Sensur av hovedoppgaver

Høgskolen i Buskerud og Vestfold
Fakultet for teknologi og maritime fag

Prosjektnummer: **2015-13**
For studieåret: **2014/2015**
Emnekode: **SFHO3201**

Prosjektnavn
Automatisere produksjonen av luftfarts-deler.
Automating the production of aerospace parts.

Utført i samarbeid med: Kongsberg Defence & Aerospace.

Ekstern veileder: Tor Sigurd Breivik

Sammendrag: Prosjektet består i å automatisere produksjonen av luftfarts-deler hos Kongsberg Defence & Aerospace. Denne prosessen foregår i dag manuelt, og er svært komplisert og tidkrevende. Grunnet en ønsket økning i produkjonen, vil KDA automatisere flere deler av denne prosessen. Dette prosjektet har hovedsaklig sett på automatisering av bolt-installasjons prosessen.

Stikkord:
- Automatisering
- Bolt-installering
- Robot

Tilgjengelig: JA

Prosjekt deltagere og karakter:

Navn	Karakter
Katrine Kallevik	
Stian Hovde	
Elvar Aspelund	
Kristoffer Lund	

Dato: 4. Juni 2015

Kjell Enger
Intern Veileder

Karoline Moholth
Intern Sensor

Tor Sigurd Breivik
Ekstern Sensor

Contents:

Idea Document

Version	Date	Reviewed by	Approved by	Satus
2.0	15.05.2015	Katrine Kallevik	Tor Sigurd Breivik	Released

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1.0 Abstract

This is a short document describing the problem given to us by Kongsberg Defence & Aerospace[1]. The purpose is to give the reader an understanding of the system that is being designed.

2.0 Revision History

Version	Date	Changes	Author
0.1	19.01.2015	• First version of the document	Stian Hovde
1.0	10.02.2015	• First released version	Stian Hovde
1.1	11.05.2015	• Spelling and formatting changes • Updated flowchart	Stian Hovde
2.0	15.05.2015	• Final version	Stian Hovde

Table 1: Revision table.

3.0 Introduction

The vision document is a preliminary report based on the final assignment at Buskerud and Vestfold University College[2]. The main purpose is to give a clear and unambiguous description of the problem and the task given to us by KDA, and create a common understanding of the project between the project group, KDA and HBV.

This document also gives a short presentation of the project members, employer and HBV, and contact information for all relevant parties.

The contents of this report provides a basis for the further work done on the project.

[1] From here on abbreviated to KDA
[2] From here on abbreviated to HBV

3.1 Project group

The project group consists of four members, two from the mechanical engineering course, and two from the electrical engineering course, at HBV.

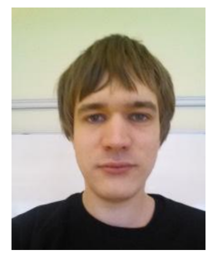
Name and info	Main responsibility area	Picture
Katrine Røisland Kallevik Mechanical engineer Email: katrine_roikal@hotmail.com Phone: 92 04 45 84	● Project leader ● Economy ● Design	
Stian Tafjord Hovde Electrical engineer Email: stian.hovde90@gmail.com Phone: 94 05 64 64	● Documentation ● Web ● Requirements analysis	
Elvar Aspelund Mechanical engineer Email: elvarsh@hotmail.com Phone: 93 87 81 77	● Systems engineering ● Mechanical simulation	
Kristoffer Lund Electrical engineer Email: kris_9942@hotmail.com Phone: 90 20 17 38	● Electrical simulation ● Testing	

Table 2: Introduction of project group.

3.2 Employer

Our employer is KDA, Aerostructures Division. Part of Kongsberg Gruppen and located about 4 km from the present day Kongsberg Industrial Park, Aerostructures is one of Europe's most advanced manufacturers, producing complex structures in high-alloy metals and composites.

KDA provides an external supervisor and examiner, and several persons to contact for information and help.

Name	Function	Contact
Tor Sigurd Breivik	External supervisor and examiner	tor.s.breivik@kongsberg.com
Alf Pettersen	Resource person	alf.pettersen@kongsberg.com
Kristian Nilsen	Resource person	kristian.nilsen@kongsberg.com
Bjørn Ivar Nilsen	Resource person	bjorn.ivar.nilsen@kongsberg.com

Table 3: Aerostructures stakeholders.

3.3 HBV

HBV provides an internal supervisor to aid us in our project, and an internal examiner.

Name	Function	Contact
Kjell Enger	Internal supervisor	kjell.enger@hbv.no
Karoline Moholth	Internal examiner	karoline.moholth@hbv.no

Table 4: HBV stakeholders.

4.0 Description of problem

4.1 Overall view

During the production of aerospace components, many time consuming and complicated manual processes are included.

- Drilling holes through composite and alloy
- Countersinking of holes
- Mounting bolts and nuts

The general task is to look at how these processes can be automated.

In agreement with KDA, we have chosen to mainly look at the process of automating the bolt assembly process, after the drilling and countersinking process is completed. Although we are only looking at this operation, KDA preferably wants a product that can complete the entire process, so it is important for us to design our product with the entire process in mind.

4.2 Process of mounting bolts

The mounting of bolts and nuts is done manually today, and is a very time consuming process. In certain areas it is also difficult to reach with pneumatic tools, which makes the process even more complicated and forces the user to use manual tools.

There are bolt types of 5 different diameters and 3 different grip lengths, with 100 bolts in total to be installed in the aerospace part.

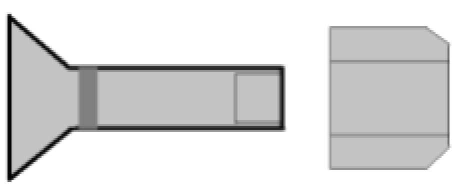
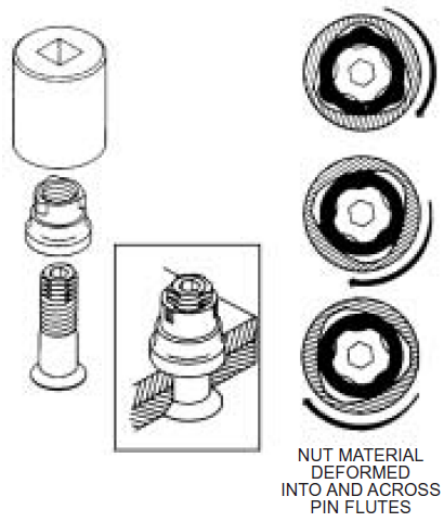


Fig. 1: Illustration of bolt and nut.

Before installation, the bolts need to be applied a thin coat of promoter and sealant. The promoter is applied first, it needs 1/2 hour to dry and has a lifespan of 24 hours. The sealant is then applied, and the bolt can be installed immediately. The sealant has a pot life of 1 hour.

Before mounting the nut and fastening, the bolt grip length must be measured. Because of the varying thickness of the materials, the grip length of the assigned bolts can vary. If the grip length is one size too short or too long, the bolt can be switched.



Figur. 2: Fastening the bolt.

The tool used to tighten the nut has a center hex key, that fits into the bolt and keeps it from rotating. The nut also has lobes that will fit into the tool. When a certain momentum is reached, the lobes will be swaged into and across the flutes of the pin, and the tool will become free running on the nut. If the swaging is found incomplete, both the nut and bolt must be replaced.

It is important that the system can control itself, and make sure that everything has been done correctly. This control needs to be done after each bolt is fastened, to make sure an error doesn't repeat itself several times. The main things to be controlled are the nut profile, the gap between the bolt head and countersink and the nut seating against the alloy.

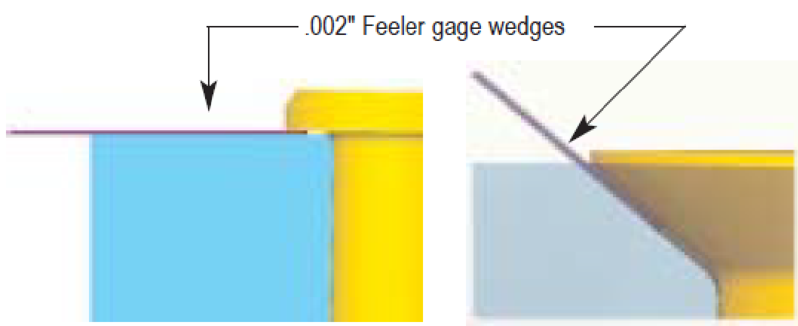


Figure 3: Controlling gap between bolt head and countersink.

The concentricity and angularity between the hole and bolt are critical, The bolt can absorb about 2° of angular misalignment. By inserting a feeler gage into the gap, and see if it jams before hitting the shank of the bolt, we can control this.

The nut profile is controlled to check if the nut has been deformed or swaged properly. This is done by using a paddle or thimble that fits perfectly on the nut if it is properly installed. If it does not pass smoothly over the nut, the bolt and nut must be removed and installed again.

4.3 Advantages of automation

To justify the time and money needed to automate such a complicated process, there needs to be significant advantages for everyone involved.

- Removal of physical labour

The manual work done can lead to complications with the neck and shoulders for the worker, removing this risk means the workers can stay in their jobs longer, and not have to retire due to health concerns.

- New workers

Automation also reduces the amount of training needed for new workers, and due to the previous advantage, less new workers are required. A new worker would also take longer time and make more mistakes than a seasoned one.

- Sickness

An automated process can not get the common cold, or any other nasty diseases, which means the production can continue without the need of calling in additional personnel.

- Production time

This is of course dependant on the final solution, but it is easy to imagine that the automated process would take less time. A fully automated system would also be able to work around the clock, which a normal worker cannot.

- Profitability

This also ties into the final product, but the increased production time and reduction of sickness benefits for the workers will increase the profit for the company.

4.4 Flowchart

Since the bolt installation process is quite complicated, we have created a flowchart describing the whole process step by step.

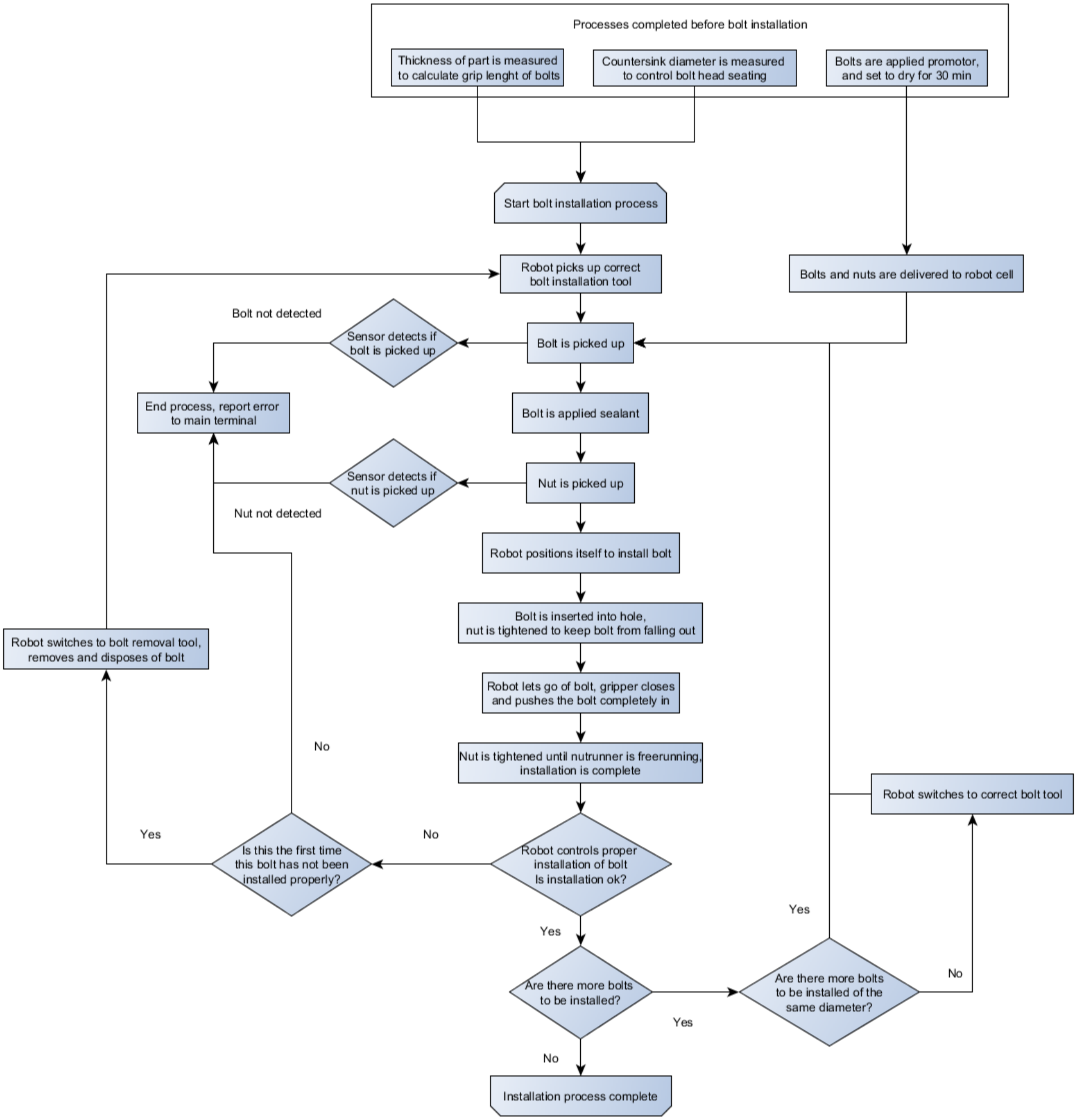


Figure 4: Flowchart of process.

5.0 Goals and objectives

5.1 Primary goals

- Evaluate and select robot.

Evaluate different robot systems and choose the best suited for the project. The robot should be able to complete all the processes involved in the bolt installation process, so that only one robot is needed.

- Create an economical analysis of automating the bolting process.

An economical analysis of the potential savings involved in automating the bolt installation process. The analysis must also cover the other parts of the assembly process, including drilling, countersinking and transportation.

- Design and produce a tool that can be connected to the robot, and perform the installation and fastening of bolts.

Design a tool that can fit into the aerospace part, and install the bolt. The tool must fit into the robot's tool changer system. The produced tool will be a "proof of concept" for KDA.

5.2 Secondary goals

- Design system to sort the bolts before installation.

100 bolts of 5 different diameters and grip lengths must be installed in the same process. A system must be designed for sorting these bolts, so the robot can easily grab the correct bolt it needs.

- Design system to apply promoter and sealant before installation.

Promoter and sealant must be applied to the bolts, while following the drying time and pot life described in the problem description. A system must be designed for this job.

- Design system that can control and confirm proper installation.

Design a system that controls the nut profile, protrusion and nut seating against the alloy. The system must also be able to remove the bolt if requirements are not met.

6.0 Sources

[1] Alcoa, *Eddie-bolt Process Manual,* cited 03.02.2015, avalible from: https://www.alcoa.com/fastening_systems_and_rings/aerospace/catalog/pdf/eddie-bolt%20process%20manual-jan06.pdf

[2] Kongsberg, *Product Group Aerostructures,* cited 04.02.2015, avalible from: http://www.kongsberg.com/en/kds/products/aerostructures/

Project Plan

Version	Date	Reviewed by	Approved by	Satus
3.0	15.05.2015	Stian Hovde	Tor Sigurd Breivik	Released

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1.0 Abstract

This document serves to provide the group and supervisors with overview of the planned progression of the project, the document will be revised if needed.

2.0 Revision History

Version	Date	Changes	Author
0.1	06.02.2015	• First version of the document.	Elvar Aspelund
1.0	10.02.2015	• First released version.	Elvar Aspelund Katrine Kallevik Kristoffer Lund
1.1	16.02.2015	• Added an activity to the activity table. • Made some changes in the terminology used in chapter 4.5 • Clarified the distribution of time estimates	Elvar Aspelund
1.2	06.03.2015	• Added an activity to the activity table.	Elvar Aspelund
1.3	16.03.2015	• Fixed spelling errors • Chapter 9 about risk has been removed, it is now in a separate document	Stian Hovde
2.0	16.03.2015	• Second released version	Stian Hovde Elvar Aspelund
2.1	27.04.2015	• Changes made to activities and estimated hours, see Iteration report document for further details.	Stian Hovde
2.2	13.05.2015	• Spellcheck and formatting changes. • Filled in total hours used. • Added documents to chapter 9.0.	Stian Hovde Elvar Aspelund
2.3	14.05.2015	• Spellcheck, review.	Katrine Kallevik
3.0	15.05.2015	• Final version.	Stian Hovde

Table 1: Revision table

3.0 Introduction

3.1 The background for the assignment

Currently at Kongsberg Defence and Aerospace, the production assembly phase of the advanced composites is a manual operation. We have been given the task to deliver a concept for automating the assembly process of the bolts that binds the composite and the titanium component together.

3.2 Scope

The scope of the project is to create a proof of concept for the tools needed to complete the process. The assignment will include an analysis of the economical benefits of automating the process. Lastly we will select a suited robot for our process. The robot should be able to do all the tasks at hand.

The project is divided into primary and secondary goals. Primary goals are selecting a suited robot, economical analysis and creating an assembly tool for the bolts. Secondary goals are tools for coating, verification of installation and a sorting station for the bolts.

3.3 Definitions of abbreviations

The following abbreviations are used in this document:

Abbreviation	Definition
KDA	Kongsberg Defence & Aerospace
FEM	Finite Element Method
FUD	Follow Up Document
HBV	Buskerud and Vestfold University College
UP	Unified Process
MOM	Minutes Of Meeting
WIP	Work In Progress

Table 2: Abbreviations.

4.0 Planning tools

4.1 Google documents

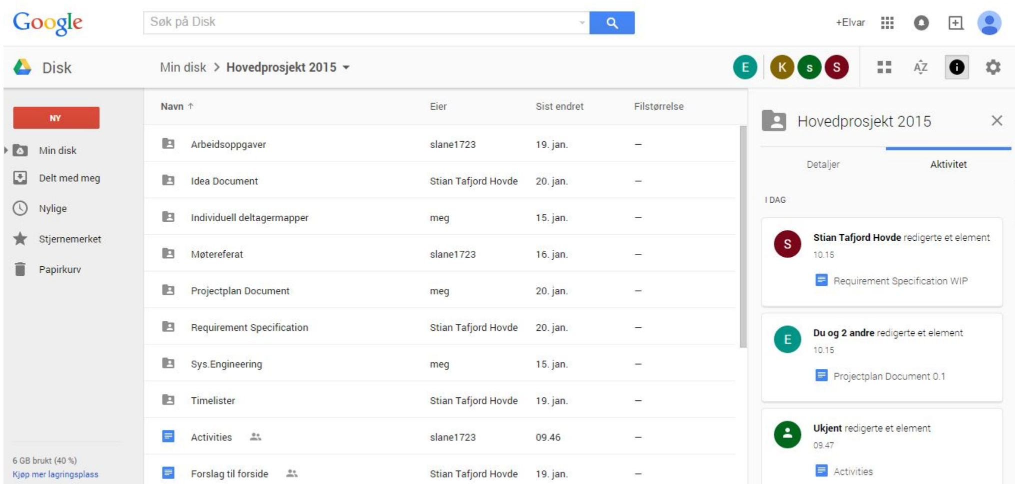

Figure 1: Google documents.

For the project we have decided on using Google documents. This is a cloud sharing software, meaning everything that is created is stored on a server. Every member has access to all documents. Logging system shows what each member has done on each document, this gives the team a great overview of the overall activity on the project. Members can also access each document and go in and add comments and inputs on content that possibly needs to be altered.

Google documents provides all the necessary tools, such as charts, file sharing and document software. This gives the team a much more complete package compare to similar software such as Dropbox.

4.2 Gantt chart

We used a Google documents Gantt template to create our Gantt chart.

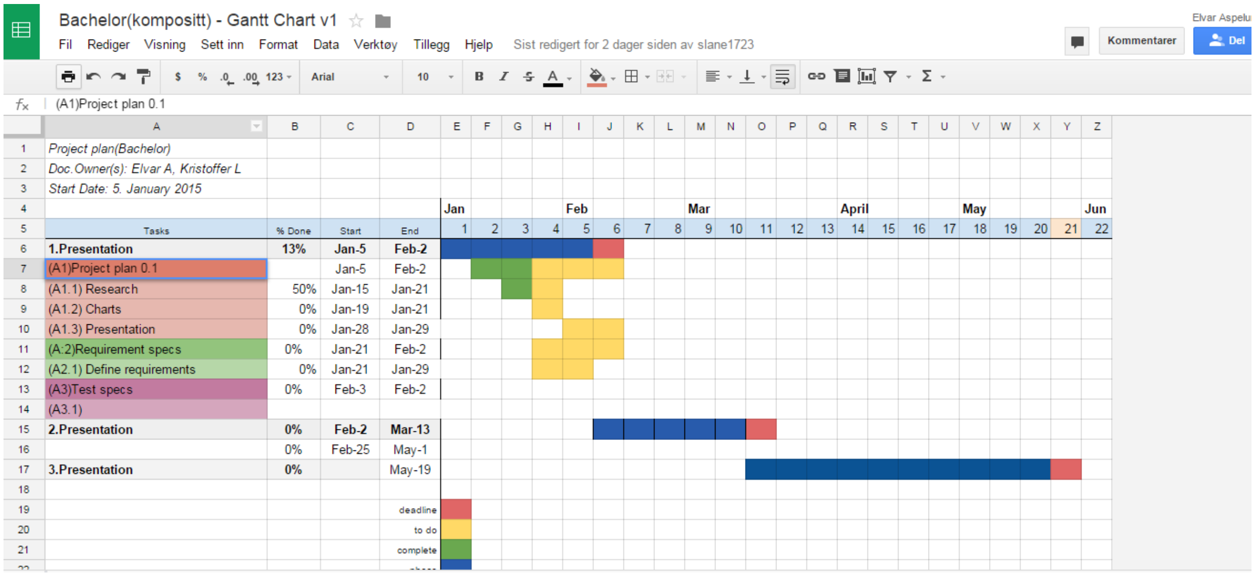

Figure 2: Gantt Chart.

The Gantt chart is used to give an overview and insight in the progression of the project. Activities are given a name and a number, a start and an end date. 0% for activities that are not started and are colored with the “to do” color. Activities that are in progress are set to 50% and completed activities are set to 100%.

The activities in the Gantt chart are not denoted with hours, but a start and end date. We have used a dedicated document for documenting hourly use on activities, and a description of work that has been done. This information is used for the FUD.

4.3 Unified process model

We have let us inspire by the Unified Process model with an iterative approach, as it states this is a mixture of linear and sequential approach. An iterative approach means that the group achieve a stepwise refinement of knowledge throughout the project.

The model is divided into four phases, and in each phase there will be a proprietary focus on some of the disciplines, as is evident in the UP-diagram. Within these phases there are a selection of iterations, with a duration time from 2 to 4 weeks. Within each iteration there is calculated additional time for adjustments, such as addition of requirements, which will affect the next iteration in the project plan. This means a recalculation of the time distribution has to be done.

Within each iteration there are a selection of activities, which are derived from the Gantt chart. Activities are given an identification number, which makes the traceability of activities and their relative requirements throughout the project life cycle clear.

The UP-model has a set of disciplines. A discipline shows the effort needed for each discipline within each phase, time estimates used are derived from the mission plan. An example of a discipline can be requirements.

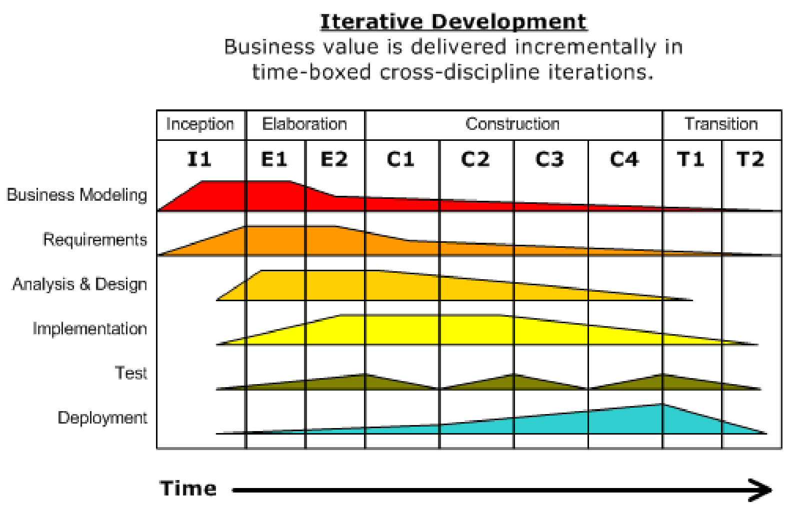

Figure 3: Unified process model.

Risk assessment is an important factor within the UP-model. We have created an overall risk assessment for the project. Later on we will include a system risk analysis, with a classification of priority for each risk factor. This is located in the risk analysis document.

The time estimates used in the UP-model is based on the data from our project plan document. The tables in the General plan chapter are divided into sections that are consistent with the UP diagram, meaning that we have a section for project planning, requirements analysis etc. Under these sections we elaborate on what type of activities and the duration of that given activity will be.

The UP-model is divided into four phases:

- **Inception:** Here the group achieve an overall understanding for the project at hand, build up a business model and get a scope of the project.
- **Elaboration:** The requirements are addressed at this phase, establish an understanding of the efforts needed to meet the requirements, concept selection and design phase.
- **Construction:** Focuses on completing construction or building the system.
- **Transition:** This is the end phase, compile the project, last check and releasing of end product and documentation

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5.0 Project modeling

When we started the project we began with creating a project plan inspired by the Unified Process model. Our model sets the foundation for the work structure for the project. This is a project with a set date and limited amount of time assigned to it. There are three major milestones, these are the three presentations that will be held throughout the project life cycle.

As described in the project plan chapter the project is divided into phases, disciplines and iterations. For each milestone we have a set of iterations, these iterations all include a cluster of activities. After an iteration is completed, a report will be filed, stating the result of that given iteration, what problems occurred and which activity needs more attention. This information is then transferred into the planning of the next iteration.

The way we have structured the planning of the project is by estimating the time expenditure per activity, and set major milestones. The planning of iterations will be done for the current and subsequent iteration. This will enable the team to make necessary adjustments in the continuing planning of the project throughout its life cycle.

As milestones are sectioned up into a set of iterations, this makes it easier for the members of the group to get a better overview of the tasks at hand. Activities and tasks within an iteration are linked to requirements set by the stakeholder.

5.1 Project phases

This is a short explanation for our setup of the four phases in the our model:

- **Inception:** Building up a business model, creating the first draft of the project plan, setting up a requirements spec and test spec. Ends with the first presentation of the project.
- **Elaboration:** Concepts selections for the different systems. Start on primary goals for concept selection and design for bolt assembly. If there is sufficient time start on secondary goals for concept selection and design which include sorting system, a station applying promoter and sealant and an after control system. Creating technology documents. Setting up a test plan to find solutions to confirm the feasibility of the requirements. Start the process of analysing the economics of automating and selection of suited robot for the task.
- **Construction:** Final designs shall be created. Testing phase for the concepts that have been selected and verifications that the requirements are met. Transitioning from design to manufacturing of the end product.

- **Transition:** End phase of the project, the product has been manufactured and tested. final documentation and completion of the project. Setting up for the final presentation and major rehearsals will be conducted. Delivery of the project.

5.2 Milestones

Each milestone is set by the dates for each presentation. Tasks that have to be included in each presentation are set by HBV.

- **1st Presentation:** First draft of the Project plan, requirement spec, test spec.
- **2nd Presentation:** Concept selection for the four different stations (mounting, sorting, coating and after control), design/testing phase. Our primary goal is the mounting station, designing and testing the tool for bolt assembly. Economical analysis, robot selection.
- **Final Presentation:** Elaborate about the experience gained from working with the project, possible demonstration of the end product and a conclusion of the project.

5.3 Iterations

As the model states, the current iteration shall be planned, and a rough sketch of the next iteration is noted. A plan for iterations that are due further out in the project will not be done in such a detailed form, but instead focusing on major events and tasks. Usually an iteration last for about 2 weeks. The activities within an iteration that are shown in the project plan diagram are derived from the gantt chart using the week numerations.

6.0 Limitations and prerequisites

As this is a student project it is given that there be some limitations. This chapter will briefly state some of the factors that could and will limit the execution of the project, and give an insight into the prerequisites needed to complete the assignment.

6.1 Limitations

The Bachelor project has a set end date. This in itself sets a limitation, as there will be a limited timeframe to complete the project. The complexity and scope of the project has to be scaled to meet this deadline. The end goal is to create a proof of concept and a model that can be used for demonstration, so time is a major limitation.

As many aspects of production are confidential, we only gain a limited insight into the workings of the processes. We are only able to view some components and manufacturing processes from a distance, this of course set some minor limitations.

With a student project there will always be the aspect of financial limitations. With a limited budget, the access to expensive tools for extensive testing will be limited. Traveling to other companies for input and research, that are based far from our location, will be limited.

6.2 Prerequisites

As this is a project received from an external company, it is a prerequisite for the group that we get a good description of the assignment at an early stage. Key requirements and a clear idea of what the end product shall be is of importance so that the planning phase can be completed at an early stage.

The basic understanding for the processes within systems engineering is of great importance for the rapid deployment of the assignment. Each member of the team participated in the systems engineering course at HBV. This has given us a much better understanding for the fundamentals of how to set up a major project.

7.0 Activities

In order to reach our milestones in the gantt diagram, we use a system of activities to divide a goal into parts. This gives us an overview we use to prioritize and set time limits on different parts of the project.

7.1 Responsibility

Only one person can be responsible per activity. This person does not need to be working with the activity directly, but is responsible for an activity to be completed within the given deadline.

7.2 Tasks

An activity can be divided into task, so that the person responsible can delegate the workload to group members. Task have shorter time periods so the overall deadline can be met. All task must be completed for an activity to be complete.

7.3 Degree of completion

In order to keep track over how far from completion an activity is, we have implemented a grading system so we can easily see where the different activities are in respect to the deadline.

- Unstarted activities are marked 0%.
- Started activities are marked 50%.
- Completed activities are marked 100%

Tasks are graded in the same way as activities.

7.4 Traceability

An activity should be traceable to one or more requirements. to achieve this we have made two tables that shows which activities belongs to a certain requirement, and which requirements an activity contains[1].

[1] See attachment 3.

7.5 List of activities

ID	Name	Description	Responsible
A0	**Administrative**		**Katrine Kallevik**
A0.1	External meetings	Meetings with KDA.	Katrine Kallevik
A0.2	Internal supervisor meetings	Meetings with Kjell Enger.	Katrine Kallevik
A0.3	Internal group meetings	Short morning meetings to discuss project related issues.	Katrine Kallevik
A0.5	Minutes of meeting	Short summary of topics discussed at a meeting.	Katrine Kallevik
A0.6	Other administrative tasks	Different tasks that has to do with planning, informing and decisions of administrative tasks.	Katrine Kallevik
A0.7	First presentation	Create and perform a presentation.	Katrine Kallevik
A0.8	Second presentation	Create and perform a presentation.	Katrine Kallevik
A0.9	Third presentation	Create and perform a presentation.	Katrine Kallevik
A0.12	Test plan	Document describing the processes of which the test will be conducted.	Kristoffer Lund
A0.13	General documentation	Adjusting documentation formats, print-outs etc.	Stian Hovde
A0.14	Iteration report	Planning and reporting status of iterations for the project.	Elvar Aspelund
A1	**Requirement Analysis & Project planning**		**Kristoffer Lund**
A1.1	Idea document	Document describing the what, why and how of the project.	Stian Hovde
A1.2	Project plan	Detailed plan of how we are managing the different sides of this project.	Elvar Aspelund

A1.3	Requirement specification	Detailed document over the different requirements our system has to achieve.	Stian Hovde
A1.4	Test specification	Detailed summary which aspect of our system will be tested..	Katrine Kallevik
A1.5	Risk analysis	List of risks that can affect the completion of our project.	Katrine Kallevik
A2	**Robot selection**		**Stian Hovde**
A2.1	Research	Acquire information about robot technology.	Elvar Aspelund
A2.2	Documentation	Create a document that explains and justifies the robot selection.	Stian Hovde
A2.3	Robot simulation	Simulating the function of the robot cell.	Elvar Aspelund
A3	**Economic analysis**		**Kristoffer Lund**
A3.1	Research	Research the economic aspect of the system. Justify choices.	Katrine Kallevik
A3.2	Documentation	Document the economical findings.	Kristoffer Lund
A4	**Design and production of bolt installation tool**		**Stian Hovde**
A4.1	Research	Acquire information of different solutions.	Stian Hovde
A4.2	Concept selection	Discuss the different solution alternatives, and decide which one is the best alternative.	Elvar Aspelund
A4.3	Design	Create a design that can be tested.	Katrine Kallevik
A4.4	Mechanical analysis	Analyse the mechanical side of the design. Justify choices.	Elvar Aspelund
A4.5	Electrical analysis	Analyse the electrical side of the design. Justify choices.	Kristoffer Lund
A4.8	Documentation	Document the design	Stian Hovde

A5	**Design of bolt sorting system**		**Katrine Kallevik**
A5.1	Research	Acquire information of different solutions.	Katrine Kallevik
A5.2	Concept selection	Discuss the different solution alternatives, and decide which one is the best alternative.	Elvar Aspelund
A5.4	Documentation	Document the system.	Katrine Kallevik
A6	**Design of promoter and sealant system**		**Elvar Aspelund**
A6.1	Research	Acquire information of different solutions.	Elvar Aspelund
A6.2	Concept selection	Discuss all alternatives and decide which one is the best alternative.	Kristoffer Lund
A6.4	Documentation	Document the system.	Elvar Aspelund
A7	**Design of verification system**		**Stian Hovde**
A7.1	Research	Acquire information of different solutions.	Stian Hovde
A7.2	Concept selection	Discuss all alternatives and decide which one is the best alternative.	Stian Hovde
A7.4	Documentation	Document the system.	Stian Hovde
A8	**Final documentation**		**Stian Hovde**
A8.1	Final review	End review of all the documents.	Stian Hovde
A8.2	Final documentation	Preparing all the documents for final release.	Stian Hovde
A8.3	Web page	Create and manage a web page that contains information of our project.	Stian Hovde
A8.4	Poster	Create a poster according to HBV requirements.	Elvar Aspelund
A8.5	A4 promotional page	Create an A4 promotional page.	Elvar Aspelund

A8.6	Project report	Final report about our experiences and comments on the project.	Stian Hovde

Table 3: Activities table

8.0 Mission plan

8.1 Meeting plan

Once a week we have a meeting with internal and external supervisor. As the group has one day per week that we work at the facilities of our employer, the meetings with the external supervisor is held there.

The group start the day with a short meeting where we address the current situation of the project, what each members have planned for the day and what he/she needs support on.

8.2 General plan

The general plan is divided into disciplines which is also represented in the our model[2]. The disciplines all have a cluster of activities.

Each activity has a roles assigned to it; the group members responsible for the activity, and estimated expenditure of time.

Activity: For traceability every task in the general plan is linked to an activity.
Task: The objective at hand, traceable to given activity.
Responsible: Who is mainly responsible for working on the task.
Hours estimated: An overall estimate of the total time used on that task.
Total Hours: The total time actually used on that given task.

Act.	Task	Responsible	Hours estimated	Total Hours
X	X	X	Xh	Xh

Table 4: Table illustration.

[2] See attachment 2.

Project planning

Act.	Task	Responsible	Hours estimated	Total Hours
A0.2	Internal meetings	Everyone	80h	47.5h
A0.1	External meetings	Everyone	160h	73.5h
A1.2	Project plan	Elvar, Kristoffer	160h	186h
A0.3	Internal group meetings	Everyone	60h	21.5h
A0.6	Other administrative tasks	Everyone	20h	25.5h
A0.5	Minutes of meeting	Everyone	20h	7h
A0.13	General documentation	Everyone	45h	58.5h
A0.14	Iteration report	Elvar	8h	21.5h

Requirement analysis

Act	Tasks	Responsible	Hours estimated	Total hours
A1.1	Idea document	Stian	30h	28h
A1.5	Risk analysis	Katrine	20h	18.5h
A1.3	Requirements spec.	Stian	85h	31h

Analysis & Design

Act	Tasks	Responsible	Hours estimated	Total hours
A4.1 A5.1 A6.1 A7.1	Research	Everyone	120h 25h 25h 25h	83h 27h 7h 33h
A2.1 A2.2	Robot selection	Stian, Elvar	25h 25h	38h 28h
A4.2 A5.2 A6.2 A7.2	Concept selection	Everyone	75h 30h 30h 30h	105h 9h 15h 7h
A4.3	Design	Elvar, Katrine	250h	227h
A3.1 A3.2	Economics analysis	Katrine, Kristoffer	25h 25h	36.5h 63h

A4.8 A5.4 A6.4 A7.4	Documentation	Everyone	120h 20h 20h 20h	143h 10h 14h 7.5h

Test

Act	Tasks	Responsible	Hours estimated	Total hours
A1.4	Test spec.	Katrine	30h	74h
A0.12	Test plan	Katrine, Kristoffer	60h	38h
A2.3	Robot simulation	Stian	40h	31.5h
A4.4	Mechanical analysis	Katrine, Elvar	110h	34.5h
A4.5	Electrical analysis	Kristoffer	70h	105.5h

Implementation

Act	Tasks	Responsible	Hours estimated	Total hours
A0.7	Presentation 1	Everyone	70h	92h
A0.8	Presentation 2	Everyone	40h	86.5h
A0.9	Presentation 3	Everyone	240h	240h
A8.2	Final documentation	Everyone	150h	101h
A8.3	Web-page	Stian	10h	17h
A8.4	Poster	Elvar	15h	15h
A8.5	A4 Promo page	Elvar	5h	5h
A8.1	Final review	Everyone	20h	28.5h
A8.6	Project report	Everyone	40h	17h
Sum total			2478h	2257h

Table 5: Mission plan.

8.3 Economy

The main objective for the assignment is to create a proof of concept for the employer to be used as a demonstrator for their management. The company will accommodate us with their workshop for manufacturing of components without any extra cost for the group. Our only expenses will be printouts, travel expenses and other administrative related expenses.

Item	Description	Cost in NOK
1	Printouts	3000,-
2	Storage devices	250,-
3	Travel expenses	500,-
4	3D-printing	200,-
5	Literature	650,-

Table 6: Budget

9.0 Documents

Documents created will have an author/owner. A second member will do a review of the document for quality assurance. Throughout the life cycle of a project a vast number of documents will be created and need verifications. The document manager will will review the documents that are set to be released. If the document manager is the author, the group leader will be the reviewer. As security is a big subject for the project the group will send all documents to the external supervisor for review and approval.

After deliberations with external supervisor we were given the approval to create our own template and structure for the documents. We have made a unique front page that every document will have. The front page includes a table for identification, stating who was the reviewer and approver, the version of the document, and a set date and status for the document.

- **Idea document**

This is a short document describing the problem given to us by KDA. The purpose is to give the reader an understanding of the system that is being designed.
Owner: Stian Hovde
Status: Finished

- **Project plan**

This document serves to provide the group and supervisors with overview of the planned progression of the project, the document will be revised if needed.
Owner: Elvar Aspelund
Status: Finished

- **Project risk document**

Document detailing the risks involved in the project, and countermeasures to them.
Owner: Katrine Kallevik
Status: Finished

- **Use Case & Test Case document**

The use-case document identifies the actors of our system and the interactions the actor has with that given system.
Owner: Elvar Aspelund
Status: Finished

- **Requirement specification**

This document is a specification of the requirements worked out by the project group based on the information given by KDA.
Owner: Stian Hovde
Status: Finished

- **Test specification**

This document sets up different tests to test the validity of the requirements.
Owner: Katrine Kallevik
Status: Finished

- **Test plan**

A more detailed version of the test specification, explaining step by step how we will perform the tests, and what the success criterias are.
Owner: Kristoffer Lund
Status: Finished

- **Test report**

The test report document contains reports from all the tests we have conducted during the project.
Owner: Kristoffer Lund
Status: Finished

- **Iteration report**

This document is for planning and conclusions of iterations during the project.
Owner: Elvar Aspelund
Status: Finished

- **Concept generation**

This document describes the different concepts that we have come up with, for systems that are able to complete the process of installing bolts into our aerospace component. It also gives a reasoning and conclusion to what concept we have chosen for our final product.
Owner: Stian Hovde
Status: Finished

- **Design document**

This document details the process in which we conducted our final design for the assembly tool. Here we go from concept to end design, describing components and their functions that were selected from second hand suppliers.
Owner: Elvar Aspelund
Status: Finished

- **Robot selection**

Document listing several robots and tool changers that are relevant for this project, and chooses one to use.
Owner: Stian Hovde
Status: Finished

- **Economical analysis**

This document contains an economic analysis of the economical advantages of automating a production line.
Owner: Katrine Kallevik
Status: Finished

- **Final report**

In the final report the project group reflects both individually and collectively over the work that has been done and the experience we have gained over the last months.
Owner: Stian Hovde
Status: Finished

10.0 Sources

[1] Methods and tools, *Understanding the unified process*, cited 06.02.2015, available from: http://www.methodsandtools.com/archive/archive.php?id=32

[2] Wikipedia, *Unified process,* cited 06.02.2015, available from: http://en.wikipedia.org/wiki/Unified_Process

11.0 Attachments

Attachment 1: Gantt chart
Attachment 2: UP-model
Attachment 3: Activity and requirement traceability.

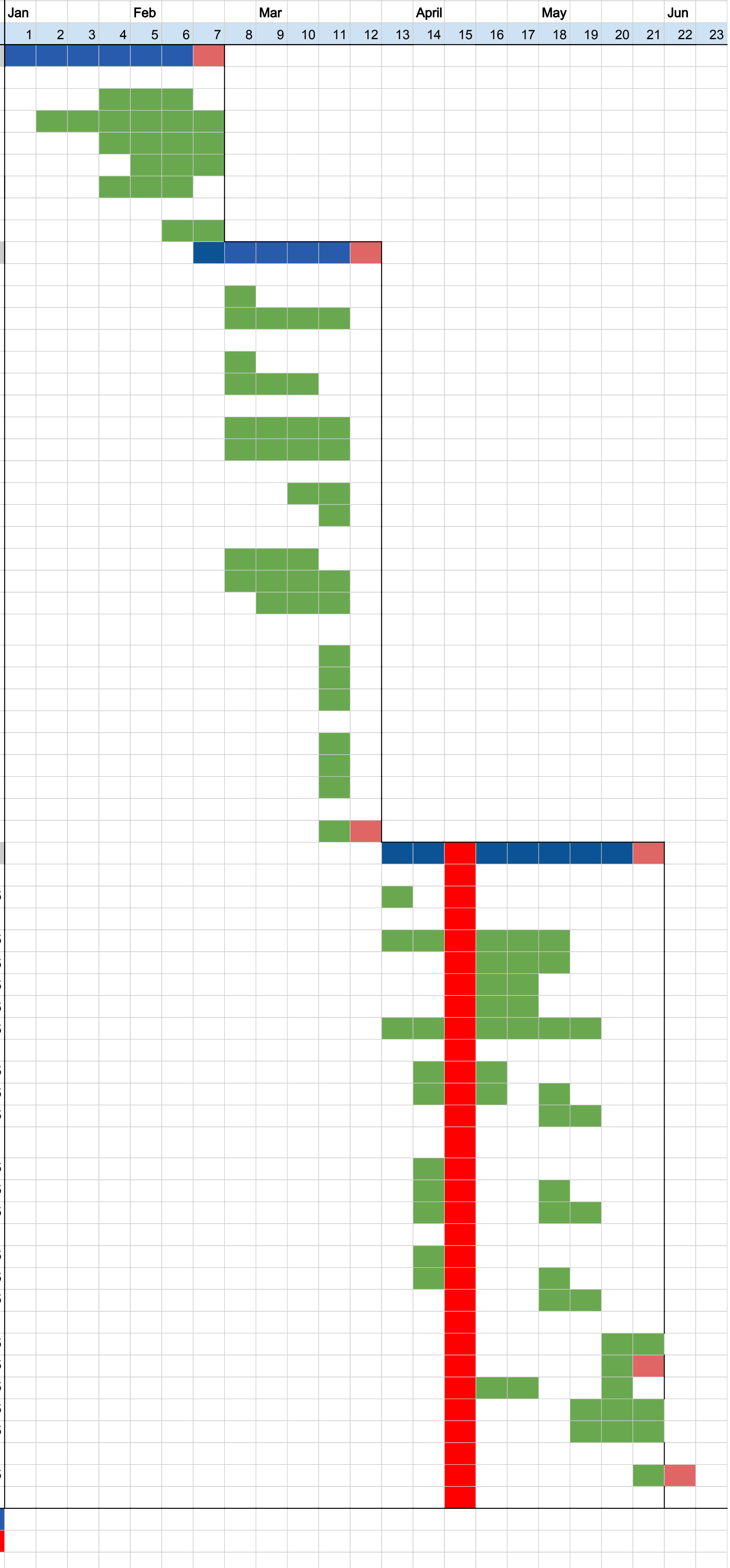
Project plan(Bachelor) Attachment 3.0

Doc.Owner(s): Elvar A, Kristoffer L

Start Date: 5. January 2015

End Date: 27. May 2015

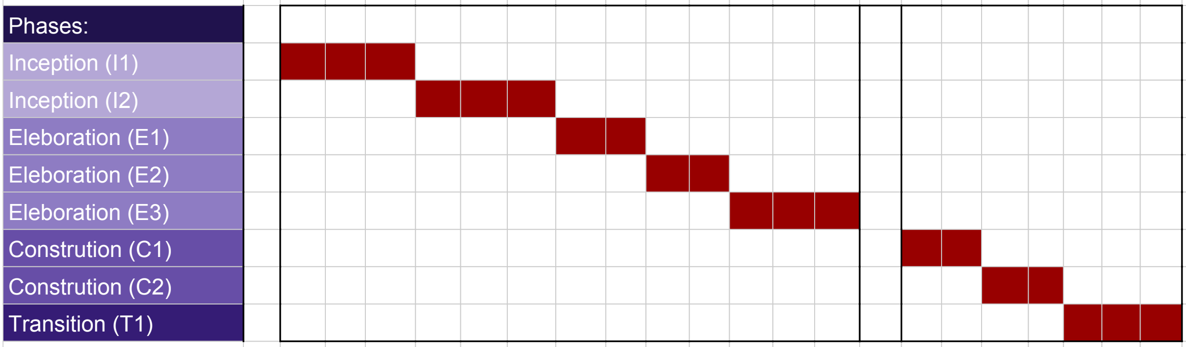
Tasks	% Done	Start	End
Milestone1	**100.00%**	**Jan-5**	**Feb-13**
(A1) Requirement Ana. & Project plan.	100.00%		
(A1.1) Idea document	100.00%	14.01.15	06.02.15
(A12) Project plan	100.00%	09.10.14	11.02.15
(A1.3) Requirement specification	100.00%	20.01.15	11.02.15
(A1.4) Test specification	100.00%	28.01.15	11.02.15
(A1.5) Risk analysis	100.00%	16.01.15	22.01.15
(A0) Administrative	100.00%		
(A0.7) First presentation	100.00%	04.02.15	13.02.15
Milestone2	**100.00%**	**Feb-13**	**Mar-23**
(A0) Administrative	100.00%		
(A0.10) First revision	100.00%	16.02.15	16.02.15
(A0.12) Test plan	100.00%	16.02.15	16.03.15
(A2) Robot selection	100.00%		
(A2.1) Research	100.00%	16.02.15	09.03.15
(A2.2) Documentaion	100.00%	16.02.15	09.03.15
(A3) Economic analysis	100.00%		
(A3.1) Research	100.00%	16.02.15	23.02.15
(A3.2) Documentation	100.00%	16.02.15	23.02.15
(A7) Design of verification system	100.00%		
(A7.1) Research	100.00%	12.03.15	23.03.15
(A7.2) Concept selection	100.00%	09.03.15	23.03.15
(A4) Design of bolt and inst.tool	100.00%		
(A4.1) Research	100.00%	18.02.15	09.03.15
(A4.2) Concept selection	100.00%	18.02.15	09.03.15
(A4.8) Documentation	100.00%	23.02.15	
(A6) Design of promoter and sealant system	100.00%		
(A6.1) Research	100.00%	09.03.15	16.03.15
(A6.2) Concept selection	100.00%	09.03.15	16.03.15
(A6.4) Documentation	100.00%	09.03.15	16.03.15
(A5)Design of bolt sorting system	100.00%		
(A5.1) Research	100.00%	09.03.15	16.03.15
(A5.2) Concept selection	100.00%	09.03.15	16.03.15
(A5.4) Documentation	100.00%	09.03.15	16.03.15
(A0) Administrative	100.00%		
(A0.8) Second presentation	100.00%	13.03.15	19.03.15
Milestone3	**100.00%**	**Mar-23**	**May-19**
(A0) Administrative	100.00%		
(A0.10) Second revision	100.00%	23.03.15	23.03.15
(A4) Design of bolt and inst.tool	100.00%		
(A4.3) Design	100.00%	23.03.15	27.04.15
(A4.4) Mechanical analysis	100.00%	13.04.15	27.04.15
(A4.5) Electrical analysis	100.00%	13.04.15	27.04.15
(A4.6) Construction	100.00%	13.04.15	27.04.15
(A4.8) Documentation	100.00%	23.03.15	27.04.15
(A5)Design of bolt sorting system	100.00%		
(A5.1) Research	100.00%	30.03.15	19.04.15
(A5.2) Concept selection	100.00%	30.03.15	03.05.15
(A5.4) Documentation	100.00%	27.04.15	10.05.15
(A6) Design of promoter and sealant system	100.00%		
(A6.1) Research	100.00%	30.03.15	05.04.15
(A6.2) Concept selection	100.00%	30.03.15	03.05.15
(A6.4) Documentation	100.00%	30.03.15	10.05.15
(A7) Design of verification system	100.00%		
(A7.1) Research	100.00%	30.03.15	05.04.15
(A7.2) Concept selection	100.00%	30.03.15	03.05.15
(A7.4) Documentation	100.00%	27.04.15	10.05.15
(A8) Final documentation	100.00%		
(A8.1) Final review	100.00%	11.05.15	19.05.15
(A8.2) Final documentation	100.00%	11.05.15	19.05.15
(A8.3) Web page	100.00%	13.04.15	17.05.15
(A8.4) Poster	100.00%	04.05.15	21.05.15
(A8.5) A4 promotional page	100.00%	04.05.15	21.05.15
(A0) Administrative	100.00%		
(A0.9) Final presentation	100.00%	18.05.15	27.05.15
Completion	**100.00%**		

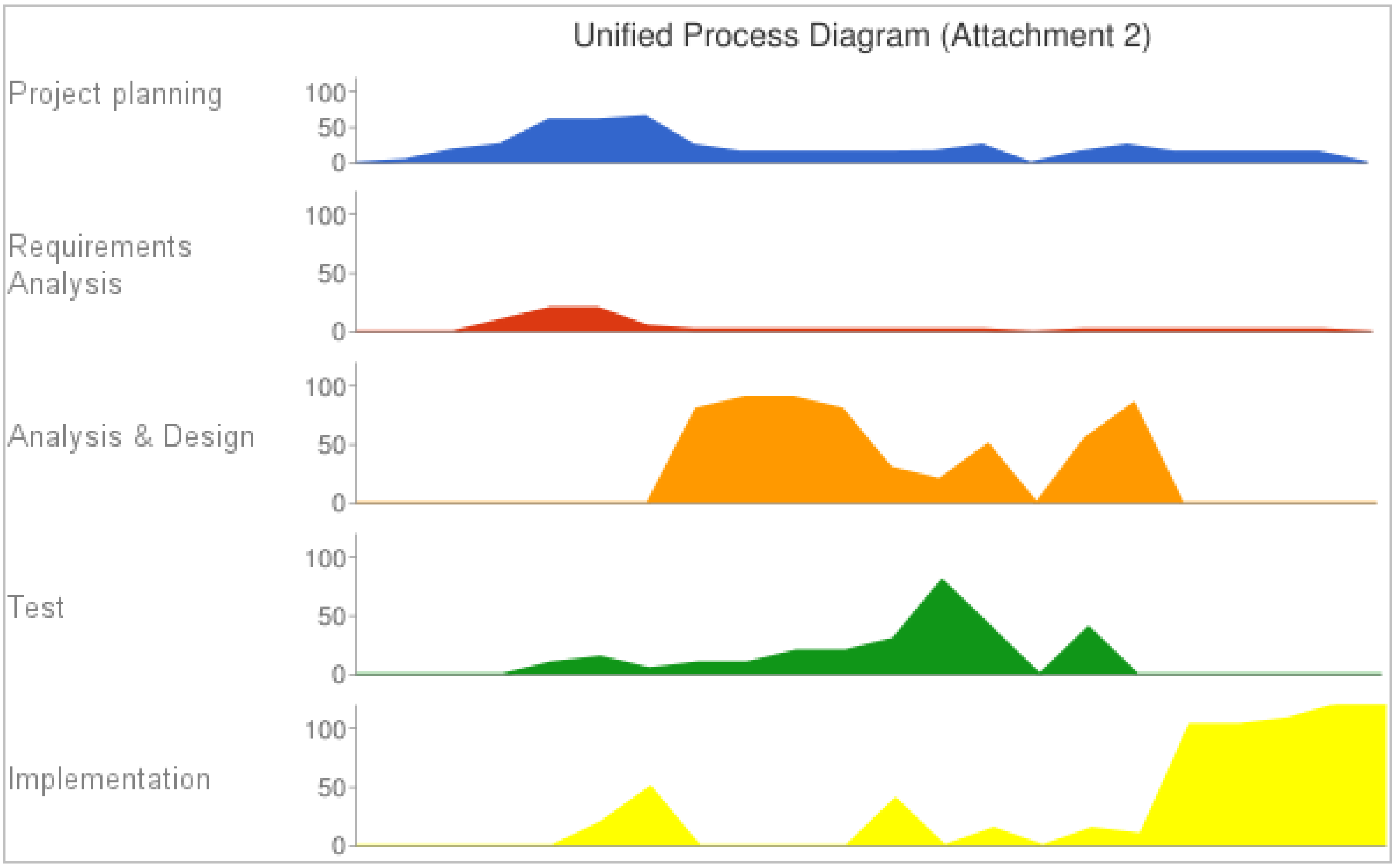


deadline		phase	
to do		exam	
complete			

Attachment 2

Milestones:							M1					M2										M3
Week:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Project planning	0	4	18	26	60	60	65	25	15	15	15	15	16	25	0	15	25	15	15	15	15	0
Requirements Analysis	0	0	0	10	20	20	5	2	2	2	2	2	2	2	0	2	2	2	2	2	2	0
Analysis & Design	0	0	0	0	0	0	0	80	90	90	80	30	20	50	0	55	85	0	0	0	0	0
Test	0	0	0	0	10	15	5	10	10	20	20	30	80	40	0	40	0	0	0	0	0	0
Implementation	0	0	0	0	0	20	50	0	0	0	0	40	0	15	0	15	10	103	10	10	12	12




Unified Process Diagram (Attachment 2)
Project planning
Requirements Analysis
Analysis & Design
Test
Implementation
100
50
0

Attachment 3: Activities-requirements table.

Activity	Requirements
(A0) Administrative	R-OTH-01 R-OTH-02
(A1) Requirement analysis & Project planning	R-OTH-01 R-OTH-02
(A2) Robot selection	R-ROB-01 R-ROB-02 R-ROB-03 R-ROB-04 R-ROB-09 R-ROB-10 R-ROB-11 R-ROB-12 R-ROB-13
(A3) Economic analysis	
(A4) Design and production of bolt installation tool	R-TOL-01 R-TOL-02 R-TOL-03 R-TOL-05 R-TOL-06 R-TOL-07 R-TOL-08 R-TOL-09 R-TOL-10 R-TOL-11 R-TOL-12 R-TOL-16 R-TOL-17
(A5) Design of bolt sorting system	R-SRT-01 R-SRT-02 R-SRT-03
(A6) Design of promoter and sealant system	R-PNS-01 R-PNS-02 R-PNS-03 R-PNS-04 R-PNS-05 R-PNS-06 R-PNS-07
(A7) Design of verification system	R-INS-01 R-INS-02 R-INS-03 R-INS-04 R-INS-05 R-INS-06 R-INS-07 R-INS-08
(A8) Final documentation	R-OTH-01 R-OTH-02

Requirements-activities table.

Requirements	Activities
Robot requirements	
R-ROB-01	(A2) Robot selection
R-ROB-02	(A2) Robot selection
R-ROB-03	(A2) Robot selection
R-ROB-04	(A2) Robot selection
R-ROB-09	(A2) Robot selection
R-ROB-10	(A2) Robot selection
R-ROB-11	(A2) Robot selection
R-ROB-12	(A2) Robot selection
R-ROB-13	(A2) Robot selection
Bolt installation tool requirements	
R-TOL-01	(A4) Design and production of bolt installation tool
R-TOL-02	(A4) Design and production of bolt installation tool
R-TOL-03	(A4) Design and production of bolt installation tool
R-TOL-05	(A4) Design and production of bolt installation tool
R-TOL-06	(A4) Design and production of bolt installation tool
R-TOL-07	(A4) Design and production of bolt installation tool
R-TOL-08	(A4) Design and production of bolt installation tool
R-TOL-09	(A4) Design and production of bolt installation tool
R-TOL-10	(A4) Design and production of bolt installation tool
R-TOL-11	(A4) Design and production of bolt installation tool
R-TOL-12	(A4) Design and production of bolt installation tool
R-TOL-16	(A4) Design and production of bolt installation tool

R-TOL-17	(A4) Design and production of bolt installation tool
Bolt sorting requirements	
R-SRT-01	(A5) Design of bolt sorting system
R-SRT-02	(A5) Design of bolt sorting system
R-SRT-03	(A5) Design of bolt sorting system
Promoter and sealant system requirements	
R-PNS-01	(A6) Design of promoter and sealant system
R-PNS-02	(A6) Design of promoter and sealant system
R-PNS-03	(A6) Design of promoter and sealant system
R-PNS-04	(A6) Design of promoter and sealant system
R-PNS-05	(A6) Design of promoter and sealant system
R-PNS-06	(A6) Design of promoter and sealant system
R-PNS-07	(A6) Design of promoter and sealant system
Inspection requirements	
R-INS-01	(A7) Design of verification system
R-INS-02	(A7) Design of verification system
R-INS-03	(A7) Design of verification system
R-INS-04	(A7) Design of verification system
R-INS-05	(A7) Design of verification system
R-INS-06	(A7) Design of verification system
R-INS-07	(A7) Design of verification system
R-INS-08	(A7) Design of verification system
Other requirements	
R-OTH-01	(A0) Administrative, (A8) Final documentation
R-OTH-02	(A0) Administrative, (A8) Final documentation

Project Risk Document

Version	Date	Reviewed by	Approved by	Satus
2.0	15.05.2015	Elvar Aspelund	Tor Sigurd Breivik	Released

Table of contents

List of tables

List of figures

1.0 Abstract

This document is an analysis of the risks for our project.

2.0 Revision History

Version	Date	Changes	Author
0.1	14.03.2015	• First version of the document	Katrine Kallevik
1.0	16.03.2015	• First released version	Katrine Kallevik
1.1	14.05.2015	• Spellcheck, review	Katrine Kallevik
1.2	14.05.2015	• Edited introduction	Kristoffer Lund
2.0	15.05.2015	• Final version of document	Katrine Kallevik

Table 1: Revision table.

3.0 Risk analysis

This document contains a collection of risks we might be subjected to through the project. The purpose of this document is to evaluate the occurrence and consequence of these, and create prevention and solution plans we can use if they occur.

3.1 Project risks:

- **Stakeholders demands**

If we do not meet the stakeholders demands.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Prioritize the requirements given and use more time on this phase in the project.		
Solution	Adjust the requirements so the assignment can be completed.		

- **Absence**

If any of us get sick, injured or for any other reason can not participate in a critical state of the project.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Try to not participate in any risky activities during the project.		
Solution	All team members must have an overview and good understanding of the overall project task.		

- **Information**

If we get too little insight in the process. This might lead to misunderstanding of the process.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Good communication with KDA.		
Solution	Go back and reschedule.		

- **The assignment**

If the project is not completed in time.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Follow a good project plan and make sure we have a good progress.		
Solution	Use more resources to get the assignment done.		

- **Technical problems**

If we lose valuable documents and work we have done.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Each of the members of the group have a responsibility of saving files and take backup copies.		
Solution	Save all documents several times and take backup copies.		

- **Mentors**

If we do not get enough supervision from our internal and external mentor, or if the availability of mentors is less than we need and expect.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Regular contact with both external and internal supervisor.		
Solution	Schedule meetings well in advance, so that it fits in everyone's schedule.		

- **Behind the schedule.**

If we are working to slow, or if there is too much to do in the assignment.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Good communication with KDA. Good communication within the group.		
Solution	Reduce the assignment and work working according to the project plan.		

- **Teamwork**

If group members disagrees and do not find a solution to the problem.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Good communication within the group.		
Solution	Try to work out our problems in the best possible way.		

- **Complexity**

If the project is too complex, and we do not have time to complete it.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Reduce A requirements, and try to constrict the project.		
Solution	Use more resources to get the project finish in time.		

- **Solution already exists**

There already exists a solution to the given task.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Make sure we have other tasks available.		
Solution	Since we have focused on a small piece of the process, there are other areas in the process we can look at .		

- **Poor research**

If the research is to poor, we might miss important technology that already exists. This might result in us doing a lot of work on unnecessary things.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	The group have to do enough research.		
Solution	Use more resources to find the best existing technology.		

- **Breach of contract with employer**

If the client breaks the contract deal.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Keep our part of the contract.		
Solution	Good communication with KDA.		

- **Sources is not well enough documented**

If we have not marked documentation well enough with regards to sources.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	It is important to have a system for documentation of sources.		
Solution	Always check sources before approving documents.		

- **Not well enough documented work.**

If our work is not well enough documented.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Documents and document structures are continuously updated.		
Solution	Make iteration reports to get clear view of progress in the project.		

3.2 System Risks

- **Zone breach**

If the security zone for robot is breached.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Make sure the robot is secured with signs or fences.		
Solution	The robot have a security zone. If the zone is breach, the security system stops all robot activity.		

- **Maintenance**

If the robot is not maintained properly and error occurs.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Make sure maintenance is maintained.		
Solution	Make sure to have a checklist for maintenance of the robot, and have a schedule for performing it.		

- **Shutdown**

Robot shutdown during its use

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Make sure maintenance is maintained.		
Solution	Its hard to prevent this from happening if it were to be the case.		

- **Software bugs**

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Impossible to prevent this from happening.		
Solution	Make sure software is simulated properly before being implemented in the system.		

- **High voltage system**

If electric current passing through the human body when the robot is maintained.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Be careful and take precautions.		
Solution	Use safety equipment.		

- **Mechanical failure**

If an unexpected failure occurs.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Make sure to have good procedures and routines if mechanical failure occurs.		
Solution	Be aware that unexpected failure may occur and take precautions.		

- **Improper installation**

If the robot is installed improperly.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Any time an industrial robot is installed it is vital to the success of the project and safety of the operators that the system is installed correctly before it is fully operational. It is therefore important with safety procedures and a checklist to make sure the robot is properly installed.		
Solution	Make sure there are several people with authorization to check that the robot is properly installed.		

- **Control errors**

If errors in the controls software occurs.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Make sure there is safety systems that can prevent this.		
Solution	Safety system that will shut the whole system down if errors in the control software is detected.		

- **Unauthorized access**

If an operator is unfamiliar with the safety hardware associated with the robotic work cell is working there.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Make sure there is strict rules for working with robots and robot cells.		
Solution	Make sure only authorized operators have access to the robotic work cell.		

- **Unqualified operators**

If any operators use equipment they are unqualified for to move parts into the robot cell.

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Material handling equipment shall only be used by qualified operators		
Solution	Only individuals who have received proper training, authorization, and licensing are permitted to operate material handling equipment.		

3.3 Economic risks

- **The company goes bankrupt.**

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Impossible to prevent this from happening.		
Solution	Make sure that we can complete our project even if this has occurred.		

- **Automation of the process is not profitable**

Risk occurrence	Small	Medium	Great
Risk consequence	Small	Medium	Great
Prevention	Impossible to prevent this from happening.		
Solution	Make sure we can continue the project as if it is profitable.		

4.0 Sources

[1] National Institute of Standards and Technology, *Guide to Industrial Control Systems (ICS) Security*, cited 15.03.2015, available from:
http://csrc.nist.gov/publications/nistpubs/800-82/SP800-82-final.pdf

[2] Bastian Solutions, *7 Industrial Robotics Hazards and How to Avoid Them*, cited 15.03.2015, available from:
http://www.bastiansolutions.com/blog/index.php/2011/01/05/7-industrial-robotics-hazards-and-how-to-avoid-them/#.VU6PXvmSw1E

[3] Production Machining, *Handling parts in a robotic cell*, cited 15.03.2015, available from:
http://www.productionmachining.com/articles/handling-parts-in-a-robotic-cell

Use Case & Test Case Document

Version	Date	Reviewed by	Approved by	Satus
2.0	15.05.2015	Kristoffer Lund	Tor Sigurd Breivik	Released

Table of contents

List of tables

List of figures

1.0 Abstract

This use case document identifies the actors of our system and the interactions the actor has with that given system. Use cases gives a description of the functions of the system. This leads to the use test cases, making the foundation of a user manual to test and use the system.

2.0 Revision History

Version	Date	Changes	Author
0.1	05.03.2015	• Created the document	Elvar Aspelund
1.0	16.03.2015	• First released version	Elvar Aspelund
1.1	12.05.2015	• Spellcheck	Stian Hovde
2.0	15.05.2015	• Second released version	Elvar Aspelund

Table 1: Revision table.

3.0 Use Case

A use case defines a set of use case instances. A use case instance is a sequence of steps that the system undertakes that yields an observable result for a given actor.

Each use case has a task of its own to perform. The collected use cases constitute all the possible ways of using the system. You can get an idea of a use case task simply by observing its name.

In the early iterations in elaboration there are only a few use cases that are considered architecturally significant. These are only briefly described beyond their description. Later in the project, some of the use cases will be described in greater detail. This means that the use case instances will be given alternative flow of process and variety of different scenarios.

Use case template:

- **Finding use cases:**
  The system provides the use case. What does the system do? How does the actor interact with the system? Will the actor need to be informed by the system or give the system necessary information? How many actors affect the system?

- **Identifying the actors:**
  An actor communicates with a use case instance of the system. Who will be using the system? Which role do they have? What do they do?

  Primary Actors:
  - The operator
    - Person responsible for operating the robot cell, and doing the everyday task that is needed for the continued operation. This includes things like refilling of the sorting system, and promoter and sealant station.

Secondary Actors:

- Training consultant
    - Person that gives the operator the necessary training to operate the robot cell.

- Technicians
    - Person in charge of routine service and maintenance of the robot cell, and keeping the software up to date. This could either be done by the operator of the robot cell, or a dedicated technician.

- **The system:**
    - The robot cell. This includes all of the robots, assembly tool system, bolt and nut sorting system, promoter and sealant system and the verification system. It is the whole enclosure in which the system operates.
    - Should deliver the product that is requested, that will be the assembly and quality control of the aerospace part.

3.1 Use cases

This chapter will show a number of use cases, it will provide an understanding of the steps the actor has to take while interacting with the system. The use cases are the foundation for our test cases that will be addressed in chapter 4.

Use case overview

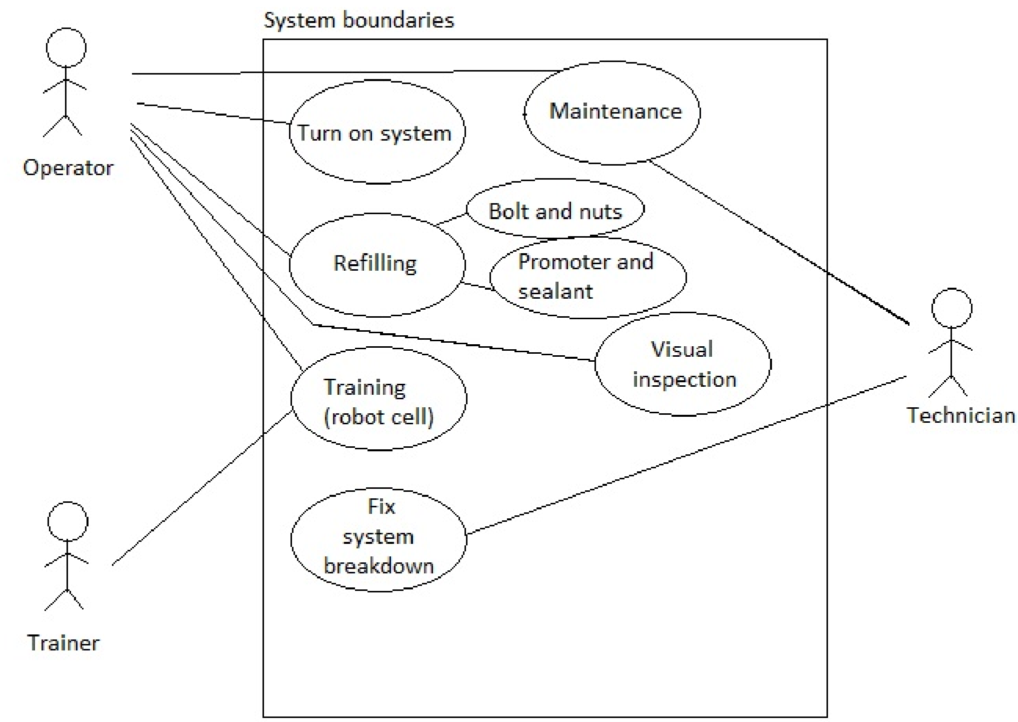
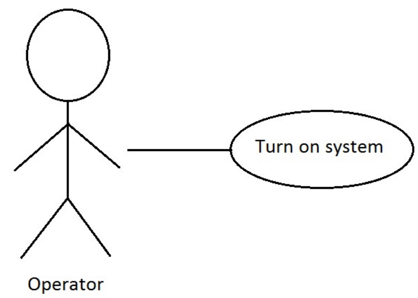


Figure 1: Use case overview.

Use case id	Actor	Scope	Use case Description
UC-1	Operator	Robot cell	The operator turns on the systems and initiates the assembly program for the robot.

Use case:
Turn on system



Postcondition	Precondition
• The system functions as expected. • Operator is able to verify success via the system panel.	• The interface is easy to access. • System panel enables the operator to start the system. • The software has a start function.

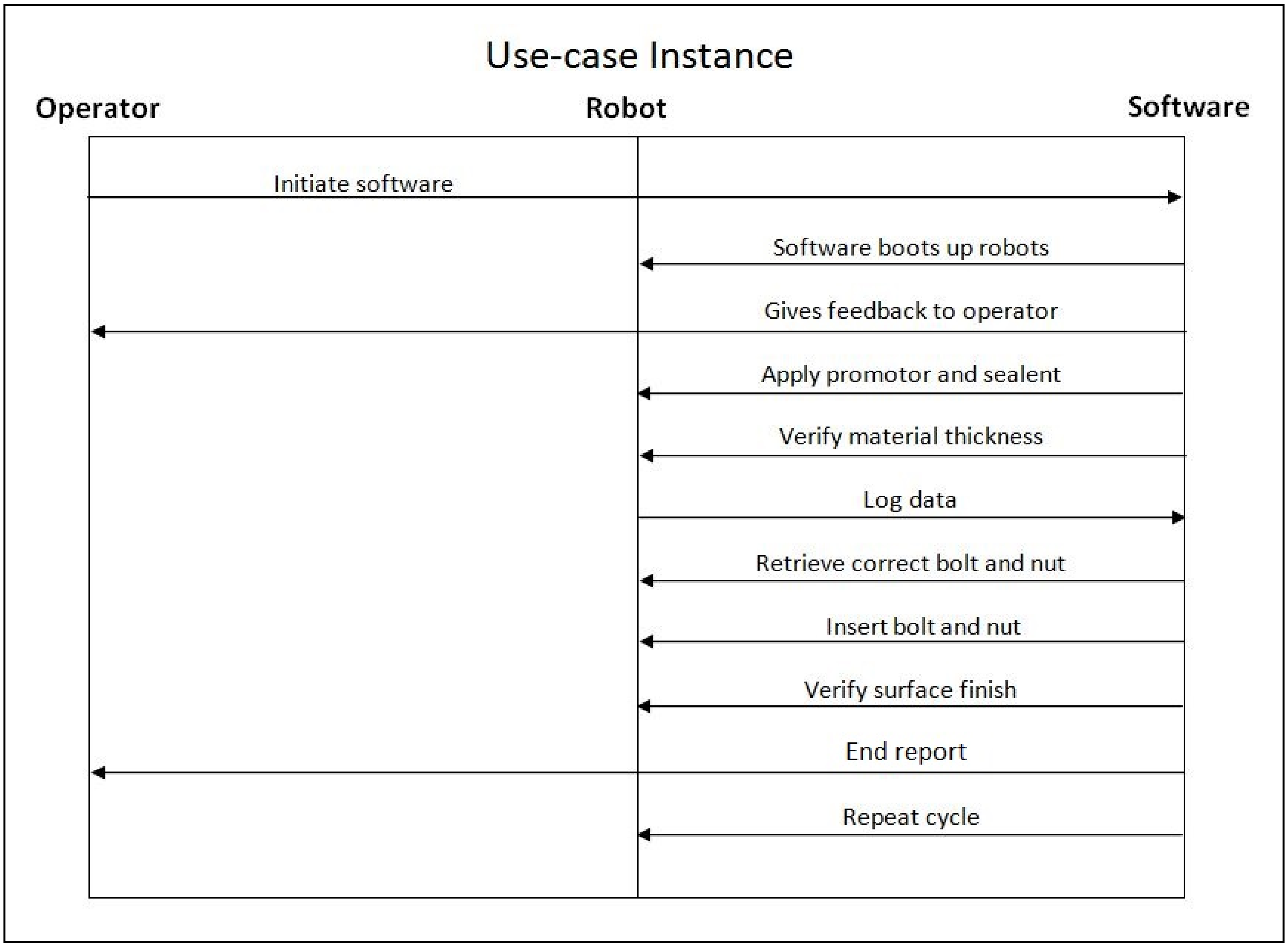
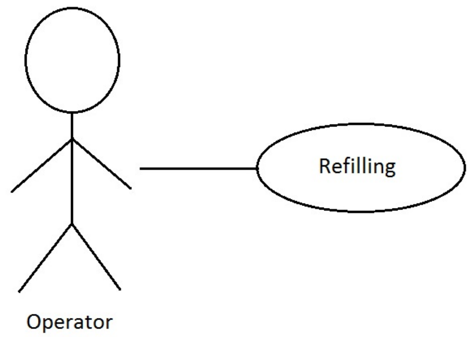


Table 2: Use case 1.

Use case id	Actor	Scope	Use case Description
UC-2	Operator	Robot cell	The operator refills the bolt and nut sorting system.

Use case:
Refilling (bolt and nut)



Postcondition	Precondition
• If system stops due to need of refilling, the operator is able to restart system after refilling. • The assembly process is able to continue. • Operator receives information that the refilling is complete.	• The system needs refilling. • Operator is notified that the system needs refilling. • System stops, operator receives notification of reason why it stops.

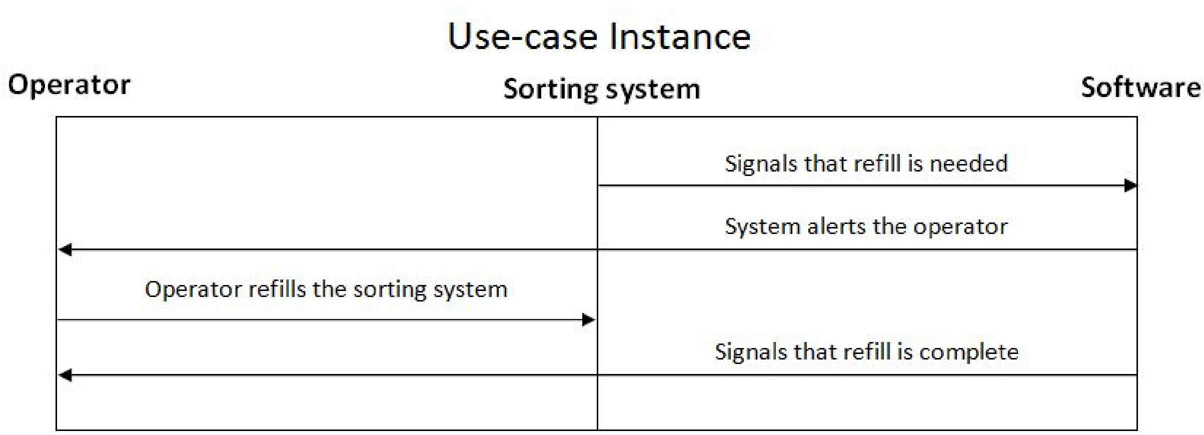
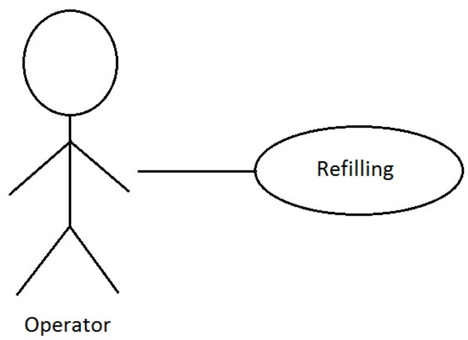


Table 3: Use case 2.

Use case id	Actor	Scope	Use case Description
UC-3	Operator	Robot cell	The operator refills the promoter and sealant system.

Use case:
Refilling (promoter and sealant)

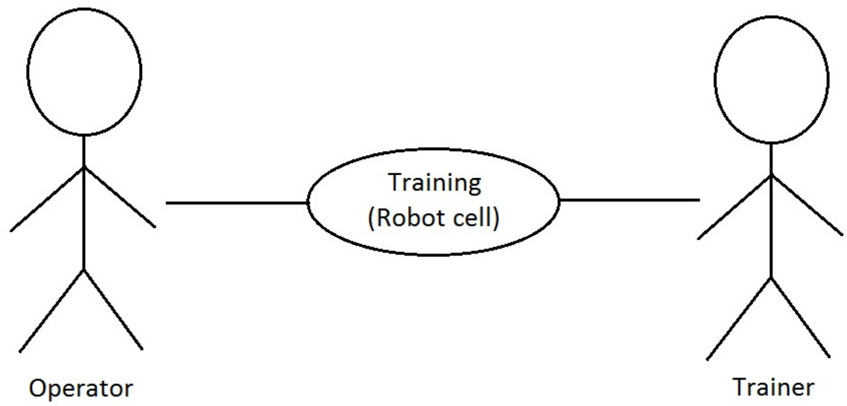


Postcondition	Precondition
● If system stops due to need of refilling, the operator is able to restart system after refilling ● The assembly process is able to continue. ● Operator receives information that the refilling is complete.	● The system needs refilling. ● Operator is notified that the system needs refilling. ● System stops, operator receives notification of reason why it stops.

Table 4: Use case 3.

Use case id	Actor	Scope	Use case Description
UC-4	Training consultant, Operator	Robot cell	Provides the operator with the necessary skills that is needed to operate the robot cell.

Use case:
Training

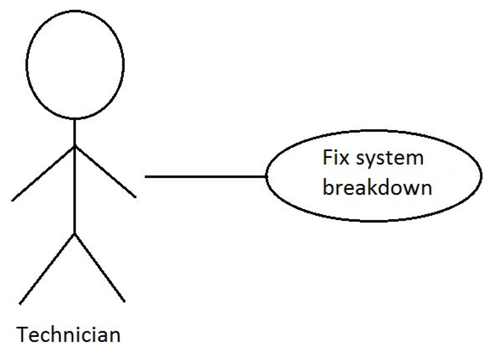


Postcondition	Precondition
• The operator has received the necessary training to operate the robot cell. • Proper user manuals are provided to the operator.	• The training consultant is qualified for the task. • The system is functional and up to date.

Table 5: Use case 4.

Use case id	Actor	Scope	Use case Description
UC-5	Technicians	Robot cell	The technicians are contacted, and run diagnostics procedures either onsite or offsite. If necessary, they perform mechanical maintenance on the system. When completed, they run a system check to verify that the problem is solved.

Use case:
Breakdown



Postcondition	Precondition
• Technicians are able to fix given problem. • Technicians provide system owner with a maintenance report.	• Operator is not able to fix problem. • The system does not function as it should. • Operator is notified that the system is faulty and is able to take necessary precautions.

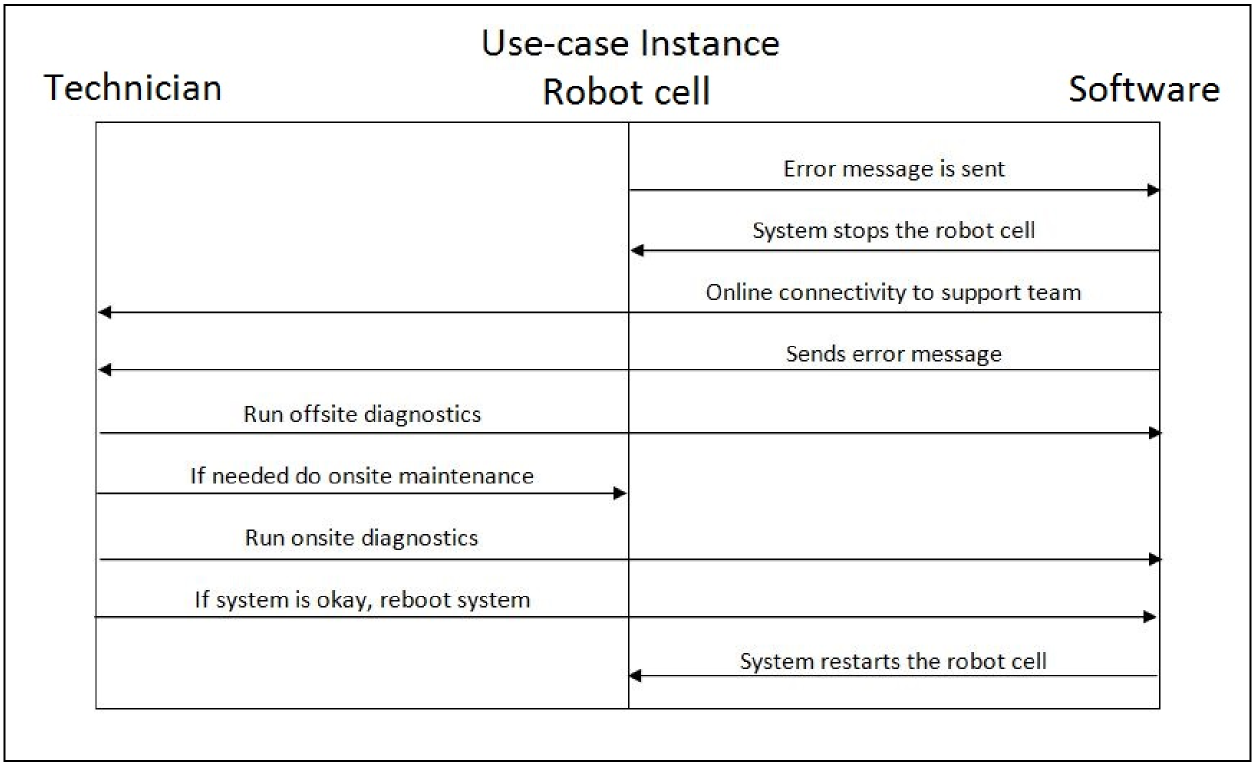
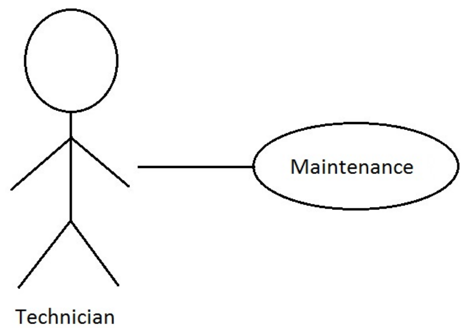


Table 6: Use case 5.

Use case id	Actor	Scope	Use case Description
UC-6	Technicians	Robot cell	Routine maintenance for the robot cell. This is done according to the specifications given by the manufacturer of the robot cell.

Use case:
Maintenance

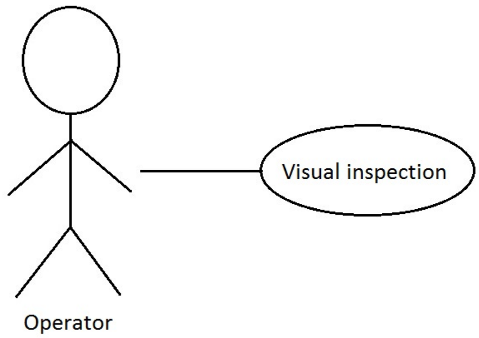


Postcondition	Precondition
• Maintenance is completed and report is filed. • Necessary updates have been done. • System is up to date	• Scheduled maintenance is due • Either robot cell operator or off site technicians complete the maintenance. • Maintenance tools are available. • Robot cell provider has necessary software/hardware updates available.

Table 7: Use case 6.

Use case id	Actor	Scope	Use case Description
UC-7	Operator	Robot cell	After the assembly process is complete, the process will be concluded with an visual inspection of the aerospace part. This is done to verify that the surface quality is good enough.

Use case:
Inspection



Postcondition	Precondition
• Assembly process has been completed to specifications • Report is filed.	• Assembly process is completed. • Aerospace part is made available for inspection.

Table 8: Use case 7

4.0 Use Case Testing

Use case testing provides the necessary steps to verify that the system works as it should. The use case tests can be provided as a user manual for the system owner to run maintenance test to ensure that the system is operational.

When testing the use cases, we need a set of preconditions and a set of postconditions. The tester should have a known input which will be a precondition and an expected output that will be a postcondition.

Test cases should always have at least two tests, one positive and one negative test for each requirement.

- Test case table description:
    - **Test case ID:** Each test case is given a unique ID that corresponds with the use case it is testing. For example, TC-1 corresponds with UC-1.
    - **Steps:** As there are number of paths the user can take during each use case, the test case must also address every path. For example, if step 1 is the first step, then step 1a is the same step but an alternative path, either giving a positive or negative result.
    - **Expected results:** This section shows the user what should happen when given command is performed.
    - **Actual result:** After physical test is completed, note the results.

4.1 Test cases

- In this chapter the use cases will be tested.

Test case ID	Test case Description	Steps	Steps to perform	Expected result	Actual result
TC-1	Operator turns on the robot software and initiates assembly program.	1	Push the "on" button on the console.	The system starts up.	
		1a	Random button pushed (not "on" button).	System remains off.	
		2	Select assembly program.	Message to user that given program is selected. Click "ok" to proceed or "cancel" to go back.	
		2a	Correct program selected.	Given program is displayed, notifying the user. Click "start" to initiate program, click "return" to go back.	
		2b	Wrong program selected.	Message to user that given program is selected. Click "ok" to proceed or "cancel" to go back	
		2c	Wrong program selected, "ok" is clicked.	Given program is displayed, notifying the user. Click "start" to initiate program, click "return" to go back.	
		3	Correct program selected. Assembly process starts.	Assembly of aerospace part is started and completed.	

Table 9: Test case 1.

Test case ID	Test case Description	Steps	Steps to perform	Expected result	Actual result
TC-2	Refilling of bolt and nuts	1	Check console to verify what needs refilling.	Message should be prompted stating what needs refilling.	
		2	Retrieve bolt and nuts from storage.	Storage should contain bolts and nuts.	
		3	Refill correct container with bolts and nuts.	Container is clearly marked with given bolt/nut diameter size.	
		4	Click “ok” on console to confirm that refilling is complete.	Massage prompted that refilling is complete and sorting system starts.	

Table 10: Test case 2.

Test case ID	Test case Descriptio n	Steps	Steps to perform	Expected result	Actual result
TC-3	Refilling of promoter and sealant	1	Check console to verify what needs refilling.	Message should be prompted stating what needs refilling.	
		2	Retrieve promoter or sealant from storage.	Storage should contain promoter and sealant.	
		3	Refill correct container with promoter or sealant.	Container is clearly marked with promoter or sealant.	
		4	Click “ok” on console to confirm that refilling is complete.	Message prompted that refilling is complete and system starts.	

Table 11: Test case 3.

Test case ID	Test case Descriptio n	Steps	Steps to perform	Expected result	Actual result
TC-5	System breakdown	1	Check console.	Error message should be prompted.	
		2	Follow instructions given by system.	Diagnostics system is initiated.	
		2a	Diagnostics not able to complete. Contact technicians.	Technicians are contacted and take over.	
		3	Diagnostics complete, system reboot needed. press “ok”.	System reboots and is operational.	
		4	Restart system.	Repeat test case TC-1.	

Table 12: Test case 5.

Test case ID	Test case Description	Steps	Steps to perform	Expected result	Actual result
TC-6	Maintenanc e	1	Retrieve service manual.	System should be equipped with proper service manuals.	
		2	Follow guidelines given in service manual.	Service is completed to specifications.	
		2a	Problem occurs that is not stated in service manual.	Contact technician.	
		3	File report that system maintenance is complete.	Document is filed.	
		4	Restart system.	Repeat test case TC-1	

Table 13: Test case 6.

Test case ID	Test case Descriptio n	Steps	Steps to perform	Expected result	Actual result
TC-7	Visual Inspection of aerospace part.	1	Visual inspection of aerospace part.	The assembly process has been completed to specifications.	
		1a	Visual inspection conclude that assembly process is not to specifications.	Take necessary actions to address the problem.	
		2	Visual inspection is complete.	Document is filed.	

Table 14: Test case 7.

5.0 Sources

[1] Interface, *Use-case-driven development*, cited 06.03.15, available from: http://www.interface.ru/rational/rup51/manuals/intro/im_feat2.htm

[2] Wikipedia, *Use case*, cited 13.03.15, available from: http://en.wikipedia.org/wiki/Use_case

Requirement Specification

Version	Date	Reviewed by	Approved by	Satus
3.0	15.05.2015	Katrine Kallevik	Tor Sigurd Breivik	Released

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List of tables

List of figures

1.0 Abstract

This document is a specification of the requirements worked out by the project group based on the information given by Kongsberg Defence & Aerospace[1].

2.0 Revision history

Version	Date	Changes	Author
0.1	21.01.2015	• First version of the document.	Stian Hovde
1.0	10.02.2015	• First released version.	Stian Hovde
1.1	18.02.2015	• Changed requirements R-ROB-02 and R-TOL-03.	Stian Hovde
2.0	16.03.2015	• Second released version.	Stian Hovde
2.1	17.04.2015	• Changed requirement R-SRT-01. • Added requirement R-ROB-12.	Stian Hovde
2.2	03.05.2015	• Changed description of requirements R-ROB-01 and R-TOL-10.	Stian Hovde
2.3	06.05.2015	• Changed description of requirement R-TOL-11. • Deleted requirements R-TOL-13/14/15.	Stian Hovde
2.4	07.05.2015	• Changed description of requirement R-ROB-04/09. • Deleted requirements R-ROB-05/06/07/08. • Added requirement R-ROB-13.	Stian Hovde
2.5	14.05.2015	• Spellcheck, review	Katrine Kallevik
3.0	15.05.2015	• Final release	Stian Hovde

Table 1: Revision table

[1] From here on abbreviated to KDA

3.0 Introduction

The requirement specification is a document that lists all the requirements that both the project group and the employer expects to be fulfilled in the final product.

The most important purpose of this document is to common understanding between all involved parties about the final product of the project, and also creates a basis for all further work done on the project.

The requirement specification is also the basis of the test specification, which describes how to test that the requirements are fulfilled.

3.1 Priorities and categories

We have chosen to divide our requirements into categories based on the goals we have set for the project. This way, we can assign priorities based on the requirements importance for that goal, and not the project as a whole. Therefore it is important to note that the priorities can not be compared across different goals.

If we did not assigning priorities this way, we could easily end up with a secondary goal having only C requirements, since it is not critical for the project's completion. We would then end up with no way of telling which requirements are the most important for that individual goal. We therefore believe our method is better for this project.

Our priorities are as follows

Priority	Description
A	Requirements that must be fulfilled for the project to be considered successful.
B	Requirements that should be fulfilled, but are not critical for the project's completion.
C	Requirements that can be fulfilled if there is time and resources for it.

Table 2: Requirement priority

3.2 Requirement ID

Each requirement is given an unique ID to be able to easily identify it, and link it to other documents.

The standard format is R-XXX-NN

- R - Letter indicating that this is the ID for a requirement.
- XXX - Three letter code indicating which goal the requirement is for.
- NN - Unique number for the requirement within the goal.

If a requirement is deleted, the requirement ID will not be used again for a different requirement. This is to avoid confusion, since the requirement ID is referenced in several other documents.

3.3 Explanation of goals

We have in accordance with KDA divided our project into primary and secondary goals. Primary goals are what KDA is most interested in completing, and will be the primary focus for our project. Secondary goals are less important to complete, but are still included in the project plan.

We feel that this makes it easier for us to see what we need to focus on. It also helps us to see what we can cut out of the project if we find out that we will not be able to complete it in time.

4.0 Requirements

4.1 Primary Goals

4.1.1 Robot requirements

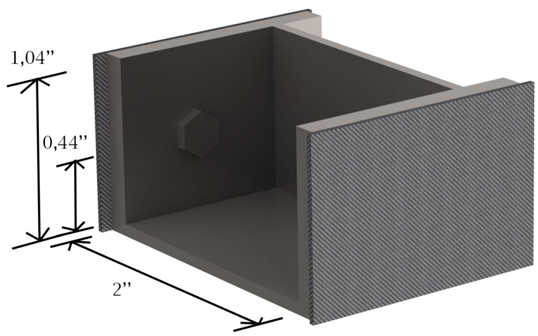
Goal: Evaluate different robot systems and choose the best suited for the project. The robot should be able to complete all the processes involved in the bolt installation process, so that only one robot is needed.

ID	Priority	Description	Traceability
R-ROB-01	A	The process shall be completed by a KUKA robot.	KDA - Tor Sigurd Breivik
R-ROB-02	A	Minimum lift capacity shall be 10 kg.	
R-ROB-03	A	The robot shall have a tool changing system.	
R-ROB-04	B	The robot shall have 6 rotational axes.	
R-ROB-09	A	The maximum repeatability shall be ±0.5 mm.	
R-ROB-10	B	The robot shall withstand temperatures ranging from +5℃ to +40℃.	
R-ROB-11	C	The maximum cycle time for the process shall be 2 minutes.	
R-ROB-12	A	During operation, access to the robot cell shall be limited to ensure safety for personnel.	
R-ROB-13	B	The minimum reach of the robot shall be 1 m.	

Table 3: Robot requirements

4.1.2 Bolt installation tool requirements

Goal: Design a tool that can fit into the aerospace part, and install the bolt. The tool must fit into the robots tool changer system. The produced tool will be a “proof of concept” for KDA.

ID	Priority	Description	Traceability
R-TOL-01	A	Bolts to be installed shall be of the Eddie bolt type with the associated nut.	KDA - Kristian Nilsen
R-TOL-02	A	Bolts shall be able to be installed within the following constrictions. 	
R-TOL-03	A	Maximum weight of tool shall be less than 10kg.	KDA - Tor Sigurd Breivik
R-TOL-05	B	The tool shall not drop any components during normal use.	
R-TOL-06	A	The tool shall perform without errors.	
R-TOL-07	A	The tool shall be designed so that it fits the robots tool changing system.	
R-TOL-08	B	The driving force of the tool shall be electrical.	
R-TOL-09	A	Any actuators shall be be located on the tool.	
R-TOL-10	A	The tool shall deliver a minimum of 10 Nm torque.	
R-TOL-11	A	The material of the tool shall handle all stresses during normal operation.	
R-TOL-12	B	The tool shall withstand temperatures ranging from +5℃ to +40℃.	

R-TOL-16	A	The service lifetime of the tool shall be 10,000 cycles	KDA - Tor Sigurd Breivik
R-TOL-17	A	The total lifetime of the tool shall be 100,000 cycles	

Table 4: Bolt installation tool requirements

4.2 Secondary goals

4.2.1 Bolt sorting requirements

Goal: Bolts of different diameters and grip lengths must be installed in the same process. A system must be designed for sorting these bolts, so the robot can easily grab the correct bolt it needs.

ID	Priority	Description	Traceability
R-SRT-01	A	4 * 100 bolts shall be installed in the same process, without stopping to be refilled.	KDA - Tor Sigurd Breivik
R-SRT-02	A	Bolts of 5 different diameters shall be installed.	KDA - Kristian Nilsen
R-SRT-03	A	Bolts of 3 different grip lengths shall be installed.	

Table 5: Bolt sorting requirements

4.2.2 Promoter and sealant requirements

Goal: Promoter and sealant must be applied to the bolts, while following the drying time and pot life described in the problem description. A system must be designed for this job.

ID	Priority	Description	Traceability
R-PNS-01	A	Promoter shall be applied to all bolts before installation.	KDA - Kristian Nilsen
R-PNS-02	A	Promoter shall dry for 30 minutes after being applied.	
R-PNS-03	B	Bolts with promoter that exceeds the life of 24 hours shall not be used.	
R-PNS-04	A	Sealant shall be applied to the bolts after promoter has dried.	
R-PNS-05	A	Sealant shall be used inside the pot life of 1 hour.	
R-PNS-06	A	Bolts with sealant that exceeds the pot life of 1 hour shall not be used.	
R-PNS-07	C	The promoter and sealant application time shall be recorded.	

Table 6: Promoter and sealant requirements

4.2.3 Inspection requirements

Goal: Design a system that controls the nut profile, protrusion and nut seating against the alloy. The system must also be able to remove the bolt if requirements are not met.

ID	Priority	Description	Traceability
R-INS-01	A	Bolt grip length shall be confirmed before installation.	KDA - Kristian Nilsen
R-INS-02	B	If error in grip length is within one size, the bolt shall be switched to one with correct grip length.	
R-INS-03	B	If error in grip length is larger than one size, the bolt shall not be installed.	
R-INS-04	A	Head seating of the bolt shall be verified before torque is applied.	
R-INS-05	A	Nut seating against alloy shall be verified.	
R-INS-06	A	Proper nut installation shall be verified.	
R-INS-07	C	If nut is not properly installed, the entire bolt shall be removed and discarded.	Alcoa[1]
R-INS-08	A	The gap between bolt head and countersink shall not be larger than 0.002 inches[2].	

Table 7: Inspection requirements

2

4.3 Other requirements

These requirements are not for one specific goal, but applies to the project as a whole.

ID	Priority	Description	Traceability
R-OTH-01	A	Documentation of the project shall meet the requirements from Buskerud University College	HBV
R-OTH-02	B	Final reports and documentation shall be in english.	KDA - Alf Pettersen

Table 8: Other requirements

5.0 Sources

[1] Alcoa, *Eddie-bolt Process Manual,* cited 03.02.2015, avalible from: https://www.alcoa.com/fastening_systems_and_rings/aerospace/catalog/pdf/eddie-bolt%20process%20manual-jan06.pdf

Test Specification

Version	Date	Reviewed by	Approved by	Satus
3.0	15.05.2015	Elvar Aspelund	Tor Sigurd Breivik	Released

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List of tables

1.0 Abstract

This document is a specification of the test methods we intend to use. The test specification discuss how to verify the various requirements of the specification. We've looked at the different requirements and evaluated which method would be best to use so that the requirement is maintained.

2.0 Revision History

Version	Date	Changes	Author
0.1	01.02.2015	• First version of the document.	Katrine Kallevik
1.0	10.02.2015	• First released version.	Katrine Kallevik
1.1	12.03.2015	• Revised entire document after feedback from 1st presentation.	Katrine Kallevik
2.0	16.03.2015	• Second released version.	Katrine Kallevik
2.1	18.04.2015	• Added TS-ROB-12. • Changed requirement description of TS-SRT-01.	Stian Hovde
2.2	07.05.2015	• Deleted tests TS-ROB-05/06/07/08 and TS-TOL-13/14/15 • Changed description of TS-ROB-01/04/09/11 and TS-TOL-10/11 • Added TS-ROB-13	Stian Hovde
3.0	15.05.2015	• Final released version	Katrine Kallevik

Table 1 Revision table

3.0 Introduction

This document consists of tests to evaluate the condition of the requirements of the requirements specification. Certain requirements must be maintained for the project to be implemented. It is therefore important that we test these requirements in a structured and systematic way.

3.1 Explanation of the test table

Traceability test report:
This tells us the traceability to the test report.

By:
This tells us who wrote the test.

Date:
This tells us when the last time the test was changed or rewritten.

Traceability requirement:
This tells us the traceability to the requirement.

Test type:
This tells us which type of test we intend to use when we are going to test the requirement.

Requirement description:
This tells us which requirement we are going to test.

Test description:
This tells us how we are going to test the requirement.

Test execution:
This explains how we are going to execute the test.

Test equipment:
This explains what kind of equipment we need to execute the test.

Approval criteria:
This explains the criteria that must be met for the test to be approved.

Possible error:
Possible errors we might encounter when we execute the tests

4.0 Test Specification

4.1 Primary Goals

4.1.1 Test of robot requirements

TS-ROB-01		
Traceability test report: TR-ROB-01	**By:** Katrine Kallevik	**Date:** 07.05.2015
Traceability requirement: R-ROB-01	**Test type:** Review and verification of specification	
Requirement description: The process shall be completed by a KUKA robot.		
TEST		
Test description: Make sure to choose a robot from KUKA.		
Test execution: The group review the specifications of the product and make sure the requirements set by the stakeholders is met.		
Test equipment: Data Sheets for robot		
Approval criteria: The robot is manufactured by KUKA.		
Possible error: Errors in data sheets.		

TS-ROB-02		
Traceability test report: TR-ROB-02	**By:** Katrine Kallevik	**Date:** 15.02.2015
Traceability requirement: R-ROB-02	**Test type:** Review and verification of specification	
Requirement description: Minimum lift capacity shall be 10 kg.		
TEST		
Test description: Make sure the robot can lift 10 kg.		
Test execution: The group review the specifications of the product and make sure the requirements set by the stakeholders is met.		
Test equipment: Data Sheets for robot		
Approval criteria: The robot lifts the part that weighs 10kg easily.		
Possible errors: The robot can not lift the amount which deskribed in data sheets.		

TS-ROB-03		
Traceability test report: TR-ROB-03	**By:** Katrine Kallevik	**Date:** 16.02.2015
Traceability requirement: R-ROB-03	**Test type:** Review and verification of specification	
Requirement description: The robot shall have a tool changing system.		
TEST		
Test description: Make sure to choose a robot that can use a tool changing system.		
Test execution: The group review the specifications of the product and make sure the requirements set by the stakeholders is met.		
Test equipment: Data Sheets for robot.		
Approval criteria: The robot is able to use a tool changing system.		
Possible errors: Error in data sheets.		

TS-ROB-04		
Traceability test report: TR-ROB-04	**By:** Katrine Kallevik	**Date:** 07.05.2015
Traceability requirement: R-ROB-04	**Test type:** Review and verification of specification	
Requirement description: The robot shall have 6 rotational axes.		
TEST		
Test description: Check that the robot has 6 rotational axes.		
Test execution: The group review the specifications of the product and make sure the requirements set by the stakeholders is met.		
Test equipment: Data Sheets for robot.		
Approval criteria: The robot can move in 6 different axis.		
Possible errors: Error in data sheets.		

TS-ROB-09		
Traceability test report: TR-ROB-09	**By:** Katrine Kallevik	**Date:** 07.05.2015
Traceability requirement: R-ROB-09	**Test type:** Review and verification of specification	
Requirement description: The maximum repeatability shall be ±0.5 mm.		
TEST		
Test description: Make sure the maximum repeatability is ±0.5 mm.		
Test execution: The group review the specifications of the product and make sure the requirements set by the stakeholders is met.		
Test equipment: Data Sheets for robot		
Approval criteria: The robot have a maximum repeatability of ±0.5 mm.		
Possible errors: Error in data sheets.		

TS-ROB-10		
Traceability test report: TR-ROB-10	**By:** Katrine Kallevik	**Date:** 17.02.2015
Traceability requirement: R-ROB-10	**Test type:** Review and verification of specification	
Requirement description: The robot shall withstand temperatures ranging from +5℃ to +40℃.		
TEST		
Test description: Make sure the robot withstand temperatures ranging from +5℃ to +40℃.		
Test execution: The group review the specifications of the product and make sure the requirements set by the stakeholders is met.		
Test equipment: Data Sheets for robot.		
Approval criteria: The robot withstand temperatures ranging from +5℃ to +40℃.		
Possible errors: The robot does not withstands temperatures ranging from +5℃ to +40℃, as described in data sheets.		

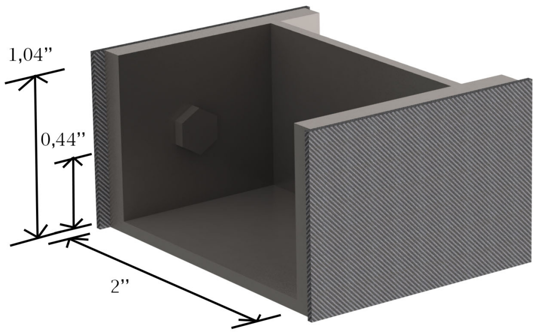
TS-ROB-11		
Traceability test report: TR-ROB-11	**By:** Stian Hovde	**Date:** 07.05.2015
Traceability requirement: R-ROB-11	**Test type:** Simulation	
Requirement description: The maximum cycle time for the process shall be 2 minutes.		
TEST		
Test description: Make sure the maximum cycle time for the process is 2 minutes.		
Test execution: The entire process is simulated in KUKA Sim, and the cycle time is recorded.		
Test equipment: KUKA Sim		
Approval criteria: The cycle time is within 2 minutes.		
Possible errors: Error in simulation, parts of the cycle is not simulated.		

TS-ROB-12		
Traceability test report: TR-ROB-12	**By:** Stian Hovde	**Date:** 18.04.2015
Traceability requirement: R-ROB-12	**Test type:** Simulation	
Requirement description: During operation, access to the robot cell shall be limited to ensure safety for personnel.		
TEST		
Test description: Make sure the robot cell is sealed off during operation, so that personnel cannot get injured by the moving robot.		
Test execution: In the simulation program, make sure that the entire working area of the robot, including end effector, is within the robot cell's enclosure. The enclosure must be sealed off during the robot's operation. Even if the robot is programmed to work in a limited area, the entire possible movement are of the robot has to be taken into consideration.		
Test equipment: KUKA robot sim		
Approval criteria: The entire movement area of the robot, including end effector, is within the robots enclosure.		
Possible errors: Robot can move outside the enclosure. Personnel is able to bypass the enclosure during operation.		

TS-ROB-13		
Traceability test report: TR-ROB-13	**By:** Stian Hovde	**Date:** 07.05.2015
Traceability requirement: R-ROB-12	**Test type:** Simulation	
Requirement description: The minimum reach of the robot shall be 1 m.		
TEST		
Test description: Make sure the minimum reach of the robot is 1 m.		
Test execution: The group review the specifications of the product and make sure the requirements set by the stakeholders is met.		
Test equipment: Data Sheets for robot		
Approval criteria: The minimum reach of the robot is 1 m.		
Possible errors: Error in data sheets		

4.1.2 Test of bolt installation tool requirements

<table>
<tr><td colspan="3">TS-TOL-01</td></tr>
<tr><td>Traceability test report: TR-TOL-01</td><td>By: Katrine Kallevik</td><td>Date: 18.02.2015</td></tr>
<tr><td>Traceability requirement: R-TOL-01</td><td colspan="2">Test type: Solidworks</td></tr>
<tr><td colspan="3">Requirement description: Bolts to be installed shall be of the Eddie bolt type with the associated nut.</td></tr>
<tr><td colspan="3">TEST</td></tr>
<tr><td colspan="3">Test description: Make sure the tool is designed so that the Eddie bolt with associated nut fits the tool.</td></tr>
<tr><td colspan="3">Test execution: Make sure the Eddie bolt type with associated nut fits the tool perfectly by using measuring tool in Solidworks.</td></tr>
<tr><td colspan="3">Test equipment: SolidWorks and computer.</td></tr>
<tr><td colspan="3">Approval criteria: The Eddie bolt with associated nut is installed and fits the tool perfectly .</td></tr>
<tr><td colspan="3">Possible errors: Design of tool must be changed because of failure.</td></tr>
</table>

TS-TOL-02		
Traceability test report: TR-TOL-02	**By:** Katrine Kallevik	**Date:** 18.02.2015
Traceability requirement: R-TOL-02	**Test type:** Solidworks	
Requirement description: Bolts shall be able to be installed within the following constrictions. 		
TEST		
Test description: The tool must fit so that the bolts can be installed.		
Test execution: Measure the tool and make sure it fits without interfering with the panel using Solidworks measuring tool.		
Test equipment: Solidworks software, cad drawings and computer.		
Approval criteria: The tool stays clear of the panel.		
Possible errors: Computer crash.		

TS-TOL-03		
Traceability test report: TR-TOL-03	**By:** Katrine Kallevik	**Date:** 18.02.2015
Traceability requirement: R-TOL-03	**Test type:** Solidworks	
Requirement description: Maximum weight of tool shall be less than 10kg.		
TEST		
Test description: Design the tool in solidworks.		
Test execution: Use solidworks to be sure that the tool does not exceeds 10 kg.		
Test equipment: Computer, solidworks.		
Approval criteria: The weight of the tool is less the 10 kg.		
Possible errors: Computer crash.		

TS-TOL-05		
Traceability test report: TR-TOL-05	**By:** Katrine Kallevik	**Date:** 18.02.2015
Traceability requirement: R-TOL-05	**test type:** Simulation test	
Requirement description: The tool shall not drop any components during normal use.		
TEST		
Test description: Make sure the tool does not drop any components when installed on robot.		
Test execution: Use simulation program to simulate use of the tool.		
Test equipment: Simulation program.		
Approval criteria: The tool does not drop any components.		
Possible errors: The simulation program is not accurate enough.		

TS-TOL-06		
Traceability test report: TR-TOL-06	**By:** Katrine Kallevik	**Date:** 18.02.2015
Traceability requirement: R-TOL-06	**Test type:** Full system test	
Requirement description: The tool shall perform without errors.		
TEST		
Test description: Make sure the tool performs perfectly when installed on robot.		
Test execution: Test the tool on the robot and a dummy model of panel for several hours to make sure the tool performs without error.		
Test equipment: Robot, tool, and dummy model of panel, eddie bolts with associated nut.		
Approval criteria: The tool performs without error.		
Possible errors: The dummy model is not made real enough.		

TS-TOL-07		
Traceability test report: TR-TOL-07	**By:** Katrine Kallevik	**Date:** 18.02.2015
Traceability requirement: R-TOL-07	**Test type:** Solidworks test	
Requirement description: The tool shall be designed so that it fits the robots tool changing system.		
TEST		
Test description: Test the tool and robots tool changing system in solidworks.		
Test execution: Use solidworks assembly to make sure the tool fit the tool changing system. Use measuring tool.		
Test equipment: Solidworks, computer, cad drawings of the tool changing system.		
Approval criteria: The tool fits the robots tool changing system.		
Possible errors: Computer crash.		

TS-TOL-08		
Traceability test report: TR-TOL-08	**By:** Katrine Kallevik	**Date:** 18.02.2015
Traceability requirement: R-TOL-08	**Test type:** Review and verification of design	
Requirement description: The driving force of the tool shall be electrical.		
TEST		
Test description: Make sure the driving force of the tool is electrical		
Test execution: The group review the design of the product and make sure the requirements set by the stakeholders is met.		
Test equipment: CAD drawings.		
Approval criteria: The driving force of the tool is electrical.		
Possible errors: Error in drawings.		

TS-TOL-09		
Traceability test report: TR-TOL-09	**By:** Katrine Kallevik	**Date:** 18.02.2015
Traceability requirement: R-TOL-09	**Test type:** Solidworks test	
Requirement description: Any actuators shall be be located on the tool.		
TEST		
Test description: Using solidworks modeling.		
Test execution: Make sure the actuators is located on the tool by using solidworks modeling.		
Test equipment: Solidworks, computer, CAD drawings.		
Approval criteria: Actuators is located on the tool.		
Possible errors: Power loss.		

TS-TOL-10		
Traceability test report: TR-TOL-10	**By:** Stian Hovde	**Date:** 07.05.2015
Traceability requirement: R-TOL-10	**Test type:** Simulation	
Requirement description: The tool shall be deliver a minimum of 10 Nm torque.		
TEST		
Test description: Make sure the tool delivers 10 Nm		
Test execution: Run a simulation in MATLAB, including losses in gears, that controls that the torque delivered to the nut is minimum 10 Nm.		
Test equipment: MATLAB		
Approval criteria: The tool delivers a minimum of 10 Nm.		
Possible errors: Error in simulation, error in calculation of gear ratios or inertia.		

TS-TOL-11		
Traceability test report: TR-TOL-11	**By:** Stian Hovde	**Date:** 07.05.2015
Traceability requirement: R-TOL-11	**Test type:** Simulation	
Requirement description: The material of the tool shall handle all stresses during normal operation.		
TEST		
Test description: Make sure the material used can handle all the stresses it is put under during normal operation.		
Test execution: Run a FEM analysis on the materials used, test it with the stress that it is put through during normal use.		
Test equipment: FEM analysis.		
Approval criteria: The material is of adequate strength.		
Possible errors: Simulation error, wrong material is used, wrong parameters is used.		

TS-TOL-12		
Traceability test report: TR-TOL-12	**By:** Katrine Kallevik	**Date:** 18.02.2015
Traceability requirement: R-TOL-12	**Test type:** FEM analysis test	
Requirement description: The tool shall withstand temperatures ranging from +5℃ to +40℃		
TEST		
Test description: Make sure the tool withstand temperatures ranging from +5℃ to +40℃.		
Test execution: Use finite element method to simulate how the tool behave in conditions with temperatures ranging from +5℃ to +40℃.		
Test equipment: Solidworks simulations.		
Approval criteria: The tool withstand temperatures ranging from +5℃ to +40℃.		
Possible errors: Computer crash.		

TS-TOL-16		
Traceability test report: TR-TOL-16	**By:** Katrine Kallevik	**Date:** 18.02.2015
Traceability requirement: R-TOL-16	**Test type:** FEM analysis	
Requirement description: The service lifetime of the tool shall be 10,000 cycles		
TEST		
Test description: Make sure the tool can handle the variable loads and stresses that can occur in simulated operation.		
Test execution: Use finite element method to calculate if the tool can handle 10,000 cycles.		
Test equipment: Solidworks simulation, computer		
Approval criteria: The tool handles 10,000 cycles.		
Possible errors: The tool is designed too fragile.		

TS-TOL-17		
Traceability test report: TR-TOL-17	**By:** Katrine Kallevik	**Date:** 18.02.2015
Traceability requirement: R-TOL-17	**Test type:** FEM analysis	
Requirement description: The total lifetime of the tool shall be 100,000 cycles		
TEST		
Test description: Make sure the tool can handle the variable loads and stresses that can occur in simulated operation.		
Test execution: Use finite element method to calculate if the tool can handle 100,000 cycles.		
Test equipment: Solidworks simulation, computer		
Approval criteria: The tools total lifetime is 100,000 cycles or more.		
Possible errors: Computer crash.		

4.2 Secondary goals

4.2.1 Test of bolt sorting requirements

TS-SRT-01		
Traceability test report: TR-SRT-01	**By:** Katrine Kallevik	**Date:** 18.04.2015
Traceability requirement: R-SRT-01	**Test type:** Review and verification of design	
Requirement description: 4 * 100 bolts shall be installed in the same process, without stopping to be refilled.		
TEST		
Test description: Make sure 4 * 100 bolts is installed in the same process, without stopping to be refilled.		
Test execution: The group review the design of the product and make sure the requirements set by the stakeholders is met.		
Test equipment: Requirements.		
Approval criteria: The robot can install 100 bolts in the same process, without stopping to be refilled.		
Possible errors: Programming fail, tool design fail.		

TS-SRT-02		
Traceability test report: TR-SRT-02	**By:** Katrine Kallevik	**Date:** 25.02.2015
Traceability requirement: R-SRT-02	**Test type:** Review and verification	
Requirement description: Bolts of 5 different diameters shall be installed.		
TEST		
Test description: Review and verification of design.		
Test execution: The group review the design of the product and make sure the requirements set by the stakeholders is met.		
Test equipment: Requirements.		
Approval criteria: The robot is able to install bolts of 5 different diameters.		
Possible errors: Programming fail, tool design fail.		

TS-SRT-03		
Traceability test report: TR-SRT-03	**By:** Katrine Kallevik	**Date:** 25.02.2015
Traceability requirement: R-SRT-03	**Test type:** Full system test	
Requirement description: Bolts of 3 different grip lengths shall be installed.		
TEST		
Test description: Make sure bolts of 3 different grip lengths is installed.		
Test execution: Members of the group will run a full system test to make sure bolts of 3 different grip lengths is being installed.		
Test equipment: Full system.		
Approval criteria: Bolts of 3 different grip lengths is being installed.		
Possible errors: Error in system.		

4.2.2 Test of promoter and sealant requirements

TS-PNS-01		
Traceability test report: TR-PNS-01	**By:** Katrine Kallevik	**Date:** 25.02.2015
Traceability requirement: R-PNS-01	**Test type:** Review and verification of design	
Requirement description: Promoter shall be applied to all bolts before installation.		
TEST		
Test description: Make sure the promoter is applied to all bolts before installation.		
Test execution: The group review the design of the product and make sure the requirements set by the stakeholders is met.		
Test equipment: 3D models, drawings.		
Approval criteria: The robot can apply the promoter to all bolts before installation.		
Possible errors: Error in models or drawings.		

TS-PNS-02		
Traceability test report: TR-PNS-02	**By:** Katrine Kallevik	**Date:** 25.02.2015
Traceability requirement: R-PNS-02	**Test type:** Review and verification of design	
Requirement description: Promoter shall dry for 30 minutes after being applied.		
TEST		
Test description: Review and verification of design.		
Test execution: The group review the design of the product and make sure the requirements set by the stakeholders is met.		
Test equipment: 3D models, drawings.		
Approval criteria: The robot let the promoter dry for 30 minutes after being applied.		
Possible errors: Error in drawings or models.		

TS-PNS-03		
Traceability test report: TR-PNS-03	**By:** Katrine Kallevik	**Date:** 25.02.2015
Traceability requirement: R-PNS-03	**Test type:** Review and verification of design	
Requirement description: Bolts with promoter that exceeds the life of 24 hours shall not be used.		
TEST		
Test description: Make sure bolts with promoter that exceeds the life of 24 hours is not installed.		
Test execution: The group review the design of the product and make sure the requirements set by the stakeholders is met.		
Test equipment: 3D models, drawings.		
Approval criteria: The robot does not use bolts which had promoter in 24 hours or more.		
Possible errors: Error in models or drawings.		

TS-PNS-04		
Traceability test report: TR-PNS-04	**By:** Katrine Kallevik	**Date:** 25.02.2015
Traceability requirement: R-PNS-04	**Test type:** Review and verification of design	
Requirement description: Sealant shall be applied to the bolts after promoter has dried		
TEST		
Test description: Make sure the sealant is applied after the promoter has dried.		
Test execution: The group review the design of the product and make sure the requirements set by the stakeholders is met.		
Test equipment: 3D models, drawings.		
Approval criteria: The robot can apply sealant after promoter has dried.		
Possible errors: Error in Models or design.		

<table>
<tr><th colspan="3">TS-PNS-05</th></tr>
<tr><td>Traceability test report: TR-PNS-05</td><td>By: Katrine Kallevik</td><td>Date: 25.02.2015</td></tr>
<tr><td>Traceability requirement: R-PNS-05</td><td colspan="2">Test type: Review and verification of design</td></tr>
<tr><td colspan="3">Requirement description: Sealant shall be used inside the pot life of 1 hour.</td></tr>
<tr><th colspan="3">TEST</th></tr>
<tr><td colspan="3">Test description: Make sure the sealant is used inside the pot life of 1 hour.</td></tr>
<tr><td colspan="3">Test execution: The group review the design of the product and make sure the requirements set by the stakeholders is met.</td></tr>
<tr><td colspan="3">Test equipment: 3D models, drawings.</td></tr>
<tr><td colspan="3">Approval criteria: The robot use the bolt with sealant within one hour.</td></tr>
<tr><td colspan="3">Possible errors: Error in drawings or models.</td></tr>
</table>

<table>
<tr><th colspan="3">TS-PNS-06</th></tr>
<tr><td>Traceability test report: TR-PNS-06</td><td>By: Katrine Kallevik</td><td>Date: 25.02.2015</td></tr>
<tr><td>Traceability requirement: R-PNS-06</td><td colspan="2">Test type: Review and verification</td></tr>
<tr><td colspan="3">Requirement description: Bolts with sealant that exceeds the pot life of 1 hour shall not be used.</td></tr>
<tr><th colspan="3">TEST</th></tr>
<tr><td colspan="3">Test description: Make sure the bolts with sealant that exceeds the pot life of 1 hour is not used.</td></tr>
<tr><td colspan="3">Test execution: The group review the design of the product and make sure the requirements set by the stakeholders is met.</td></tr>
<tr><td colspan="3">Test equipment: 3D models, drawings.</td></tr>
<tr><td colspan="3">Approval criteria: The robot use the bolt with sealant within one hour.</td></tr>
<tr><td colspan="3">Possible errors: Errors in models or drawings.</td></tr>
</table>

TS-PNS-07		
Traceability test report: TR-PNS-07	**By:** Katrine Kallevik	**Date:** 25.02.2015
Traceability requirement: R-PNS-07	**Test type:** Review and verification of design	
Requirement description: The promoter and sealant application time shall be recorded.		
TEST		
Test description: Make sure the promoter and sealant application time is recorded.		
Test execution: The group review the design of the product and make sure the requirements set by the stakeholders is met.		
Test equipment: 3D models, drawings.		
Approval criteria: The application time of sealant and promoter is recorded.		
Possible errors: Errors in models or drawings.		

4.2.3 Test of inspection requirements

TS-INS-01		
Traceability test report: TR-INS-01	**By:** Katrine Kallevik	**Date:** 15.03.2015
Traceability requirement: R-INS-01	**Test type:** Prototype testing	
Requirement description: Bolt grip length shall be confirmed before installation.		
TEST		
Test description: Make sure the grip length is confirmed before installation.		
Test execution: Measure the grip length before installation and make sure the robot choose the right grip length.		
Test equipment: Prototype.		
Approval criteria: The robot choose right grip length before installation.		
Possible errors: The robot choose wrong grip length.		

TS-INS-02		
Traceability test report: TR-INS-02	**By:** Katrine Kallevik	**Date:** 25.02.2015
Traceability requirement: R-INS-02	**Test type:** Prototype testing	
Requirement description: If error in grip length is within one size, the bolt shall be switched to one with correct grip length.		
TEST		
Test description: Make sure the robot switch to correct size of grip length if there is error in grip length within one size.		
Test execution: Force the robot to choose wrong grip length and make sure it can switch to the right size.		
Test equipment: Prototype.		
Approval criteria: The robot can switch to correct size of grip length.		
Possible errors: The robot installs the bolt with wrong grip length.		

TS-INS-03		
Traceability test report: TR-INS-03	**By:** Katrine Kallevik	**Date:** 15.03.2015
Traceability requirement: R-INS-03	**Test type:** Prototype test	
Requirement description: If error in grip length is larger than one size, the bolt shall not be installed.		
TEST		
Test description: Make sure the robot does not install bolts with grip length larger than one size.		
Test execution: Force the robot to choose a bolt with grip length larger than one size and make sure it does not get installed.		
Test equipment: Prototype.		
Approval criteria: The robot does not install bolts with grip length larger than one size.		
Possible errors: The robot install bolt with grip length larger than one size.		

TS-INS-04		
Traceability test report: TR-INS-04	**By:** Katrine Kallevik	**Date:** 15.03.2015
Traceability requirement: R-INS-04	**Test type:** Prototype test	
Requirement description: Head seating of the bolt shall be verified before torque is applied.		
TEST		
Test description: Make sure head seating of the bolt is verified before torque is applied.		
Test execution: Make the robot install the bolt with head seating wrong and make sure the robot can detect the mistake before applying torque.		
Test equipment: Prototype.		
Approval criteria: The robot detects the mistake and and the head seating is verified before torque is applied.		
Possible errors: Head seating is not verified before torque is applied.		

TS-INS-05		
Traceability test report: TR-INS-05	**By:** Katrine Kallevik	**Date:** 15.03.2015
Traceability requirement: R-INS-05	**Test type:** Prototype test	
Requirement description: Nut seating against alloy shall be verified.		
TEST		
Test description: Make sure nut seating against alloy is verified.		
Test execution: Install the bolt with nut seating wrong and make sure the system can detect the mistake.		
Test equipment: Prototype		
Approval criteria: The nut seating against alloy is verified.		
Possible errors: The nut seating against alloy is not verified.		

<table>
<tr><th colspan="3">TS-INS-06</th></tr>
<tr><td>Traceability test report: TR-INS-06</td><td>By: Katrine Kallevik</td><td>Date: 15.03.2015</td></tr>
<tr><td>Traceability requirement:R-INS-06</td><td colspan="2">Test type: Prototype</td></tr>
<tr><td colspan="3">Requirement description: Proper nut installation shall be verified.</td></tr>
<tr><th colspan="3">TEST</th></tr>
<tr><td colspan="3">Test description: Make sure proper nut installation is verified.</td></tr>
<tr><td colspan="3">Test execution: Install the nut improper and make sure the system finds out and install the nut proper.</td></tr>
<tr><td colspan="3">Test equipment: Prototype.</td></tr>
<tr><td colspan="3">Approval criteria: Proper nut installation is verified.</td></tr>
<tr><td colspan="3">Possible errors: Proper nut installation is not verified.</td></tr>
</table>

<table>
<tr><th colspan="3">TS-INS-07</th></tr>
<tr><td>Traceability test report: TR-INS-07</td><td>By: Katrine Kallevik</td><td>Date: 27.02.2015</td></tr>
<tr><td>Traceability requirement: R-INS-07</td><td colspan="2">Test type: Simulation test/prototype testing</td></tr>
<tr><td colspan="3">Requirement description: If nut is not properly installed, the entire bolt shall be removed and discarded.</td></tr>
<tr><th colspan="3">TEST</th></tr>
<tr><td colspan="3">Test description: Simulation/prototype test where the group simulate and find out if the nut is not properly installed.</td></tr>
<tr><td colspan="3">Test execution: Simulate the process in a simulation program. Prototype testing where we try to install the nut improperly, and the robot is programmed to remove bolt and discard it.</td></tr>
<tr><td colspan="3">Test equipment: Simulation program and prototype.</td></tr>
<tr><td colspan="3">Approval criteria: The not properly installed nut and bolt is removed and discarded.</td></tr>
<tr><td colspan="3">Possible errors: Error in simulation or prototype.</td></tr>
</table>

TS-INS-08		
Traceability test report: TR-INS-08	**By:** Katrine Kallevik	**Date:** 25.02.2015
Traceability requirement: R-INS-08	**Test type:** Solidworks	
Requirement description: The gap between bolt head and countersink shall not be larger than 0.002 inches.		
TEST		
Test description: Make sure the gap between bolt head and countersink is not larger than 0.002 inches.		
Test execution: The gap between bolt head and countersink is measured.		
Test equipment: Measuring tool in solidworks, computer.		
Approval criteria: The gap between bolt head and countersink is not larger than 0.002 inches.		
Possible errors: Power loss.		

4.3 Test of other requirements

TS-OHT-01		
Traceability test report: TR-OHT-01	**By:** Katrine Kallevik	**Date:** 25.02.2015
Traceability requirement: R-OHT-01	**Test type:** Review of documentation	
Requirement description: Documentation of the project shall meet the requirements from Buskerud University College.		
TEST		
Test description: The documentation of the project meets the requirements from Buskerud University College.		
Test execution: The group review all the documents and make sure the requirements set by the stakeholders are met.		
Test equipment: Visualisation.		
Approval criteria: Documentation meet the requirements set by Buskerud University College.		
Possible errors: Some of the requirements from Buskerud University College is not met.		

TS-OHT-02		
Traceability test report: TR-OHT-02	**By:** Katrine Kallevik	**Date:** 25.02.2015
Traceability requirement: R-OHT-02	**Test type:** Review of documentation	
Requirement description: Final reports and documentation shall be in english.		
TEST		
Test description: Make sure the reports and documentation is in english.		
Test execution: The group review all the documents and make sure the requirements set by the stakeholders are met.		
Test equipment: Visualisation.		
Approval criteria: The documentation is in english.		
Possible errors: Typing error.		

Test Plan

Version	Date	Reviewed by	Approved by	Satus
2.0	15.05.2015	Stian Hovde	Tor Sigurd Breivik	Released

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List of figures

1.0 Abstract

This document describes how we are planning to test our system. It contains descriptions of test method and test phases.

2.0 Revision History

Version	Date	Changes	Author
0.1	19.02.2015	• First version of the document	Kristoffer Lund
1.0	16.03.2015	• First released version	Kristoffer Lund Katrine Kallevik
1.1	18.04.2015	• Added TS-ROB-12 to simulation test.	Stian Hovde
1.2	07.05.2015	• Deleted tests TS-ROB-05/06/07/08 and TS-TOL-13/14/15 • Added TS-ROB-13 to review and verification tests	Stian Hovde
1.3	14.05.2015	• Updated status of completion of test tables	Kristoffer Lund
2.0	15.05.2015	• Final version	Kristoffer Lund

Table 1: Revision table

3.0 Introduction

The purpose of this document is to describe how we plan to test our system. The reason we conduct tests is to reveal weaknesses in our system and to improve the final products quality. This document is meant to improve the efficiency and quality of the tests, since testing requires a lot of resources and is time consuming.

Our biggest limitation in this project is time. Since the project deadline is in the middle of may, it may not be enough time to complete a full system test. Another limitation factor is the number of resources we have at our disposal. We might also use a lot of time with the design tests, and this could possibly push back the prototype testing.

4.0 Test phase description

We have planned to do tests in differents phases in our project. The following describes test method and which tests are to be done in that phase from the test specification.

4.1 Review and verification.

When a document is ready for release, it gets tested by a member of the group that has not participated in writing it. This is a static verification test to check if the document meets the documentation requirements we have. When this is done, the document is sent to our internal and external supervisor for validation. If the document fails its validation, it will be rewritten with the new requirements from the internal/external supervisor, and the process will be repeated. A document can only be released if it passes this verification & validation process.

Test responsible in this phase: Stian Hovde

Review and verification tests			
Test specification ID	**Description**	**Status**	**Test report ID**
TS-ROB-01	The chosen robot is manufactured by KUKA	100%	TR-ROB-01
TS-ROB-02	The robot can lift 10kg	100%	TR-ROB-02
TS-ROB-03	The tool changer must be appropriate for the system	100%	TR-ROB-03
TS-ROB-04	The robot must have enough rotational axes for bolting process	100%	TR-ROB-04
TS-ROB-09	Max. repeatability of robot	100%	TR-ROB-09
TS-ROB-10	Min. and max. ambient operational temperature of robot	100%	TR-ROB-10
TS-ROB-13	Min. reach of the robot	100%	TR-ROB-13
TS-PNS-07	Recorded sealant and promoter time test	0%	TR-PNS-07

TS-OHT-01	Document verification test	100%	TR-OHT-01
TS-OHT-02	Typing error verification test	100%	TR-OHT-02

Table 2: Review and verification tests.

4.2 Design test

These tests are meant to be done in the design phase of our project. They are designed to be done while the different parts of our system are on the drawing board, and are meant to reduce the amount of failed tests later on. These tests are thorough and will be utilizing the incremental test method.

The incremental test method is a method that resembles bottom up testing. Bottom up testing starts with the smallest parts of a system and works itself outwards. The incremental test method also works itself outwards, but it tests the most critical components first. This gives us an edge in finding any errors early, rather than discovering them later on in prototype and full system testing. This helps us in using less resources to complete testing later on in the project, since design errors are far less time consuming to correct in the design phase.

Since the designs are both mechanical and electrical, the tests of a design are separated into electrical tests and mechanical tests.

Test responsible for electrical design in this phase: Kristoffer Lund
Test responsible for mechanical design in this phase: Katrine Kallevik

Design tests			
Test specification ID	**Description**	**Status**	**Test report ID**
TS-TOL-01	Eddie bolt design test	100%	TR-TOL-01
TS-TOL-02	Tool fitment design test	100%	TR-TOL-02
TS-TOL-03	Tool weight design test	100%	TR-TOL-03
TS-TOL-07	Tool changing design test	100%	TR-TOL-07
TS-TOL-08	The tool shall be driven by electricity	100%	TR-TOL-08
TS-TOL-09	Actuator position design test	100%	TR-TOL-09
TS-TOL-10	The tool shall be able to apply 10 Nm of torque	100%	TR-TOL-10
TS-TOL-11	Verify the material used to create the tool.	100%	TR-TOL-11
TS-TOL-12	Ambient temperature design test	0%	TR-TOL-12
TS-TOL-16	Tool lifetime FEM analysis test	100%	TR-TOL-16
TS-TOL-17	Tool lifetime FEM analysis test	100%	TR-TOL-17
TS-SRT-01	Bolt assembly design test	0%	TR-SRT-01
TS-PNS-01	Promoter design test	0%	TR-PNS-01
TS-PNS-02	Promoter drying time	0%	TR-PNS-02
TS-PNS-03	Promoter pot life test	0%	TR-PNS-03
TS-PNS-04	Sealant design test	0%	TR-PNS-04
TS-PNS-05	Sealant drying time	0%	TR-PNS-05
TS-PNS-06	Sealant pot life test	0%	TR-PNS-06
TS-INS-08	Gap between bolt head and countersink test	0%	TR-PNS-08

Table 3: Design tests.

4.3 Simulation test

Simulation test is testing we intend to do in a simulation program, where we have simulated the whole process. This is where we find out if the whole process works before we produce a prototype. We insert robot cells and tools and simulate the entire process of sorting and bolt installation.

Test responsible for simulation testing: Elvar Aspelund

Simulation tests			
Test specification ID	**Description**	**Status**	**Test report ID**
TS-ROB-11	Max. cycle time of the complete bolting process	0%	TR-ROB-11
TS-ROB-12	Ensuring the safety of the robot cell for personnel	0%	TR-ROB-12
TS-TOL-05	Test to make sure the tool doesn't drop any bolts	0%	TR-TOL-05
TS-SRT-02	5 differents sized bolts installment test	0%	TR-SRT-02
TS-SRT-03	Different grip length installment test	0%	TR-SRT-03
TS-INS-07	Removal of wrongly installed bolt test	0%	TR-INS-07

Table 4: Simulation tests.

4.4 Prototype test

Prototype testing is testing of an early sample of the bolt installation with a bolt and nut sorting system. The prototype is designed in order to evaluate the performance of the bolt installation. In this test we will only focus on the bolt sorting system and the bolt installation, not the full system. The group build a prototype and runs the system to its breaking point to find out if there is something thats needs to be changed in the module. It is here we see whether the system actually works or not. This system may be changed several times before the system runs the way we want it to.

Test responsible for prototype testing: Kristoffer Lund

Prototype tests			
Test specification ID	**Description**	**Status**	**Test report ID**
TS-INS-01	Bolt grip length test	0%	TR-INS-01
TS-INS-02	Bolt grip length error test	0%	TR-INS-02
TS-INS-03	Bolt grip length larger error test	0%	TR-INS-03
TS-INS-04	Head seating of bolt test	0%	TR-INS-04
TS-INS-05	Nut seating test	0%	TR-INS-05
TS-INS-06	Accepted bolt installation verifying system test	0%	TR-INS-06
TS-INS-07	Removal of wrongly installed bolt test	0%	TR-INS-07

Table 5: Prototype tests.

4.5 Full system test

Full system test includes all the phases the robot will complete. This includes drilling and countersinking, bolt sorting, installation and control after the whole process. This phase is the last one to be performed. The group have all the modules and tests the system to its breaking point to find weakness in the installation.

In this phase the main focus for testing is:

- Security
- Functionality
- User friendliness
- Operation

Test responsible for full system tests: Katrine Kallevik

Full system tests			
Test specification ID	**Description**	**Status**	**Test report ID**
TS-TOL-06	Tool performance test	0%	TR-TOL-06

Table 6: Full system tests.

5.0 Traceability

In order to keep trace of which requirement is tested we have made a traceability system. Since the requirements have a unique ID system, we have chosen to expand this system to include test specification and test report.

The requirement ID form is: R-XXX-NN, where the R means requirement. We have added test specification (TS) and test report (TR) to this, so the requirement number (XXX-NN) is the same as the test.

Example: R-TOL-02 (requirement ID)
TS-TOL-02 (test specification ID)
TR-TOL-02 (test report ID)

This gives a good overview of which test goes with which requirement.

6.0 Test Strategy

All of the requirements must be tested at least one time. As the project slides forward we might see the need for more requirements. The new requirements will then be added to the requirements document and the test document. Some of the requirements may be tested multiple times during each phase. Figure 1 shows our planned progress for for testing.

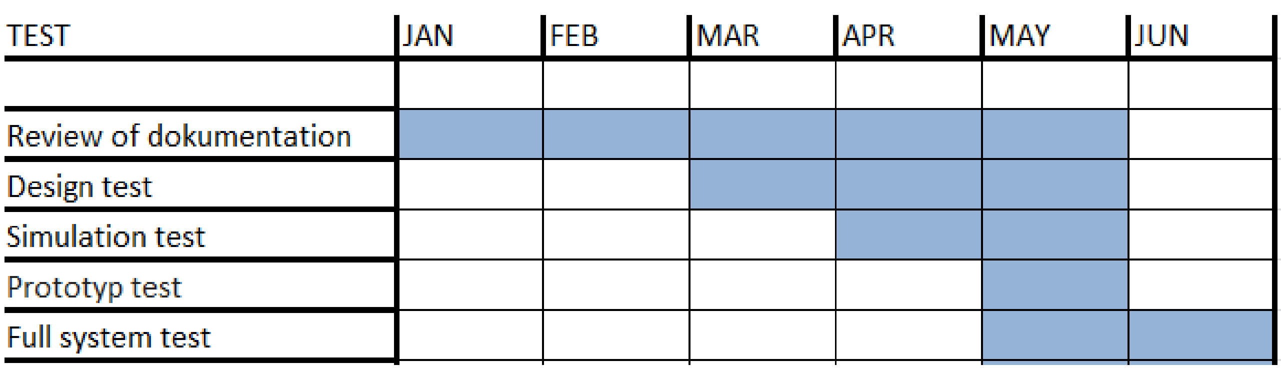


Figure 1: Test progress plan.

7.0 Test documentation

Each conducted test must be documented in the Test report document. This document contains the test result and number of errors occurred of all tests conducted, and is meant to be easily written and easy to read for the persons that has not conducted the test.

If the test conducted is of a larger scale, the person conducting this test can write a separate document to better explain the results of the test. The test report is written just like a smaller one, but the extra document is referred to in the document attachment box.

"Test report nr": "Test report name"		
Traceability requirement: "requirement number"	**Responsible:**	**Execution date:**xy.zf.2015
Document attachment:	**Test type:**	**Test number:**
Requirement description:		
Test		
Expected results:		
Actual results:		
Information		
Number of errors:		
Error description:		
Improvements:		
Test result: "Passed/failed"		

Figure 2: Test report template.

8.0 Sources

[1] Buskerud & Vestfold University College, *Prosjekthåndbok ver 2015,* cited 19.02.2015

Test report document

Version	Date	Reviewed by	Approved by	Satus
1.0	15.05.2015	Katrine Kallevik	Tor Sigurd Breivik	Released

Table of contents

List of tables

List of figures

1.0 Abstract

This document contains the completed tests and their result. The test reports only contains short descriptions about the results, and are meant to be easy to read.

2.0 Revision History

Version	Date	Changes	Author
0.1	27.02.2015	• First version of the document	Kristoffer Lund
1.0	11.05.2015	• First released version.	Kristoffer Lund Stian Hovde Elvar Aspelund Katrine Kallevik

Table 1 Revision table

3.0 Introduction

This document contains our test reports. These reports does only contain the test results, the test description is explained in the test specification document.

3.1 Test report explanation

- **Title:** The title contains the test report number, test name and requirement priority.
- **Traceability requirement:** This is which requirement the test is related to. There might be several tests to a requirements, so if one test is marked passed doesn't mean that the requirement is met.
- **Responsible:** Name or initials of the person/persons that conducts the test.
- **Execution date:** Date of the day the test was conducted.
- **Document attachment:** If there is an extra document used to describe the test, the name and number is written here.
- **Test type:** Description of what kind of test was done. for example FEM, Electrical measurement, simulation etc.
- **Test number:** If a test is failed, improvements must be done. This means that a test can be repeated multiple times, and needs to be numbered accordingly.
- **Requirement description:** A short description of the requirement.
- **Expected result:** Anticipated result of the test, the result shall contain the numbers and performances the requirement anticipates.
- **Actual result:** The result of the item subjected to the test.
- **Error description:** If any error occurs during the test, they shal be described here.
- **Improvements:** suggestions for improvements of the errors that occurred in the test.
- **Test result:** Passed/Failed. A test is only passed if no errors were observed during the test.

4.0 Robot test reports

TR-ROB-01/02/03/04/09/10/13: Robot documentation test		
Traceability requirement: R-ROB-01, R-ROB-02, R-ROB-03, R-ROB-04, R-ROB-09, R-ROB-10, R-ROB-13.	**Responsible:** Stian Hovde	**Execution date:** 07.05.2015
Document attachment: Robot selection	**Test type:** Verification of documentation.	**Test number:** 1
Requirement description: The process shall be completed by a KUKA robot. Minimum lift capacity shall be 10 kg. The robot shall have a tool changing system. The robot shall have 6 rotational axes. The maximum repeatability shall be ±0.5 mm. The robot shall withstand temperatures ranging from +5℃ to +40℃. The minimum reach of the robot shall be 1 m.		
Test		
Expected results: The documentation of the robot we have chosen shows that the parameters of our robot is within our requirements.		
Actual results: The robot fits all our requirements.		
Information		
Number of errors: 0		
Error description:		
Improvements:		
Test result: Passed		

Table 2: Robot documentation test.

5.0 Tool test reports

TR-TOL-10: Gear test		
Traceability requirement: R-TOL-10	**Responsible:** Elvar Aspelund	**Execution date:** 22.04.2015
Document attachment: Chapter 6 Test report document.	**Test type:** Structural test	**Test number:** 1
Requirement description: The tool shall deliver a minimum of 10 Nm torque.		
Test		
Expected results: The gears cogs are subjected to 1466.6N. The yield strength of the material selected for the gears is 1750MPa. So the forces have to be lower than the yield strength, and the gears can not fatigue during the operational lifetime.		
Actual results: With applied forces the gear experiences pressure forces of 886MPa. With the selected material, the gears will not buckle during operations and will not fatigue.		
Information		
Number of errors: 0		
Error description:		
Improvements:		
Test result: Passed		

Table 3: Gear test

TR-TOL-11: Gripper plate static test		
Traceability requirement: R-TOL-11	**Responsible:** Elvar Aspelund	**Execution date:** 24.04.2015
Document attachment: Chapter 6 Test report document.	**Test type:** Structural test	**Test number:** 1
Requirement description: The material of the tool shall handle all stresses during normal operation.		
Test		
Expected results: During operational conditions the plate has to remain stable, this is necessary to ensure precision during the assembly process. Ran static test to verify that the plate will not bend and deform under normal conditions.		
Actual results: The results show that the maximum displacement during normal operations will be about 0.51mm. Maximum stresses are at 32.7MPa, the yield strength of the material selected is 75,8MPa. Conclusion: Gripper plate will not fatigue or plastic deform during operational lifetime of the tool.		
Information		
Number of errors: 0		
Error description:		
Improvements:		
Test result: Passed		

Table 4: Gripper plate static test

TR-TOL-11: Interface plate		
Traceability requirement: R-TOL-11	**Responsible:** Elvar Aspelund	**Execution date:** 30.04.2015
Document attachment: Chapter 6 Test report document.	**Test type:** Structural test	**Test number:** 1
Requirement description: The material of the tool shall handle all stresses during normal operation.		
Test		
Expected results: The material selected has a yield strength 75.8MPa. The forces that the plate is subjected to during operations must be lower than the yield strength.		
Actual results: Ran two test, one uniform load distribution, this resulted in forces of 1.16MPa and a non-uniform test, to simulate the scenario of when the tool is in a vertical position, this resulted in forces of 0.014Mpa. Both scenarios are far from the yield strength of the material. So the operational scenario of the interface plate should not be a problem for the plate.		
Information		
Number of errors:		
Error description:		
Improvements:		
Test result: Passed		

Table 5: Interface plate

TR-TOL-10: Actuator torque		
Traceability requirement: R-TOL-10	**Responsible:** Kristoffer Lund	**Execution date:** 06.05.2015
Document attachment: Design document	**Test type:** Matlab	**Test number:** 1
Requirement description: The tool shall deliver a minimum of 10 Nm torque.		
Test		
Expected results: Tested with 12 Nm of load(20% higher than required).		
Actual results: 12 Nm at load. The motor can deliver about twice as much. The gearbox is designed to handle torque up to 14.12 Nm.		
Information		
Number of errors: 0		
Error description:		
Improvements:		
Test result: Passed		

Table 6: Actuator torque.

TR-TOL-01/03/08/09: Tool design tests		
Traceability requirement: R-TOL-01 R-TOL-03 R-TOL-08 R-TOL-09	**Responsible:** Kristoffer Lund	**Execution date:** 06.05.2015
Document attachment: Design document	**Test type:** Verification	**Test number:** 1
Requirement description: Bolts to be installed shall be of the Eddie bolt type with the associated nut. Maximum weight of tool shall be less than 10kg. The driving force of the tool shall be electrical. Any actuators shall be be located on the tool.		
Test		
Expected results: A review of our design shows that the design meets these requirements.		
Actual results: The design meets all of our requirements		
Information		
Number of errors: 0		
Error description:		
Improvements:		
Test result: Passed		

Table 7: Tool design tests.

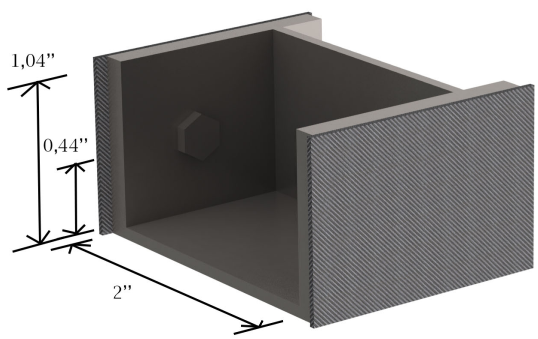
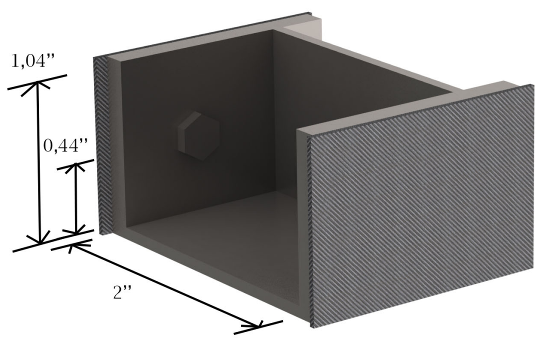
TR-TOL-02: Installation		
Traceability requirement: R-TOL-02	**Responsible:** Katrine Kallevik	**Execution date:** 03.05.2015
Document attachment: Design document	**Test type:** Solidworks measure	**Test number:** 1
Requirement description: Bolts shall be able to be installed within the following constrictions. 		
Test		
Expected results: For the bolts to be able to be installed within the constrictions, the nutrunner (tool who picks up the bolt for installation) have to fit. We expected the nutrunner to fit.		
Actual results: The nutrunner did not fit in width.		
Information		
Number of errors: 1		
Error description: The diameter of the nutrunner that installs the nut was too large.		
Improvements: We must resize the gear.		
Test result: Failed		

Table 8: Installation test 1

TR-TOL-02: Installation		
Traceability requirement: R-TOL-02	**Responsible:** Katrine Kallevik	**Execution date:** 09.05.2015
Document attachment: Design document	**Test type:** Solidworks measure	**Test number:** 2
Requirement description: Bolts shall be able to be installed within the following constrictions.		



Test
Expected results: For the bolts to be able to be installed within the constrictions, the nutrunner has to fit within the spacing of the adjacent bolts. We expected the nutrunner to fit.
Actual results: The nutrunner fits in height and in width.

Information
Number of errors: 0
Error description:
Improvements:
Test result: Passed

Table 9: Installation test 2

TR-OHT-01/02: Documentation		
Traceability requirement: R-OTH-01 R-OTH-02	**Responsible:** Stian Hovde	**Execution date:** 14.05.2015
Document attachment:	**Test type:** Review	**Test number:** 1
Requirement description: Final reports and documentation shall be in english. Documentation of the project shall meet the requirements from Buskerud University College		
Test		
Expected results: The final documentation should meet the requirements of HBV, and be in english.		
Actual results: All of the final documents meets our requirements		
Information		
Number of errors: 0		
Error description:		
Improvements:		
Test result: Passed		

Table 10: Documentation test

TR-TOL-16/17: Fatigue test		
Traceability requirement: R-TOL-16 R-TOL-17	**Responsible:** Elvar Aspelund	**Execution date:** 22.04.2015
Document attachment: Chapter 6: Gear test	**Test type:** FEM analysis	**Test number:** 1
Requirement description: The service lifetime of the tool shall be 10,000 cycles. The total lifetime of the tool shall be 100,000 cycles.		
Test		
Expected results: The gears have to be able to operate during the operational lifetime of the system.		
Actual results: The gears are able to handle the operational conditions. The gears will not fatigue during the lifetime of the tool.		
Information		
Number of errors: 0		
Error description:		
Improvements:		
Test result: Passed		

Table 11: Fatigue test.

6.0 Mechanical testing

This chapter will give a description for how the testing of the designed components were conducted. Testing will include mechanical components of the end effector, from small component such as gears and structural components. Software that was used to conduct the tests is Solidworks: Finite Element Method (FEM). Components from other suppliers will not be design tested, only referred to technical specification data.

6.1 Gear test

The test is conducted on the small gear mounted on the axle of the electric motor. The gear must be able to deliver 13.275 Nm of torque to the reuleaux triangle gear. Based on this information, using the theory of construction techniques, we have arrived at a design that is able to transfer the torque needed.

Material selected for the gears is 1.2842 (MnCrV8) alloy cold-work tool steel.
This kind of alloy tool steel belongs to high carbon alloy steel (carbon mass fraction is over 0.80%), Chromium is key element of alloy with mass fraction below 5% generally.

6.1.1 FEM

The fixtures (green arrows) have been placed on the contact surfaces, where the axle of the electric motor will be in contact with the cog.

The force (purple arrows) applied to the cog is 1466 N. During operation, only one cog will be in contact with the larger gears cog at a time.

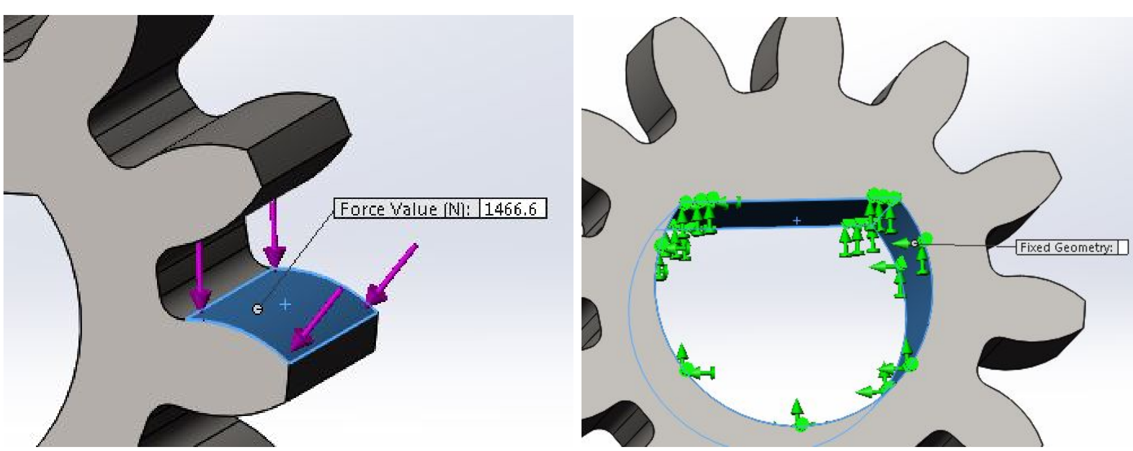


Figure 1: Fixture and force placement

With an applied force of 1466.6 N, the cog experiences stresses up to 886 MPa. As the result shows, this is lower than the yield strength of the selected material, which has a given yield strength of 1750 MPa.

The test result from using the Finite Element Method (FEM), gives a visual presentation of the stress distribution throughout the cog. As shown, the highest accumulation of stress will be at the base of the tooth as expected. The forces applied will not lead to material fatigue within the operational lifetime of the tool.

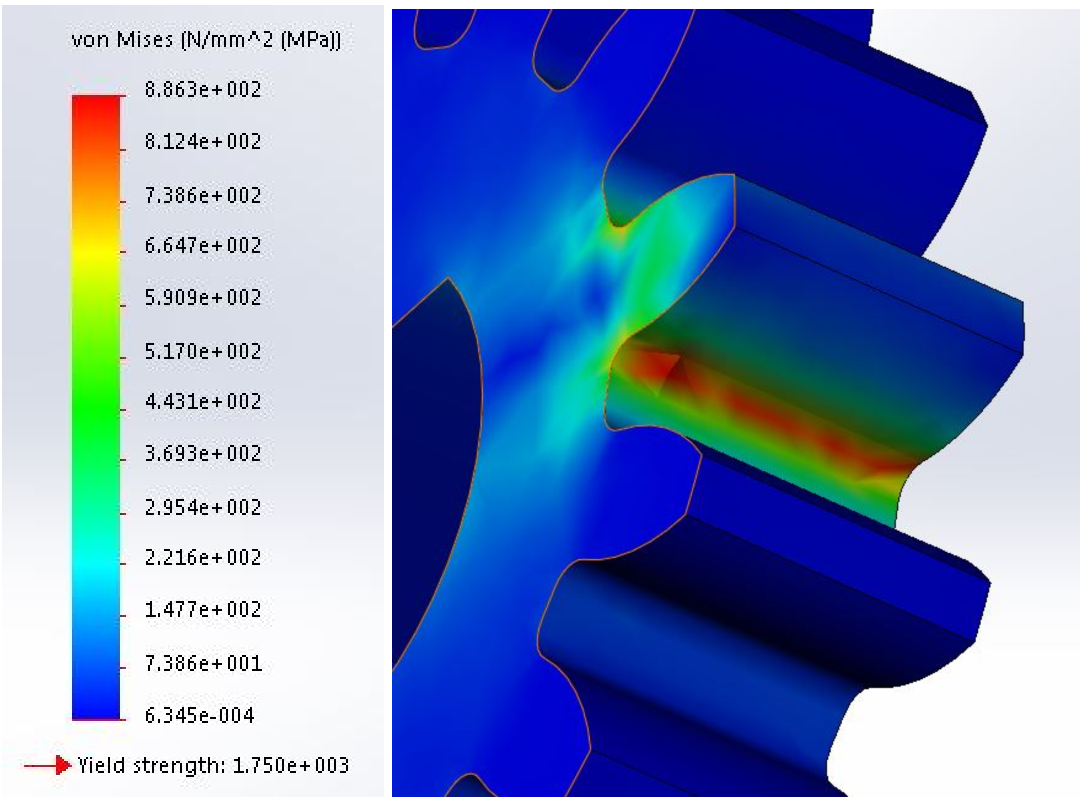


Figure 2: Stress distribution

For the fatigue test we calculated that with a service cycle consisting of 10,000 cycles, would mean the cog of the gears would impact at maximum loads about 20,000,000 times. Using this data we ran a fatigue test.

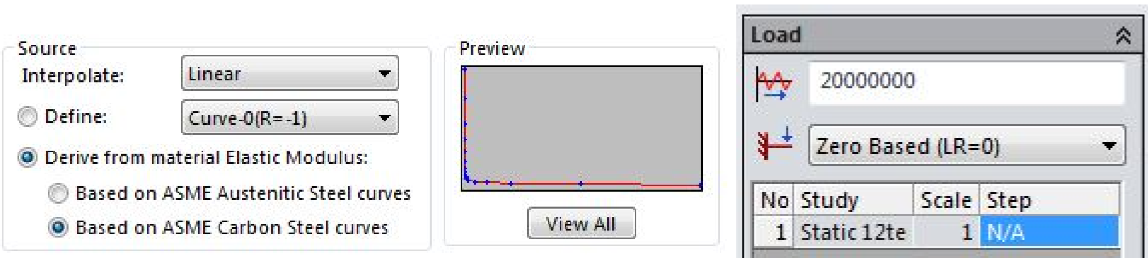


Figure 3: S-N curve for the material, The load event

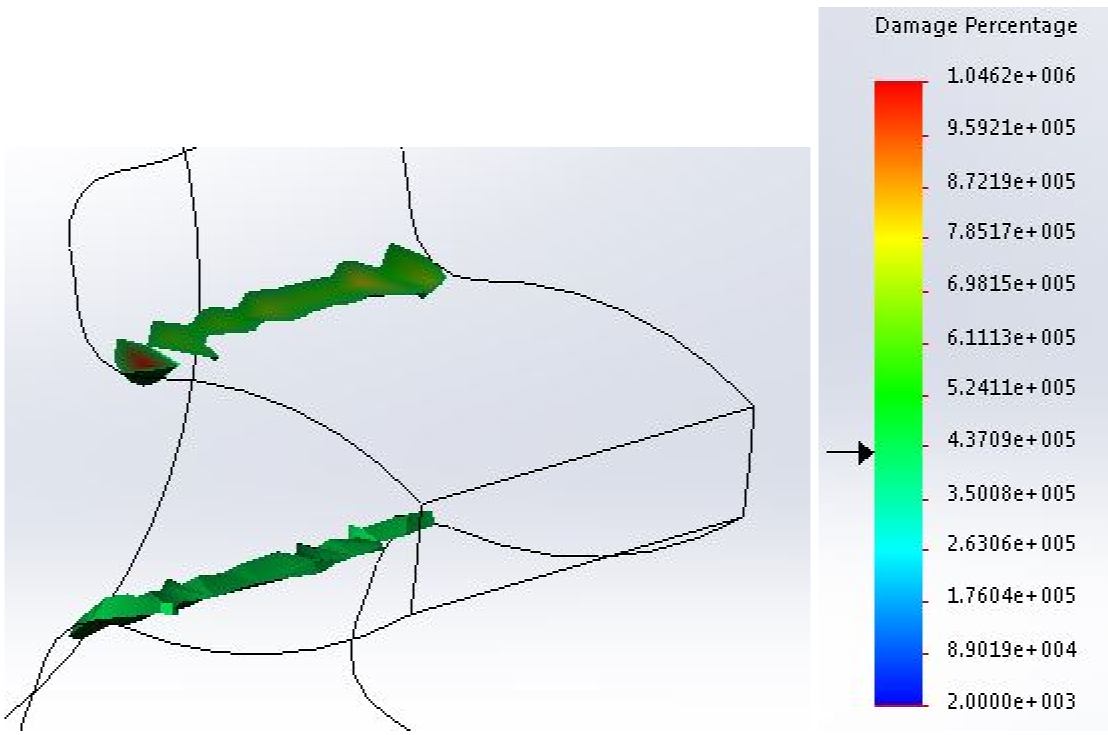


Figure 4: Damage percentage in the cog.

The damage plot shows the percentage of the life of the structure consumed by the defined fatigue events. The load input is set to zero based, this means that the cog is forced in one direction and then returns to its original position.

6.2 Gripper plate static test

The gripper plate connects the linear actuator to the gripper arm. We have undertaken a static test to verify that when the plate is horizontal, it will not bend from the weight of the gripper arm.

We have tested two different types of material:

- AISI 1020 Carbon steel.
- 2024 Aluminium alloy.

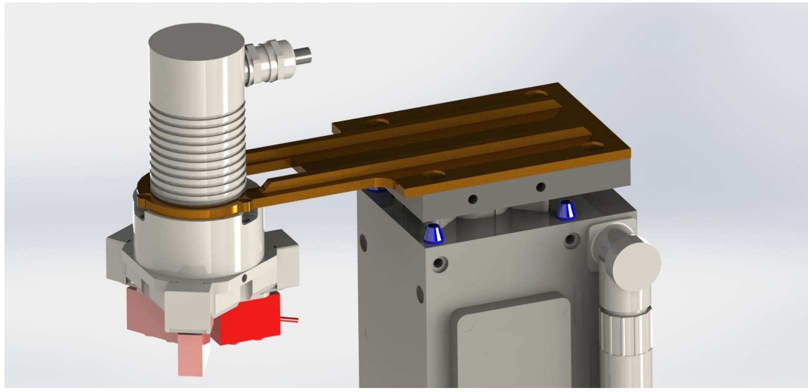


Figure 5: Gripper plate with mounted gripper arm.

6.2.1 FEM

We added fixtures to the bolt holes connecting the gripper plate to the linear actuator. The applied force is concentrated in the bolt holes where the gripper arm will be fastened to the plate. The gripper arm has a weight of 0.98 kg.

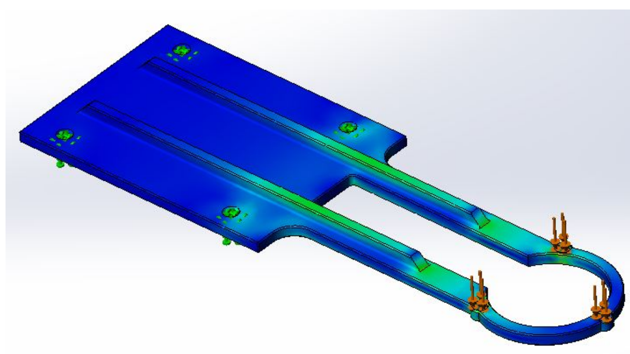


Figure 6: Illustration of fixture and force placement

With an applied force of 9.8 N, the stress distribution that the gripper plate experiences are minimal when using carbon steel as the selected material, stresses upward of 12.4 MPa are evident in the bolt holes for the gripper arms connection points. The yield strength of the material is 351.6 MPa.

Using 2024 Aluminium alloy, the gripper plate has a stress distribution upward of 32.7 MPa with a material yield strength of 75.8 Mpa. The connection points are in the elastic area for the material, and the plate will not experience material fatigue due to the loads and operational conditions.

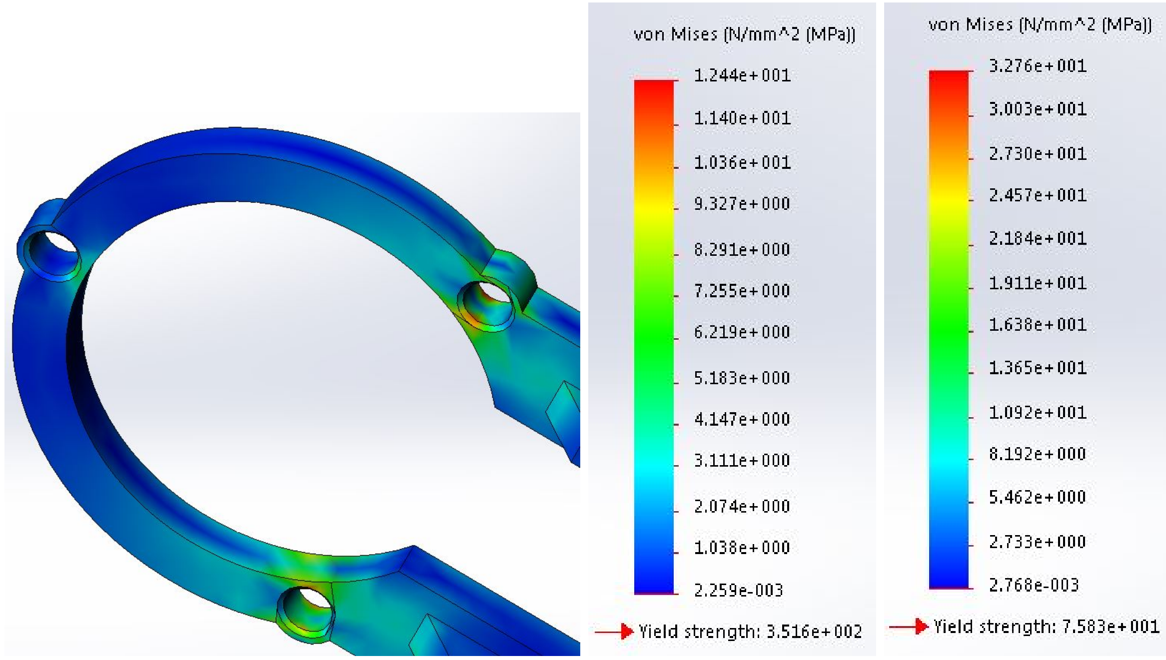


Figure 7a: Stress distribution, 7b: AISI 1020 Carbon steel, 7c: 2024 Aluminium alloy.

6.3 Interface plate test

The interface plate must be able to withstand the forces its subjected to during operational conditions.

6.3.1 FEM

We have used the weight of the end effector to simulate a static uniform and a non-uniform distribution test. The nonuniform test will simulate the forces on the plate when the end effector is in a vertical position. Due to the weight of the end effector, the distributed load is 84.4N

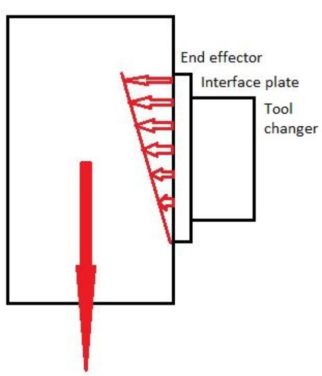


Figure 8: Non-Uniform distribution

KONGSBERG

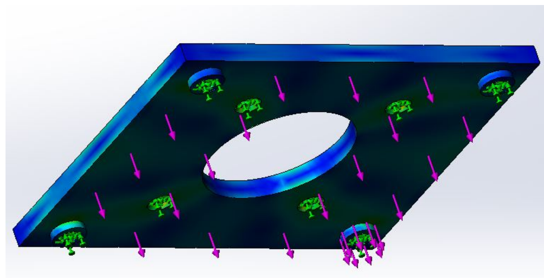


Figure 9: Fixtures and forces placement

Fixtures (green arrows) were placed in the bolt holes, for both the linear actuator and the tool changer. For the static uniform load distribution test, the force (purple arrows) were placed on the contact surface between the linear actuator and the interface plate. For the non-uniform load distribution test, selected a coordinate system and follow the proper steps for non-uniform test.

The material selected for the plate is 2024 Aluminium alloy. The tool changer is made of high strength aluminium, then there will not be a problem with corrosion between the two contact surfaces.

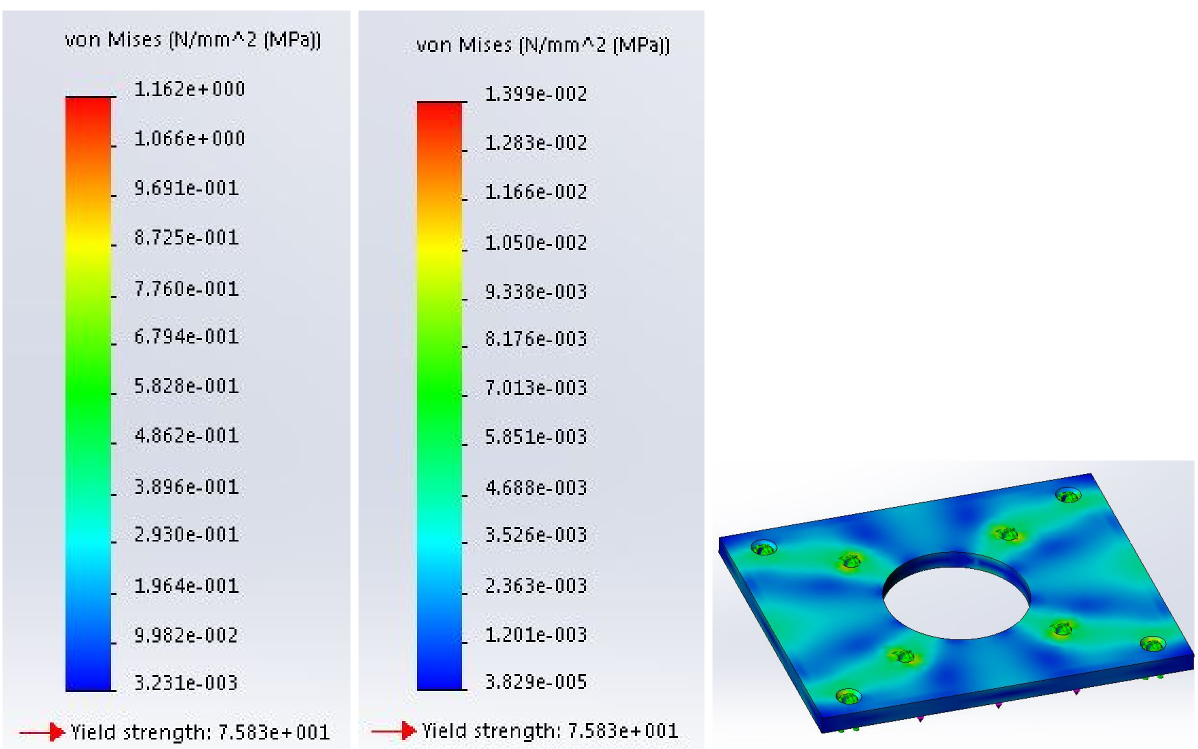


Figure 10a: Uniform load distribution 10b: non-Uniform load distribution results 10c: Stress distribution

6.3.2 Results

The interface plate under uniform load distribution sees 1.16MPa and the yield strength of the material is 75.8MPa. During the non-uniform load test, the plate only experiences 0.014MPa. Conclusion of the test, the interface plate will be able to handle the forces with ease.

7.0 Installation test

The installation test requires that the nutrunner is small enough to enter the aerospace part, and install the nut. We found out that we had designed the gear too big for the nutrunner to fit in between the adjacent bolts. When the first test was performed the diameter was too wide for the nutrunner to fit.

We reduced the diameter of the gear and redesigned the nutrunner to make it fit the shortest and the narrowest areas in the panel, and we succeeded. We managed to reduce the radius of the end of the nutrunner from 16.5 mm to 13 mm. These changes made the nutrunner pass the test.

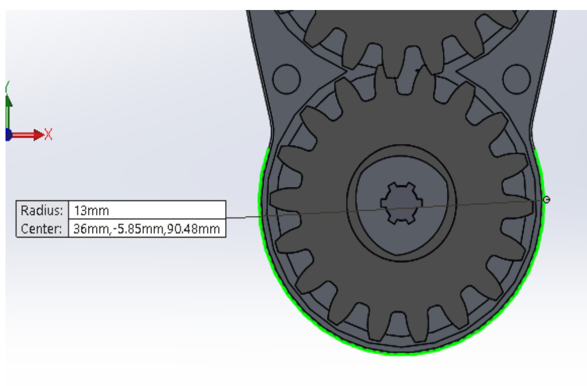


Figure 11: Nutrunner.

8.0 Sources

[1] CCSteels, *Cog material*, cited 22.04.2015, available from:
http://www.ccsteels.com/Tool_steel/867.html

Technology Document: Concept Generation

Version	Date	Reviewed by	Approved by	Satus
2.0	15.05.2015	Katrine Kallevik	Tor Sigurd Breivik	Released

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1.0 Abstract

This document describes the different concepts that we have come up with, for systems that are able to complete the process of installing bolts into our aerospace component. It also gives a reasoning and conclusion to what concept we have chosen for our final product.

2.0 Revision History

Version	Date	Changes	Author
0.1	23.02.2015	• First version of the document.	Stian Hovde
1.0	16.03.2015	• First released version.	Stian Hovde Elvar Aspelund
1.1	26.03.2015	• Added sources to chapter 11.0. • Added chapter 6.8 & 6.9. • Added info to chapter 5.3.1, 6.1.2 & 10.0	Elvar Aspelund
1.2	14.04.2015	• Changes to chapter 5.0 & 6.0 based on feedback from Tronrud. • Added chapter 5.4. • Spellcheck.	Stian Hovde
1.3	16.04.2015	• Added chapter 8.2 & 8.3. • Added chapter 9.7.	Katrine Kallevik
1.4	20.04.2015	• Added chapter 7.1 & 7.2. • Added cycle times to robot cell concepts.	Stian Hovde
1.5	21.04.2015	• Added chapter 7.3 & 10.3.	Stian Hovde
1.6	06.05.2015	• Added chapter 10.4.1 & 10.4.2. • Reworded chapter 9.7. • Added info to chapter 8.	Stian Hovde Elvar Aspelund
1.7	12.05.2015	• Spellcheck. • Updated table of contents. • Updated figures and tables.	Katrine Kallevik Kristoffer Lund Stian Hovde
2.0	15.05.2015	• Final released version	Stian Hovde Elvar Aspelund

Table 1: Revision table.

3.0 Introduction

The main goal of our project is to design a system that is able to complete an aerospace assembly process. In this document we will look at the overall solution to the problem, and describe concepts for the robot cell that will solve our problem. We will also describe our concepts for the robot end effector, or tool, that will install the bolt and nut. We will conclude with a selection process and an explanation for the choices that were made.

4.0 Methods

The first part of our concept generation phase was a research phase, where we looked at already existing solutions and see what is possible to achieve. Seeing how other companies have automated their production lines really helped to spark our imaginations.

We were also lucky enough to be allowed a tour of the production facilities at Kongsberg Automotive, where they have automated most of the process. This gave us helpful insight into automation of assembly processes. We also got a lot of advice and many questions answered by the employees there.

The next phase was a brainstorming, combining the knowledge we have gained with our own imagination, to come up with concepts that will solve the problem at hand.

To decide which of our concepts we will be moving forward with, we will be using the decision-matrix method. We believe this is a good way to quantify the different options, and objectify our opinions of them.

5.0 Concepts for complete solution

In this chapter we describe the concepts we have come up with for a solution to the whole process. It will give a quite broad description of the concept, since the technical explanation of the modules will be explained in their own sections.

The placement of the robot can vary, hanging from the ceiling or the walls.

Since the bolts have 5 different diameters, we might need 5 tools to accommodate this. We will look closer at this in the tool selection. This means that we might need a large tool rack in the robot cell to hold all these tools. Switching between tools also takes up a lot of time, and has to be taken into account.

The cycle times described in this process are purely for comparison between the concepts, and should not be taken as any reference as to how long the final cycle time of the system will be.

5.1 Two robots system

This concept uses two robots that work independently of each other, to complete the bolt installation process.

5.1.1 Functionality

The aerospace part is guided on rails into the robot cell, guaranteeing proper placement of the aerospace part. One robot will have a tool that can pick up the bolt and insert it into the hole. The other robot will have a tool that can pick up the nut and fasten it to the bolt. As the nut tool is operating, the bolt tool is able to retrieve the next bolt and insert it, since the bolt is fastened only from the nut side. After the bolt has been fastened, the process repeats until all the bolts are installed.

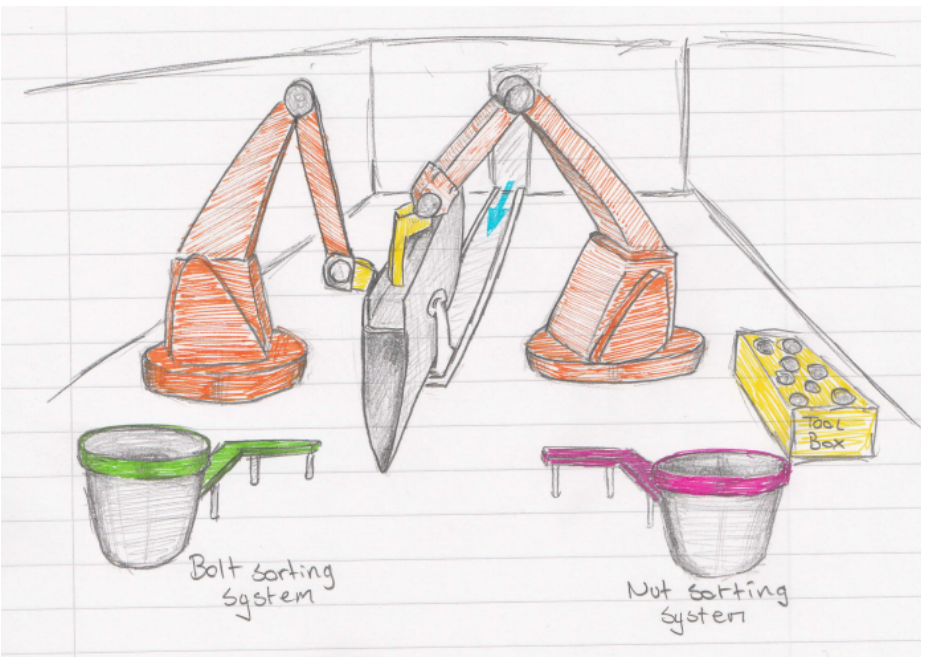


Figure 1: Two robot concept

5.1.2 Advantages and disadvantages

The main advantage with this concept is that it decreases the cycle time, since it has two robots that can do operations independently of each other. It also makes the tool design easier since the tool only need to handle one operation.

The first obvious disadvantage is the price. Two robots means twice the price, including programming and setup costs. Another disadvantage is the extra space the second robot have to occupy.

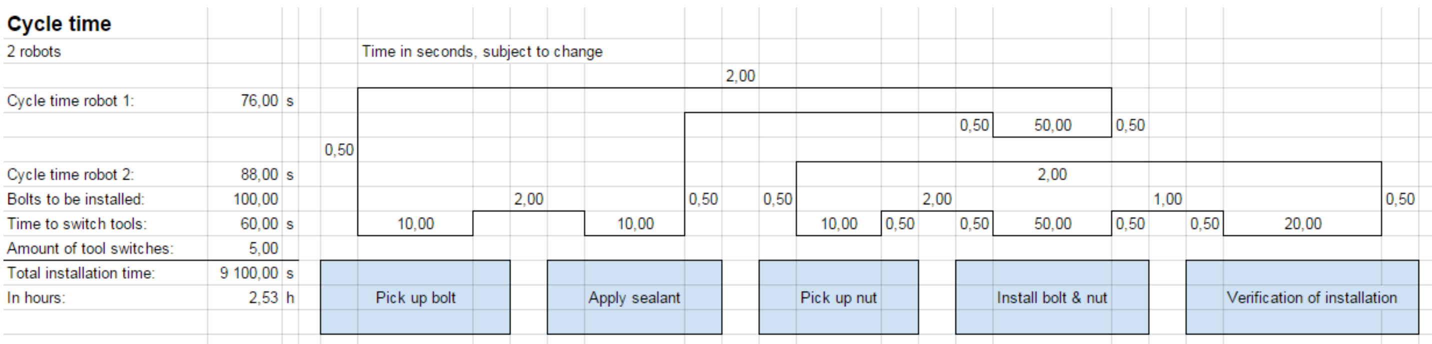


Figure 2: Example of cycle time for two robots.

The cycle time we see here is she shortest of all the three concepts. This is because the two robots are able to work independently of each other, and can therefore complete the processes in the system at a much faster rate.

5.2 One robot with separate bolt handling

This concept has one robot with a nut installation tool. The bolt is inserted via a stationary system.

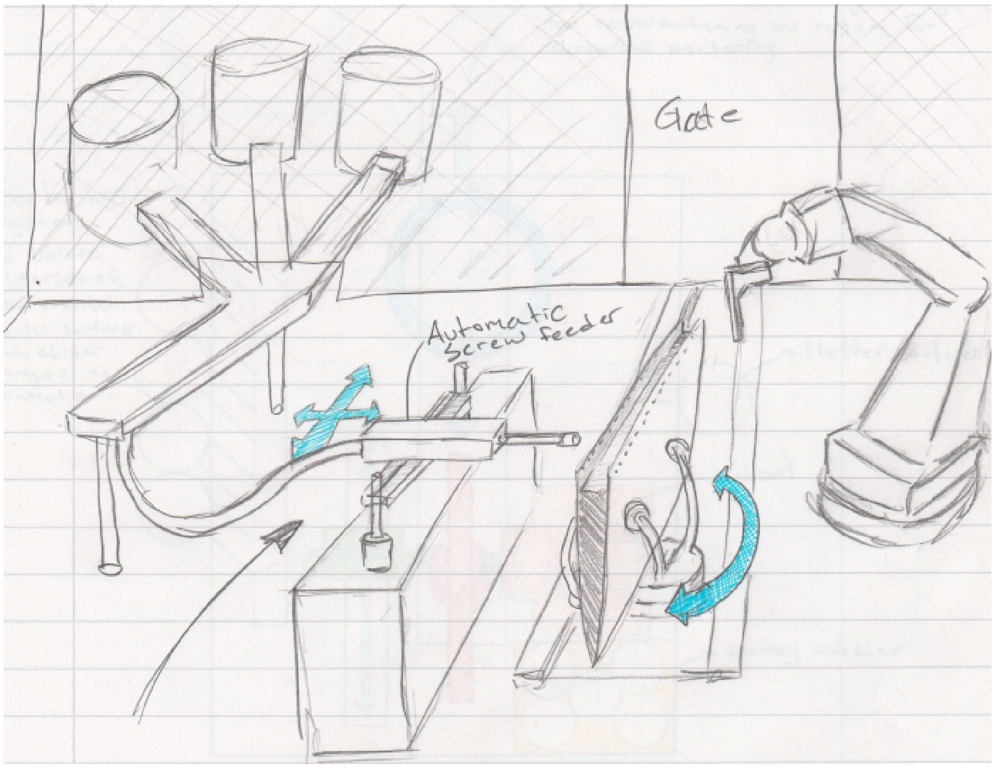


Figure 3: One robot with separate bolt handling concept

5.2.1 Functionality

After the bolts have been sorted, and applied the sealant, the bolt is fed to the bolt installer. It then inserts the bolt into the correct hole, awaiting the nut to be installed.

The robot picks up the correct nut installation tool, if not already equipped. The robot then picks up the correct nut, and positions itself to fasten the nut to the bolt. As soon as the nut has been fastened, the bolt installer can move on to the next bolt to be installed, since the bolt is tightened only from the nut side. After the nut is tightened properly, the robot picks up the next nut, and the process is repeated.

5.2.2 Bolt installer

The bolt installers job is to grab the bolt, insert it into the correct hole, and keep it pushed into the hole while the nut is being fastened. We have a few concepts that solve this problem.

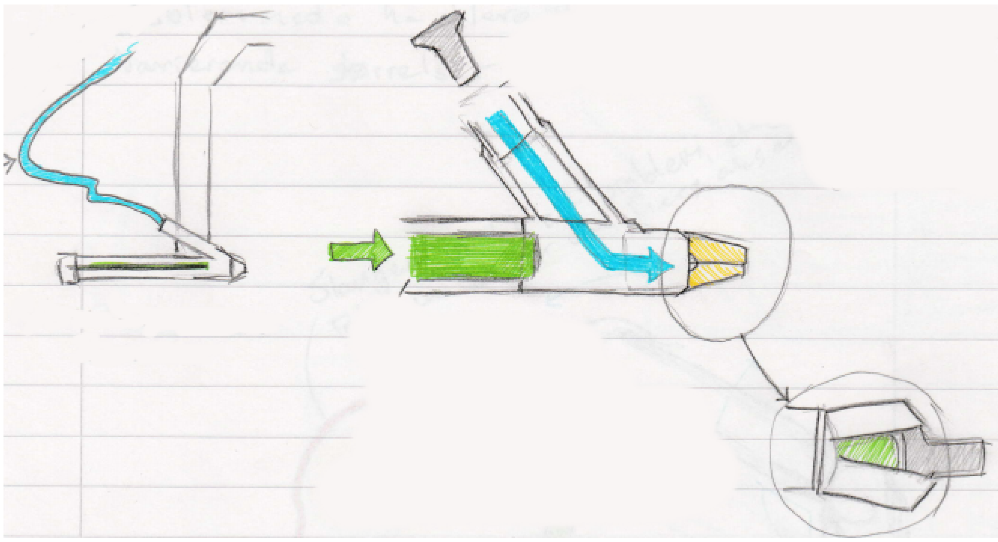


Figure 4: Bolt feeder system concept

One solution is a bolt feeder system, that feeds the correct bolt to the bolt installer via an air pressurized tube. The end of the installer has a clamp that stops the bolt from being shot out from the air pressure. When the bolt installer is in position, a piston will push the bolt out. This will in turn cause the clamp to open. The piston pushes the bolt all the way into the hole, and awaits the robot to fasten the nut.

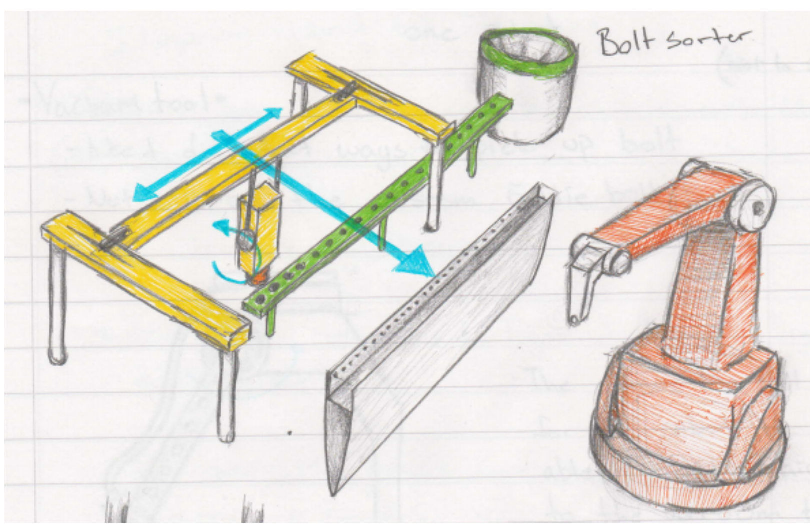


Figure 5: Bolt installer with bolt pickup.

Another solution is to have the bolt installer being able to pivot and pick up the bolt itself. The gripper could be one of the concepts described in chapter 6.2. This will also give the bolt installer easy access to a sealant station where it could apply the sealant to the bolt, before it is installed into the aerospace part.

5.2.3 Advantages and disadvantages

The advantages of this concept is that it makes for an easier tool design, since we move the bolt handling from the robot to the bolt installer. This will also increase cycle time, since the bolt installer can move on to the next bolt as soon as the robot has fastened the nut.

The problem with this concept is that the aerospace part will have to turn around 180° when one side is finished with the bolt installation. This means it will require more space than the other designs. This will also affect the advantage of the cycle time, decreasing its effectiveness. The price of the mechanical system can also become quite costly, possibly even more than a second robot. Lastly, the working area of the mechanical system is much more limited than a robot would be.

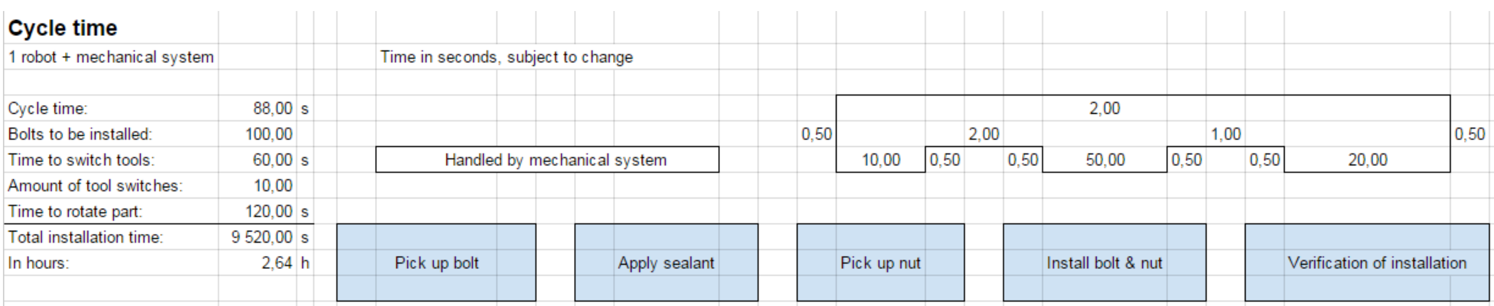


Figure 6: Example of cycle time for one robot and mechanical system

The cycle time of this concept is almost the same as the two robots concepts. The added time is due to the part having to rotate 180° when the bolts are installed on one side. The amount of tool changes also doubles, since it has to go through all 5 diameters on each side.

5.3 One robot with one tool

This concept uses only one robot, that has a tool that can pick up both the bolt and nut, and install them.

5.3.1 Functionality

The aerospace part arrives on a guide rail that holds it in the correct position. The robot, with the correct installation tool, then picks up both the bolt and nut. The robot positions itself to the aerospace part, and installs the bolt and nut. The process is repeated until all the bolts are installed.

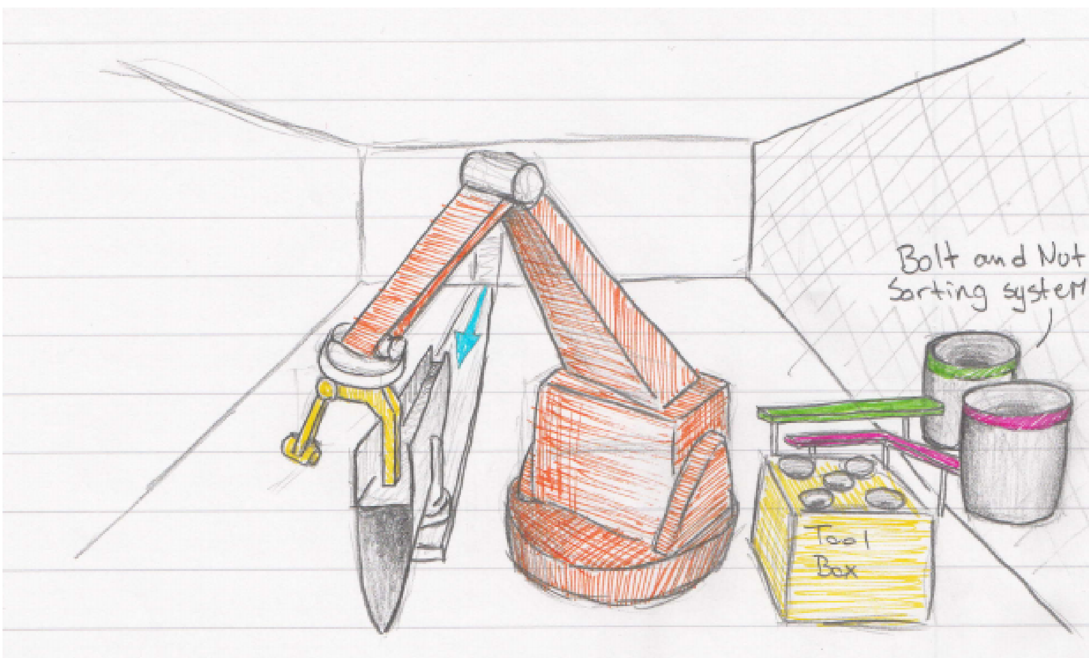


Figure 7: Single tool concept

5.3.2 Advantages and disadvantages

The main advantages of this concept is the cost of the system. A single robot that handles all the processes are substantially cheaper than our other concepts, including programming cost and time. This concept will also occupy less space. Having fewer elements in the system also means that the failure rate will be less.

The disadvantages are that our tool design will get much more complicated, since it will now have to handle both the bolt and nut. The cycle time will also be reduced for the same reason.

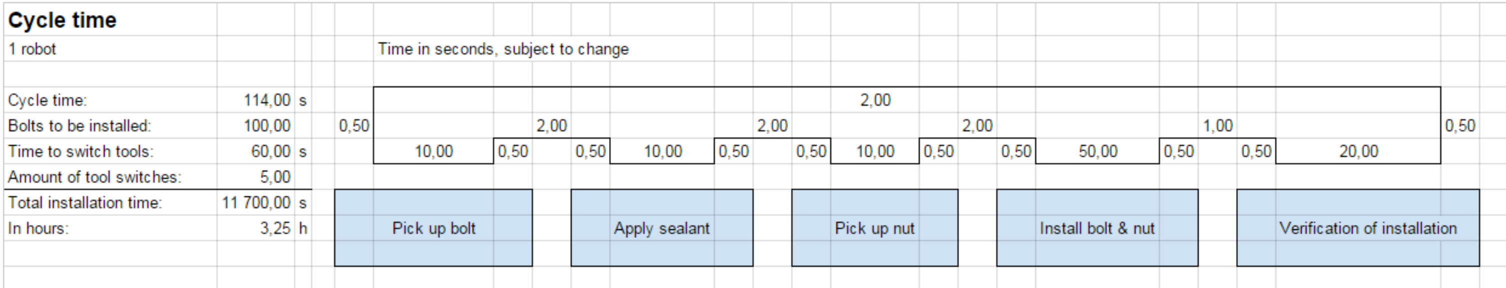


Figure 8: Example of cycle time for one robot.

This cycle time is the highest of all our concepts. This is because we now have only one robot handling all the processes in the system.

5.4 Health & Safety

When working with robots, the safety of personnel and parts has to be considered. This is a vital part of the robot work cell design. The contents of this chapter applies to all of our robot cell concepts.

The work area around the robot has to be secured, so that personnel are not able to get in while the robot is running. Even if the robot is programmed to operate in a specific area, one has to take into consideration that it could theoretically move within its entire maximum movement range. This entire area, including the end effector length, has to be secured.

A way to solve this is to set up a fence around the work cell. This fence stops any personnel from unintentionally moving inside the operation range of the robot. The fence needs to also cover any equipment the robot needs to interact with. The fence needs a gate for for example maintenance access. A system could be developed that slows down or even stops the robot if this gate is opened while its operating. If any parts need to be fed to the robot by personnel during operation, it should be possible to deposit these on the outside of the cell. A conveyor belt, or rotary table, could then bring the parts into the cell for the robot to access.

A newer safety system uses vision modules to monitor the edges of the work cell. If any foreign object breaches this perimeter, the robot is either slowed down, or stopped completely. The intruder can also be notified about the danger, either visually, or audibly. Once the hazard zone is clear, the robot can reset and resume normal operations.

If any of these safety measures fails, it is important to also have an emergency stop button, that immediately cuts the power to the robot, and any other equipment.

Another thing to take into consideration is that the aerospace part we are working on is very expensive. Any damage to this during production, would incur massive losses for our employer. We must therefore take active counters in securing the part from damage.

6.0 Concepts for end effector

In this chapter we describe our concepts for the end effector that will fit on our robot. In other words, it is the tool that will perform the bolt and nut installation process.

An important issue is the fact that we have bolts of 5 different diameters that needs to be installed. We have decided to use 5 different tool sizes for each diameter, instead of designing a system that can adapt to each diameter. This is because a system like this would be very complicated, considering the special way the bolt has to be installed. While the nutrunner is rotating, the center hex key has to stay stationary. Both the nutrunner and hex key has to change diameter for each bolt size. Designing a system that accomplishes this would be very complicated, and would probably not fit within our aerospace part.

Another reason for this is that Alcoa has a very strict procedure of how the bolts are to be installed. Tampering too much with how the tool is designed, might cause problems to arise in this procedure. The aerospace industry is justifiably very strict on this, we will therefore use the official bolt installers from Alcoa as long as practicable.

All our tools will also need a special designed tool interface plate, to be able to connect with the tool changer system.

6.1 One tool vacuum bolt gripper

This concept features one tool with one rotating arm. The rotating arm is equipped with a vacuum gripper, and the other has a nutrunner in a fixed position.

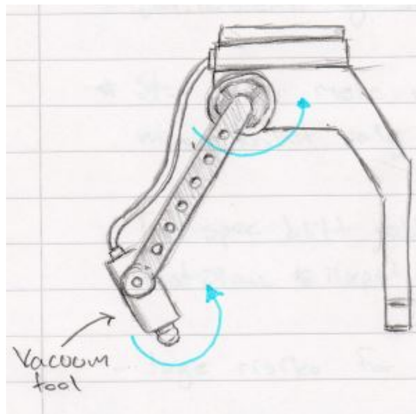


Figure 9: One tool gripper.

6.1.1 Functionality

The eddie bolt part of the tool has a fixed position, while the second arm has two rotating joints. This makes it possible to retrieve bolts by using a vacuum tool at the end of the rotating arm. The bolt is of a lightweight alloy so the pressure needed to create vacuum will be low.

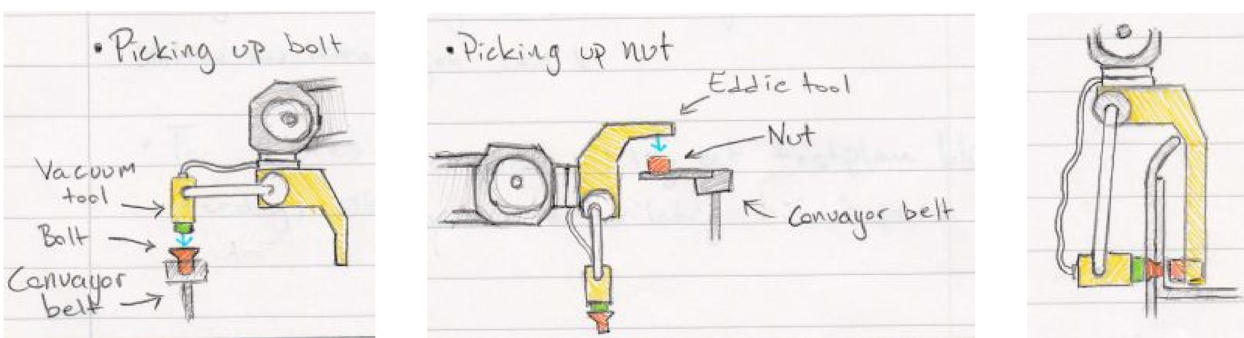


Figure 10: Process of assembly

6.1.2 Advantages and disadvantages

The vacuum gripper makes it easier for the tool to insert the bolt, since it only is in contact with the bolts head.

The main disadvantage for this concept is that the vacuum must be maintained during the retrieval of the bolt so that the bolt is not dropped. It also has a higher number of moving mechanical parts. Programming the robot will be more complicated, as the the rotating arm and tool needs to be parallel and perpendicular with the nutrunner. The proper angle of the bolt tool has to be guaranteed, so that the bolt will enter the countersunk hole correctly and not cause damage to the aerospace part.

6.2 One tool 3-Finger gripper

This concept features one tool with one rotating arm. The rotating arm is equipped with a 3-finger gripper, and the other has a nutrunner in a fixed position.

6.2.1 Functionality

For retrieval of bolt the 3-finger gripper tool has one rotating axis. After retrieval of bolt the 3-finger gripper rotates to correct position and uses a sliding system to insert the bolt.
It is possible to implement rotating axis on the gripper arm itself, this could be useful depending on which sealant concept is selected.

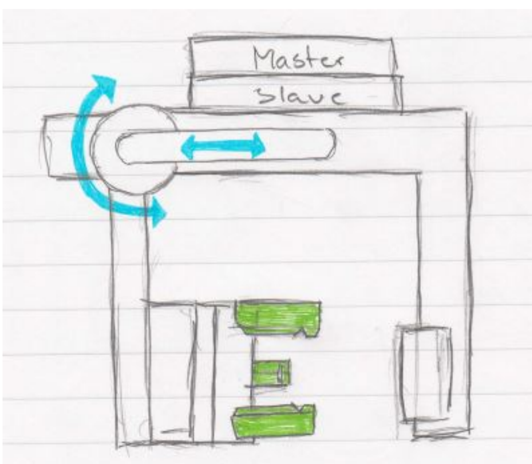


Figure 11: 3-finger gripper tool

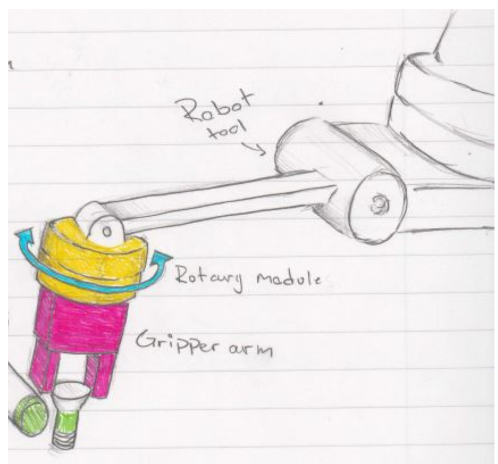


Figure 12: Rotating gripper

6.2.2 Advantages and disadvantages

Advantages are that the gripper arm is able to rotate, making it easier to apply the sealant. It has a flexible end joint making retrieval of bolts easier. The gripper arm off the shelf technology.

Disadvantages are that the gripper needs to be in contact with the underside of the bolt head, making it difficult to install the bolt flush into the airframe.

6.3 One tool actuator gripper arm

One tool with eddie bolt tool in fixed position. Bolt receiver arm equipped with gripper extender.

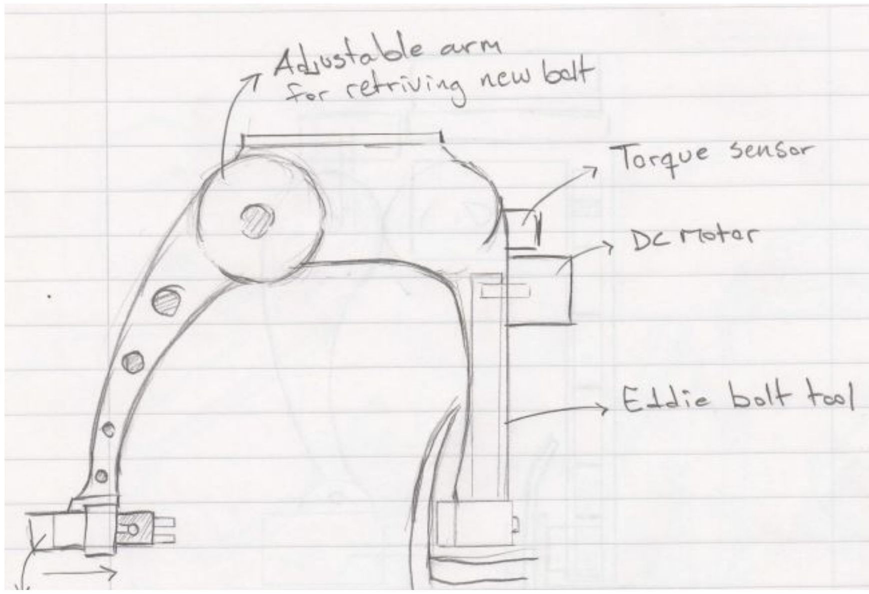


Figure 13: Extender gripper tool

6.3.1 Functionality

The bolt retrieval arm can rotate for easier access to bolts. The retrieval arm is equipped with an actuator system that is able to extend the gripper arms reach, and ensure smooth insertion of the bolt.

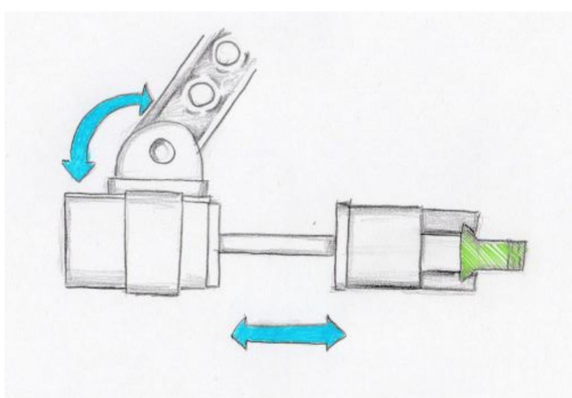


Figure 14: Extender function

6.3.2 Advantages and disadvantages

Advantages are that the gripper extender makes the insertion of the bolt easier. This is also off the shelf technology.

Disadvantages are weight concerns, we have to keep the tool weight low to meet our requirement. This concept also features many moving parts, making the overall design much more complex. We also need a pneumatic system for gripper arm extender.

6.4 One tool bolt gun concept

One tool equipped with a bolt gun system.

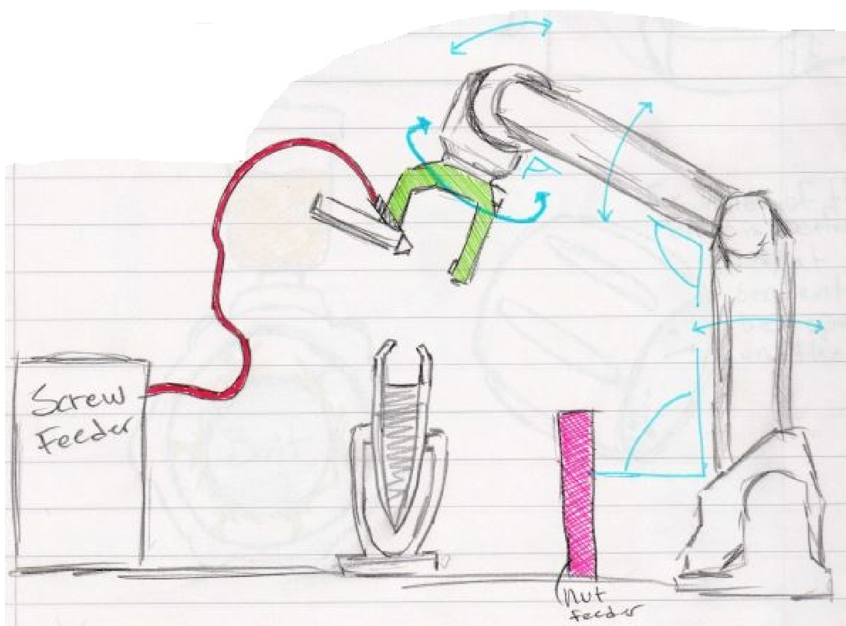


Figure 15: Bolt gun concept

6.4.1 Functionality

The bolts are fed through a tube system from the bolt collection station. When it arrives at the bolt tool, an internal piston in the bolt tool pushes the bolt out of the tool. With controlled force the bolt will enter the aerospace hole in a safe manner.

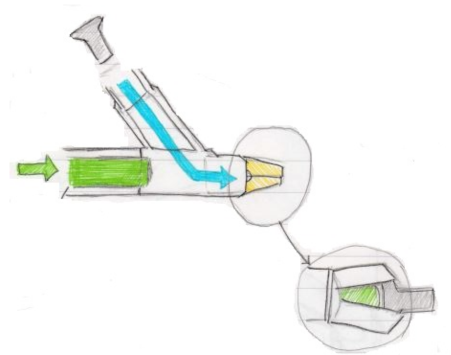


Figure 16: Bolt gun function

6.4.2 Advantages and disadvantages

Advantages are fast assembly time, and that the concepts consists of off the shelf technology.

Disadvantages are that there could be a problem with applying sealant, as it is fed through the tube. The tube could get entangled or the robot could rip the tube out of the feeder.

6.5 Vacuum bolt gripper

End effector with a vacuum gripper.

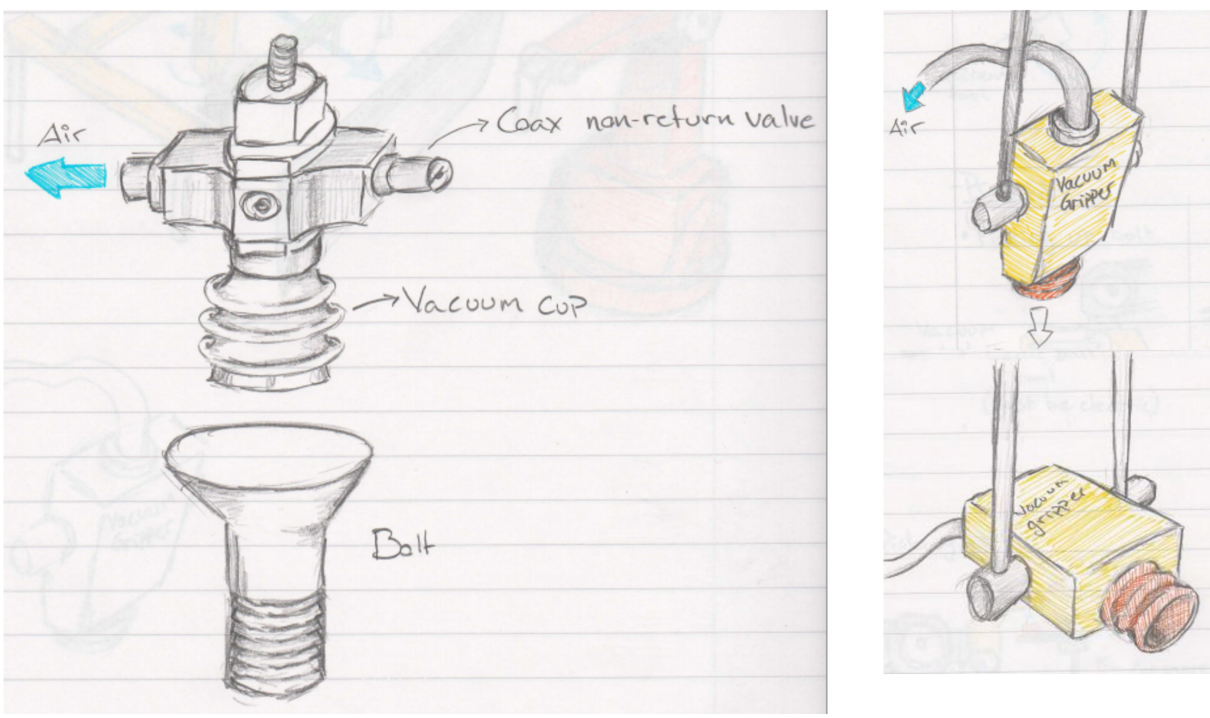


Figure 17: Vacuum tool concept

6.5.1 Functionality

The vacuum bolt gripper uses air suction to grab the bolt, and hold it while positioning it in the right hole.

Since the gripper does not come into contact with the underside of the bolt head, it gives easy access to apply the sealant to the bolt. It also makes it easy to push the bolt completely into the hole, while the nut is fastened.

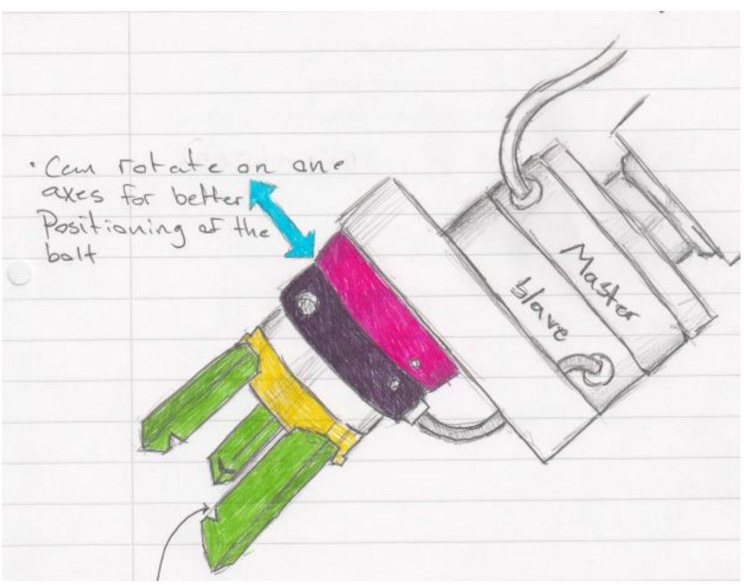
6.5.2 Advantages and disadvantages

Advantages are that it is off the shelf technology, and quite a simple design.

Disadvantages are that the concept tool is pneumatic, while the rest of the system is electrical. This means we have to run an additional tube to supply the air to the tool. We also have to guarantee vacuum after retrieving the bolt, so that the bolt is not dropped.

6.6 Three-point gripper

3-finger gripper with movable end joint.



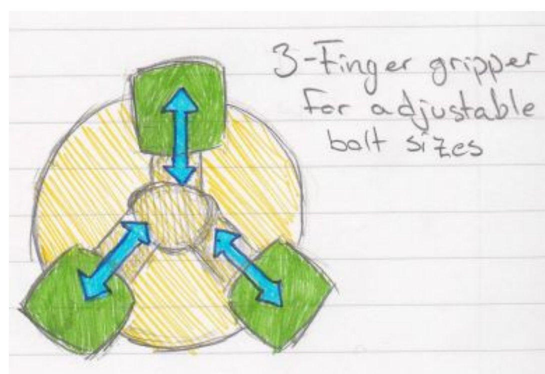


Figure 18: 3-Finger gripper

6.6.1 Functionality

This is tool uses three finger for precision pick up of the Eddie bolt. The upper joint has the ability to move, so that minor positioning adjustments are possible when installing the bolt.

6.6.2 Advantages and disadvantages

Advantages are that is a one tool fits all bolt sizes concept, flexible end joint makes for more precision instalment of bolt. This is also off the shelf technology.

Disadvantages are that the gripper needs to be in contact with the underside of the bolt head, making it difficult to install the bolt flush into the airframe.

6.7 Nutrunner

The nutrunner picks up the nut, positions it and fasten it to the bolt. Since the Eddie bolt has a very special installation procedure, the head of the nutrunner will be similar to the official Eddie bolt installation tools.

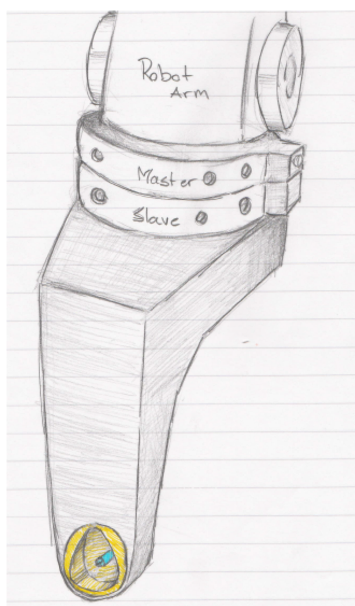


Figure 19: Nutrunner concept.

The nutrunner will be designed to fit into the tightest space where bolts needs to be installed. Since the structure of the aerospace part is curved inwards where the tool has to enter, the nutrunner head has to be extended so it can reach all the way to the base of the protruding bolt when installing the nut.

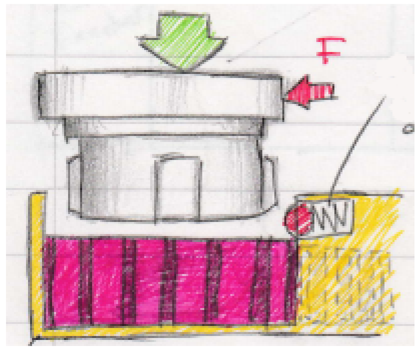


Figure 20: Concept to grab the nut.

The nutrunner head needs to have a way of keeping the nut securely fastened during transportation between the sorting station and installation point. A solution to this is to have a small ball attached to a spring, that is forced inwards when the nut is picked up. The spring will exert a force on the nut that keeps it from falling off. When the nut has been installed, the nutrunner will easily be able to release the nut, since it is now fastened properly to the bolt.

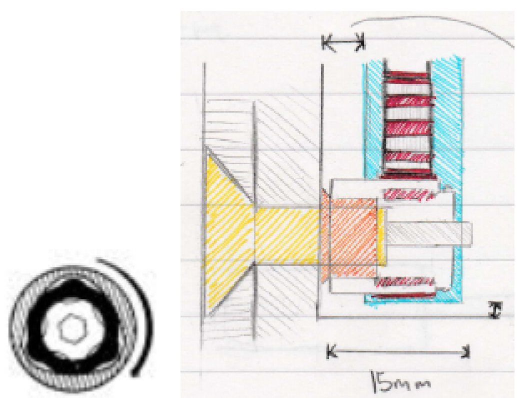


Figure 21: Nutrunner head.

The shape of the nutrunner head is exactly like the official Eddie bolt installation tools. It is shaped like a rounded off triangle to fit onto the nut, and be able to swage off the lobes of the nut to ensure proper installation. There is also a center hex key that fits into the drive recess of the bolt, and remains stationary while the nut is being installed.

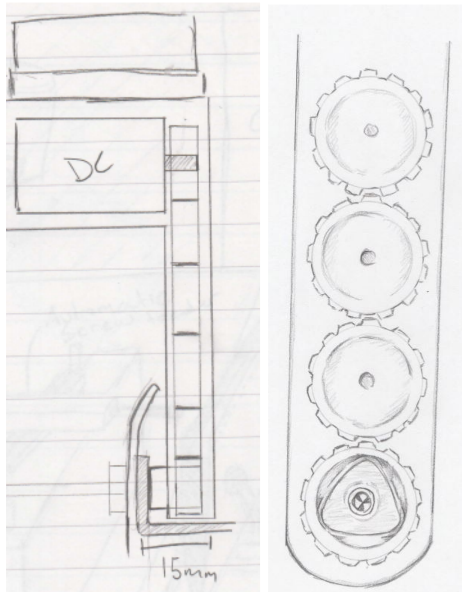


Figure 22: The stem of the nutrunner.

The nutrunner will be driven by an electric DC motor. To transfer the torque to the head of the nutrunner, a series of gears are placed in the stem of the tool. The gears must be dimensioned small enough to fit into the confined space of the aerospace part, but large enough to handle the torque of the motor without breaking.

6.8 One tool STAR

One tool gripper arm with sliding horizontal guidebase and five headed nutrunner.

6.8.1 Functionality

The gripper tool and the nutrunner is in a fixed parallel position. The gripper tool is mounted on a sliding guidebase so that the space between the gripper and nutrunner is enlarged, making it possible for the retrieval of bolts and nuts from the sorting stations. The nutrunner tool has to have a rotating mechanism to be able to align with the gripper arm.

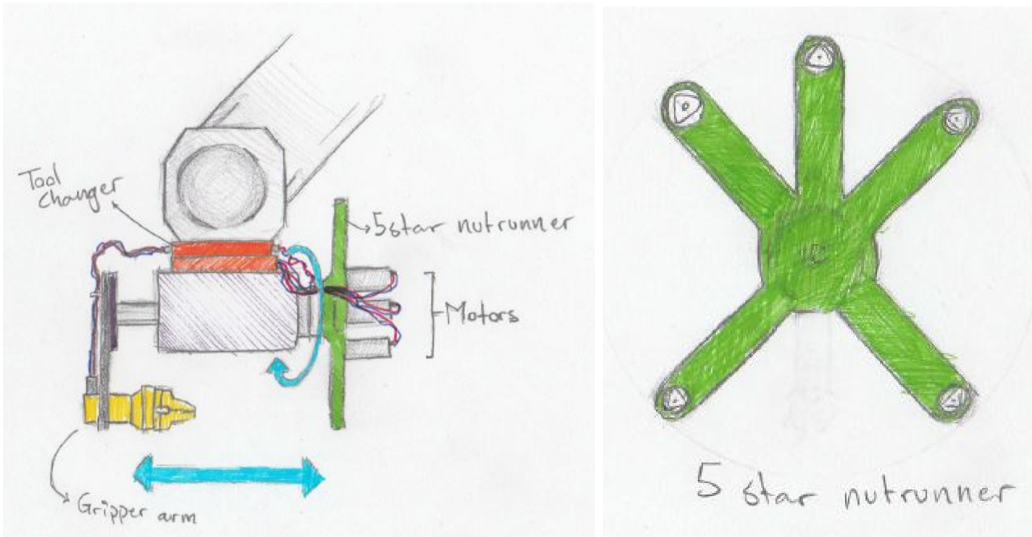


Figure 23: One tool STAR end effector

6.8.2 Advantages and disadvantages

Since the tool will be able to accommodate all the different nut sizes, there will be no need to switch tools during the bolt installation process.

The disadvantages of this concept is apparent. As it has a rather complex design, the five star nutrunner will need a rotating mechanism. The five different arms need to have a big enough angle from each other, so that they do not come into contact with the aerospace part during assembly.

6.9 Horizontal slider concept

A design of simplicity, bolt tool and nutrunner are aligned parallel and perpendicular to each other, with a horizontal guiding base.

6.9.1 Functionality

This concept has a guiding base for adjusting the space between the nutrunner and the gripper tool, the nutrunner will remain in a fixed position. This concept is basically the same as the concept in chapter 6.8 but with only one nutrunner per tool.

The gripper tool could be equipped with a tool that has an internal rod for pushing the bolt into the hole and maintaining pressure until the nut is properly fastened. Another solution is that the gripper tool itself could close its fingers after releasing the bolt, and push the bolt firmly in. When the nut is fastened hard enough, the gripper arm can remove itself. Then the nutrunner is able to apply enough torque to plastic deform the nut.

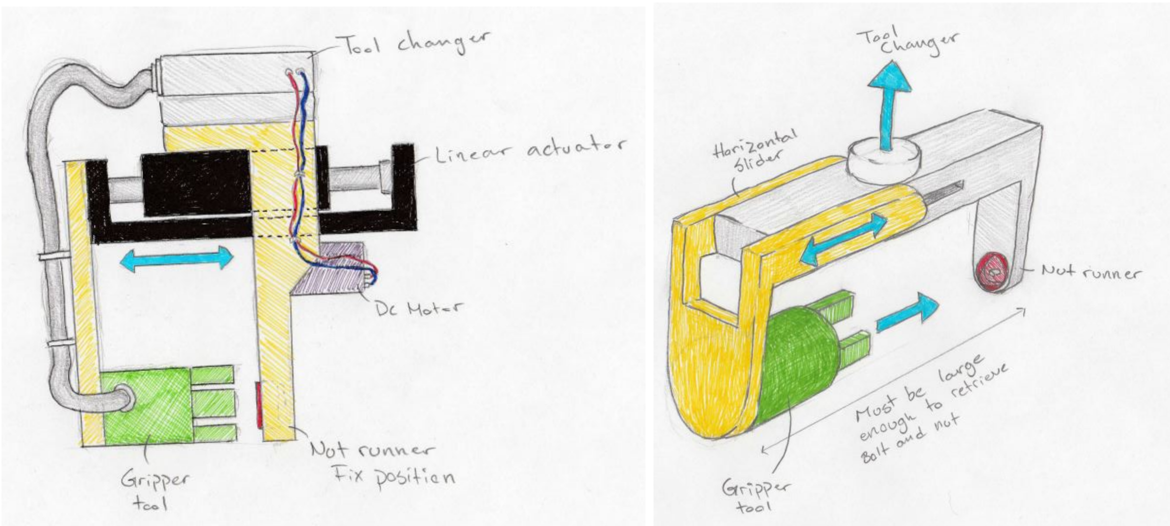


Figure 24: Horizontal slider concept 1.

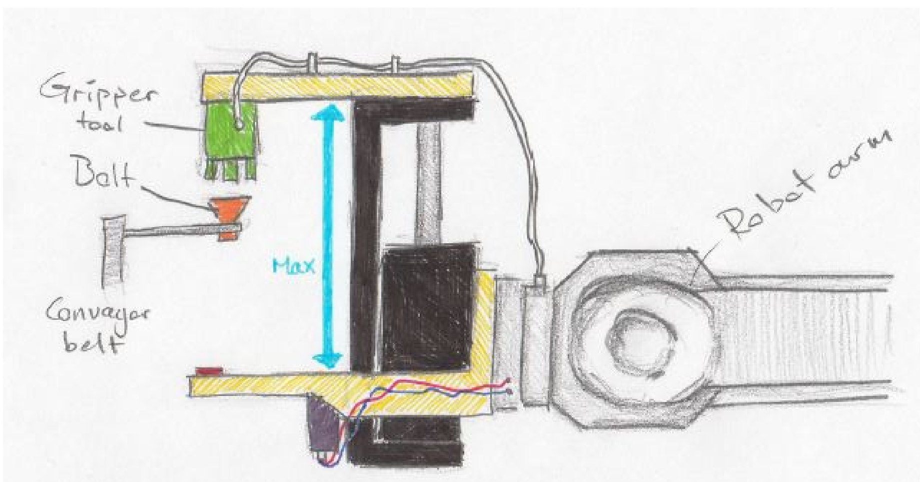


Figure 25: Horizontal slider concept 2.

6.9.2 Advantages and disadvantages

The advantages for this tool is the simplicity of its design. Easy access for the tools both when retrieving and mounting the bolts and nuts.

Disadvantages are that there is a need for one tool per bolt size.

7.0 Concepts for verification of proper installation

7.1 Verifying grip length of bolts

The grip length of the bolt is the part that sticks out of the material after the bolt has been inserted into the drilled hole. This length must be verified, since it is critical for proper nut installation.

The simplest way of controlling the grip length needed for the different bolts, is to measure the thickness of the composite and alloy of the aerospace part. The composite can vary a bit in thickness, while the alloy is within standardized size. When the composite and alloy is glued together, the glue can also vary in thickness, and will affect the final value. Calculating the total thickness will allow the system to calculate which grip length is needed. We will therefore be looking at concepts that will complete this task.

7.1.1 Ultrasonic thickness measurement

The ultrasonic thickness gauge uses sound waves to measure the thickness of a material. The sound waves are sent through the material, and is either picked up on the other side, or bounces off the edge of the material and passes back through it. Depending on the time it takes the sound wave to pass through, and the specific speed of sound in the material, we are able to calculate the thickness.

After a discussion with NDT[1] experts at Kongsberg, it turns out that it is very difficult to measure the thickness using ultrasonic means. The transition between composite and glue gives very weak signals, and the result you would end up with is very unreliable. Due to these reasons we will not be considering this method for our system.

7.1.2 Mechanical thickness gauge

Another way of measuring the thickness is to use a standard mechanical thickness gauge. This method simply uses two plates that are brought together until they rest on the surfaces of the materials. The distance between the plates is then the thickness of the material.

[1] Non-Destructive Testing

Figure 26: Example of mechanical thickness gauge.

It should be quite simple to adapt this technology to fit on a robot. The tool would only consist of two plates, and a system for measuring the distance between them. The plates could be made about the size of the bolt diameters, and then it could measure the distance where each hole will be drilled.

Since the product we are working on is very expensive, it is important to ensure that it does not get damaged during production. Since the mechanical gauge needs to be driven into contact with the airframe, this is a very real concern with this concept. It will also take a lot of time to reposition the robot and measure the thickness across the whole part.

7.1.3 3D Scanner

A 3D scanner is able to scan our entire aerospace part, and produce a 3D model on a computer. It is then a simple matter to measure the thickness where we need to.

In the recent years, 3D scanning has become accurate enough to enable us to use it for our project. The problem arises when we look at the price of these systems. The scanners with the accuracy we need for our purpose, borders the price of the robot itself. We therefore believe that this method is not well suited for this project.

7.2 Controlling head seating of bolt

Proper head seating of the bolt means that the bolt fits properly into the countersink, and that the bolt head is flush or below the surface of the material.

The easiest way of controlling this is to measure the diameter of the countersink. As long as the diameter is within the correct limits, the bolt should fit perfectly. We will therefore be looking at solutions that can measure this diameter.

7.2.1 Laser profilometer

The laser profilometer uses a laser and a detector to measure the diameter of countersinks. The concept behind this system is developed by Electroimpact Inc. As the laser is run over the countersink, it provides a cross section profile of the countersink.

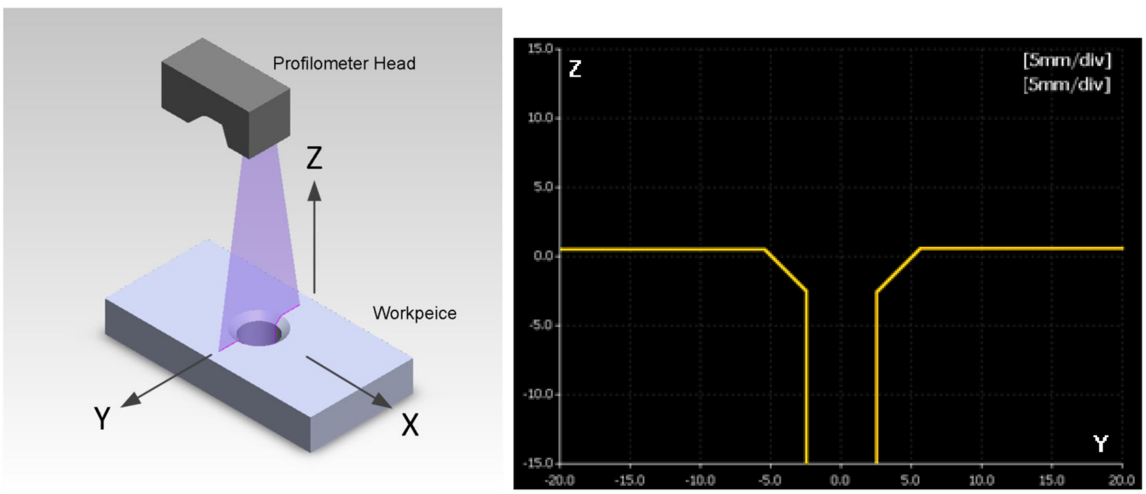


Figure 27: Laser profilometer with countersunk cross section.

Since the controller can compensate for any debris or other foreign materials present on the countersink, the profilometer is able to run without the need for periodic cleaning of the countersink. This allows the laser profilometer to continuously measure the countersinks, without the need to break the countersink process. This also means that the laser profilometer could be placed on the countersink tool, allowing it to both continuously control the countersink process, and measure the countersink diameter.

7.2.2 Countersink/chamfer gauge

The countersink gauge is a cone shaped instrument that is able to measure the diameter of a countersink. It does this by measuring the depth that the cone shaped member has fallen into the hole, where is comes to a stop. There is always a linear relationship between the distance that the cone travels into the part and the diameter of the countersink.

Figure 28: Countersink gauge example.

This method is very simple to implement, making it a valid choice for our system. This technology has existed for a long time, and there are many solutions on the market.

The main problem of this method is that it cannot compensate for debris and foreign materials in the countersink. This means that the countersink has to be cleaned out before being measured, not allowing continuous control during countersinking. Depending on the angle of the countersinks, you might also need to switch between different sized gauges.

7.3 Controlling nut profile

The nut profile is controlled to check if the nut has been deformed or swaged properly. This is done by using a paddle or thimble that fits perfectly on the nut if it is properly installed. If it does not pass smoothly over the nut, the bolt and nut must be removed and installed again.

Alcoa, who delivers the bolts we use in this project, has a strict system on how the nut profile shall be controlled. We will therefore be using official Alcoa equipment, and modifying it as little as possible to fit it on our robot. A method for this is to modify the thimble to fit onto a robot tool, and then using force sensors to detect if the thimble encounters any resistance when it is passed over the nut.

There are several 6-axis force sensors on the market, specifically suited for robots. These can be mounted before our tool changing system, which means we will only need one of them. An additional benefit with these is that they can aid in guiding the bolt when it is inserted into the hole. It can also sense if the robot comes into contact with our aerospace part, thus reducing the chance of it being damaged during production.

Figure 29: Thimble and paddle inspection gages from Alcoa.

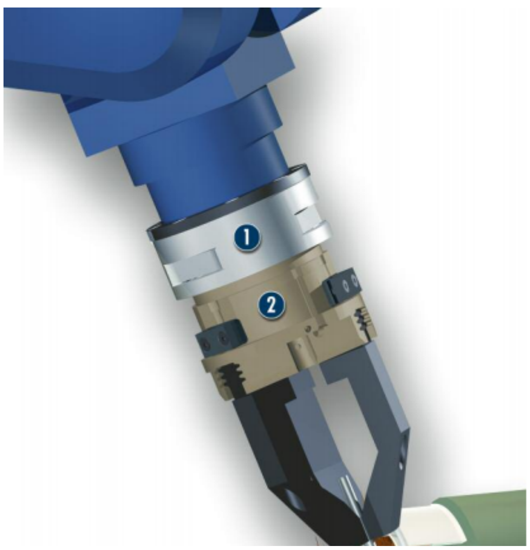


Figure 30: Illustration of force sensor (1) with tool (2).

To ensure an error does not repeat itself, the nut profile should be controlled after every installed bolt. To do this without switching tools, the thimble could be placed on the bolt installation tool. That way, the robot can easily control the nut profile after each installed bolt.

8.0 Concepts for bolt and nut sorting

8.1 Nut-sorter

One conveyor belt with a gateway system for each nut diameter.

8.1.1 Functionality

The station will be divided into five compartments with gates. This is to accommodate for the different diameter sizes. As the bolts and nuts arrive from the supplier already sorted, there will be no need for a sorting system. The operator will only need to place the nuts into the right diameter gate station. Before arriving at the robot station, a guiding system must be used to ensure that the nut is positioned correctly.

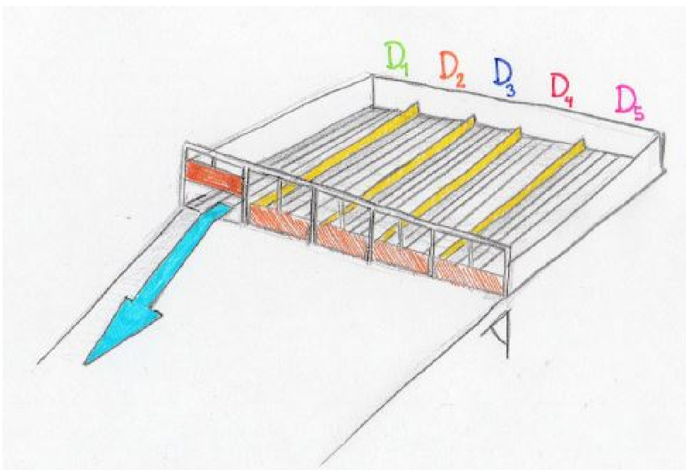


Figure 31: Non-sorter.

Another aspect of the conveyor belt system for the nuts is proper alignment. The nutrunner has one special gear, the last gear of the system. It has an open center with an reuleaux triangle shape so it can retrieve the nut. So in designing the conveyor belt system, this issue has to be addressed. This means that the nut and the reuleaux triangle has to be properly aligned as shown in the illustration.

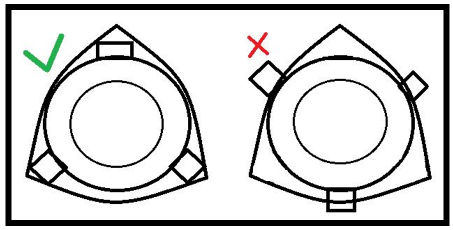


Figure 32: Proper alignment of nut and reuleaux triangle gear.

8.1.2 Advantages and disadvantages

The advantages is that there is no need for an over engineered sorting system. The conveyor pick and place belt will need a system that can verify the position of the nut, either with a vision system or a mechanical guiding system.

Using a vision system makes the system more expensive, and the cycle time of the process could be prolonged. The vision system will have to communicate with the robot so that the reuleaux triangle is properly aligned, this will make the programming of the system more complex.

8.2 Magazines

The bolts arrive from the supplier already sorted, and the promoter will be manually applied. The bolts are placed in magazines manually, and ready to be picked up by the robot for application of sealant and then assembly. The magazines have their own unique ID, so that the robot can collect the correct bolt with the appropriate grip length and diameter based on the ID number of the magazines. There will be 15 magazines in total.

8.3 Pallet system

This concept is based on a pallet system. One pallet per bolt diameter. As the promoter is manually applied to the bolts, the bolts could either be manually placed in the pallet, or a pick and place system could be used. If a pick and place system would be used, then there will be a need for a custom designed bin or tray for the bolts, so that the pick and place system is able to collect the bolts. The pallet has a unique ID, which makes it possible for the robot to detect each pallet, and then be able to collect the proper bolt with correct diameter and grip length.

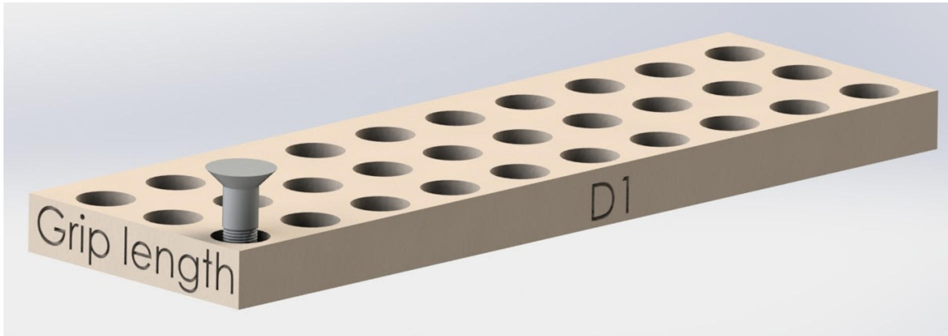


Figure 33: Pallet with bolt.

8.3.1 Pallet and sealant

Using the pallet system will ease the process of applying the sealant, after the sealant is applied, the bolts are placed into the pallet. As shown in the illustration, the pallet will not be in contact with the sealant area of the bolt. The bolts can then be delivered to the assembly robot.

The size of the pallet can be adjusted, depending on the need of the system. This can be better verified during physical tests. Since the sealant has a short pot life, the number of bolts will vary depending on the cycle time of the system.

9.0 Concepts for application of promoter and sealant

Before the bolt installation can begin, the bolt has to have a layer of promoter and sealant applied. The sealant can either be deliver in monotube form with internal mixing chamber, or delivered in separate packages from the supplier. If sealant and hardener is delivered in separate packages from the supplier, it will be necessary to design a custom system with internal mixing chamber for sealant and hardener, as illustrated below.

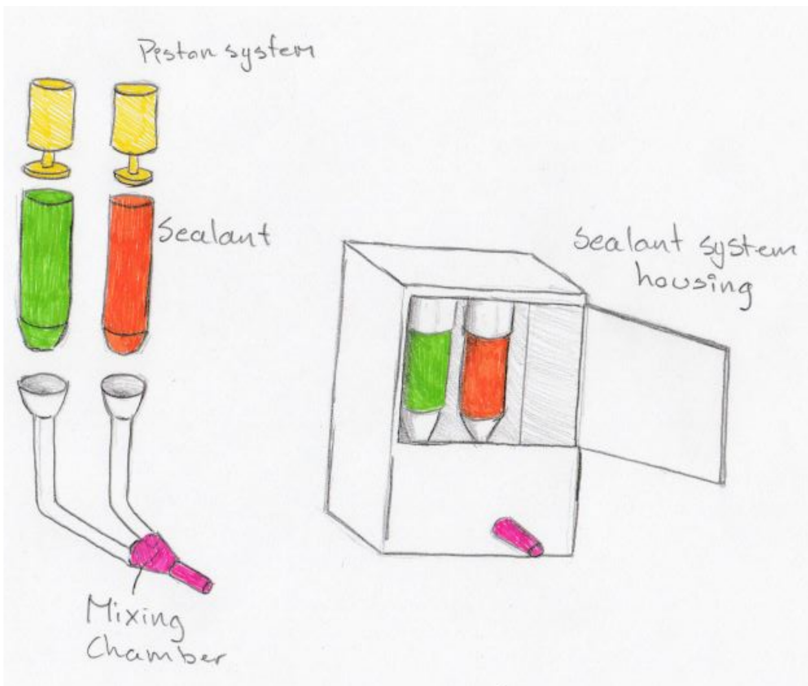


Figure 34: Internal mixing chamber concept.

9.1 Stationary tube sealant system

The sealant station is in a fixed position, either with a monotube sealant system, or an internal separate mixing system.

9.1.1 Functionality

The robot will collect a bolt and move it to the sealant station. There the gripper arm will move into position into the sealant stick, and the gripper arm tool will rotate about its axes and the sealant will be applied.

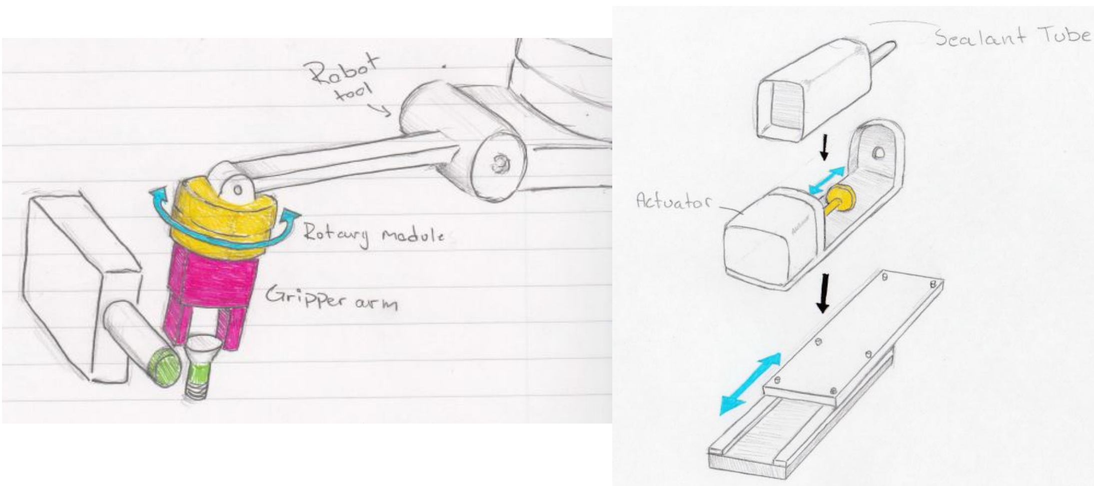


Figure 35: Stationary tube sealant system concept

The sealant station will contain an actuator system that will hold the monotube in place, while a piston will force the sealant out of the tube. The actuator system is mounted on an gliding base system, so that the tube can move in or out of the casing house to preserve the pot-life of the sealant.

9.1.2 Advantages and disadvantages

With a stationary system, access to the sealant housing can be placed outside the safety zone of the robot cell, making refilling easier and safer. It can also accommodate both separate sealant hardener system or monotube system.

Disadvantages are that the system has many mechanical moving components, and the sealant station is an advanced design.

9.2 Pick and place sealant system

A stationary mechanical retrieval system handles the bolts, while the robot is equipped with a sealant tool.

9.2.1 Functionality

Bolts arrive at the pick and place station via a conveyor system, and the bolt is picked up. The robot equips a sealant tool. The robot enters a fixed position and the pick and place units gripper rotates about its axes, and the sealant is applied to the bolt. Then the bolt is placed in a bolt seating and the robot can change to the assembly tool, and begin the assembly process. The most effective way to to this process would be to apply sealant to all the bolts of same diameter. Then the robot would change to the correct assembly tool, and install the bolts.

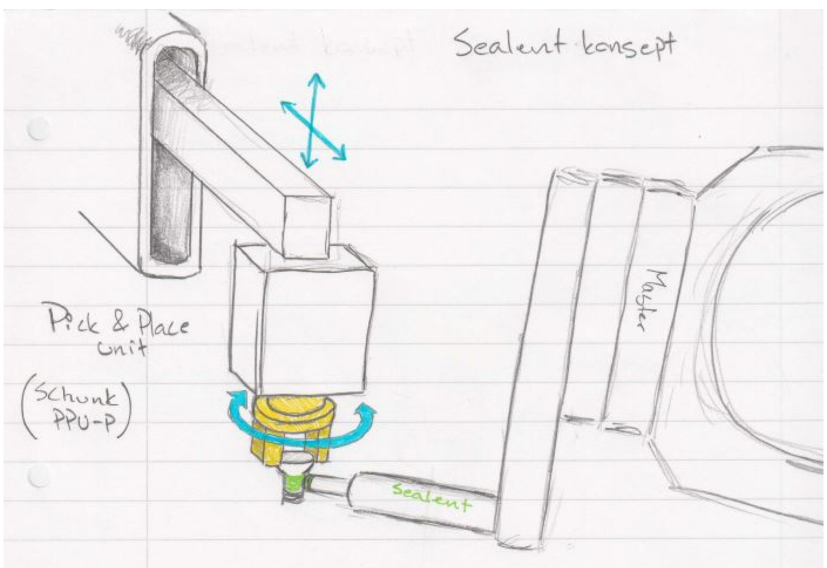


Figure 36: Pick & Place sealant system concept.

9.2.2 Advantages and disadvantages

Some advantages are that the robot is given an additional task to complete, making it more versatile. The sealant system has an uncomplicated design. And finally the Pick and Place unit is off the shelf technology.

The disadvantage with this concept is that it will prolong the overall assembly time, as the robot has to change tools more often.

9.3 Solo pick and place sealant system

The sealant system is fully independent of the robot. A pick and place system handles the application of the sealant.

9.3.1 Functionality

Pick and Place system (yellow color) retrieves the bolt, and places it in front of the sealant station (green color). The gripper arm on the Pick and Place system rotates, and the sealant is applied to the bolt. The bolt is then placed on a conveyor belt where the robot can retrieve the bolts.

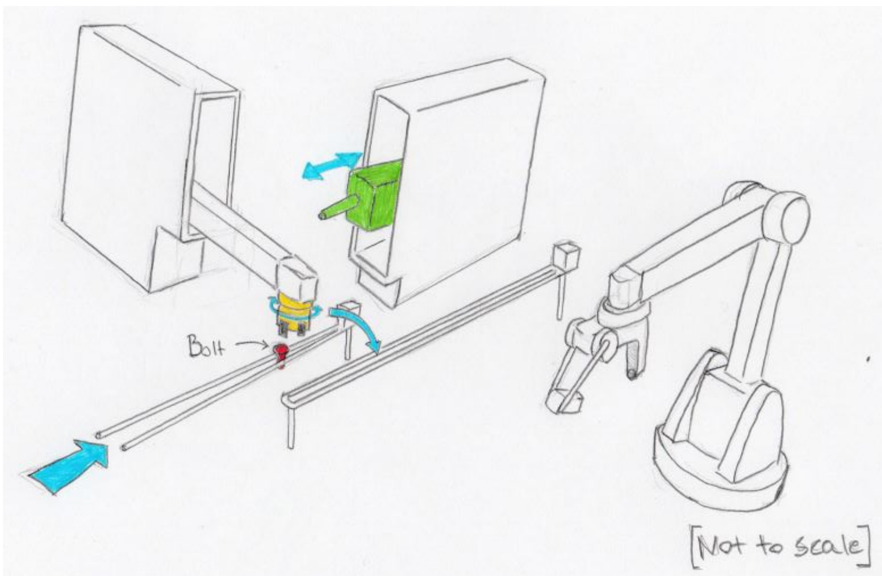


Figure 37: Solo Pick and Place sealant system concept.

9.3.2 Advantages and disadvantages

In this concept, the sealant system is fully independent of the robot. This means the sealant system can apply sealant continuously while the robot is in assembly mode. There is also no need for extra end effector for the robot.

The disadvantage with this concept is that a more complicated conveyor belt system needs to be designed.

9.4 Promoter down & up concept

The down & up concept involves a stationary system to apply the promoter to the bolts.

9.4.1 Functionality

The operator opens the dispenser lid, places the bolts inside the container, and closes the lid. Then the piston system lowers the bolts into the promoter. It then rises and the bolts are set to dry for 30 minutes. The tray is then tilted so that the bolts roll down the conveyor belt to its next destination.

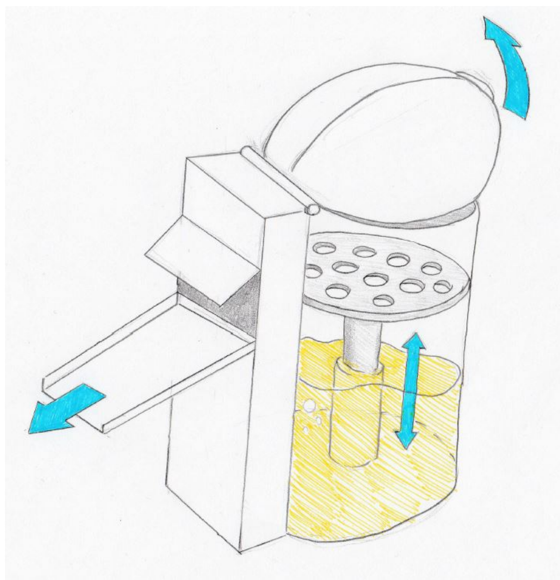


Figure 38: Promoter down & up application system concept.

9.4.2 Advantages and disadvantages

The advantage with this concept is that the closed container system prevents hazardous gases to leak out into the workstation.

Some disadvantages might be that any contamination that gets into the promoter during application, will stay there until the promoter is changed. Also, when changing and cleaning the promoter, the system could clog up if not properly cleaned.

9.5 Promoter spray`n go concept

The spray`n go concept features a spray booth chamber to apply the promoter to the bolts.

9.5.1 Functionality

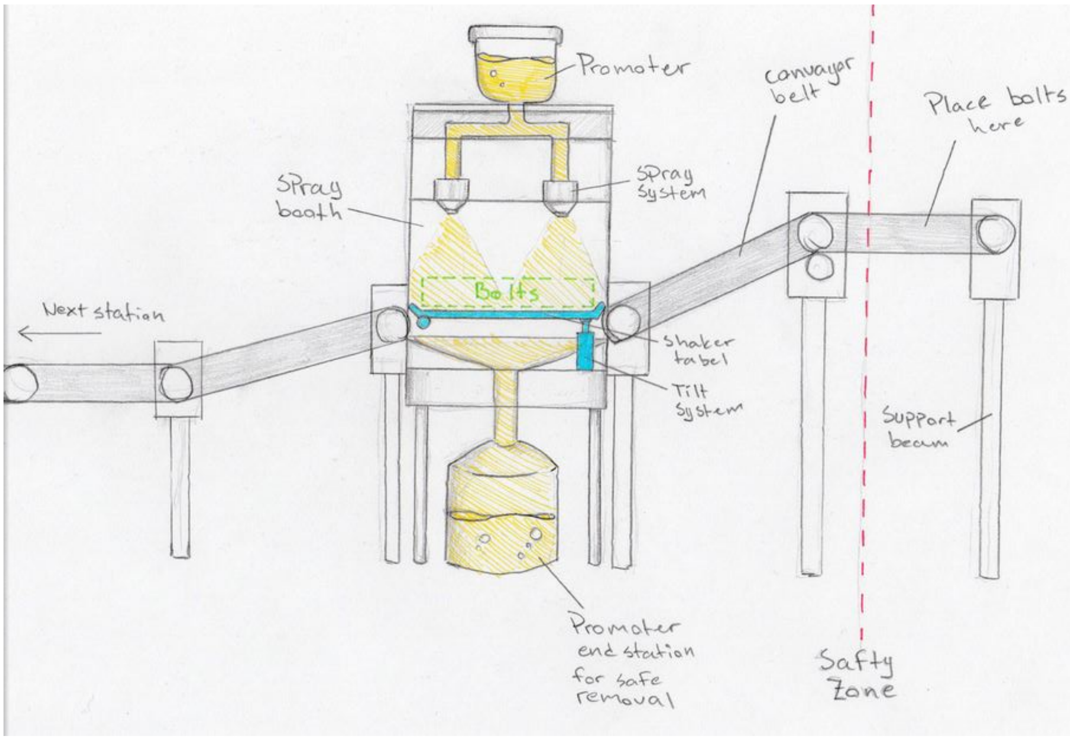


Figure 39: Spray booth concept.

The bolts are placed onto a perforated conveyor belt, and arrive at the spray booth. The spray booth has a shaker table to ensure that the promoter is applied properly. The promoter is applied to the bolts using paint guns, which can control the amount of promoter that is used. The shaker table tilts and the bolt roll onto the conveyor belt and continues to its next station.

To clean the system paint thinner could be used. The spray booth runs one cycle and flushes out the system.

9.5.2 Advantages and disadvantages

By using a spray booth, the amount of promoter applied can be controlled, which will reduce unnecessary usage. The use of a chamber also reduces the user's exposure of harmful gases, and it is easy to clean and maintain. The refilling station could be placed outside the robot zone for safe refilling, without having to shut the robot down.

The disadvantage with this concept is that it is quite a complicated design, that also takes up a lot of space.

9.6 The promoter tumbler

A rotating chamber with integrated promoter spray system

9.6.1 Functionality

The bolts arrive from the sorting system and enter the tumbler. The container is properly sealed from outside sources of debris and foreign materials. The tumbler starts to rotate and the promoter is sprayed into the chamber. The tumbler will take one batch of bolts at a time, so that the different sets of diameters and grip length will not be mixed. The tumbler will have a gate system which will also function as an off ramp for offloading the bolts.

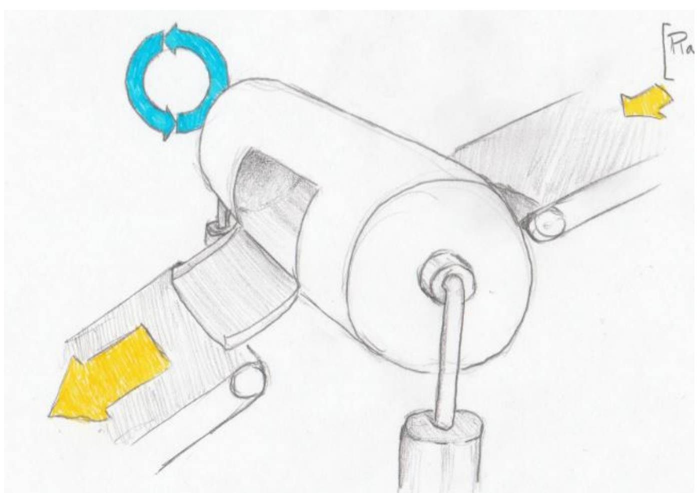


Figure 40: The promoter tumbler concept.

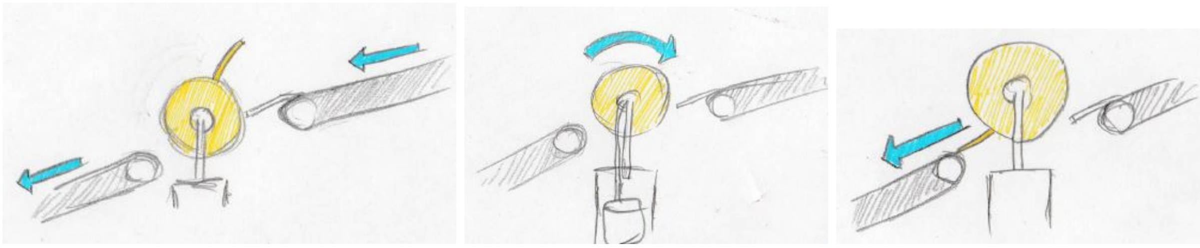


Figure 41: The tumbler process. 1: Bolt entry. 2: Rotates to apply promoter. 3: Process complete, bolt exit the tumbler.

9.6.2 Advantages and disadvantages

As the system rotates, the amount of promoter needed will be reduced, ensuring that the bolts are properly coated.

Disadvantage of this concept will be guaranteeing that the tumbler gate has the right alignment to the conveyor belt. Complications may arise when cleaning and maintaining the system, and during offloading of the bolts.

9.7 Manual application of promoter

One of the solutions we have considered for the application of promoter, is to keep the process manual, as it is done today. The argument for this is that automating the process does not save any time, since the promoter has to dry for 30 minutes no matter what. It also does not save personnel, as a person has to enter the process anyways to deliver the bolts to the system. Having this person apply the promoter at the same time, is a simple and effective way to complete this process.

10.0 Discussion & Conclusion

In this chapter we will discuss the different concepts we have described in this document, and end up with the concept that we believe will suit our project the best.

To make this selection, we have decided to use the decision matrix method, also known as the Pugh method. The decision matrix method is frequently used in engineering for making design decisions. In the matrix, we list the different criterias that needs to be fulfilled by the alternatives we have. We then grade the alternatives based on how well it fulfills that criteria:

- "+" indicates that the alternative fulfills the criteria to a great extent.
- "0" indicates that the alternative fulfills the criteria to some extent.
- "-" indicates that the alternative fulfills the criteria to a slight extent.

Each criteria is also weighted based on how important it is, either for the project group or the stakeholders. The weight is given from 1 to 5, and is then multiplied by the score for that criteria. Finally, the sum of the score will tell us which of the alternatives is the best solution for us.

The decision matrix is a simple but effective tool to use when deciding between several alternatives. It helps us to quantify the different variables we have to take into consideration. Since many often have a preconceived favourite when making these decisions, it also helps us to objectify our choice.

10.1 Complete solution selection

Criteria explanation:

- **Price:** Total cost of the complete cell. Lower price scores higher.
- **Production time:** Time used to complete the bolting process. Lower time scores higher.
- **Low complexity:** The complexity of a cell, where lower complexity is prefered because of service and general maintenance.
- **Robot cell size:** Required space in the factory for the robot cell. Less required space scores higher.
- **Tool complexity:** How complex the design of the tool has to be, to complete the bolt installation process. Lower complexity score higher

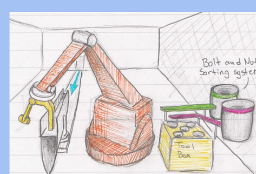
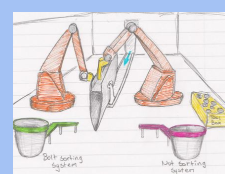
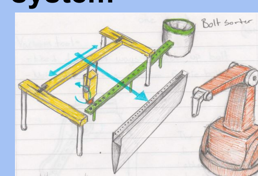
Criteria	**Weight**	**1: One robot** 	**2: Two robots** 	**3: One robot, mechanical system** 
Price	5	+	-	-
Production time	3	-	+	0
Low complexity	4	+	0	-
Robot cell size	2	+	-	-
Tool complexity	2	-	+	+
Weighted sum of "+"		11	5	2
Weighted sum of "-"		5	7	11
Highest score wins		6	-2	-9

Table 2: Decision matrix for complete solution.

The group discussion is based around the criterias in our decision matrix. We have three concepts for the robot cell system, here we look at the entire system.

The one robot cell system gains the highest score when it comes to price, because this system will only contain one robot. From information gained from Tronrud Engineering, we learned that a mechanical system rather than a complete robot system would be much more expensive. This system also demands less space for the cell.

The complexity for the single robot cell is low, meaning the downtime for the system will be lower than the other systems. A more complex system has a higher failure rate.

Only major setback for a one robot cell system is the production time of the aerospace part. The production time criteria has a weight of 3, because the production of the aerospace part is not a high volume production. We have concluded that automation will none the less provide a more stable and continuous production rate and thus be more efficient than a manual process.

The tool complexity is based on how complex the design of the tool has to be. A more complex design means longer development time, more parts that can go wrong, and higher cost. We have given this a low weight as we believe these disadvantages are not as vital when compared to our other criteria.

As we can see from the decision matrix, the selection process has eventually landed us on the single robot system. This is the system we will be using for our project.

10.2 End effector selection

Criteria explanation:

- **Design complexity:** This criteria will be weighted high for low complexity of design, and that the tool will be more compatible with the other systems of the robot cell.
- **Flexibility:** All over more capability to perform all the tasks needed, as there are five different bolt and nut sizes, the more the one tool can handle, the higher the score.
- **Durability:** The tool will have a long estimated life expectancy, the longer expectancy the higher the score.
- **Off-shelf parts:** The more parts that can be ordered from external suppliers, the higher the score, as this will mean easier to change parts and service for the tool.
- **Price:** The lower estimated end price of the tool, gives a higher score.
- **All-electric system:** We have a requirement that the driving force of the tool shall be electrical, so an all electric tool will score higher.

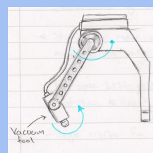
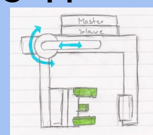
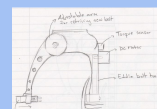
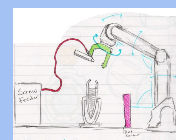
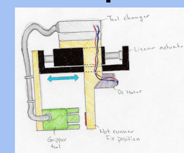
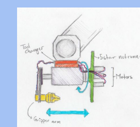
Criteria	Weight	1: One tool vacuum bolt gripper 	2: One tool 3-Finger gripper 	3: Actuator gripper arm 	4: One tool bolt gun concept 	5: Horizontal slider concept 	6: One tool STAR 
Design complexity	5	0	0	-	-	+	-
Flexibility	3	0	0	0	-	0	+
Durability	4	0	+	+	-	+	-
Price	2	+	+	+	-	+	-
All-electric system	3	-	+	+	-	+	+
Weighted sum of "+"		2	9	9	0	14	6
Weighted sum of "-"		3	0	5	17	0	11
Highest score wins		-1	9	4	-17	14	-5

Table 3: Decision matrix for end effector.

For design complexity, tools with more moving parts and overall more complex design scored low. For example in concept 6, the five star tool must have a rotating system to select the correct nutrunner, and each nutrunner needs its own motor, thus a more complex system.

As for flexibility, the only concept that handles all the nut sizes is concept 6. Concept 4 is the only concept that gets a negative score, as it is the least flexible tool. The concept will not be compatible with the sealant system, as the sealant must be applied before assembly, the sealant would clutter the feeding tube.

For durability, two concepts score negative. Concept 6 due to complexity of design and that it would have a high risk of error. Concept 1 scores negative for the vacuum tool, as it is a pneumatic system.

The price of the tool will of course be lower with lower complexity. The bolt gun concept will be more expensive as it needs its own feeding system, and the five star tool with its complex design.

The all electric system criteria rules out the system that is pneumatic.

After this selection process we can see that we have ended up on concept 5; the horizontal slider. This is the concept that will be the basis for our end design.

10.3 Verification systems selection

As we have seen from our concepts, the measurement of grip length and nut profile only has one viable solution. To measure the grip length we will use a mechanical thickness gauge, that measures the thickness of the aerospace part before installation. For the nut profile verification, we use the standard inspection instrument from Alcoa, and adapt it to fit our robot.

For the bolt head seating inspection, we have two concepts that are viable solutions. We will run them through a decision matrix to find the best one suited for our project.

Criteria explanation:

- **Price:** The cost of the system, including development and implementation. Lower price score higher
- **Continuous measurement:** The ability of the system to measure countersinks as they are being drilled.
- **Flexibility:** The ability of the system to adapt to different countersink diameters.

Criteria	Weight	1: Laser profilometer	2: Countersink gauge
Price	4	-	+
Continuous measurement	4	+	-
Flexibility	3	+	-
Weighted sum of “+”		7	4
Weighted sum of “-”		4	7
Highest score wins		3	-3

Table 4: Decision matrix for verification of head seating.

The price of the system is based on how much the components will cost, and development and implementation to fit it to a robot. The countersink gauge is already existing technology, that one can easily get a hold of. The laser profilometer is still new technology, and includes more expensive parts. This is why the gauge is rated higher in this section.

The laser profilometry scores high when it comes to continuous measurement and flexibility. Unlike the countersink gauge, the profilometer can compensate for any debris in the countersink, meaning the countersink does not need to be cleaned before measuring. The profilometer is also able to measure every diameter needed, while the gauge needs different sizes for different diameters.

All of these things considered, we end up with the laser profilometer as our best choice. It gives us a faster, continuous and more accurate reading of the countersink diameter than the gauge.

10.4 Promoter and sealant system selection

10.4.1 Sealant system selection

Criteria explanation:

- **Price:** The cost of implementing the concept into our system. Low price scores higher
- **Application time:** The time it takes for the bolts to be applied the sealant.
- **Complexity:** How complex the system is. Lower complexity scores higher.
- **Size:** How large area the concept will occupy. Smaller area scores higher.
- **Compatibility:** How well the concept integrates into the entire system, better integration scores higher.

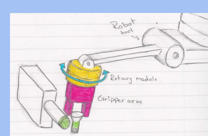
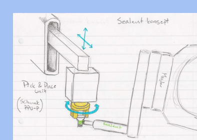
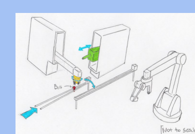
Criteria	Weight	1: Stationary tube sealant system 	2: Pick & Place sealant system 	3: Solo Pick & Place sealant system 
Price	3	0	0	-
Application time	3	-	-	+
Complexity	4	-	-	0
Size	4	+	+	-
Compatibility	5	0	0	+
Weighted sum of “+”		4	4	8
Weighted sum of “-”		7	7	7
Highest score wins		-3	-3	1

Table 5: Decision matrix for sealant system.

Concept 1 and 2 will require separate robot tool, this will make the system more complex. Longer cycle time and not as compatible with various robot cell concepts.

Concept 3 is an independent system, this concept will work well with the sorting concept, and the overall robot cell system. A complete pick and place system will be more expensive, but this will not be a determining factor for the end price of the complete system.

For this concept there will be a need for a specialized conveyor belt, the system has to be able to detect the proper bolt with the correct diameter and grip length. After the sealant is applied, the system will place the bolts on a pallet with a unique id. The system logs the time of application. This is needed due to the short pot life of the sealant. The system should be programmed to apply sealant to the right amount of bolts per cycle, so that the pot life requirement is maintained.

10.4.2 Promoter system selection

Criteria explanation:

- **Price:** The cost to implement the concept into our system. Low price scores higher
- **Application time:** The time it takes for the bolts to be applied the promoter, not including the 30 minutes of drying time. Shorter time scores higher
- **Complexity:** How complex the system is. Lower complexity scores higher.
- **Size:** How large area the concept will occupy. Smaller area scores higher.

Criteria	Weight	1: Down & Up	2: Spray ‘n go	3: Tumbler	4: Manual
Price	4	0	-	0	+
Application time	1	+	+	0	0
Complexity	3	0	-	0	+
Size	3	0	-	-	0
Weighted sum of “+”		1	1	0	7
Weighted sum of “-”		0	10	3	0
Highest score wins		1	-9	-3	7

Table 6: Decision matrix for promoter system.

Concept 2 is the most complex system and therefore also the most expensive. The cheapest option is of course to leave the application manual as it is today. This is also the least complex concept as it does not include any automation.

Concept 1 and 2 have a more targeted application format and will therefore use less time than the other two concepts. This criteria is weighted low since the application time is very short to begin with, and the most time consuming part of the process is the drying time.

As for the size, concept 2 and 3 will take up more space, as they have to be integrated into the bolt delivery system.

In the end we find that leaving the promoter application manual as it is done today is the best solution. This makes sense since the savings on automating this process is very small. The bolts has to dry for 30 minutes no matter what, and personnel has to enter the process to deliver the bolts anyways. Applying the promoter to the bolts as they are delivered by personnel is therefore the best solution to this part of the system.

10.5 Bolt and nut sorting system selection

Criteria explanation:

- **Price:** The cost to implement the concept into our system. Low price scores higher
- **Compatibility:** How well the given concept work in collaboration with the other systems.
- **Independency:** Higher grade is given for the system of higher independency, meaning that the system is not highly dependent on the presence of an operator.
- **Complexity:** How complex the system is. Lower complexity scores higher.

Criteria	Weight	1: Nut-sorter	2: Pallet system	3: Magazines
Price	4	0	0	-
Compatibility	5	0	+	-
Independency	4	+	0	-
Complexity	3	+	+	-
Weighted sum of “+”		7	8	0
Weighted sum of “-”		0	0	16
Highest score wins		7	8	-16

Table 7: Decision matrix for bolt and nut sorting system.

Concept 1 is the only concept for the nuts, this is straightforward conveyor belt system. It will be compatible with most system, no major problems for the robot to retrieve the nuts. The operator will only need to insert the nuts onto the platform. Very low complexity.

Concept 2: This system will work well with the sealant station, the pallet glides along a conveyor belt system. As the promoter is manually applied, either the robot or the operator could place the bolts onto the pallet, giving the system a 0 for independency. The system has a very low complexity.

Concept 3: This system will not work well with the sealant system, as is will be cluttered due to the sealant. The operator will have to manually install the bolts into the magazines. The pallet and magazines system are only designed for the bolt system, therefore the selection for the nut system was added to this selection process, as it is the only concept generated.

11.0 Sources

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[4] Schunk, *Gripper tools*, cited 05.03.2015, available from: http://www.schunk.com/index_select_your_country2.html?r=1

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Technology Document:
Design Document

Version	Date	Reviewed by	Approved by	Satus
1.0	15.05.2015	Kristoffer Lund	Tor Sigurd Breivik	Released

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1.0 Abstract

This document details the process in which we conducted our final design for the assembly tool. Here we go from concept to end design, describing components and their functions that were selected from second hand suppliers and also components that we custom designed.

2.0 Revision History

Version	Date	Changes	Author
0.1	16.04.2015	• First version of the document	Elvar Aspelund
1.0	15.05.2015	• Final release of the document	Elvar Aspelund Kristoffer Lund Stian Hovde Katrine Kallevik

Table 1: Revision table.

3.0 The concept

The end effector will be based on the horizontal slider concept. Here we will look for components from other suppliers, since we want to minimize the number of parts that need to be custom designed. Basically, we have shortened the list of components that we will design down to the gripper plate, nutrunner and the interface plate for the tool changer. The nutrunner design will be based on Alcoa bolt tool design.

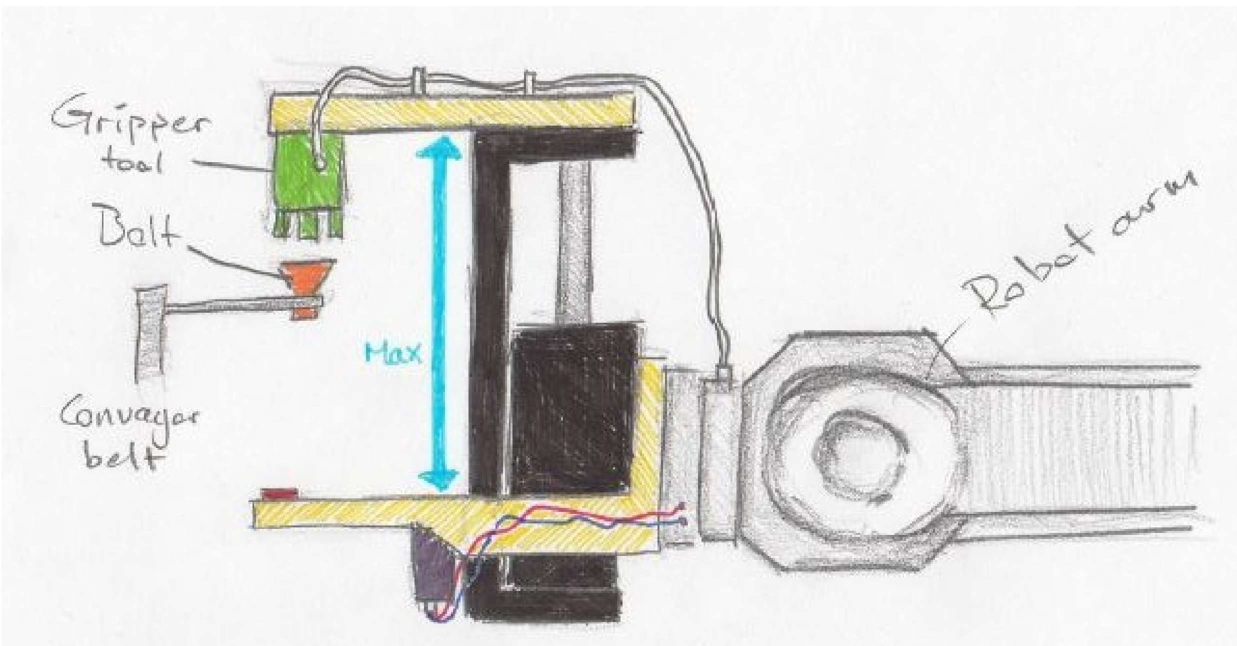

Figure 1: Bolt tool concept drawing.

4.0 Components

We have chosen to use components from Schunk in our design. This is because their components were recommended by Tronrud Engineering because of their quality and reliability. A quick look at the Schunk web pages also showed that they had all the components we needed. Having all the components from the same producer is an advantage when it comes to supply and support.

4.1 Gripper

The ENZ gripper from Schunk is a servo-electric 3-finger centric gripper with large gripping force and high moment capabilities thanks to multiple-tooth guide. It is a ideal standard solution for numerous fields of application, and is highly versatile thanks to controlled gripping force, position and speed. The gripper will be used to collect and position the bolt for installation.

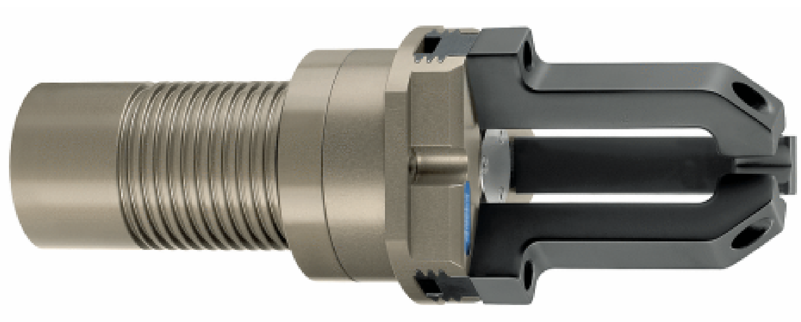

Figure 2: ENZ Electrical 3-Finger gripper.

Description	ENZ Electrical 3-Finger gripper
Stroke per finger	6 mm
Weight	0.98 kg
Recommended workpiece weight	2.5 kg
Max finger length	80 mm
Max finger weight	0.35 kg
Repeatability	0.01 mm
Nominal current	2 A

Operating voltage	24 V
Ambient temperature	+5°C to +55°C

Table 2: ENZ gripper technical specifications.

A servo controller is required to operate the gripper. Schunk recommends their MCS-12 controller. The gripper also has an integrated resolver that measures the position of the gripper fingers.

Designation	Description	Colour[1]
U	Motor Phases	Black
V		Red
W		White
SHD	Shielding	-
OSZ+	+Reference	White/red
COS+	+Cos	Black
COS-	-Cos	Red
SIN+	+Sin	Yellow
SIN-	-Sin	Blue
GND	-Reference (Ground)	White/yellow

Table 3: ENZ gripper connection table.

4.1.1 Gripper controller

The controller for the gripper is the MCS-12. The MCS controller is an electronic device that is used to actuate/control mechatronic modules. To save money and weight, the controller will not be placed on the end effector itself. The cables from the gripper to the controller will be routed through the tool changer system. This way we only need one controller for all our end effectors.

[1] Using the standard Schunk connection cable

Figure 3: MCS-12 controller.

Integration of the control electronics into the higher-ranking control plan can be implemented via the communication interfaces Profibus, CAN-bus, or conventional digital inputs/ outputs.

4.1.2 Force measuring jaw

Force measuring jaws can be installed to this gripper. They are able to measure the force applied to the workpiece and is therefore also able to detect if there is a bolt picked up. This can be used as a security to control that the gripper has the bolt and that it is not dropped.

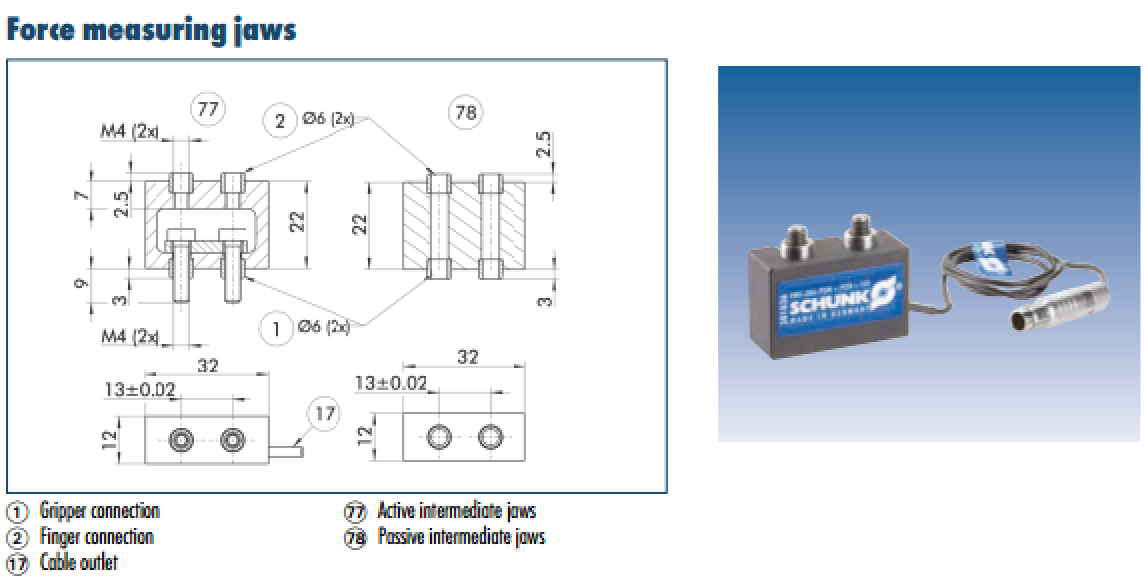

Figure 4: Force measuring jaws.

The jaws are screwed on between the gripper base jaw, and the gripper fingers, which comes in contact with the workpiece. Gripping forces on the top jaw result in a flow of force through intermediate jaw. Strain gauges inside the intermediate jaw react to the resulting deformation.

There are active and passive intermediate jaws. At least one active force measuring jaw is required per gripper, the rest can be passive. Each active intermediate jaw requires an electronic processor. The electronic processor is used to prepare, display and forward the measurement results. It is equipped with a housing connector and socket for connecting the force measuring jaw and the connection cable.

Aderfarbe im Kabel Colour of cable core	Pin im Stecker am FMS-A1 Pin in FMS-A1 connector	Bedeutung des Signals Significance of signal
gelb / yellow	5	+ 24 V DC
grau / grey	6	GND
grün / green	4	Reset (Nullabgleich des Ausgangssignals) 24 Volt für 100ms Reset (zero adjustment of output signal) 24 Volt for 100ms
braun / braun	1	+ UA (geschirmt) (– 5 bis + 5 V DC) + UA (protected) (– 5 to + 5 V DC)
weiß / white	2	– UA (geschirmt / protected)
Schirm / Protection	3	Schirm / Protection

Bei der Gerätebuchse handelt es sich
um den Typ ODU-Mini-Snap
Baugröße 0, 6-polig
The machine socket is type
ODU-Mini-Snap
Size 0, 6-pin

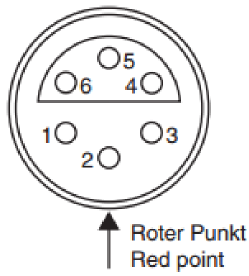

Figure 5: Connection cable for the force measuring jaw.

4.1.3 Fingers

The fingers of the gripper are mounted after the force measurement jaw, and is used to pick up the bolt itself. They need to be designed so they can easily get a good grip around the bolt, and not risk dropping it before it’s installed.

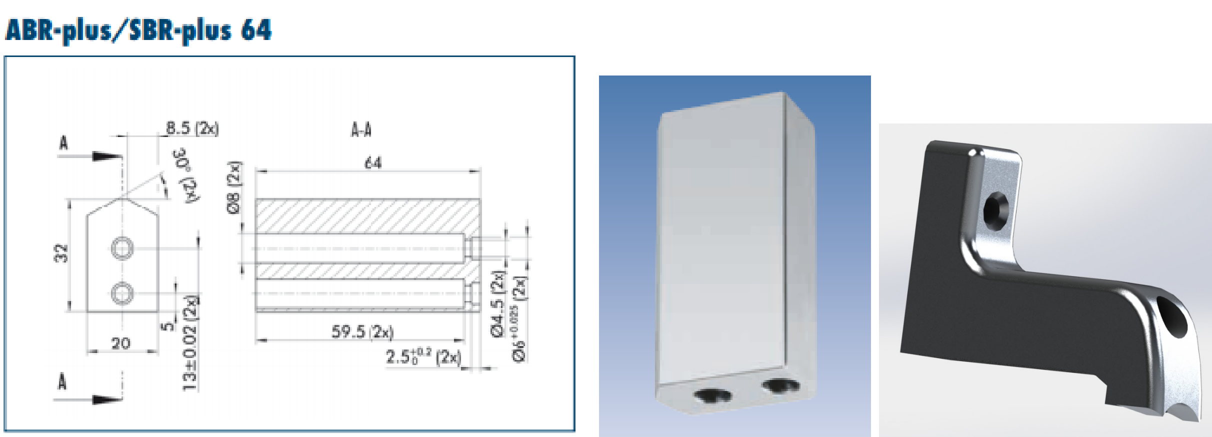

Figure 6: Finger blanks for the ENZ gripper.

The fingers available for our gripper are blanks that can be machined out to fit our needs. It is available in two different materials. The material of the ARB is aluminium, while the SRB is a steel alloy[2]. Alternatively if any other materials are preferred, one can design the entire finger from scratch. 3D printed parts in plastic would be an economical alternative.

4.1.4 Gripper plate

The gripper plate connects the gripper arm to the linear actuator. Material tested is AISI 1020 Carbon steel and 2024 Aluminium alloy. See attachment 1 for 2D drawing.

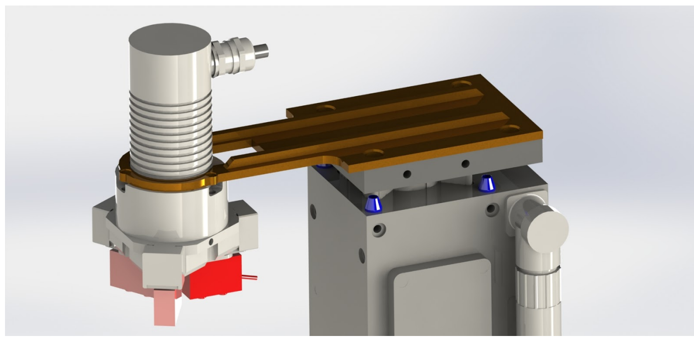

Figure 7: Gripper plate.

Weight of the gripper plate:

- AISI 1020 Carbon steel: 619.68 grams.
- 2024 Aluminium alloy: 219.63 grams.

After consulting with Tronrud Engineering we have decided to use 2024 Aluminium alloy for the gripper plate. Recommended surface treatment for the aluminium is anodization. Anodizing the aluminium plate will increase the natural oxide layer on the surface of the metal, through an electrolytic passivation process. Other materials that also could be suited for the task is carbon fiber or high strength polymer.

The gripper plate has to be designed so that the gripper arm is positioned perpendicular to the nutrunner. The center point for the gripper fingers in closed position has to be on point with the nutrunners center point. This is to ensure proper alignment of the bolt and nut during installation.

4.2 Linear module

The linear motor drive type LDN is a directly driven drive module for linear movements. The driving force is transmitted directly to the slide without any mechanical transmission elements. The overall concept of the linear motor drive is characterized by its extremely compact design.

[2] 16 MnCr 5

Thanks to the good guidance of the slide and the light-weight design of the axis, the drive reaches very high speeds, accelerations and repeat accuracies.

In our design the profile will be static and connected directly to the tool interface plate. The slide will be moving and has the gripper connected to it. The nutrunner will be fastened to the bottom of the LDN.

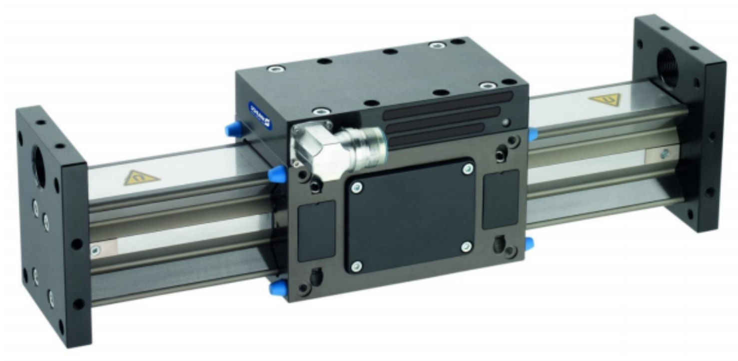

Figure 8: LDN universal linear module.

Description	**LDN**
Useful stroke	100-2700 mm (100 mm increments)
Repeatability	0.01 mm
Maximum speed	4 m/s
Maximum acceleration	40 m/s²
Maximum payload	15 kg
Housing weight	3 kg
End plate weight	0.75 kg
Maximum current	2.1 A
Operating voltage	7-12 V
Ambient temperature	+10°C to +40°C

Table 4: LDN universal linear module technical specifications.

The driving force, acceleration and speed of the slide is manipulated by regulating the phase and the amplitude of the electrical current applied at the primary part. As standard a magnetic measuring system integrated in the axis is used to determine the current position of the drive. Optical or absolute stroke measuring systems are available as options.

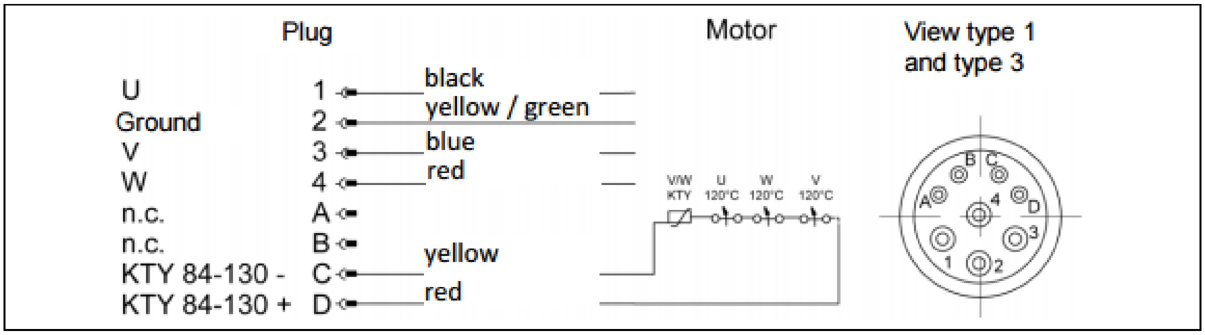

Figure 9: LDN motor connection.

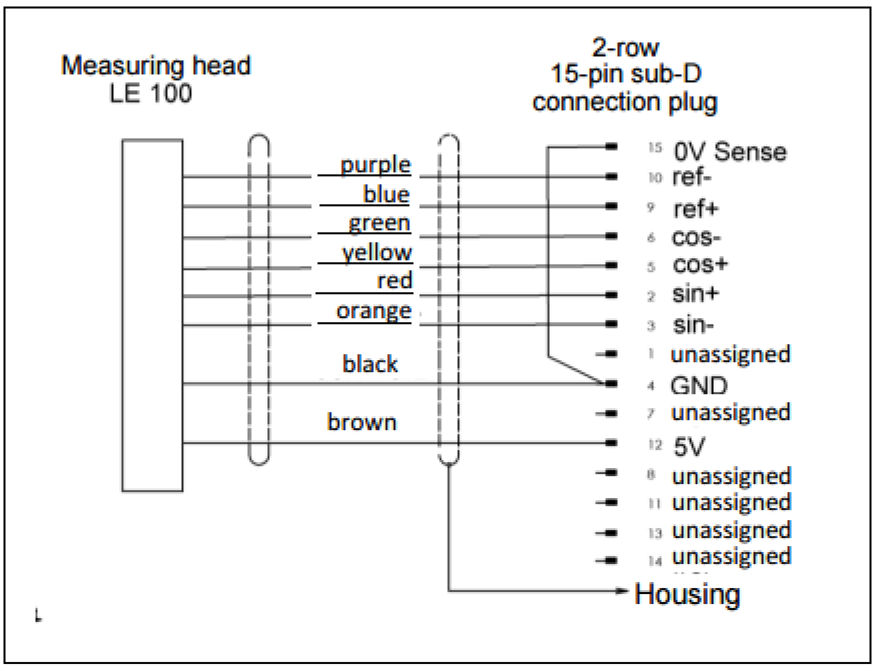

Figure 10: LDN measuring system connection.

4.3 Nutrunner

The design of the nutrunner is a modification of the original tool from Alcoa. It is designed to fit the shortest and the narrowest areas in the panel.

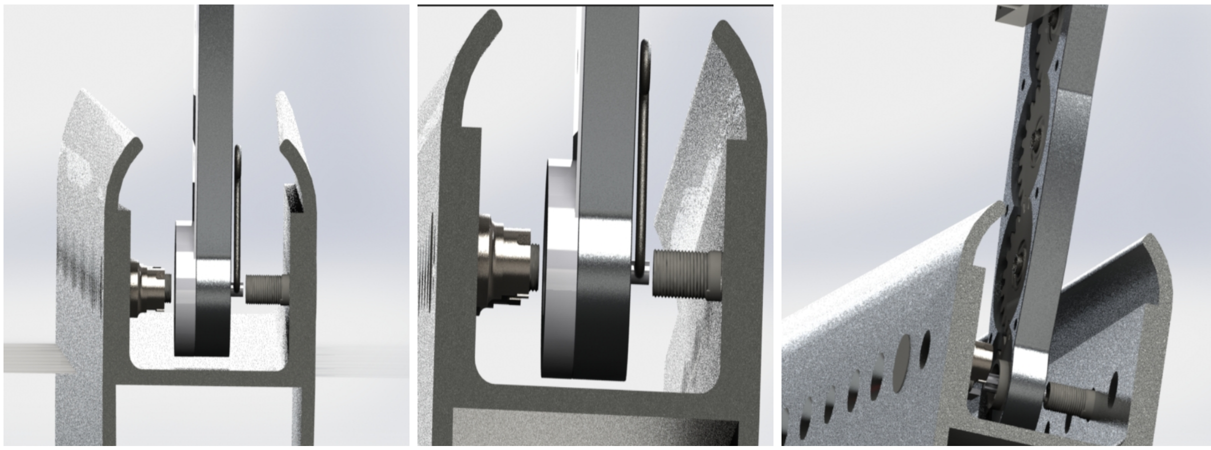

Figure 11: Nutrunner in aerospace part with bolts.

The nutrunner consists of a housing, gears, bearings, axial bearings, hex key, and shafts. For the nut to enter the bolt properly, we have designed the top of the nutrunner to pick up the nut. A hex key installed in the middle of the gear and a formed center in the gear will help to keep the bolt in the right position. A ball lock system will keep the nut in place until the bolt is installed.

The hex key is designed to be able to handle a bit of movement which is vital to the installation of the nut. If the hex key is too stiff, the components may harm the panel. We therefore designed a spring to make it movable. This spring is also something the original tool from alcoa have.

The housing of the nutrunner is minimized to enter the most narrow areas of the panel. For this to happen, all of the components are carefully calculated so that the space inside the nutrunner is optimalized.

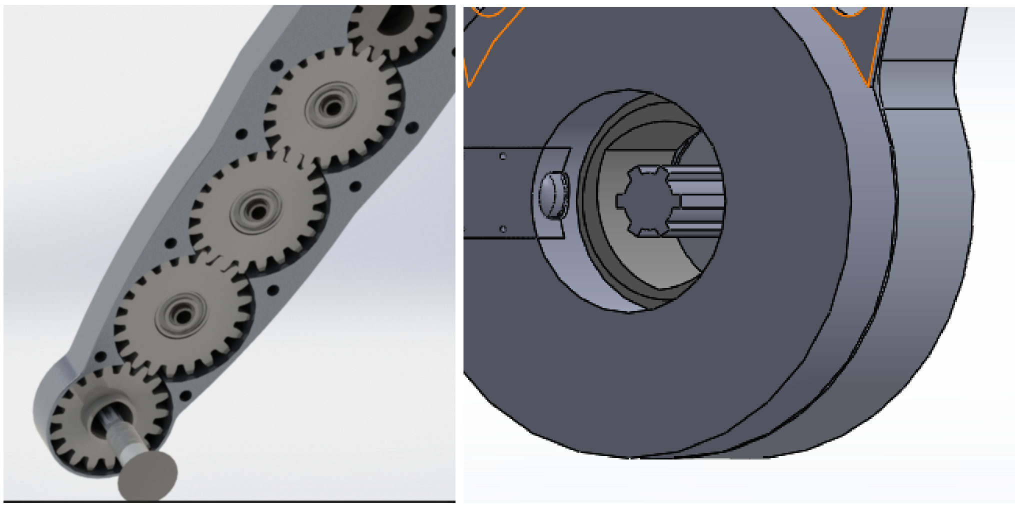

Figure 12: Nutrunner with gears and hex-key.

The gears are carefully chosen after calculation and selection. It has been performed a FEM analysis on the gears to make sure that they can handle the stress. The bearings is of the type needle. They are really small, but they will not be exposed for too much stress.

4.3.1 Ball lock

A vital part of this nutrunner is a system that keeps the nut from falling out while the robot moves around. To accomplish this, we will use a ball-lock system. The ball lock system puts a force on the nut when it is inserted and keeps it in place until it is installed.

The ball will have an oval shape with the ends pointing in and outwards of the nutrunner. This is to allow the ball to rotate as the nut is fastened, but not let the ball rotate in the in and out directions, as this would let the nut fall out easily.

The ball will be connected to a spring, that allows the ball to give way when a nut is entered. The other end of the spring will have a force pressure sensor. This can detect when a nut has entered, and if it falls out before installation. We will use a force sensing resistor for this job, as the area it has to cover is very small.

Figure 13: Small force sensing resistor.

We have chosen to use the FSR 400 from interlink electronics. This is a very small sensor, that can be cut to fit our tool. The force sensitivity range is 0.1 to 10 newtons. Force sensing resistors are not very accurate, but this is not a major concern for us since we only have to measure two states; if the bolt is present or not. As increased force is applied to the surface of the sensor, the resistance decreases.

To calculate the force needed on the nut to keep it from falling out, we first measure the weight of the nut to be 1.3 grams. The largest force pulling the nut out is the gravity:

$$G = 1.3 \times 10^{-3} \times 9.81 = 0.013N$$

This means that the friction force on the nut has to be larger than the gravitational force:

$$F_f > G = 0.013N$$

The coefficient of friction between titanium and steel is 0.48. The force needed from the ball lock on the nut must therefore be larger than:

$$\mu = \frac{F_f}{F_b} \Rightarrow F_b = \frac{F_f}{\mu} = \frac{0.013N}{0.48} = 0.027N$$

The next step is to find a spring that can deliver this force. We simply use hooke's law for this:

$$F = kx$$

Where F is the force, x is the distance the spring is compressed, and k is the spring coefficient. Measuring on our model for the tool we find x = 0.5 mm.

$$k = \frac{F}{x} = \frac{0.027N}{0.0005m} = 54\frac{N}{m}$$

Now we just have to find a spring with a coefficient larger than this, and that is small enough to fit our tool. We will look at the 70027S from Century Spring Corp.

Property	70027S Spring
Outer diameter	2.24 mm
Lenght	3.3 mm
Spring coefficient	876 N/m
Maximum load	1.07 N

Table 5: 70027S Spring properties.

As we can see, these properties are well within our requirements, this spring is therefore perfect for our use.

4.3.2 Gears

For the purpose of the project we have calculated the specifications for the gears, although most of Alcoa's Eddie bolt installation tools utilizes common components such as gears and bearings. We have based our nutrunner design on the Eddie bolt installation tool and therefore similar gear setup. We used rushgears.com to get custom designed gears.

The last large gear[3] will have a special design, as it needs an open center for the hex key, and the nut itself. The center of the gear will have a reuleaux triangle so that the nut material will be deformed into and across the pin flutes.

- *For the internal gears and cogs we recommend standardised parts, select proper diameter and teeth number. For our design we chose 16/12 teeth ratio.*

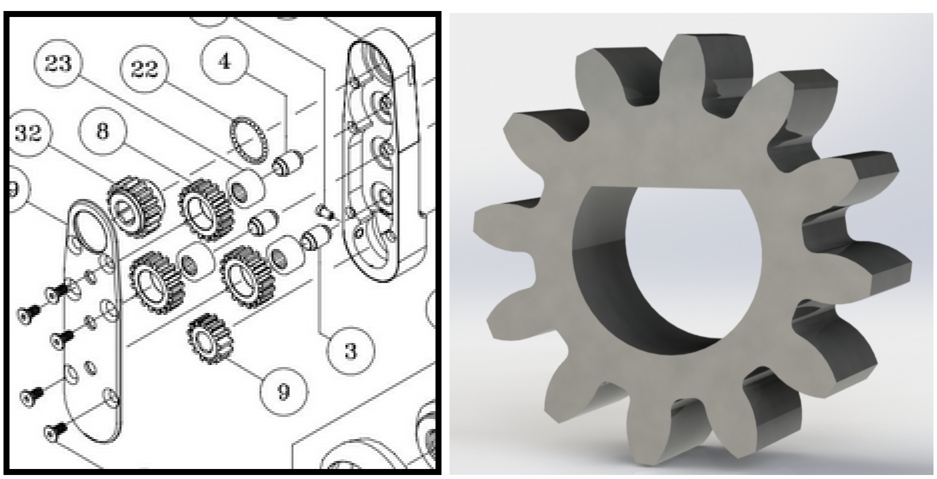

Figure 14: Small gear[4] and Eddie bolt tool design.

[3] Gear nr 32
[4] Gear nr 9

The nutrunner is powered with an electric motor. One of the requirements for the tool is that the weight cannot exceed 10 kg. To be able to have a small sized motor we use gears of different sizes to gear up the output. The necessary output torque is 13.275 Nm (with efficiency loss due to gear friction), the motor delivers an input torque of 12.32 Nm.

We have used construction methods to give a calculated example for the proper size of the gears and cogs for the nutrunner.

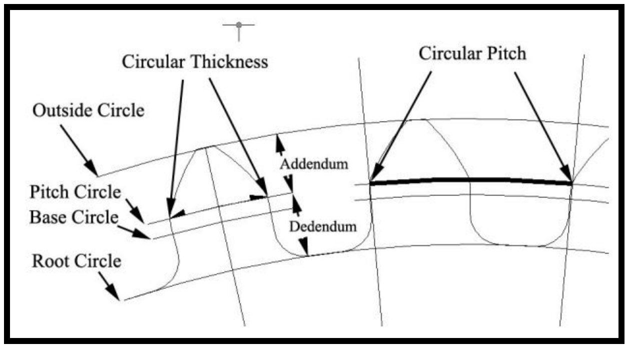

Figure 15: Cog parameters.

Metric module: To find the module, divide pitch diameter (PD) in millimeters by the number of cogs (N). Module (M) represents the amount of pitch diameter per cog.

$$M = \frac{PD}{N}$$

M=1.2mm
Z_1=12 (The number of cogs for the gear)

Both gears are created using the same data for cog width and cog spacing. s_n is the cog width and e_n is the spacing between the cogs.

$$s_n = \frac{p}{2} - 0.5 \times M$$

$$e_n = \frac{p}{2} - 0.5 \times M$$

The gears have three driven parameters:

Small gear:
Outside circle:

$$d_{a1} = d + 2 \times M = 14.4 + 2 \times 1.2 = 16.8mm$$

Pitch diameter:
$$d_1 = M \times z_1 = 1.2 \times 12 = 14.4mm$$

Root circle:
$$d_{f1} = d_1 - 2 \times 1.25 \times M = 14.4 - 2 \times 1.25 \times 1.2 = 11.4mm$$

Large gears:
Outside circle:
$$d_{a1} = d + 2 \times M = 25.2 + 2 \times 1.2 = 27.6mm$$

Pitch diameter:
$$d_1 = M \times z_2 = 1.2 \times 21 = 25.2mm$$

Root circle:
$$d_{f1} = d_1 - 2 \times 1.25 \times M = 25.2 - 2 \times 1.25 \times 1.2 = 22.2mm$$

Center spacing:
To find the center spacing. Use the sum of both gears pitch diameters and divide the sum by two. That will give a center spacing equal to a=19.8mm in this example.

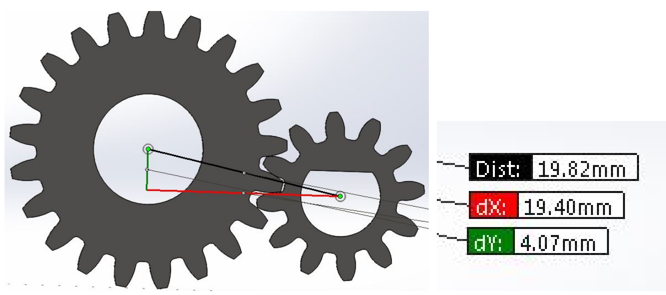

Figure 16: Gear center spacing.

Cog number for the large gear:
$$a = \frac{M \times z_1 + M \times z_2}{2}$$
$z_2 = 21$

Using the number of cogs we are able to find the gear ratio:
$$i = \frac{z_2}{z_1}$$

4.3.3 DC motor and gear system

The DC motor and gear system is responsible for applying the correct amount of torque to the Eddie nuts, so they can deform correctly for a successful installation. To be able to calculate the different variables from the DC motor parameters we have used Matlab. This gives us the ability to try out different motors without the need to purchase them.

DC motors are part of the electromechanic branch of physics, and are used to convert electric energy to rotational energy. This means that there are two equations that balances a DC motor.

Voltage equation:

$$V_a - V_{Ra} - V_{La} - V_c = 0$$

Where V_a is terminal voltage, V_{Ra} is the voltage across the inner resistance of the motor, V_{La} is the voltage in the field windings and V_c is the back-emf voltage.

Torque equation:

$$\tau_e - \tau_{\omega'} - \tau_\omega - \tau_l - \tau_f = 0$$

Where τ_e is the electromagnetic torque, $\tau_{\omega'}$ is the torque due to acceleration of rotor, τ_ω is the torque from the velocity of the rotor, τ_l is the torque from the load and τ_f is the friction constant.

These equations have i_a and ω as variables. When we solve the equations for the derivative of these we get:

Current equation:

$$\frac{d}{dt}i_a = \frac{V_a}{L_a} - \frac{i_a r_a}{L_a} - \frac{K_e \omega}{L_a}$$

Where L_a is the inductance, K_e is the voltage constant, i_a is the current, r_a is the resistance of the motor and ω is the rotational speed of the axle.

Rotational speed equation:

$$\frac{d}{dt}\omega = \frac{K_t i_a}{J} - \frac{B\omega}{J} - \frac{T_l}{J} - \frac{T_f}{J}$$

Where K_t is the torque constant and J is the total inertia of the motor and load.

In order to simulate the motor in Matlab we used the Simulink application and created a mathematical block diagram.

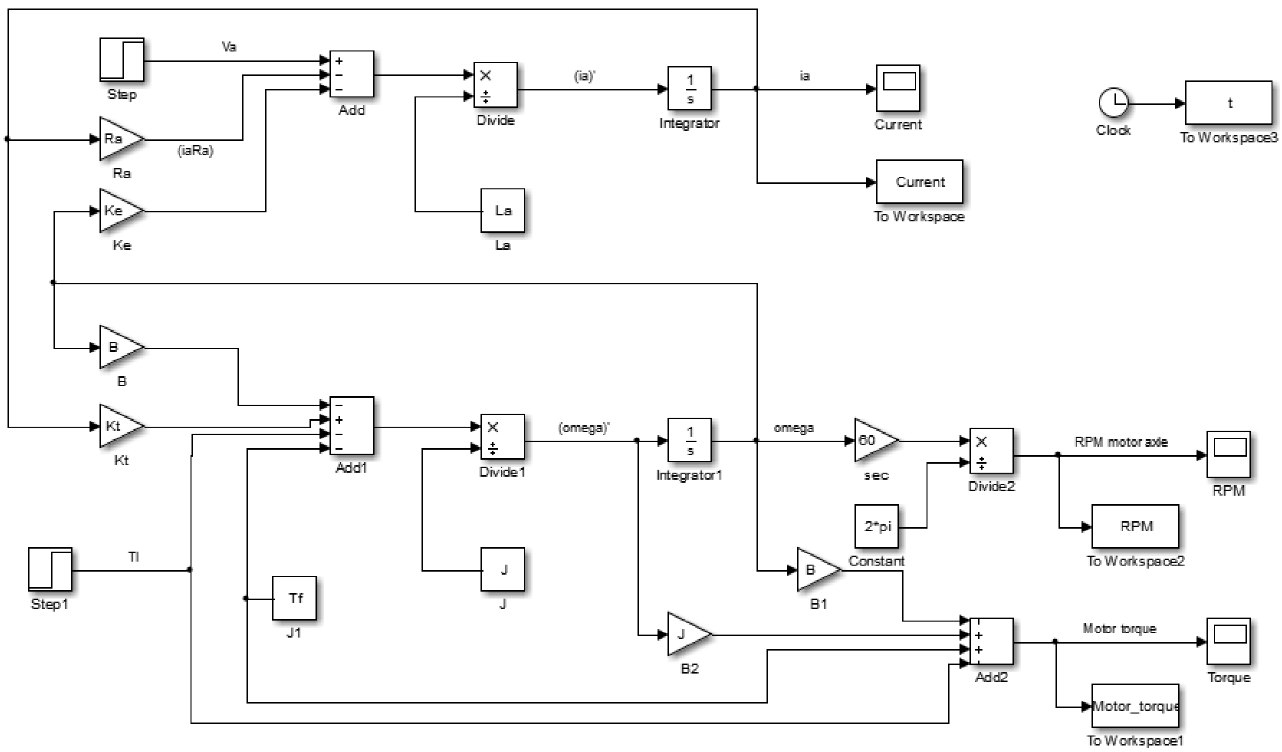

Figure 18: Simulink block diagram.

To achieve a high output torque using a motor that must be as small as possible, we opted for a small motor with a gearbox mounted to it. Pittman Motors offers a wide range of DC motors and gearboxes that are designed to be fitted together. To calculate the needed torque of the motor we have to begin with the gearbox.

Pittman Motors G40A Planetary Gearbox	
Maximum Load	14.12 Nm (2000 oz-in)
Weight (mass)	311.8g (11 oz)
Length	43.2 mm (1.700 inches)
Exact ratio	52/3 (17.3:1)
Efficiency	0.81
Shaft Rotation	Bi-directional

Table 6: Datasheet values of Pittman Motors Gearbox.

The needed torque at gearbox axle:

Torque needed because of cogs efficiency:

$$\frac{12Nm}{(0.98)^5} = 13.275Nm$$

Cog ratio:

$$N = \frac{z_1}{z_2} = \frac{12}{16}$$

Torque needed at gearbox axle due to gear ratio:

$$13.275Nm \times \frac{12}{16} = 9.956Nm$$

Torque needed because of gearbox efficiency:

$$\frac{9.956Nm}{0.81} = 12.291Nm$$

Load Torque at DC motor axle:

$$12.291Nm \times \frac{3}{52} = 0.709Nm$$

The Brushed Commutated DC servo Motors from Pittman Motors are made to fit the gearbox we have selected. We decided to try out the 14204 series model, since its peak torque is about twice of what we need[5]. This indicates that this motor operates near the middle of its maximum values of speed and torque, and is not overloaded.

To verify this, we used the DC motors values from the datasheet and computed load to simulate the motor in the simulink model.

Pittman Motors Brush Commutated DC Servo Motor 14204 series	
Supply Voltage (V_a)	24.0 V
Torque Constant (K_t)	0.061 Nm/A (8.67 oz-in/A)
Voltage Constant (K_e)	0.061 V/rad/s (6.41v/krpm)

[5] 1.4402 Nm, from datasheet.

Terminal resistance (r_a)	1.01 ohm
Inductance (L_a)	1.60 mH
Peak Torque	1.4402 Nm (204 oz-in)
Viscous Damping Factor (B)	1.21×10^{-5} Nm s/rad (0.18 oz-in/krpm)
Coulomb Friction torque	0.0113 Nm (1.6 oz-in)
Rotor Inertia (J at axle)	2.61×10^{-5} kgm2 (0.0037 oz-in-sec2)
Weight (Mass)	997.9 g (35.2 oz)

Table 7: Datasheet values of Pittman motors DC motor.

Calculated inertia of the system:

$$J = J_{axle} + J_{load}$$

Inertia of gears:

16.8 mm gear (12 cogs):

$$J_1 = \frac{1}{2}mr^2 = \frac{1}{2}(4.29\times10^{-3}kg)(\frac{16.8mm}{2})^2 = 2.93\times10^{-5}kgm^2$$

27.6 mm gear (21 cogs):

$$J_{2,3,4} = \frac{1}{2}mr^2 = \frac{1}{2}(15.31\times10^{-3}kg)\left(\frac{27.6mm}{2}\right)^2 = 1.46\times10^{-6}kgm^2$$

21.6 mm gear (16 cogs) with nut:

$$J_5 = \frac{1}{2}mr^2 = \frac{1}{2}(28.82\times10^{-3}kg)\left(\frac{21.6mm}{2}\right)^2 = 2.44\times10^{-6}kgm^2$$

Total inertia of load:

$$J_{load} = J_1 + \left(\frac{12}{21}\right)^2\left(J_2 + J_3 + \left(\frac{21}{16}\right)^2(J_4 + J_5)\right)$$

Total inertia of system:

$$J = J_{axle} + J_{load} = 2.93\times10^{-5}kgm^2$$

In the figures below we see the rotational speed (RPM),Current drawn (I_a) and Torque the motor delivers with the given load from the gearbox. The voltage is put on at t = 1 second, and and the load is activated at t = 2 seconds.

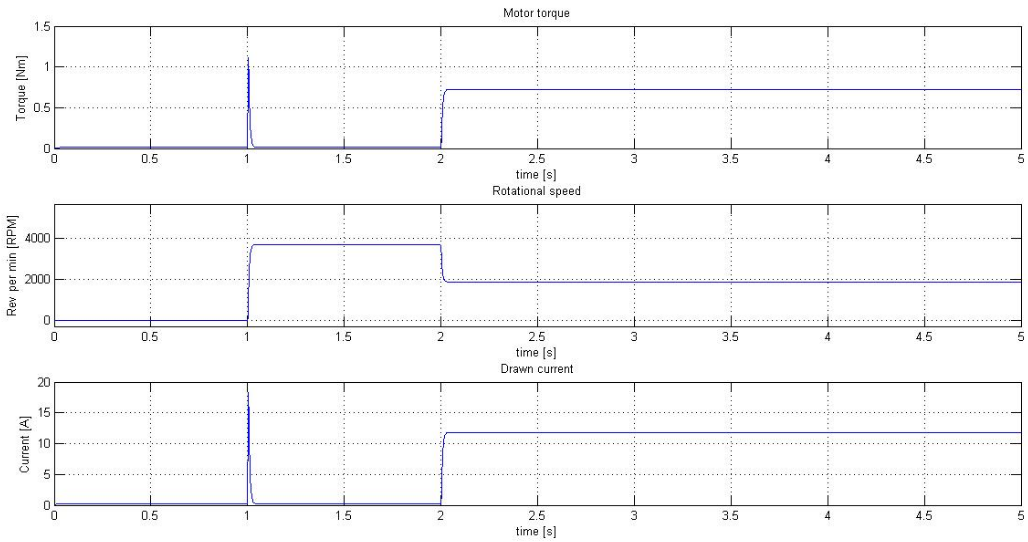

Figure 18: Motor performance from matlab simulation.

As we can see the speed and torque delivered by the motor, and the current drawn becomes constant after a little while. When we zoom in closer we can read the constant values.

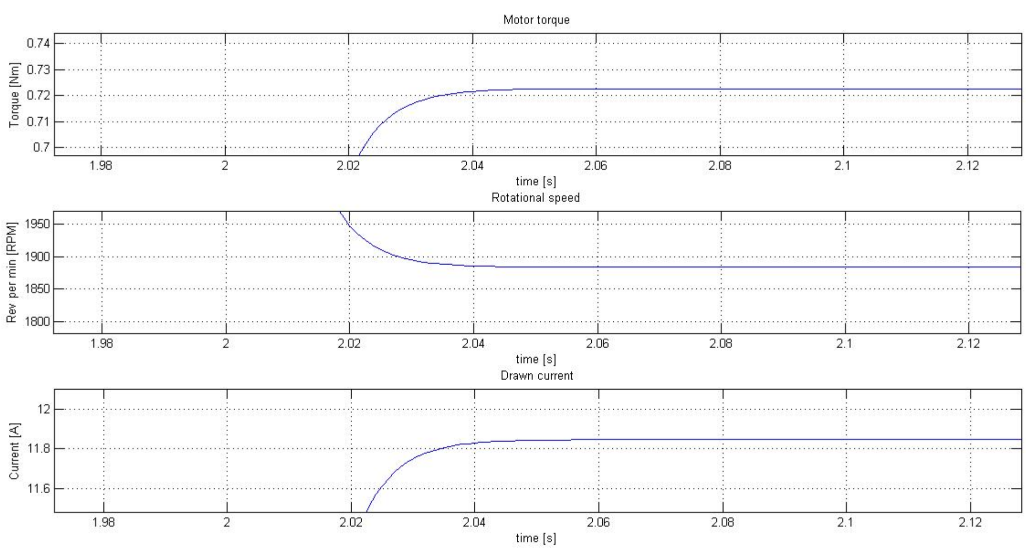

Figure 19: Zoomed view of motor performance from matlab simulation.

Here we can see that the motor torque is about 0.720 Nm. That is because the motor has to overcome the friction constant and the viscous damping factor to become equal to the load torque. The result of this simulation is that the DC motor stabalizes itself when the torque from the motor becomes equal to the torque of the load, friction, and damping factor. At this torque level the axle of the motor spins at 1890 RPM and the drawn current is about 11.8A.

Now we can calculate the rotational speed at the gearbox axle and final gear:

Rotational speed at gearbox axle:

$$\frac{3}{52} \times 1890RPM = 109.04RPM$$

Rotational speed at final gear due to gear ratio:

$$\frac{12}{16} \times 109.04RPM = 81.78RPM$$

If we compare the simulated motor torque (0.720Nm) and the mid range torque of the motor (0.7201Nm, which is the peak torque divided by two), we can conclude that they are almost exactly equal. This means that the DC motor with this load operates in the middle of its torque range, and is able to handle loads up to double the size of which we have used in this simulation.
Therefore the motor is not overloaded in terms of torque or speed in this system, and is suited for this specific use.

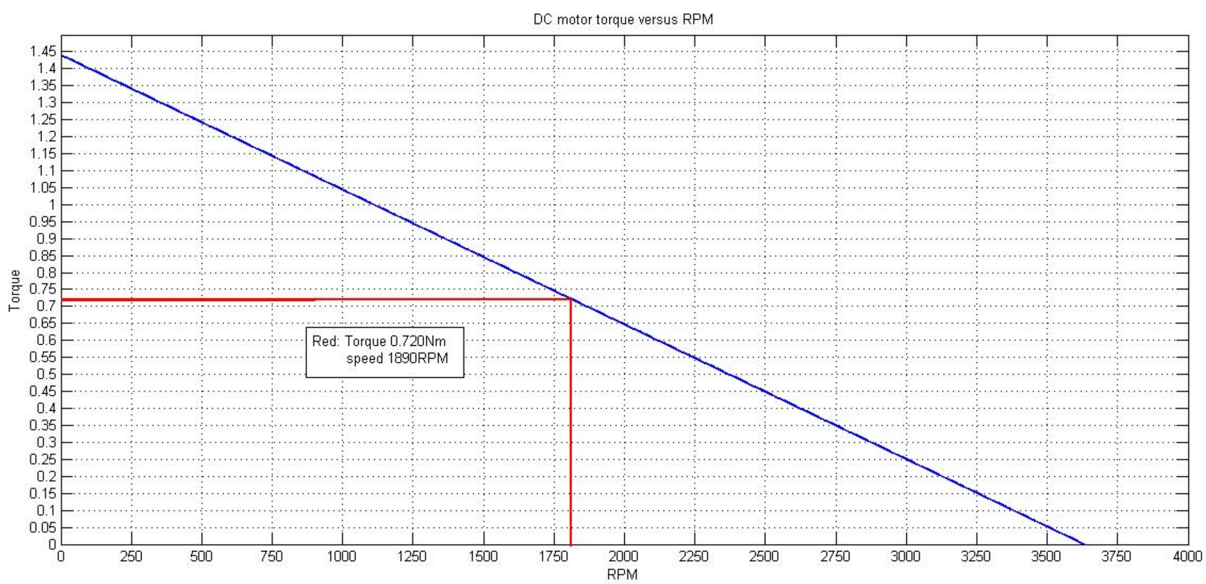

Figure 20: Relationship between torque and speed.

When a system experience a change on either its input or output, there is a little occurrence of delay before the system is stabilized again. This delay is call rise time, and when the system is stable we call it steady-state.

The system in matrix form:

$$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$

$$\begin{bmatrix} \dot{\omega} \\ \dot{i_a} \end{bmatrix} = \begin{bmatrix} \frac{-B}{J} & \frac{K_t}{J} \\ \frac{-K_e}{L_a} & \frac{-R_a}{L_a} \end{bmatrix} \begin{bmatrix} \omega \\ i_a \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{L_a} \end{bmatrix} V_a$$

$$y = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} \omega \\ i_a \end{bmatrix} + 0$$

To figure out what these values for this DC motor is we have to find the transfer function of the system. we used Matlab to compute and plot the response.

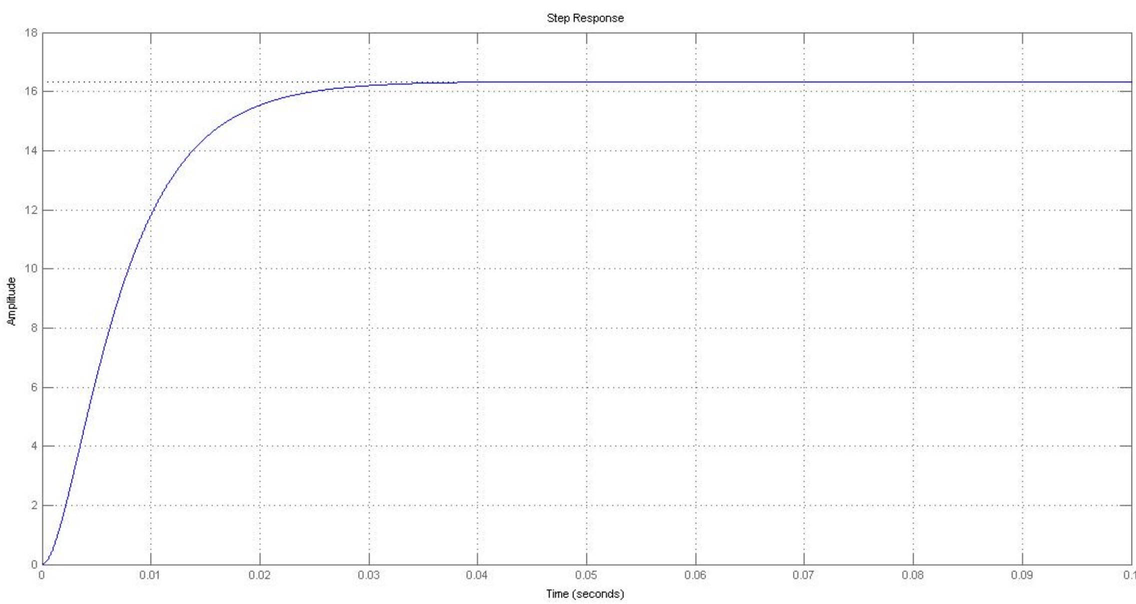

Figure 21: Step response of DC motor system.

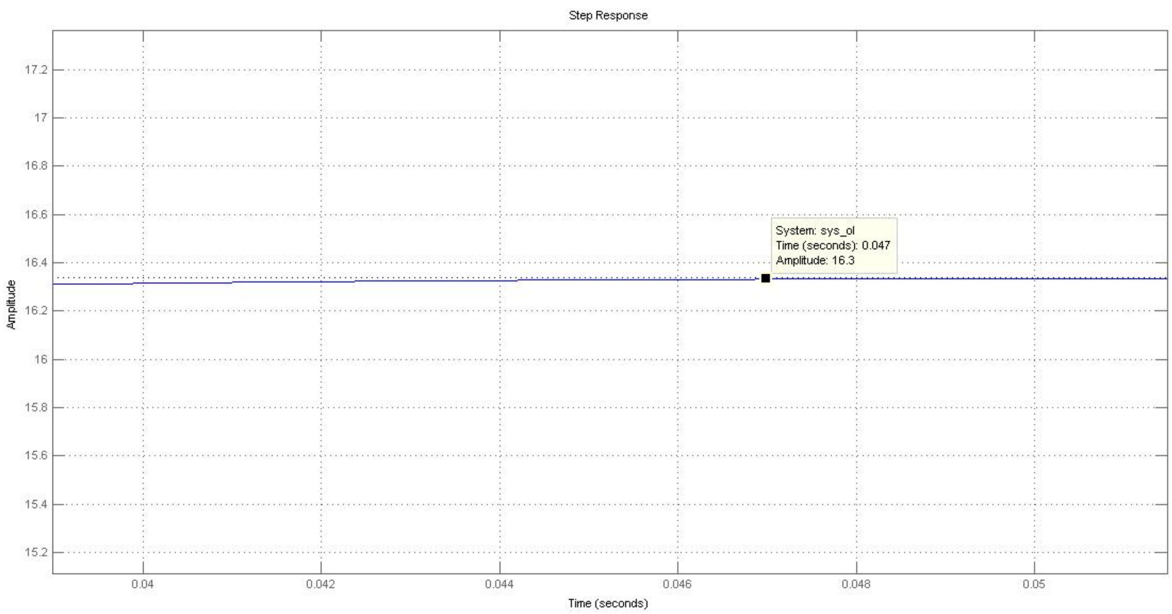

Figure 22: Zoomed view of the DC motor step response.

As we can see the rise time of the system is about 47 milliseconds. Which is a very fast response.

4.3.4 Position sensor

To be able to put the nuts into the reuleaux triangle properly, we need to know the orientation.

The best way to keep track of this, is to use an absolute optical encoder with multi-revolution measurement. This is a sensor that can track the position and velocity of a rotating shaft.

An absolute optical sensor is basically a disc that is connected to a shaft. The disc has tracks that are made up of transparent and non-transparent segments, which allows a light source to shine through the transparent segments. The light emitted is picked up by photodetectors (light sensors) that translates the light on/off signal to ones and zeroes. The number of different tracks on the disk determines the number of different positions the sensor can detect. In other words one track is one bit.

For example: If a disk has four tracks, the sensor has 2^4 =16 different positions it can monitor.

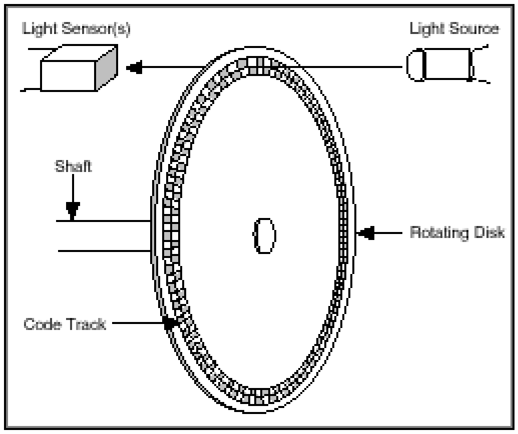

Figure 23: Optical encoder disc illustration.

The multi-revolution side of an absolute sensor is another disc which counts the number of revolutions the shaft has made.

Wachendorff Automation is a company that makes a series of absolute optical encoders that are highly durable and has high resolution.

Encoder WDGA 58B absolute SSI magnetic, with EnDra - Technology	
Sensor Data	
Singleturn resolution	Up to 16384/360° (14 bit)
Singleturn accuracy	<0.35°
Singleturn repeat accuracy	<0.20°
Multiturn	Up to 40 bit
Mechanical Data	
Starting torque	<1 Ncm
Permissible shaft loading	125/220 N radial 120 N axial
Shaft Ø	6/10 mm
Shaft length	12/20 mm
Shaft material	Stainless steel
Flange material	Aluminium
Service life	1 x 10^9 revs. at 100 % rated shaft load

	1 x 10^{10} revs. at 40 % rated shaft load 1 x 10^{11} revs. at 20 % rated shaft load
Weight	202 g
Max. operating speed	8000 RPM
Electrical Data	
Supply voltage	10 VDC up to 30 VDC 4.75 VDC up to 5.5 VDC Max. 80 mA
Power consumption	Max. 0.8 W

Table 8: Datasheet values of absolute optical encoder.

This sensor offers an angular resolution up to:

$$\frac{360}{2^{14}} \approx 0.022^\circ$$

This means that we can use it to recognize the angular displacement of our shaft with steps of 1° . Which is sufficient for the use of this tool system.
The use of counting the revolutions(multi-revolution) is to verify the position of the gear with the nut, by counting the revolutions on the gear with the sensor on.

For example: If the gear ratio of the two gears is 2:1 (two turns on input gear equals one turn on output gear),then we know that each time the input gear has done two turns the output gear has done one. This means that we know that if the input gear is 40° off equilibrium, the output gear is 20° off equilibrium

4.4 Tool changer

The tool changer we have selected is the SWS-021 from Schunk. This is due to the fact that it is the smallest tool changer available that has the possibility to mount the electrical connections we need.

Figure 24: Schunk SWS-021 tool changer.

This tool changer has space to mount two modules that can relay electrical signals. The modules we can chose from are:

- K19: 19 pins, 3A 50V
- K26: 26 pins, 3A 50V
- KM14: 12 pins, 5A 250V. 2 pins 13A 250V

As our DC motor uses more than 3A, we will need one KM14 module. The other module must then be a K26, to account for the amount of electrical pins we need.

Module	**3A/50V max**	**5A/250V max**	**13A/250V max**
Gripper	5+1	3	-
Force measurement jaw	4+1	-	-
Linear actuator motor	2	3+1	-
Linear actuator measurement system	7+1	-	-
Ball-lock sensor	2	-	-
DC motor	-	-	2
DC motor encoder	5	-	-
Total:	**25+1**	**6+1**	**2**

Table 9: Electrical connections to tool.

4.4.1 Tool changer interface plate

The interface plate is the connection point between the end effector and the tool changer.

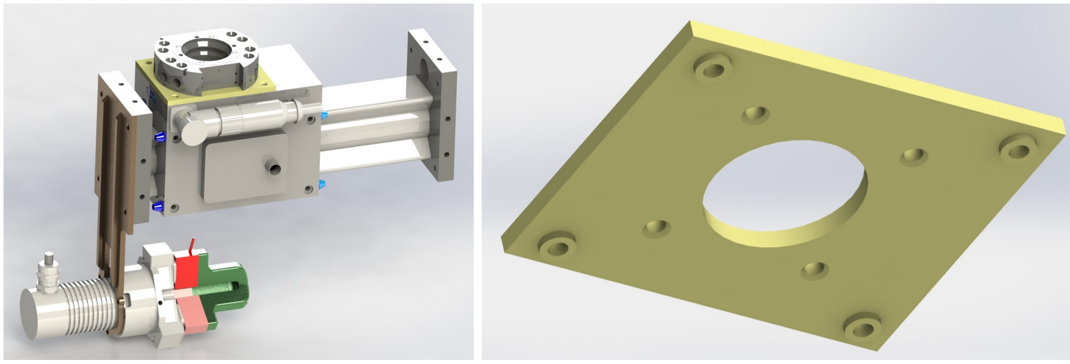

Figure 25: Assembly photo of the interface plate.

The design is based on the dimensions of the linear actuator and the tool changer.
Material selected is 2024 Aluminium alloy. The weight is 106.33 grams.

- *Assembly of interface plate, use bolts based on the specifications given by the tool changer and linear actuator supplier.*

5.0 Conclusion for the end design

From concept to end design. We have worked hard to meet all the requirements set by our stakeholders. We strived for simplicity in the overall design, as there will be a need for five versions of the tool to meet the different bolt sizes. Simplicity in design is of importance for our assignment. This will ensure durability, lower price and an easier manufacturing process.The tool is completely electric, which was one of our sub requirements.

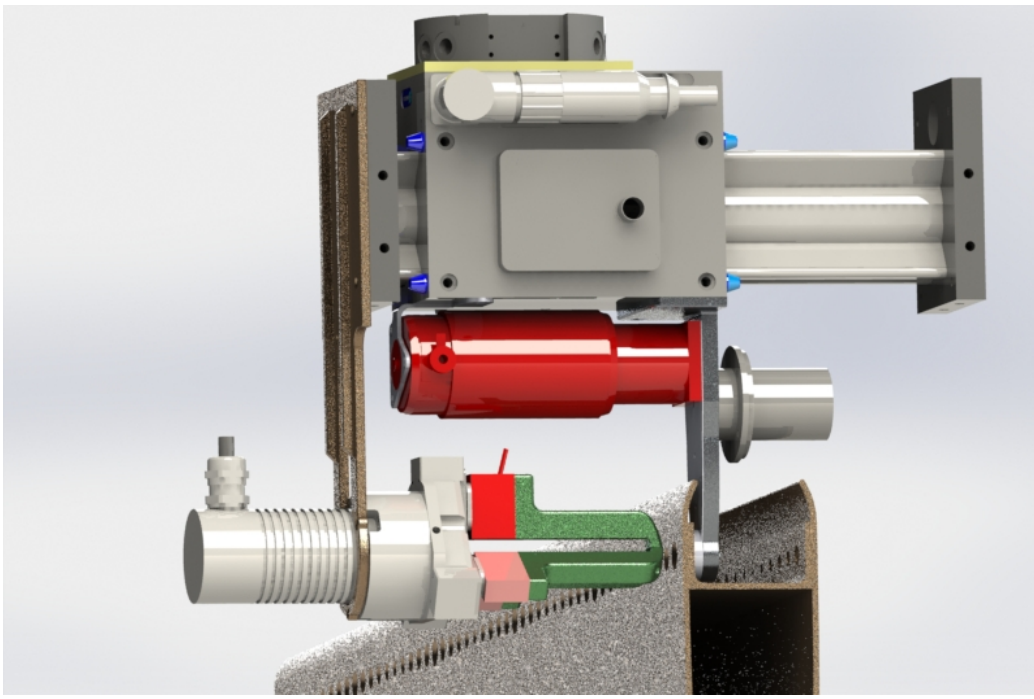

Figure 26: The finished design of the end effector[6].

The tool has two main functions; retrieval and assembly. When retrieving the bolt and nut the linear actuator arm will expand. The gripper arm is equipped with three fingers, these will then open and close to collect the bolt. The gripper arm has pressure sensors mounted so that the system will be able to verify that the bolt has been collected. Then the robot will rotate the end effector 180 for retrieval of the nut. The nutrunner is equipped with a ball-lock system, this is to ensure that the nut itself will remain in place during transport.

Then the robot enters the assembly position, and the linear actuator starts closing the gap between the gripper arm and the nutrunner. Sensors will detect if the bolt collides with the aerospace part. When the bolt is properly positioned and locked in place with the hex key, the DC motors starts and the nut will be fastened. Necessary torque will be applied so that the assembly process is conducted after the requirements set by our stakeholder.

[6] See attachment for assembly BOM for end effector

5.1 Robot cell

Using KUKA Simulation Layout, we have created a rough simulation of our robot cell. Since we don't know the sizing of all the parts in the cell, this simulation is not to be taken as a final product. It is also not possible to import parts from for example Solidworks, so we had to get creative when making the different objects in the simulation.

The advantage of setting up this simulation is that it's visualising the final product much easier than what plain text can do, making it much easier for both us and our customer to see what we will eventually end up with.

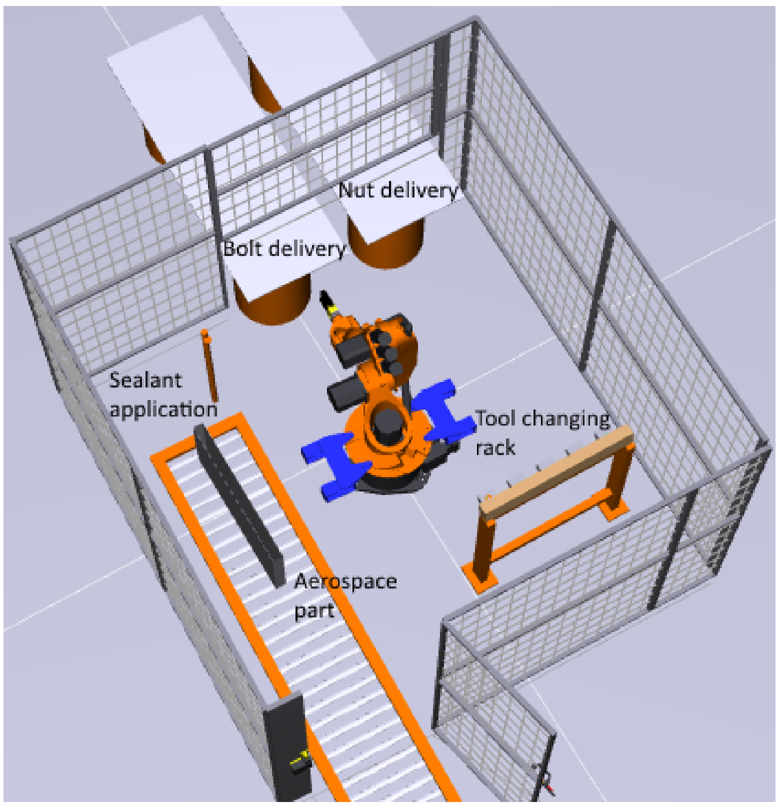

Figure 27: Simulation of robot cell.

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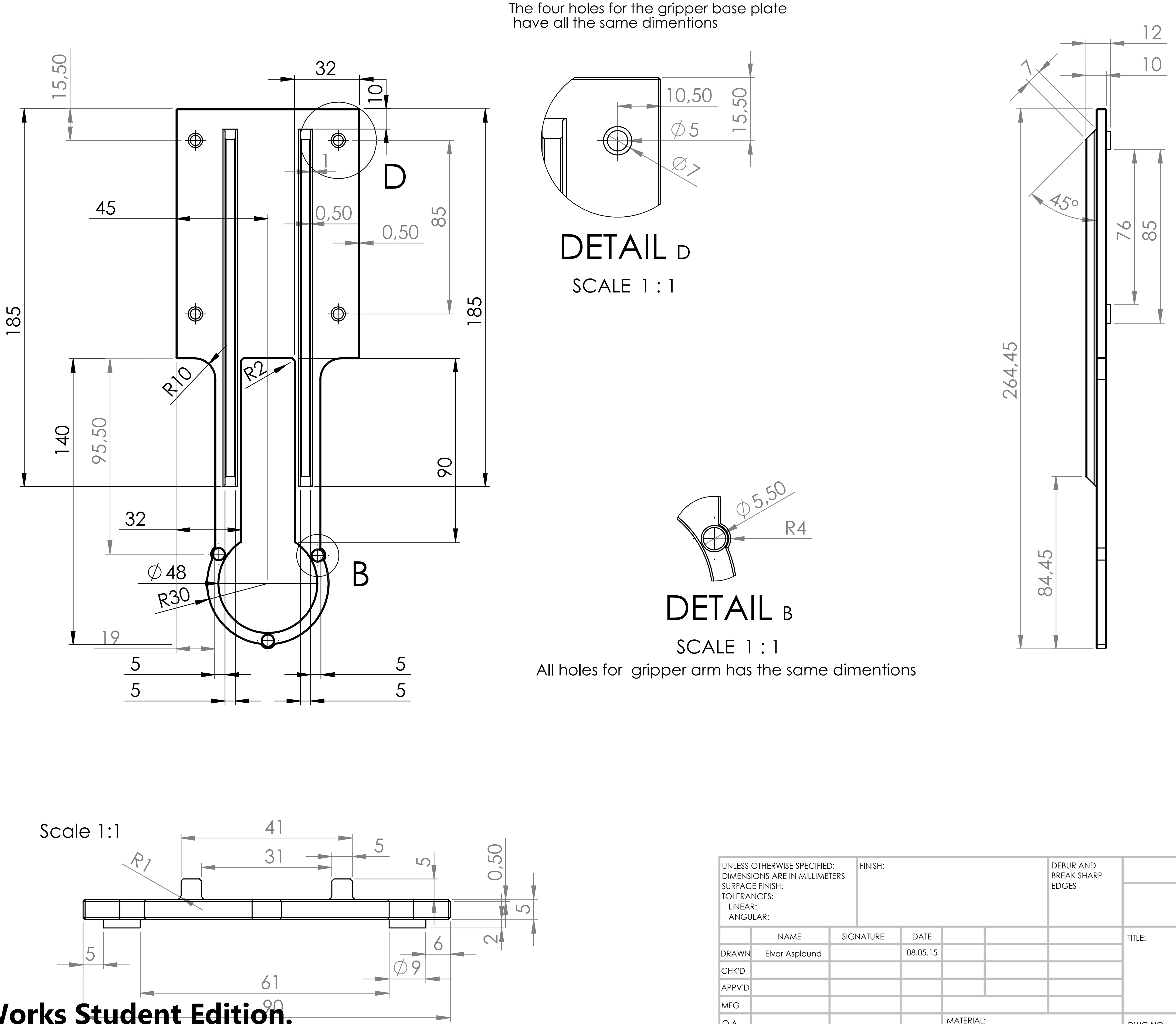
7.0 Attachments

Attachment 1: Gripper plate 2D drawing
Attachment 2: Bolt gripper assembly BOM



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SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

SOLIDWORKS

	NAME	SIGNATURE	DATE
DRAWN	Elvar Aspleund		08.05.15
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Gripper plate

MATERIAL:

2024 Aluminium

DWG NO.

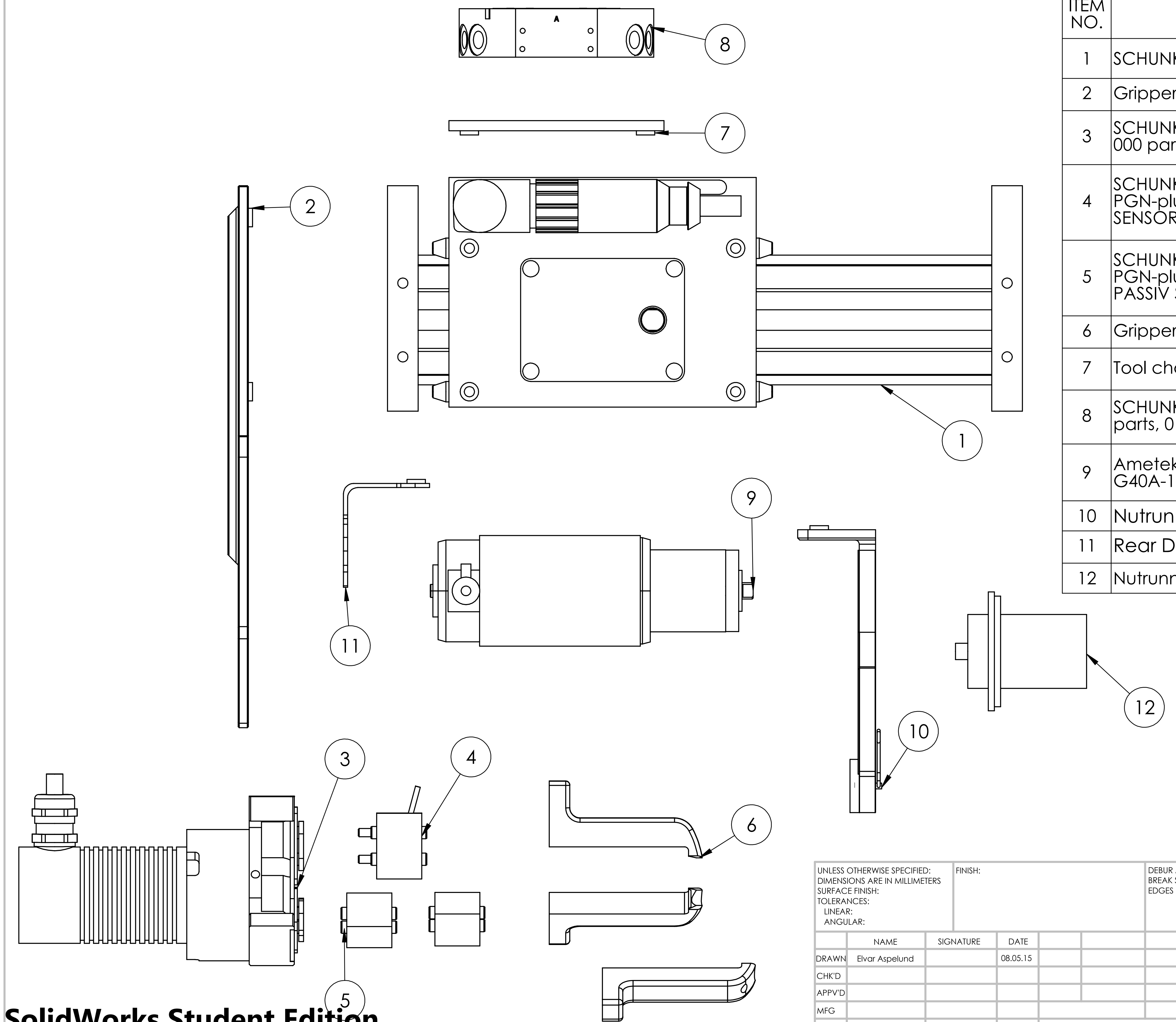
1

A3

WEIGHT: 221.23 grams

SCALE:1:2

SHEET 1 OF 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	SCHUNK-LDN-ES-0100, 100001		1
2	Gripper plate		1
3	SCHUNK-37306110 EZN 064-SD, 000 part		1
4	SCHUNK-0301832 FMS-ZBA PGN-plus 64 _ PZN-plus 64 SENSOR		1
5	SCHUNK-0301833 FMS-ZBP PGN-plus 64 _ PZN-plus 64 PASSIV SENSOR		2
6	Gripper finger		3
7	Tool changer interface		1
8	SCHUNK-SWA 021-000-000-parts, 01		1
9	Ametek-Pittman-14204-24.0V-G40A-17.3-0000		1
10	Nutrunner		1
11	Rear DC Motor plate		1
12	Nutrunner sensor		1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Elvar Aspelund		08.05.15
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT: 8KG

TITLE:

Bill of material

DWG NO.

bolt gripper assembly BOM

A3

SCALE:1:10

SHEET 1 OF 1

Technology Document: Robot Selection

Version	Date	Reviewed by	Approved by	Satus
2.0	15.05.2015	Kristoffer Lund	Tor Sigurd Breivik	Released

Table of contents

List of tables

List of figures

1.0 Abstract

In this document we look at the different robots that are suited to the process of assembling our aerospace part. We also look at suited tool changing systems. In the end we have a discussion and conclusion to which robot and tool changer we have selected.

2.0 Revision History

Version	Date	Changes	Author
0.1	06.03.2015	• First version of the document.	Stian Hovde
1.0	16.03.2015	• First released version.	Stian Hovde
1.1	01.05.2015	• Rewritten chapter 5.0 due to a change in the requirements for robot. • Edited chapter 6.0 & 7.2.	Stian Hovde
1.2	07.05.2015	• Added chapter 5.1.3. • Edited chapter 7.1.	Stian Hovde
1.3	12.05.2015	• Updated formatting and wording	Stian Hovde
1.4	14.05.2015	• Spellcheck, review	Katrine Kallevik
2.0	15.05.2015	• Final version	Stian Hovde

Table 1: Revision table

3.0 Introduction

One of the primary goals for our project is to find a suited robot that can complete the bolt installation process that we are trying to automate. This document will provide an overview over robots that we have found to be suited, and give a reasoning as to which robot we have chosen for the project. We will also be looking at tool changing systems, since this is one of the requirements for our robot.

The prices stated in this document is only for the robot/tool changer itself. Any additional options, for example vision systems, will be an added cost. Programing, commissioning and testing of the robot will also add to the price. It is important to keep in mind that the price of the robot is just a fraction of the cost of the complete system.

4.0 Methods

The main methods we will use is searching the internet for information about different robot and tool changer producers. We will also try to get into contact with personnel within the different companies that can help us with our questions.

Kongsberg Defence & Aerospace have also been in contact with Tronrud Engineering, and will try to include the project group in the meetings that will take place between them. We hope to gain valuable information from these meetings.

To select our robot and tool changer we will be using the decision-matrix method. We believe this is a good way to quantify the different options, and objectify our opinions of them.

5.0 Suited robots

Industrial Robots have seen a massive boom over the past few decades, with as many as 1,600,000[1] robots being installed worldwide. This number is only expected to increase over the years to come. Due to this, there are a multitude of companies manufacturing industrial robots.

Kongsberg Aerostructures has set a requirement we shall use a KUKA robot for this project. KUKA is one of the largest manufacturers of robots in the world, and has both service and distribution available in Norway.

Since Kongsberg has expressed their interests to automate more parts of their production, KUKA is a good choice. While a smaller company might have a robot that is better suited for our needs, it does not provide a large spectrum of robots that might be needed later. Also, having robot service easily available close to the company reduces a lot of problems that may arise, like extended downtime, language barriers, etc. Kongsberg has also acquired the KUKA simulation tool, which is another factor that made KUKA the final choice.

Since one of the most important factor when choosing a robot is the maximum payload, we have used our requirement of minimum 10 kg to find the robots listed in this chapter. The robots selected are also listed as suitable for assembly operations in the manufacturer's documentation. The final selection and discussion around it takes place in chapter 7.

[1] According to the International Federation of Robotics

5.1 KUKA Robotics

KUKA is a german manufacturer of industrial robots and robot systems. They released their first robot in 1973, the first to have six electric motor-driven axes. Today KUKA is one of the largest manufacturers of robotic systems in the world. KUKA offers a unique and wide range of industrial robots and robot systems, covering all common payload categories and robot types.

Tronrud Engineering, located in Hønefoss, is a supplier of KUKA robots, and can deliver both stand-alone robots and complete solutions. A KUKA service center is located in Hov.

5.1.1 KR AGILUS

Figure 1: KR AGILUS series

With the KR AGILUS series, KUKA is presenting a comprehensive small robot family. The performance of the KR AGILUS series is unique in its payload category. It sets standards with five or six axes, very high speeds, short cycle times and an integrated energy supply system. The robots also require no change of lubricant. This makes them ideally suited to continuous, uninterrupted productivity.

There are 3 variants that has a maximum payload of 10 kg; the KR 10 R900 SIXX, KR 10 R1100 FIVVE and KR 10 R1100 SIXX.

Technical specifications:

Parameter	KR 10 R900 SIXX	KR 10 R1100 SIXX	KR 10 R1100 FIVVE
Payload	10 kg	10 kg	10 kg
Reach	901 mm	1101 mm	1101 mm
Axes	6	6	5
Protection	IP54 (optional IP67)	IP54	IP54 (optional IP67)
Mounting	Floor, ceiling, wall	Floor, ceiling, wall	Floor, ceiling
Dimensions robot base	209 x 207 mm	209 x 207 mm	209 x 207 mm
Robot weight	52 kg	54 kg	53 kg
Position repeatability	0.03 mm	0.03 mm	0.03 mm
Maximum speed	Axis 1: 300 °/s Axis 2: 225 °/s Axis 3: 225 °/s Axis 4: 381 °/s Axis 5: 311 °/s Axis 6: 492 °/s	Axis 1: 300 °/s Axis 2: 225 °/s Axis 3: 225 °/s Axis 4: 381 °/s Axis 5: 311 °/s Axis 6: 492 °/s	Axis 1: 300 °/s Axis 2: 225 °/s Axis 3: 225 °/s Axis 4: - Axis 5: 311 °/s Axis 6: 492 °/s
Ambient temperature during operation	+5℃ to +45℃	+5℃ to +45℃	+5℃ to +45℃
Price	230,000 NOK	238,000 NOK	227,000 NOK

Table 2: KR AGILUS technical specifications

5.1.2 LBR IIWA 14 R820

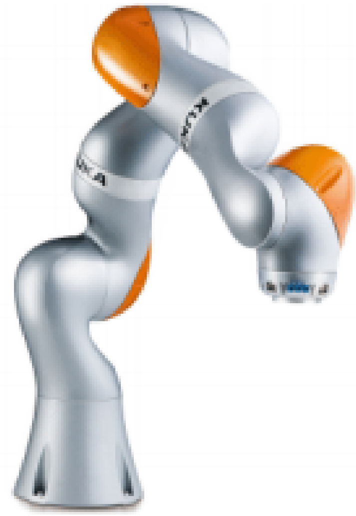


Figure 2: LBR IIWA 14 R820

The LBR IIWA is the world’s first sensitive lightweight robot suitable for use in industrial applications. The robot has integrated, sensitive torque sensors in all seven axes, they respond to the slightest of external forces and enable safe collision protection. This makes the robot ideal to work in close proximity to humans, and eliminates much of the safety precautions needed in a robot cell.

The kinematic system of the LBR IIWA is based on the human arm. The seven axes makes it highly flexible, and ideal to work in confined and difficult installation situations. All cables are routed entirely through the arm, protecting them from harm.

Technical specifications:

Parameter	**LBR IIWA 14 R820**
Payload	14 kg
Reach	820 mm
Axes	7
Protection	IP54
Mounting	Floor
Dimensions robot base	-
Robot weight	29.9 kg
Position repeatability	0.15 mm
Maximum speed	Axis 1: 85 °/s Axis 2: 85 °/s Axis 3: 100 °/s Axis 4: 75 °/s Axis 5: 130 °/s Axis 6: 135 °/s Axis 7: 135 °/s
Ambient temperature during operation	+5℃ to +33℃
Price	748,000 NOK

Table 3: LBR IIWA 14 R820 technical specifications

5.1.3 KR 16

Figure 3: KR 16-2

The KR 16 family of robots are particularly suitable for small-scale activities such as component testing, assembly of small parts, or grinding, polishing and bonding. The streamlined design offer outstanding accessibility, even in confined spaces.

The standard KR 16-2 version is the one that suits our project. Other versions are available for specialized use, for example arc-welding, glass handling, and clean rooms.

Technical specifications:

Parameter	KR 16-2
Payload	16 kg
Reach	1611 mm
Axes	6
Protection	IP65
Mounting	Floor, ceiling, wall
Dimensions robot base	500 x 500 mm
Robot weight	235 kg
Position repeatability	0.05 mm
Maximum speed	Axis 1: 156 °/s Axis 2: 156 °/s Axis 3: 156 °/s Axis 4: 330 °/s Axis 5: 330 °/s Axis 6: 615 °/s
Ambient temperature during operation	+5℃ to +55℃
Price	310,000 NOK

Table 4: KR 16 technical specifications

6.0 Suited Tool Changers

A robotic tool changer is a device that connects to the arm end of the robot, and allows the robot to automatically switch out end effectors. This makes a robot able to perform several different tasks, instead of just one.

Figure 4: Typical setup of tool changer system.

The tool changer consists of a master plate and a tool plate. The master plate is connected to the arm end of the robot, and a tool plate is connected to each end effector the robot wishes to use. Most tool changers uses pneumatics to lock the master and tool plates together. Configurable pass through ports allows the tool changer to pass utilities such as electrical signals, pneumatics, water etc.

A robot interface plate and tool interface plate needs to be designed for the tool changer. These connects the robot to the master plate, and the tool to the tool plate. Most tool changer producers can supply custom interface plates, but they can also be designed by the customer.

The simplest way to select a tool changer is to select one with a payload similar to that of the robot. This is only accepted if the expected moment exerted on the tool changer is low or moderate. If the exerted moment is high, or if we want a tool changer more specifically suited for the task, we have to calculate the static moment of the tool.

After tool changers with suited moment capacity are found, we can further narrow down the selection based on our needs for pneumatic and electrical ports, repeatability, and temperature ratings.

The tool changers listed in this chapter have been chosen based on our robots requirement of a minimum payload of 10 kg.

6.1 Schunk

As all the modules we have chosen for our end effector are from Schunk, we have also chosen to use their tool changers. Having all the components from the same producer is an advantage when it comes to supply and support.

Schunk GmbH is a German manufacturer of automation solutions. Schunk's tool changers features short changing times between handling unit and tool, very low weight due to the use of high tensile aluminum, and high durability as functional parts are made of hardened steel. Schunk is also a supplier of ATI, the world leading developer of robotic accessories and robot arm tooling.

Figure 5: Schunk SWS series tool changer

Technical specifications:

Parameter	SWS-005	SWS-011	SWS-I-011	SWS-021
Payload	8 kg	16 kg	16 kg	25 kg
Repeatability	0.01 mm	0.01 mm	0.01 mm	0.015 mm
Moment capacity	13 Nm	25 Nm	34 Nm	56.5 Nm
Weight (when coupled)	0.37 kg	0.21 kg	0.59 kg	0.8 kg
Pneumatic pass-through ports	6 x M5	6 x M5	4 x M5	8 x G 1/8”
Electrical pass-through ports	Customizable (1 module)	Customizable (1 module)	6 x 3A/50V	Customizable (2 modules)
Ambient temperature during operation	+5℃ to +60℃	+5℃ to +60℃	+5℃ to +60℃	+5℃ to +60℃

Table 5: Schunk tool changer technical specifications

7.0 Discussion & Conclusion

In this chapter we will discuss the different robots and tool changers available to us, and end up with the robot and tool changer that we believe will suit our project the best.

To make this selection, we have decided to use the decision matrix method, also known as the Pugh method. The decision matrix method is frequently used in engineering for making design decisions. In the matrix, we list the different criterias that needs to be fulfilled by the alternatives we have. We then grade the alternatives based on how well it fulfills that criteria;

- “+” indicates that the alternative fulfills the criteria to a great extent.
- “0” indicates that the alternative fulfills the criteria to some extent.
- “-” indicates that the alternative fulfills the criteria to a slight extent.

Each criteria is also weighted based on how important it is, either for the project group or the stakeholders. The weight is given from 1 to 5, and is then multiplied by the score for that criteria. Finally, the sum of the score will tell us which of the alternatives is the best solution for us.

The decision matrix is a simple but effective tool to use when deciding between several alternatives. It helps us to quantify the different variables we have to take into consideration. Since many often have a preconceived favourite when making these decisions, it also helps us to objectify our choice.

7.1 Robot

We will use the decision matrix to select our robot. Our criteria will be based on the requirements we have for the robot, and other factors we and KDA feel is important.

Criteria explanation:

- **Payload:** The maximum payload of the robot. Since running the robot at it maximum payload decreases the overall lifetime, robots with higher payloads than our requirement scores higher.
- **Axes:** The number of axes on the robot. Robots with our requirement of 6 axes scores higher.
- **Reach:** The maximum reach of the robot. Robots that work on their maximum reach has a lower accuracy, so higher reach scores better.
- **Repeatability:** The accuracy of the robot on repeated actions. Lower scores better.
- **Size:** The size of the robot, including the reach. All of this has to be fenced in for safety, increasing the area of the robot cell.

- **Weight:** Weight of robot. Lower scores better.
- **Speed:** The maximum speeds of the robot. A robot that does not run on its maximum payload can run at higher speeds. Higher scores better.
- **Price:** The price of the robot. Lower scores better.

Criteria	**Weight**	**KR 10 R900 SIXX**	**KR 10 R1100 SIXX**	**KR 10 R1100 FIVVE**	**LBR IIWA**	**KR 16-2**
Payload	5	0	0	0	+	+
Axes	3	+	+	-	-	+
Reach	3	-	0	0	-	+
Repeatability	5	+	+	+	0	+
Size	2	0	0	0	+	-
Weight	1	+	+	+	+	0
Speed	2	+	+	+	0	+
Price	4	+	+	+	-	0
Weighted sum of "+"		15	15	12	8	18
Weighted sum of "-"		3	0	3	10	2
Highest score wins		12	15	9	-2	16

Table 6: Decision matrix for industrial robot

As we can see from the matrix, the KR 16-2 wins by a slight margin. A small change in the weighting of the criteria can easily change the victor. Based on what we have rated as the most important criteria, the KR 16-2 wins.

Our most important criteria is the payload and repeatability of the robot. Since our tool needs to enter a very small area, the repeatability is critical. As for the payload, all our robots meet the criteria, but we have given a higher score to the higher payload robots. This is because a robot running on close to its maximum payload has a decreased lifespan compared to the others. We believe the small increase in price from the KR 10 to the KR 16 is worth this increase in lifespan. It is important to take into consideration that the price of the robot is only a small factor in the price of the entire robot cell. As an added bonus, we also get a longer reach on our robot, meaning we do not need to put our robot on a conveyor belt to reach everything it needs to.

7.2 Tool changer

During the design of our end effector, we have noticed that we need a large number of electrical connections to our tool. This is based on one of our requirements that the driving force of the tool shall be electrical.

When we look at our suited tool changers, we can see that the SWS-I-011 only have 6 electrical pass-through ports. The SWS-005 and SWS-011 have the option to install one electrical module, but the largest one available for these only has 20 ports. These are both far too little for the amount of electrical ports we need. We will therefore choose the SWS-021 as our tool changer. This model has the option to install two electrical modules, that can each have up to 26 ports.

As previously mentioned, it is vital to control that the moment capacity of the tool changer is within the limits of the tool. The SWS-021 has a moment capacity of 56.5 Nm, so we can calculate the maximum distance to the center of gravity, with our maximum payload of 10 kg:

$$W * D = M \Rightarrow D = \frac{M}{W} \Rightarrow D = \frac{56.5Nm}{9.81m/s^2 * 10kg} = 0.576m$$

Where W is the weight of the tool, M is the moment capacity of the tool changer, and D is the distance from the tool changer base to the tool’s center of mass. As we can see, this distance is well away from any reasonable length of our tool design. It is therefore safe to say that this tool changer will be able to handle the static moment of our tool.

8.0 Sources

[1] KUKA, *KR AGILUS series datasheet*, cited 07.03.2015, available from: http://www.kuka-robotics.com/res/sps/f776ebab-f613-4818-9feb-527612db8dc4_PB0001_KR_AGILUS_en.pdf

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Advanced Aerospace Assembly

Economic Analysis

Version	Date	Reviewed by	Approved by	Satus
2.0	15.05.2015	Elvar Aspelund	Tor Sigurd Breivik	Released

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1.0 Abstract

This document contains an economic analysis of the economical advantages of automating a production line.

2.0 Revision History

Version	Date	Changes	Author
0.1	20.02.2015	• First version of the document	Kristoffer Lund
1.0	16.03.2015	• First released version	Kristoffer Lund Katrine Kallevik
1.1	09.05.2015	• Added chapter 6	Katrine Kallevik
1.2	10.05.2015	• Updated formatting	Stian Hovde
1.3	10.05.2015	• Added tables and figures	Katrine Kallevik
1.4	12.05.2015	• Spellcheck, edited tables and figures	Katrine Kallevik Stian Hovde
2.0	15.05.2015	• Final version	Katrine Kallevik

Table 1: Revision table

3.0 Introduction

Kongsberg Defence & Aerospace[1], Aerostructures Division, wishes to have parts of their production automated. In order to achieve this, they require an analysis of automated productions that they can use as a sales pitch to their management.

To better understand the advantages of automating a process, we have studied the different benefits a robot can provide. Since most of the benefits are economically related, it makes sense to have economy as the main sales pitch when automating any production.

4.0 Production

The production at KDA today is a manual because the process is complex and time consuming. However, given its repetitive nature it can benefit from automation. The key in reducing the costs of airframe production, is to reduce the percentage of manual labor the process requires today. This increases the profit margin and gives better room for negotiations in a sale. In addition automation can increase the output number of products manufactured, thereby increasing the production efficiency.

In general, production of airframe structures can be divided into two parts, Fabrication and Assembly.

- **Fabrication:** This is the part of the production that involves making the parts, components, and pieces that are delivered to assembly for installation.

- **Assembly:** This is where all the fabricated material are drilled, countersunk and bolted together into an airframe.

Assembly is the part of production that has the greatest chance of being successful. This is because the current technology on today's market is able to replace most of the manual labor, and has a smaller risk of creating errors. It is also the part of production with the highest rate of human labor.

The challenge of this type of production is to meet the high standards the product is expected to have. To meet these high standards the system will most likely become complicated and expensive, but the high initial cost of these kinds of systems will be earned back in the long run.

[1] From here on abbreviated to KDA

5.0 Advantages and disadvantages

To optimize the use of an automated process certain issues must be evaluated. The general idea is to automate parts of the production that can benefit from higher assembly rate or accuracy. The key of choosing the parts of a process to automate, is the downtime of the process.

For example: it is not necessary to speed up a part of an assembly, if the volume of parts needed in that assembly isn't of large capacity. This will lead to a large standstill of the production and will be ineffective.

The same principle is used for accuracy. Automating a process with the intent of increased accuracy should only be used where there is a need for lower rate of wrongly produced products or human accuracy is not sufficient. Also the downtime must be considered here since precision processes has a habit of being slow.

With this in mind the general advantages and disadvantages are as follows.

5.1 Advantages

- **Increased productivity:** An automated process can increase productivity in two ways. One is to be quicker than existing assembly system. The other is to be slower or just as fast as the existing system, but be able to work around the clock. Either of these solutions concludes with the same thing, higher production volume.

- **Improved quality:** Since robots are more precise than humans, they ensure that the margin of error in a production is lowered. Thus improving the quality.

- **Improved consistency of output:** Because robots are only able to do what they are programmed for, they can only be consistent. An error in a product can therefore only be caused by malfunctioning tools or foreign objects that is present where it shouldn't. For example if a robot that drills holes in a plate produces holes that are not up to production standards. The error is most likely to be a worn/faulty drill bit.

- **Reduced human labor cost:** An automated process replaces the human laborers in a manual process. this opens up for these workers to become operators and will reduce the chance of injury and human fatigue.

5.2 Disadvantages

- **Security:** While an automated process is very good at doing a process repeatedly, it cannot comprehend any change in the process by itself. If any foreign object comes into the reach of a robot, a robot with low intelligence will not take any procedure to ensure a good level of safety.

  This problem can always be bypassed with clever engineering. However, this can become costly, and the more an automated process comes in contact with human workforce, the more expensive the safety engineering becomes.

- **Development and initial costs:** Any development is costly and has a risk of being terminated by the sheer cost of it. Automation of a process is no different, and has a risk of not becoming profitable. However, with a good pre-study of the aspects and advantages these systems offer, the risk of going over budget is greatly lowered.

6.0 Manual versus automatic production analysis

We have analysed manual versus automatic production, in order to better understand the economical benefits and disadvantages when implementing a new production system.

Assumed information:

Manual production (hours):
- 32.5 hours per part, 760 NOK per hour = 24,700 NOK
- Number of hours per year 4,680 = 2.4 FTEs
- Capacity of 12 units per month - an estimated 144 units per year
- Cost of goods sold is unknown
- The pursuit of increased production to 22 units per month

Automatic production:
- Investment robot 8,000,000 NOK
- Operating cost robot per year 80,000 NOK
- Lifetime robot 15 - 20 years
- One man on hours = 1,950 hours of 760 NOK = 1,482,000 NOK

The first thing we've done is to set up an accounting of how many units being produced today. The cost of manual production, and the cost of automatic production.

Manual work	**1 Part**	**12 Parts**	**144 Parts**
Hours	32.50	390.00	4,680.00
Salary per hour	760.00	760.00	760.00
Costs	***24,700.00***	***296,400.00***	***3,556,800.00***

Table 2: Manual work, today's production units.

Automatic	**1 Part**	**22 Parts**	**264 Parts**
Hours	7.39	162.50	1,950.00
Salary per hour	760.00	760.00	760.00
Costs manually work	***5,616.40***	***123,500.00***	***1,482,000.00***
Operating costs Robot	303.00	6,666.67	80,000.00
Total Costs	***5,919.40***	***130,166.67***	***1,562,000.00***

Table 3: Robot, desired production units.

We keep investment costs outside the math yet, since it is desirable to see if the investment earns in isolation. The figure underneath shows the cost difference between manual and automatic production on a monthly basis.

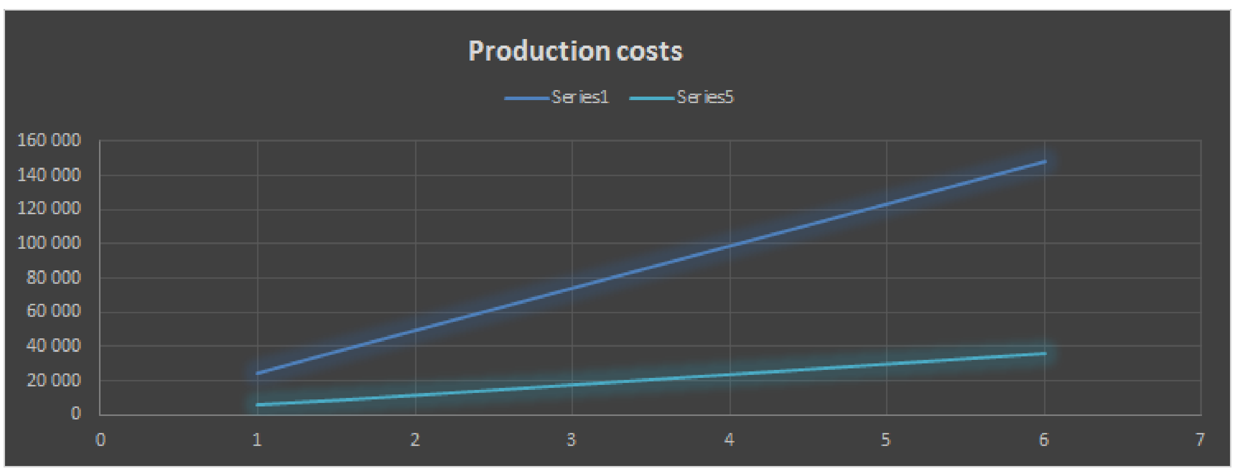

Figure 1: Production costs

Considering that the automatic process produces 120 more units per year, we have seen how much this would cost to produce manually. The ratio would have been as follows:

Manual work	1 Part	22 Parts	264 Parts
Hour	32.50	715.00	8,580.00
Salary per hour	760.00	760.00	760.00
Costs	***24,700.00***	***543,400.00***	***6,520,800.00***

Table 4: Manual work desired production units.

Isolated savings per year by producing 264 units (which was requested) then becomes:

264 parts per year	
Manual work	6,520,800.00
Robot	1,562,000.00
Difference	***4,958,800.00***

Table 5: Isolated savings 1.

At the current production of 144 units per year:

144 Parts per year	
Manual work	3,556,800.00
Robot	1,562,000.00
Difference	***1,994,800.00***

Table 6: Isolated savings 2.

It is now interesting to see how long it will take to recoup the cost of the robot. The investment is set to 8,000,000 NOK. We use today's production numbers of 144 units.

Investment robot	Savings per year	Number of years profit	Number of months
8,000,000.00	1,994,800.00	4.01	48.13

Table 7: Recoup the costs.

The investment will be paid off after 4 years and 1 month.

We look at the annual cost basis of an accounting view

- Assuming that the robot has a lifespan of 20 years, with a depreciation of 5% annually

Accounting					
Robot	**1 month**	**1 year**	**5 years**	**10 years**	**20 years**
Hours	162.50	1,950.00	9,750.00	19,500.00	39,000.00
Salary per hour	760.00	760.00	760.00	760.00	760.00
Costs human res.	***123,500.00***	***1,482,000.00***	***7,410,000.00***	***14,820,000.00***	***29,640,000.00***
Operating costs robot	6,666.66	80,000.00	400,000.00	800,000.00	1,600,000.00
Depreciation robot	33,333.33	400,000.00	2,000,000.00	4,000,000.00	8,000,000.00
Large service				250,000.00	500,000.00
Total costs	***130,166.66***	***1,562,000.00***	***7,810,000.00***	***15,620,000.00***	***31,240,000.00***

Table 8: Accounting robot.

Consequently, the total cost of production over 20 years will be 31.24 million using the robot. The cost of goods is not taken into account.

Accounting					
Manual	**1 Month**	**1 year**	**5 years**	**10 years**	**20 years**
Hours	390.00	4,680.00	23,400.00	46,800.00	93,600.00
Salary per hour	760.00	760.00	760.00	760.00	760.00
Costs human res.	***296,400.00***	***3,556,800.00***	***17,784,000.00***	***35,568,000.00***	***71,136,000.00***

Table 9: Accounting manual.

Using manual labour will cost 56% more than when using an automated process over a period of 20 years.

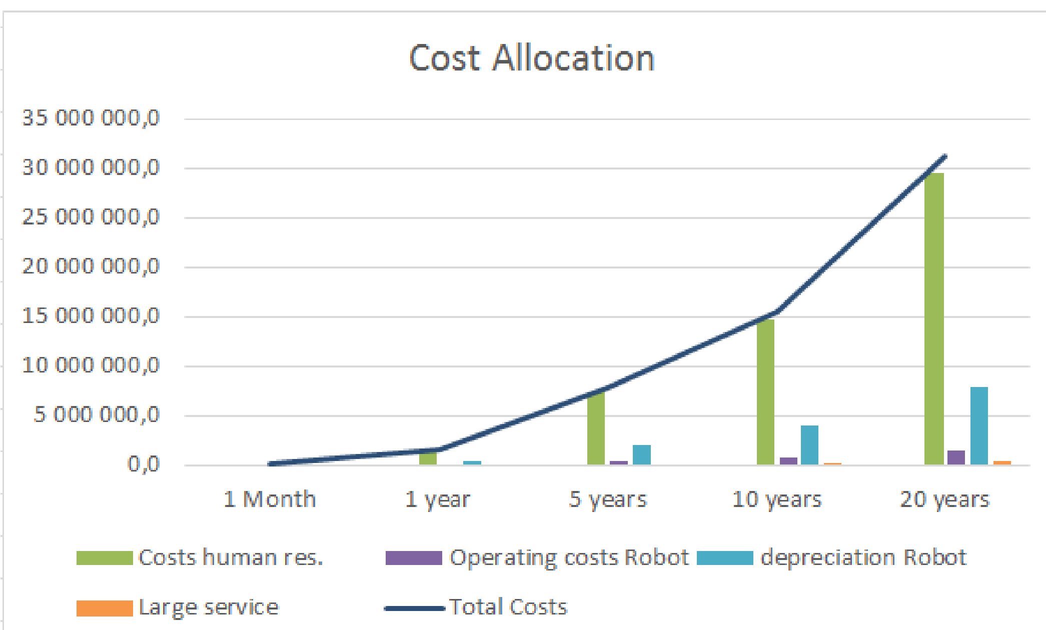

Figure 2: Cost allocation.

Cost allocation accounting shows that the human cost is still the largest cost in the process.

The result of this analysis is that the production can greatly benefit for automation economically.
In addition an automated system offers benefits within safety and quality. We can safely conclude that an investment will benefit KDA greatly in the long run.

7.0 Sources

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Iteration Report

Version	Date	Reviewed by	Approved by	Satus
2.0	15.05.2015	Stian Hovde	Tor Sigurd Breivik	Released

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1.0 Abstract

This document contains the planning and execution of the iterations. Information derives from our Gantt chart and the project plan. Each iteration has a report, stating the success level of the iteration.

2.0 Revision History

Version	Date	Changes	Author
0.1	06.02.2015	• First version of the document.	Elvar Aspelund
0.2	15.02.2015	• Iteration I2 report. Planning iteration E1. • Added priority system to activities. • Updated layout of activity tables.	Elvar Aspelund
0.3	18.02.2015	• Time estimates and removed secondary goal from E1 iteration. • Added info to E1 report.	Elvar Aspelund
0.4	05.03.2015	• Planned iteration E2 and concluded iteration E1.	Elvar Aspelund
0.5	16.03.2015	• Changed chapter 1. • Report for iteration E2. • Corrected iteration table 2.	Elvar Aspelund
0.6	16.03.2015	• Corrected spelling & format of document.	Stian Hovde
1.0	16.03.2015	• First released version.	Elvar Aspelund
1.1	14.05.2015	• Spellcheck & formatting changes.	Katrine Kallevik Stian Hovde
1.2	15.05.2015	• Added final report Transition T1. • Added final estimated hours.	Elvar Aspelund
2.0	15.05.2015	• Final version of document.	Elvar Aspelund

Table 1: Revision table.

3.0 Introduction

The Iteration report document will show the planning of each iteration, and what activities have been included in that iteration. After each iteration is concluded, the team will make a short summary of what was completed, difficulties that were met and how they plan to proceed. Here the proper estimation of time expected for each activity is of importance. As the project has finite amount of time, we will not be able to over spend to much time on any given activity. If an activity is completed before schedule then the extra time can be diverted to others activities. The iteration report does not include time used on internal/external meetings.

4.0 Priority assessment

We have set up a priority list for the activities within each iteration. This is to make the iterations more structured and execution more efficient.

As an example is the priority of activities for robot selection. As we have minimal experience when it comes to robot selection, that will have a higher priority. This is because we have to gather a large amount of information to be able to give a valid conclusion on selecting a robot.

- **Basis for activity priority**

Priority assessment	C	B	A
Consequence of non completion	Small	Medium	Great
Priority	Activities will be graded on level of priority based on the group's knowledge on given subject, and the activities impact on the progression of the project.		
Occurrence	If because of unseen occurrences the activity can not be completed in given time frame.		
Solution	When concluded that the activity will not be completed within given date, the group must halt progress and hold a group meeting, and necessary replanning has to be done.		

Table 2: Activity priority system.

5.0 Planning

- **Inception (I1)**

  No major preplanning.

- **Inception (I2) Week nr: 5, 6, 7**

  First iteration of project plan, requirement spec and test spec will be completed, concluding with the first presentation

Activities	Estimated time	Total time
(A1.1) Idea document	20h	16h
(A1.2) Project plan	140h	136h
(A1.3) Requirement specification	25h	16h
(A1.4) Test specification	30h	26.5h
(A1.5) Risk analysis	15h	7h
(A0.7) First presentation	70h	73,5h

Table 3: Inception 2 (Week 5, 6, 7).

- ## Elaboration (E1) Week nr: 8, 9

Starting and completing the robot selection and economical analysis is the major priority for this iteration. We also start on the test plan, and begin research on primary goal: design of bolt and installation tool.

Activities	**Week nr**	**Priority**	**Estimated time**	**Total time**
(A0) Administrative				
(A0.10) First revision	8	**C**	10h	1h
(A0.12) Test plan	8, 9, (10, 11)	**A**	40h	15h
(A2) Robot selection				
(A2.1) Research	8	**A**	20h	18h
(A2.2) Documentation	8	**B**	20h	1h
(A3) Economic analysis				
(A3.1) Research	8	**A**	25h	13h
(A3.2) Documentation	8	**A**	25h	30.5h
(A4) Design of bolt and installation tool				
(A4.1) Research	8, 9, (10)	**A**	50h	47h
(A4.2) Concept selection	8, 9, (10)	**B**	60h	41h
Activities added to iteration				
(A1.4) Test specification			0h	31h
(A4.8) Documentation (Bolt tool)			0h	4h
Total time used			260h	201,5h

Table 4: Elaboration 1 (Week 8, 9).

- **Elaboration (E2) Week nr: 10, 11**

The economical analysis has been given a higher priority, and has been delegated more work hours for this iteration.

From the Gantt chart we originally planned to start testing and end-design of bolt and installation tool within this iteration. This has been moved to milestone 3. This was done because we were informed by our internal supervisor that for presentation 2 the main focus will be on project progress and concept selection. We have therefore moved forward concept selection for secondary objectives, so that they can be included in presentation 2. The concept selection for the secondary objectives will continue in M3.

Test spec received more attention last iteration, and the test plan will be completed within this iteration. The test plan has a high priority for presentation 2. The economic analysis has to be completed within M3, thus it has a lower priority for this iteration.

Activities	Week nr	Priority	Estimated time	Total time
(A0) Administrative	10, 11	**A**		
(A0.12) Test plan			60h	31,5h
(A3) Economic analysis	10, 11	**B**		
(A3.1) Research			20h	14h
(A3.2) Documentation			40h	12h
(A4) Design of bolt and inst.tool	10	**A**		
(A4.1) Research			10h	9h
(A4.2) Concept selection			10h	25,5h
(A4.8) Documentation	10, M3		20h	20h
(A2) Robot selection	10	**C**		
(A2.2) Documentation			20h	23h
(A7) Design of verification system	11, M3	**C**		
(A7.1) Research	10, 11		10h	11h
(A7.2) Concept selection	11		10h	0h

(A6) Design of promoter and sealant system	11, M3	C		
(A6.1) Research			10h	7h
(A6.2) Concept selection			5h	4.5h
(A6.4) Documentation			5h	13h
(A5)Design of bolt sorting system	11, M3	C		
(A5.1) Research			10h	9h
(A5.2) Concept selection			5h	4h
(A5.4) Documentation			5h	0h
Activities added to iteration				
(A1.4) Test specification			0h	8h
(A2.1) Research (Robot)			0h	8h
(A1.5) Risk analysis			0h	5h
(A1.2) Project plan			0h	14h
Total time used			240h	218,5h

Table 5: Elaboration 2 (Week 10, 11).

- **Elaboration (E3) Week nr: 12, 13, 14**

  This iteration included the second presentation and easter break. Week 14 we started early with exam rehearsals. The plan is to send a copy of the concept technology document to Tronrud Engineering to feedback on our selection process. This iteration has been for research and selection. We will select our primary tool and robot.

Activities	Week nr	Priority	Estimated time	Total time
(A0) Administrative	12	A		
(A0.10) Second revision			10h	0h
(A0.8) Second presentation			40h	84.5h
(A0.2) Internal meetings			4h	5h
(A0.1) External meetings			12h	11h
(A4) Design of bolt and inst.tool		A		

(A4.3) Design	14		20h	0h
(A4.8) Documentation	14		30h	8h
(A5) Design of bolt sorting system	13	**C**		
(A5.1) Research			20h	15h
(A5.2) Concept selection			20h	0h
(A6) Design of promoter and sealant system	13	**C**		
(A6.1) Research			30h	0h
(A6.2) Concept selection			10h	0h
(A6.4) Documentation			10h	0h
(A7) Design of verification system	13	**C**		
(A7.1) Research			30h	19h
(A7.2) Concept selection			20h	3h
Activities added to iteration				
(A4.2) Concept selection Bolt tool			0h	35h
(A8.3) Web page			0h	17h
(A0.6) Iteration report			0h	5h
(A0.3) Internal group meetings			0h	2h
(A0.5) Minutes of meeting			0h	2h
(A1.2) Project plan			0h	1h
(A7.4) Verification system documentation			0h	2h
Total time used			240h	209.5h

Table 6: Elaboration 3 (Week 12, 13, 14).

- **Construction (C1) Week nr: 16, 17**

First iteration of construction, the group will have the main goal of designing and testing the bolt and installation tool for this iteration. Some of the components for the tool will be of the shelf parts from secondhand distributors. The parts that need to be custom designed for our assignment will be driven by the parameters of the shelf components.
The group have decided to do some changes to the overall plan for the coming iterations, instead of working on primary and secondary goals, we will have one iteration that is solely dedicated to our primary technical goal, this is to ensure the completion of the bolt and installation tool.

Activities	Week nr	Priority	Estimated time	Total time
(A0) Administrative	16, 17	B		
(A3.2) Documentation			25h	0h
(A0.1) External meetings			8h	2h
(A0.2) Internal meetings			8h	4h
(A4) Design of bolt and inst.tool				
(A4.3) Design	16, 17	A	80h	107h
(A4.4) Mechanical analysis	17	B	110h	6h
(A4.5) Electrical analysis	17	B	70h	68h
(A4.8) Documentation	16, 17	B	20h	43h
Activities added to iteration				
(A7.4) Verification system Documentation			0h	5.5h
(A4.1) Bolt tool research			0h	16h
(A0.5) Minutes of meeting			0h	0.5h
(A8.3) Web page			0h	1h
(A1.3) Requirement specification			0h	0.5h
(A1.4) Test specification			0h	0.5h
(A7.2) Verification system concept selection			0h	2h
(A2.2) Robot selection documentation			0h	1h

(A6.4) Promoter and sealant documentation			0h	1h
(A0.6) Other admin task			0h	3h
(A0.3) Internal group meetings			0h	2h
(A0.13) General documentation			0h	3h
Total time used			320h	266h

Table 7: Construction 1 (Week 16, 17).

- **Construction (C2) Week nr: 18, 19**

We have restructured our plan for this iteration. Some tasks have been removed, and hours redistributed, this is listed below:

Deleted activity:	Estimated hours		Redistributed hours to activities	Redistributed Estimated hours
A0.4	20h		A4.1	+70h
A0.10	10h		A4.2	+25h
A0.11	10h		A4.3	+170h
A4.6	40h		A4.8	+100h
A4.7	110h		A4.4	+55h
A5.3	30h		A4.5	+15h
A7.3	30h		A8.6 (new)	+40h
			A0.13	+20h
			A8.1	+20h
			A8.2	-30h
Total Hours	270h			485h

Table 8: Redistribution of hours.

the 212 hours that had not been distributed in the project plan, has now been distributed to the given activities in the table above. These are hours that were not included due to end of the extra course the students had this semester. This has always been seen as an extra buffer for the group.

This is the last construction iteration. Here we will conclude all the remaining work. When we receive the simulation tool from Kuka robotics, we will start simulating the process. Selecting the remaining secondary concepts is due in this iteration. We will complete the economical analysis. We will create a promo page and a poster for the bachelor theses, and we will conduct the remaining test on the end effector. The design aspect of the secondary goals has been removed from our project plan, the estimated hours for this task has been relocated to other activities. The construction of our primary goal has also been removed from our project plan, this is because we will only deliver a proof of concept.

Activities	**Week nr**	**Priority**	**Estimated time**	**Total time**
(A0) Administrative	18, 19	**A**		
(A0.1) External meetings			8h	26h
(A0.2) Internal meetings			8h	8h
(A4) Design of bolt and inst.tool	18, 19	**A**		
(A4.3) Design			123h	79h
(A4.4) Mechanical analysis			84h	21.5h
(A4.8) Bolt tool documentation			40h	77h
(A5)Design of bolt sorting system	18, 19	**C**		
(A5.2) Concept selection			26h	1h
(A5.4) Documentation			20h	6h
(A6) Design of promoter and sealant system	18, 19	**C**		
(A6.2) Concept selection			25.5h	0h
(A6.4) Documentation			6h	0h
(A7) Design of verification system	18, 19	**C**		
(A7.2) Concept selection			25h	0h
(A7.4) Documentation			12.5h	0h
(A8) Final documentation	18, 19	**B**		
(A8.4) Poster			15h	9h
(A8.5) A4 promotional page			5h	0h

Activities added to iteration				
A0.14 Iteration report			0h	5h
A0.13 Generell dokumentation			0h	13h
A2.3 Simulation			0h	29h
A0.5 Minutes of meetings			0h	2h
A4.1 Bolt tool research			0h	6h
A2.2 Robot documentation			0h	6h
A8.6 Project end report			0h	17h
A8,2 Final documentation			0h	8h
A1.3 Requirements specification			0h	1h
A0.12 Test plan			0h	2.5h
A1.4 Test specification			0h	1h
A4.5 Bolt tool electrical analysis			0h	41.5h
A0.3 Internal group meetings			0h	0.5h
A0.6 Administrative tasks			0h	2h
A1.2 Project plan			0h	2h
A1.5 Risk analysis			0h	1h
A3.2 Economic documentation			0h	19h
Total time used			320h (+78h)	384h

Table 9: Construction 2 (Week 18, 19).

- **Transition (T1) Week nr: 20, 21, 22**

This is the final iteration. We will be sending a copy of our documents to KDA in week 20, this is because KDA wishes to have a read through before we hand over our final document. The first week of the iteration will mainly be for documentation and last review of document, before we send them to print. The remainder of the iteration will be for the last presentation. KDA has requested an rehersal of the last presentation at their facilities. This will be beneficial for the group as we will get valuable input, before the big day.

Activities	Week nr	Priority	Estimated time	Total time
(A0) Administrative				
(A0.9) Final presentation	21, 22	**A**	240h	240h
(A8) Final documentation				
(A8.1) Final review	20	**A**	20h	34.5h
(A8.2) Final documentation	20	**A**	150h	85.5h
(A8.3) Web page	20	**B**	10h	0h
(A8.4) Poster	20	**A**	15h	15h
(A8.5) A4 promotional page	20		5h	5h
Activities added to iteration				
A0.14 Iteration report			0h	5h
(A8.4) Poster			0h	8h
Total time used			440h	393h

Table 10: Transition 1 (Week 20, 21, 22).

6.0 Iteration report

- **Inception (I1)**

  The first two iterations were set to 3 weeks duration. This is because it is the starting phase of the project and more time is needed to set up the foundation for the project. No major planning was done in the first phase, meaning we all worked together as a team to set up a plan and decide on which systems engineering model that we would follow.

  Starting phase of the project was ad hoc style, meaning we didn't have a specific plan from the beginning. We started researching different systems engineerings models that could be suited for our project.

  Our assignment got more specific during the first inception. Through meetings with our employer we got a more broader view of what they wanted as an end result, and requirements were put on paper.

- **Inception (I2)**

  First revision of tasks have been completed. After the first presentation we got some feedback on what needed to be changed. Changes had to be done with the terminology in the project plan regarding choice of systems engineering model. Much more clarity in the test spec was needed.

  We went to Kongsberg Automotive to get inspiration at information on how they have automated their production line.

  During the iteration we noted that some changes to the mission plan regarding distribution of time per activity had to be done. To give a better overview of time distribution per activity and easier transition to the iteration report document. No major hurdles to report from this iteration.

- **Elaboration (E1)**

After discussion with our employer, changes were done to the requirement spec. The requirement for robot went from minimum payload of 60 kg to 10 kg.

Changes to the iteration were done. We removed secondary goal activities and pushed forward design of bolt and installation tool activity with one week. This was done due to a meeting with Tronrud Engineering would take place in week 9, and we would receive additional info for selecting a suited robot.

The meeting with Tronrud was delayed to week 10. This will not have major impact on our next iteration, as we have re planned and taken into consideration that the robot selection would be delayed. This will not affect the progress of our project, as we are still able to continue concept selection for the assembly tool, and robot selection will be done on a later date. The robot selection does not affect other elements of the project.

After feedback from the first presentation, we used additional time for the test specification activity. We have also put extra attention on the economical analysis. This deviates some from what we originally planned, but seeing how important this element is to our employer it has been given extra attention. These decisions will be taken into the planning of the next iteration.

- **Elaboration (E2)**

The plan for this iteration was to focus on economical analysis, concept selections and test plan. Time wise we have been able to follow our plan for the iteration rather good, some members of the group have been sick, this has not had a major impact on the progress of the iteration.

We have received numbers from our employer to finish the first draft of the economical analysis. For the robot selection we have been in contact with the robot suppliers, and received valuable information. The first draft of the document is complete, and the selection process will be due in M3.

This iteration has had a lot of focus on concept brainstorming. Primary goal concept are nearing selection, while secondary goals need some additional time, as is planned in the coming iterations. First draft of the test plan has been completed as planned.

Additional time was given to the test spec, to do last finish touchup for the second presentation. We have also added use-cases and test-cases to our project plan.

- **Elaboration (E3)**

The iteration Started with the second presentation , week 12 was mainly dedicated to the presentation, creating the Prezi presentation and rehearsals. We received good feedback from our presentation, the second revision was therefore a bit shorter than estimated.

We had a meeting with Tronrud Engineering at KDA. During the meeting the focus was on concept selection, what our thoughts were on the assignment, and Tronrud gave us useful information for our selection process. They were positive for the work we have done so far, and we were invited to come and visit them in Hønefoss. This could really benefit the group's knowledge on how a large scale company works toward automating processes for other businesses.

After we concluded with our concept selection process for the bolt assembly tool and robot selection, we sent a draft of the concept technology document to Tronrud, so that they could give us proper feedback on our selection process.

- **Construction (C1)**

After a group consultation we have decided to use this iteration for the assembly tool, our primary goal. We received feedback on our selection process from Tronrud, and we have now made choices and selected components for our end effector. The goal has been to use as many off the shelf parts as possible, as this will make service and ordering new parts much easier. The custom designed part for our end effector is mainly completed, last touch up will be done in the next iteration. We have conducted structural tests using FEM (Finite element method) and done electrical analysis using Matlab.

- **Construction (C2)**

We finally received the simulation tool from KUKA Robotic. We have started the simulation studies, which will be featured in our final presentation. The design of the end effector has been completed, and we have conducted test for the mechanical components.

We decided to reduce the number of test for the nutrunner, as this is based on Alcoa’s existing design. We have tested the new gears, as these have been reduced in size. We concluded that the tool housing would not undergo critical stresses. We also used Matlab to do electrical studies to verify the workings of the DC Motor.

The economical analysis is complete, here we used the number we were given from KDA. Due to security reasons we were not able to get detailed numbers of every aspect of the process, but this was not a critical aspect. We used the numbers given, and created a good estimate.

We had the pleasure of visiting Tronrud Engineering, this was truly a great experience, and we got good feedback. We have also consulted with them over e-mail. After feedback from Tronrud we have conducted our robot selection. We also consulted with Tronrud regarding material selection for the designed parts.

- **Transition (T1)**

For this iteration we have the main task of completing document, final review and spellcheck. We added an extra week to the iteration, this is the third presentation week. As the project has already been handed in when the presentation is held, we added it to the last iteration.

Everything is going as planned. Minor adjustments have been made to many of the documents, rewriting sentences and general spellcheck. We have created the final report, the poster and promo page has been made. And we have started to create a simulation of the robot cell and the tool itself. This will be part of the third presentation. With this we conclude our project.

Final Report

Version	Date	Reviewed by	Approved by	Satus
1.0	15.05.2015	Elvar Aspelund	Tor Sigurd Breivik	Released

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1.0 Abstract

This document serves as a final report of the project. Here the project group reflects both individually and collectively over the work that has been done and the experience we have gained over the last months.

2.0 Revision History

Version	Date	Changes	Author
0.1	03.05.2015	• First version of the document	Stian Hovde
1.0	15.05.2015	• First released version of the document	Kristoffer Lund Stian Hovde

Table 1: Revision table.

3.0 Project Evaluation

3.1 Project model

The project model that we used during this project has been a modified version of the Unified Process model. At first we had planned to follow UP, but we quickly realized we had to modify it to make it fit with our project.

We got some feedback after the first presentation from our internal examiner about our model. She suggested that we implemented use-case diagrams, and that helped with creating our full system tests and greatly improved our understanding of who we had to consider when we were designing the system.

The iteration reports helped us to plan what we were going to work with in detail, and having two weeks iterations kept our pace up during the project. With the iterations we were easily able to adjust to changes during the project. After each iteration we concluded on what had been done, and planned the next iteration, as the project has had a life of its own. This meant when we received input from external sources, or our own internal supervisor, we were able to adjust to changes. We created an iteration report document, so that we could have an overview of the changes and thoughts we had during each iteration.

We have learned what a properly planned project model has to offer to a project like this. It can be tedious at first, but the reward later on is an excellent work method that offers a great deal of flexibility.

3.2 Project work

Early in the project we decided that the best way to do group work for us, was to have a permanent room at school. This enabled us to sit together every scheduled work day and ask each other questions and throw ideas around the table. Thus increasing the efficiency of our work.

We have also had the opportunity to work one day of the week at the offices of KDA in Kongsberg. This helped us alot with all the question we had about how they make their products today, and enabled us to quickly resolve them. One of the challenges during the project has been the fact that we have not been able to see, first hand the manufacturing process. Although our employer has gone to great lengths to ensure that we have gotten the necessary information needed to complete the assignment. If we were able from day one to go to the assembly station to see all the different aspects of the assembly process, this would have given us valuable first hand insight of the workings of creating an aerospace part. But we met the challenge with optimism, and feel that the end result of our project reflects that we truly have been able to overcome this challenge.

The group dynamics has worked well since we have know each other for years now. So we haven't had any surprises in terms of work quality and work enthusiasm.

3.3 Challenges

At the start of the project, we suspected that the lack of knowledge between us of automation and robotics was going to be the most difficult challenge. However to our surprise this wasn't as difficult as we anticipated, since there are many educational books and documents available.

What we learned was to use our project model to evaluate and rank the different challenges from high to low risk of interfering with the progress of our project. We then tackled those with the highest risk first to ensure a healthy progress in our project.

3.4 Final result

When we started this project, we wanted to come to a point where we could test a physical prototype. This turned out however to be an ambitious goal, due to the complexity needed to successfully install the bolts into the product.

Although we did not come to this point, we believe we are not far off from where we wanted to be. We have a design which is mostly made out of components that can be ordered. This means that our next step in the project would have been to order and manufacture all the components, put it all together and start prototype testing. Which in our minds is not far off what we wanted to do in the beginning of January. All things considered we can be proud of what we have accomplished.

3.5 Presentations

During our project we have had two presentations. The third and final will take place after this document is written. The greatest challenge during these presentations has been to present a subject that is well known to us, but not to our listeners. Trying to convey this in a good way, and make our thoughts understandable, has been an important focus for us during preparations.

3.6 Individual evaluation

3.6.1 Katrine Kallevik

This has been an incredibly exciting bachelor assignment. I've learned a lot, and also got a lot more interested in automation processes and robotics than I had when we started. We have been fortunate to be involved in company visits, where they specialize in this area. We have also been very fortunate to have had coaches who have shown great interest in what we were working on, and trying to help us as best they could. The task has been challenging at times, but we have found solutions that we are proud of. I've learned a lot about how it is to work as a team over a long period. I think we have managed it incredibly well. I am very proud of our finished product.

3.6.2 Elvar Aspelund

This has truly been an great experience. During the project we have gotten an inside look into the workings of automating production for companies. We visited Kongsberg Automotive and Tronrud Engineering, they gave us a tour of their facilities and we received valuable information.
When we started the project, we had rather limited knowledge when it came to automating production lines, as had our employer. So the group worked together and we collectively have gained a lot of new knowledge. Today we have a vast insight into the workings of automating a production line. All the different aspects that has to be taken into considerations, for the robot cell to work as it should.

The teamwork has been really good, throughout the project. We have had no problems when dividing tasks between the group members. Each have taken their responsibility to see that the task is completed. Overall the bachelor thesis has been a fun, educational and a challenging experience.

3.6.3 Stian Hovde

Already having an interest in the products being produced at Arsenalet, I was very excited to get a project from them for our bachelor assignment. Working on automating their production line has been both challenging and educational. I am proud of our final product, and feel like it is a good starting point for KDA to further develop the automation process. Overall, I am very satisfied with how our project has been, and believe it is a well suited ending to three years of study.

3.6.4 Kristoffer Lund

This project has been exciting and educational right from the beginning. I have learned a lot about automation and not just robotics. And used knowledge i have learned in school to design, test and verify. Our group has worked well together, since we mostly have been working in the room together. This enabled us to quickly resolve problems we encountered. I have also enjoyed the field trips we made to Kongsberg Automotive and Tronrud. They gave us valuable information on design methods and how automation can greatly improve production.

3.7 Final thanks

As our final words, we would like to thank everyone that has helped us along the way. Without these people, the project would not be where it is today.

- Karoline Moholth for her work as internal examiner, and good and constructive feedback during our project
- Kjell Enger for his work as internal supervisor, and for guiding us in the right direction along the way.
- Tor Sigurd Breivik for his work as external supervisor and examiner, and an endless source of help and information.
- Kristian Nilsen, Alf Pettersen, Bjørn Ivar Nilsen and everyone else at Kongsberg Aerostructures, for giving us this project and providing invaluable support.
- Cato Horten, Johnny Moen, Olav Tronrud and everyone else at Tronrud Engineering, for great help and assistance, and a trip we will never forget.
- Jan Myrene and Ulf Bræin, for an insightful tour of the facilities of Kongsberg Automotive in Hvittingfoss.
- Frode Grimsbø at KUKA Norway, for technical help on robotics.

4.0 Timesheets

4.1 Katrine Kallevik

Description	Activity number	Hours		Description	Activity number	Hours
External meetings	A0.1	16,00		Bolt tool research	A4.1	10,00
Internal supervisor meeting	A0.2	11,00		Bolt tool concept selection	A4.2	8,00
Internal group meetings	A0.3	5,00		Bolt tool design	A4.3	118,50
Minutes of meetings	A0.5	-		Bolt tool mechanical analysis	A4.4	4,00
Administrative tasks	A0.6	17,50		Bolt tool electrical analysis	A4.5	-
First presentation	A0.7	22,00		Bolt tool documentation	A4.8	2,00
Second presentation	A0.8	29,5		Sorting research	A5.1	22,00
Third presentation	A0.9	60,00		Sorting concept selection	A5.2	8,00
Test plan	A0.12	5,00		Sorting documentation	A5.4	4,00
General documentation	A0.13	38,00		Promotor and sealant research	A6.1	3,00
Iteration report	A0.14	-		Promotor and sealant concept selection	A6.2	6,00
Idea document	A1.1	-		Promotor and sealant documentation	A6.4	-
Project plan	A1.2	7,50		Verification research	A7.1	-
Requirements specification	A1.3	2,00		Verification concept selection	A7.2	-
Test specification	A1.4	68,00		Verification documentation	A7.4	-
Risk analysis	A1.5	18,50		Final review	A8.1	13,5
Robot research	A2.1	-		Final documentation	A8.2	5,5
Robot documentation	A2.2	-		Web page	A8.3	-
Robot simulation	A2.3	-		Poster	A8.4	-
Economic research	A3.1	15,5		Promotional A4 page	A8.5	-
Economic documentation	A3.2	35,00		Project end report	A8.6	-
					SUM	**555,00**

Table 2: Timesheet Katrine.

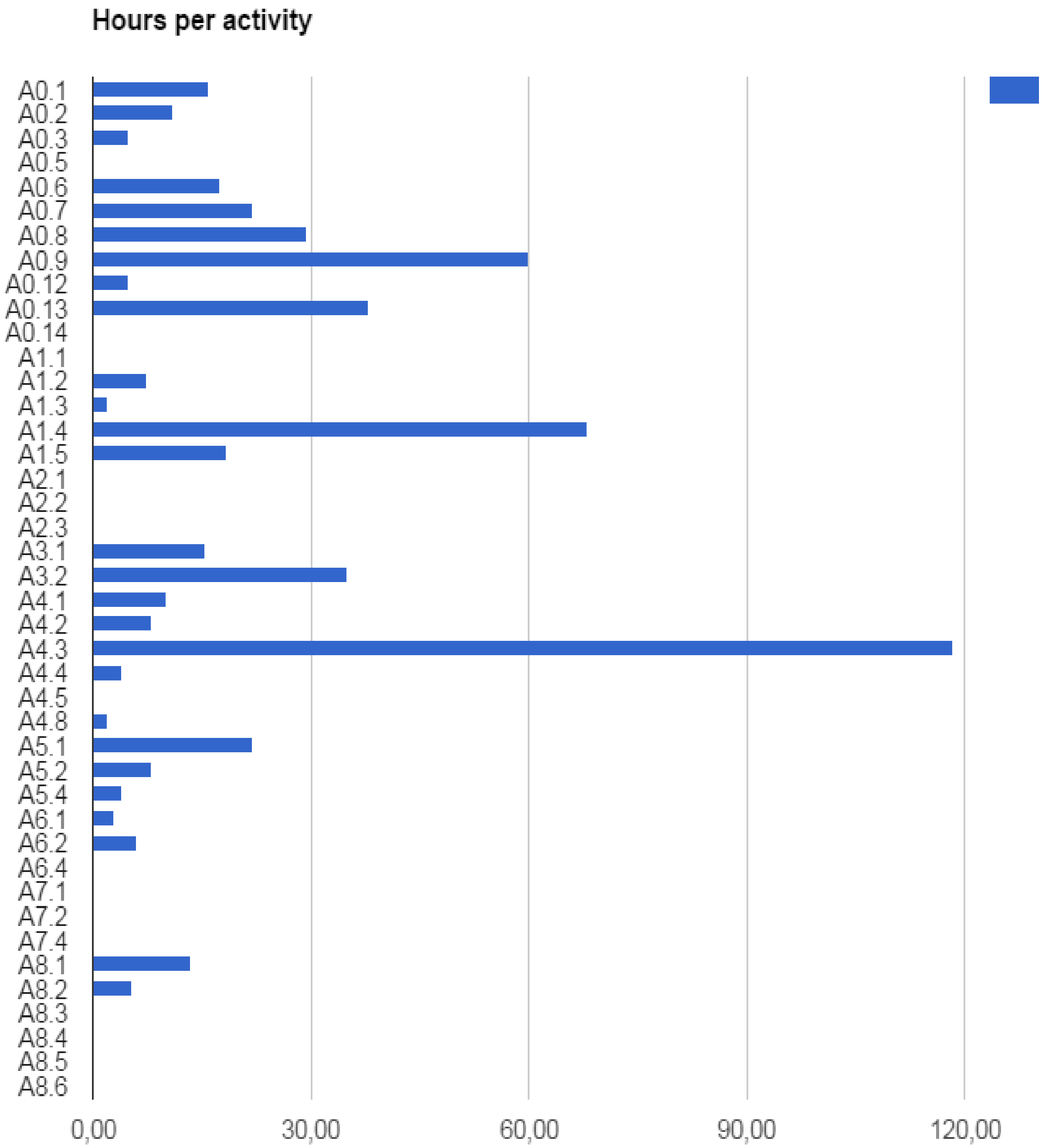

Figure 1: Hours per activity Katrine.

4.2 Elvar Aspelund

Description	Activity number	Hours		Description	Activity number	Hours
External meetings	A0.1	16,50		Bolt tool research	A4.1	32,00
Internal supervisor meeting	A0.2	12,50		Bolt tool concept selection	A4.2	64,00
Internal group meetings	A0.3	1,50		Bolt tool design	A4.3	58,00
Minutes of meetings	A0.5	-		Bolt tool mechanical analysis	A4.4	30,50
Administrative tasks	A0.6	8,00		Bolt tool electrical analysis	A4.5	-
First presentation	A0.7	21,00		Bolt tool documentation	A4.8	44,50
Second presentation	A0.8	18,00		Sorting research	A5.1	5,00
Third presentation	A0.9	60,00		Sorting concept selection	A5.2	1,00
Test plan	A0.12	-		Sorting documentation	A5.4	6,00
General documentation	A0.13	8,00		Promotor and sealant research	A6.1	3,00
Iteration report	A0.14	20,50		Promotor and sealant concept selection	A6.2	9,00
Idea document	A1.1	-		Promotor and sealant documentation	A6.4	10,00
Project plan	A1.2	93,00		Verification research	A7.1	-
Requirements specification	A1.3	-		Verification concept selection	A7.2	-
Test specification	A1.4	-		Verification documentation	A7.4	-
Risk analysis	A1.5	-		Final review	A8.1	5,00
Robot research	A2.1	14,00		Final documentation	A8.2	15,00
Robot documentation	A2.2	1,50		Web page	A8.3	-
Robot simulation	A2.3	8,00		Poster	A8.4	15,00
Economic research	A3.1	-		Promotional A4 page	A8.5	5,00
Economic documentation	A3.2	-		Project end report	A8.6	1,00
					SUM	**586,50**

Table 3: Timesheet Elvar.

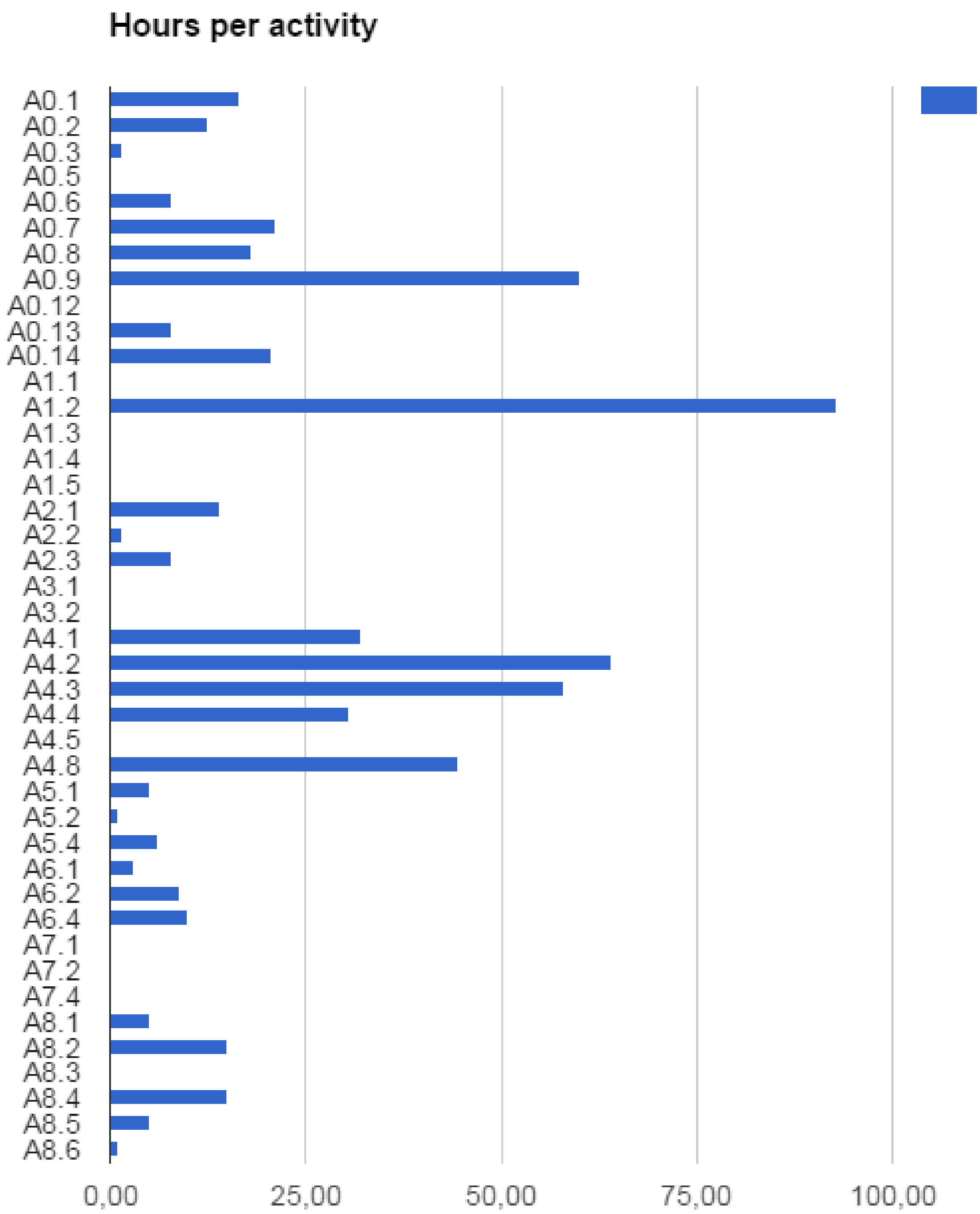

Figure 2: Hours per activity Elvar.

4.3 Stian Hovde

Description	Activity number	Hours		Description	Activity number	Hours
External meetings	A0.1	21,00		Bolt tool research	A4.1	46,00
Internal supervisor meeting	A0.2	13,00		Bolt tool concept selection	A4.2	21,50
Internal group meetings	A0.3	7,50		Bolt tool design	A4.3	50,50
Minutes of meetings	A0.5	3,50		Bolt tool mechanical analysis	A4.4	-
Administrative tasks	A0.6	-		Bolt tool electrical analysis	A4.5	-
First presentation	A0.7	25,00		Bolt tool documentation	A4.8	52,50
Second presentation	A0.8	21,00		Sorting research	A5.1	-
Third presentation	A0.9	60,00		Sorting concept selection	A5.2	-
Test plan	A0.12	0,50		Sorting documentation	A5.4	-
General documentation	A0.13	12,50		Promotor and sealant research	A6.1	1,00
Iteration report	A0.14	1,00		Promotor and sealant concept selection	A6.2	-
Idea document	A1.1	28,00		Promotor and sealant documentation	A6.4	4,00
Project plan	A1.2	13,00		Verification research	A7.1	7,00
Requirements specification	A1.3	29,00		Verification concept selection	A7.2	7,00
Test specification	A1.4	2,50		Verification documentation	A7.4	7,50
Risk analysis	A1.5	-		Final review	A8.1	5,00
Robot research	A2.1	24,00		Final documentation	A8.2	42,50
Robot documentation	A2.2	26,50		Web page	A8.3	17,00
Robot simulation	A2.3	23,50		Poster	A8.4	-
Economic research	A3.1	-		Promotional A4 page	A8.5	-
Economic documentation	A3.2	-		Project end report	A8.6	3,00
					SUM	**576,00**

Table 4: Timesheet Stian.

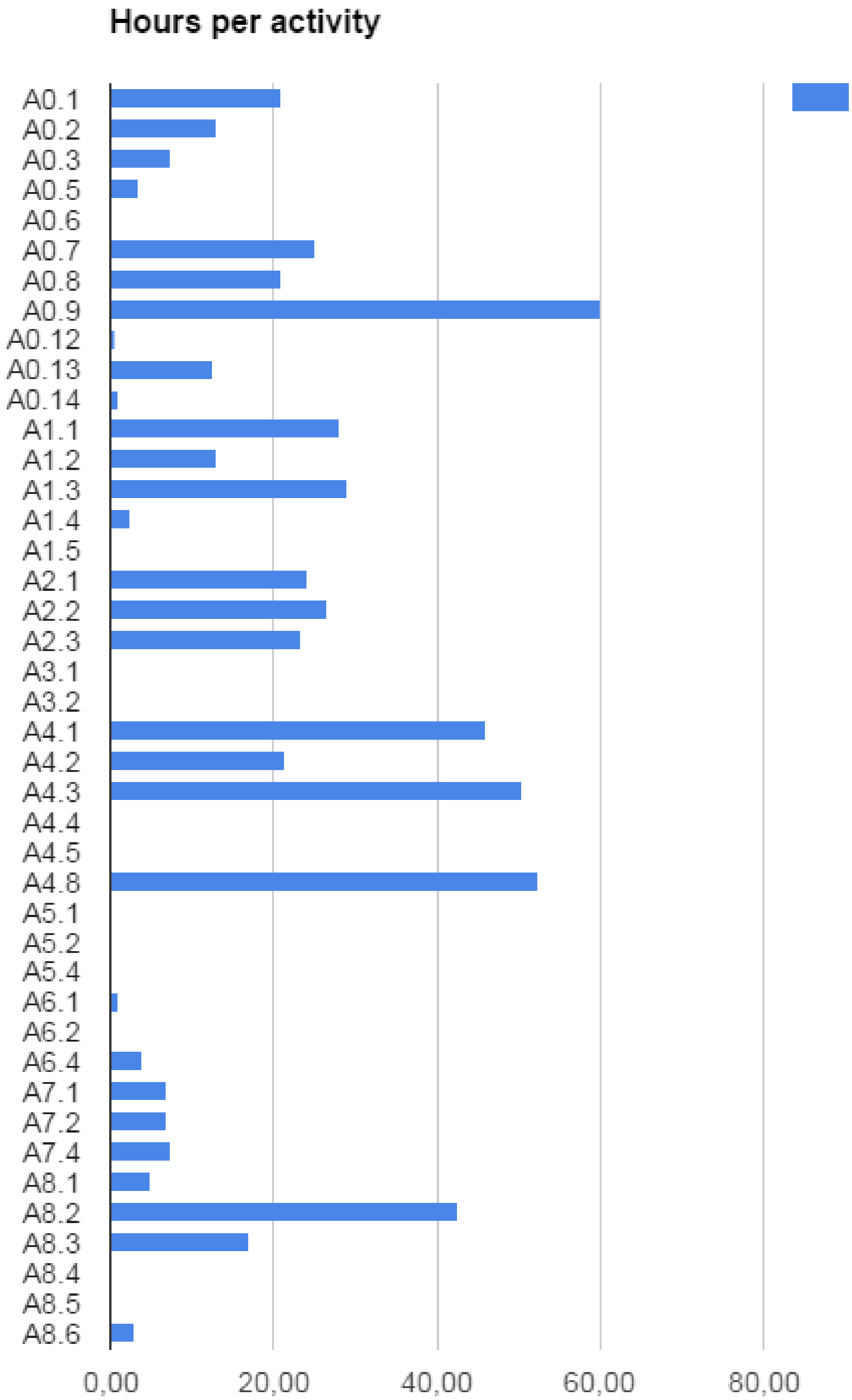

Figure 3: Hours per activity Stian.

4.4 Kristoffer Lund

Description	Activity number	Hours		Description	Activity number	Hours
External meetings	A0.1	20,00		Bolt tool research	A4.1	-
Internal supervisor meeting	A0.2	11,00		Bolt tool concept selection	A4.2	11,50
Internal group meetings	A0.3	7,50		Bolt tool design	A4.3	-
Minutes of meetings	A0.5	4,00		Bolt tool mechanical analysis	A4.4	-
Administrative tasks	A0.6	-		Bolt tool electrical analysis	A4.5	105,50
First presentation	A0.7	24,00		Bolt tool documentation	A4.8	44,00
Second presentation	A0.8	18,00		Sorting research	A5.1	-
Third presentation	A0.9	60,00		Sorting concept selection	A5.2	-
Test plan	A0.12	32,50		Sorting documentation	A5.4	-
General documentation	A0.13	-		Promotor and sealant research	A6.1	-
Iteration report	A0.14	-		Promotor and sealant concept selection	A6.2	-
Idea document	A1.1	-		Promotor and sealant documentation	A6.4	-
Project plan	A1.2	72,50		Verification research	A7.1	26,00
Requirements specification	A1.3	-		Verification concept selection	A7.2	-
Test specification	A1.4	3,50		Verification documentation	A7.4	-
Risk analysis	A1.5	-		Final review	A8.1	5,00
Robot research	A2.1	-		Final documentation	A8.2	38,00
Robot documentation	A2.2	-		Web page	A8.3	-
Robot simulation	A2.3	-		Poster	A8.4	-
Economic research	A3.1	21,00		Promotional A4 page	A8.5	-
Economic documentation	A3.2	28,00		Project end report	A8.6	13,00
					SUM	**545,00**

Table 2: Timesheet Kristoffer.

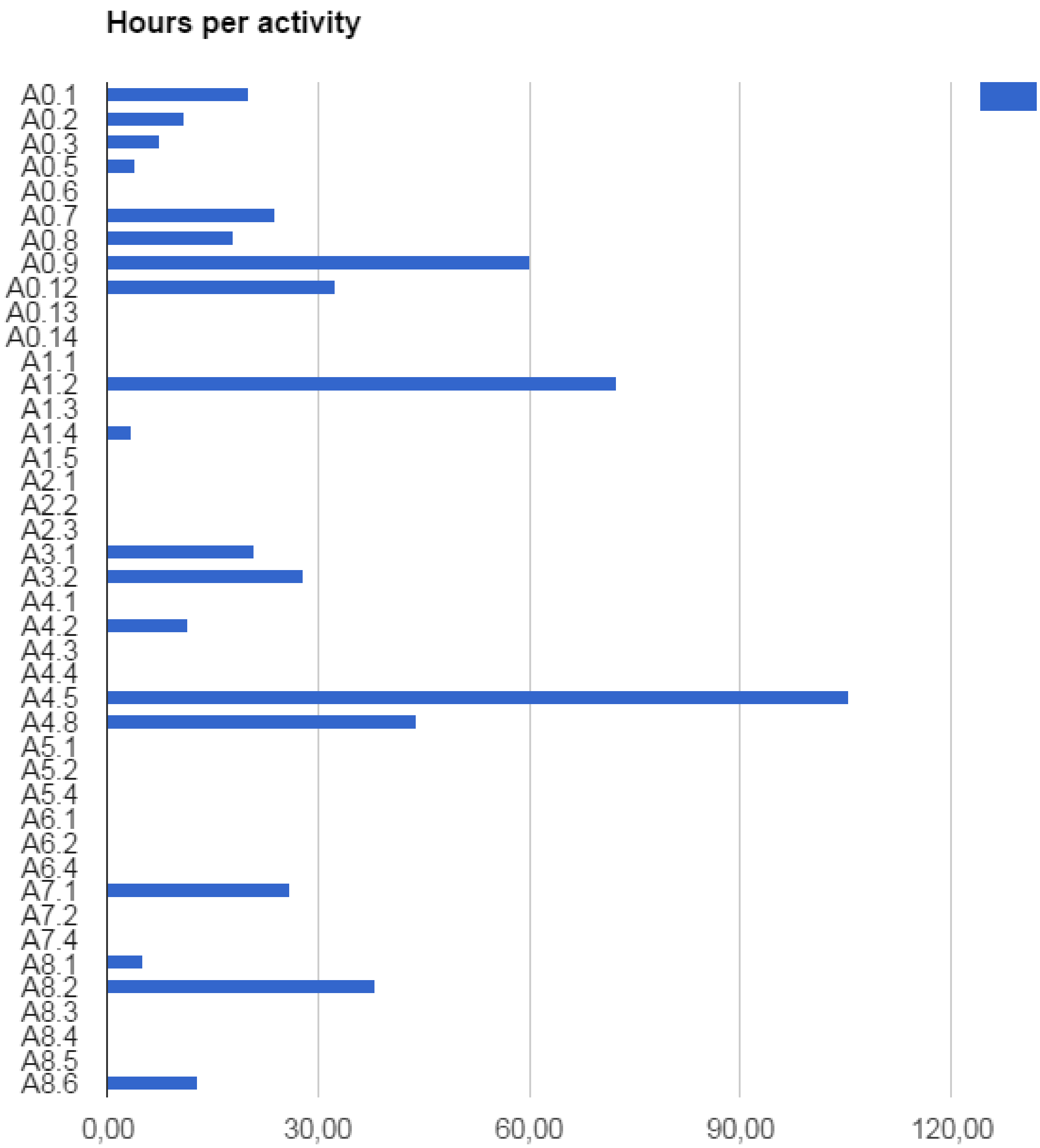

Figure 4: Hours per activity Kristoffer.