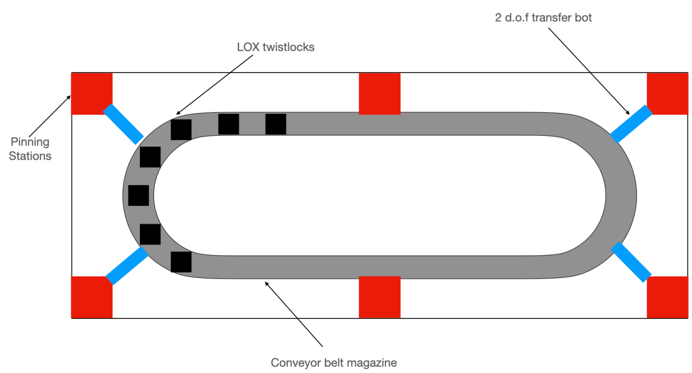


Figure 3.2: Conveyor magazine with indexed positions

This way, it was convenient to access any lock and, at the same time, reject a faulty lock. Transferring the lock from the magazine to the corner casting and vice-versa would be via a two d.o.f pinning station.

Fixed magazine To reduce the complexity of the magazine, a concept where the locks are in a fixed position in the magazine is developed. The locks are stored in the magazine hanging upside down, in the same way as in the corner castings of all containers. The locks can then be inserted into and removed from the magazine with the same motion as the pinning and de-pinning of a container. The fixed magazine is illustrated in yellow in figure 3.3.

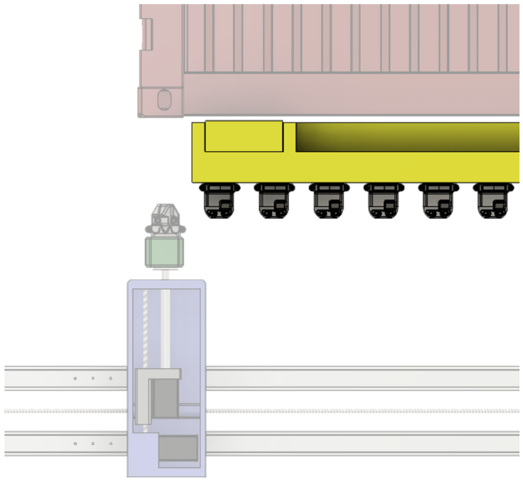


Figure 3.3: Illustration of the fixed magazine shown in yellow

3.1.2 Pinning mechanism

The pinning station must be able to perform a vertical linear and twisting motion to successfully perform a pinning operation and the same motion in reverse to perform a depinning operation.

Gravitational operated pinning station By utilising the gravitational force when loading the container on top of the machine, the pinning station could be powered via hydraulic pressure generated from the weight of the container. This would result in the pinning motion synchronous with the lowering of the container. Also, the pinning station would not need any external power to operate. To achieve the desired linear and twisting motion a cam and follower could be implemented as seen in figure 3.4.

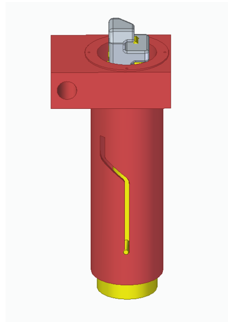


Figure 3.4: Pinning station with cam and follower

If a synchronous pinning motion is undesirable, hydraulic accumulators could achieve a non-synchronous movement. The hydraulic pressure could then be stored to be used when the container is fully in place. It should be noted that a cam and follower results in a gradual twist during the linear movement. This differs from the movement during manual pinning as it is first a strictly linear movement and finished by a strictly rotating movement.

Electrical operated pinning station By using two independent electrical actuators, the desired pinning operation could be performed for the linear movement and one for the twisting motion. A linear guide rail and a rotating lead screw could achieve linear movement. An independent electrical motor can achieve the twisting motion.

No matter what kind of actuation, the pinning station will require a solution for gripping and releasing the locks. This can be done using a claw mechanism that would need at least one more actuator. Using a box with a spring-loaded interior is also possible to clamp the locks by the hooks. The clamping mechanism would release when the linear actuator moves down after pinning. A CAD representation of an electrical-driven pinning station with the box-gripper can be seen in figure 3.5

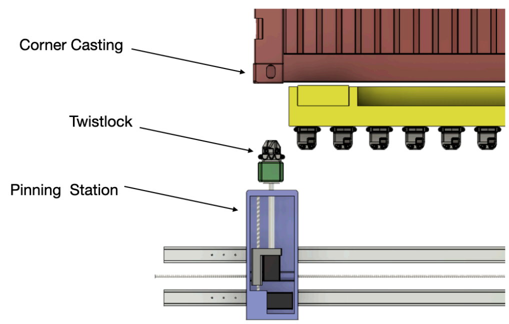


Figure 3.5: Electrical operated pinning station

Dampened pinning station Since the forces when loading a container on the pinning station are significant and potentially damaging, it could be suitable to include some kind of dampening in the pinning station. This could be done by mounting a spring under the pinning station. This could then absorb some of the forces when loading the container to the pinning station. The displacement of the pinning station could also be used to detect the presence of a container or errors. A conceptual design of this can be seen in figure 3.6

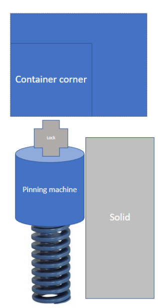


Figure 3.6: Dampened pinning station

Another way to protect the actuators from the forces when loading the container could be to use a compliant actuator. The force from the container would then simply push the actuators down. Both the complaint and dampened pinning stations would allow the locks to be raised while lowering the container. This allows the locks to be used as a guide when reducing the container; this is strengthened by the twistlocks having a cone-shaped head.

Positioning of pinning stations If the machine can handle both 20 ft or 40 ft containers, at least six pinning stations are required, or two fixed and two pinning stations can move horizontally. In the case of six fixed pinning stations, 3 and 4 in figure 3.7a would be deactivated during the pinning of a 40ft container, and 5 and 6 would be deactivated during the pinning of a 20 ft container.

Allowing pinning stations to move would allow the pinning stations to adjust to the container size. During the pinning of a 20 feet container, the movable pinning stations would be in position C and D in figure 3.7b. If a 40 feet container were pinned, the pinning stations could move to positions E and F.

(a) Fixed pinning station - Top view

(b) Movable pinning station - Top view

Figure 3.7: Positioning of pinning stations

3.1.3 Magazine - pinning station interaction

There must be some interaction between the magazine that holds the locks and the pinning station responsible for performing the pinning and depinning. This interaction is achieved using a 'transfer bot'. The transfer bot's design heavily depends on the magazine's design. However, the most important part of this interaction was the orientation of the lock. The twistlock is heavy and does not have a stable centre of gravity; thus, suspending the lock is challenging.

It was decided that independent of the magazine design, the best way to interact with the lock is either using the top conical lock or the bottom hooks, refer Figure 2.2b. This ensures the lock is always vertical, to eliminate the need for complex motions to correct the orientation of it.

Thus, the locks are suspended in the magazine despite its type, into a corner casting-like fixture. The gripper will too be similar to the corner casting. This greatly simplifies the interaction design.

3.2 Concept evaluation

To evaluate the different concepts for each subsystem, a Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis was made; see appendix D. From that, the strengths and weaknesses of each concept became clear. These were then compared to the requirements to choose the winning concept.

For the magazine solutions all different magazine solutions were also plotted in a graph comparing robustness and complexity. As seen in figure 3.8, the fixed magazine has high robustness and lower complexity than the other concepts, both desired features of the design.

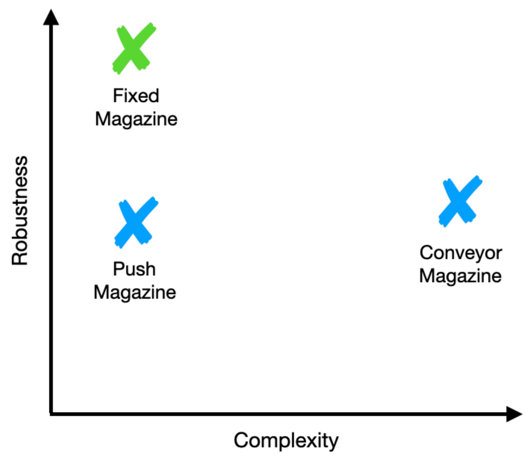


Figure 3.8: Evaluation chart of Magazine Concepts

3.3 Selected concept

The selected concept is a fixed platform designed to accommodate both 20 and 40 ft containers. It incorporates modular "pinning stations" and a twistlock magazine, providing a versatile solution for container handling operations. This section will overview the platform's key features and outline its capabilities.

3.3.1 Fixed platform

The fixed platform serves as a stable foundation for container handling activities. Its primary purpose is to hold containers of varying sizes, ensuring efficient operations securely. Designed to accommodate both 20 and 40 ft containers, the platform offers flexibility to adapt to different cargo requirements in logistics and transportation. Additionally, the platform is equipped with container fittings that enable it to be easily moved with a reach stacker. Figure 3.9 visually represents the fixed platform, including its dimensions and layout. To further illustrate the capabilities of the selected platform, figure 3.10 showcases the platform with 20 and 40-ft containers placed on top of it.

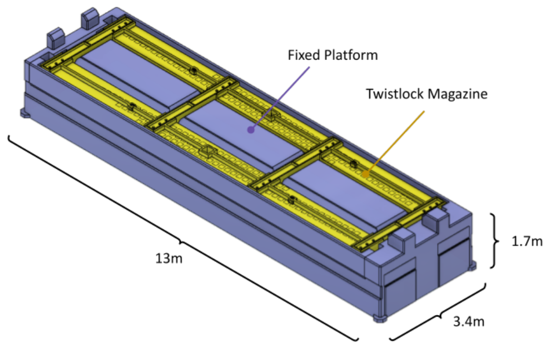
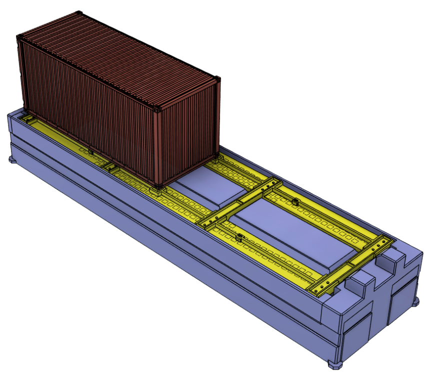
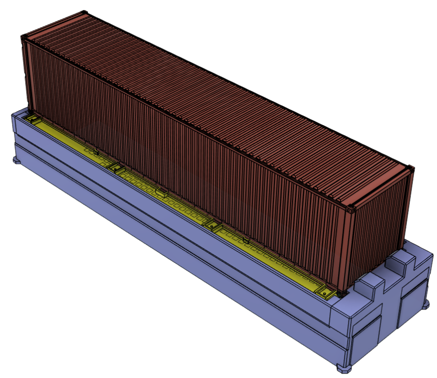


Figure 3.9: Final concept - Fixed platform



(a) Fixed platform with 20ft container



(b) Fixed platform with 40ft container

Figure 3.10: Platform with stacked containers of different sizes

3.3.2 Modular pinning stations

The actuator system of the platform consists of six modular pinning stations, with one station positioned at each corner of the container. These pinning stations enable precise three-axis motion control, allowing for vertical, horizontal, and rotational adjustments. Refer to figure 3.5 for a visual representation of a pinning station and figure 3.11 for their integration into the fixed platform, providing a better understanding of the actuator system's design and functionality.

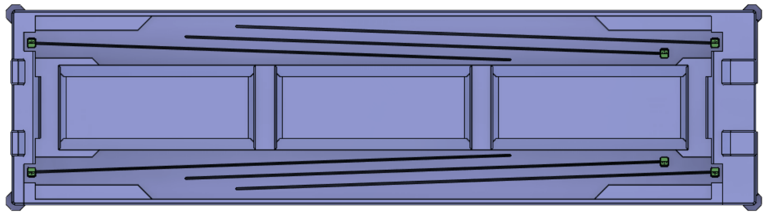


Figure 3.11: Horizontal paths of the pinning stations

3.3.3 Twistlock magazine

Efficient container pinning and depinning are achieved by incorporating a twistlock magazine, as shown in figure 3.12. The magazine features slots that are designed similarly to standard container corner castings, securely holding the twistlocks in place. Each pinning station includes 40 twistlock slots, providing a sufficient supply for container pinning or depinning operations. Currently, there is ongoing discussion regarding the arrangement of the magazines. The diagonal placement optimises space utilisation, while the parallel placement allows for the potential inclusion of support for 45 ft containers and eliminates the issue of half-full magazines during magazine switching.

The twistlock magazines are stackable, allowing for convenient storage and transportation of the twistlocks. This feature promotes operational efficiency and minimises equipment storage's required space. Furthermore, the twistlock magazines can be easily transported using a reach stacker, ensuring seamless integration into the container handling process.

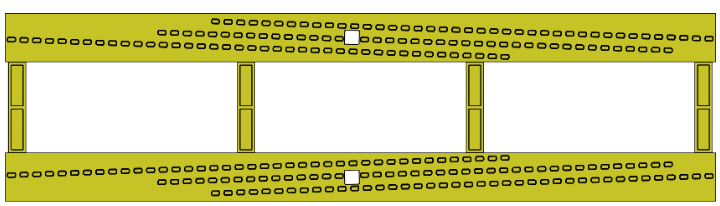


Figure 3.12: Twistlock magazine viewed from the bottom

4 Discussions and conclusions

Taking into consideration the paramount need for a robust machine, the choice with least moving parts combined and simple mechanisms became the obvious choice.

Throughout the design process, the most recurring point of resistance has been manipulation from one moving system to another moving system. That is, the interaction between the magazine and pinning station. The decision to keep the magazine rigid has simplified the system significantly in contrast to a moving magazine.

Additionally, each pinning station only contains one moving unit. This means that the HMI along with diagnostics and manual intervention should be more manageable.

The operational speed of the machine may be a point of concern due to the long travel distance required when the magazine is nearing empty. However, the subsequently increased precision and lowered failure rate makes up for lost speed in a long term perspective.

Also, further investigation has to be made into dimensioning the pinning machine for a container's impact forces.

The concerns that remain to be addressed through prototyping or testing are the aspects regarding operator container positioning and making a practically feasible magazine. The angled magazines meet the number of locks specified by the product requirements. On the other hand, their total weight is concerning. Furthermore, although operators that work with stacking containers are highly precise according to first hand sources, without a well-tested guide, there is no way to know how the machine will impact operator precision.

Currently, the prototype appears to be capable of meeting most requirements.

5 Future work

This section will discuss the future work, i.e. the plan for the fall period. It will be categorised under two subsections; team organisation and time plan. The first subsection will elaborate more about team management and later about how different tasks are scheduled.

5.1 Team Organisation for fall period

The team will be divided into sub-teams to focus on different aspects like; Mechanical design, Controls and Electronics, Software, etc. Once the design phase is complete, the team will divide into sub-teams responsible for manufacturing and testing. The team members will rotate between teams to ensure uniform learning and contribution. The aim is to have team meets weekly and communicate with the stakeholder and coach regularly.

5.2 Time plan

Roughly the fall period will consist of the following major activities:

- Recap final concept
- Detailed CAD of concept
- Research components
- Order components
- Building
- Assembly
- Testing
- Report writing

The detailed time plan can be found in appendix E. The aim is to finalise the detailed design and CAD within the first few weeks and then build, assemble and test the prototype. The two most critical tasks are ordering components and testing due to their unpredictable nature. Thus, these tasks will run in parallel to other tasks. The report will be written congruently with other tasks. The team aims to build a working prototype for one corner and develop a complete conceptual solution for the whole machine. A buffer period of 15 days is kept in December to ensure the project finishes ahead of schedule and there is a safety margin.

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Appendix A Container standard dimensions

Table A.1: Container dimensions

Name	**Length**	**Width**	**Height**	**Empty weight**	**Max weight**
20 ft standard height	19′10.5″ (6.058 m)	8′ (2.438 m)	8′6″ (2.591 m)	2200 kg	36 000 kg
20 ft high cube	19′10.5″ (6.058 m)	8′ (2.438 m)	9′6″ (2.896 m)		36 000 kg
40 ft standard height	40′ (12.192 m)	8′ (2.438 m)	8′6″ (2.591 m)	3800 kg	36 000 kg
40 ft high cube	40′ (12.192 m)	8′ (2.438 m)	9′6″ (2.896 m)	3935 kg	36 000 kg
45 ft standard height	45′ (13.716 m)	8′ (2.438 m)	8′6″ (2.591 m)		36 000 kg
45 ft high cube	45′ (13.716 m)	8′ (2.438 m)	9′6″ (2.896 m)	4500 kg	36 000 kg

Appendix B Interview

Interview with a dock worker from Gothenburg

May 15th 2023

Questions

1. Where have you been located during these 17 years? At a port area?
[*swe] Vart har du varit stationerad under dom här 17 åren?*

At a port area in Gothenburg

Vid en hamn i Göteborg

2. What have your roles and responsibilities looked like?
[*swe] Hur har dina roller och ansvarsområden sett ut?*

Been working with straddle carrier, high trucks that moves containers in the port. Also he's been driving container cranes for many years, loading and unloading ships. Now he works as a mechanic for the cranes.

Jobbat med gränsletruck, höga truckar som flyttar containrar i hamen. Också kört containerkranar i många år. Lastat och avlassat fartyg. Nu är han mekaniker på kranarna.

3. What type of locks are you using currently? Has it always been the same?
[*swe] Vilka typer av lås använder ni idag? Har det alltid varit så?*

Been using a lot of different locks, both manual and half-automatic.

Använt massa lås. Både manuella men även halvautomatiserade lås

4. Can you describe the current working procedure for the locking?
[*swe] Kan du beskriva den nuvarande lösningen för låsningen?*

When placing a container you look at the corners of the containers for placing them correctly, there's no cone that you can use for guidance. So the procedure for placing the containers is fully visual. Small boats can swing a lot so in those cases a lot of fine touch is needed for placing the containers correctly.

There's been one crush accident on a workers arm relative the pinning procedure, however the worker did not follow the right procedure that they were supposed to.

Vid placering kollar man på hörnlådorna för att placera rätt, finns ingen "tratt" som man kan använda för guidning. Rätt placering sker rent visuellt. Fidebåtar (små) kan gunga mycket så där krävs det mycket känsla för att placera containrarna rätt.

Olyckor har hänt 1 gång, en som klämt handen när de gjorde på ett sätt man inte fick.

5. What is the attitude towards today's solution among the workers?
   [*swe] Hur upplever du inställningen till dagens lösning bland arbetarna?*

The dock workers actually like pinning and depinning locks, they see it as a nice break to all the other work they do. He believes no dock worker in the world wants automated locks since that would remove job opportunities for them. However, he can see there is a risk by doing it manually since the containers easily can swing around when bad weather, especially the empty containers.

Ingen hamnarbetare i världen som vill ha automatiserad låsning. Hamnarbetare tycker det är skönt att gå ut och plocka koner (lås), så det gör de gärna. Containrarna kan lätt hamna i gung vid blåst, speciellt tomma containrar.

6. How long would you say it takes for a reach stacker to lower a container onto another container? How many containers are handled per hour?
   [*swe] Hur lång tid skulle du säga att det tar för en reachstacker att sätta en container ovanpå en annan container? Hur många containrar hanteras per timme?*

The time to lower a container onto another one totally depends on the type of ship, now adays the goals is to be at 30 containers/hour.

It is possible to carry 2 of the 20 ft containers at once, which improves the effectivness a lot rather than handling only 40 ft containers.

Tid att sänka ner en container på annan beror helt på typ av båt, nu för tiden mål att ligga på ca 30 containrar i timmen.

Kan bära 2 st 20 ft samtidigt, så då blir effektiviteten mycket snabbare än om man bara hanterar 40 ft containrar.

Appendix C Concept development Pugh Matrix

		pinning action		pinning/deconning same m/c		Pinning stations	
Critera (0-5)	Importance	Synchronous	Non-synchronuous	Yes	No	Sliding stations	Fixed multiple stations
Convenience	3	4	3	5	2	3	3
Exception handling	4	1	4	3	4	2	3
Cost	2	4	2	3	2	3	4
Safety	5	2	5	0	0	1	5
Relalibilty	5	2	3	2	4	2	5
Adaptiblity	4	0	0	5	0	5	3
Speed	4	5	3	0	0	2	4
Automatic	3	4	3	2	4	4	4
Magazine capability	3	0	0	5	1	1	4
	Total:	76	90	84	61	81	131

Guides		Common bed for 20/40ft		Magazine deconning lock goes in place	
Guide channel	Free placement	Yes	No	Yes	No
5	2	5	2	4	2
4	2	3	3	3	3
2	4	4	2	3	4
4	2	4	4	0	0
5	2	3	4	2	4
1	4	5	1	3	4
0	0	0	0	4	1
0	0	2	4	5	1
0	0	2	4	5	3
84	58	102	90	98	78

Appendix D SWOT analysis

D.1 Lock Magazine

	Strength	Weakness	Opportunities	Threats
Push magazine. Alternative 1: Push on locks	Simple to implement. Space efficient. Easy to change magazine.	Only possible to select first lock in line (need somewhere to get rid of malfunctioning locks)		The locks can jam when pushed forward.
Push magazine. Alternative 2: Belt	Less force needed to move locks forward. Space efficient regarding locks.	Only possible to select first lock in line (need somewhere to get rid of malfunctioning locks). Harder to change magazine. Magazine takes up a lot of space.		
Push magazine. Alternative 3: Rotating spiral	Simple to implement. Easy to change magazine.	The locks risk not keeping the exact orientation. Only possible to select first lock in line.		
Magazine belt	Possible to select which lock should be used (and not used) in each corner	Complicated Hard/complicated to change magazine.		May require manual loading of magazine in the machine.
Fixed magazine	No moving parts for the magazine. Very simple to change magazine. Space efficient.	Difficulty fitting 40 locks length wise inside the bounding box of the m/c	Possible to design the pinning stations/transfer mechanisms so that more than one corner can use same set of locks. Possible to select which lock should be used.	May require more motions and complexity from the pinning station/transfer mechanism

D.2 Pinning mechanism

	Strength	**Weakness**	**Opportunies**	**Threats**
3-axis pinning station	Flexible with magazine type	Lots of moving parts		Can be damaged by impact forces
Spring loaded Pinning station	Container can be loaded directly upon lock	Finding suitable dampeners can be difficult. Can not take horizontal loads		Linear rod might get deformed if load is not axial
Pinning station Platform	Should be able to handle impact forces	Finding suitable dampeners can be difficult. Can not take horizontal loads	Can posistion container directly on the lock	
Box gripper	Removes the need for horizontal movement	Requires good synchronization with the belt		

Appendix E Gantt chart

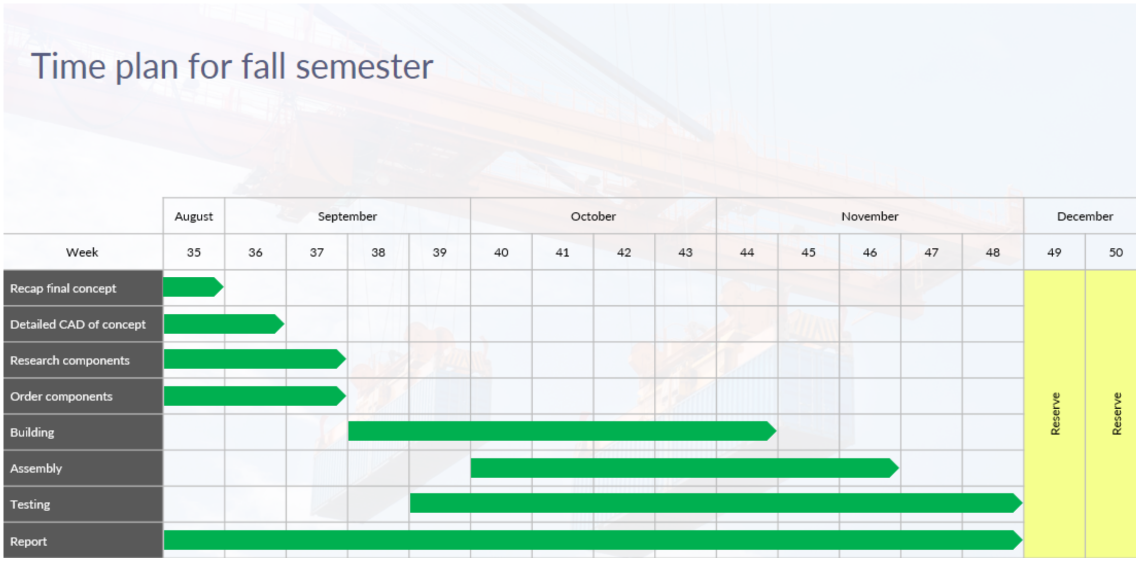

Figure E.1: Gantt chart for the fall semester