Sensur av hovedoppgaver

Universitetet i Sørøst-Norge
Fakultet for teknologi og maritime fag

Prosjektnummer: **2018-14**
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Prosjektnavn/Project name
Elektrisk Giraktuator
Electric Gear Actuation

Utført i samarbeid med: Kongsberg Automotive

Ekstern veileder: Kristian Ahlberg

Sammendrag: Oppgaven tar for seg en løsning for elektrisk gir aktuering. Løsningen som er valgt er radiell innkobling med en solenoid bak hver tann i girsystemet.

Stikkord:
- Elektrisk
- Gir
- Aktuering

Tilgjengelig: JA

Prosjekt deltagere og karakter:

Navn	Karakter
Arild Bernhardsen	
Vemund Bakka	
Yayun Chen	
Torjus Haugerud	
Kristian Risnes	

Dato: 8. Juni 2018

Henning Gundersen Intern Veileder	Karoline Moholth Intern Sensor	Kristian Ahlberg Ekstern Sensor

General

Project Name :	Electrical Gear Actuator

Student:	Kristian Leth Risnes
Discipline :	Electrical Engineer
Student number :	137357
Email :	kristian.risnes@gmail.com
Student:	Yayun Chen
Discipline :	Machine Engineer
Student number :	141708
Email :	edithchen03@gmail.com
Student:	Torjus Haugerud
Discipline :	Machine Engineer
Student number :	134463
Email :	Torjushaugerud168@hotmail.com
Student:	Arild Bernhardsen
Discipline :	Machine Engineer
Student number :	137434
Email :	Arild.bernhardsen@gmail.com
Student:	Vemund Bakka
Discipline :	Electrical Engineer
Student number :	137431
Email :	Vemundbakka@gmail.com
Educational Institute :	University of Southeast Norway
Address :	Hasbergs vei 36, 3616 Kongsberg
Tutor :	Henning Gundersen
Contractor :	Kongsberg Automotive
Address :	Dyrmyrgata 48, 3611 Kongsberg
Contact Persons :	Kristian Ahlberg & Steffen Johnsen

Abstract

Kongsberg Automotive wants to replace their existing transmission system, and have therefore given an assignment; develop an electrical linear gear actuation system. In this report you are guided through all the steps to make this system possible, and all the different concepts that has been evaluated, before the project team have decided what is the best solution after two and a half year with experience from USN.

Contents

List of Figures

List of Tables

1 Introduction

The project team was given a problem from Kongsberg Automotive; heavy duty vehicle of today uses pneumatic or hydraulics to make gear changes, but Kongsberg Automotive sees a untouched market with using an electrical solution instead. Additionally, the regulatory organs seems to be moving in a direction where fully electric vehicles are favoured.

People who operates heavy duty vehicles, such as truck drivers, want an automatic transmission instead of a manual transmission. The problem with using the standard automatic transmission technology, is that it cannot handle the power from heavy duty vehicles and will therefore breakdown. The solution for this in 2018 is to transform a normal manual transmission, into an automatic manual transmission with the use of pneumatic or hydraulic to make the linear movement, and then use a GCU, Gear Control Unit, to control the motion.

There are different reasons for leaving the pneumatic/hydraulic solutions but the main reason is; since a truck is using a combustion engine and an electrical control unit for the engine. It will be a better solution to use an electrical gear actuator for the transmission, instead of adding a second control system for hydraulic/pneumatic actuation.

The task for the electrical actuator is to make three different linear motion; backward, neutral and forward. A gear actuator is until now been done with a shift fork, that goes from the axle inside the transmission and through it where it is attached to the hydraulic or pneumatic actuation system. When making this actuation movement electric, there is a new possible solution; attach the actuator directly on the gear, which is inside the transmission.

1.1 KA

Kongsberg Automotive is a local placed company here in Kongsberg, which have specialized in heavy duty vehicles, but do also deliver parts to the car industry. Kongsberg Automotive is mostly known for their AMTs (Automated Manual Transmissions) for trucks, but they also deliver parts to Jaguar, Land Rover/Range Rover and other car brands. To the car industry they deliver everything from hood cables, to transmission parts.

2 Project Planning

2.1 Project model: Unified Process

After reviewing and comparing several project models as displayed in the Pugh matrix in figure 1. The Unified Process has become the one for this project.

Pugh matrix for the project model selection

Evaluation Criteria \ Project model	Unified Process	CAFCR	Waterfall	Vee Model	Agile/Scrum	The Spiral Model
	Points: 1-5					
Iterative	5	5	0	1	5	5
Handle change	4	4	1	2	4	4
Adaptive approach	4	3	3	3	4	3
Process simplicity	3	3	5	5	4	3
Flexibility	4	3	1	1	4	3
Team collaboration	4	4	4	4	5	4
Traceability	4	4	3	4	3	4
Documentation	5	4	5	4	3	4
Sum Points	33	30	22	24	32	30

Figure 1: Pugh matrix for project model selection

The Unified Process is not only a software engineering process, but also a process framework that can be adapted and extended to suit the needs of a project. Here a workflow known as Knowledge Base Development has been added in this project model. Knowledge Base Development is when the team learns new knowledge or find solutions to a problem, record this knowledge or solution in a simple way that can be used for the same problem in the future. This is an efficient method that is being used by KA.

The modified Unified Process becomes as displayed in figure 2. Vertical axis represents all workflows, which are visited through every iteration under four phases (Inception; Elaboration; Construction and Transition). For more information about the project model, please refer to Project Model report.

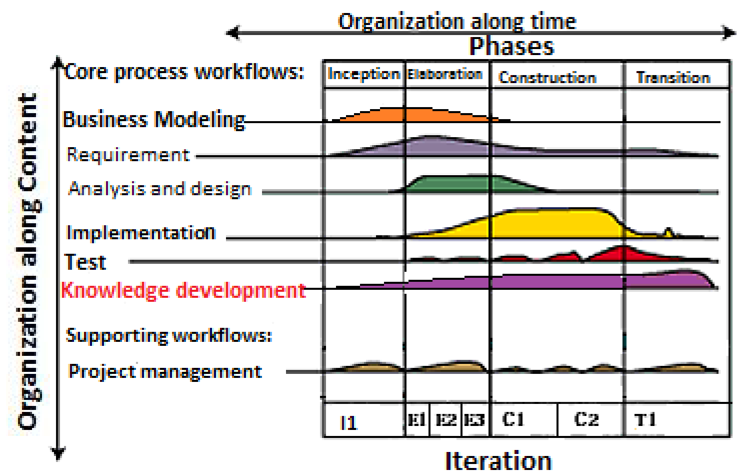


Figure 2: Modified Unified Process for EGA
[3]

2.1.1 Project Schedule

According to the Unified Process the project is divided into four phases and every phase includes different iterations. The schedule for every iteration is displayed in figure 3, which is below.

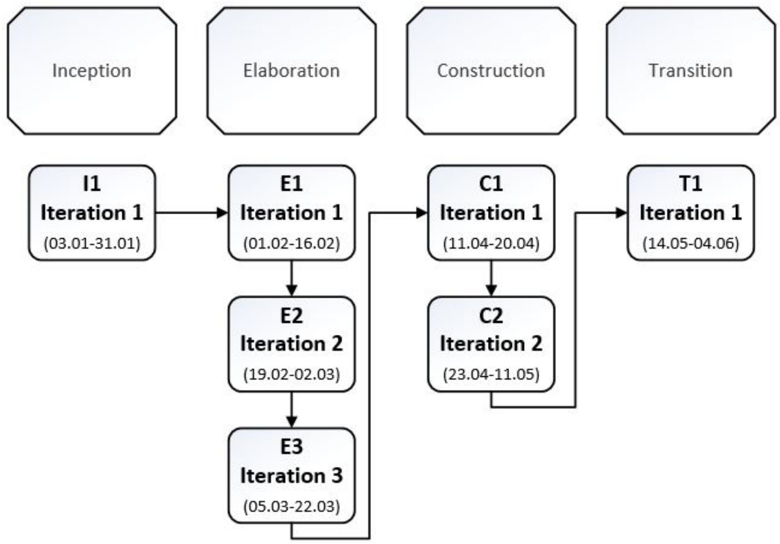


Figure 3: Iteration schedule

The main activity for every iteration is displayed below in figure 4. Meanwhile the activity list has been made for every iteration (see example figure 5). For more information about the iteration activity list, please refer to the Iteration Report.

In order to control the project plan better, the team has used a Gantt chart to plan the schedule and follow up the project. An example from the Gantt Chart has been displayed as the figure 6, which is below. To see a Gantt chart over the project, pleas refer to Gantt overview.

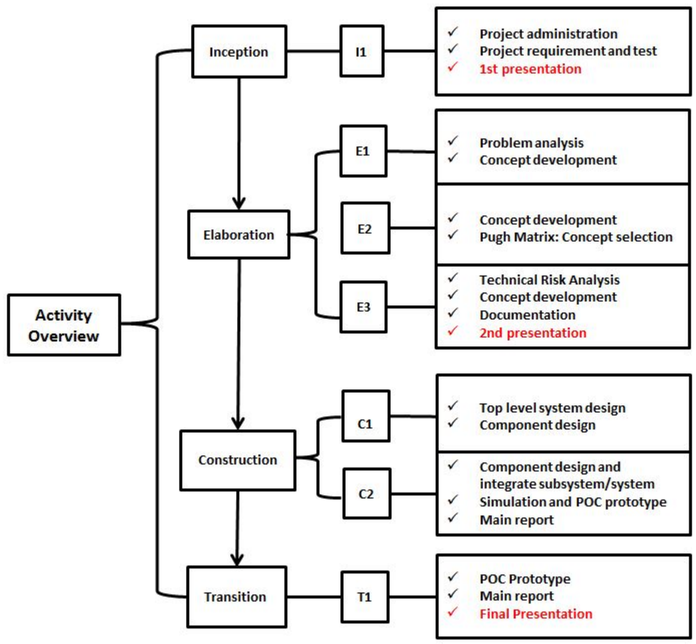


Figure 4: Main activities of project

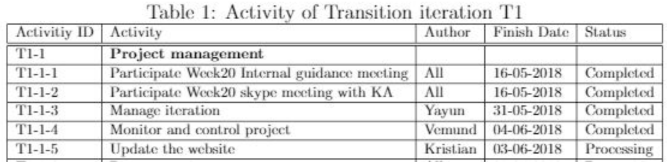
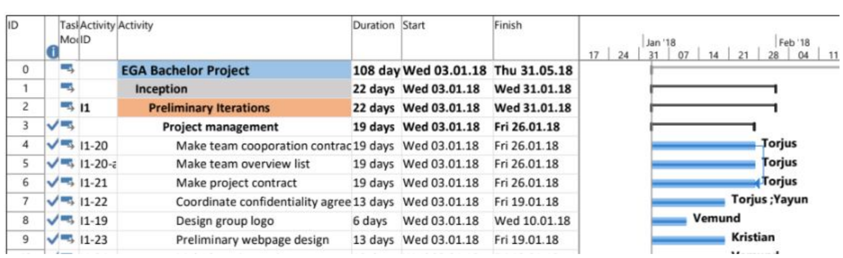


Table 1: Activity of Transition iteration T1

Activitiy ID	Activity	Author	Finish Date	Status
T1-1	**Project management**			
T1-1-1	Participate Week20 Internal guidance meeting	All	16-05-2018	Completed
T1-1-2	Participate Week20 skype meeting with KA	All	16-05-2018	Completed
T1-1-3	Manage iteration	Yayun	31-05-2018	Completed
T1-1-4	Monitor and control project	Vemund	04-06-2018	Completed
T1-1-5	Update the website	Kristian	03-06-2018	Processing

Figure 5: An example of Activity list



ID	Task Mode	Activity ID	Activity	Duration	Start	Finish
0			EGA Bachelor Project	108 day	Wed 03.01.18	Thu 31.05.18
1			Inception	22 days	Wed 03.01.18	Wed 31.01.18
2		I1	Preliminary Iterations	22 days	Wed 03.01.18	Wed 31.01.18
3			Project management	19 days	Wed 03.01.18	Fri 26.01.18
4		I1-20	Make team cooporation contrac	19 days	Wed 03.01.18	Fri 26.01.18
5		I1-20-a	Make team overview list	19 days	Wed 03.01.18	Fri 26.01.18
6		I1-21	Make project contract	19 days	Wed 03.01.18	Fri 26.01.18
7		I1-22	Coordinate confidentiality agree	13 days	Wed 03.01.18	Fri 19.01.18
8		I1-19	Design group logo	6 days	Wed 03.01.18	Wed 10.01.18
9		I1-23	Preliminary webpage design	13 days	Wed 03.01.18	Fri 19.01.18

Figure 6: An example of Gantt chart project plan

3 Process

3.1 Stakeholders

In a school / company project such as this, it is important to see all the different key actors. The difference from a university project and a ordinary project, is that the project team is graded from the teacher and not only for what they deliver to the customer. Since this project have these two important key actors, customer Kongsberg automotive and censors from the university, the project team decided to make a stakeholder diagram. The stakeholder diagram is suitable to see how and who the project relates to and how they relate to each other.

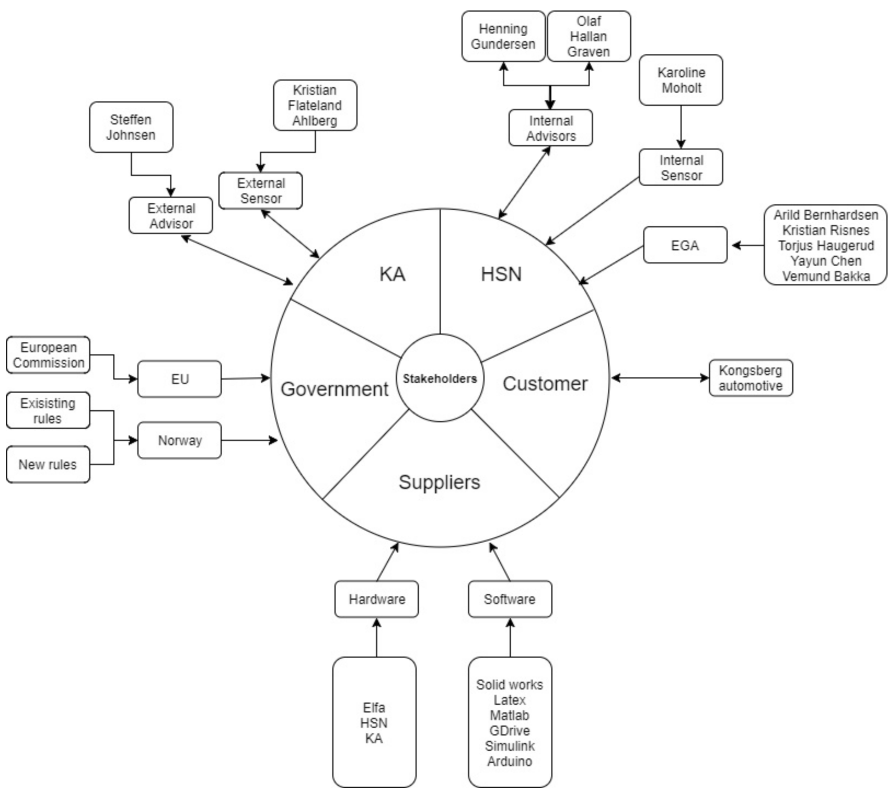


Figure 7: Stakeholder Diagram

To see more information about the different stakeholders, see stakeholder report.

3.2 Requirements & Tests

3.2.1 Requirements

Some of the requirements was given from Kongsberg Automotive, and some was made by the project team. A hierarchical structure with main requirements or categories were made, and then the requirements was placed under the correct hierarchy.The same system was also developed for the tests, and to make the navigation easy; hyperlinks was made between requirements ID and test ID. In addition, EGA wanted to have the ability to trace the requirement back to its owner or stakeholder. Therefore a stakeholder column was added, this way it is possible to track the results from the test back to the stakeholder.

For simplicity when dealing with larger amounts of requirements, Excel have a functionality called "grouping" that have been used. This means that it is possible to open or close categories and subcategories of requirements, as can be seen in figure 8. Keep in mind that there are more columns along the horizontal axis, but the figure only displays how the overview is designed.

		Requirement		Priority (A-C)	Description
−	2	Req 01	Temperature		
	3	R 01.1	Minus	A	The system shall withstand -40 degrees celsius
	4	R 01.2	Plus	A	The system shall withstand +125 degrees celsius
+	5	Req 02	Force		

Figure 8: Small cutout of the requirement doc

Additionally the requirements are a split between functional and non-functional requirements, connected to active stakeholders and linked to the test as previously mentioned. All this can be seen in figure 9, which is a continuation of figure 8.

Functional/Non-Functional	Active stakeholder	Test ID
NF	Kongsberg Automotive, Hardware supplier	T01.1
NF	Kongsberg Automotive, Hardware supplier	T01.2

Figure 9: Small cutout of the requirement doc 2

The full list of requirements can be found in the requirement overview.

3.2.2 Tests

Similarly as the requirements, the tests is organized under the main categories and have the same functionality.

		Test	Goal	Approach
2	Test 01	Temperature		
3	T01.1	Electrical Minus	Verify that the system shall withstand -40 degrees	1. Complete system test 2. Place electrical system in cooling room (-40C) 3. Test while cooled 4. Test after reheating 5. Test 64 hours in stable tempreature
4	T01.2	Electrical Pluss	Verify that the system shall withstand +125 degrees	1. Complete system test 2. Place electrical system in heating room (125C) 3. Test while heated 4. Test after cooling 5. Test 64 hours in stable tempreature
5	Test 02	Force		

Figure 10: Small cutout of the test doc

However, there are several important categories that is crucial to focus on in the test document. These categories are:

- Testability
  The project teams subjective rating from 1-3 on how difficult the test is to perform.
- Resources
  A simple listing of the resources necessary to perform the test, this is not expected to be finished until testing phase has begun.
- Results
  A field that is supposed to tell the reader if the test verified the requirement or not, as with resources this is not expected to be finished until testing phase has begun.

As with the requirement document, the test document can be found in the test overview.

3.3 Brain storming & Process tools

When the requirements and tests where set, it was important to start as fast as possible to develop concepts and concept ideas to Kongsberg Automotive. As the project team was brainstorming for adequate ideas, it was also important to use some process tools. With the help of the process tools, it was possible to start the brainstorming phase and not get side tracked. These tools could be used as guideline to where this project should go. The tools that was used:

1. Blackbox
2. Functional Block Diagram
3. Context Diagram

For a overview look on the different tools, see problem analysis report When the project team was brainstorming, the idea was that nothing was stupid and everything went on the board. It was important that everything got to the surface, because the "idea maker" maybe thought it would not work because of something, then maybe one of the other team members had a solution for this problem that would make the idea viable.

3.3.1 Blackbox

As the name says, the Blackbox is a black box where it is possible to set the different inputs and the outputs of the system. In other words, you can see the outcome of your project with the different inputs which is given. As can be seen in figure 11, in this case the inputs are signals from the GCU (Gear Control Unit), and the outcome is a gear change. The gear change can be: backward, neutral and forward.

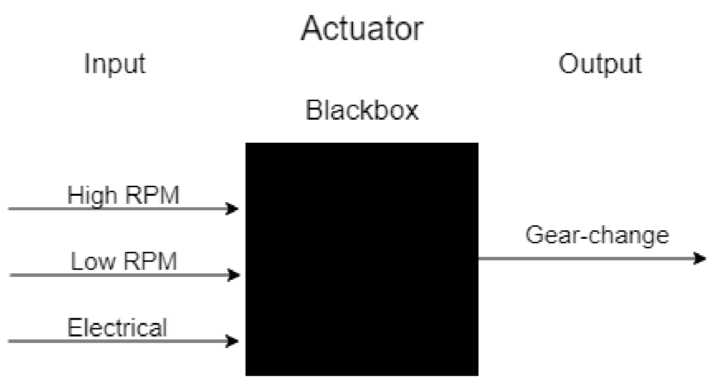


Figure 11: Blackbox

The "clue" with this tool, is that you can see what goes in and comes out, but not how to get it done. For more information about this process tool, see black box report.

3.3.2 Functional Block Diagram

The Functional block diagram is the next step after the Blackbox. The idea of the Functional block diagram is that it describes whats inside the Blackbox and what is needed to get the different outcomes. This can be seen in figure 12, the different components that is needed to make the output that the project group wants, which in this case is the three different positions: backward, neutral and forward.

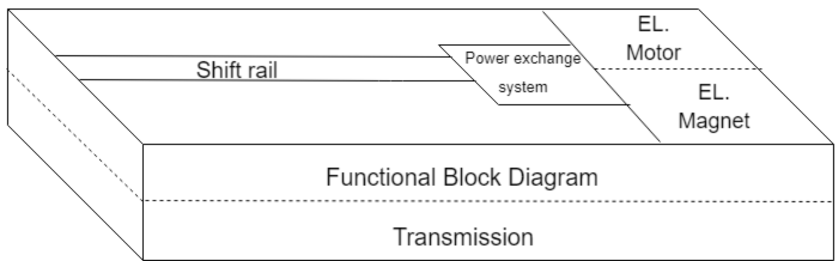


Figure 12: Functional Block Diagram

For more information about the Functional bock diagram, see functional block diagram report

3.3.3 Context Diagram

When the Blackbox and the functional block diagram is made, it is possible to see: inputs, outputs and what is needed to make those outputs. The next step then is to make a context diagram, where it is possible to see your project or device in a situation. In this case, as it is possible to see in figure 13, how the device is affected by the rest of the truck and not only the transmission.

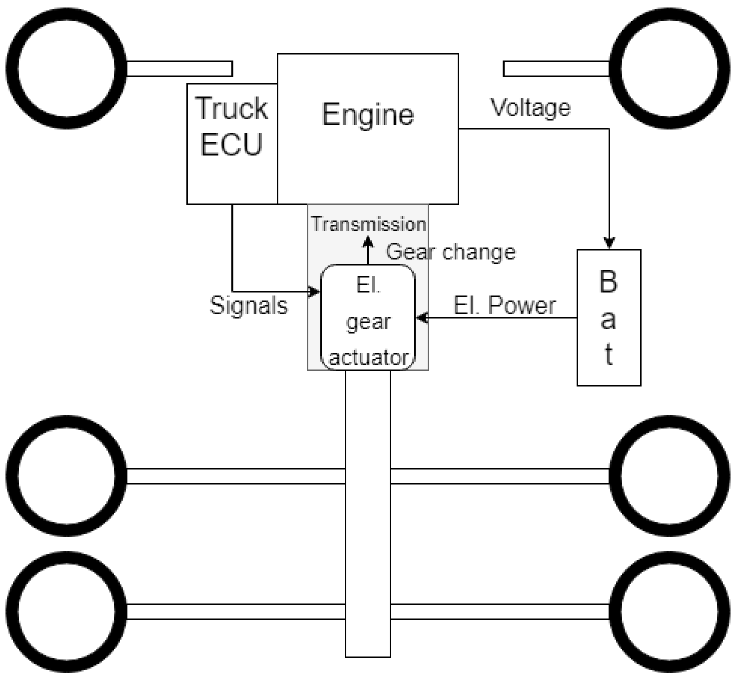


Figure 13: Context Diagram

For more information about the Context diagram, see context diagram report.

3.4 Traceability

When writing, and developing a product it is important to have a good traceability. This traceability is the the only thing that secure the customers wishes, and can be the difference between total failure and a quality product. There is different ways to achieve this traceability, but there is a couple of things that is important.

1. Talk with the customer, Kongsberg Automotive
2. Track the requirements
3. Iterations

In this case it is important to talk to the customer, which is Kongsberg Automotive and have a transparent communication. In other words, be open about changes and share alternatives with the customer and be open for suggestions.

It is also important to track the movements and reiterate. This have been done through the process, and can be seen in figure 14.

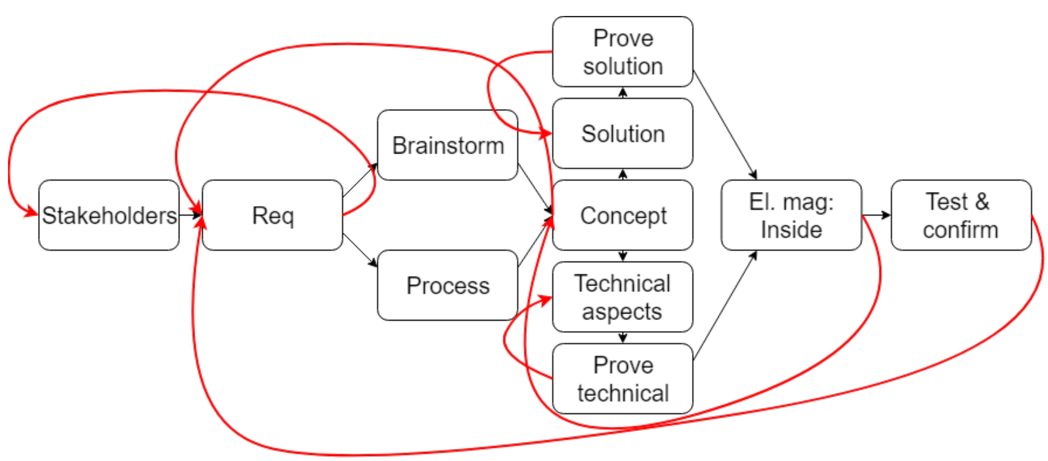


Figure 14: Traceability illustration

Here it is possible to see how the project team started with the stakeholders, before developing the requirements. After this, the requirements was iterated with the stakeholders, to see if there was some stakeholders that was missing. After this it was safe to go trough the requirements one more time, before starting on the brainstorming and process phase. When the project group felt that they where moving forward, they looked back on the requirements, to see if project was still "on track". This is the method that was used trough the project, to make sure that nothing was forgotten or un-turned.

This way the project team felt that they could cover all the bases, and deliver a quality product to Kongsberg Automotive with the requirements and expectations that where given.

3.4.1 Document traceability

In regards to traceability in documents, the project team can trace different versions of documents by the added footers in the left bottom quadrant of all documents. This is to make sure members of the team always works in the newest version. Additionally the system is used as a confirmation that the documents is the newest version by double checking the PDF footer against the revision table. The revision documents are 3 different documents consisting of tables related to every document created

- Template revisions
  Covers revisions of the different templates the project team has used
- Administrative revisions
  Covers all the administrative documents created during the project
- Technical revisions
  Covers the technical documents created during the project

3.4.2 Activity traceability

Every activity has an ID. The activity ID has been used to trace and control the activity situation under every iteration. For example, Documentation Activity ID is T1-1-6 (see the figure 15 below) under the last iteration T1. The Time registration list displays how many hours have been used for this activity. This will provide a reference for the progress of updating the Gantt Chart. Meanwhile the activity list will also be updated. This helps the team to control the work completion progress and refine the project plan.

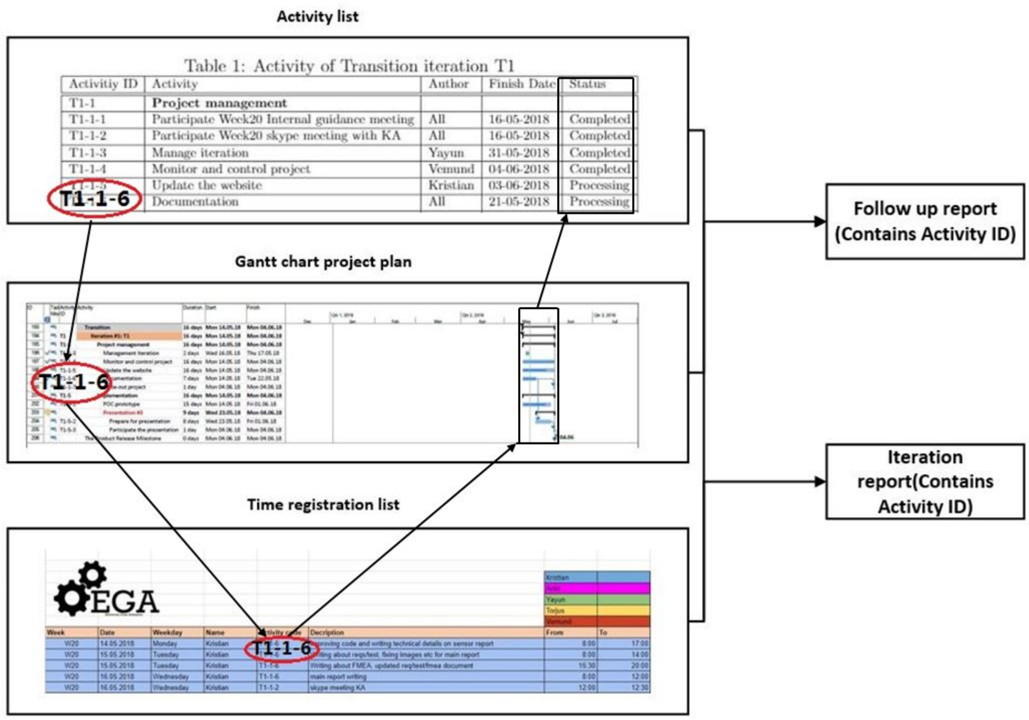


Figure 15: Activity ID traceability

4 Concepts

From early in the project, Kongsberg Automotive has wanted a broad specter of different concepts to chose from. This is something the project group has worked on, and have also delivered a variety of different concepts.

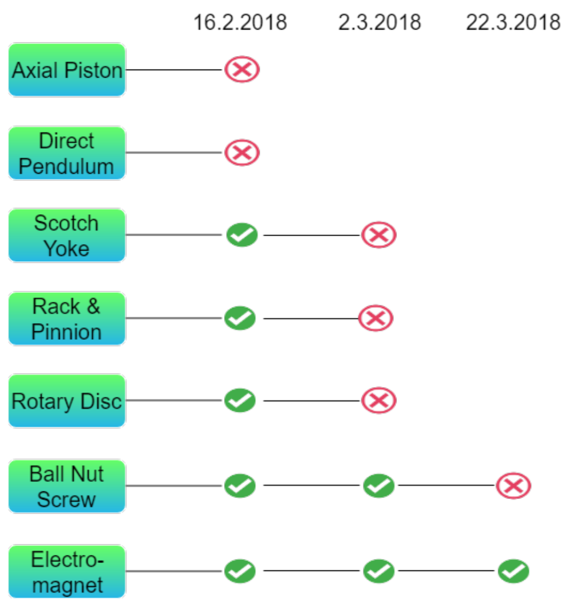


Figure 16: Concept overview

From figure 16 it is possible to see the different concepts that the project group have explored and when they was cleared not viable. The dates are days the project group have had meetings and discussions around the different concepts, and decided if they should continue or be cleared not viable. For more information about this overview, see concept overview report.

4.0.1 Axial Piston

Declared not viable: 16.02.2018
Concept description:
The Axial piston concept idea is from the hydraulic Axial Piston Pump. Therefor the work principle is quite similar. The difference is that this concept will perform linear motion.

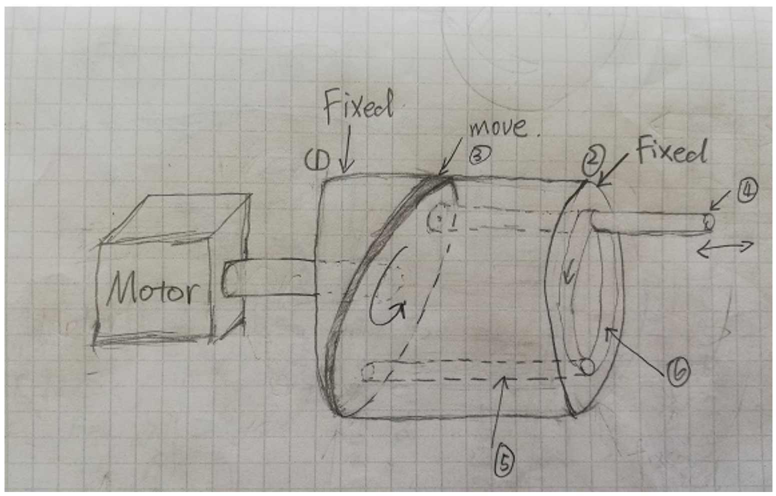


Figure 17: Axial Piston concept

For more information about this concept, see Axial Piston report.

4.0.2 Direct Pendulum

Declared not viable: 16.02.2018
Concept description:
The Direct Pendulum is as the name says, a pendulum movement which is controlled with an electrical engine to make the pendulum move. With this concept it was possible to make the movement direct, linear and it also consists of few parts.

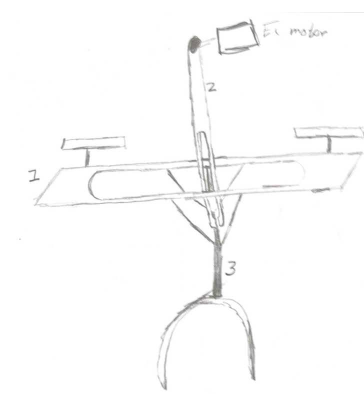


Figure 18: Direct Pendulum concept

In figure 18 it is possible to see how the concept was thought.
For more information, see Direct Pendulum report.

4.0.3 Scotch Yoke

Declared not viable: 02.03.2018
Concept description:
The Scotch Yoke is an old invention, and was also used on steam locomotives. The idea is that something that is linear, develops a rotational movement. The thought behind this concept is possible to see in figure **??**.

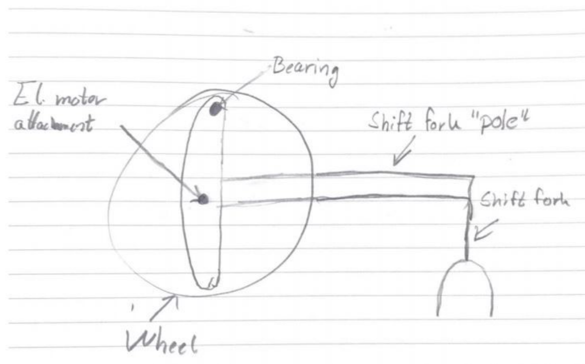


Figure 19: Scotch Yoke concept

The thing that really differ this concept from a normal Scotch Yoke, is that it works the other way around. The electrical motor will develop the rotation, which then develops a linear movement.
For more information, pleas Scotch Yoke report.

4.0.4 Rack & Pinion

Declared not viable: 02.03.2018
Concept description:
Rock and Pinion is a simple linear actuator, it uses a pair of gears which convert rotational motion into linear motion (see the figure below).

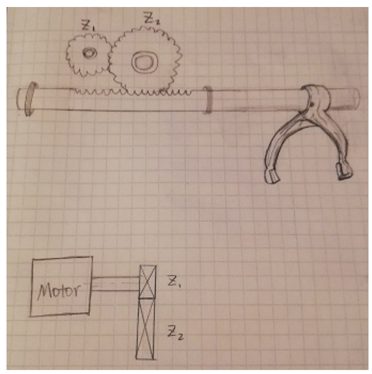


Figure 20: Rack and pinion concept

For more information about the concept, please refer to Rack and Pinion Report.

4.0.5 Rotary Disc

Declared not viable: 02.03.2018
Concept description:
The idea was a disc, or a plate that have tracks that diverge from centre of the disc. When rotating the disk, a pin attached to the track is then moved in a linear motion back and forth.

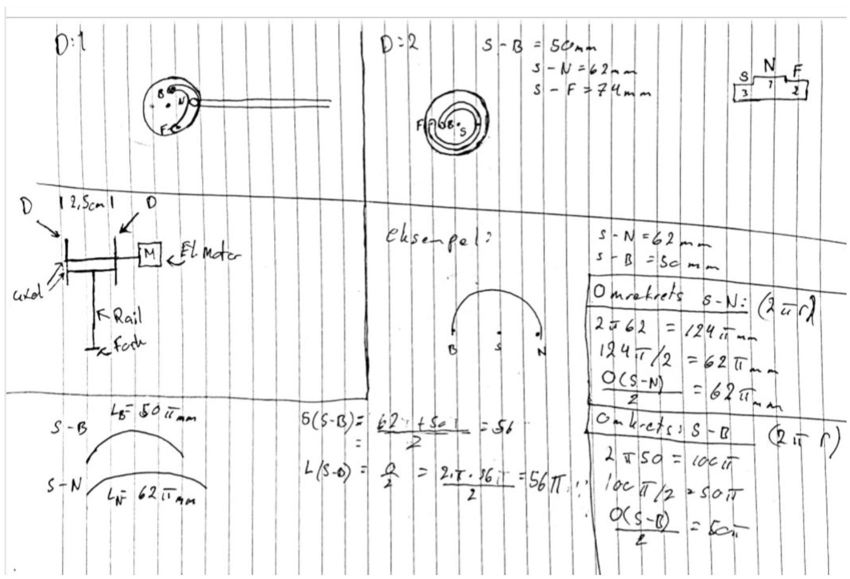


Figure 21: Rotary Disc

For more information, see Rotary Disc report.

EGA

4.0.6 Ball Nut Screw

Declared not viable: 22.03.2018
Concept description:
Ball nut screw is a well proven mechanical concept that is widely used throughout the industry.
The principle builds on an endless circulation of balls that is acting like a ball bearing. The screw has windings shaped like a ball bearing groove.
The nut contain the balls and is designed in several different solutions, all having the exit of the balls connected in one shape or another to the entry point on the other side of the nut.
Since the nut has much of the same characteristics as a ball bearing there is very little friction in the mechanical rotary/linear transfer.

The concept is described in more detail in k-brief named:

"Knowledge-Brief Consept Ball Screw 1.0"
Reference T.21

4.0.7 Electromagnet

Concept description:
Since Kongsberg Automotive wants change towards electric solutions, electromagnets was a natural solution to explore. There are 2 different ideas, both can be seen hand sketched below in figure 22.

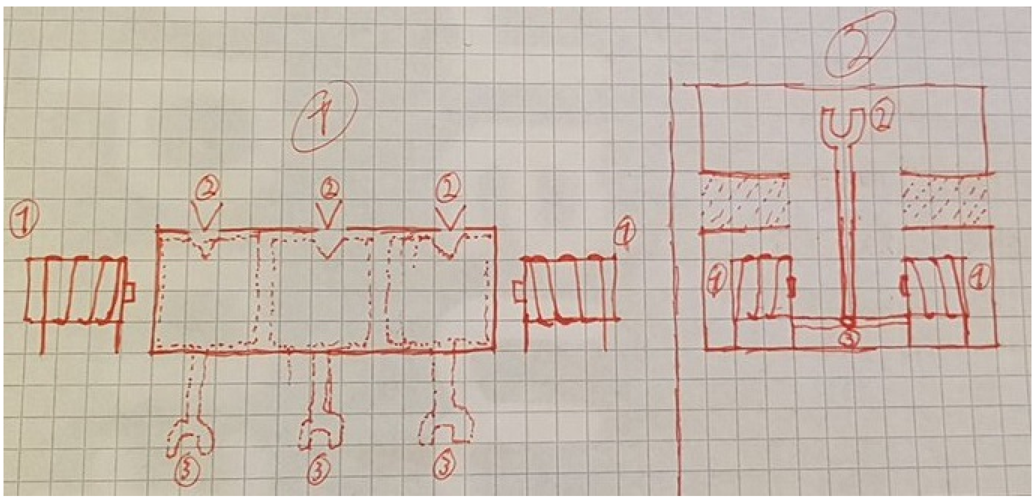


Figure 22: Hand draw magnet concepts

As can be seen there is not much differentiating the two concepts. Both of them has several magnets that can move the shift fork. The only thing separating them is that one of them (the one on the left) is supposed to be inside the transmission, while the one on the right is supposed to move the fork through an extended arm. This allows for a less hostile working environment for the electronics, but may be harder to achieve the forces needed.

For more information about this concept, see Elmag concept report.

4.1 Concept Pugh

The five most viable concepts was put in a pugh matrix, to see how they compared to each other. For more information about the pugh matrix and the thought behind the weighting and criteria, see pugh matrix concept report and pugh matrix criteria report.

Pugh Matrix						
Criteria	Score	Rack and Pinion	Rotating Disc	Ball Screw	Electro-magnet	Scotch Yoke
Physical size	4	4	2	4	5	1
Maintenance	2	3	4	5	4	4
Production Cost	5	4	2	3	4	3
Manufacturing Method	4	4	2	3	4	3
Life cycle	3	4	4	4	4	4
Reliability	5	4	5	5	4	4
Requirement complexity	3	3	4	5	4	4
Assembly	4	4	4	5	5	5
Innovativness	4	2	3	4	5	1
Modulability	3	5	5	5	2	5
Technical solution	3	3	3	4	5	3
Competitiveness	3	3	3	5	4	3
Score	40	156	144	183	181	140

Table 1: Pugh matrix: Concept

4.2 Electromagnet & Ball nut screw

A Pugh matrix is just a tool to compare, and from this pugh matrix the project team got two different concepts which did good. It was therefore decided that both; Ball Nut screw and Elecotrmagnet concept should be further investigated and showcased on presentation II. The project group believed that both of these was adequate solutions which "would get the job done". Both of these concepts went trough a patent search, to see if there is something similar on the market today.

4.2.1 Patent search

One of the requirements given from Kongsberg Automotive was that the developed solution shall not be patented. Patents are though to analyze and find, and therefore the project group was offered a course in how to search and analyze patents (See KA Patent report for more information). As a search engine Google patents [2] was used, mainly because there was no other free good alternatives.

Continuously throughout the project the group has used Google patents after a brainstorming sessions, and has also drawn inspiration and ideas from reading different patents. Per project end there has not been found any patent directly effecting the design, but a similar positional measurement technique exists (see position report for more info)

For the radial solution, no patents of similar design has been found. Therefore the project team feels safe to recommend this concept for further development. Search phrases used while searching for patents on this specific concept is amongst others:

Table 2: Patent phrases overview

Radial	**Gear**	**Actuation**
Radial gear switching	Gear actuation	Gear actuation
Radial gear solenoid	Solenoid gear actuation	Electric gear actuation
Radial gear activation	Gear activation	Electric gear switching
Radial solenoid gear	Solenoid gear activation	Ball screw actuation
Solenoid radial gear activation	Solenoid gear switching	Ball screw gear actuation

4.3 Choice of el-mag concept

After presentation II, with the help from Steffen Johansen and Kristian Ahlberg, it was decided that the project group should focus on the Electromagnet solution. The project group sat down and started to look at different ways to make this possible. Some suggestions where developed, but they were quickly thrown away because of one of the need; the concept solution needs to go automatically in initial position, which is neutral, mechanically. After some development, the project group found three different potential solutions.

1. Electromagnet: Dog
2. Electromagnet: Reluctance Radial
3. Electromagnet: Inside

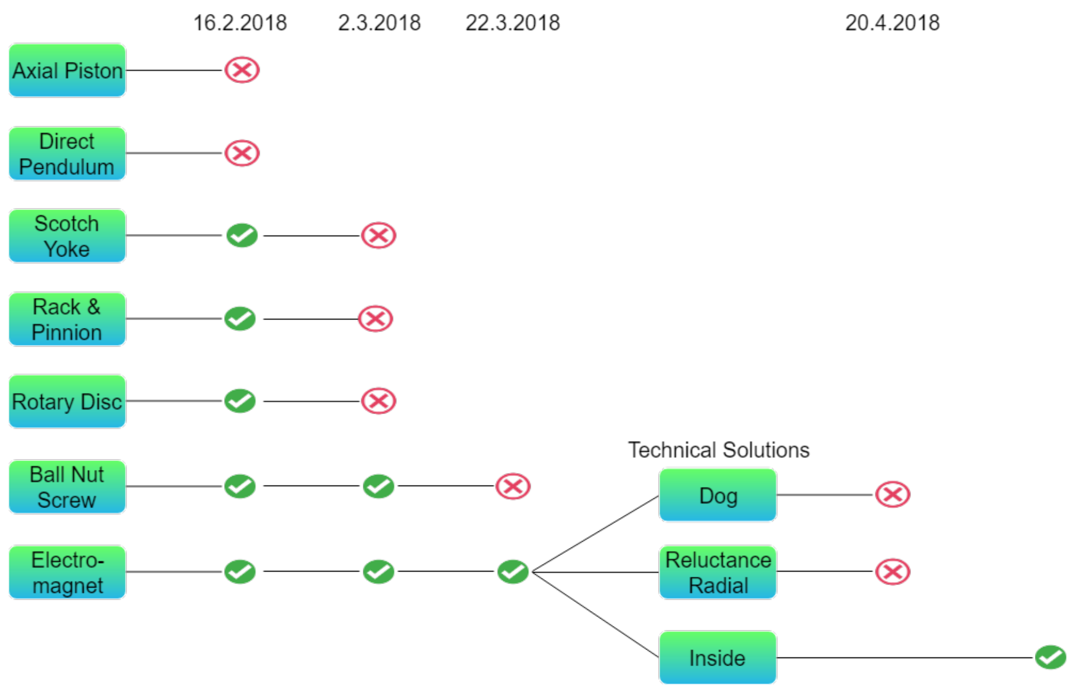


Figure 23: Concept overview with electromagnet solutions

4.3.1 Electromagnet: Dog

Declared not viable: 20.04.2018
Concept description:

Elmag dog concept is developed to meet customers desire for a radial engagement which is done electrically.

The concept is developed as a part of two alternative main solutions, one with a motor driving the engagement of the teeth and this one that is meant to be the simplest most viable solution for this project.

The concept was developed after considering the groups wishes which was to find a radial solution. Further concerns was; no permanent magnetic construction, electrical engagement low forces. The concept is based on induction and was innovative or rather experimental. More information can be seen on the knowledge brief in the reference.

Reference:
T.37 Knowledge-Brief Radac Elmag dog concept description R1.0
T.38 Knowledge-Brief Radac Elmag dog concept evaluation R1.0

4.3.2 Electromagnet: Reluctance Radial

Declared not viable: 20.04.2018
Concept description:
The reluctance motor is the last in line of many iterations with induction motor. The concept started with looking at rotary induction motors and the K-Brief "Induction shifter function description" was developed Ref. T.36. The reluctance shifter concept was meant to be driven by a motor described in the document T.42 Induction shifter function description.

Background for these concepts can be read about in the documents; T.44, T.45 and T.46 which deals with the forces involved with shifting gears. This new concept is meant to work around the issues associated with conventional gear shift. Reference: T.39, T.36, T.44, T.45, T.46,

5 Electromagnet: Inside

5.1 Description

As mentioned in the introduction, the task for the project team was to develop an electrical actuator which could do three positions. After some discussion with Kongsberg Automotive, it was concluded with that a radial solution was the most innovative.

The concept is different from the existing method, where the movement is done outside of the transmission and moves a lever inside, which is called the gear fork. This solution is instead on the gear inside the transmission, and moves the teeth that actuates the different gears. Another advantage with this system, is that now it needs two positions instead of three; activated or neutral.

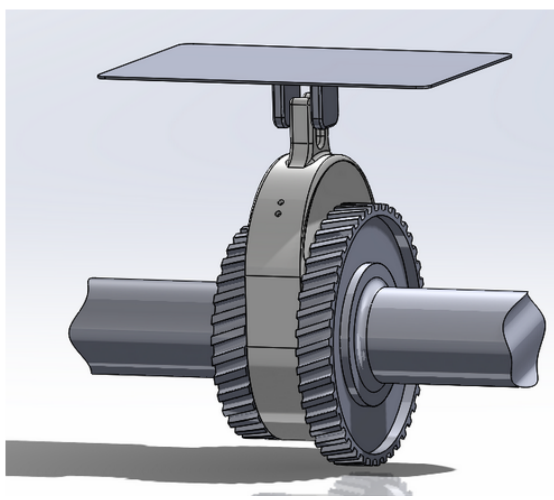


Figure 24: Concept overview

In figure 24 it is possible to see a render of how the concept will look. This is thought that will sit on the hub locked to the axle. It will be solenoids on both sides, and this will have the ability to choose between two gears and neutral. Over is the slipring lock, and brush holder, before everything is bolted to the "roof" of the transmission.

5.2 System

This device consists of several subsystem, as can be seen in figure 25.

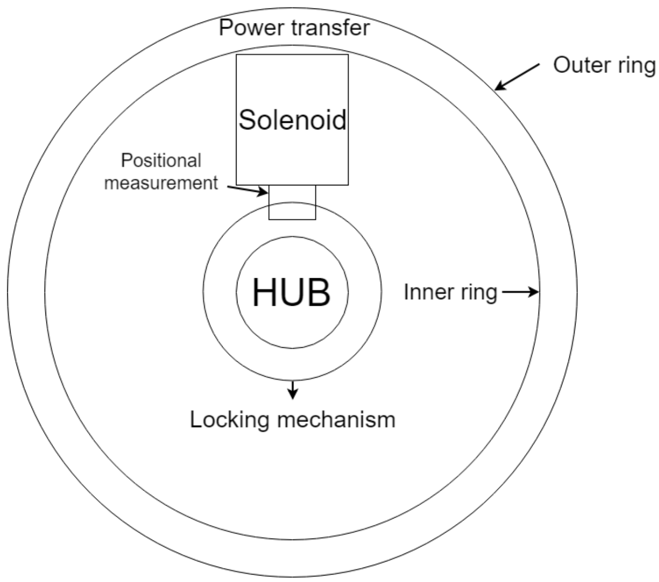


Figure 25: Caption

On the outer edge of the circle, is the outer ring, and then is the inner ring. Between here is the power transfer system. This is what makes it possible for this device to transfer electricity into the inner ring and to the solenoids.

After the power transfer, is the solenoids. This is the second subsystem, which makes the radial connection possible.

Then there is the positional measurement, which measures if the teeth are in place or not.

The fourth subsystem is the locking mechanism, which will lock the teeth either inside or outside. In other words, lock the teeth in gear or in neutral.

At last is the materials, of the whole system. How to make it withstand all the power and the hostile environment.

5.2.1 Subsystem: Power transfer

A major challenge with this system is the fact that the device needs to rotate. Therefore has the project team decided that the best solution is to split it up in two different parts. Inner ring, and outer ring. The difference between these, is that the inner ring will rotate, when the outer ring will stand still. With this system, it is possible to use several different power systems, and the ones that EGA have looked into is:

1. Slipring
2. Induction
3. Diamond Roll-Ring

These three are some of the best solutions on the market, for power transfer from still to rotary. The challenge with this subsystem, as rest of the project, is the small build space.

Slipring

The slip ring is a old, but well tested technology for exactly this type of challenges. It is quite easy, it consists of three different parts: Brush holder, Brushes and a Collector ring. The idea is that the brush holder holds the brush against the collector ring, which rotates on the rotating part. The biggest problem with this technology is wear, therefore have EGA decided to look into other technologies also.

Induction

Induction is based on electromagnetism, and makes it possible to transfer electricity between air. This way it will be no wear. The principle in theory is quite simple, where you send AC current which pulses at xHz, which will send flux out of the coils, this flux will "activate" the flux on the other side and send the current over. As said, in theory this works quite good. In reality on the other hand, this is quite hard. Especially when the build space is this small.

Diamond Roll-Ring

This is a new technology, where they use rather known factors. It used the same idea with a inner ring, and a outer ring. The thing is between these rings, there is a gold ring which also rotates. Gold have a good leading capabilities and therefore this seems like a good idea.

Pugh Matrix After looking into these different ideas, EGA put them through a Pugh matrix:

Pugh Matrix				
Criteria	Score	Slipring	Diamond Roll-Ring	Induction
Size	3	4	2	1
Price	3	4	2	3
Efficiency	2	4	5	2
Maintenance	3	1	4	5
Difficulty	1	4	3	1
Score		39	37	33

Table 3: Pugh matrix: Power transfer

From this the slipring wins, and is also the right choice to continue with. The only real problem with sliprings is the fact that they wear, this wear is difficult and unreliable to calculate without testing the different materials against each other. This testing, the project team did not have time for, but it was possible to calculate the different materials and some forces.

The best materials for the brushes is Copper Graphite, it is more expensive then the regular graphite, but the current density is much higher which justifies the price. Copper graphite current density is 15.5amps per cm^2 which means that the area that is needed is about: $1.54cm^2$. Which is doable.

For the brush, the team found a spring test analysis for testing wear in slip rings, which said that the ideal pressure is about 40kPa.

For the collector ring, brass is the adequate choice, because of robustness and leading capabilities.

For more information about the power transfer, see Power Transfer report.

5.2.2 Subsystem: Solenoid

1. **Force Analysis**

In order to design a solenoid system that has enough force to complete the motion, which is pushing the teeth into the channel and pulling back to the original position in the required time. A force analysis is performed on the mechanical system. Firstly, Please see the figure 26 below. The solenoids are placed inside the sleeve and rotates with the main shaft. The synchronized corn is on the main shaft but rotates with the gear that rotates with the layshaft. The solenoid function is to make the gear connect to the main shaft and rotates at same speed. This happens when the solenoid pushes the teeth into the channel.

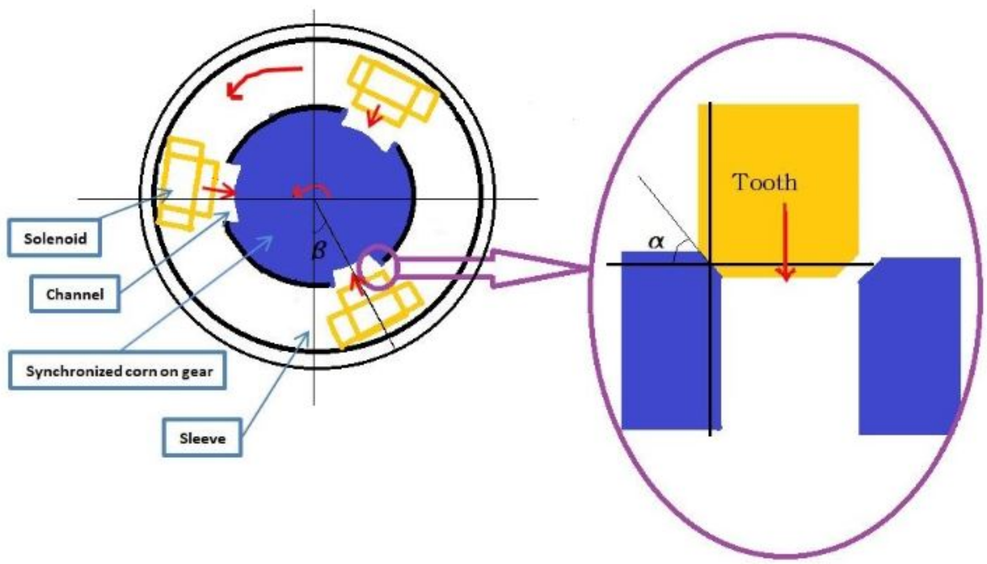


Figure 26: System illustration

A tooth has been taken into force analysis as displayed in figure 27 below. Since the solenoid is also rotating with the sleeve while pushing the tooth an angle β is there to illustrate the position of the solenoid.

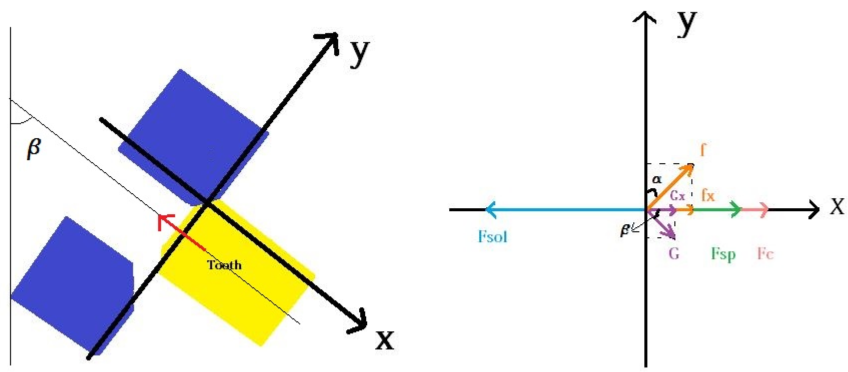


Figure 27: Force analysis illustration

- Centrifugal Force
  Because of the rotation, the tooth will be a subject to a centrifugal force (Fc as marked pink colour in figure 27).
- Spring Force
  Because of the spring, which is used for pulling back the tooth to initial position when the current is off. There is therefore a spring force (Fsp as marked green colour in figure 27) on the tooth.
- Friction
  When the tooth contacts with the synchronized corn and tries to slip into the channel. It will have a friction (f as marked orange colour in figure 27).
- Gravity
  There is always a gravity(G as marked purple colour in figure 27)
- Solenoid Force
  The drive force from solenoid (Fsol as marked blue in figure 27). In order to push the tooth, the solenoid force must win over forces in the opposite direction as displayed the below figure:

$$Fsol \geq G_x + f_x + Fsp + F_c \tag{1}$$

(Remark: More information about the Force analysis, Force calculation and Matlab code. Please refer to the Force Analysis Report) With help of the Matlab, the minimal solenoid force is shown the below figure 29.

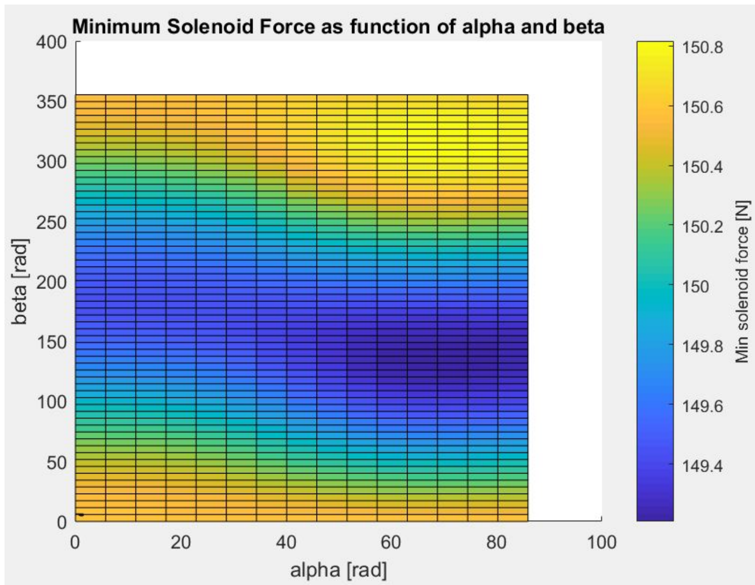


Figure 28: Force result from Matlab

The above figure 29 displays that different positions(β) of the solenoid needs different force, but the difference is quite small. The angle α also effects the force, anyway the largest force is 150.8N. In other words, the Solenoid force should be greater than 150.8N.

2. **Solenoid design**

According to the force analysis result and the size requirement (requirement ID:R.07.3), The Solenoid size will be smaller than 50x50mm and it should generate a force greater than 150.8N to push the tooth in 40ms.

- Working principle

Working principle is that an electric current flows through a coil winding, and creates the electromagnetic field. An armature/-plunger is placed inside of the solenoid and free to move. The magnetic field then applies a force to the armature and the plunger will be pushed out. Meanwhile the spring will be compressed.

When the magnetic field is off, the spring will drag the plunger back to the initial position. See figure 29 below.

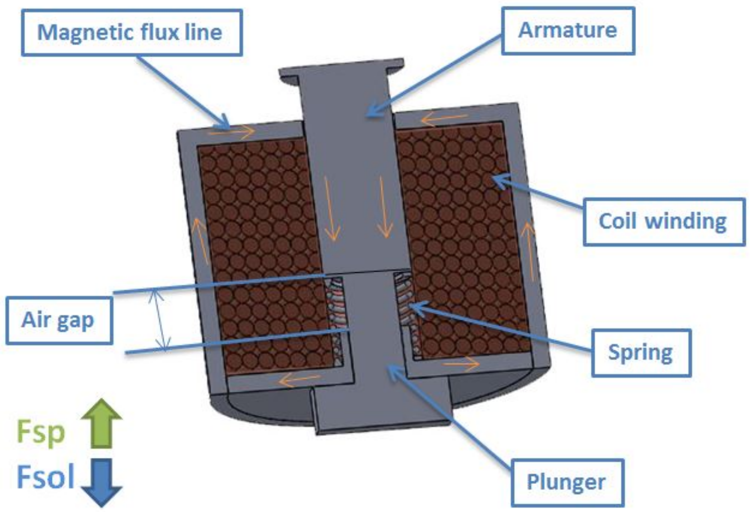


Figure 29: Solenoid design

- Design Process

The project team combined the mathematical analysis with the simulation in Matlab/Simulink to determine the correct solenoid for the system.

Firstly, Coil analysis and calculation modelling.

Secondly, Solenoid force from magnetic field analysis and calculation modelling.

Thirdly, Solenoid plunger motion analysis and calculation modelling.

(Remark: The details about the Mathematical analysis and simulation modelling, refer to Solenoid Report)

As result from the test, the parameter of the solenoid becomes

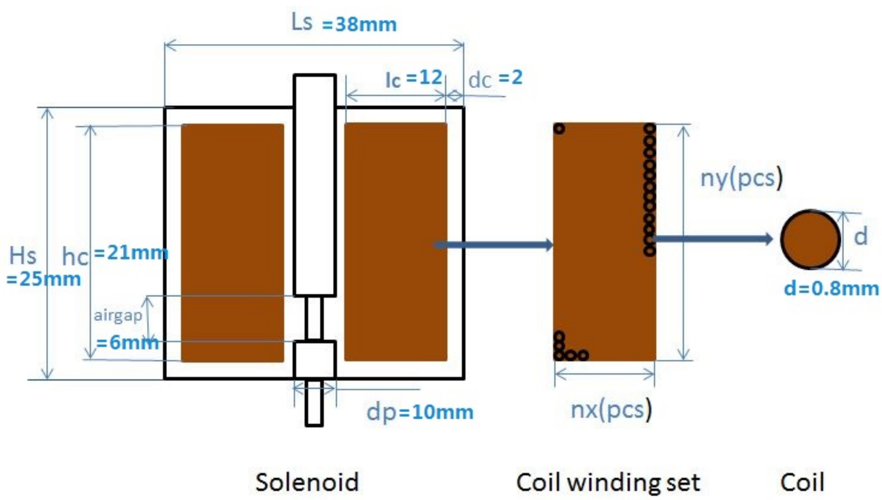


Figure 30: Solenoid parameter

The force from the solenoid with this parameter is displayed the figure 31 below.

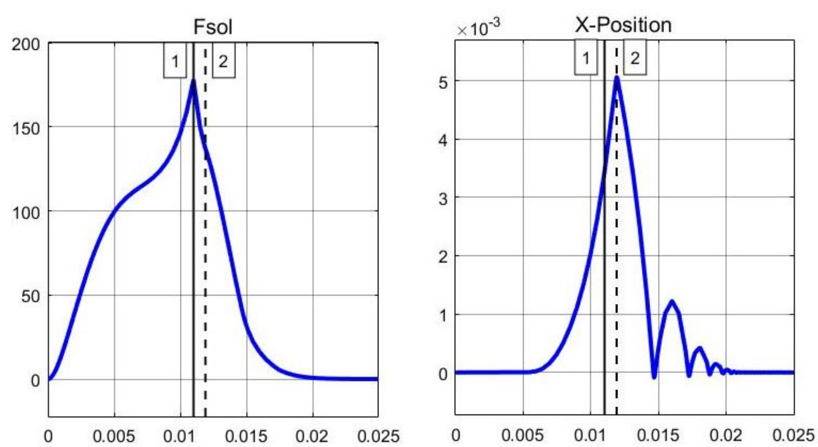


Figure 31: Force and Stroke

The voltage and current will be displayed in the figure 32 below.

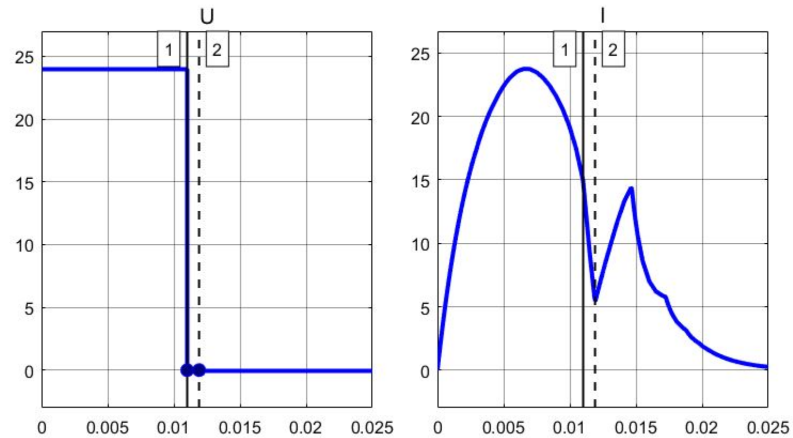


Figure 32: Voltage and Current

Under the stroke, the temperature of the coil will increase, see figure 33 below.

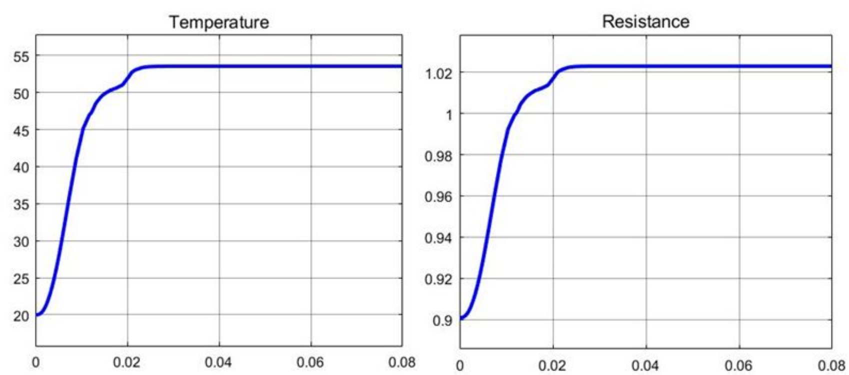


Figure 33: Temperature and Resistance

The solenoid will become as displayed in figure 34. Then it is possible to generate a force up to 178N to complete the 5mm strokes in 12ms

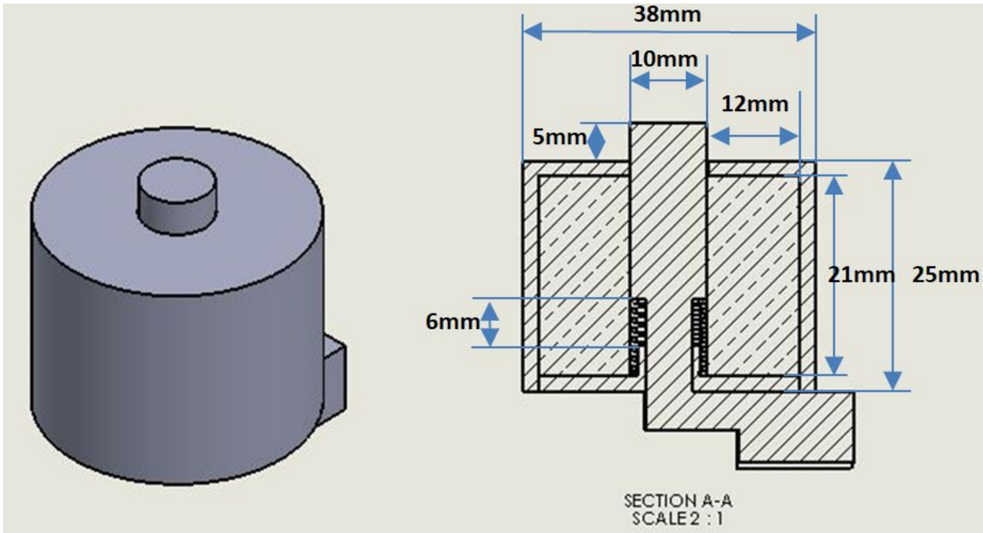


Figure 34: Solenoid

For more information about the solenoid design, refer to the Solenoid Report.

5.2.3 Subsystem: Positional measurement

For positional measurement a variety of technologies was looked at. Ultimately when the concept selection finalized and a solenoid concept has been chosen, the two technologies that outclassed the other was the hall-effect sensors and current measurement. Out of these, both seemed to fulfill the requirements, and therefore the current measurement was chosen because of a perceived difference in cost. Simple current measurement looks to be doable without large costs, especially if the GCU proves to be able to handle the computational part of the design.

When a solenoid is powered, it needs a certain amount of current before it starts moving. When you power on the current, it will start building up until it reaches the threshold of movement, then it will be reduced by a certain amount based on the characteristics of the solenoid until it is in the out-most position. This can bee seen in the graph below, where the movement of the plunger is only between (1) and (2). The graph is from a Texas instruments article discussing positional measurement of DC solenoids [4]

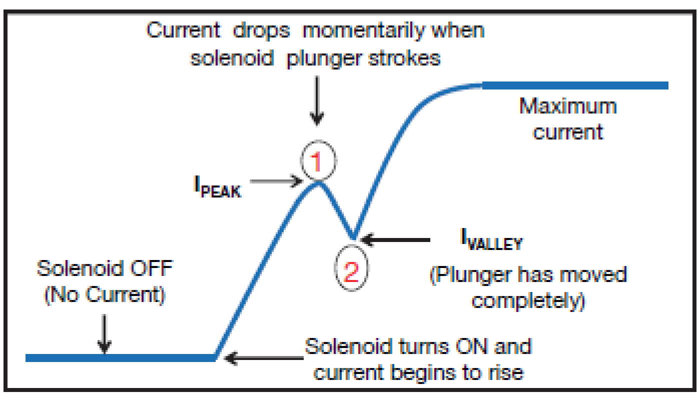


Figure 35: Positional measurement subsystem overview

The idea is that a current sensor will be connected to the power input and to the solenoids, which will then send a signal to the GCU who can calculate whether or not the plunger has started moving, or is in the end position based on known characteristics beforehand.

The system overview can be seen in figure 36:

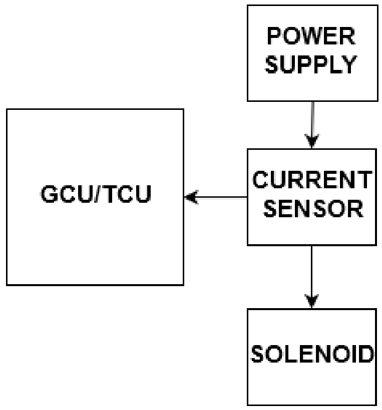


Figure 36: Subsystem: Positional measurement overview

Since the final concept of using solenoids for radial gear activation was developed fairly late in the project, there was no time to get equipment to test this in practice. So instead the group showed how one can easily find the turning points of the current curve using python to analyze a data set retrieved from a MATLAB simulation of a simple DC solenoid. The code and more information can be found in the positional measurement report. The results are that one can quite easily find the turning points by analyzing current samples against simple mathematical expressions. The result of the simulation can be seen in figure 37

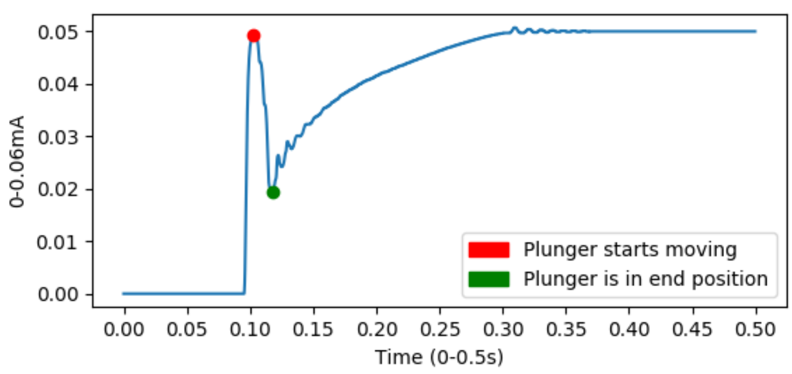


Figure 37: Turning points analyzed in python

5.2.4 Subsystem: Locking mechanism

Kongsberg automotive gave a requirements, which says that; if the electricity disappears the teeth shall retract to neutral position. For this concept, the project team decided that there where two possible solutions:

Angled Teeth This idea is that the tooth have a certain angle, and when it is in locked position it will stay there.

Locking Mechanism A form of mechanical lock, that will lock the teeth in position.

After some discussion; the project team thought that a locking mechanism would be the best solution. The reason for this is quite simple: when using a locking mechanism, the solenoids does not need extra power to "push" the teeth in place. The extra power would be necessary if the teeth was angled.

From this a concept was developed:

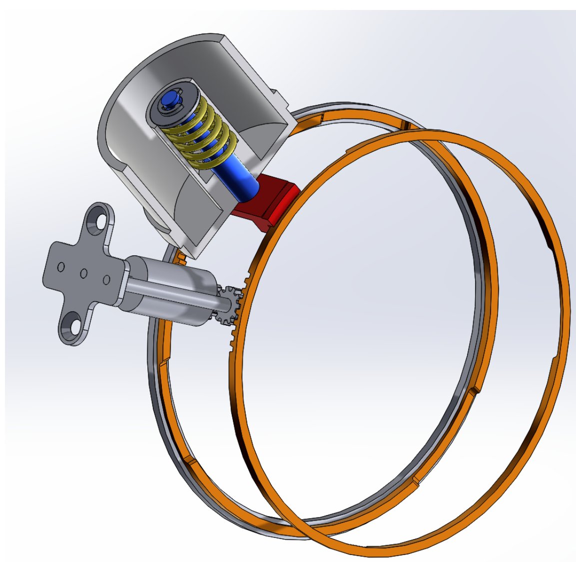


Figure 38: Locking Mechanism

In figure 38 it is possible to see a render of the locking mechanism, which will slide back and forth to lock the teeth at place. The cuts that the ring will slide in, is cut in two different places on the teeth. The reason for these cuttings, is because then it is possible to lock the teeth in neutral and in gear position.

This solution was developed quite late in the process, which also means that the group did not have the time to calculate the different forces that is affected on the locking mechanism. From a calculated guess, EGA are quite sure that this system will work.

For more information about this locking mechanism, see Lock Mechanism report and T.57.

5.2.5 Subsystem: Materials

When designing the subsystem level artifacts on the magnetic concept inside the gearbox, one issue was setting itself apart from the rest as a big problem that always seemed to cause for concept after concept to fail. This issue was build space.

This enforced high stresses on small geometry, difficulty and complex assembly solutions. There are many different options to go around this, and one is the accessible materials and manufacturing methods, and the many different advantageous characteristics that can be presented in that area. Different materials can tolerate great stress and at the same time, low weight. Those are typically expensive. Others are strength against deformation, but are typically brittle and will wear down faster. For every benefit, there will be a drawback at the other end. The job where to find the perfect material to each specified area of the operation.

Newer and better manufacturing methods such as composite and 3D print allow for products to be produced in a way that has never been possible before. With geometry that have much more direct benefits in characteristics to accommodate certain tasks.

In a operation like the magnetic gear actuator, some issues that where obvious where high stress, complex geometry, abrasive wear and fatigue, all that can be met in various ways. Cost efficient materials and manufacturing methods have been evaluated against higher performance methods. This is to make sure that the high end solution versus cheaper but viable solutions both meet the requirements of the product. For future development, this can be evaluated against the market as the possibility of different manufacturing methods occurs. For more information see material report.

6 Proof of Concept, Electromagnet

6.1 Description

In the assignment description from Kongsberg automotive, it was given a task for making a Proof of Concept (PoC). A PoC is a easier prototype, where prototype needs to be an almost finished product a PoC only needs to show something of the concept; for example just a movement.

In this PoC, the project group decided to make a 1:1 scale PoC where one of the three movement is displayed. The plan is to put this device into something that looks like a open transmission.

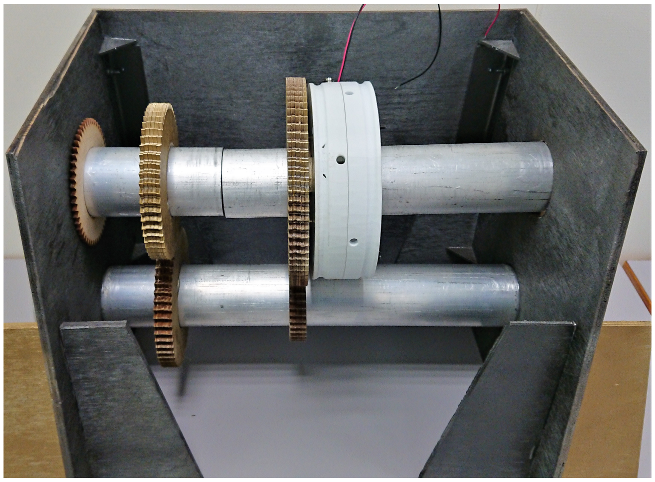


Figure 39: PoC Transmission Overview

When doing the movement, the device will display how it activates a gear and can go back to neutral. The plan is that when you are rotating the aluminum tube in the top left, the tube in the bottom will rotate too. When the bottom tube is rotating, it will also start rotating the upper gear to the right. The idea here is that the upper tube to the right will not rotate, in other words stay in neutral, until the actuator is activated.

6.2 Control

The tubes will be rotating manually and the actuator will be activated with a button. This button will be controlled through a Arduino Nano. The reason for this system is that the solenoid, which controls the tooth movement, needs an external power supply. The solenoid needs 12V and 0.4Amp, and the Arduino is just capable of giving 5V and 0.04Amp at maximum. Therefore it was needed to make a circuit with a switch, so it can be possible to control the solenoid.

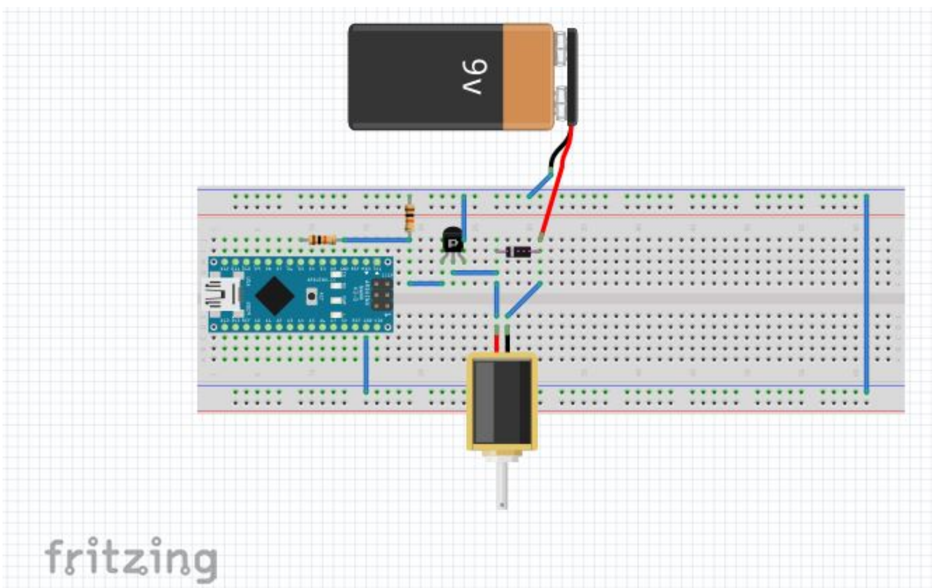


Figure 40: Arduino Nano circuit

In figure 40 it is possible to see how the circuit will look. It consists of:

1. External power supply
2. Arduino Nano
3. Two resistances
4. Diode
5. MOSFET
6. Solenoid

6.3 Device

The white actuation device is printed in a 3D-printer, and made from polymer. This material is cheap, and easy to print with a high accuracy as seen in figure 41.

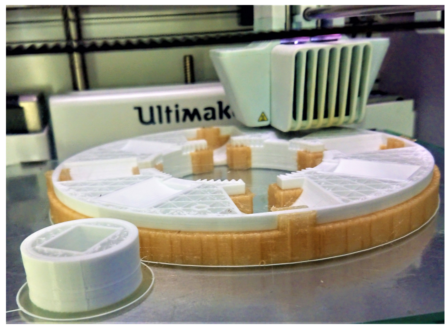


Figure 41: Print of the device

The printing was done in two sections, first one side, then the other side. This way it was possible to build in the solenoid and to take it apart later if that was needed.

There was some small errors underway, which lead to some handwork. The group needed to file some of the plastic, to get it to fit correctly. This was done pretty fast, and was not a problem for the device.

6.4 PoC Conclusion

This PoC was needed to display and validate that the movement is possible. This was displayed perfectly, and it is therefor possible to conclude that this PoC was a success. For more information, and explanation about the PoC, see Proof of Concept report.

7 Failure mode and effects analysis

After first starting with a standard risk analysis to determine administrative risks and risks related to project cooperation, the team decided that a more comprehensive analysis was needed for the technical part of the project. The choice landed on **F**ailure **M**ode and **E**ffect **A**nalysis [1] because one of the group members had experience with it, and the rest of the group liked the concept after reading about it.

	A
1	System/ Subsystem
2	Elmag concept (F01)
5	Solenoid F02)
10	Sensors (F03)
12	Slipring(F04)
15	Controller(F05)

Figure 42: Overview over columns in FMEA

FMEA is old and well tested, and the main benefit for the project team is the ability to see both local and system level effects of risks. In figure 42 you can see the columns, and similarly as the requirement and test the FMEA has been split up into risks organized after what system or subsystem they effect.

System/ Subsystem	F ID	Item	Potential failure mode
Solenoid F02)			
	F02.1	Solenoid	Lack of power

Figure 43: Overview over FMEA elements 1

Next up we can see from figure 43 that when you maximize a main category that you can see one or more risk factors marked with blue. Every risk has what is called an "F ID" so we can trace and reference them in documents. Further on it is necessary to specify what item or part the risk is valid for. At last but not at least the potential failure mode, who indicates what can go wrong with that specific item.

Potential cause(s) / mechanism	Mission Phase	Local effects of failure	Next higher level effect
Wrong calculations	Elaboration phase	Cannot perform linear movement	System does not work properly

Figure 44: Overview over FMEA elements 2

Then the next elements in the FMEA is "potential cause". In that field one or more of the causes for why the risk might happen will be listed. After that is the "mission phase" which includes all the project design phases, as well as "under use". Then there is "Local effects of failure" which explains what the effect is on the lowest possible level. Next up there is the "Next higher level effect" which is the same as the local effect just bumped one level up in the system view.

System Level End Effect	(P) Probability (estimate)	(S) Severity	(D) Detection (Indications to Operator, Maintainer)
It will not be possible to do a gearchange	B	V	2

Figure 45: Overview over FMEA elements 3

Three levels of effect is enough for us, so in figure 45 the last effect is called "System Level End Effect" and will contain information about what the problem will do to the whole system. Then a standard risk analysis is done, by classifying the probability, severity and detection (see FMEA report for the classification tables), it is possible to calculate the overall risk level.

Risk Level P*S (+D)	Actions for further Investigation / evidence	Mitigation / Requirements
Moderate	Disassemble the system, removed solenoid and test it with test T02.1	Verify calculations and simulations

Figure 46: Overview over FMEA elements 4

In the last figure (46), the risk level is calculated. Additionally there will be information about possible actions that can be performed to gather more information about the problem. The last element is "Mitigation" and will contain information about what can be done to minimize the change of the risk occurring. Additionally requirements can be linked here if they are relevant. For a full list of risks, see FMEA overview.

8 What is the next step

What is the next step for KA, when the project team have handed over the project? What should KA do then.

8.1 Positional measurement

Since the project has focused on still samples until now, the next step is to build a prototype and sample the current so you can set the correct parameters and check that the sampling rate is high enough for accurate measurement. The software will obviously have to be rewritten in a fitting language, and some other features will need to be added.

When the plunger starts moving it will not move the tooth perfectly in to the gear right away. There is a round per minute difference in the range of 20-100rpm between the rotating hub and the gear, which means the system will have to compensate for that. One way of doing that is to measure the difference between the maximum and minimum peak of the curve, and code it

8.2 Power transfer

As mentioned before, further on for this concept is the importance of finding the wear coefficient with the help of testing. The brush pressure is already recommended, so the next thing would be to slide copper graphite against brass, to see how fast it wear.

Another thing to look into is the possibilities to use induction transfer. As mentioned, at this point it will be difficult, but it is important to stay up to date with the technology. Probably in some years this would be a reality.

8.3 Locking Mechanism

As mentioned several times before, since the locking mechanism was developed so far into the process it has not been calculated forces. Because of this, EGA suggests that the next person who works on this project will do these calculations.

9 Reflection

When the project started in January, the project team had some challenges. These challenges were mostly around the team and the team leader, where the team had another vision for the project then the team leader. This was settled fast with a change of team leader. After this, the project team environment has been good. Of course, there have been some discussion, but just out of passion for the concept.

We must admit that to write a thesis for the university, and for a private company is not an easy task. Knowing that the team is watched in every turn, makes decision-making quite hard. The reason for this is because we will not only be judged by what that decision lead to, but also how we made that decision. When bearing these kind of thoughts, things starts to take time, since we want to cover our tracks and show to the customer and the sensors that the decisions that have been made is viable. With the help of system engineering, it is possible to be prepared for how to document correctly and cover your bases. The thing that systems engineering does not prepare you for, is the challenges and decisions that should be made for the project. In addition to this, system engineering is also just a tool, and everything can be customized for the better or worse. There are none right answers, albeit there are good guidelines.

The project has gone well. We have meet challenges in every step on the way, but that is some of the "joy" with making something from scratch. From Kongsberg Automotive we have had nothing but good support, and they have never been hard to reach. Most of the challenges have been solved as a group, but over time. There is, to bad, not possible to solve these kinds of challenges on the spot, but after some time the solution will always reveal itself.

All in all, this have been fun, yet a challenging project. We as a team have learned a lot about working in groups over a longer period and the importance of a multi-discipline team. Also, we have learned the importance to use all the knowledge in a team when taking decisions. As mentioned this is a multi-discipline team, which also means that we have different backgrounds which then again gives different views and solutions when meeting a problem. Everyone in the group agrees that the most important thing that have been learned this year, is the importance of including and listen to all team members. When a group works together and push each other, is when the good ideas reveal itself!

10 Conclusion

The project team was given an assignment from Kongsberg Automotive; develop an electrical linear gear actuator for heavy duty vehicles. From the beginning the plan was to develop an actuator outside of the transmission, which could move the transmission sleeve into gear. This have been vastly changed, and now the actuator has been placed inside the transmission. As mentioned through the report, placing the actuator inside the transmission have resulted in a lot of challenges because of the lack of build space.

When placing the actuator inside the transmission, some of the major challenges have been; Power transfer, positional measurement, materials which is needed to build this device and how to make the motion, all in a restricted build space. The best solution for this was to build a small push/pull solenoid inside the device which moves the teeth in and out of gear. This was made possible with a slipring system, which transfer electricity from the stationary to the device that rotates. The device must be built in a tough material, which will withstand the hostile environment there is inside a transmission. At last there was the positional measurement system, which will measure if the teeth are in gear or not. All this have been made doable, but it has not been tested.

With the help of the PoC, EGA has been able to prove that the movement is possible and with hand calculations it can be concluded with that it should handle the forces. Therefore, EGA will conclude with that this system shall be doable in the real world, but it will strive to handle the 10 years without maintenance because of the slipring system.

References

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[3] Scott Ambler. Enhancing the unified process. http://www.drdobbs.com/enhancing-the-unified-process/184415741, October 1999. (read 23.01.18).

[4] Manu Balakrishnan & Navaneeth Kumar N. Detection of plunger movement in dc solenoids. www.ti.com/lit/wp/ssiy001/ssiy001.pdf, 06 2015. (read 10.05.2018).

Stakeholders

EGA

May 4, 2018

Abstract

This report is a documentation on the different stakeholders, and how they affect this project. The EGA team also tries to put the different stakeholders in main categories and will display them visually in which way they influence this project.

Contents

List of Figures

1 Introduction

Before the project group can start with any technical decisions, the stakeholders have to be set. From the stakeholders it is possible to set the requirements, which the whole project is based on. The easiest and best way to find and set stakeholders, is to see who are affected by this project, or who are affecting this project.

2 Stakeholders

When trying to simplify the stakeholders, the project team decided that the best way was to visualize it in a diagram. The different individual stakeholders and stakeholder groups are going to be explained after figure 1.

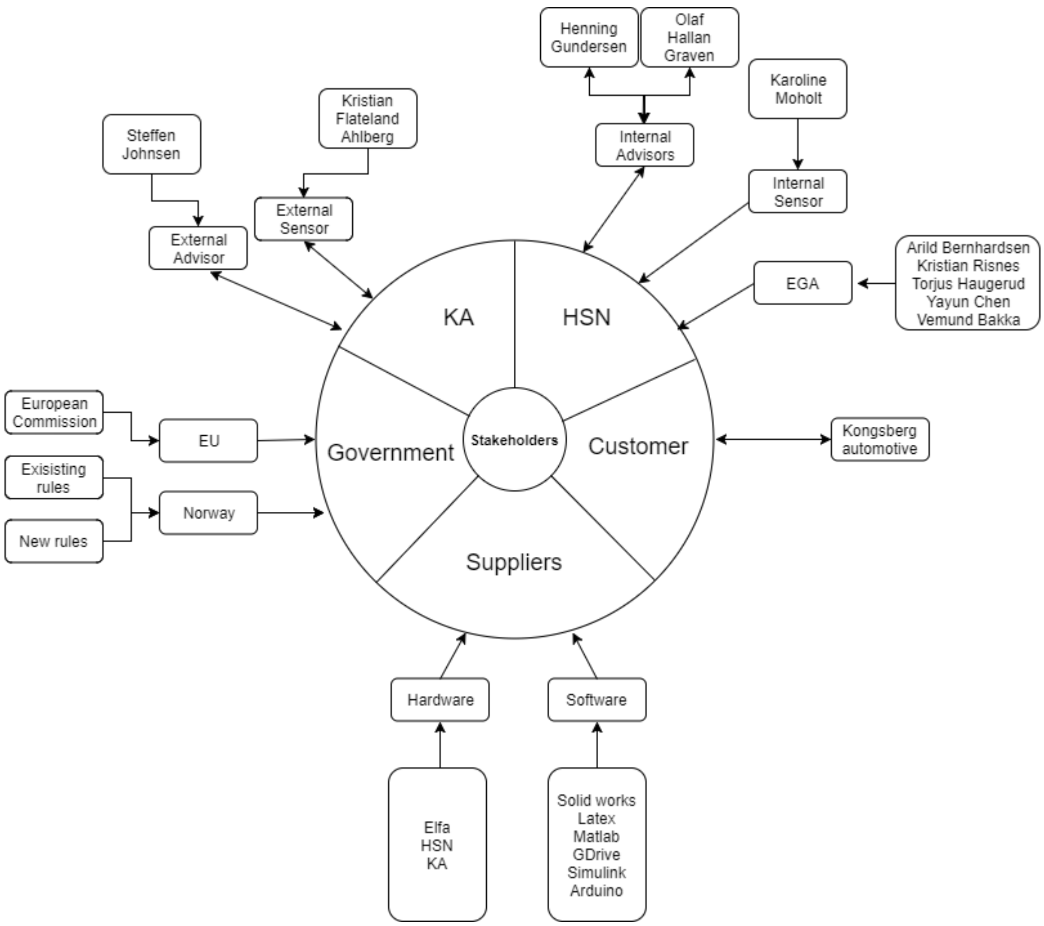


Figure 1: Stakeholder Diagram

2.1 Stakeholder Categories

The project team have decided that the best way to get a overview of the different stakeholders, is to divide them into different categories. The different categories are:

- HSN - Høyskolen i Sørøst Norge
- Customer - The project teams customer
- Suppliers - People or Organizations who supply the project group in one way or another
- Government - Norway, EU or other governing bodies
- KA - Kongsberg Automotive

This way the separation of the different stakeholders is clear, and understandable for the reader. The categories are based on the different individual stakeholders.

2.2 Stakeholder Groups

After separating the different groups, the next step was to put the different stakeholders in individual groups. The reason for this dividing was so it was possible to put several stakeholders into one group, and maintain the overview.

- Internal Advisiors
- Internal Sensors
- EGA (Electrical Gear Actuator)
- Software
- Hardware
- Norway
- EU - European Union
- External Advisors
- External Sensors

2.3 Stakeholders

The different stakeholders have been picked out on the background of how relevant they are for the project. The project team have tried to pick the stakeholders, who are directly affected by the project. When a stakeholder is affecting a project directly, they also end up in the requirements lists. The best example on this kind of stakeholder, is the one from the government category. These types of stakeholders usually have different laws and/or regulations that the project has to fulfill.
The different stakeholders are:

- Henning Gundersen
- Olaf Hallan Graven
- Karoline Moholt
- EGA
- Kongsberg Automtive
- Solid Works
- Latex
- Matlab & Simulink
- Google Drive
- Arduino or Raspberry pi
- Elfa
- HSN
- KA
- New laws and regulations
- Existing laws and regulations
- European Commission
- Steffen Johnsen
- Kristan Flateland Ahlberg

3 Conclusion

All the stakeholders have been picked out from the information that Kongsberg Automotive has delivered. The stakeholders also have been picked with the knowledge that this project is a collaboration between the university and Kongsberg Automotive.

Even though this is a technical project from Kongsberg Automotive, it is important for the group to keep in mind that this project is a school project. Everything EGA does are going to be graded by the school censors, with the help from an external censor at Kongsberg Automotive. Therefore it is important to fulfill the needs from Kongsberg Automotive, albeit the project group has to keep the university in mind as an important stakeholder.

Problem analysis

EGA

May 4, 2018

Abstract

This report is a overview of how EGA have analyzed the task given from KA, with three different tools. The tools that have been used is: Blackbox, Functional Block Diagram and the Context Diagram. This is just a short overview, and the different tools have their own individual reports.

Contents

List of Figures

1 Introduction

In this project the EGA project team have decided to use different analysis tools. The goal is to use these tools to analyze the problem, and help the group as a whole to develop the best concept. The three different tools that have been used is:

1. Blackbox
2. Functional Block Diagram
3. Context diagram

The reason for this overview document is to display the different tools, and give a short description. For more information about the different tools, how the tools have been used, and what the project team concluded with is possible to read in the individual documentation. All the three different tools from the systems engineering book [1].

2 Blackbox

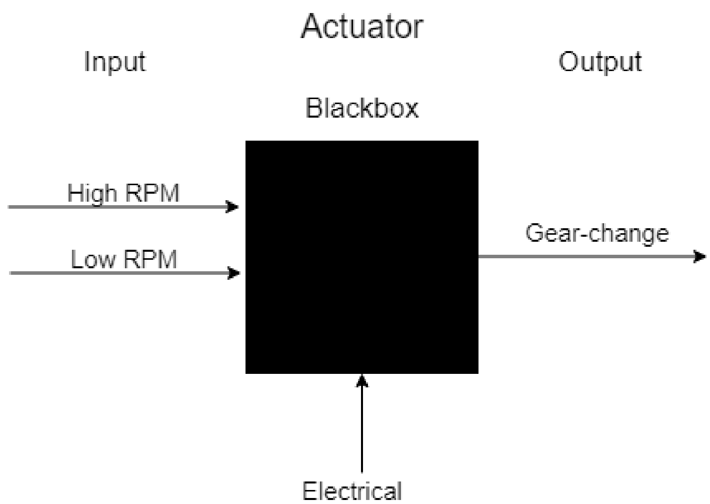


Figure 1: Blackbox

The focus on a Blackbox needs to be held to the different inputs and outputs. The different inputs are the things that will activate the Blackbox, and then the output is going to happen with the help of the Blackbox.

In this case, the different activation is: High RPM, Low RPM. The actuator also needs to be electrical, therefore it is placed in the diagram. When the Blackbox gets its signals, it is going to do a gear change. If this change are going to be up, down or neutral depends on the input.
For more information, read the report on the Blackbox

3 Functional Block Diagram

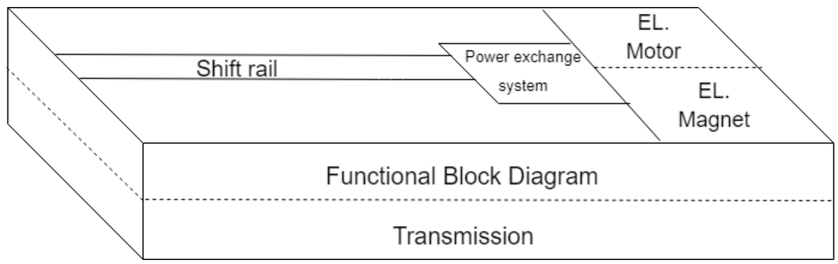


Figure 2: Functional Block Diagram

A functional block diagram is displaying the different parts that the system needs, or what the system needs to make the action possible. In this case it need some kind pf activation, like a El. motor or an electromagnet. After that, it should have type of power exchange system. At last it is the shift rail, which the shift fork is attached to. The shift fork is the part that will go inside the transmission, and do the actual movement and gear change.

The Functional block diagram also displays how the parts can stay, to make everything possible. But, just as the Blackbox, this is just a tool and do not need to be followed.

For more information, read the report about Functional Block Diagram.

4 Context Diagram

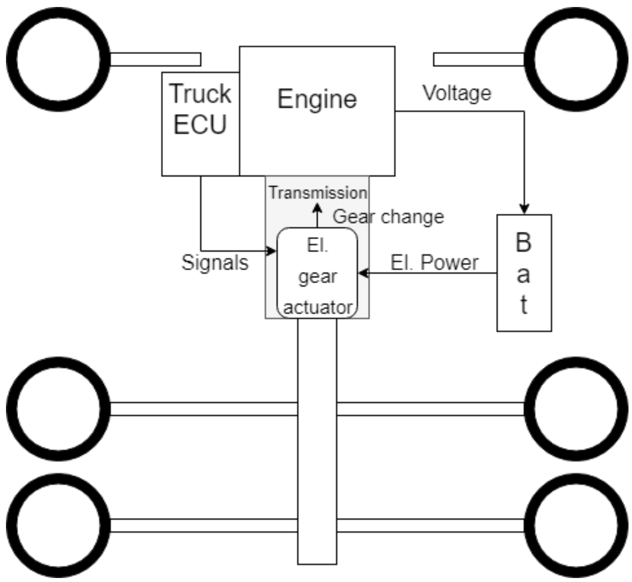


Figure 3: Context Diagram

A context diagram displays the Blackbox or different parts in a their right context. In this project the part is a gear actuator, therefore it is placed close or on the transmission.

In figure 3 it can be seen what parts that are going to influence the actuator system. The system can be divided into to groups.

1. Electrical Power
2. Electrical Signals

The main difference here is the strength, or quantity of the current and/or voltage. The electrical power are going to feed the el. motor or the el. magnet, while the signals from the ECU are just going to give signals if it is time to do a gear change or not.
For more information, read the report on context diagram.

5 Conclusion

These tools have been crucial for the developing of different concepts for the EGA team. With the help from these kind of tools, it is much easier to see the different things that will influence the project. It also have the advantages that it is possible to visualize the different things that needs to be developed. This way it is easier to describe and explain the different parts and phases of the project.

References

[1] Karel Th. Veenvliet G. Maarten Bonnema and Jan F. Broenink. *Systems Design and Engineering*. Taylor Francis Group, LLC, 2016.

Blackbox

EGA

May 4, 2018

Abstract

This is a document on how EGA have used Blackbox as a tool to see the different functions of the project, before starting to think about concepts and design. When working this way the project team is able to see just the functions and not think about the design. The reason for this, is that the team does not lock there thoughts to only one concept, and can keep the concepts open, but the functions closed.

Contents

List of Figures

1 Introduction

The Blackbox is a system engineering tool [1], that the project group choose to use. A Blackbox is, as it says, just a black box. The thought is that the user does not know the design of what they are making, just what it is supposed to do. This is helpful because this way you are not locking the thought process to a concept, but rather to what the concept shall do. What the concept shall do is called output, while how the Blackbox is activated is called input.

1.1 Function of a Blackbox

The way the project team have used the Blackbox, is combined with the brainstorming phase. This way the project team have been able to keep the direction of the project, without braking the creativity. It is important to keep in mind that the Blackbox is just a tool, and is best used combined with other tools, such as:

1. Functional Block Diagram
2. Context Diagram

2 The Blackbox

At the start of the project, the project team looked at what the Blackbox is going to do. What is the output of the Blackbox going to be. EGA started with analyzing the project description, which was given from KA. Just from the name of the project: "Electrical Gear Actuator", it is possible to have some knowledge about what the Blackbox is going to do. But, there is thousands of ways to make actuators, therefore the project group still has to find the best way to solve this project within the given requirements.

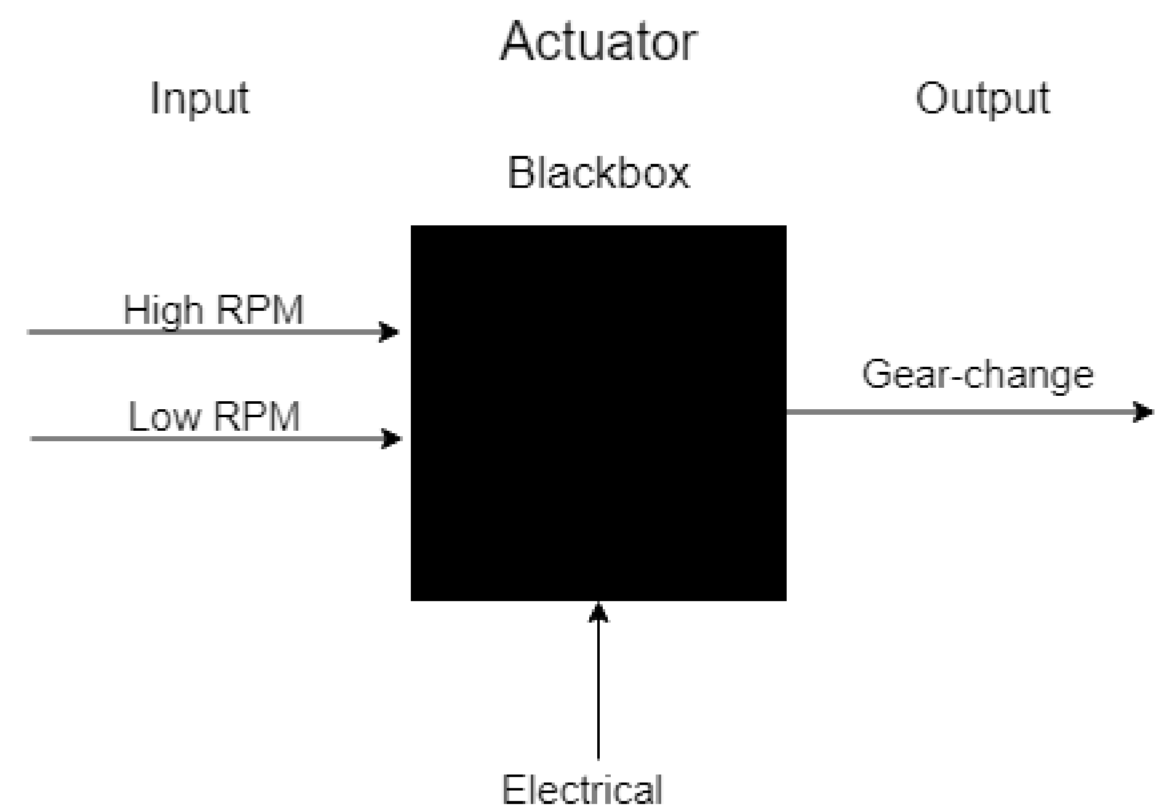


Figure 1: Actuator Blackbox

The first thing that was clarified; what was the Blackbox or actuator going to do. The task for the actuator is to do a gear-change, therefore this is the only output given in figure 1. What kind of technology the gear-change operation are going to use is not decided, and is therefore just a black box.

The two different inputs:

1. High RPM
   The thought is that the Blackbox, or actuator shall do a gear-change up when the RPM is sufficient.

2. Low RPM
   Same thought as high RPM, just the other way around. When the RPM is low, the gear-changer will shift down.

As it is possible to see in figure 1, there is a arrow called electrical. The reason for this, is that one of the requirements given form KA is that the actuator shall be electrical. This arrow symbolizes that the the whole box needs to be electrical.

3 Conclusion

To conclude EGA will say that this have helped the team to keep a track on what the actuator or Blackbox are going to do. With this kind of tools, it is easy to see the functions of a project without a concept.

References

[1] Karel Th. Veenvliet G. Maarten Bonnema and Jan F. Broenink. *Systems Design and Engineering*. Taylor Francis Group, LLC, 2016.

Functional Block Diagram

EGA

May 4, 2018

Abstract

A description about how functional block diagram works, and how the project team have used this tool. The idea is that this tool, helps the project team to find the different parts that the system needs.

Contents

List of Figures

1 Introduction

Functional Block Diagram [1] is the next logical step after a Blackbox. The difference between a Blackbox and a functional block diagram, is while the Blackbox is what the system are going to do, the functional block diagram is what the Blackbox are consisting of.

This is extremely important for this project, where it is well described what the concept are going to do, but not how. With the functional block diagram it is possible to see what is needed to make the different inputs and outputs possible.

Again, as mentioned in the Blackbox. The functional block diagram is just a tool, and works best with the support from:

1. Blackbox
2. Context Diagram

2 Functional Block Diagram

This is a diagram that displays the overview of a simple actuator. The thought is that; with a type of electrical power, for example an electrical motor, solenoid or electromagnet can produce the linear movement on the shift rail.

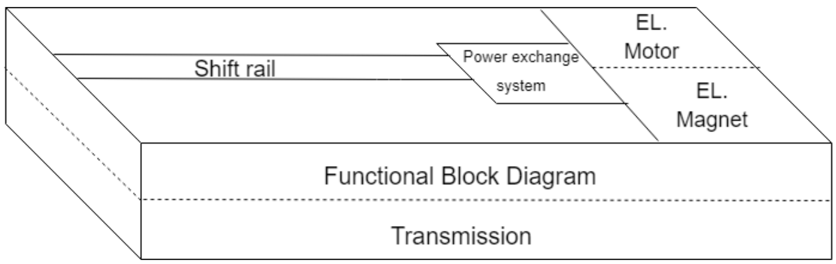


Figure 1: Functional Block Diagram

As it can be seen in figure 1 the functional block diagram consists of three different parts, which is mounted on the transmission.

1. Electrical Motor / Electromagnet
   At this point in the process, the EGA team does not know what the best power supplier is. When working with brainstorming simultaneously with system engineering, a idea with electromagnet was mentioned. This can be a good solution, and since the team want to keep an open mind it was decided to include the electromagnet idea.

2. Power Exchange System
   This is a system that can make an exchange for power, for example gears. A large gear to a smaller gear, have an power exchange.

3. Shift Rail
   This is the part that will be connected to the shift fork. This is also the part that will actually move, and this is where the power "ends".

As said, this is a functional block diagram and has none connection with reality, and design. The reason for developing this is so the project team can see which parts the project consists of, and how they are connected.

3 Conclusion

With this tool, the EGA group are able to see what kind of parts the system needs as a whole. This is obvously just estimated, and can change as the project goes on. The plan is to use the functional block diagram, to get an idea of what kind of components that is needed.

References

[1] Karel Th. Veenvliet G. Maarten Bonnema and Jan F. Broenink. *Systems Design and Engineering*. Taylor Francis Group, LLC, 2016.

Context Diagram

EGA

May 4, 2018

Abstract

This report explain short what a context diagram is, and how the EGA team have used it to have control over the different parts that may or will influence the actuator.

Contents

List of Figures

1 Introduction

A context diagram[1] shows how the system works in a context. The system is the Blackbox and the functional block diagram. In this case the context diagram will display what is going to influence the system, and what the team have to keep in mind when developing this actuator. When developing this context diagram, the project team will take a look at the context for a gear actuator. Try to find and set up the different parts are connected to the actuator, and how it influences the system. The context diagram is just a tool, and works best with the support from:

1. Blackbox
2. Functional Block Diagram

2 Context Diagram

At figure 1 it is possible to see the parts that are influenced with the gear actuator.

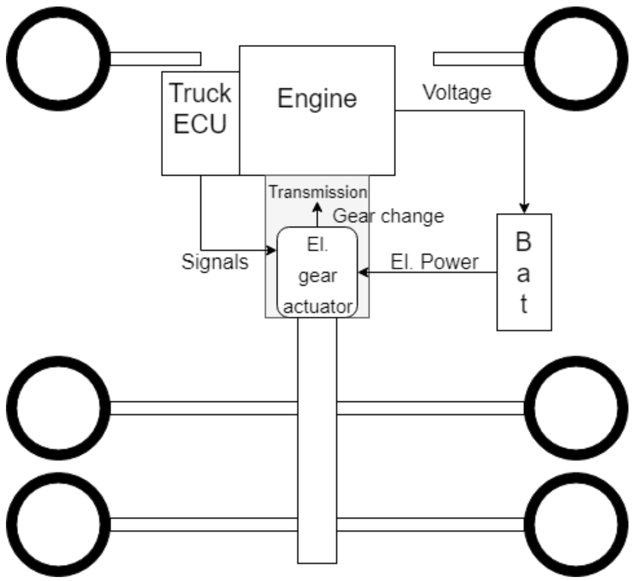


Figure 1: Context Diagram

The system can be divided into two different systems.

1. Electrical Power
2. Electrical Signals

The big difference between these two systems, is the power they are going to deliver. Not so surprising, the electrical power system needs to deliver a lot more power, then the electrical signals system. Therefore the EGA team have been thinking about a system that gets the electrical power from the vehicle / trucks battery. This way the actuators El. motor or El. magnets gets a lot more power, then it would from the ECU or another control unit. Even though the system gets its electrical power from the battery, it still needs to get the different signals. These signals are going to tell when the actuator needs to do a gear change, and when not to. Those signals are probably going to be administrated by the ECU, and know when the vehicle is low or high on the RPM. The mentioned signals are going to be low voltage signals (5V).

3 Conclusion

With the help of a context diagram, it is possible to see the different things that may influence the system. The project team also thinks that this was a good tool, to keep the brainstorming phase in the right direction.

References

[1] Karel Th. Veenvliet G. Maarten Bonnema and Jan F. Broenink. *Systems Design and Engineering*. Taylor Francis Group, LLC, 2016.

Pugh Matrix report: Criteria

EGA

May 4, 2018

Abstract

As more concepts starts making their appearance in the project, the group needs some tools to help with sorting out the different values of the different concepts. This tool shall help the project team to decide whether to discard a concept or to pursue it. A Pugh matrix is a reliable tool for this job.

The Pugh matrix in this report will be evaluating the criteria that every concept should accommodate. Also every criteria has been emphasized with number 1 - 5 so that the influence of every criteria is properly organized.

Contents

1 Introduction

In this report, a brief and accurate explanation of the criteria in the concept Pugh-matrix will be given.
Deriving this criteria can be done in several different ways, but the main goal is to understand the customer needs, wishes and transform this into engineering criteria. While this would be the most desirable way to do it, it has proven difficult to acknowledge customer needs. From the teams point of view, the customer is Kongsberg Automotive (KA) and the needs has been evaluated and transformed into engineering characteristics by KA.
It is important to still ensure a strong understanding between the customer/employer and the team. Although a different interpretations of the problem and requirements may cause issues, but it also allows for a more "out of the box" way of thinking. That is why this report concludes derived criteria which has not yet been discussed with KA

2 List of Criteria

2.1 Physical size of concept

When designing and developing concepts, it is important to keep a good grasp on the physical size of the product. In the vehicle business, size and weight are always critical factors. So the team should try to create a actuator that does not surpasses the original pneumatic actuator in weight and size considerably. The optimal actuator should be smaller and weigh less then the original one. Smaller size also opens for a better solution with module based product.

This criteria is also highly related to some of the stakeholders, like the customer (Volvo, Scania). These customers do not want a large, bulging or space wasting product. Therefore it is important for the project and the customer to keep a the product as small as possible.

- This criteria is emphasized to 4

2.2 Maintenance

How much maintenance is needed, and how easy is this service to perform are also important to keep in mind. There is requirements from KA that says that the product shall be maintenance free for 10 years, so this is not a big issue for the team to consider. The project team still chose to take this into account, due to probability off malfunction for the product when in service.

One of the requirements given from KA, is that this product shall last a minimum of 10 years. Even though the system shall last for 10 years, something may happen and it should be possible to do maintenance on the product after that time. In other words, it is important in case something happens, and for the lifecycle of the product.

- This criteria is emphasized to 2

2.3 Production costs

Costs of a product are always high stakes in a project, and this project is no different. Cost of production, cost of manufacturing, cost of assembly or other factors that can influence the product in a economical manner.

As everything that is produced, cost is important for the customer. EGAs customer for this product is KA, and they do not want to pay more than they have to. Also, if the price to build is high, it will also be high for KAs customer. If the price is high for KAs customer, they may go another place to buy their gear actuator.

- This criteria is emphasized to 5

2.4 Manufacturing method

How the product is going to be manufactured is a high risk factor, depending on the concept that are chosen. If the manufacturing process is not considered when selecting concepts, the product could end up being way to costly to manufacture, or even impossible to manufacture. This is therefore a medium/high risk criteria. It is possible to get lucky if this is not considered, but it is high probability to end up with a predominantly issue. Because of this, the criteria is being listed in the Pugh-matrix.

For the main stakeholder, KA. The manufacturing method is an important point on how they can manufacture the different parts for the product. If KA have the possibility to make the parts "in house", it will be much easier and cheaper.

- This criteria is emphasized to 4

2.5 Life cycle

Life cycle are a span of the product in service and then how it is disposed of after. We must consider if the product should be recyclable-. There is a big difference if the product are considered toxic waste or if it is Eco-friendly waste. It is important that the team are taking this into consideration, but the risk of creating a dangerous waste is minimal concerning this product.

For every stakeholder, the life cycle is important. This point do not only tell how the product will do after the warranty time, but also how the product will be recycled. In other words; it is important for KA, because they have to show that they make quality, and it is important for the world that it is recyclable.

- This criteria is emphasized to 3

2.6 Reliability

The reliability of the product is highly important to the user and the customer of the product. What is the malfunction rate of the product, and how difficult is it to keep a low malfunction rate over a long life span? The user shall know that every time he/she wants to change gear, the gear change happens. This is a stakeholder requirements to maintain a low malfunction rate, but it is decided in addition to have reliability as a criteria.

Reliability is the equivalent to quality, if the product is reliable it i also a quality product. For KA this is important, that they deliver a quality item that works every time it has to. That is why this criteria may be on of the most important criteria for the customer, and main stakeholder Kongsberg Automotive.

- This criteria is emphasized to 5

2.7 Requirement complexity

How difficult is the concept to accommodate the requirements. This is of little concern to the customer or the stakeholder, but is important to consider for the team when working further on with the concepts.

Most of the requirements are given from the main stakeholder and customer, Kongsberg Automotive. The requirements that are not given from the customer, is approved from the customer. Therefore it is important to see how easy it is to fulfill the given criteria.

- This criteria is emphasized to 3

2.8 Assembly

It is important to consider that with every concept, there shall be a assembly team of people and robotics. If the assembly of the product is to complex, then the cost will go up. This is therefore a direct issue that must be consider when designing and constructing the concepts. The golden rule is to always strife to achieve the solution with the easiest possible assembly.

Just as important as manufacturing method, is the assembly for Kongsberg Automotive. If it is easy, and do not require a lot of special tools to assembly, it can also be done "in house". Therefore, for the customer this is an extremely important point to keep the production cost down.

- This criteria is emphasized to 4

2.9 Innovative

Innovation is always something to reach for in production, and we are trying to create cutting edge solutions to the ever evolving market. This is difficult to achieve and therefore we have decided to use innovation as a criteria. Is is not a direct risk of failure, but should be considered important while in concept phase

Since this is a university task, it is given that the customer Kongsberg Automotive want new eyes and new solutions. Because of this, and that everybody wants new and innovative solution, it is not only important for the main stakeholder; KA, but also for the market.

- This criteria is emphasized to 4

2.10 Modulability

One request from the main stakeholder KA has been to make the product module based. Allowing easy replacement of parts that have higher risk of fatigue or failure. This criteria will also include how flexible and versatile the actuator is to fit other heavy duty vehicles.

- This criteria is emphasized to 3

2.11 Technical solution

The concept is technically strong and reliable. Is the final product meeting high end technology demands. Is the concept generally a good technical solution. Is it easy and functional.

For Kongsberg Automotive it is important that this product is as reliable as possible, easy to manufacture, cheap and holds the high requirement for technology that is needed in todays world. This point also covers the seamlessnes for the product, and how easy it is from

- This criteria is emphasized to 3

2.12 Competitive

As a last criteria, competitive is an area which also has a great influence on our product. If the product that are created are not better than what is already exists then we are sure to end up with failure. In this matter, there are many factors that comes into play. The product may not be cheaper, but faster. Or it may be more Eco-friendly and therefor can be used in areas where more polluting products can not. Maybe it is not better now, but forecast indicate that it will be indispensable in a decade or so. There are many ways a product can be competitive, but we have to ensure that it is in some way, so that our employer can rest assure that the product will yield returns.

Competitvnes is one of the most important criterias, for EGA customers: Kongsberg Automotive. But it is even more important for Kongsberg Automotives customers (Volvo, Scannia). If it is better options on the marked, and they are cheaper this is the options the manufactures will choose.

- This criteria is emphasized to 3

Pugh Matrix Concept Report

EGA

May 4, 2018

Abstract

The Pugh Matrix concept report, is a overview and explanation on how and why the different concepts have gotten their score in the Pugh Matrix. This report sets up all criteria, and then the different concepts are mentioned with a score, and why they got that score.

Contents

List of Figures

List of Tables

1 Introduction

This is a document where the concepts that EGA have thought out, are set against each other to find the most suitable concept. This have been done in a Pugh matrix, which weigh concepts up against different criteria. Both the concepts and the criteria have their own documents, which explains and describes the thought behind.

The report shall also be used as an overview, and as an explanation on the thought behind the weighting of the concepts. It is important to keep in mind that a Pugh Matrix is just a tool, and therefore the different criteria needs to be adequate. Because; if the criteria is adequate, it is easier to see which concepts that stands out positively or negatively.

2 Physical size of concept (4)

2.1 Rack and Pinion

Author: Yayun Chen
The physical size is mainly depending on the size of the motor, on the rack and pinion. Here it is important to choose the right motor, because it affects other components size as well as cost. At present the motor's torque is about 1Nm and the physical size will be small. Meanwhile, this actuator is going to be installed on the outside of the transmission, just as Scotch Yoke and the Rotating disc. If compared with those two concepts, the rack and pinion will be smaller in size. Therefore it earns itself a 4 under this criteria.

2.2 Rotating Disc

Author: Arild Bernhardsen
The rotary disc is not the best concerning physical space. The concept relies on its strength from radial force which increases in the distance from disc centre. This is transferred to mean physical diameter of the rotary disc. There are ways to go around this problem, but the main strength of this concept is the size of the rotary disc itself. If the diameter of the disc is narrowed, the main strength of this concept also weakens. This is why this concept gets 2 points on this criteria.

2.3 Ball Nut Screw

Author: Torjus Haugerud
Physical size of concept: 5
Example size: Distance from flange to centre of the sleeve 150mm
Hight above flange: 50mm
Length not including motor: 180mm
Width: 100mm

2.4 Electro Magnet

Author: Kristian Leth Risnes
Depending if the concept will be electromagnets that moves the fork outside of the gearbox through an extender or if the electromagnets are placed directly on the sleeve will affect the size. However, the size is relative to other concepts who will still be somewhat small in regards to the electromagnets we've already looked at. (some examples are [1] and [2]) **Grade: 5**

2.5 Scotch Yoke

Author: Vemund Bakka
The Scotch Yoke system is based on the outside of the transmission, which gives it some more space. Another problem is that it can not be placed over the transmission, it has to be placed on the side. Because of the movement. Even though, the system take some room because of;

1. The rotating disc
2. The Shift "Pole", which goes inside the transmission
3. A decent sized electrical motor.

The movement of the scotch yoke is only 25mm, but with all these parts it earns itself a 1.

3 Maintenance (2)

3.1 Rack and Pinion

Author: Yayun Chen
The system has a simplistic design, which usually makes it simple to perform the maintenance on. Due to all components are standardized, it requires normal skills and tools to conduct maintenance. But if the damage is to the rack and pinion components, the entire system may have to be replaced with a new one. Because of this, the criteria gets 3.

3.2 Rotating Disc

Author: Arild Bernhardsen
Few moving parts and easy assembly creates a low need of maintenance on this concept. A disc and a wheel bearing is the only moving parts that is required, because of this, the concept gets 5 points.

3.3 Ball Nut Screw

Author: Torjus Haugerud
Maintenance: 5 No special needs for maintenance. The ball screw is expected to be connected to sufficient lubrication system.
Attachment: 1 (Google disk-Bachelor project-S.U.D-Torjus-Attachments)

3.4 Electro Magnet

Author: Kristian Leth Risnes
Generally there is very little maintenance with electromagnets of this size, the main point would be terminals if there is heat issues or other wear.

Since the activation time is short, the heat issues will not be a problem for a concept like this.

Therefore the only maintenance required should be regular mechanical maintenance caused by the moving parts of the concept. **Grade: 4**

3.5 Scotch Yoke

Author: Vemund Bakka
The Scotch Yoke only consists of 2 moving parts and an electrical motor. Since the system only have those few parts, the maintenance is low and durable. The biggest concern, if the quality of electrical motor and metal is high enough, is the bearing between the rotating disc and shift "Pole". Because of this, it earns itself a 4.

4 Production costs (5)

4.1 Rack and Pinnion

Author: Yayun Chen
The most expensive subsystem could be the electrical motor, but it still can be chosen as standard as other subsystems. Therefor, production cost will be reasonable. Consequently, it will be scored 4.

4.2 Rotating Disc

Author: Arild Bernhardsen
The parts in the rotary disc are most likely to be manufactured as custom parts and that is highly expensive. It also have to endure high tensile stress which puts a demand of high quality materials. This also is highly expensive. This concept need very few manufactured parts, and this is weighing up for the expensive manufacturing methods. All these factors constitutes a relatively high production cost. Because of this, the concept get 2 points in this criteria

4.3 Ball Nut Screw

Author: Torjus Haugerud
Production costs: 3

These prices are based on the cheapest option. Quality may not be sufficient therefore prices may be underestimated. Renown manufacturer like SKF or FAG are considerably more expensive.

These prices are not included volume discount.

Production cost depends on production method and design.

It is possible to buy standard ball nut screws which can be reasonable priced from NOK 150,-.

Type of bearings depend on design
Price example for one bearing, large quantity will result in a lower price.

Axel diameter 10mm:
Radial load 62xx series NOK 20,-
Axial load 52xx series NOK 40,-

Axel diameter 20mm:
Radial load 62xx series NOK 25,-
Axial load 52xx series NOK 70,-

Prices are found on the internett and must be seen as guidelines only. Actual price quote has to many variables to be exact, i.e. estimate only.

4.4 Electro Magnet

Author: Kristian Leth Risnes
Since the electromagnet concept consists of 2 or more magnets affecting the shift fork, the production costs should be low. Electromagnets are durable and fairly inexpensive, so the cost looks to be equal or lower than other concepts. **Grade: 4**

4.5 Scotch Yoke

Author: Vemund Bakka
The Scotch Yoke system only consist of four moving parts; rotating disc, shift "pole", bearing and an electrical motor. On the background of the few parts, the cost should be low. The thing that will rise the price, is the high quality which is needed in the strong electrical motor and metal. The metal parts probably have to be machined, or custom ordered. Even so, the cost price will be in the middle, and it earns itself a 3.

5 Manufacturing method (4)

5.1 Rack and Pinnion

Author: Yayun Chen
Rack and pinion is a mature technical solution, therefore, the manufacturing method is consummate. For KA it is better to purchase the rack and pinion component and assemble it in the factory. It is easy and economized method, so this criteria gets 4.

5.2 Rotating Disc

Author: Arild Bernhardsen
As a manufacturing method, the first obvious and easiest choice would be milling, which is an expensive way of manufacture parts in a serial production. Alternatively, forging could be used as a production method instead of milling. Because of high dimension accuracy, this will be expensive. On the background of high tensile stress relative to size, it is important to use high quality materials and adequate manufacturing methods. Rotary disk gets 2 points.

5.3 Ball Nut Screw

Author: Torjus Haugerud
Manufacturing method: 3
Manufacturing process depends on the mechanical design. The screw can be turned and grinded or it can be rolled. The process can be done to create a very precise product, or the tolerances can be larger and thus make the manufacturing process simpler.

5.4 Electro Magnet

Author: Kristian Leth Risnes
Manufacturing electromagnets is a fairly easy procedure, and can be done in-house if it is found to be a cheaper solution. The rest is similar to other concepts, with eg. Forge a frame where the shift fork can be moved by the magnets. **Grade: 4**

5.5 Scotch Yoke

Author: Vemund Bakka
The Scotch Yoke system is a basic mechanical solution, and will be easy to develop. The problem on the other hand, is that none of the parts are ”shelf items” and needs to be custom made. If KA have the possibility to make the parts themselves, it will be quite easy. This possibility i reckon KA have, and will therefore earn this criteria a 3.

6 Lifecycle (3)

6.1 Rack and Pinnion

Author: Yayun Chen
This product is designed for at least 10 years. It goes through five primary stages. Each stage has its costs, risks and opportunities, and how long they remain at any of the life cycle stage.

1. Development
   This product requires small capital investment to develop. The resources are available already.

2. Introduction
   Marketing cost could be high under this stage.

3. Growth
   During this stage, it is striving to increase market share.

4. Maturity
   The competition from other products will increase, the product may need to be updated. But the production cost will be decreased due to the mature of the manufacturing process.

5. Decline
   Due to the market saturation and high competition. The products market share will decline.

After the product dispose, the material could be recycled. However, the lubricating oil is not environment friendly. In a score it earns 4 for this criteria.

6.2 Rotating Disc

Author: Arild Bernhardsen
Depending on manufacturing method, the disc should score high on life cycle criteria. Standard metallic alloy disc and some ball bearings are not difficult to recycle. In this concept, how to dispose the product is something the user does not need to consider during the purchase, service and disposal phases. The disposal phase has no negative effect on any stakeholders, which earns this concept 4 points.

6.3 Ball Nut Screw

Author: Torjus Haugerud
Lifecycle: 4
The ability to be recycled depends on materials chosen. Aluminium and steel are easily recycled. If materials like composite are chosen, the recycling can be more difficult.

6.4 Electro Magnet

Author: Kristian Leth Risnes
The life cycle for the electromagnet concept should be good as long as it is designed for minimal terminal wear, and should easily be able to hold for over 10 years. Afterwards some parts can be reused, and there should be no toxic waste coming from this solution. **Grade: 4**

6.5 Scotch Yoke

Author: Vemund Bakka
The Scotch Yoke system is a clean mechanical system, with an electrical motor. None of the parts in this system are dangerous, hard to contain, hazardous or extremely expensive. Therefore it is easy to recycle when it is not in use anymore. On the behalf of this information, the concept earns itself a 4.

7 Reliability (5)

7.1 Rack and Pinnion

Author: Yayun Chen
As mentioned before the rack and pinion is a mature solution. The technique is quite stable and all products will be tested to meet the requirements before it releases to the market. For this reason, it deserves a 4.

7.2 Rotating Disc

Author: Arild Bernhardsen
Few moving parts, easy construction and little complex geometry are key features on the rotation disc. All of those factors that contributes to a reliable product. With few radial cycles ¡ 0.25M/Y (Millions per Year), the chance of fatigue are also low, earning rotation disc 5 points on this criteria.

7.3 Ball Nut Screw

Author: Torjus Haugerud
Reliability: 5
There should be no reliability problems with the ball nut screw concept.

7.4 Electro Magnet

Author: Kristian Leth Risnes
Since the concept idea assumes that the project team is able to come up with a mechanical solution that can withstand the hard and sudden forces of the electromagnet switching on and off, the concept should be reliable up until the life cycle is complete and the system is scheduled for replacement.
Grade: 4

7.5 Scotch Yoke

Author: Vemund Bakka
The Scotch Yoke system is a reliable, as long as the quality is met. The only part which is vulnerable, is the bearing between the shift "pole" and the rotation disc. Because of this, it scores a 4.

8 Requirement complexity (3)

8.1 Rack and Pinnion

Author: Yayun Chen

Key Req.	**Score**
Temp	3
Velocity	4
accuracy	3
Robust	3
Maintenance free	4
Production	3
Sum	**3.3**

Table 1: Key Requirements Rotary Disc

This system is easy to meet the functional requirements, but there are still some solutions that needs to be improved. For this reason it gets 3.

8.2 Rotating Disc

Author: Arild Bernhardsen

Key Req.	**Score**
Temp	3
Velocity	5
accuracy	2
Robust	5
Maintenance free	5
Production	3
Sum	**3.8**

Table 2: Key Requirements Rotary Disc

By putting the rotary disc up against the key requirements the score ends up with 4 points on requirement complexity.

8.3 Ball Nut Screw

Author: Torjus Haugerud

Requirement complexity: 5 This concept can easily be constructed to meet the requirements.

Key. Req	**Score**
Temp	5
Velocity	5
Accuracy	5
Robust	5
Maintenance free	5
Production	3
Avg.	**4.7**

Table 3: Key requirement Ball Nut Screw

8.4 Electro Magnet

Author: Kristian Leth Risnes
Since the concept is in it's infancy yet, it is hard to determine how easy it can meet the functional requirements. But assuming the mechanical construction can withstand the forces, the concept scores **Grade: 4**

8.5 Scotch Yoke

Author: Vemund Bakka

Key. Req	**Score**
Temp	3
Velocity	4
Accuracy	4
Robust	4
Maintenance free	5
Production	4

Table 4: Key requirement Scotch Yoke

With the help of this table, it was possible to set the concept up against the different functional requirements and give them a score. The score goes from one to five, where one is quite bad and five is exceptional.

9 Assembly (4)

9.1 Rack and Pinnion

Author: Yayun Chen
The main process of the product is concentrated in the assembly and testing of the product. The assembly process will not be complex as all components are standardization, and the skill is mature in the industry. As a result, it deserves a 4.

9.2 Rotating Disc

Author: Arild Bernhardsen
Rotary disc is getting a high score on assembly on the basis of few parts required in this product. Rotary disc gets 5 points on this criteria.

9.3 Ball Nut Screw

Author: Torjus Haugerud
Assembly: 5

The assembling process must be considered during the design process. There are plans for assembly tool that are intended to aid assembly. This should shorten assembly time to about 30 sec.

Score is given assuming assembly tool works as intended.

9.4 Electro Magnet

Author: Kristian Leth Risnes
Assembly of the electromagnet concept will be very straight-forward. A robot or something similar should easily be able to place the electromagnets on the frame and solder the terminals correctly. The grading of this criteria is dependent on a solution where the electromagnets are placed externally, and not directly on the sleeve. That would complicate the assembly process.
5
If the electromagnet is placed directly on the sleeve, it will be considerable harder to assemble. Therefore it will get a much lower score, if this is the solution the project team ends on.

9.5 Scotch Yoke

Author: Vemund Bakka
The Scotch Yoke only consists of two moving parts and a bearing, which leads to that this concept is easy to assemble. If it is so easy that a robot can do it, is hard to predict, but most likely it could be possible. Because of this, the concept earns itself a 5.

10 Innovative (4)

10.1 Rack and Pinnion

Author: Yayun Chen
Although the idea developed in the idea phase, the technology have been used in decades. Because it is an old and well used technology, it has been used to similar things, which also Google patent could confirm. Even so, the patents that was found is not a match and it is possible to ”design around it”. As a result, it gets 2.

10.2 Rotating Disc

Author: Arild Bernhardsen
Low complexity and implementation of cutting edge technology awards lower score on innovation for the rotary disc. Although the concept is not mirroring any typical everyday products, it is neither a breakthrough invention on its own. Score for innovation is 3 points.

10.3 Ball Nut Screw

Author: Torjus Haugerud
Innovative: 4

Ball screw linear motion is widely used in industry machines. The understanding of innovative in this context is; used in a new and better solution.

Ball screw concept is not a very innovative solution by itself. Yet the concept is given four points. The relatively high score is based on a vision in which functionality and ease of assembly is considered. As the estimate is a vision ”the proof is in the pudding”. i.e. the result depends on an efficient and thorough process.

10.4 Electro Magnet

Author: Kristian Leth Risnes
Magnetic gearing in itself is not new or innovative, but this specific purpose was not found as a previously made solution. The concept might have a patent problem, but should be doable to design around it or make a good concept that might be usable as soon as the patent is void. However if the electromagnets can be placed directly on the sleeve this looks to be very innovating, and as far as EGA knows, not any patents either. **Grade: 5**

10.5 Scotch Yoke

Author: Vemund Bakka
The Scotch Yoke system is an old, and well tested system. Because of this, it earns itself a 1.

11 Modulability (3)

11.1 Rack and Pinnion

Author: Yayun Chen
The system includes main components as motor, rack and pinion. If any of them are damaged, it will be replaced by a new one. So this criteria earns 5.

11.2 Rotating Disc

Author: Arild Bernhardsen
Concerning internal modulability of the product, it will be easy to change different disc sizes to enhance different specifications on the actuator like the velocity/power parameters. This earns the points of 5.

11.3 Ball Nut Screw

Author: Torjus Haugerud
Modulability: 5
The intended design as a unit that can easily be adapted to and mounted to a variety of applications. The assembly are intended to be replaced as a whole unit.

11.4 Electro Magnet

Author: Kristian Leth Risnes
This concept scores very bad in modulability, because of the size and strength of the electromagnets used. It can be designed in a more general way, but this is not purposeful. Definitely easier to scale down then up. **Grade: 2**

11.5 Scotch Yoke

Author: Vemund Bakka
The Scotch Yoke system consists of few parts, which means that it would be easy to make as a whole module. When it is a module, it will be one box and is therefore easy to switch out. Because of this, that it can be build as one module it gets a 5.
But, design submodules inside the module, that can be harder. But, as said, it consists of few parts so if it needs to be more module based is another thing.

12 Technical solution (3)

12.1 Rack and Pinnion

Author: Yayun Chen
This concept is meeting the technology demands well and it is simple and functional. But it also has its drawbacks, which is leakage because of the simplicity of the system, it places a greater strain on the individual parts. For this reason alone, it gets 3.

12.2 Rotating Disc

Author: Arild Bernhardsen
Functionality relative to complexity is above average on this concept, but the simplicity creates a big issue which causes lack in accuracy. To compensate, there will be applied additional solutions which will have a negative effect on the technical solution, giving 3 points to the rotary disc.

12.3 Ball Nut Screw

Author: Torjus Haugerud
Technical solution: 4

Ball Screw solution has every possibility to be a neat design. The wav factor in the finally design depends on decisions made.

12.4 Electro Magnet

Author: Kristian Leth Risnes
In regards to the same arguments as for innovation, this will score very high if it is possible to place the electromagnets directly on the sleeve, and will be, if controlled precisely, a seamless and solid technical solution. **Grade: 5**

12.5 Scotch Yoke

Author: Vemund Bakka
The Scotch Yoke is basic and easy to understand solution, which also means that it is easy to build. Because of the simplicity, it also is exposed for a lot of force on the bearing. Another negative thing is that there is noe power exchange. Therefore, it earned itself a 3.

13 Competitive (3)

13.1 Rack and Pinnion

Author: Yayun Chen
As this concept has been in the market already, it has its commercial value and technical level. EGA thinks it is possible to make an even better version. But at this point, the team has not had the time to immerse itself in this solution. Therefore, it is difficult to determine how it can be improved, this criteria therefore gets a 4. If there is no way to improve this concept it gets a 2.

13.2 Rotating Disc

Author: Arild Bernhardsen
Since the actuator is electrical, it is competitive on its own. Compared to other electrical solutions, there are few factors that stands out on the rotary disc, giving this 3 points.

13.3 Ball Nut Screw

Author: Torjus Haugerud
Competitive: 5

The ball screw is safe, reliable, effective, quick, adaptable. Weather it is competitive is up to the design and manufacturing process.

13.4 Electro Magnet

Author: Kristian Leth Risnes
If the size is not a issue and the requirements can be fulfilled, this solution should be very competitive, mainly because of the speed and maintenance factor **Grade: 4**

13.5 Scotch Yoke

Author: Vemund Bakka
The Scotch Yoke is not used that much reverted as it is planned in this concept, therefore it is quite competitive. Even though, it also needs a lot of power to work reverted, contrary to the normal way. Therefore it earns itself a 3.

References

[1] makerle. Dc12v 120kg 264lb electric lifting magnet holding electromagnet solenoid p100/40. https://www.ebay.com/i/322230760456?rt=nc. (read 01.03.18).

[2] szmwkj. 100mm holding electromagnet lift 120kg solenoid. https://www.ebay.com/itm/100mm-Holding-Electromagnet-Lift-120kg-Solenoid-New/262142079827?hash=item3d08e2b353:g:-nkAAOSw4DJYfNdf. (read 01.03.18).

Concept: Overview

EGA

May 4, 2018

Contents

1 Introduction

A short summary of the different concepts, and why they either are viable or not. This is also an overview to see where in the process the concepts fell through, and a short why. If there are any more questions about different concepts, see the concepts report.

2 Viable Concepts

The different concepts who lived through the group discussions, and gets a OK from Steffen and Kristian from Kongsberg Auotomotive:

2.1 Electro Magnets

Electro Magnet solution:
Concept Idea was developed: 14.02.2018

Discussion: 16.02.2018
Investigate if this is possible in a practical solution, and do a patent search.

Discussion: 22.02.2018
Presented to Kristian from KA, and he thought this was an exiting idea. The project group agreed that this concept is the most 'out of the box' concept. This concept will be taken in to the Pugh Matrix, but will also be included forward. The project team have started to think about prototype solutions for this concept.

Discussion: 02.03.2018
The concept went through a Pugh Matrix, where it was clearly the most exciting and 'out of the box' concept. Because of this, and all the possibilities, the concept went through and will continue towards presentation II.

Discussion: 22.03.2018
The concept is going to be the final solution for the thesis, the decision was taken with the help from Kongsberg Automotive.

Discussion: 18.04.2018 The concept got different kinds of solution, which will be brought to KA.

Discussion: 22.04.2018 Kongsberg Automotive thought that the solution with the radial locking mechanism was interesting, so the group did a vote and concluded that this was the most innovative and interesting solution.

3 Not Viable Concepts

Ideas that did not survive the analysis and / or group discussion:

3.1 Direct Pendulum

Direct Pendulum solution:
Concept idea was developed: 14.02.2018
Idea made by: Vemund Bakka

Discussion: 16.02.2018
Under the discussion, the project team agreed on that this ideas was not worthy to spend time on.
Main points:

1. Strength of the El. motor
2. Quiality of the parts
3. Price, to make it possible

For more information, see the report about Direct Pendulum.

3.2 Scotch Yoke

Scotch Yoke solution:
Concept idea was developed: 21.02.2018

Discussion: 21.02.2018
The project group wants include it in the Skype meeting with Kristian from KA

Discussion: 22.02.2018
Presented to Kristian from KA, he did not say anything special about this concept. Will be included in the Pugh Matrix, which will be done Wednesday 28.02.2018

Discussion: 02.03.2018
Under the discussion after the pugh matrix, the Scotch Yoke concept was declared not viable.
Main points:

1. The physcal size and placement was a big drawback
2. Old technology
3. Not very effective

For more information, see the report about Scotch Yoke.

3.3 Rack and Pinion

Rack and Pinion solution
Concept idea was developed: 14.02.2018

Discussion: 16.02.2018
Must do a patent search, see if there are problems with different existing ideas and / or patents.

Discussion: 22.02.2018
Presented to Kristian from KA, he did not say anything special about this concept. Will be included in the Pugh Matrix, which will be done Wednesday 28.02.2018

Discussion: 02.03.2018
The Rack and Pinion solution was presented in the Pugh matrix, where it was declared not viable. BUT, the project team will still bring this concept as a plan B. This is still a very good concept, and it is a safe idea. Therefore it will be held in background, in case the project meets any problems with the other concepts.
Why it did not survive the Pugh Matrix:

1. Not very innovative
2. Basic solution

For more information, see the report about Rack and Pinion.

3.4 Rotation Disc

Rotation solution:
Concept idea was developed: 14.02.2018

Discussion: 16.02.2018
Must look at different practical solution for the rotatory device, and do a patent search.

Discussion: 22.02.2018
Presented to Kristian from KA, he did not say anything special about this concept. Will be included in the Pugh Matrix, which will be done Wednesday 28.02.2018

Discussion: 02.03.2018
Under this meeting the project team had the Rotation disc in a Pugh matrix, where it got a decent score. Even so, it did not get picked out to continue one. The main reasons for this is:

1. The physical size of the device
2. Production costs of the concept
3. Manufacturing method

For more information, see the report about Rotation Disc.

3.5 Axial Piston

Axial Piston solution:
Concept idea was developed: 14.02.2018

Discussion: 16.02.2018
Under the meeting 16.02.2018, the EGA team concluded that the Axial Piston concept was not viable .

1. To much uncertainty
2. A lot need to be special made

For more information, see the report about Axial Piston.

3.6 Ball Nut Screw

Ball Nut Screw Solution:
Concept idea was developed: 20.01.2018

Discussion: 16.02.2018
Must do a patent search, see if there are problems with different existing ideas and / or patents.

Discussion: 22.02.2018
Presented to Kristian from KA, he did not say anything special about this concept. Will be included in the Pugh Matrix, which will be done Wednesday 28.02.2018

Discussion: 02.03.2018 Under the Pugh matrix discussion, the project team agreed on that the Ball Nut Screw is going to continue as a viable concept. There are still missing some documentation, but this will be straightened out by Monday 05.02.2018, for further iteration.

Discussion: 22.03.2018 Kristian and Steffen from KA decided that the elecotrmagnet concept was more innovative then the Ball Nut Screw, therefore the project group decided to continue on the elecotrmagnet concept. For more information pleas see the report about Ball Nut Sctrew.

Concept: Direct Pendulum

EGA

May 4, 2018

Abstract

This report is an inspection to see if the Direct Pendulum concept is viable. The things that will be mentioned is how the system works, different parts, advantages, disadvantages and at last a conclusion if this idea is viable.

Contents

List of Figures

1 Introduction

The goal behind this idea is to use as few parts as possible, and keep it as mechanical as possible. Which also means that it will be, most likely, cheaper to develop. These kind of system obviously have a lot of advantages and disadvantages, which will be mentioned later in the report.

Figure 1 is an example of how it will look like as a concept, where figure 2 is the different parts which are named 1, 2 and 3.

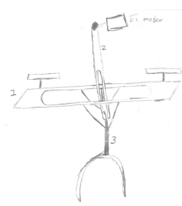


Figure 1: Concept

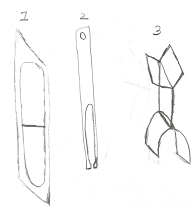


Figure 2: Parts

1.1 Concept

Figure 3 displays how the concept is thought as a whole system, and how it is put together:

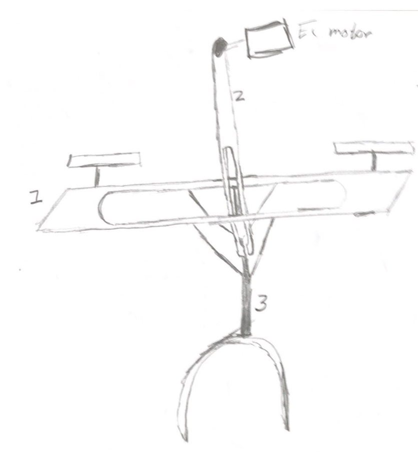


Figure 3: Sketch - Concept

The thought is that the electrical motor will move the pendulum circular, while the linear slider still moves the shift fork in a linear movement.

When the pendulum is moving circular, there will be roller bearings in the linear sliders. These roller bearings will make the linear slider movement with a small friction coefficient. When the electrical motor turn to left, the shift fork will move to the left and vice verca.

The two small blocks behind the linear slider, is the attachment for the linear slider. The thought is that when the electrical motor moves, the linear slider still needs to be steered correctly.

1.2 Parts

The three different parts that the system will consist of:

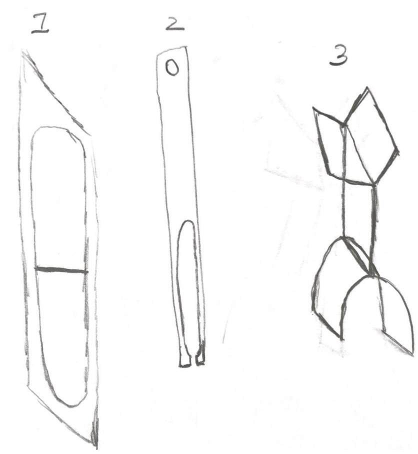


Figure 4: Sketch - Parts

The three different parts are;

1. Linear slider
   This is the linear part where the shift fork is attached. This part makes the linear movement possible, because of the hole which is cut out of the slider.

2. Pendulum from El. motor
   This part is attached to the El. motor, and moves the linear slider from left to right or vica verca.

3. Shift fork
   This is the part that puts the transmission in gear.

2 Advantages and Disadvantages

2.1 Advantages

1. Just three moving parts
   Since it is just three moving parts, it will be a low cost to develop it.

2. Size
   Since it is only three parts, it will be small and easy to make it fit.

3. Sensors
   It will be easy to place direct and indirect sensors.

4. Build
   This concepts is easy to make an Proof of Concept model of, unfortunately the real version will be much harder.

2.2 Disadvantages

1. Size of El. motor
   The biggest drawback is the power of the El. motor. Since the El. motor is direct to the shift fork, there are not any power exchange. In other words, the power needed to move the shift fork is 1:1 to the El. motor. This also means that the El. engine needs to be powerful and big, wich also means expensive and large in size.

2. Quality on the metal
   The quality on the metal needs to be exceptional, which also means expensive.

3 Conclusion

This concept is not viable.
Because, the quality and strength of the El. motor and metal are going to be to high. High quality, also means expensive. The direct pendulum concept will also be hard to realize with Kongsberg Automotive's requirements, which is set to an extremely high standard. Therefore are this concept not viable.

Concept: Scotch Yoke

EGA

May 4, 2018

Abstract

This report is an inspection to see if the Scotch Yoke concept is viable. The things that will be mentioned is how the system works, different parts, advantages, disadvantages and at last a conclusion if this idea is viable.

Contents

List of Figures

1 Introduction

The Scotch Yoke principle is an old invention, which also is in use today. This proves that the Scotch Yoke is a safe solution for the project, the problem on the other hand is that it this concept are quite "boring". Boring will say that there is nothing innovative about it.

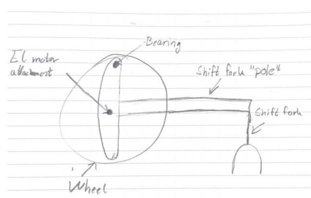


Figure 1: Concept

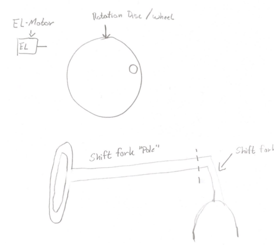


Figure 2: Parts

1.1 Concept

The thought behind this system is that the electrical motor will rotate the Rotating Disc. When the rotating disc is rotating, it will move the Shift Fork "Pole" in a linear movement. This will be made possible with the hole in the Shift Fork "Pole", which then moves with the rotation. In this connection between the Rotational Disc and the Shift Fork "Pole", it is needed a rotational bearing.

A challenge here is that the Scotch Yoke system is usually used the other way around, this will say that it uses linear movement to make rotational movement. Because of this, the system works the wrong way. Therefore, the electrical motor needs to be quite strong. The project group have calculated an approximation of the power to drag 1200N over 90° in 0.06s:

$$P = \tau * \omega = 117Nm * 26.17Rad/s = 367W \tag{1}$$

$$\omega = \frac{Rad}{s} = \frac{0.5Rad}{0.006s} = 26.17Rad/s \tag{2}$$

$$\tau = F * r(sinx^{\circ}) = 1200N * 9.75mm(sin90^{\circ}) = 11.7Nm \tag{3}$$

From equation 1 it is possible to see that the electrical engine needs approximately 367W, which is a decent sized electrical motor.

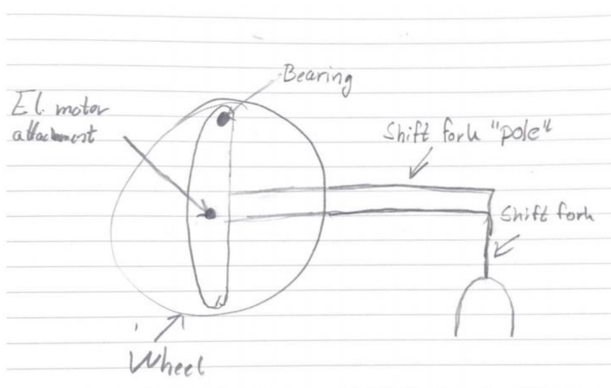


Figure 3: Scotch Yoke Concept

1.2 Parts

The Scotch Yoke system is a easy system, which consists of few parts. This can be seen in figure 4, where the different parts are sketched out.

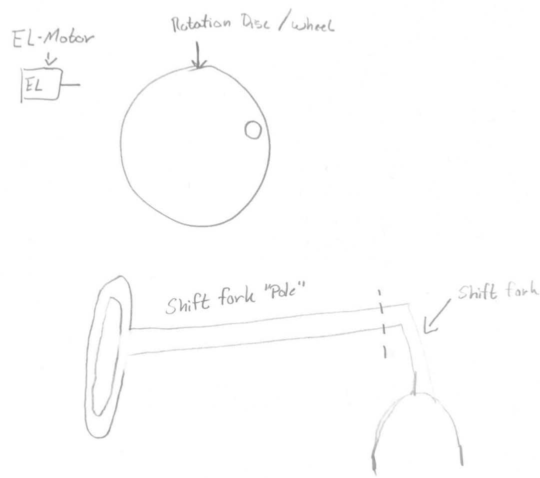


Figure 4: Caption

Parts included in the Scotch Yoke system:

1. Rotating Disc
2. Shift Fork "Pole"

Obviously this system also needs an electrical engine, but this is the two different moving parts. Between the Shift Fork "Pole and the rotation disc, it is also needed a bearing. This bearing is also one of the most vulnerable parts in this concept idea.

2 Advantages and Disadvantages

2.1 Advantages

1. Few parts
   There are only two different parts

2. Direct movement
   The movement are direct from the electrical motor, to the shift fork.

3.

2.2 Disadvantages

1. Strong electrical motor
   Because of the wrong way power exchange of the wheel, the system needs a strong electrical engine.

2. Quality of the material
   Even though the system only consists of a few parts, the parts need to be in a high quality. The reason for the high quality is the stress with direct movement.

3. Size of the Rotational Disc
   The rotational disc are going to take up a lot of space. Because of this, the best placement for this concept would be over or on the side of the transmission.

3 Conclusion

At this point, there is not possible to see if this concept idea is viable. It will go through the Pugh matrix on Wednesday 28.02.2018.

The Scotch Yoke went through a Pugh Matrix, where it was declared not viable compared to the other concepts. It did quite bad at both innovation and the physical size of the concept, which proved that the Scotch Yoke was not the best solution for this project. For more information, pleas look at the report for the Pugh matrix.

References

Concept: Electromagnet

EGA

May 4, 2018

Abstract

This report is a quick look on the electromagnet concept that was conceived as an idea at a brainstorming session the project group had in February.

Contents

List of Figures

1 Introduction

The electromagnet is quite simple in design, a magnetic field is generated by an electric current flowing through windings of copper coil [2]. And it is possible to use this phenomenon to "lift" or move the gear fork (if made in a ferrous material) position.

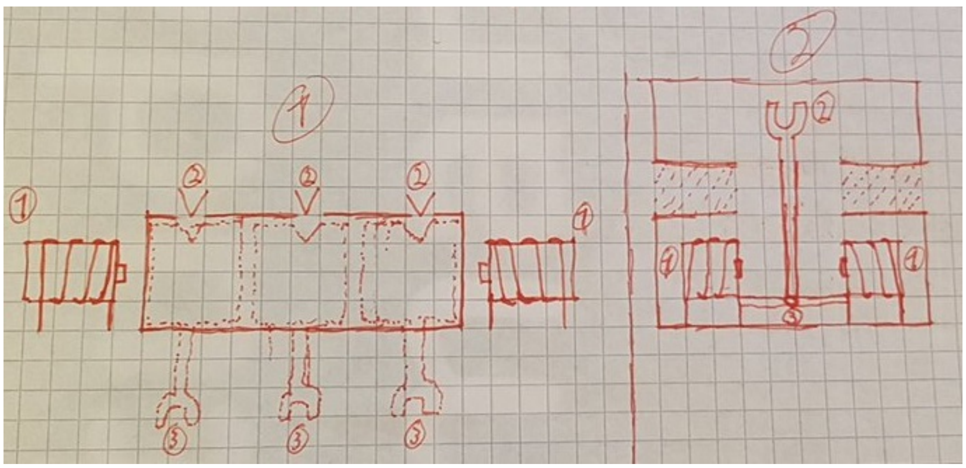


Figure 1: Shows both concepts as drawn during brainstorming

2 Concept

The idea behind this concept is having 2 or more electromagnets "pulling" or "lifting" the gear fork in position. By using electromagnets you achieve great speed, but the forces can be brutal and might need some form of "brake", either by using springs or some other mechanical system. When the concept is developed further, the force from the electromagnet and onto the fork can be calculated with the equation derived here [1]:

$$F = (N * I)^2 * 0 * (A/(2(g)^2)) \tag{1}$$

Where N = Number of turns, I = Current, 0 = Magnetic constant, A = Area and g = Gap between objects.

Since it is already known that the force in and out of gear must equal either 1200N or 750N. It is possible to play around with the other parameters of this equation to find the best gap, area of the object etc.

The group has though about a couple of different ideas for this concept. With the main differences being if the electromagnets should be inside the gearbox or outside the gearbox. There was also suggested one concept where the electromagnets are placed directly on the sleeve inside the gearbox.

2.1 Parts

The electromagnet concept is fairly straightforward, with only two or more electromagnets. This can be easily seen in figure 2 where you can see how the two electromagnets, marked (1), will "pull" the gear fork, marked (3), to either side.

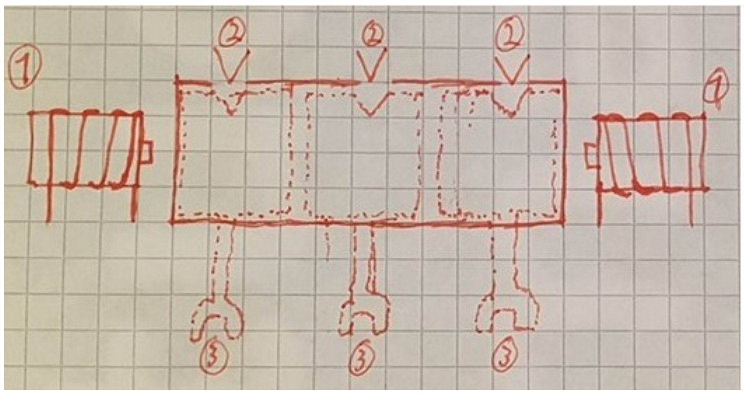


Figure 2: Shows the first EL. mag concept

3 Advantages and Disadvantages

3.1 Advantages

1. Quick gearshift
   Because of the strong instant force of electromagnetism the gearshift will be done very quickly.

2. Physical size
   The physical size of this concept should be relatively small compared to other concepts because you only need a couple of electromagnets built around the fork.

3.2 Disadvantages

1. Strong forces
   The mechanical construction must be able to take the sudden and "hard" forces in play when you activate the electromagnet.

2. Stray magnetic fields
   This goes both ways, some sort of sensors can be impacted by the electromagnetic field produced in this concept. And if there are other strong magnetic fields present in the construction.

3. Magnetic remanence
   Residual magnetic properties in the affected gear fork might make the fork "wander" in neutral position.

4 Conclusion

Altogether this concept looks promising, mainly because of the quick gearshift, physical size and the innovative aspect of it. In the pugh matrix it was evaluated to a second place, so depending on further discussion this concept might be developed further.

References

[1] Richard A. Clarke. The force produced by a magnetic field. http://info.ee.surrey.ac.uk/Workshop/advice/coils/force.html#nfringe, 10 2010. (read 04.05.2018).

[2] Marshall Brain & Lance Cooper. How electromagnets work. https://science.howstuffworks.com/electromagnet.htm, 04 2000. (read 04.05.2018).

Concept:Axial Piston

EGA

May 20, 2018

Abstract

This report is an inspection to see if the Axial Piston concept is viable. The things that will be mentioned is how the system works, different parts, advantages, disadvantages and at last a conclusion if this idea is viable.

Contents

List of Figures

1 Introduction

1.1 Concept

The Axial piston concept‘s idea is from the hydraulic Axial Piston Pump. Therefor the work principle is quite similar. The different is this concept will perform linear motion.
Work principle (refer to the figure 1):
Two pistons or more are fixed on the Rotation plate ③ , when the Rotation plate begins to rotate on the fixed Swash plate ① that gives a different position. Which leads to these pistons run follow the track ⑥ on the fixed plate ② and reaches different stroke. The piston gives full stroke at the top of Swash plate and gives zero stroke at the bottom of Swash plate. It could have more pistons, this depends on how often going to shift gear and how effective is going to be.

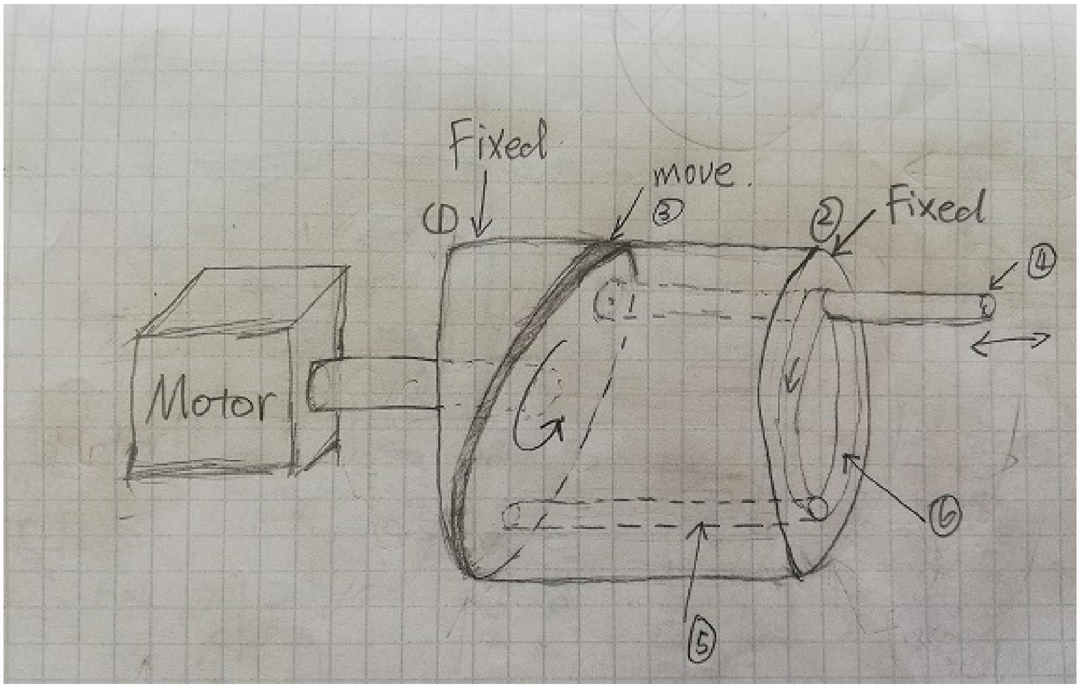


Figure 1: Axial Piston Actuator

1.2 Components

From the above figure shows that the Axial Piston system includes the following components:

- Motor
- Axial
- Swash plate (as marked ① on the figure)
- Rotating plate (as marked ③ on the figure)
- Piston (as marked ④ ⑤ on the figure)
- Cylinder
- Fixed plate with running track (as marked ② on the figure)

2 Advantages and Disadvantages

2.1 Advantages

1. Could reach full stroke in short time

2.2 Disadvantages

1. There are many interface, it will cause high friction
2. Under high temperature condition, it needs special lubrication oil that will increase the price
3. The construction might cost high
4. Because the piston moving direction, that might need higher static force to push or pull

3 Conclusion

This is an interesting idea concept. However, the team needs not only to identify and improve many uncertain aspects, but also to be limited by the time of the thesis. Based on this, the team will not continue this concept.

Rotation Disc

A concept analysis

Pro	con
Quick linear movement	Difficult to maintain in accurate position
Easy manufacturing	Low accuracy
Robust power transmission	Low “hold in gear” strength
Easy production	
Allow usage of «low» effect engine	
Low maintenance	
Highly reliable	
Long lifetime	

Requirements accommodation:	1 – easy	2-Normal	3 - Hard

REQ-ID - accommodation	REQ-ID - accommodation
01 – 3	15 – 2
02 – 2	16 – 3
07 – 2	17 – 1
08 – 2	18 – 1
09 – 2	18 – 1
11 – 2	19 – 1
12 – 3	20 – 1
13 – 2	21 – 1
14 – 2	22 – 1
Sum	32 - 18 = 14

Score formula: accommodation points – 18 = final score

Best score is 0

Lowest score is 36

Summary

We have done a top-level system analysis on the rotating disc.

As a first impression of the analysis on the rotating disc concept we can conclude with several benefits and drawbacks.

The main benefits to the rotating disc is the simplicity of the construction to meet the requirements of lifecycle and durability and also the requirement which states the need to a very fast and high velocity gear change.

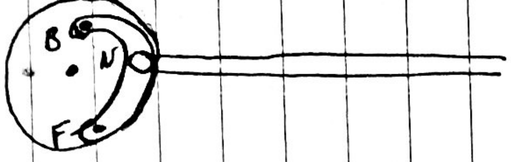
The rotating disc, as a first impression view, are considered a cheap and reliable solution.

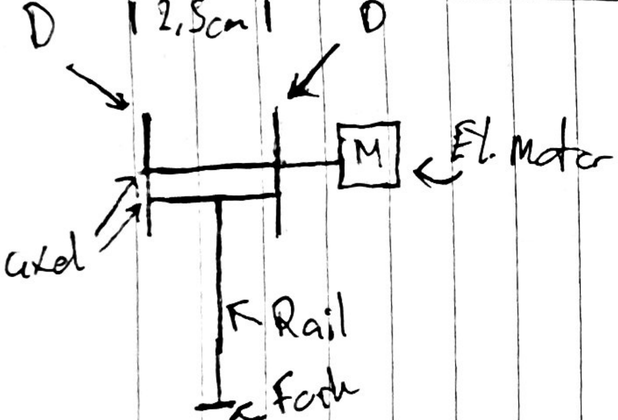
The analysis concluded with one main drawback.

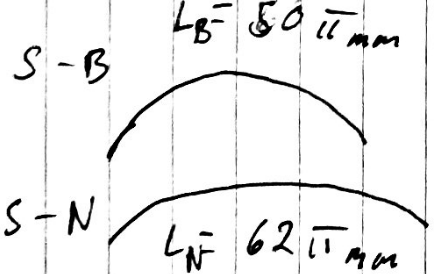
- Low, or difficult to obtain and maintain, precision on the gear diverter(shalter), which is a level A requirement

This is a major drawback that should be considered with high importance

D:1







$6(S-B) = \frac{62\pi + 50\pi}{2} = 56$

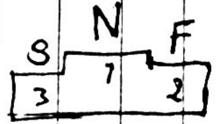
$L(S-B) = \frac{O}{2} = \frac{2\pi \cdot 56\pi}{2} = 56\pi$!!

D:2

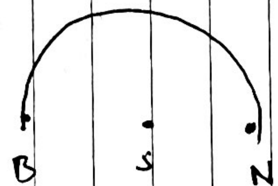
S - B = 50 mm

S - N = 62 mm

S - F = 74 mm



Eksempel?



S - N = 62 mm

S - B = 50 mm

Omkrets S-N: ($2\pi r$)

$2\pi 62 = 124\pi$ mm

$124\pi / 2 = 62\pi$ mm

$\frac{O(S-N)}{2} = 62\pi$ mm

Omkrets S-B ($2\pi r$)

$2\pi 50 = 100\pi$

$100\pi / 2 = 50\pi$

$\frac{O(S-B)}{2} = 50\pi$

Concept: Rack and Pinion

EGA

20-02-2018

Abstract

This report is an inspection to see if the Rack and Pinion concept is viable. The things that will be mentioned is how the system works, different parts, advantages, disadvantages and at last a conclusion if this idea is viable.

Contents

List of Tables

List of Figures

1 Introduction

1.1 Concept

Rack and Pinion is a simple linear actuator, it uses a pair of gears which convert rotational motion into linear motion. The main part of the system are rack and pinion, so the system names Rack and Pinion.
Work Principe:
The pinion is the circular gear and the rack is a linear gear. When the motor drives the pinion, it will cause the rack to move relative to the pinion, thus enabling the conversion of rotational motion and linear motion.
A preliminary sketch of the system is shown the below figure 1.

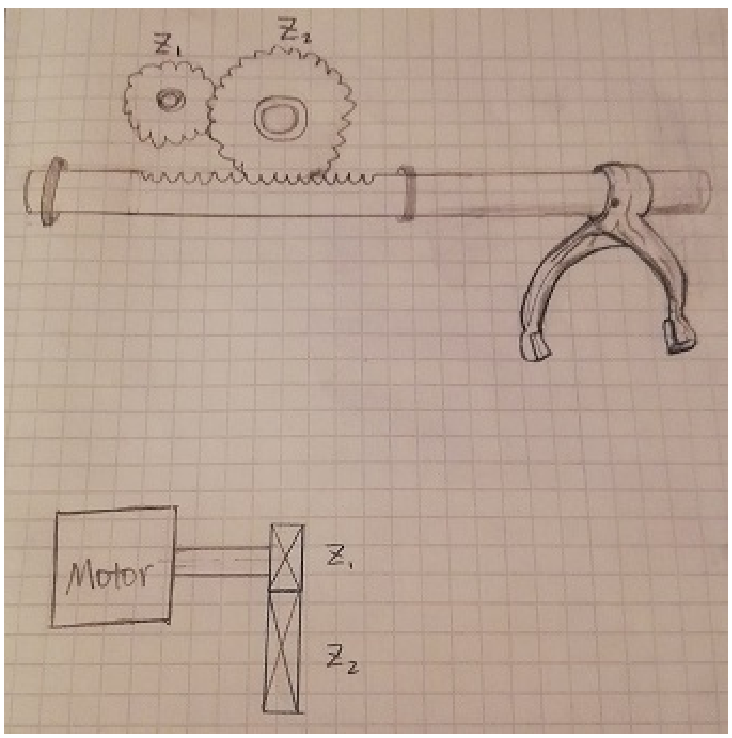


Figure 1: Rack and Pinion Actuator

1.2 Components

The Rack and pinion comprises the following components.

- Motor
- Pinion (could be gear set)
- Rack
- Fork
- Other electronic parts

2 Advantage and Disadvantage

2.1 Advantages

1. Simple construction
2. Low production cost
3. Compact system

2.2 Disadvantages

1. Friction
2. Under the high temperature condition, it requires high quality lubrication oil
3. Low innovation

3 Conclusion

According to the Pugh Matrix, the Rack and Pinion will not be continued. The most reason is the concept is not innovative. For more details please refer to the Pugh Matrix Concept report.

Patent Course

EGA

May 21, 2018

Abstract

The project group visited Kongsberg Automotive for a introduction course of patent search and analyses. Geirfinn Eide was the instructor, and thought the project team the different techniques to understand how patents work and how to find the way through it.

Contents

1 Introduction

Wednesday 14.02.2018, the project group had planed with Kongsberg Automotive to have a patent course. The patent course instructor was Geirfinn Eide. Geirfinn who have had long experience with patents, could give the project team valuable information. The main questions the project group had; "How to search for patents" and "How to analyze patents". Not only could he give information about these topics, but he also had insight in how the patent office works, albeit he used to work at the patent office in Oslo. He also gave a lot of personal tips and tricks, if one of the project team members wanted to patent something in the future.

2 Patent course

This is a summary of the different things that Geirfinn explained and taught at the course. These points are really helpful in understanding the procedure of a patent, and helpful for EGA to know where to start when they are doing the patent search.

2.1 Importance

A patent is a document that proves, that this idea is yours. The idea behind a patent, is that you can prove that the idea is your, with the support from the government.

A patent is only valuable 20 years from the day, a person files for it. Even though the patent filing can take up to 3 years until it's done. Another important point is that the patent is going to be official after 18months from the applying, but other people can still not use it without the owners consent.

2.2 Search engines

There are different sites where it's possible to search for patents, but for EGA Google patents https://patents.google.com/ is the first choice. This is a free version of a patent search engine, with most of the patents around the world. The user interface is not as good as the ones that costs money, but since they cost about 100.000kr per year Google patents is a good alternative.

The main difference between the ones that costs money, and the free one is the user interface. The ones that are not free, are set up a different way, which makes it possible to search for words different places in the text. They also do a calculation to find the patents that you are most likely looking for, which they show in a percentage.

The patent search engine from Google does not do any of this, but it uses Boolean algebra. This means that it is possible to split up words and can make the search experience a bit easier.

2.3 Analyze

A patent is divided in different parts;

1. Drawings / Sketches
2. Introduction, explanation
3. Claims, or requirements for the patent

The first thing to look at is the drawings, try to see and understand if the patent applies for the concepts that are searched for. The next thing then, is to read the claims.

The claims are the important thing, when reading the patent. This is the claims or requirements that have been set from the government about this specific patent. Usually there is only one main claim, and several under claims. These under claims are just supporting the main claim.

The main claim is the important one, if your concept doesn't interfere with the patent there is no problem. If though, the concept interferes with the main claim. The next step is to read the under claims, and see if there is some differences. Should one of the under claims be different, the your concept is in the clear.

This leads up til the final point; How to manipulate a concept, so it doesn't interfere with a existing patent. The rule is quite simple, if one of the claims are different from the concept, it's ok to fill out the patent application. Therefore, if the concept is equal to the patent, you can always manipulate or change it. If you only change a small part, the probability for getting the patent approved are high, almost guaranteed.

3 Summary

This was extremely educational for the project team, and made an impossible task doable. With this kind of information, and methods, EGA can start on the searches right away.

Geirfinn Eide also said that he always is just a email away, and will try to help the group if needed.

Force Analysis

EGA

May 20, 2018

Abstract

In order to design a solenoid system that has enough force to complete the mission, which is pushing the tooth to the channel and pulling back to the original position in the required time. A force analysis is performed on the machine system and calculate the result with the help of Matlab. This report is mainly to describe how the team approach the force analysis.

Contents

List of Figures

List of Tables

1 Description

1.1 Subsystem and surrounding situation

- Subsystem situation:
  The subsystem solenoids are placed inside the sleeve that is fixed to hub and rotates with the main shaft.

- Surrounding situation:
  The first or second gear with the synchronized corn is on the main shaft but rotates with the gear that rotates with the layshaft. There are three channels on the synchronized corn.

- Relation(see figure 1):
  When the solenoid push the teeth into the channel, the sleeve will connect the gear, and the gear will run together with main shaft at same speed, so that the gears on the layshaft will transmits drive from input shaft to the main shaft. Even to achieve the purpose of shifting gear.

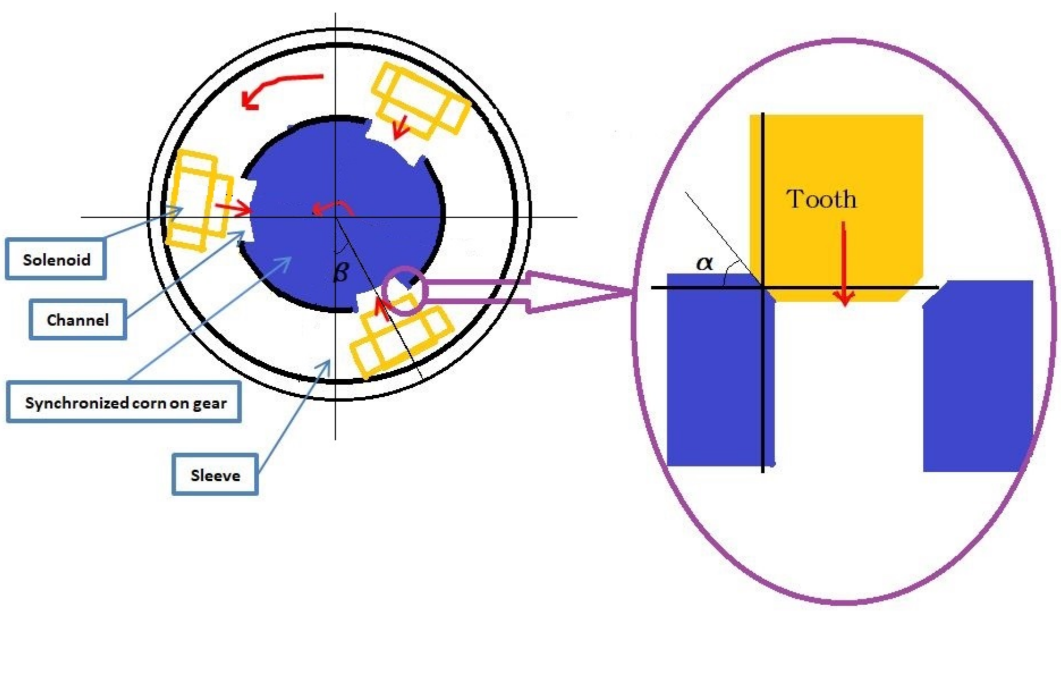


Figure 1: $\alpha - \beta - illustration$

1.2 Force analysis

Since the solenoid rotates, in order to analysis the force in the right way, the team uses the angle $\beta(0^\circ \leq \beta \leq 360^\circ)$(see the figure 1-right) to describe the position of solenoid. For example, when $\beta = 0^\circ$ or $\beta = 360^\circ$, the solenoid is at the bottom of the vertical. When $\beta = 90^\circ$, the solenoid will be at the right of the horizontal. Taking a solenoid at β position and analysis force on the contact object tooth as shown the following figure 2:

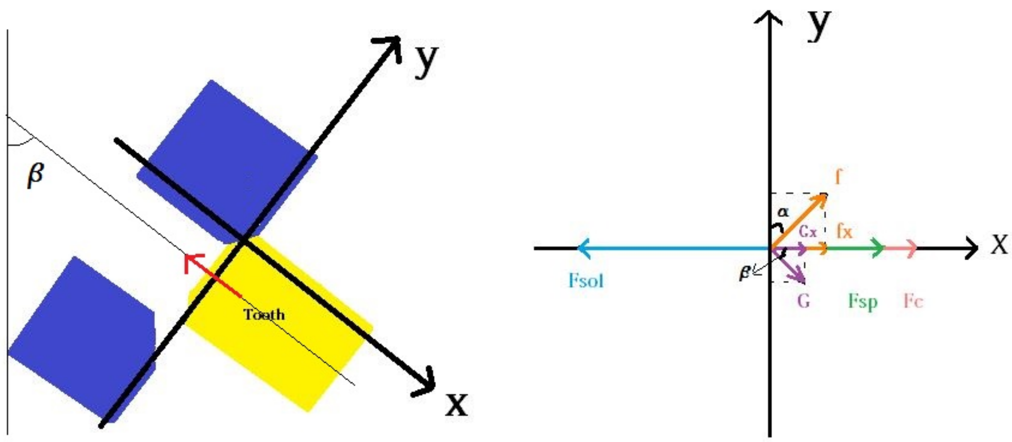


Figure 2: Force analysis-illustration

Firstly, the subsystem solenoid rotates when tooth is pushed, so the tooth is subjected a centrifugal force (F_c -marked pink colour in figure 2). It always points in the direction opposite to the pushing direction. Therefore, the solenoid must win this force to push.
Here the centrifugal force will be:

$$F_c = m \cdot r \cdot \omega^2 [1, p.\ 160] \tag{1}$$

(Remarks: this section‘s all parameters definition please refer to table 1 below)

Secondly, when a tooth contacts the synchronized corn and trys to slip into the channel. It will have a friction(f-marked orange colour in figure 2).

The friction is at the contact face that has an angle α to the synchronized corn plane as shown in figure 1-left. α is between $0°$ and $90°$ and effects the friction, therefore, it will be determined the optimal number for α.
Here the friction will be:

$$f = \mu \cdot N \tag{2}$$

Thirdly, It always has the gravity (G-marked purple colour in figure 2) on the system.
Here the gravity will be:

$$G = m \cdot g \tag{3}$$

Fourthly, There is one spring inside the solenoid, so it will be a spring force(Fsp-green colour mark in figure2) on the tooth and the direction is same as centrifugal force.
Here the spring force will be:

$$Fsp = k \cdot x \tag{4}$$

In additional, Normal force(N) for calculating the friction. To make normal force more intuitive, use friction f as the x-axis for N analysis (refer to figure 3).

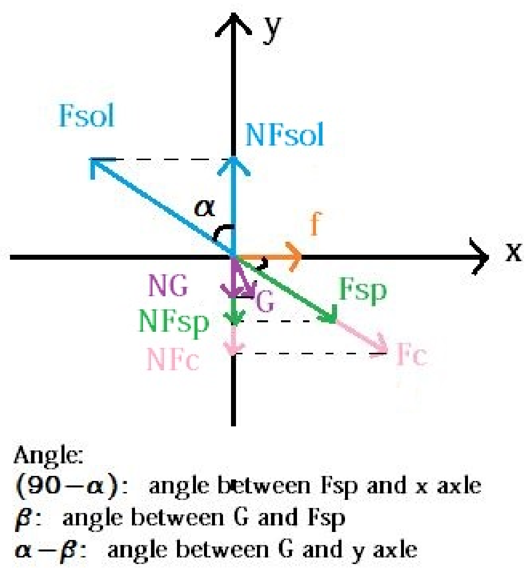


Figure 3: Normal force-illustration

Here the normal force become:

$$N = N_{Fsol} - (N_G + N_{Fsp} + N_{Fc}) \tag{5}$$

Among this

$$N_{Fsol} = Fsol \cdot \cos\alpha \tag{6}$$

$$N_G = G \cdot \cos(\alpha - \beta) \tag{7}$$

$$N_{Fsp} = Fsp \cdot \cos\alpha \tag{8}$$

$$N_{Fc} = F_c \cdot \cos\alpha \tag{9}$$

So the friction equation (2) become

$$f = \mu \cdot (N_{Fsol} - (N_G + N_{Fsp} + N_{Fc})) \tag{10}$$

Last, the solenoid force(Fsol-marked as blue colour in figure 2). From the figure 2: the solenoid force must be at least equal to the total force of others on x-axle in order to push the tooth. It can be expressed as follows:

$$Fsol \geq G_x + f_x + Fsp + F_c \tag{11}$$

Among this

$$G_x = G \cdot \cos\beta \tag{12}$$

$$f_x = f \cdot \sin\alpha \tag{13}$$

Set equation (10) into the (13):

$$f_x = \mu \cdot (N_{Fsol} - (N_G + N_{Fsp} + N_{Fc})) \cdot \sin\alpha \tag{14}$$

Set the equation (6) and (13) into the equation (11):

$$Fsol \geq G_x + \mu \cdot (Fsol \cdot \cos\alpha - (N_G + N_{Fsp} + N_{Fc})) \cdot \sin\alpha + Fsp + F_c \tag{15}$$

$$Fsol \geq \frac{G_x - \mu \cdot (N_G + N_{Fsp} + N_{Fc}) \cdot \sin\alpha + Fsp + F_c}{1 - \mu \cos\alpha \sin\alpha} \tag{16}$$

Table 1: Calculation parameter list

Symbol	**Quantity**	**Value**	**Remarks**
Fsol	Force from solenoid		
m	Mass of a tooth	56.72g	
g	Acceleration of gravity	9.8 m/s^2	
Fsp	Force from spring		
k	Spring constant	10000 N/m	
x	Moving position	$0 \sim 5mm$	
r	Radius of synchronous cone	40mm	
ω	Angle velocity	209.44 rad/s	2000rpm
Fc	Centrifugal force		
f	Friction		
μ	Friction constant	0.85 [1, p. 34]	
N	Normal force on the contact face		
G	Gravity		
G_x	Gravity on x axle		see figure 2
f_x	Friction on x axle		see figure 2
Fsp	Spring force		
N_G	Normal gravity force on contact face		See figure 3
N_{Fsp}	Normal spring force on contact force		See figure 3
N_{Fc}	Normal centrifugal force on contact force		See figure 3
N_{Fsol}	Normal solenoid force on contact force		See figure 3
α	Tooth contact angle		See figure 1
β	Solenoid position angle		See figure 1

Implement all equation in the Matlab(please click here 3 to find the code) and the result shows as follows:

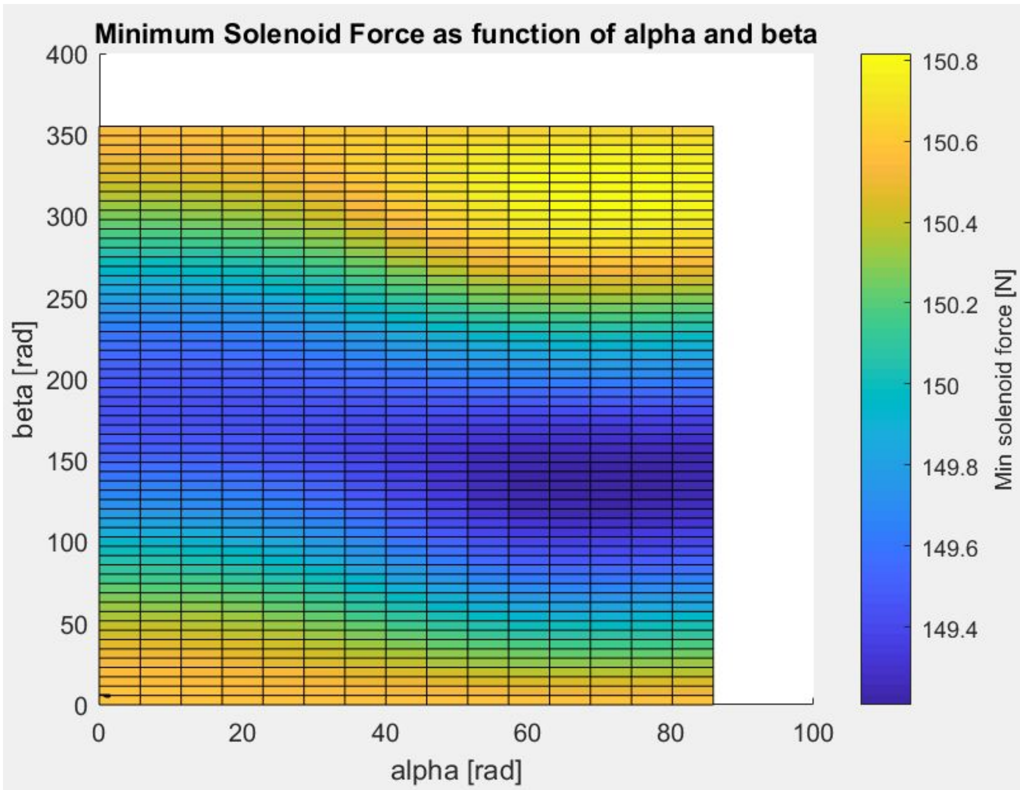


Figure 4: Solenoid force result from Matlab

The figure 4 shows that the minimum force required when $60° \leq \alpha \leq 90°$ and $100° \leq \beta \leq 150°$.So in the design of the tooth, the angle α can choose around 70° . However for solenoid the solenoid force should be greater than 150.8N. In additional, the centrifugal force is 100.012N and Spring force is 50N. The maximum friction and gravity on x axle are about 0.8N. It is very little.

2 Conclusion

With the help of Matlab and theoretical force analysis, the solenoid should be designed to generate a force great than 150.8N.

3 Matlab code

```
mu = 0.850 ; %friction coefficien
k = 10000; %spring constant
m = 0.057; %kg, mass of a tooth
g = 9.8; %acceleration of gravity
r = 0.04; %m, radius of syncron cone
omega = 2000/60*2*pi; %rad/s,2000rpm, angular velocity
x =5/1000;
alpha = 0:0.1:(pi/2); %contact face slope angle
beta  = 0:0.1:(pi*2); %solenoid position
[ALPHA,BETA] = meshgrid(alpha,beta);%returns 2d grid coordinates
G = m*g; %gravity
Fsp = k*x; %spring force
Fc = m*r*omega^2; %centrifugal force
NG = G*cos(ALPHA-BETA); %normal force of gravity
NFsp = Fsp*cos(ALPHA); %normal force of spring force
NFc = Fc*cos(ALPHA); %normal force of centrifugal force
%NFsol = Fsol*cos(ALPHA); %normal force of solenoid force
%N = NFsol - (NG + NFsp + NFc);% total normal force
%f = mu*N;
Gx = G*cos(BETA); %gravity on x-axle
%fx = f*sin(ALPHA);%friction on x-axle

minimumFsolenoid = (Gx-mu.*(NG+NFsp+NFc).*sin(ALPHA)+Fsp+Fc)./(1-my.*cos(ALPHA).*sin(ALPHA));
%%
figure()
s=surface(ALPHA./(2*pi)*360,BETA./(2*pi)*360,minimumFsolenoid);
xlabel('alpha [deg]')
ylabel('beta [deg]')
zlabel('minimumFsolenoid [N]')
cb = colorbar;
cb.Label.String = 'Min solenoid force [N]';
title('Minimum Solenoid Force as function of alpha and beta')
```

Figure 5: Solenoid force calculation code from Matlab

References

[1] Carl Nordling and Jonny Österman. *Physics Handbook*. Studentlitteratur,Lund, sixth edition edition, 2006.

Pugh Matrix: Concept selection r 3.0 (group discussion)							
	Concepts (1-5)						
Criteria	**Weighted criterias (1-5)**	**Rack and pinior**	**Rotating Disc**	**Ball Screw**	**Electro-Magnets**	**Scotch Yoke**	**Notes**
Physical size of concept	4	4	2	4	5	1	
Maintenance	2	3	4	5	4	4	
Production costs	5	4	2	3	4	3	
Manufacturing method	4	4	2	3	4	3	
Lifecycle	3	4	4	4	4	4	
Reliability	5	4	5	5	4	4	
Requirement complexity	3	3	4	5	4	4	
Assembly	4	4	4	5	5	5	
innovative	4	2	3	4	5	1	
Modulability	3	5	5	5	2	5	
Technical solutio	3	3	3	4	5	3	
Competitive	3	3	3	5	4	3	
Score:	40	156	144	183	181	140	

Iteration report

EGA

19-05-2018

Abstract

The purpose of this report is to document the process and summary of all iterations in more detail. Particularly including the following points:

- Iteration activity list
- what the team have done
- What the team should have done
- What the team have learned

Contents

List of Tables

List of Figures

1 Introduction

According to Unified process, The team has divided the project into four phases and every phase includes different iteration. The schedule of every iteration as shown below figure 1:

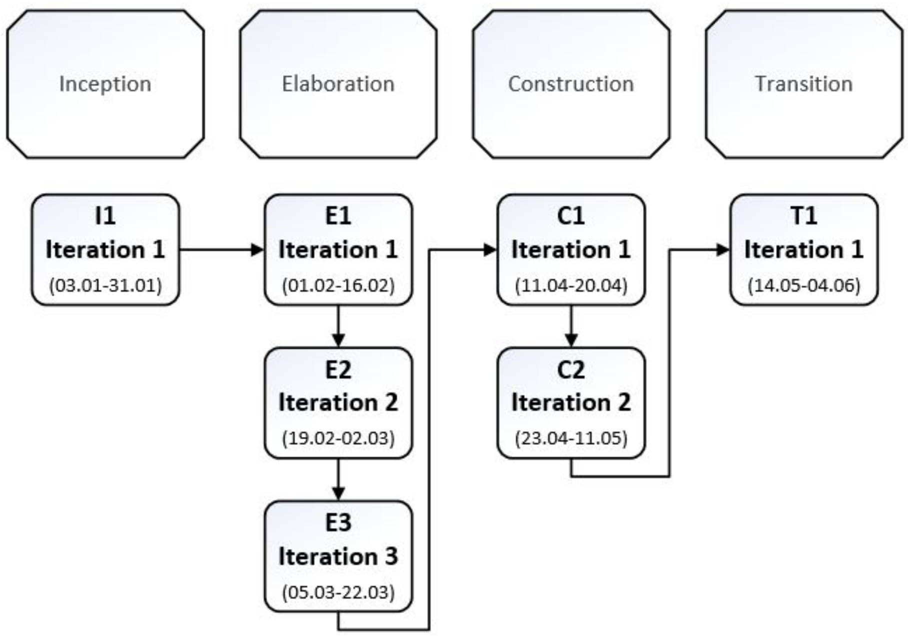


Figure 1: Iteration overview

2 Phase 1: Inception

2.1 Iteration I1

2.1.1 Introduction

This is the preliminary iteration of the Inception Phase. The team focus on establishing administration system and preparing all requirements for the first presentation.

2.1.2 Iteration Content

Duration: From 03.01.2018 to 31.01.2018
Activity: As following table 1

Table 1: Activity of Preliminary iteration I1

Activitiy ID	Activity	Author	Finish Date	Status
	Project management			
I1-1	Make initial activity plan	Yayun	19-01-2018	Completed
I1-2	Participate Week1 KA meeting	All	03-01-2018	Completed
I1-3	Participate Week1 Plenary meeting	All	05-01-2018	Completed
I1-4	Participate Week2 Internal guidance meeting	All	08-01-2018	Completed
I1-5	Participate Week2 Plenary meeting	All	08-01-2018	Completed
I1-6	Participate Week2 Plenary meeting	All	10-01-2018	Completed
I1-7	Participate Week2 Plenary meeting	All	11-01-2018	Completed
I1-8	Participate Week2 Plenary meeting	All	12-01-2018	Completed
I1-9	Participate Week2 Plan meeting	All	12-01-2018	Completed
I1-10	Participate Week3 Internal guidance meeting	All	17-01-2018	Completed
I1-11	Participate Week3 Information meeting	All	17-01-2018	Completed
I1-12	Participate Week3 Plenary meeting	All	17-01-2018	Completed
I1-13	Participate Week3 Progress meeting	All	19-01-2018	Completed
I1-14	Participate Week3 Plan meeting	All	19-01-2018	Completed
I1-15	Participate Week4 Internal guidance meeting	All	24-01-2018	Completed
I1-16	Participate Week4 Plenary meeting	All	24-01-2018	Completed
I1-17	Participate Week4 Progress meeting	All	26-01-2018	Completed
I1-18	Participate Week4 Plan meeting	All	26-01-2018	Completed
I1-19	Design group logo	Vemund	10-01-2018	Completed
I1-20	Make Team cooperation contract	Torjus	26-01-2018	Completed
I1-20-a	Make team overview list	Torjus	26-01-2018	Completed
I1-21	Make project contract	Torjus	26-01-2018	Completed
I1-22	Coordinate school and KA with Confidentiality agreement	Torjus	19-01-2018	Completed
I1-23	Preliminary Webpage design	Kristian	19-01-2018	Completed
I1-24	Make Latex instruction	Vemund	19-01-2018	Completed
I1-25	Develop document template by Latex	Kristian	19-01-2018	Completed
I1-25-a	Develop a reference system template by Latex	Kristian and Arild	26-01-2018	Completed
I1-26	Determine a system for time list registration	Kristian and Vemund	12-01-2018	Completed
I1-27	Determine a program for Gantt Chart	Yayun	10-01-2018	Completed
I1-28	Research and determine a project model	Yayun	19-01-2018	Completed
I1-29	Make a Preliminary project plan according to the project model	Yayun	19-01-2018	Completed
I1-30	Initial document of project model	Yayun	19-01-2018	Completed
I1-39	Risk analysis	Kristian	31-01-2018	Completed
	Business Modeling			
I1-41	Refine roles and responsibility	Torjus	24-01-2018	Completed
	Requirement			
I1-31	Initial literature study	Arild and Vemund	26-01-2018	Completed
I1-32	Preliminary requirement understanding	All	26-01-2018	Completed
I1-32-a	Make requirement document	Arild	26-01-2018	Completed
I1-33	Vision document preparing	Arild	26-01-2018	Completed
	Analysis and Design			
I1-38	Perform project management process	Yayun	26-01-2018	Completed
	Test			
I1-34	Preliminary test plan	all	26-01-2018	Completed
	Knowledge development			
I1-40	Conclude what we learn	All	31-01-2018	Completed
	Presentation 1			
I1-35	Make Presentation slides	Arild	26-01-2018	Completed
I1-36	Prepare for presentation 1	All	30-01-2018	Completed
I1-37	Participate the presentation 1	All	31-01-2018	Completed

2.1.3 Iteration Summary

What the team have done:

1. Administration: The team has built the management foundation, namely, defined project model; refined roles and responsibilities; standardized documentation; analyzed risk.

2. Technical part: The team has defined a system for Requirement and test plan. For instance, the templet and ID system for requirement and test plan.

3. Others: The team has done a part of literature study and concept searching but without any documentation.

4. Documentation: 120% of the administration documents has been prepared but only 50% of the technical documents has been done for the first presentation.

   Administration documents has been prepared as following list:

   - Delegation
   - Project model report
   - Cooperation Contract
   - Project contract
   - Confidentiality agreement
   - Document standard instruction and templet
   - Risk analysis
   - Initial project plan
   - Group overview list
   - Vision document
   - Logo
   - Personality test report
   - Project assignment

Technical documents has been prepared as follows:

- Simple requirement report
- Test plan templet

What the team should have done:

- Technical part: Should have addressed all requirements and have an entirely test plan, which contains information about the purpose and the goal of the testing. In addition, the test plan should identify which strategies will be used in the testing and what resources are needed.
- Documentation: Should have prepared 100% documents of requirement and test plan.

What the team have learned:

- Focus on and prioritize the main task
- Better time management
- Always have a project overview
- Everything should be documented

3 Phase 2: Elaboration

3.1 Iteration E1

3.1.1 Introduction

This is the first iteration of the Elaboration Phase. Hence this iteration names E1. The team focus on requirement analysis and concept development.

3.1.2 Iteration Content

Duration: From 01.02.2018 to 16.02.2018
Activity: As following table 1

Table 2: Activity of Elaboration iteration E1

Activitiy ID	Activity	Author	Finish Date	Status
E1-1	**Project management**			
E1-1-1	Make activity plan	Yayun	08-02-2018	Completed
E1-1-2	Participate KA course	All	01-02-2018	Completed
E1-1-3	Participate Week6 Iteration meeting	All	09-02-2018	Completed
E1-1-4	Participate Week6 Internal guidance meeting	All	07-02-2018	Completed
E1-1-5	Participate Week7 Iteration meeting	All	14-02-2018	Completed
E1-1-6	Participate Week7 Internal guidance meeting	All	14-02-2018	Completed
E1-1-7	Manage iteration	Yayun	13-02-2018	Completed
E1-1-8	Monitor and control project	Vemund	15-02-2018	Completed
E1-1-9	Evaluate project scope and risk	All	15-02-2018	Completed
E1-1-10	Plan for next iteration	Yayun/Vemund	16-02-2018	Completed
E1-1-11	Refine project plan	Yayun	15-02-2018	Completed
E1-1-12	Update the website	Kristian	15-02-2018	Completed
E1-2	**Business modeling**			
E1-2-1	Cost / benefit analysis	Arild	15-02-2018	Completed
E1-3	**Requirement**			
E1-3-1	Define the stakeholders	Vemund and Kristian	09-02-2018	Completed
E1-3-2	Understand stakeholders need	All	15-02-2018	Completed
E1-3-3	Update the requirement	Arild/Torjus/Vemund/Kristian	09-02-2018	Completed
E1-3-4	Understand all requirement	All	09-02-2018	Completed
E1-3-5	Analyze the problem	All	15-02-2018	Completed
E1-3-6	Manage changing requirements	All	15-02-2018	Completed
E1-4	**Analysis and Design**			
E1-4-1	Analysis behavior	All	15-02-2018	Completed
E1-4-2	Concept development	All	16-02-2018	Completed
E1-4-3	Define concept candidate	All	16-02-2018	Completed
E1-4-4	Refine the concept	All	16-02-2018	Completed
E1-4-5	Sketch concept framework	All	15-02-2018	Completed
E1-4-6	FMEA	All	15-02-2018	Processing
E1-5	**Implementation**			
E1-5-1	Present all concept to Group	All	16-02-2018	Completed
E1-6	**Test**			
E1-6-1	Update test plan	Arild	9-02-2018	Processing
E1-7	**Knowledge development**			
E1-7-1	Further Literature study	All	15-02-2018	Processing
E1-7-2	Further Patent search	All	15-02-2018	Processing
E1-7-3	Make brief description for every concept	All	15-02-2018	Completed
E1-7-4	Patent course with KA	All	14-02-2018	Completed
E1-7-5	Make K-Briefs(A3) template	Torjus	15-02-2018	Completed

3.1.3 Iteration Summary

<u>What the team have done:</u>

1. Concept: Under this iteration the team focused on the concept development and has developed more than five initial concepts. In the end the team evaluated to five candidate concepts, which are
   - Rack and Pinion
   - Ball Nut Screw
   - Rotation
   - Electro-Magnets
   - Scotch Yoke
2. Activity ID: The team has changed the ID system to a better way such as E1-1 for the Project management, and under this workflow's activity ID will be from E1-1-1 to E1-1-n. It is better for us to manage the activity list.
3. Patent search: The team has been searching the patent from google patent, however, it was law efficiency, therefor they asked one patent course from KA. It was helpful.
4. Economy: The team did consideration of the cost of every concept.
5. Continue from I1: Continued to work with requirement report and test plan from I1. Which are marked as light green colour on the Gantt Chart of project plan.
6. Team work: From the iteration I1 and the feedback of the first presentation the team realized that it has been focusing much on the administration instead of technical parts as requirement and test plan. Those technical parts were the main requirements of the first presentation. Therefor in case the same situation happen, the team took this subject to discuss and looked for how the team could do better from now on.

   One suggestion to the team was the leader could take the responsibility as to have the project overview, which was missing from the iteration I1. Once the leader has overview, so the team could move forward in the right direction, for example what kind of activity should be priorities. However the team leader disagree with this. With further discussion, consideration and suggestion from school, the team voted a new leader in the end. Please refer to the following figure to see the vote result.

Figure 2: Vote result

7. Documentation: The documents have been produced under this iteration as shown below:
   - Meeting report
   - Project plan
   - Activity list E1
   - Iteration report
   - Requirement report
   - Simple concept sketch

<u>What the team should have done:</u>

- Test plan: Machine test plan is not finished yet, Continue working to be finished
- Literature: Should have done a part of literature study.

What the team have learned:

- Team work: Respect each other and move forward
- Knowledge: How to search the patent and how to use the K-Brief A3.

3.2 Iteration E2

3.2.1 Introduction

This is the second iteration of the Elaboration Phase. The iteration names E2. The team is working on the concept development and will define two concept under this iteration.

3.2.2 Iteration Content

Duration: From 19.02.2018 to 02.03.2018
Activity: As following table 1

Table 3: Activity of Elaboration iteration E2

Activitiy ID	Activity	Author	Finish Date	Status
E2-1	**Project management**			
E2-1-1	Participate Week8 Internal guidance meeting	All	21-02-2018	Completed
E2-1-2	Participate Week8 Iteration meeting	All	23-02-2018	Completed
E2-1-3	Manage iteration	Vemund/Yayun	02-03-2018	Completed
E2-1-4	Monitor and control project	Vemund	02-03-2018	Completed
E2-1-5	Evaluate project scope and risk	All	02-03-2018	Completed
E2-1-6	Plan for next iteration	Yayun/Vemund	02-03-2018	Completed
E2-1-7	Refine project plan	Yayun	02-03-2018	Completed
E2-1-8	Update the website	Kristian	02-03-2018	Completed
E2-1-9	Participate skype meeting with KA	All	22-02-2018	Completed
E2-1-10	Participate Week9 Internal guidance meeting	All	28-02-2018	Completed
E2-1-11	Participate Week9 iteration meeting	All	02-03-2018	Completed
E2-1-12	Documentation	All	02-03-2018	Completed
E2-2	**Business modeling**			
E2-2-1	Cost / benefit analysis	Arild	02-03-2018	Processing
E2-3	**Requirement**			
E2-3-1	Update the requirement	All	23-02-2018	Completed
E2-4	**Analysis and Design**			
E2-4-1	Concept development	All	02-03-2018	Completed
E2-4-2	Refine the concept	All	02-03-2018	Completed
E2-4-3	FMEA	All	02-03-2018	Processing
E2-5	**Implementation**			
E2-5-1	Present Candidate concept to KA	All	22-02-2018	Completed
E2-6	**Test**			
E2-6-1	Update test plan	all	02-03-2018	Processing
E2-7	**Knowledge development**			
E2-7-1	Further Literature study	All	02-03-2018	Processing
E2-7-2	Further Patent search	All	02-03-2018	Processing
E2-7-3	Make K-Briefs (A3) for every candidate concept	All	21-02-2018	Completed

3.2.3 Iteration Summary

What the team have done:

1. Concept: The team continued working on the concept development. After presented all five concepts to KA, the team began to work on the Pugh Matrix. With help of Pugh Matrix, the concepts were assessed to two concepts, which are Ball Nut Screw and Electro-Magnets.
2. Patent search: related patents have been recorded. Specially for Rack and Pinion and Ball Nut Screw.
3. Economy: It has been a certain consideration for every concept, for example production cost, assembly cost.

4. Continue from I1: Continued to update test plan
5. Continue from E1: Continued to work with literature study, patent search, and FMEA.
6. Team work: The team has started a team building activity.
7. Documentation: The documents have been produced under this iteration as shown below:
   - Meeting report
   - Project plan
   - Activity list E2
   - Iteration report
   - Pugh Matrix criteria report
   - Pugh Matrix concept report
   - K-brief concept
   - Test report (electron)

What the team should have done:

- Test plan: Machine test plan is still not finished yet, Continue working to be finished
- Literature: The literature study is through all the process, so it is difficult to see how much they have done or should have done. The team will document better in the next iteration.
- FMEA: The team has been considering the technical risk analysis but still missing documentation.
- Economy: A cost benefit brief report should have been started.

What the team have learned:

- Knowledge: Latex language
- Team work: Focus on project

3.3 Iteration E3

3.3.1 Introduction

This is the final iteration of the Elaboration Phase. The iteration names E3. The team is working on the documentation and preparation for the second presentation.

3.3.2 Iteration Content

Duration: From 05.03.2018 to 22.03.2018
Activity: As following table 1

Table 4: Activity of Elaboration iteration E3

Activitiy ID	Activity	Author	Finish Date	Status
E3-1	**Project management**			
E3-1-1	Participate Week10 Internal guidance meeting	All	07-03-2018	Completed
E3-1-2	Participate skype meeting with KA	All	08-03-2018	Completed
E3-1-3	Participate Week10 Iteration meeting	All	09-03-2018	Completed
E3-1-4	Participate skype meeting with KA	All	15-03-2018	Completed
E3-1-5	Participate Week11 Internal guidance meeting	All	14-03-2018	Completed
E3-1-6	Participate Week11 Iteration meeting	All	16-03-2018	Completed
E3-1-7	Participate Week12 Internal guidance meeting	All	21-03-2018	Cancelled
E3-1-8	Participate Week12 Iteration meeting	All	21-03-2018	Cancelled
E3-1-9	Manage iteration	Vemund/Yayun	19-03-2018	Completed
E3-1-10	Monitor and control project	Vemund	22-03-2018	Completed
E3-1-11	Evaluate project scope and risk	All	19-03-2018	Completed
E3-1-12	Plan for next iteration	Yayun/Vemund	22-03-2018	Processing
E3-1-13	Refine project plan	Yayun	19-03-2018	Completed
E3-1-14	Update the website	Kristian	22-03-2018	Completed
E3-1-15	Documentation	All	19-03-2018	Completed
E3-2	**Business modeling**			
E3-2-1	Cost / benefit analysis	Arild	19-03-2018	Processing
E3-3	**Requirement**			
E3-3-1	Update the requirement	All	19-03-2018	Completed
E3-4	**Analysis and Design**			
E3-4-1	Concept development	All	19-03-2018	Completed
E3-4-2	Refine the concept	All	19-03-2018	Completed
E3-4-3	FMEA	All	19-03-2018	Completed
E3-4-4	3D modelling	All	12-03-2018	Processing
E3-5	**Implementation**			
E3-5-1	Electro-Magnets concept prototype	All	19-03-2018	Pending
E3-5-2	Prepare for the second presentation	All	22-03-2018	Completed
E3-5-3	Present the project‘s second presentation	All	22-03-2018	Completed
E3-6	**Test**			
E3-6-1	Update test plan	all	19-03-2018	Completed
E3-7	**Knowledge development**			
E3-7-1	Further Literature study	All	19-03-2018	Completed
E3-7-2	Further Patent search	All	19-03-2018	Completed

3.3.3 Iteration Summary

<u>What the team have done:</u>

1. Continue from E1,E2: Continued to work with test plan and FMEA.
2. Concept: With help of KA,The Electro-Magnets concept become the final concept for project.
3. Presentation: Second presentation has been completed

4. Documentation: The documents have been produced under this iteration as shown below:
   - Meeting report
   - Project plan
   - Activity list E2
   - Iteration report
   - Test report
   - Requirement report
   - Stakeholder report
   - Problem analysis report
   - Mechanical factor understanding report
   - DC motor report
   - Sensor report
   - K-brief

What the team should have done:

- Concept: The team took longer time to determine the final concept.
- Time management: The team should have better time management.
- Documentation: A lot of documentations have been prepared for the second presentation. The team should choose the most important document.

What the team have learned:

- Time management: better time management.
- Documentation: main documentation for the important part of the project and simple documentation for others.

4 Phase 3: Construction

4.1 Iteration C1

4.1.1 Introduction

This is the first iteration of the Construction Phase. The iteration names C1. The team is working on the Top level system design of electromagnetic concept and prepare the material for the POC prototype.

4.1.2 Iteration Content

Duration: From 11.04.2018 to 20.04.2018
Activity: As following table 1

Table 5: Activity of Construction iteration C1

Activitiy ID	Activity	Author	Finish Date	Status
C1-1	**Project management**			
C1-1-1	Make activity plan	Yayun	12-04-2018	Completed
C1-1-2	Participate Week15 Internal guidance meeting	All	11-04-2018	Completed
C1-1-3	Participate skype meeting with KA	All	12-04-2018	Completed
C1-1-4	Participate Week15 Iteration meeting	All	13-04-2018	Completed
C1-1-5	Participate Week16 Internal guidance meeting	All	18-04-2018	Completed
C1-1-6	Participate Week16 Iteration meeting	All	20-04-2018	Completed
C1-1-7	Manage iteration	Yayun	18-04-2018	Completed
C1-1-8	Monitor and control project	Vemund	20-04-2018	Completed
C1-1-9	Evaluate project scope and risk	All	20-04-2018	Completed
C1-1-10	Plan for next iteration	Yayun/Vemund	20-04-2018	Completed
C1-1-11	Refine project plan	Yayun	20-04-2018	Completed
C1-1-12	Update the website	Kristian	20-04-2018	Completed
C1-1-13	Documentation	All	20-04-2018	Completed
C1-2	**Business modeling**			
C1-2-1	Cost / benefit analysis	Arild	20-04-2018	Completed
C1-3	**Requirement**			
C1-3-1	Management changing requirements	All	20-04-2018	Completed
C1-4	**Analysis and Design**			
C1-4-1	Top level system design	All	20-04-2018	Completed
C1-4-2	Design component	All	20-04-2018	Processing
C1-4-3	Calculation input	Yayun	20-04-2018	Completed
C1-4-4	Material input	Arild	20-04-2018	Completed
C1-4-5	Sensor input	Kristian	20-04-2018	Completed
C1-4-6	El.magnet input	Venmund	20-04-2018	Completed
C1-4-7	3D modeling input	Yayun/Arild	20-04-2018	Completed
C1-5	**Implementation**			
C1-5-1	Prepare the POC prototype material	Kristian	20-04-2018	Completed
C1-6	**Test**			
C1-6-1	Management changing test plan	All	20-04-2018	Completed
C1-7	**Knowledge development**			
C1-7-1	Further Literature study	All	20-04-2018	Completed
C1-7-2	Further Patent search	All	20-04-2018	Completed

4.1.3 Iteration Summary

What the team have done:

1. Continue from E3: Continued to work with concept development.
2. Concept: Two in-sleeve concepts concepts have been developed.
3. Documentation: The documents have been produced under this iteration as shown below:
    - Meeting report
    - Project plan
    - Activity list C1
    - Iteration report
    - POC prototype document
    - Concept A3

What the team should have done:

- Concept: The team should determine one concept under this iteration. Because of this the component design still can not be done.
- Time management: The team should have better time management.

What the team have learned:

- Time management: better time management.

4.2 Iteration C2

4.2.1 Introduction

This is the second iteration of the Construction Phase. The iteration names C2. The team is working on the component design, the POC prototype and the main report.

4.2.2 Iteration Content

Duration: From 23.04.2018 to 11.05.2018
Activity: As following table 1

Table 6: Activity of Construction iteration C2

Activitiy ID	Activity	Author	Finish Date	Status
C2-1	**Project management**			
C2-1-1	Participate Week17 Internal guidance meeting	All	25-04-2018	Completed
C2-1-2	Participate Week 17 skype meeting with KA	All	26-04-2018	Completed
C2-1-3	Participate Week17 Iteration meeting	All	27-04-2018	Completed
C2-1-4	Participate Week18 Internal guidance meeting	All	02-05-2018	Completed
C2-1-5	Participate Week18 Iteration meeting	All	04-05-2018	Completed
C2-1-6	Participate Week19 Internal guidance meeting	All	09-05-2018	Completed
C2-1-7	Participate Week 19 skype meeting with KA	All	10-05-2018	Completed
C2-1-8	Participate Week19 Iteration meeting	All	11-05-2018	Completed
C2-1-9	Manage iteration	Yayun	09-05-2018	Completed
C2-1-10	Monitor and control project	Vemund	11-05-2018	Completed
C2-1-11	Reevaluate project scope and risk	All	11-05-2018	Completed
C2-1-12	Plan for next iteration	Yayun/Vemund	11-05-2018	Completed
C2-1-13	Refine project plan	Yayun	10-05-2018	Completed
C2-1-14	Update the website	Kristian	11-05-2018	Completed
C2-1-15	Documentation	All	11-05-2018	Completed
C2-1-16	Visit KA	All	02-05-2018	completed
C2-2	**Business modeling**			
C2-2-1	Cost / benefit analysis	Arild	11-05-2018	Completed
C2-3	**Requirement**			
C2-3-1	Management changing requirements	All	11-05-2018	Completed
C2-4	**Analysis and Design**			
C2-4-1	Design Component	All	27-04-2018	Completed
C2-4-2	Refine the architecture	All	04-05-2018	Completed
C2-4-3	Simulation: Simulink	Yayun	11-05-2018	Completed
C2-4-4	Simulation: FEM analysis	Torjus	11-05-2018	Processing
C2-4-5	Simulation: ORCAD-Circuit	Kristian/Vemund	11-05-2018	Completed
C2-4-6	Simulation: electric magnet field	KristianVenmund	11-05-2018	Cancelled
C2-4-7	Final CAD	Torjus	11-05-2018	Processing
C2-4-8	Final calculation input	Yayun	04-05-2018	Completed
C2-4-9	Final sensor input	Kristian	27-04-2018	Completed
C2-4-10	Final magnet input	Vemund	27-04-2018	Completed
C2-4-11	Final material input	Arild	11-05-2018	Completed
C2-5	**Implementation**			
C2-5-1	Integrate subsystem/system	All	04-05-2018	Completed
C2-5-2	Build POC prototype	All	11-05-2018	Processing
C2-6	**Test**			
C2-6-1	Test and evaluate	All	11-05-2018	Completed
C2-7	**Knowledge development**			
C2-7-1	Final Literature study	All	11-05-2018	Completed
C2-7-2	Final Patent search	All	11-05-2018	Completed

4.2.3 Iteration Summary

What the team have done:

1. Continue from C1: Continued to work with component design.
2. Concept: Final concept has been determined and developed the component
3. Documentation: The documents have been produced under this iteration as shown below:
   - Meeting report
   - Project plan
   - Activity list C2
   - Iteration report
   - POC prototype document
   - Technical attachment documents to the Main Report
4. Remarks: Activity C2-4-6 has been cancelled because the software costs too much to use. This has been marked yellow colour on the project plan Gantt Chart. The Activity C2-4-4 has not taken into place, therefor, it is also marked as yellow in the Gantt Chart.

What the team should have done:

- 3D modelling: 3D modelling should have been finished under this iteration.
- Time management: The team should have better time management.

What the team have learned:

- Time management: better time management.

5 Phase 4: Transition

5.1 Iteration T1

5.1.1 Introduction

This is the last iteration of the project. It is under the Transition phase so this iteration names T1 . The team is working on the main report, building POC prototype and prepare to the final presentation.

5.1.2 Iteration Content

Duration: From 14.05.2018 to 04.06.2018
Activity: As following table 1

Table 7: Activity of Transition iteration T1

Activitiy ID	Activity	Author	Finish Date	Status
T1-1	**Project management**			
T1-1-1	Participate Week20 Internal guidance meeting	All	16-05-2018	Completed
T1-1-2	Participate Week20 skype meeting with KA	All	16-05-2018	Completed
T1-1-3	Manage iteration	Yayun	31-05-2018	Completed
T1-1-4	Monitor and control project	Vemund	04-06-2018	Completed
T1-1-5	Update the website	Kristian	03-06-2018	Processing
T1-1-6	Documentation	All	21-05-2018	Processing
T1-1-7	Close-out project	All	04-06-2018	Processing
T1-5	**Implementation**			
T1-5-1	POC prototype	All	03-06-2018	Processing
T1-5-2	Prepare for Presentation 3	All	03-06-2018	Processing
T1-5-3	Participate Presentation 3	All	04-06-2018	Coming

5.1.3 Iteration Summary

What the team have done:

1. Documentation: a main report will be completed before 22.may.
2. POC prototype: a Proof of concept prototype will be completed before the presentation.

What the team should have done:

- Time management: The team should have better time management.

What the team have learned:

- Time management: better time management.

Project model

EGA

May 21, 2018

Abstract

This document is to introduce how the team determine the project model for the project and team. It is mainly describe the structure of the modified Unified Process, and how it is going to be implemented in the project.

Contents

List of Figures

List of Tables

1 Acronyms

POC Proof of Concept
UP Unified process
RUP Rational unified process
KA Kongsberg Automotive AS
HSN University College of Southeast Norway
EGA Electrical Gear Actuation

2 Background

There are many kinds of project models for product development process. Some are best for managing enormous projects; some are best for small business; some are less documentation but more effective. With many different options available, It is important for the team to evaluate which one is right for the project and team.

First of all the team thinks about what the team needs. According to the project assignment, the team is encouraged to develop a concept "outside the box" , thereby many iterations will be implemented to define the concept. Meanwhile there should be a clear time-line and achievement for every iteration. Those processes should be efficient. The team's final goal is to demonstrate the functionality with a POC prototype and suggest further work. So the team gets to delivery prototype and knowledge development.

Secondly, considering the team environment, the team is agree to have regular meeting on Wednesday and Friday, other days the team would like to work alone due to the specific circumstances. Therefore the team needs a process that works well for teamwork and individual work.

After reviewing and comparing a number of project models as shown below Pugh Matrix, the team focus most on Unified Process and Scrum. But as known that Scrum Meeting is very important for Scrum process, and it holds every working dag face by face. It doesn't match the teams working style. Another concern is scrum has less documentation. So the team determines the UP as the project management process in the end.

Pugh matrix for the project model selection

Project model / Evaluation Criteria	Unified Process	CAFCR	Waterfall	Vee Model	Agile/Scrum	The Spiral Model
	Points: 1-5					
Iterative	5	5	0	1	5	5
Handle change	4	4	1	2	4	4
Adaptive approach	4	3	3	3	4	3
Process simplicity	3	3	5	5	4	3
Flexibility	4	3	1	1	4	3
Team collaboration	4	4	4	4	5	4
Traceability	4	4	3	4	3	4
Documentation	5	4	5	4	3	4
Sum Points	33	30	22	24	32	30

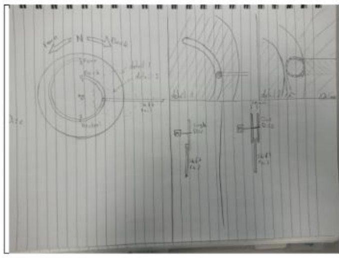
Figure 1: Pugh matrix for project model selection

3 Introduction

The unified process is not only a software engineering process but also a process framework that can be adapted and extended to suit the needs of a project group. KA as our bachelor assignment‘s provider has a good experience with Knowledge-based development. Which is a way to make the knowledge visible and keep everything simple for the user. For example, Making a A3 concept K-Brief(see the figure 2 under) The team would like to take KA‘S experience and implement to the process. So the team adds the knowledge development workflow to the UP model (please refer to the Figure 3 below).

Concept *K-Brief*

Concept name: Rotating Disc	Concept revision NO.: R 1.0	Author: EGA	K-Brief owner: EGA
Concept NO.:	Date: 21 Feb. 2018	Concept idea: EGA	Support document:



Description:

Rotating disc concept.

Gear shift rail is connected to a rotating disc with tracks that deviate from disc centre. Track distance from center generate correct displacement in shift rail to accommodate requirements.

Analysis and Calculation:

Requirements accommodation:
1 – easy 2-Normal 3 - Hard

REQ-ID - accommodation	REQ-ID - accommodation
01 – 3	15 – 2
02 – 2	16 – 3
07 – 2	17 – 1
08 – 2	18 – 1
09 – 2	18 – 1
11 – 2	19 – 1
12 – 3	20 – 1
13 – 2	21 – 1
14 – 2	22 – 1
Sum	32 - 18 = 14

Best score = 0
Lowest Score = 36

Advantages	Challenges/possibl solutions
Quick linear movement	Difficult to maintain in accurate position
Easy manufacturing	Low accuracy
Robust power transmission	Low "hold in gear" strength
Easy production	
Allow usage of «low» effect engine	
Low maintenance	
Highly reliable	
Long lifetime	

Additional information:
We have done a top-level system analysis on the rotating disc.

As a first impression of the analysis on the rotating disc concept we can conclude with several benefits and drawbacks.

- The main benefits to the rotating disc is the simplicity of the construction to meet the requirements of lifecycle and durability and also the requirement which states the need to a very fast and high velocity gear change.

The rotating disc, as a first impression view, are considered a cheap and reliable solution.
The analysis concluded with one main drawback.

- Low, or difficult to obtain and maintain, precision on the gear diverter(shalter), which is a level A requirement

Figure 2: KBrief

4 Process structure

The process structure of modified UP is same as the original Unified Process. The process has two dimensions:

1. The dynamic dimension (horizontal axis) represents time and shows the lifecycle of a project which expresses cycles, phases, iterations and milestones. The lifecycle structure

2. The static dimension (vertical axis) represents core process workflows, which group activities logically by nature and expresses activity, artifact, worker and workflow.

    - Workers, the ”who”
    - Activities, the ”how”
    - Artifacts, the ”what”
    - Workflows, the ”when” [2]

The whole process structure as shown below figure 2.

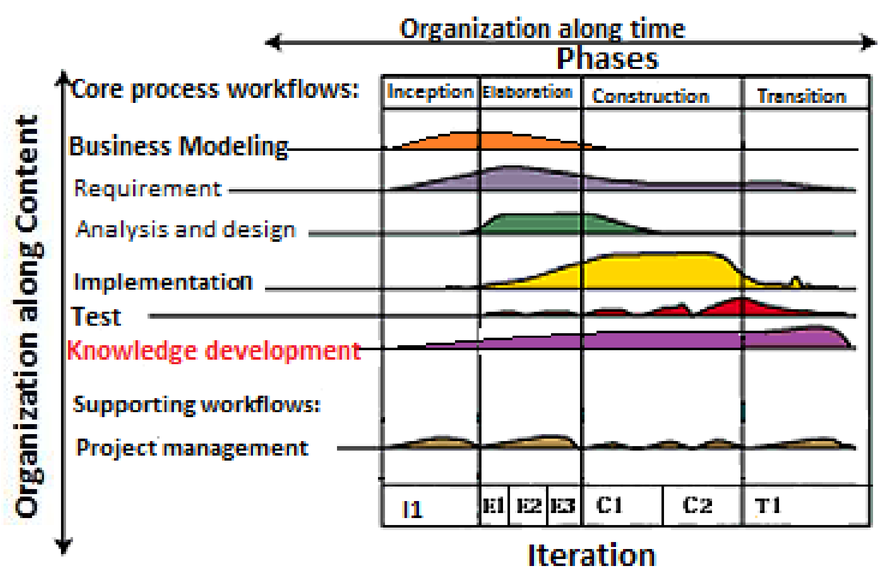


Figure 3: Modified Unified process [1].

4.1 Phase

The all project lifecycle is divided by the phases which are respectively

- Inception
- Elaboration
- Construction
- Transition

1. Inception Phase

   Under this inception phase, the team finishes the preliminary iteration and establishes administration system, for example developing a document template by latex, defining all workers responsibilities, finding a project model, initializing a project plan and so on. Meanwhile the team does analysis the requirement and prepare for the presentation 1.

2. Elaboration Phase

   There are three iterations under this phase, which are Elaboration iteration #1(E1), Elaboration iteration #2(E2) and Elaboration iteration #3(E3). During this phase, the team focus on requirement analysis and couple alternative concepts are developed and determined. In addition, the project high risk elements are addressed and eliminated; A project plan is completed. In a word the team makes sure the architectural foundation is stable and the resources to the project is ready.

3. Construction Phase

   There are two iterations have been taken place under this phase. Which are respectively C1,C2. During the two iterations, the final concept is determined and all the components and features are developed and integrated into the prototype, and some features are tested by simulation.

4. Transition Phase

   The last phase, the team is working on the main report, POC prototype building and Preparation of Final presentation. There is only one iteration under this phase, which is called T1.

4.2 Milestone

At the end of every phase there is a main milestone the team would achieve. The details of the projects milestones are illustrated as the figure 3 below.

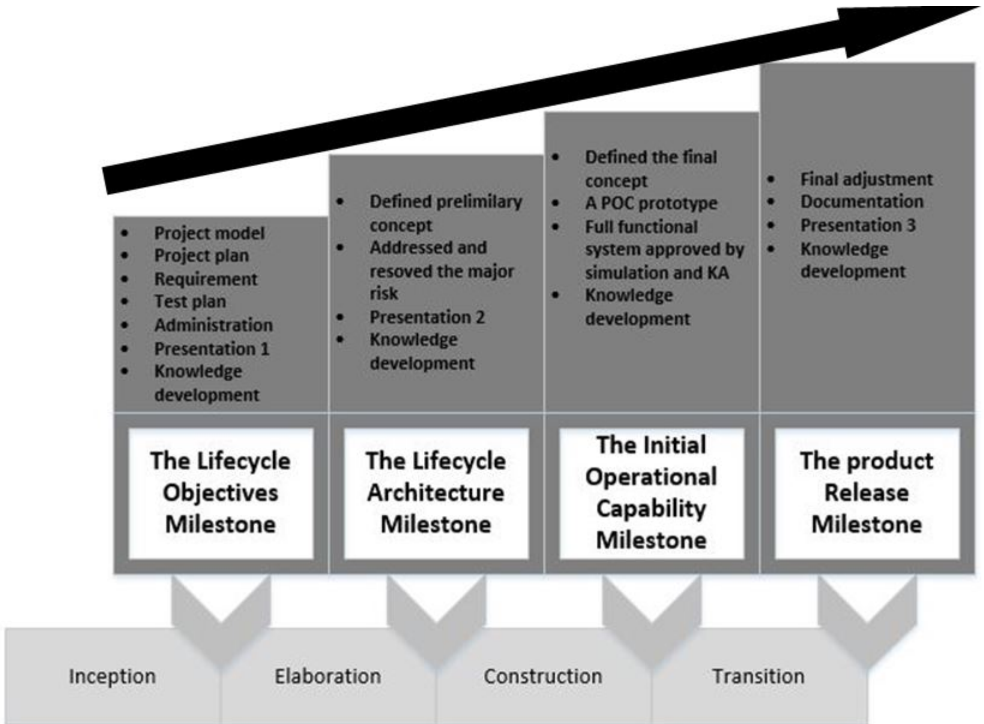


Figure 4: EGA project milestone

4.3 Workflows

As shown from the figure 2, the team have added the knowledge development workflow to the UP. The workflows are as follows:

- Business modeling
- Requirement
- Analysis and design
- Implementation
- Test
- Knowledge development
- Project management

The workflows will be visited through every iteration as shown under figure 4.

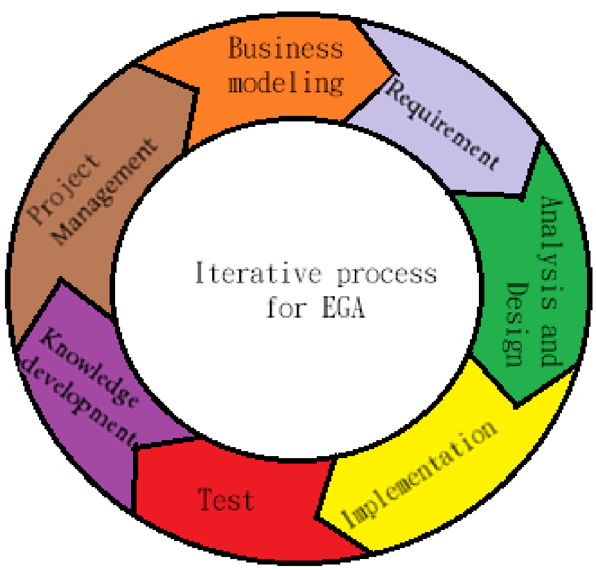


Figure 5: Iterative process with workflows

4.4 Iteration activities

The team makes iteration plan for every iteration and every activity has own ID as shown from the under table 1, the activity ID is easy for the team to track.

Table 1: Arrangement of the activity ID

Phase	Iteration NO.	Relative activity ID
Inception phase	I1	I1-1 $\sim I1 - n$
Elaboration phase	E1	E1-1 $\sim E1 - n$
Elaboration phase	E2	E2-1 $\sim E2 - n$
Construction phase	C1	C1-1 $\sim C1 - n$
Construction phase	C2	C2-1 $\sim C2 - n$
Construction phase	C3	C3-1 $\sim C3 - n$
Transition phase	T1	T1-1 $\sim T1 - n$

The following table 2 shows the iteration activity list template the team used.

Table 2: Activity of Preliminary iteration

Activitiy ID	Activity	Author	Finish Date	Status
	Project management			
	Business Modeling			
	Requirement			
	Analysis and Design			
	Test			
	Knowledge development			

4.5 Artifact

A resulting artifacts list from every iteration activities as shown below table 3.

Table 3: Artifact list of Preliminary iteration

Related Activies ID	Resulting Artifacts	Status

References

[1] Scott Ambler. Enhancing the unified process. http://www.drdobbs.com/enhancing-the-unified-process/184415741, October 1999. (read 23.01.18).

[2] Philippe Kruchten. *The Rational Unified Process An Introduction Second Edition.* Addision Wesley, second edition edition, 2000.

Positional measurement report

Electric gear actuation

May 21, 2018

Abstract

The purpose of this report is to shed some light on different technologies that can be used to sense the position of a mechanically displaced part. Additionally to recommend and propose a complete system for positional measurement related to safety and controllability of the complete gear change system.

Contents

List of Figures

1 Technology alternatives

1.1 Introduction

Positional measurement is an important factor in actuating systems that has two or more established positions. This relates to safety in two aspects:

- Equipment
  Without a system to measure and control based on position, the equipment can be damaged. For example by the motor using too much force in the wrong part of the movement cycle, or both gears being activated on the same time which will destroy the transmission.

- People
  Using a similar example as above, the group can picture a scenario where a system without a positional measurement system might end up bringing harm to the operators.

More about risks, especially those caused by positioning or gearing, read the FMEA.

Further on there are a lot of different variables to consider when selecting one or more measurement systems. This report will contain parts about direct versus indirect measuring, contact and non-contact measuring devices all while looking at different technologies that might be applicable to the actuator system that is being developed.

1.2 Proximity / Displacement sensors

A proximity or a displacement sensor is a sensor that detect objects or materials by for example either looking for changes in the electromagnetic field, or changes in the return signal of electromagnetic radiation. Detection can also be done by physical switches, resistive elements or other forms of "physical" detection. Usually proximity is used for sensors that switches either on/off, while displacement sensors gives you the amount of distance the object has been moved. At the first glance these types, especially those using electromagnetic fields, can be useful for positional measurement in an electric actuator. The reason for this is that they consists of few or none mechanical parts, so the durability is generally very good. Depending on construction, some of these sensor can be used as both a proximity sensor and a displacement sensor. Therefore this report won't divide the two while discussing, since both options might work depending on concept selection.

1.3 Non-contact sensors

1.3.1 Inductive proximity sensors

Inductive sensors is commonly used for speed and position measurement. Because of the way they function, they can often be used in more hostile environments.

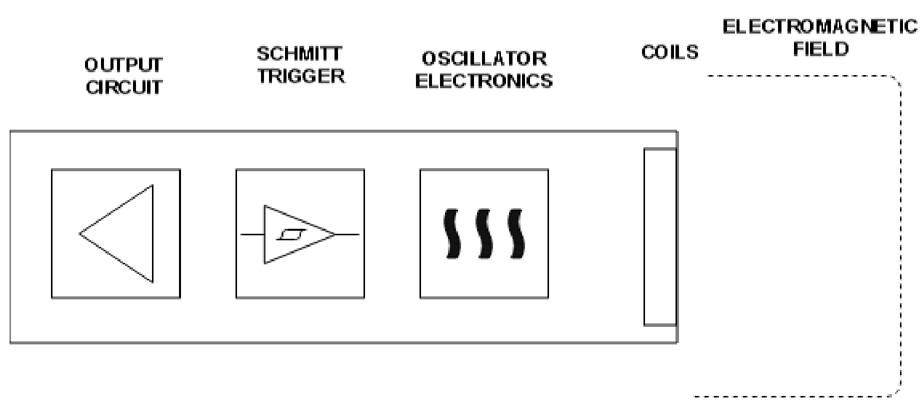


Figure 1: Example of Induction Sensor

The general principle for how inductive sensors work is supplying an electric current through a coil. When a conductive or magnetically permeable material then enters the magnetic field produced by the current flowing through the coil, the coil's inductance changes [6, p. 42]. The reason for the change in inductance is because of a phenomenon called "eddy currents", which very simply explained means that there are some currents induced in the conductive material. This changes the amplitude of the current, and at a certain threshold you can use this to trigger a switch. Usually the switch is called a "Schmitt trigger", which triggers when the oscillations amplitude lowers to a certain threshold. As soon as the amplitude is back up (when you remove the conductive material), the Schmitt trigger reverts back to it's previous signal.

Benefits

- No moving parts
- Applicable to various environments
- Good performance in hostile environments

Drawbacks

- Stray magnetic fields might affect the sensor
- Physical size - larger than other type of sensors
- If you need high precision the production will be expensive
- Can only sense ferrous materials
- Limited sensing distance

1.3.2 Hall-effect sensors

Hall-effect sensors are sensors that gives a varying output based on the proximity of a magnetic field. The principle is that the magnetic field draws the electrons in e.g a wire to one of the sides, which in turn results in a potential voltage difference that is measurable. [6, p. 45]. By for example connecting magnet to the end of the object you want to find the position of, you can use a hall sensor as a displacement sensor or proximity switch. An obvious advantage to using hall sensors is that there is no contact required. If a concept with a brushless d.c motor is chosen, it will likely have hall sensors in it to determine what windings to activate based on where the rotor (magnet) is.

Benefits

- No-contact sensor
- Fitting for severe environments

Drawbacks

- Not at the top of the list in measuring accuracy
- Likely requires amplifier circuits in addition

1.3.3 Current measurement

In some types of solutions like precise motors or solenoids/electromagnets it should be possible to measure the current draw to sense the position. In some cases you can estimate the position, and in other cases like a solenoid plunger the current draw is a direct result of where in the movement cycle the plunger is. In the motor example the position would be a direct result of the load on the motor.

Since a solenoid solution has been chosen the current measurement discussed forward will be in regards to solenoids. Figure 2 below is an ideal current graph from a report about motion detection of plungers in DC solenoids made by Texas Instruments [8].

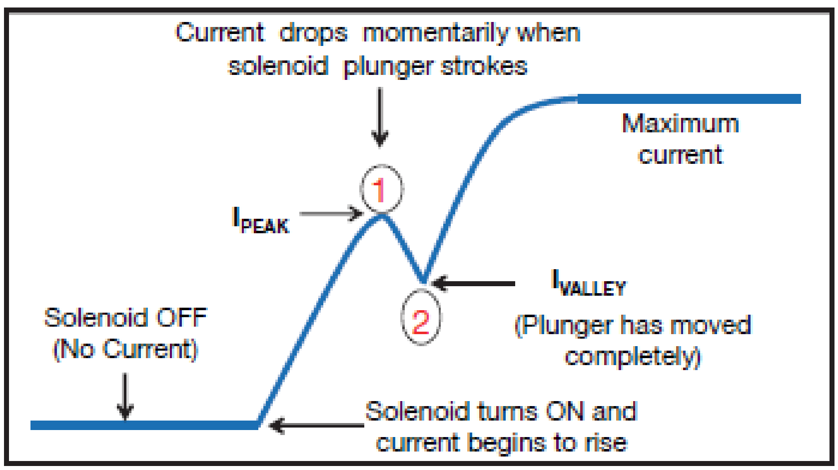


Figure 2: Ideal current curve for DC solenoid

As you can see in the figure there is a current drop from point (1) to point (2). This current drop is caused by what is called back EMF, which is reverse voltage that appears every time you change the magnetic field by moving the plunger. This back EMF reduces the current until the plunger is in the out-most position. The idea is to utilize this voltage drop, and detect whether or not the plunger is in start or end position, or in and out of gear in this case.

Benefits

- Can be placed outside gearbox
- Should be easy to design and implement
- Cheap

Drawbacks

- Can only sense if it is in or out
- Requires high sample rate

1.4 Contact sensors

1.4.1 Mechanical switches

A mechanical switch or a limit switch is usable in a lot of situations. The general principle is that you have a small electrical switch that requires an object to physically activate it. This is the easiest and cheapest (depending on the materials and environment requirements) sensor to produce.

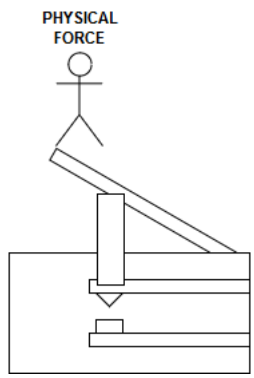


Figure 3: Example of Limit Switch

As seen in figure 3 there are few parts in play in a limit switch. The stick-figure represents the physical force acting upon the electrical switch and activating it, letting us know that the "object" (in this case the stick figure) is in proximity.

Benefits

- Easy to install and produce
- "Direct" measurement since it is in contact with the material it is measuring

Drawbacks

- Susceptible to wear because of mechanical parts
- Possibly bad with large forces

1.4.2 Strain Gauge Sensors

These types of displacement sensors use strain-gauged elements to measure displacement. The general principle is using a material that changes resistance proportional to the strain it is subjected to. Building on top of this you can produce a sensor with for example a shaft and a spring that strains a material like in figure 4.

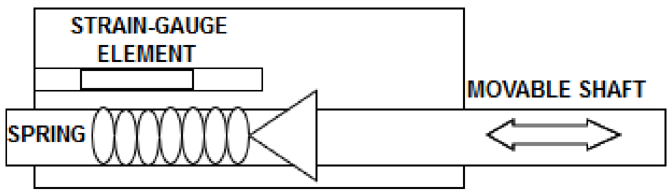


Figure 4: Example of Strain-Gauge Displacement Sensor

A problem with this configuration is that the change in resistance is so minuscule, this type of sensor requires something like a Wheatstone-bridge (fig 5) to be able to measure the change in volts instead of resistance. A Wheatstone-bridge is a configuration of known resistances that we use to measure an unknown resistance.

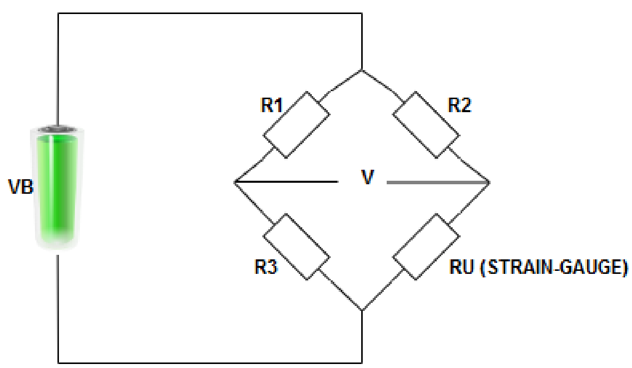


Figure 5: Example of Wheatstone-bridge

We measure difference in voltage between the two sides and will get the output in volts or millivolts instead of the very low changes in resistance that is hard to measure.

Benefits

- Low power consumption
- Accurate direct measuring
- Does not need a flat surface

Drawbacks

- Depending on the type of material used in the strain-gauge element, these may by very temperature sensitive. Making them not relevant for this project because they can not comply with R01.1 and R01.2 (See requirement report)
- Needs very specific construction to be accurate across thousands of actuators

1.4.3 Potentiometer displacement sensor

A potentiometer, or potmeter for short, works by using an resistance element and a moving "contact" that can tap into the resistance element along the whole path. By then using a shaft or other means of movement you can change the resistance of the potmeter, and if you have the reference values, calculate how much the displacement is. In practice you measure the changing voltage over the potmeter and look at the change in voltage and therefore indirectly resistance.

Since this has constantly moving parts, potmeters have generally a short life cycle compared to other types of displacement sensors discussed in this report. Because of the 2+ million gearshifts in the products life cycle, a potmeter seems like a not viable solution. Unless the group can find a type of potmeter technology with a high enough amount of cycles.

Benefits

- Cheap
- Easy to install

Drawbacks

- Not designed for 2+ million gearshifts (wear)
- Noise
- Friction

1.5 Summary & selection

Unfortunately not all relevant technologies or products are studied in this report, mainly because of the clash between time and workload. However, now that a concept is chosen (see concept report for more information), it is easier to narrow down the options and see what is most fitting for this system. Additionally some of the sensor types can be dismissed purely because of the difficulty for them to meet the requirements.

Most of the measurement technologies in this report has some strengths that would be beneficial for positional measurement in the actuator that is being developed. But when choosing the ideal solution the project group will not look only on what is beneficial, but also what kind of technology or product that can fulfill the requirements. Especially the temperature requirements will be hard to meet. Because of the temp requirements the selection heavily favours hall-effect sensors and current measurement.

When comparing hall-effect sensors and current measurement there is 2 factors to consider. Pricing is probably the most important one in the automotive industry, as long as it is not at the expense of safety. In that aspect; current measurement wins by a far margin because of the cheap ability to measure current outside of the gearbox or at the control unit. If hall-effect sensors are chosen they would need to be mounted precisely on the concept itself, and because of that they would also need to meet the temperature requirements which would higher the price.

The other factor is the possibility to meet the requirements, and since the position requirement requires the sensor system to only sense end and start positions both systems seems to qualify this aspect. Since both alternatives fulfill the requirements but current measurement seems cheaper overall, that is what EGA will focus on moving forward.

2 Solution

As stated in the previous section, current measurement seems like the optimal choice for a concept like the one the group has decided to go for.

To reiterate what was discussed earlier, current measurement in DC solenoids shows that the current rises to a local maximum before dropping until the plunger is in the out-most position. This voltage drop will be used to find out when the plunger has started movement (local maximum on the curve), and when the plunger is in end position (local minimum). A simple current sensor can be used to send a varying signal to the controller.

To utilize this without having access to specifics about gear control units or transmission control units some assumptions has been made:

- Assume that the GCU/TCU is capable of handling signals varying in strength
- Assume that the GCU/TCU has memory and can store signals or measurements
- Assume that the GCU/TCU can do calculations in a short amount of time (hard to find specifics in regards to processing power)

If these assumptions are shown to be false, this concept is still viable, it just creates the need for a separate control/measurement unit that can control/calculate position based on the current measurement.

2.1 Technical details

2.1.1 System overview

As shown in figure 6, the idea is that a current sensor will we connected between the power supply and the solenoid, which sends a signal to the GCU/TCU. This removes the need for components dealing with the temperature requirements of the system. As the current sensor can be placed outside the gearbox.

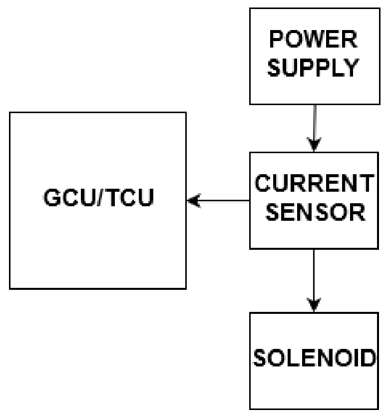


Figure 6: System overview

2.1.2 Sampling rate

If the system is expected to use the full movement time, which is 60 ms according to requirement R03.4. Tests are required to find the exact sample per second limit, but it can be estimated based on the movement time. The system in the next section has about 4000 samples per second, but the movement time is less then 50 milliseconds, therefore it is assumed that a safe sample per second to start testing on is about 4000 s/s.

2.2 Software

To get a feeling of how this system will work, it was necessary to find some sample data to play around with since the equipment at hand could not give us satisfying results. Therefore mathworks solenoid simulation [3] was opened, and the current and time values extracted into text files. This data had about 1800 current samples over 0.5 seconds. And even though the values are not exactly equal to our project, the general principle of finding the current dip remains the same. No matter what the software and variables will be.

This data was then parsed into python using a small block of code that gave each line in the text file an index and placed them in a python list. After that every line was stripped of eventual spaces, so that only clean data remained. After that there was a list available with about 1800 data points. This was enough data to show how it is possible to find the "turning points" of the current curve and identify when the plunger starts moving, and when it is in end position. Bear in mind that EGA does not have a software engineer employed yet, so the code is a simple concept to show that you can find the turning points using simple math and analyzing close and distant samples to identify the right turning point. In addition this is an analysis of a data set, and in the next iteration it is required to use live samples and "while" logic instead of just iterating through a data set.

```python
def retrieve_current(file: str):
    current_data = []
    current_data_clean = []
    with open(file) as f:
        current_data = f.read()
        current_data = current_data.split('\n')
    # Removes spaces from every item in the list
    for i in current_data:
        s = str(i).replace(' ', '')
        current_data_clean.append(s)
    return current_data_clean
    f.close
```

To find the first turning point (when the solenoid plunger has built up enough current to start moving), the code code checks if the current item in the list satisfies this mathematical expression:

$$li[i-1] =< li[i] >= li[i+1] \tag{1}$$

li[i] is the current value, and the equation is only true when the current value is greater or equal then the one before and after. The function **check1** checks if the equation is true, and if it returns true, calls for a more comprehensive check:

check3 is essentially the same as check1, except it compares the current value versus the 50 values before and after. If this returns true the first turning point has been found and check2 will be called. That means the plunger has started moving.

The number 50 is found by testing the code with different sample sizes, and will probably not be the same in the final system. The checks are split up to save time, if check1 is not passed there is no need to call for check3.

```
def check1(li, i0,i1):
    for i in range(i0,i1):
        if li[i] >= li[i-1] and  li[i] >= li[i+1]:
            if check3(li, i) >= 49:
                check2(li, i, len(li)-1)
                return i
                break

def check3(li, i):
    var = 0
    for n in range(1,50):
        if li[i] >= li[i-n] and li[i]>= li[i+n]:
            var = var + 1
    return var
```

When the first turning point has been found and the plunger has started moving, the code needs to find the end position. Therefore the code needs to check if the following is true:

$$li[i-1] => li[i] <= li[i+1] \quad (2)$$

Other then checking for a different equation, **check2** and **check4** works exactly the same as **check1** and **check3**

```
def check2(li, i0,i1):
    for i in range(i0,i1):
        if li[i] <= li[i-1] and li[i] <= li[i+1]:
            if check4(li, i) >= 49:
                return i
                break

def check4(li, i):
    var = 0
    for n in range(1,50):
        if li[i] <= li[i-n] and li[i]<= li[i+n]:
            var = var + 1
    return var
```

If both these checks passes, the endpoint has been found, and the plunger can not move any further. This means that a signal can be sent to the control unit to switch over to holding current.

2.3 Results

The python library matplotlib [1] has been used to plot the graph and the turning points. The first result is the point where plunger starts moving. In figure 7 you can see where in the curve that is located.

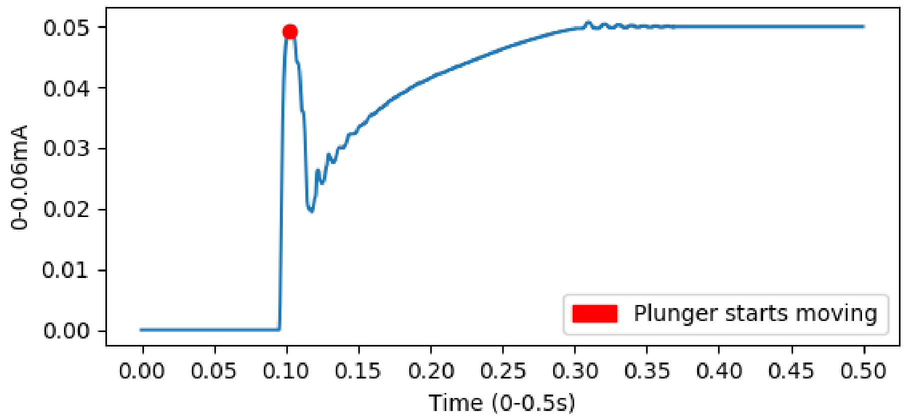


Figure 7: First turning point

Then the second turning point is plotted, and in figure 8 it can be seen where in the curve the plunger is in end position.

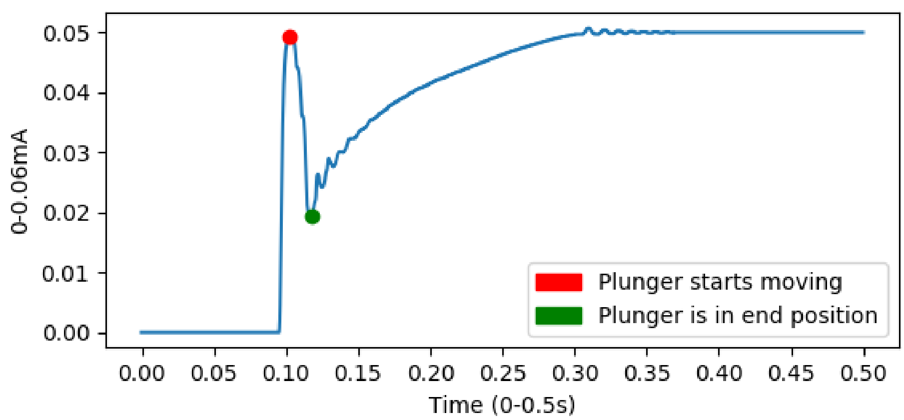


Figure 8: Second turning point

The following code was used for plotting:

```python
############### PLOTTING ###############

li = retrieve_current("current_solenoid.txt")
p1 = check1(li, 15, len(li))
p2 = check2(li,check1(li, 15, len(li)), len(li))
y_axis = li
# inserts a bunch of zeroes in the beginning of the list
# for visual purposes
for i in range(0, 362):
    y_axis.insert(0, 0)
# creates an x-axis for time from 0-0.5s
# with the same amount of data points as the current list
x_axis = (np.arange(0, 0.5, 0.5 / 2150))
plt.plot(x_axis, y_axis)
# labels the axis
plt.xlabel("Time (0-0.5s)")
plt.ylabel("0-0.06mA")
# adds more ticks on the axis
plt.xticks(np.arange(0, 0.55, step=0.05))
plt.yticks(np.arange(0, 0.6, step=0.01))
# adds legends
label_one = "Plunger starts moving"
label_two = "Plunger is in end position"
green = mpatches.Patch(color='red', label=label_one)
red = mpatches.Patch(color='green', label=label_two)
plt.legend(handles=[green, red])
# plots the values
# (+ the extra zeroes added for better visuals)
plt.plot(x_axis[p1+362], y_axis[80+362], 'ro')
plt.plot(x_axis[p2+362], y_axis[144+362], 'go')
plt.show()
```

2.4 Patent issues

There are some patents to be aware of when implementing this solution. The closest one and the one the team has tried to design around is [9]. Since it is possible to circumvent the patent by designing around the first claim, that is what the group has tried to achieve. The first claim states that the patent revolves around measuring the current slope of the inductor in regards to predetermined slopes. In this specific case the number of slopes and intervals is 3.

As it is possible to see in the chapter about the technical solution, the system developed by EGA checks every single value against the previous and the next value. If it suspects a local maximum the code will then do a more comprehensive check to find out if the plunger has started moving. The same is true for the end point.

Therefore it is shown that this specific solution does not infringe on the closest patent the group could find regarding this way of measuring solenoid plunger position.

3 Next steps / Conclusion

- Current sampling possibilities
  Looking at different current sampling possibilities, e.g using hall sensor as current sensor [7] to reduce possible points of failure in the electrical connections, which can be a problem in high temperature environments. There are many exciting possibilities in this area, and if a non-intrusive way of measuring holds up to the requirements it will probably be superior to other solutions.

- Live sampling & testing
  This is crucial to build the next iteration of the system. This requires hardware in form of current sensors, a prototype system that can mimic the movement cycle of the end system and last but not least at solenoid that is built according to the specifications and calculations the project group has done.

- Connected to the last point, gathering of data sets to test on that is more realistic, with the current curve between point between movement and end will start increasing again because of the rpm difference between the gear and the tooth. This effect needs to be accounted for in the software.

- Testing
  Start tests on prototype equipment to gather information about wether or not the sampling rate is okay etc.

3.1 Resources

3.1.1 Language

- Python version: 3.5.2 [5]

3.1.2 Libraries

- matplotlib version 2.0.2 [1]

- numpy version 1.13.1 [2]

3.1.3 IDE

- Pycharm Community Edition 2017.1.5 [4]

4 Appendix: code

```
import numpy as np
import matplotlib.pyplot as plt
import matplotlib.patches as mpatches

# Orders and sorts data from txt file pulled from simulink
def retrieve_current(file: str):
    current_data = []
    current_data_clean = []
    with open(file) as f:
        current_data = f.read()
        current_data = current_data.split('\n')
    # Removes spaces from ever item in the list
    for i in current_data:
        s = str(i).replace(' ', '')
        current_data_clean.append(s)
    return current_data_clean
    f.close

# finds the local maximum
# check1, checks if the current item in list is larger
# or equal then the previous/next item
def check1(li, i0,i1):
    for i in range(i0,i1):
        if li[i] >= li[i-1] and  li[i] >= li[i+1]:
            if check3(li, i) >= 49:
                check2(li, i, len(li)-1)
                return i
                break


# called by check1
# check3, redoes check1 but in a range of +- 50 closest
# items in the list
def check3(li, i):
    var = 0
    for n in range(1,50):
        if li[i] >= li[i-n] and li[i]>= li[i+n]:
            var = var + 1
```

```
    return var

# called by check1
def check2(li, i0,i1):
    for i in range(i0,i1):
        if li[i] <= li[i-1] and li[i] <= li[i+1]:
            if check4(li, i) >= 49:
                return i
                break

# called by check2
# check3, redoes check2 but in a range of +- 50 closest
# items in the list
def check4(li, i):
    var = 0
    for n in range(1,50):
        if li[i] <= li[i-n] and li[i]<= li[i+n]:
            var = var + 1
    return var




################ PLOTTING ################
li = retrieve_current("current_solenoid.txt")
p1 = check1(li, 15, len(li))
p2 = check2(li,check1(li, 15, len(li)), len(li))
y_axis = li
# inserts a bunch of zeroes in the beginning of the list
# for visual purposes
for i in range(0, 362):
    y_axis.insert(0, 0)
# creates an x-axis for time from 0-0.5s with the same
# amount of data points as the current list
x_axis = (np.arange(0, 0.5, 0.5 / 2150))
plt.plot(x_axis, y_axis)
# labels the axis
plt.xlabel("Time (0-0.5s)")
plt.ylabel("0-0.06mA")
# adds more ticks on the axis
```

```
plt.xticks(np.arange(0, 0.55, step=0.05))
plt.yticks(np.arange(0, 0.6, step=0.01))
# adds legends
label_one = "Plunger starts moving"
label_two = "Plunger is in end position"
green = mpatches.Patch(color='red', label=label_one)
red = mpatches.Patch(color='green', label=label_two)
plt.legend(handles=[green, red])
# plots the values
# (+ the extra zeroes added for better visuals)
plt.plot(x_axis[p1+362], y_axis[80+362], 'ro')
plt.plot(x_axis[p2+362], y_axis[144+362], 'go')
plt.show()
```

References

[1] Matplotlib. https://matplotlib.org/2.0.2/index.html. (read 19.05.2018).

[2] Numpy 1.13.1. https://pypi.org/project/numpy/1.13.1/. (read 19.05.2018).

[3] Solenoid. https://se.mathworks.com/help/physmod/simscape/examples/solenoid.html. (read 11.05.2018).

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[5] Python 3.5.2. https://www.python.org/downloads/release/python-352/, 06 16. (read 19.05.2018).

[6] William Bolton. *Mechatronics - Electronic control systems in mechanical and electrical engineering*. Pearson Education Limited, sixth edition edition, 2015.

[7] Paul Emerald. Non-intrusive hall-effect current-sensing techniques provide safe, reliable detection and protection for power electronics. https://www.allegromicro.com/~/media/Files/Technical-Documents/STP98-1-Non-Intrusive-Hall-Effect-Current-Sensing-Techniques.ashx?la=en&hash=D3618D0190A0DF07302B71CC554D2188E6699577. (read 19.05.2018).

[8] Manu Balakrishnan & Navaneeth Kumar N. Detection of plunger movement in dc solenoids. www.ti.com/lit/wp/ssiy001/ssiy001.pdf, 06 2015. (read 10.05.2018).

[9] Stephen Rober. Solenoid actuator motion detection. https://patents.google.com/patent/US7432721B2/en. (read 10.05.2018).

Subsystem:Solenoid

EGA

May 21, 2018

Abstract

The project team develops a gear shift system with six solenoid subsystems. Three solenoid systems are used to change to the first gear and the other three are used to change to the second gear. Those solenoid systems are mounted in a sleeve inside the gearbox, and implement the linear motion at radial direction. In order to design and develop a suitable solenoid system, the project team used Matlab/Simulink in combination with the theoretical analysis to determine the optimal solenoid parameters. This report is mainly to introduce the Solenoid system and how it was designed.

Contents

EGA

List of Figures

List of Tables

1 Introduction

The solenoid system is a type of electromagnet system that converts the electrical energy into mechanical energy [14], which is expressed in the form of pull or push motion. Working principle is that an electric current flows through a coil winding, and creates the electromagnetic field as shown below the figure 1.

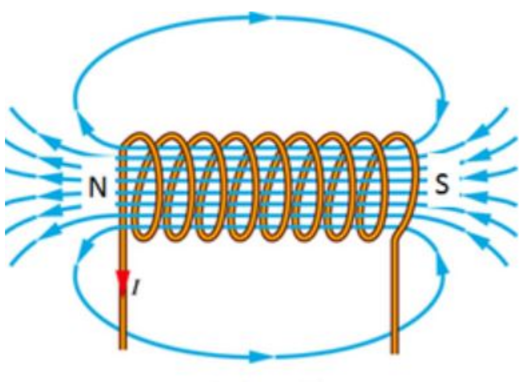

Figure 1: Solenoid Work Principe [4]

An Armature and plunger are placed inside of the solenoid (see figure 2). The magnetic field then applies a force to the armature and the plunger will be pushed out. Meanwhile the spring will be compressed. When the magnetic field is off, the spring force Fsp will drag the plunger back to the initial position.

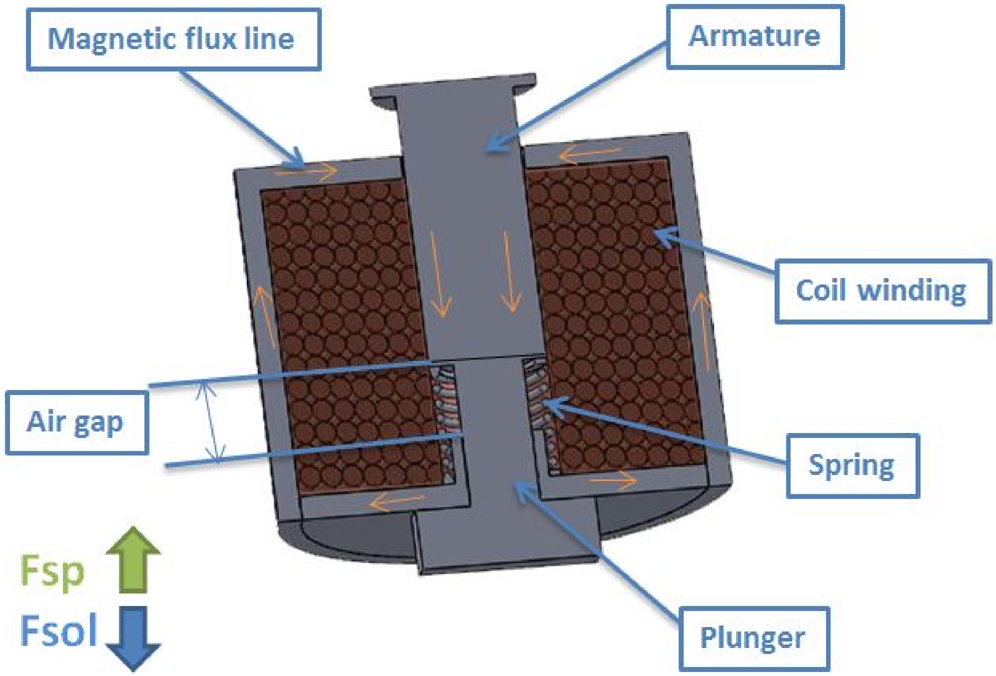

Figure 2: Solenoid Cross section view

2 Solenoid design

2.1 Background information

As mentioned in the abstract, the system shall include six solenoids and they will be installed in the sleeve, inside the transmission. In other words, the size for the solenoids are limited. According to the requirement (Requirement ID:R.07.3, see the figure 3), a solenoid system size will not be more than 50x50mm. However, not only is the six solenoid systems installed, but also other subsystems are installed in this hollow cylinder(sleeve) (see figure 3).Therefore, the size of the solenoid system will smaller than 50x50mm. Referring to the previous force analysis and calculations, one solenoid system should generate a push force greater than 150.8N.

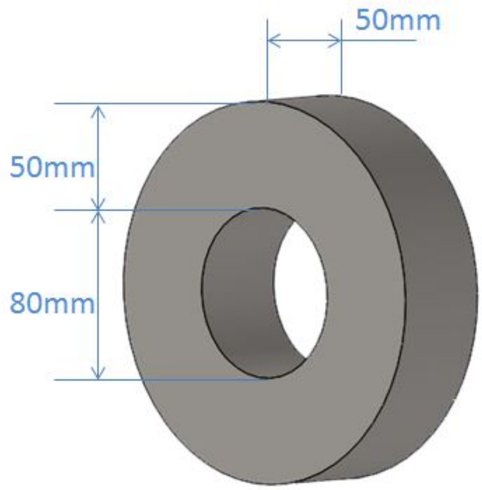

Figure 3: Sleeve size requirement-illustration

2.2 System Main Components

Below figure 4 is the main components of the solenoid system displayed:

Lock and House
Lock and house, is also called a shell, which are surrounding the coil winding set and also concentrates the magnetic field. It is a ferromagnetic material with high permeability.

Permeability is a measurement scale for measuring materials ability to support the formation of the magnetic field within itself [13]. Here the steel would be chosen, because it has a high permability.

Coil winding set
The coil windings is normally made by copper. Copper is not only a good electrical conductive material, but it can also operate at high temperatures. The purpose of coil windings is to generate a electromagnetic field by passing current.

Spring
The spring is to drag the plunger and tooth back to the initial position without power in the solenoids.

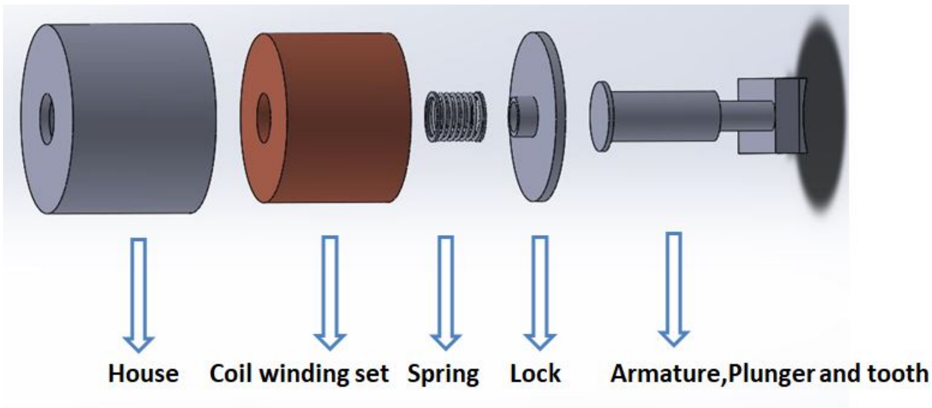

Figure 4: Solenoid Main Components

Armature and Plunger

The Armature and plunger are placed inside of the solenoid and is freely to move. It will transfer the solenoid force to the contact part. In addition, it can also transfer the force in the opposite direction, such as spring force. The material of the armature is the same as the Lock and House with a high permeability.

2.3 Mathematical modelling

The solenoid system is a simple structure with limited size. The force Fsol generated by the solenoid depends on the diameter of the coil, length of the coil, number of coil winding, DC voltage, air gap and the permeability of the material and so on. Under this section, these elements will be taken into account in the design and simulated in Matlab/Simulink.

2.3.1 Coil Resistance calculation:

The coil resistance is changed according to the temperature changes. Therefore it is necessary to check this.

First step: Calculate the total length of the coil.

Figure 5 displays the cross-section of the solenoid, the brown colour areas represent the coil winding.

Table 1: Coil resistance calculation parameter list A

Symbol	Definition	Value	Remarks
Hs	Height of solenoid	25mm	Refer figure 5
Ls	Diameter of solenoid	38mm	
dp	Diameter of plunger	10mm	
airgap	Air gap	6mm	minimum=1mm
A_{dp}	Areal of air gap		$A_{dp} = \pi(dp/2)^2$
dc	Thickness of solenoid house	2mm	
hc	Height of coil winding set		hc=Hs-2dc
lc	Diameter of coil winding set		lc=1/2(Ls-2dc-dp)
d	Diameter of coil	0.8mm	
A_{coil}	Areal of coil		Acoil= $\pi(d/2)^2$
nx	No. of winding x axle		nx=lc/d
ny	No. of winding y axle		ny=hc/d
N	Total No. of winding		N=nx*ny
$L_{winding}$	Total length of winding		
R_{20}	Copper resistance at temperatre $20°C$		
ρ	Copper resistivity at $20°C$	$1.68\times10^{-8}\Omega \cdot m$[5]	

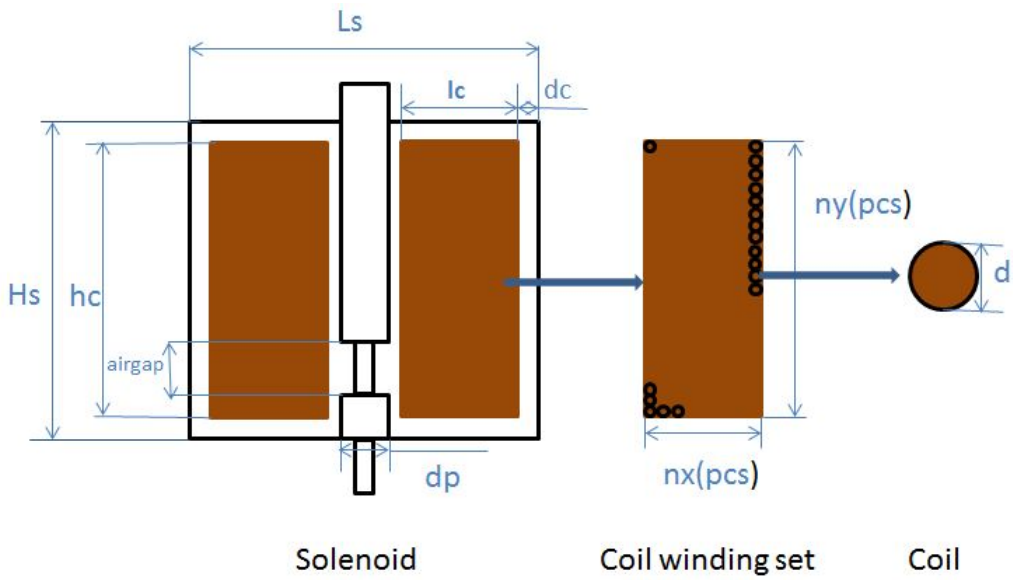

Figure 5: Coil resistance calculation parameter-illustration-1

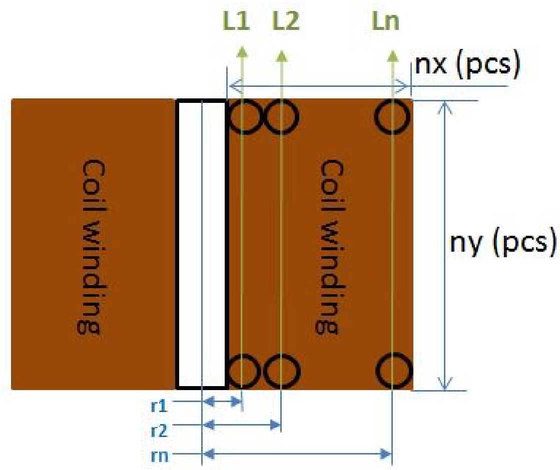

Figure 6: Coil resistance calculation parameter-illustration-2

To calculate the total length of the coil, the coil windings is divided into n rows such as the green marks in figure 6. The number of row is from n=1 to n=nx.
The first row radius: $r_1 = 1/2(dp + d)$
The second row radius: $r_2 = 1/2(dp + 3d)$
The No. n row radius: $r_n = 1/2(dp + (2n - 1)d)$
Thee length of the first low coil winding: $L_1 = 2\pi r_1 \cdot ny$
The length of the second row coil winding:$L_2 = 2\pi r_2 \cdot ny$
The length of the No. n row coil winding: $L_n = 2\pi r_n \cdot ny$
The total length of all rows coil winding :$L_{winding} = L_1 + L_2 + ... + L_n$
In other words, it will be summarize as:

$$L_{winding} = \sum_{n=1}^{n=nx} \pi(dp + (2n - 1)d) \cdot ny \tag{1}$$

Second step: Calculate the resistance at room temperature at 20°C.

$$R_{20} = \rho \frac{L_{winding}}{A_{coil}} [5] \tag{2}$$

If the coil diameter is increased it will also increase the areal of the coil, but the length of the coil will be decreasing. Equation 2 shows that the resistance will decrease in this situation. According to Ohm‘s law U=IR, when DC is used as the input voltage the current will increase. This should be considered when deciding the appropriate solenoid parameters, in order to prevent high current.

Third step: Calculate the temperature change.

Table 2: Coil resistance calculation parameter list B

Symbol	Definition	Value	Remarks
Density	Copper density	$8.96{\times}10^6 g/m^3$[3]	
Vsol	Volume of the copper coil		
msol	Mass of the copper coil		
c	The specific heat capacity of copper	0.386 J/g*K [1]	
P	Power		
I	Current		
Q	Heat		
dT	Change in temperature		
T_0	Temperature at $20°C$		
T_{coil}	Temperature		
Krt	Temperature coefficient	$0.00404/°C$[8]	

The power is:

$$P = I^2 \cdot R_{coil}(T)[5] \tag{3}$$

The heat will be:

$$Q(t) = \int P dt[5] \tag{4}$$

The temperature change will be:

$$dT = \frac{Q(t)}{m_{sol}c}[10, p.\ 193] \tag{5}$$

The final step: Calculate the resistance Change:

$$R_{coil} = R_{20}(1 + Krt \cdot (T_{coil} - T_0))[8] \tag{6}$$

$$R_{coil} = R_{20}(1 + Krt \cdot dT) \tag{7}$$

2.3.2 Solenoid force calculation:

A magnetic force will be generated when the current flows through the coil winding, this magnetic force is called solenoid force.

Table 3: Solenoid force calculation parameter list

Symbol	**Definition**	**Value**	**Remarks**
ε	Induced electromotive force,emf		
voltageIn	DC Voltage	24V	
Φ	Magnetic flux		
B	Magnetic flux density		
H_{air}	Magnetic field intensity for air		
H_{steel}	Magnetic field intensity for steel		
μ_0	Air permeability	$1.256\times10^{-6}H/m$[13]	
f(B)	Nonlinear function for steel		
F_{MMF}	Magnetomotive Force		unit [AT]
L_{steel}	Length of steel		
F_{sol}	Force from Solenoid		

First step Calculate the current that flows through the coil.

The magnetomotive force (F_{MMF}) is analogous to voltage or electromotive force. It is required to drive the magnetic flux in the magnetic circuit. The magnetic pressure, which sets up the magnetic flux in a magnetic circuit is called Magnetomotive Force [6]. It can express as:

$$F_{MMF} = NI[12] \tag{8}$$

and

$$F_{MMF} = HL[12] \tag{9}$$

Equation (9) for this system become:

$$\longrightarrow F_{MMF} = H_{air} \cdot airgap + H_{steel} \cdot L_{steel}[12] \tag{10}$$

Combining equation (8),(10):

$$NI = H_{air} \cdot airgap + H_{steel} \cdot L_{steel} \tag{11}$$

The magnetic field intensity for air and steel:

$$H_{air} = \frac{B}{\mu_0}[12] \tag{12}$$

$$H_{steel} = f(B)[12] \tag{13}$$

Remark: ferromagnetic materials such as steel, which have a nonlinear BH-curve[7] see the following figure for an example of the BH-curve for steel.

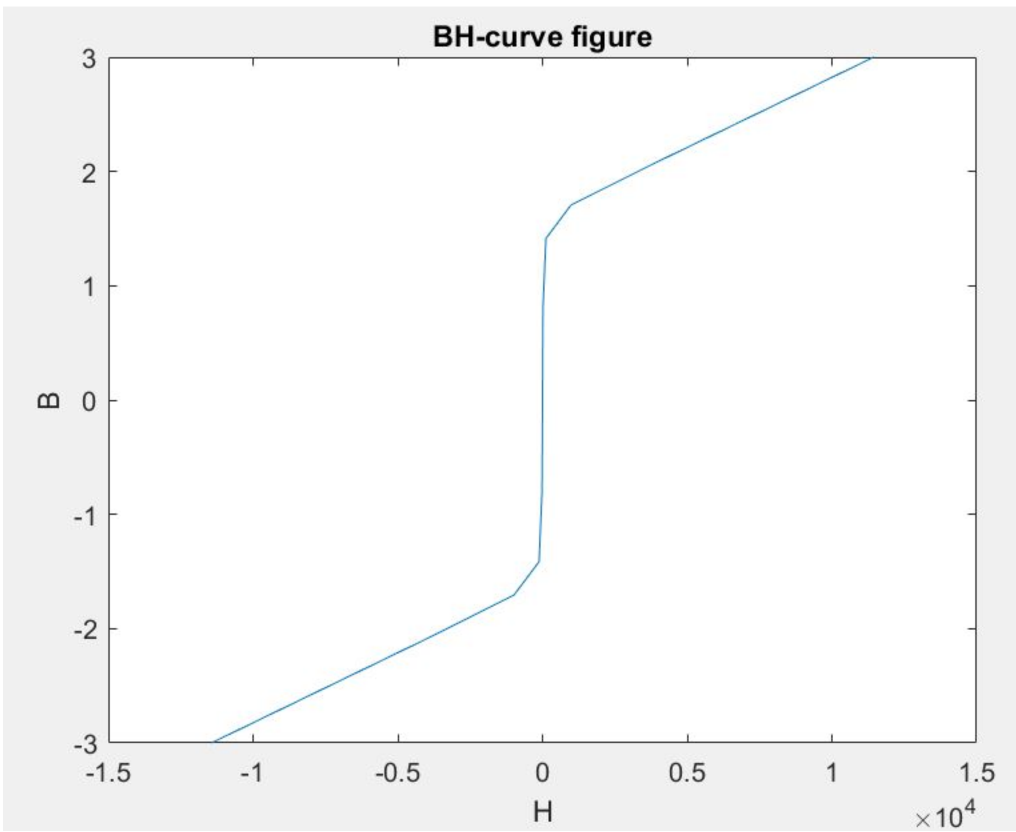

Figure 7: Steel BH curve
[9]

Combining equation (11),(12),(13):

$$NI = \frac{B}{\mu_0} \cdot airgap + f(B) \cdot L_{steel} \tag{14}$$

$$\longrightarrow I = \frac{\frac{B}{\mu_0} \cdot airgap + f(B) \cdot L_{steel}}{N} \tag{15}$$

Second step: Calculate the magnetic flux density.
According to Faraday's law: the induced emf which appears in a coil of wire containing N loops is[2, p. 478]:

$$\varepsilon = -N\frac{d\Phi}{dt} \tag{16}$$

According to Ohm's law and Lenz's law:

$$-\varepsilon = VoltageIn - IR_{coil} \tag{17}$$

Combining equation (16),(17):

$$N\frac{d\Phi}{dt} = voltageIn - IR_{coil} \tag{18}$$

$$\Longrightarrow \frac{d\Phi}{dt} = \frac{voltageIn - IR_{coil}}{N} \tag{19}$$

$$\Longrightarrow \Phi = \int \frac{voltageIn - IR_{coil}}{N}dt \tag{20}$$

The magnetic flux Φ through a surface $A_{dp} is[10, p. 295]$:

$$\Phi = \int B \cdot dA_{dp} \tag{21}$$

For magnetic flux perpendicular to the surface A, the equation (21) become :

$$\Longrightarrow B = \frac{\Phi}{A_{dp}} \tag{22}$$

Final step:: Calculate the force from solenoid.

$$F_{sol} = \frac{A_{dp}B^2}{2\mu_0}[12] \tag{23}$$

2.3.3 Solenoid plunger(with tooth) motion

Table 4: Solenoid plunger+tooth motion parameter list

Symbol	Definition	Value	Remark
F_{net}	Total force		
m	Mass of tooth and plunger	57g	
a	Acceleration		
v(t)	Velocity		
x	Stroke		

According to Newton's Second Law:

$$F_{net} = m \cdot a \quad (24)$$

(Remark: the more explanation on F_{net} , please refer to 4.3)

$$v(t) = \int a dt \quad (25)$$

$$x = \int v dt \quad (26)$$

2.3.4 Result from Matlab/Simulink

After implementing the equations Matlab/Simulink (for the Matlab code and simulink modelling please see4), the result is displayed as:

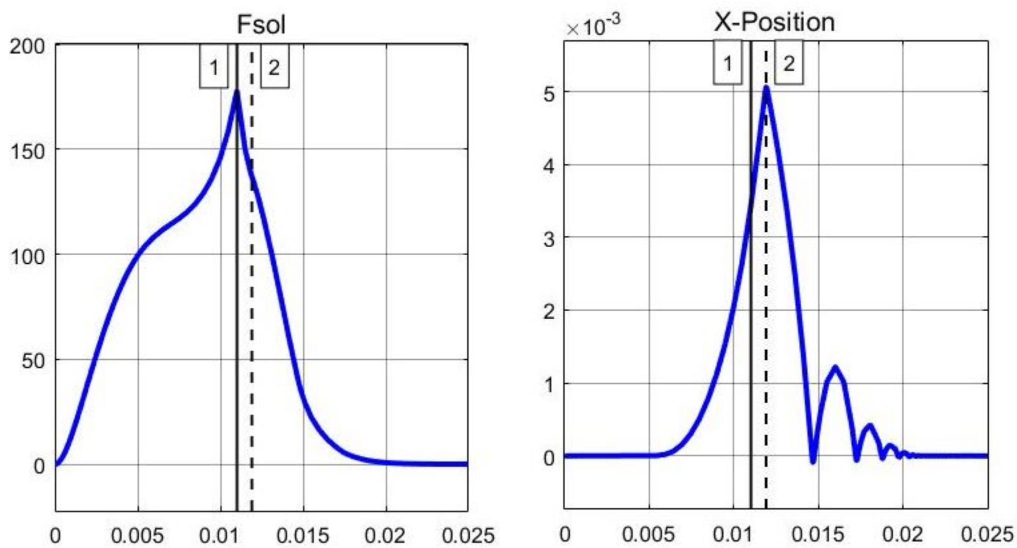

Figure 8: Solenoid force and stroke

It displays that the solenoid can generate the force of 178N in about 11ms and it will complete the stroke 5mm in 12ms. It meets the requirement to complete the stroke in 40ms.

In addition, the peak current will reach 23.8amp. After the voltage turns off (as shown in figure 9 that line one is the turn off point), the current decrease a little and then increase again(see the figure 9). This is because of the back emf.

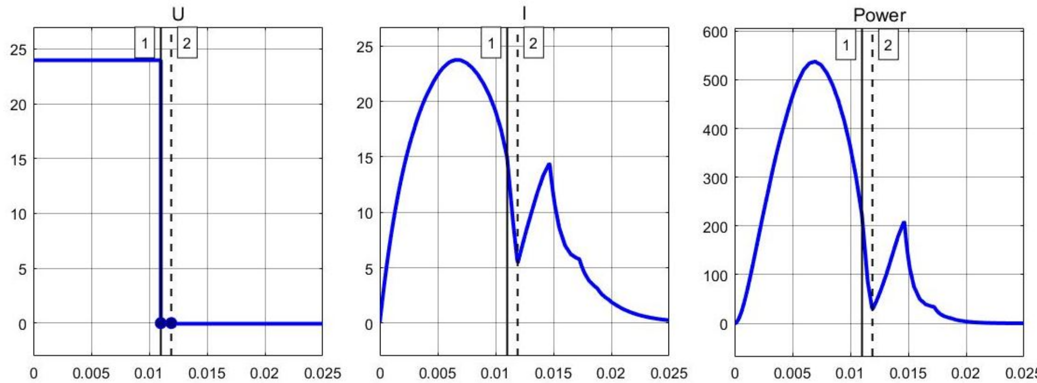

Figure 9: Voltage vs Current vs Power

It is necessary to turn off the voltage earlier, because if this is not done the solenoid force will be around 800N (see figure 10) when the tooth contacts the bottom of the channel, there will be a relatively large impact to the surface. (It is 130N (refer to figure 8) when the voltage is off).

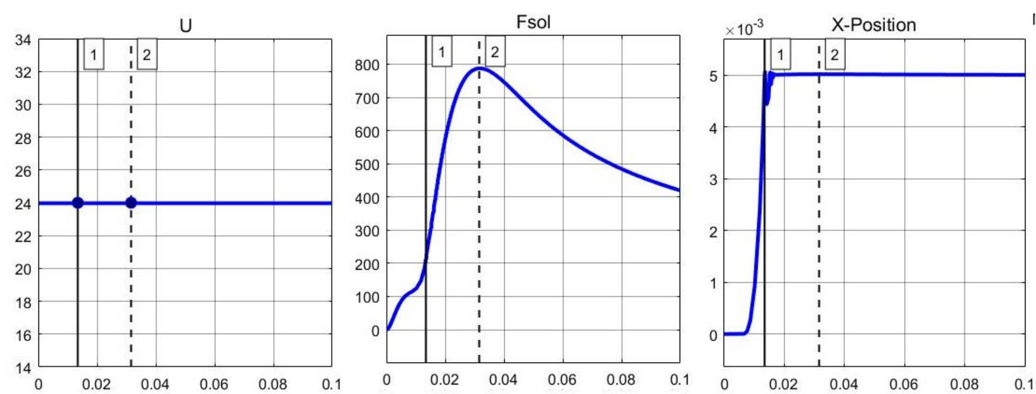

Figure 10: Without turning off DC voltage A

Meanwhile the temperature will rise (refer to figure 11) to more than 160 degrees, which will damage the system. Therefore, it will be a control system to control the voltage.

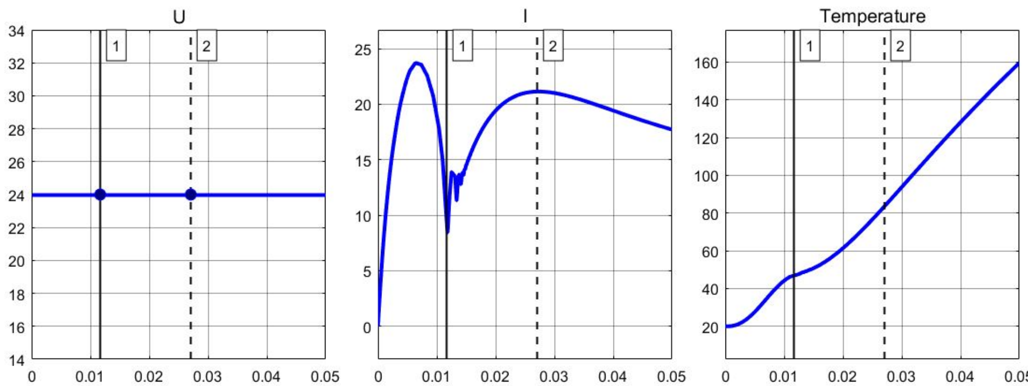

Figure 11: Without turning off DC voltage B

With the control system, the temperature increases 24 degree under the 5mm motion. For more details please see figure 12.

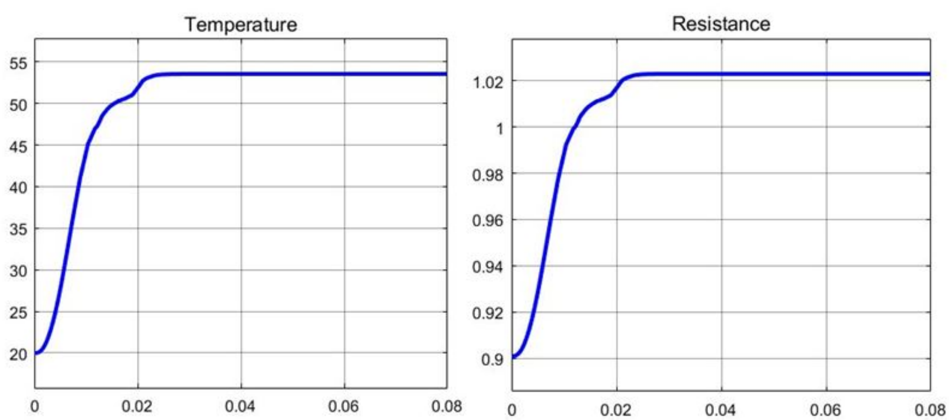

Figure 12: Temperature and resistance change

3 Conclusion

After analysis and tests, the solenoid becomes as displayed in figure 13. It is possible to generate the force 178N to complete the 5mm strokes in 12ms.

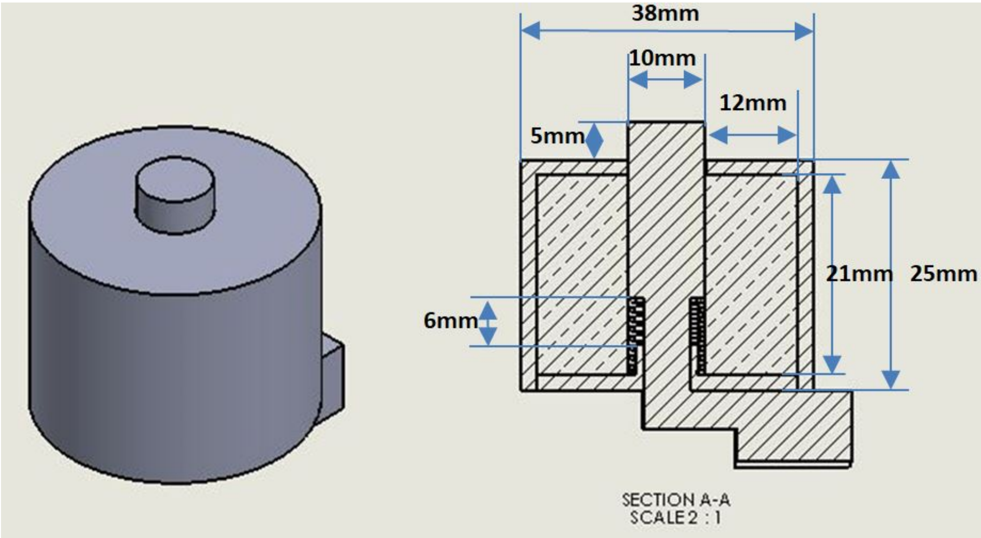

Figure 13: Solenoid design

4 Matlab code and Simulink modelling

4.1 Simulink: Resistance system modelling

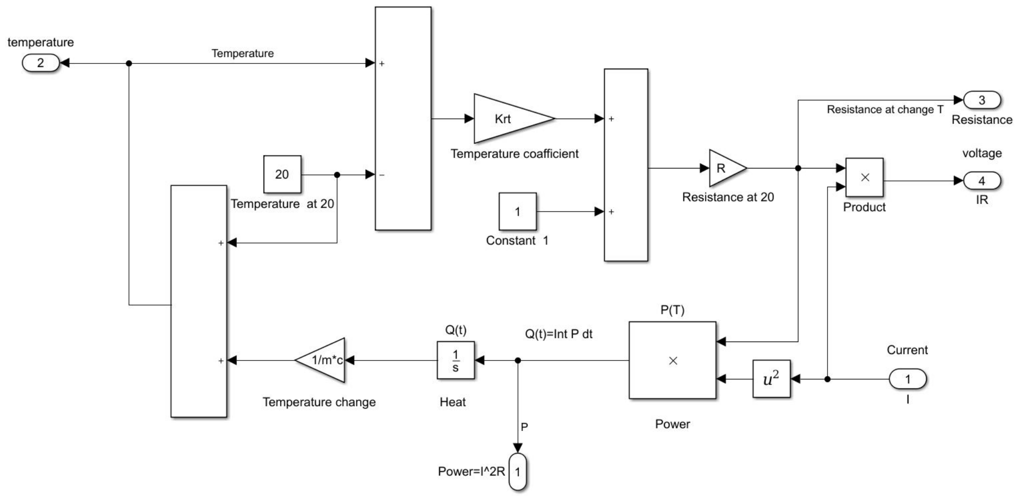

Figure 14: Simulink: Resistance system modelling

This model is a sub-model of the solenoid force system model.It is mainly a description of equation (3),(4),(5)and (6), which are explained in section 2.3.1 please see 3. Those equations are making a loop in the model and resets the initial value. An example has been illustrated in the below figure 15.

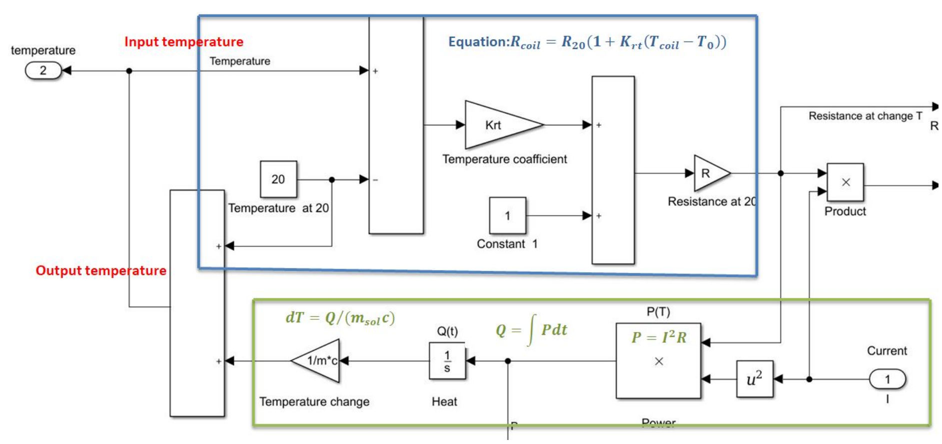

Figure 15: Explaination of simulink

4.2 Simulink: Solenoid force system modelling

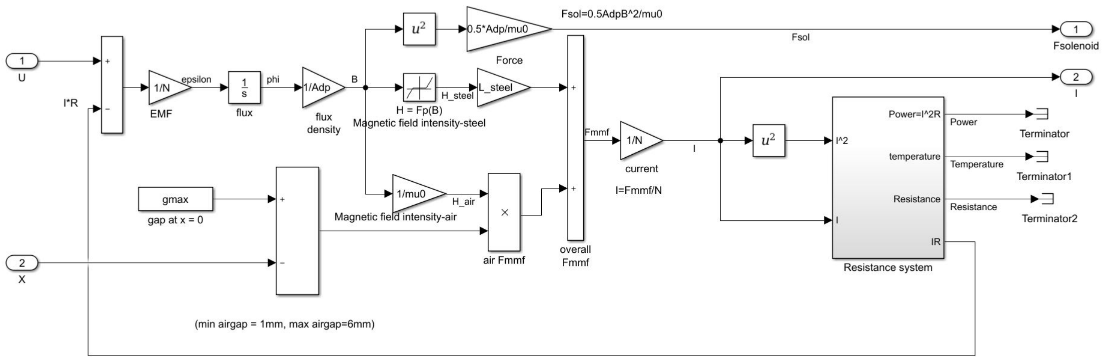

Figure 16: Simulink: Solenoid force modelling
[9]

Equation (11),(12),(13),(19),(20),(22),(23)(please click 11 to see the equation explanation) are implemented in this model and are from section 2.3.2.

This model can calculate a solenoid force that is an output from the magnetic system and continue to be used for the top level modelling.

Remark 1: The Magnetic Hysteresis does not take into this modelling.

Remark 2: Here the maximum air gap is 6mm when the stroke x = 0. Therefore, from figure 16 shows a function that the maximum air gap(gmax) subtract stroke x to get the new air gap value.

4.3 Simulink: Solenoid plunger with tooth motion system

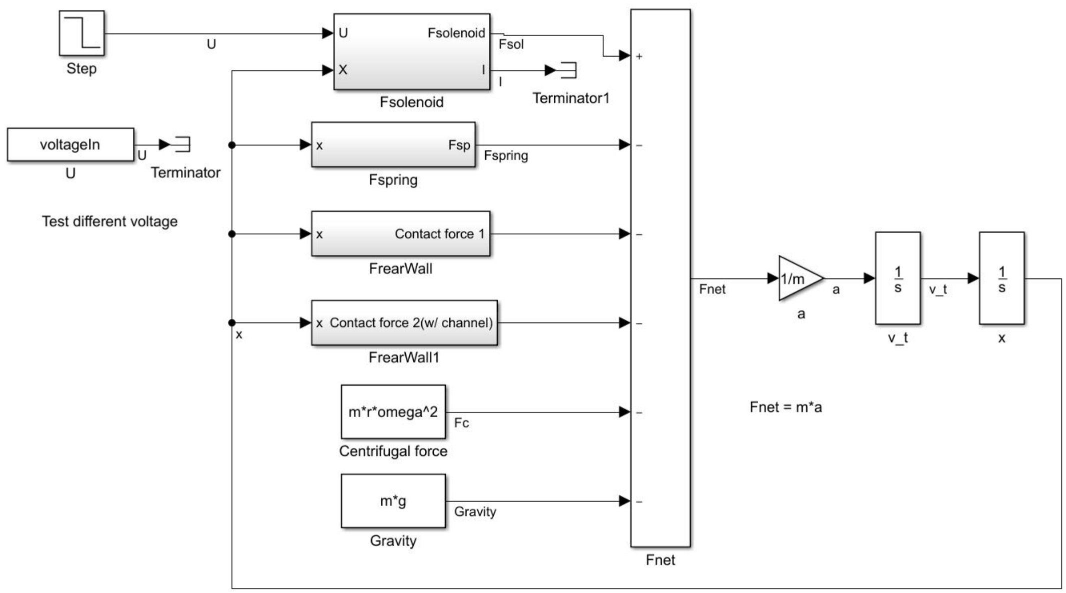

Figure 17: Simulink: Motion modelling

Newton's second law has been implemented in this model. Furthermore, the acceleration is integrated to get the tooth velocity, in turn, the velocity is integrated to obtain the tooth position(see equation24)

The total force F_{net} is:

$$F_{net} = Fsol - Fsp - F_{wall1} - F_{wall2} - F_c - G \tag{27}$$

Table 5: Total force parameter list

Symbol	Definition	Value	Remarks
F_{net}	Total force		
Fsol	Solenoid force		
m	Mass of tooth and plunger	57g	
ω	Angle velocity	209.44 rad/s	2000rpm
r	Radius of the synchronized corn	40mm	
G	Gravity		
g	Gravity acceleration	9.8 m/s^2	
β	Solenoid position angle		$0^{\circ C} \sim 360^{\circ C}$
x	stroke		
F_c	Centrifugal force		
Fsp	Spring force		
k	Spring constant	10000N/m	
k_s	Stiff spring constant	3000*k	
F_{wall1}	Contact force with spring		
F_{wall2}	Contact force with the bottom of channel		
ζ	Damping ratio		0.15
c	Damping coefficient		

Among this, The centrifugal force F_c is:

$$F_c = m \cdot r \cdot \omega^2 \tag{28}$$

The spring force Fsp is:

$$Fsp = k \cdot x \tag{29}$$

The gravity G is:

$$G = m \cdot g \tag{30}$$

(Remark: the gravity actually is $G = m \cdot g \cdot \cos\beta$. Take the worst case into account as $\beta = 0$ the gravity will be at the appositive direction of the solenoid force. In addition, the friction is negligible so it is ignored in this modelling)

Two contact forces have been implemented in this model, so that they can prevent the plunge(with tooth) to overshoot. This is one kind of damping system. For example, when the spring drags the tooth back to the initial position, it should be stopped at that position. When the tooth is pushed into the channel, it should stop at $x = 5mm$ position. Please refer to figure 18 under.

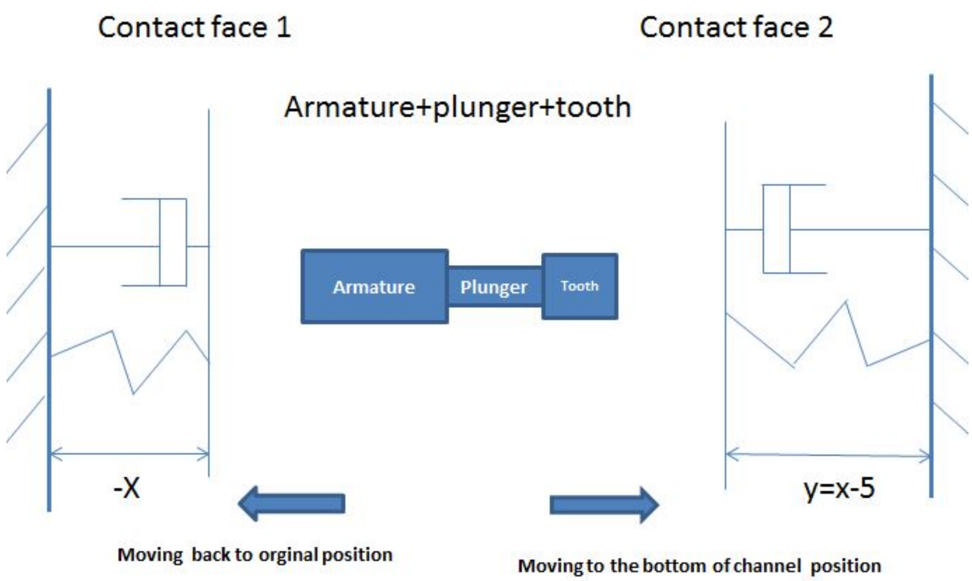

Figure 18: Damping system illustration

The contact force F_{wall1} of the contact face 1:

$$F_{wall1} = c \cdot dx/dt + k_s x[11] \tag{31}$$

The damping coefficient c is :

$$c = 2\zeta\sqrt{mk_s}[11] \tag{32}$$

Set equation (32) into equation (31):

$$\Longrightarrow F_{wall1} = 2\zeta\sqrt{mk_s}dx/dt + k_s x \tag{33}$$

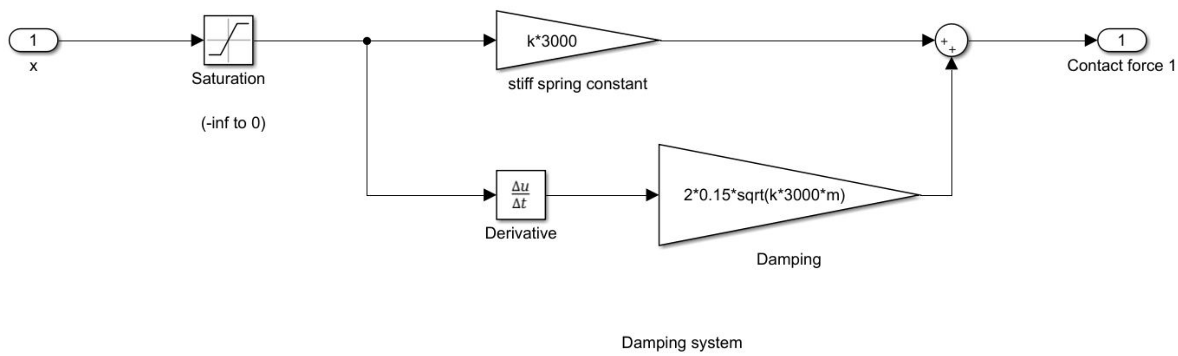

Figure 19: Simulink:Contact force 1 modelling

Figure 19 displays the modelling of this damping system. When the stroke becomes -x (means overshoot), this model will give one contact force to push back to the original position to prevent overshoot. The saturation label function is to accept the right data of x. Here the upper limited is 0 and the lower limited is $-\infty$. For example, when the input x=-1, the output x = -1 from saturation label. If the input x=1, the output x will be 0.

The contact force F_{wall2} of contact face 2 become:

$$F_{wall1} = 2\zeta\sqrt{mk_s}dy/dt + k_s y \tag{34}$$

Where $y = x - 5$ in this modelling. This system will prevent the tooth to overshoots when it contacts the bottom of the channel. Therefore, one contact force will be given when x is greater than 5mm. Regarding the model, please see figure 20 below.

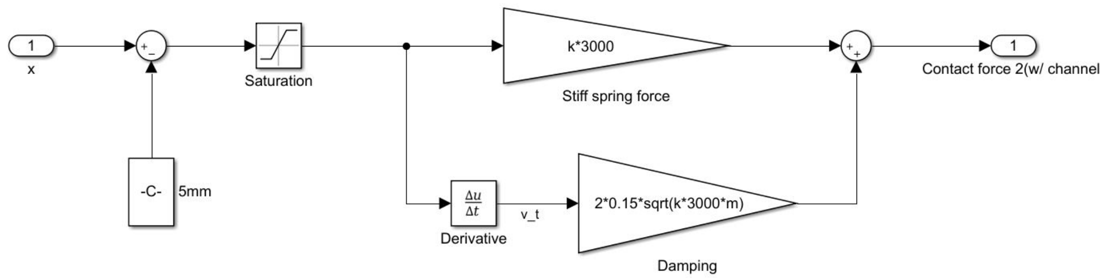

Figure 20: Simulink:Contact force 2 modelling

The saturation label value: the upper limit is ∞ and the lower limit is 0. It means if the input $y \leq 0$, the output y=0; and if the input $0 \leq y \leq \infty$, the output y= input y. The rest functions of model are same as the contact force 1 modelling.

Those two damping functions model is used in the Simulink model to stop the tooth motion at the right position. In the future the control system or damping system will be more researched.

4.4 Matlab code

The following figure is the Matlab code for Simulink modelling.

```
voltageIn = 24;
%Coil calculation
d = 0.0008; %coil diameter
Acoil = pi*(d/2)^2; %coil cross setion area
Hs = 0.025;%solenoid high
Ls = 0.038;%solenoid diameter
dp = 0.010; %Armature diameter
Adp = pi*(dp/2)^2; % airgap area
dc = 0.002; %cover thickness
lc = 1/2*( Ls - 2*dc - dp); %coilset length
hc = Hs - 2*dc ; %coilset high
nx = floor( lc/d); %No. of winding length
ny = floor( hc/d); %No. of winding high
N = nx*ny; %No. of all windings
Lwinding = 0; % initialization
for n = 1:nx
    Lwinding = Lwinding + pi*(dp+(2*n-1)*d)*ny;
end
  disp(['total length of coil:' num2str(Lwinding)])

rho = 1.68e-8; %copper resistivity at 20degree
R = rho*Lwinding/Acoil; %reistance of coil in copper material at 20 degree
Krt = 0.00404; %[1/degree] thermal coefficient of copper
I = voltageIn/R; %current
mu0 = 1.256e-6; %air permiability
gmax = 0.006; %max gap
airgap = 0.001; % minimun gap
L_steel = 2*(Hs+Ls)+(Hs-airgap-gmax);%path on steel
run bhdata.m %f(B) B-H curve
% BHcurve
% figure();
% plot(0.5*(BHcurve.Hp+BHcurve.Hn),BHcurve.B)
% xlabel('H')
% ylabel('B')
% title('BH-curve figure')

% Force
k = 10000; %spring constant
m = 0.057; %kg, mass of a tooth and plunger
g = 9.8; %acceleration of gravity
r = 0.04; %m, radius of syncron cone
omega = 2000/60*2*pi; %rad/s,2000rpm, angular velocity

%Temperature
density = 8.96e+6; %g/m^3 cooper density
vsol = pi*((Ls-2*dc)/2-dp/2)^2*Hs; % voulum of the copper coil
msol = density*vsol; %g, mass of coil
c = 0.386; %J/g*K, copper specific heat capacity
```

Figure 21: Matlab code for Simulink modelling

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Subsystem: Power Transfer

EGA

May 21, 2018

Abstract

When developing the concept; El.magnet: Inside, it was needed to have a system to transfer electricity between the stationary and the rotary gear. Here EGA have done research about different systems, which have the ability to transfer electricity from stationary to rotary and which one will suit this concept best.

Contents

List of Figures

List of Tables

1 Introduction

The concept that has been chosen rotates, this means that the solenoids needs to get electrical power and signals from something that stands stationary. There is some ways to get electrical power and signals from stationary to something that rotates. Unfortunately there is not that many ways, which includes a method that does not have any wear.

In this report the project team will see on the different ways which is possible to use, and how they can be implemented. There are also a lot of challenges with this kind of power/signal transfer, which the project team will try to detect.

2 Slipring

A slip ring is most used when something need to transfer electrical signals, or power to something that rotates. There are two different types of slip rings, and there is two types of usage of slip rings. The difference of types and usage have nothing with each others to do. The two types are:

1. Slip ring
2. Separated slip ring

The main difference between these two types are how they work, the "normal" slip ring is transferring the electricity trough the center. Separated slip ring on the other hand transfers the electricity from the side, and on to the rotating part. For illustrations of the two types, see figure 1 and figure 2. There is also a third type slip ring, which is called: Diamond Roll-Rings, see figure 3. The difference between this and the other two types, is that the Diamond Roll-Ring is brush less. Since it is brush less, it is no maintenance. On the other hand, there are some other challenges with this type from Diamond Roll-Ring [11] like price and size.

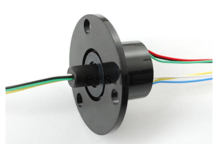

Figure 1: Slip ring

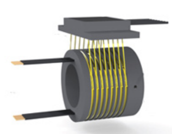

Figure 2: Separated slip ring

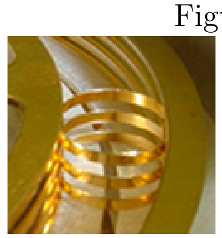

Figure 3: Diamond Roll-Rings

As mentioned above, slip rings are used to transfer signals or power. The difference between these two are the size of the slip ring. Usually slip rings which transfer signals are smaller than the ones who transfer power. This is basic electronics, where higher current needs wider cables. It is also possible to transfer digital signals, but this is something that is mentioned later. For the Diamond Roll-Ring, there is a difference, since it is metal it can handle a much larger current.

2.1 Concept

For the concept that EGA have chosen, separated slip ring or Diamond Roll-Ring is the best choice. This way it will be possible to transfer the signals and power from the ring which stands still, to the ring that rotates.
To make the separated slip ring possible, you need:

1. Brushes
2. Collector Ring
3. Brush Holder

This is needed to make the connection. The brush will rest on the copper ring, and will therefore transfer the electricity to the inner ring.
To make the Diamond Roll-Ring possible you need:

1. Diamond Roll-Ring
2. Space

One of the biggest challenges with this solution is the space. At this point it is designed to rotate with the inner ring, and to have outer ring which sends the electricity. If it is possible to lock the roll-ring, so it can rotate at the same place, it will be possible to use this technology. For the Electromagnet: Inside concept, there is no doubt that the Diamond Roll-Ring is the best solution, if the space is big enough.

2.2 Separated slip ring

2.2.1 Brushes

One of the biggest challenge with a separated slip ring, is the brushes. These brushes does not last forever, which means that they have to be switched after a certain time. This certain time is not set, and can be developed to be quite high, the problem with having long lasting brushes is that they take some space. These brushes can be made in for example:

1. Graphite — 10amp per $1cm^2$
2. Copper Graphite — 15.5amp per $1cm^2$

Most used is the graphite brush [10] because it is cheaper then the copper graphite. Here is a comparison between graphite prices [9] figure 4 and copper prices [6] figure 5.

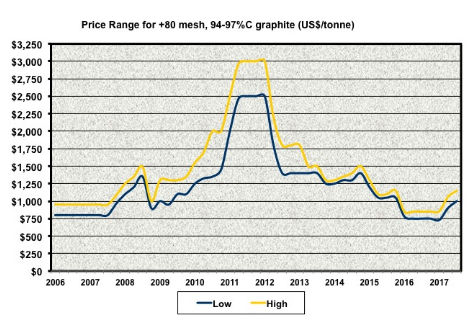

Figure 4: Graphite prices

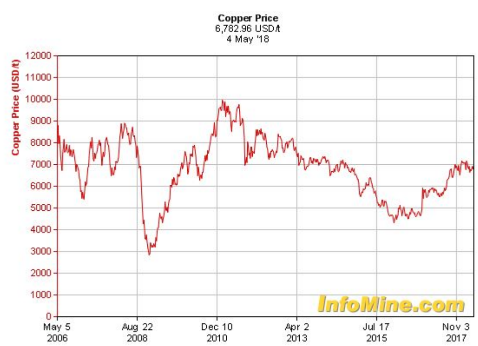

Figure 5: Copper prices

Both graphs are given in US dollars, and in metric tons. As it is easy to see from the graph, the Copper prices is vastly higher then the Graphite.

This is the equation used for calculation of electric current density:

$$J = \lim_{A \to 0} \frac{I}{A} \tag{1}$$

Where:

1. J = Electric current density
2. I = Current
3. A = Area

The current density equation, is a equation where it is possible to calculate the area which is needed to transfer Xamp. For example between the brush and the collector ring.

It is therefore possible to make this equation, so it display the area which is needed.

$$A = \frac{I}{J} \tag{2}$$

From the analysis that have been made from the syste simulation that have been done, the amps that is needed is: 23,8Amp. This can be rounded up to 24Amp.

For copper graphite, it will be:

$$A = \frac{I}{J} = \frac{24amp}{15.5amp/cm^2} = 1.54cm^2 \tag{3}$$

and regular graphite:

$$A = \frac{I}{J} = \frac{24amp}{10amp/cm^2} = 2.4cm^2 \tag{4}$$

Since the area is given in square centimeters, it can be in any form that is wanted as long it fulfill the area. As can be seen from equation 3, it only needs $1.54cm^2$ compared to $2.4cm^2$ which is quite a lot when the dimensions are this small. But as mentioned above, and displayed, in figure 4 and 5 copper graphite is much more expensive.

Wear

The biggest problem with slip rings, is the brushes and wear. This is something that have been looked into. The wear formula that has been look into is: Archard's equation[2]:

$$Q = \frac{KWL}{H} \tag{5}$$

Where:

1. Q is the total volume of wear debris produced
2. K is a dimensionless constant
3. W is the total normal load
4. L is the sliding distance
5. H is the hardness of the softest contacting surfaces

The steady state equation[1] have also been looked at:

$$V = K\frac{PL}{3H} \tag{6}$$

Where:

1. V = Volumetric loss
2. K = Dimensionless constant
3. P = Normal load
4. D = Distance
5. H = Hardness, Brinell

The problem with both of these equations is that you have to have a K = dimensionless constant, this is also called "wear rate". This wear rate is different from material to material, and same with the different surface. The only way to get a good wear rate, is to test the materials and measure the wear. This is also one of the next steps for this project, for the persons who will continue.

2.2.2 Collector Ring

The collector rings are just rings that goes around the receiver side. These rings are made in some type of material which have good "leading capacity", some of the matierals that are usually used is:

1. Bronze
2. Steel
3. Stainless steel
4. Brass

These are not the types that conducts, leads, the electricity best, that is [7]:

1. Silver (Pure) - 105
2. Copper - 100
3. Gold (Pure) - 70
4. Aluminum - 61
5. Brass - 28
6. Steel (Stainless included) - 3-15

Silver, gold and copper are quite expensive to use to leading electricity, but it is used when it is needed. Places these expensive materials is used, is for example The International Space Station. For normal use; Bronze, Steel, Stainless steel or Brass is used. Brass is probably the best choice for this task, because of the leading capabilities compared to price.

2.2.3 Brush Holder

The brush holder is the contraption that holds the brush, and apply the right pressure. A brush holder is normally a mechanical device, with a spring to make the right pressure.

The right pressure was possible to find from figure 6, which is a experiment that has be done about graphite wear against slip rings. The pressure should be around 40kPa, for best transfer efficiency and the least wear [5].

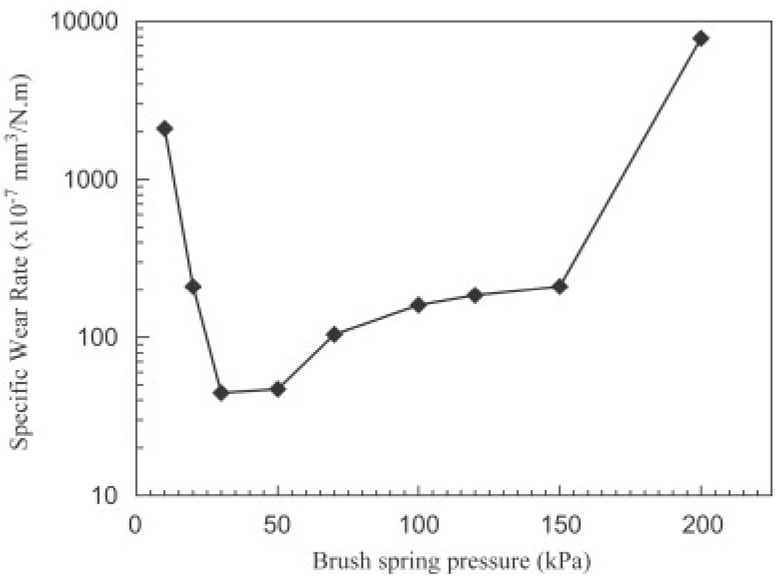

Figure 6: Wear to pressure rate

2.2.4 Existing alternative

From the 20amps which is required, it has been found a suitable of the shelf product [4]. This has the ability to transfer 25amps, and has the size of: 1/2" and 1/4", which can be translated to: 12.7mm and 6.35mm. These sizes are suitable for the build space the project group have been given from Kongsberg Automotive. On the other hand, it does not say how long it will approximately last, before it has to be switched out.

2.3 Diamond Roll-Ring

Diamond Roll-Ring is a new technology, which have been used for among other things; The International Space Station and he US Navy for its SPS-48E Air Search Radar system [12]. In other words, this technology is currently used at demanding places. The idea behind this technology is that you have a ring, which circulates around the thing that rotates from the sender side. See figure 7 for an illustration.

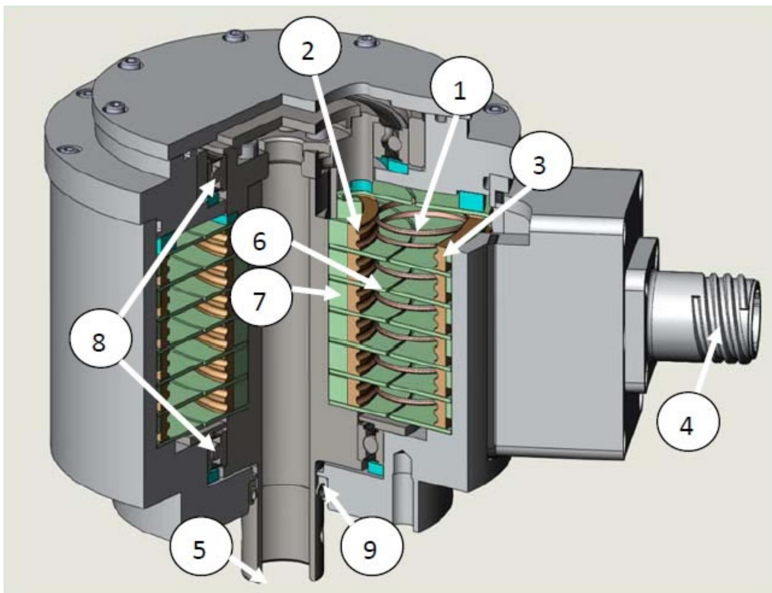

Figure 7: Diamond Roll-Ring illustration

If you look at figure 7, the number one is pointing at the diamond roll ring, and two is pointing at the receiving end, while three is pointing at the sending end. Like this there is possible to let the Diamond Roll-Ring rotate freely, even though it has the connection.

2.3.1 The Roll-Ring

The Diamond Roll-Ring in itself is a 19mm gold plated ring, which have the ability to transfer the electricity from the outer ring to the inner ring. It has to be mentioned that the outer ring and the inner ring also is made from the the same as the Diamond Roll-Ring. This roll-ring has the ability to transfer up to 4000V, 15Mb/s with data with a frequency of 30Hz.
The roll ring have also an 99.966% transfer efficiency, which also makes it perfect for data signals also. In other words, this technology could be used both to send power and signals/data signals. There is no direct number of lifetime for this roll-rings, but they say they have had rings that have been doing 240million rotation without trouble, this is not enough for the elmagnet: inside concept, but it is not that far away either.
Another negative thing about the Diamond Roll-Ring, is that it is really hard to get any information about this company and the rings. Especially if you want more information then it is given from the website[11].

2.3.2 Space

As said, a big problem is the space. When the roll-ring has to rotate freely, as shown in figure 7, it takes a lot more space then there is in a transmission. A way to make this a reality, is if the roll ring has the possibility to rotate around its own axis, and can therefor rotate at the same place. This is something that was not possible to get an answer to, but probably not at this point. Maybe it will be possible in some years.

3 Induction

Another way to transfer power from stationary to rotary, is with induction. Induction have a big advantage, which is that there is no wear or dirt. Induction is a type of wireless power transfer, which work with the help of electromagnetism.

3.1 Challenges

With the help of electromagnetic or electromagnetic fields, it is possible to send large currents and voltages through air. With this technology there is two challenges for the Elmagnet: Inside concept:

1. Power loss through air
2. Size

This are just challenges at this time, in a couple of years, with the help of "Moor's law"[8], it will probably be usable and will be used for almost everything.

The idea behind wireless induction charging is quite simple, even though it is quite hard to implement it to reality. Easy explained it can be said like this, but there is a catch; it needs to be AC (Alternating current). One side is connected to a stable power supply, and sends current through coils which is cycling at X Hz, which then transports flux out of the coils. On the other side there is a receiver, and when this receiver is close enough (around 4cm), the transported flux is interacting with the receiver. Flux is the quantity of something that passes through a surface, in this case it will be electrons passing though the coils/wires and air. This makes the electrons move on the receiving end, which causes the electricity to transfer through air.

There are different types of induction power transfer, but one of the technology that could work is the QI (pronounced as "chee", same as Chinese for 'energy flow'). QI is a standard for power transfer, and is found in almost all "mainstream" devices that uses wireless power transfer. These devices can be everything from new smart phones to cars. Another positive thing with the QI system, is that it is open source, and everybody who wants can download the specifications.

3.1.1 Power loss through air

As one of the challenges said, it is the power loss through air which is the problem. This is not news, but just a problem that when you are transferring electrical power or signals through air it loses some strength. This can of course be fixed with sending stronger signals, but when the concept already need 20Amps per solenoid, it is limited to how much more it is possible to send. In figure 8 it is possible to see how the power efficiency decreases as the distance increases [3].

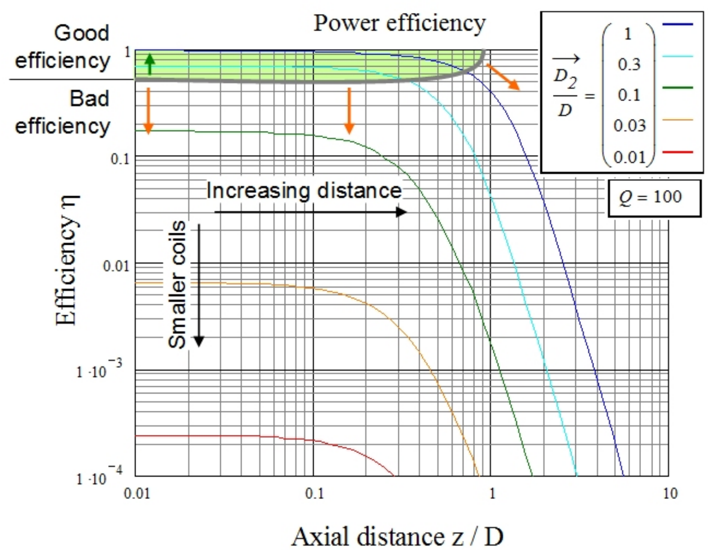

Figure 2 Power efficiency for an inductive power transfer system consisting of loop inductors in dependence on their axial distance z with size ratio as parameter. Calculated for a quality factor of Q = 100

Figure 8: Power efficiency decreases over distance

3.1.2 Size

One other problem with this type of technology is the size, because it needs to have a sender end and a receive end. Since EGA's concept is rotating, this means that it needs to be two tubes. A sending tube, and a receiving tube.

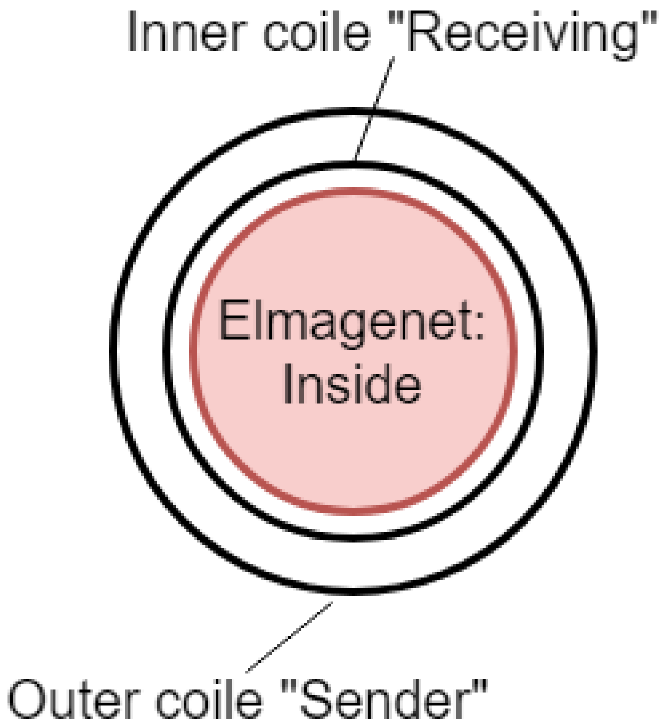

Figure 9: Coils illustration

Here it is possible to see a illustration of how the coils will be around the concept. The size of the coils depends on the size of currents and voltages that will be sent through it. A big problem with this concept; Elmagnet: Inside, is the size and if it needs a coil around it, it will be hard to make it in to reality. In some years, when the technology around wireless power transfer is better, it will be possible to use this solution.

4 Pugh Matrix

Just for simplicity, all the mentioned power transfer solutions have been placed in a Pugh matrix.

Pugh Matrix				
Criteria	Score	Slipring	Diamond Roll-Ring	Induction
Size				
Price				
Efficiency				
Maintenance				
Difficulty				
Score				

Table 1: Pugh matrix, without score

4.1 Different criteria

The criteria score is going from 1, not that important to 3, very important. The different concept will score from 1 to 5 on how good they make the criteria.

4.1.1 Size

The first and most important criteria is the size, because this will be inside a transmission. Therefore this is one of the important criteria, and is scored a max on 3.

4.1.2 Price

Price is one of the most important things, if the price is to high there is no reason to validate the solution. Therefore this criteria got a 3.

4.1.3 Efficiency

Efficiency, is how efficient the power transfer is. If it lose 90% of the current and voltage in the transfer it is a no go. Therefore it got a 2, because some wiggle is OK. If a solution is good, but have a high efficiency lose, it is possible to give more power from the main power supply, but this is not wanted.

4.1.4 Maintenance

The requirement from KA is that the concept shall last for 10 years without maintenance, there it is important that the power transfer system also can live this long. Therefore it got a 3.

4.1.5 Difficulty

How difficult is it to make the solution possible. In these days almost everything i possible, but it is important to try to see the solution in a system.

4.2 Scores

This is the different scores that the solutions have gotten, and why.

4.2.1 Size

1. Slipring - 4
   Slipring is the smallest solution for the power transfer, since it only needs a little ring on the concept, and brushes that can stand still. The brushes though are going to take some space, but they will stay still in one direction.

2. Diamond Roll-Ring - 2
   The Diamond Roll-Ring needs some space, because of how it works. The ring needs to have the possibility to circulate around the inner ring. If there is a solution where the Diamond Roll-Ring can circulate around its own axle, then it will be possible to build it like a slip ring and will take less space. Until then it only earns itself a 2.

3. Induction - 1
   Induction is, without doubt, the solution which takes up the most space. This is because of the number of coils that is needed to transfer this amount of current. If it was possible to have less coils, it would also do better in the pugh.

4.2.2 Price

1. Slipring - 4
   The slipring prices do vary a lot, it all depends on which materials that is chosen to use. But it has the ability to be rather cheap or expensive, depending on the quality.

2. Diamond Roll-Ring - 2
   It has not been possible to find any prices of this choice, but they do only take customization orders, which leads the group to think that this is quite expensive.

3. Induction - 3
   Induction technology is not that expensive, but there is some cost to make it work correctly.

4.2.3 Efficiency

1. Slipring - 4
   Slipring is a good choice to for this point, becuase it got direct contact with materials that leads electricity good!

2. Diamond Roll-Ring - 5
   From what is possible to read about Diamond Roll-Ring, it has a efficiency of 99.735% which is insane.

3. Induction - 2
   This is the biggest drawback with induction, the loss through air is quite big.

4.2.4 Maintenance

1. Slipring - 1
   The biggest drawback with slipring is the maintenance, and dust which appear with usage of sliprings. The transmission needs some kind of service after sometime to clean, and switch brushes.

2. Diamond Roll-Ring - 4
   The seller says zero maintenance, but the EGA project group do believe the roll ring maybe get some wear after 10years. For now it will get a 4, recommend to do some more research.

3. Induction - 5
   Zero maintenance, therefore it got a top score.

4.2.5 Difficulty

1. Slipring - 4
   This is the easiest to do solution, almost plug and play. Need a receiver ring and some brushes to send electricity.

2. Diamond Roll-Ring - 3
   Quite simple, but need a ring which can rotate freely between sender and receiver.

3. Induction - 1
   This is quite hard to make good, with sender and receiver coils. Not only is the technology quite hard to realize, but it is also quite hard to make space efficient.

4.3 Winner

Pugh Matrix				
Criteria	Score	Slipring	Diamond Roll-Ring	Induction
Size	3	4	2	1
Price	3	4	2	3
Efficiency	2	4	5	2
Maintenance	3	1	4	5
Difficulty	1	4	3	1
Score		39	37	33

Table 2: Pugh matrix with score

A pugh matrix is just a tool, to compare different solutions. When looking at this pugh, it is easy to see how close the different solutions where. Slipring wins with just two points, but still it is the safest solution. The slip ring is the best solution at this point, because of the problems with limited space.

As mentioned before, a big challenge with slipring is the fact that they wear. This will say that the brushes needs to be replaced. This is something that have been looked into, calculating how "big" brushes that is needed to meet the requirements from Kongsberg Automotive. To find this answer have been a challenge, and at this point it cannot be said.
On the other hand, slipring is the best for this concept at this point. The slipring have a high efficiency rate, and can survive the though conditions.

5 Whats next

The next to do for either KA or the next student group is to test wear between copper graphit and brass. This is the only way to find the wear rate, which is needed to find the wear.

Another thing that is worth looking into is the ability to use induction. If it could be possible to build the device a little different or if it could get a little more space, then induction would be a good solution. This is something for the next group to look into, and try to develop a good concept.

6 Conclusion

It is possible to conclude that for now, slip rings is the best solution. It is not a perfect solution, but the best for this device because of the lack of space. In a near future it will possible be to use some kind of induction transfer, and this would no doubt be the best solution for KAs requirements.

The slip rings will do the job, and will be quite close to the lifetime requirement. As mentioned before, this has to be tested and cannot be confirmed before that.

7 REF

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Subsystem: Locking mechanism

EGA

May 21, 2018

Abstract

ABSTRACT

Contents

List of Figures

1 Introduction

When developing this electrical transmission system, it was crucial to find a mechanism that locks the gear. The project group have looked at several different mechanisms, everything from angled tooth to mechanical locking system. This have been one of the main challenges with the electromagnet: Inside concept. The solution that looks like is the best, is a clean mechanical system with an electro motor.

One of the biggest challenges with this locking mechanism, it that it needs to, as the solenoids, to retract when the power is gone. Therefor there is going to be placed a spring with the electrical motor, which will retract the locking mechanism and then activate the solenoid spring.

Because of this system, it will be possible to put the transmission i neutral if there is a power loss. Another advantages with this system is that it does not need any electrical power to go to neutral, when it is in use either.

This system idea was a genius solution from one of the team members in EGA, but it was not made before one of the last weeks. Because of this, none of the members have had the time to calculate the different forces that is needed. But, a adequate electro motor have been found.

2 System

This system consists of a moveable ring and a electro motor with a gear system, which can move the ring. Beyond this, all the teeth have a small cut where the ring will slide in and lock them. The teeth have this cut in both positions, which will say that it is possible to lock the teeth in both in gear and in neutral.

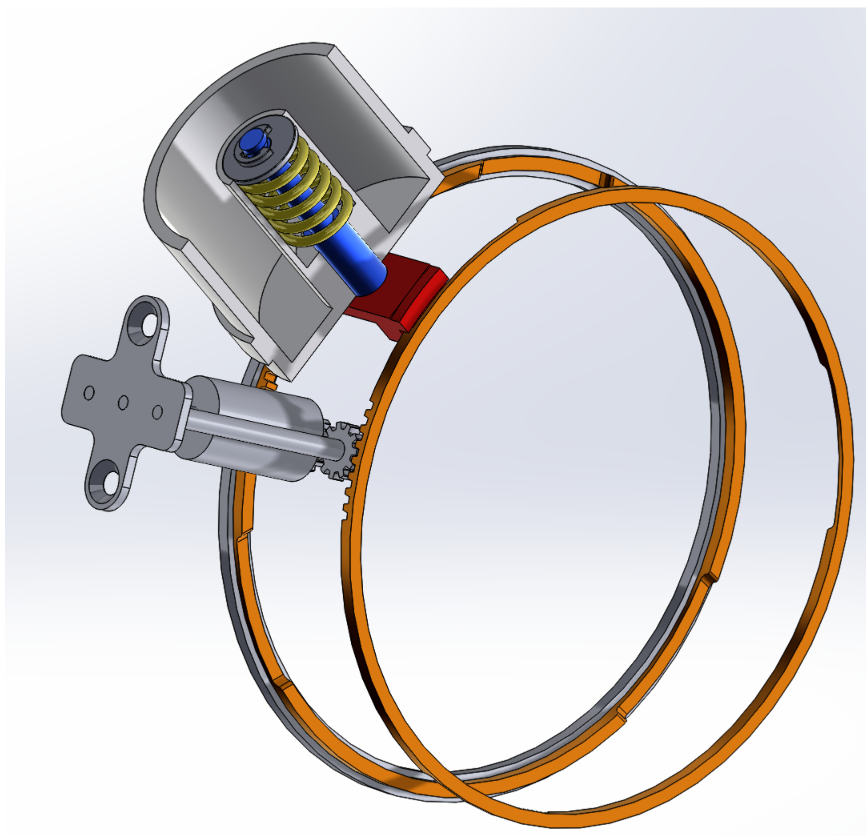

Figure 1: Ring

2.1 Ring

Ring, is a name that has been given til the mechanism that rotates around, and physically locks the teeth. This ring is just a normal metal ring, which has been cut in a special pattern.

In figure 1 is it possible to see the mentioned cut in the ring. When the part that is cut out is at the teeth, it is possible to get the teeth out and in gear. After the gear movement, it will slide back and hold the teeth down. Just the same way the teeth will be held up, with the ring.

2.2 Electro motor

As mentioned in the introduction, this solution was developed rather close to the end. This means that the project team has not have had the time to calculate the power needed for the electro motor. After some research, a motor which should be adequate has been found. This motor shall have enough power, and have the right size!

The electrical motor is a 12V miniature DC motor and builds 10*12*28mm. This dimensions are perfect for this device, to control the locking ring. This is a existing motor, which should be "plug and play" product. [1]. Of course this is not 100% sure, but it is a calculated guess.

2.3 Spring system

Since the lock, like the solenoids, needs to retract when the power is gone, is therefore equipt with a spring system. This spring system will retract the lock, and slide the lock back to "open" position.

The spring has to be strong enough to pull the lock-ring back to neutral. This shall be doable with a quite low force.

3 Further on

The next steps for this solution is to calculate the different forces that is needed to make this a reality. The main points should be:

1. Force to turn the locking ring, for the motor
2. Force needed to turn the locking ring back to neutral, when the power is off.
3. Force on the ring itself

This needs to be calculated, to check if this solution is viable.

4 Conclusion

There is not possible to conclude for sure about this solution, before someone has calculated the missing forces. But as a calculated guess, EGA believes that this is a viable solution.

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Subsystem:Material report

EGA

May 21, 2018

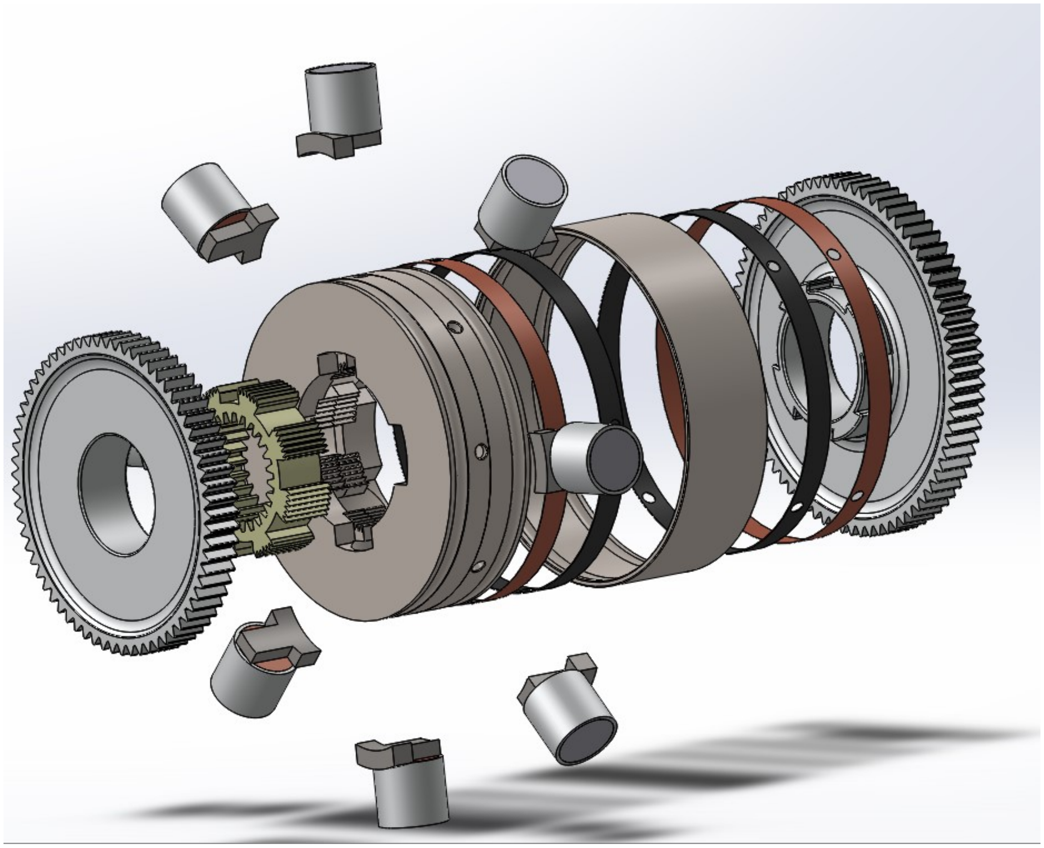

Figure 1: Actuator

General

Subtitle : Analysis of material requirements in construction

Educational Institute : Høyskolen i sørørst Norge

Address : Hasbergs vei 36, 3616 Kongsberg

Tutor : Henning Gundersen

Contractor : Kongsberg Automotive

Address : Dyrmyrgata 48, 3611 Kongsberg

Contact Persons : Kristian Ahlberg & Steffen Johnsen

EGA

Abstract

In this report, the selection of materials are to be means-tested against functionality of the construction.

Factors of material characteristics that are being evaluated in this report are:

- Strength
- Resistance against corrosion
- Resistance against fatigue
- Surface treatment
- Elasticity
- Manufacturing

The construction are divided into segments and the report evaluates the characteristics of each segment separately.

A composed evaluation of the construction as a unit follows as an ending of this report.

Contents

List of Figures

List of Tables

1 Introduction

The main goal of the material analysis is to ensure a sustainable, robust and safe construction and that requirements derived from contractor, user and production team are met with highest possible satisfaction.
In a exciting and constant forward moving market, there are multiple various manufacturing possibilities. Widely used production methods are Forging and casting, while new methods are entering the market such as composite and 3D printing. These are considered highly reliable with a wider range of accommodating complex geometry in products. The possibilities of these production methods will be evaluated against production time, material character benefits and cost.

1.1 Composite

A introduction to characteristics of composite

In many products, certain qualities and characteristics are needed to ensure a safe construction. Typical products like vehicles and tall buildings have need of tough materials to carry much weight. Basically the vulnerable parts of the products are constructed to withstand the stress. Here the entire current product is manufactured with homogeneous characteristics to withstand such stress and this production methods makes for a higher cost. Although only certain areas of this product will have the benefits from this enhancement, and other areas of the same product can sometimes work against itself and generate even higher stress on the product. This should be avoided whenever possible. Analogy it is easy to imagine a H-Beam of carbon steel. Only the periphery areas of the product is exposed for stress and it is easy to see the beam has been manufactured accordingly.

In complex geometric constructions, it is difficult and sometimes impossible to ensure good material characteristics in only these affected areas when using traditional production methods. And that is where composite is generating many advantages and allows for very good material characteristics throughout the product with high precision. Composite is a heterogeneous characteristic adhesive manufacturing method and are build by layers with different materials that accommodate the specific need in every area of the construction. Typical benefits in composite is high an-isotropic strength with very low weight. Generally 1/8 of stainless steel. High resistance against wear. This characters are dependent of production methods and quality.

Disadvantages in composite is the complex production. It is time consuming and difficult to ensure the quality on the end product. Sometimes adhesive failure can expose the product for unforeseen collapse. The quality of the product is not only based on the materials in use, but also the skill of the operators in the production.[2, p. 25]

1.2 3D-Printing of metals

Metal 3D-print is the newest cutting edge technology in manufacturing methods, and it is a rapid growing utilization of 3D print in the industry. The benefits from 3D print instead of ordinary manufacturing methods is many, but the consistent benefit is clear. Cost.

With 3D print methods, it is possible to produce intricate geometry that can accommodate high demands in material characteristics such as low weight in conjunction with high strength. And this can be custom manufactured without the time consuming, and expensive process it is to shape parts from a piece of metal.

In terms, 3D printing is not as new as one should think. The first ever 3D printer was created by Chuck Hull in 1983. The company "3D systems" where created and the 3D printer adventure had begun.[3] There has been a slow and certain development of the technology since.

One of the main reasons for the now rapid growth in 3D printing market is the expiring of patents on the 3D print technology. The technology has been expensive and unavailable since the end of last century, but after expiration of key-technology patents, the market has been experiencing rapid expansion and prices ten times cheaper. An example is the Fused Deposit Modeling (FDM) which are a polymeric additive method, are widely used today. This patent was expired in 2009[4] which allowed for cheaper and better machines in commercial use.

Other printing methods, that is generating metal based parts, are the Liquid-based stereolithography (SLA) and Selective Laser Sintering (SLS).[4]. Both uses lasers to create metal desktops and parts. Also this patent has expired, in 2014. Which was the same year a metal 3D printed part was used in a jet fighter for the first time. According to BAE Systems, that delivered the parts, the savings was more than 300.000 pounds.[5]
Two years later, 3D printed metal parts are widely used in custom made applications, for instance in the SpaceX shuttle. Even though this is still a expensive manufacturing method, there are big expectations of 3D printing as a commercial manufacturing method in the decade to come.

2 Manufacturing segments

Every segment will be evaluated separately and treated as a product in it self. This will produce different benefits, risk criteria and needs in characteristics. This will be evaluated in the summary and a fictional assembly will derive the final prerequisites and limitations on what and how the product is to be manufactured.

2.1 HUB

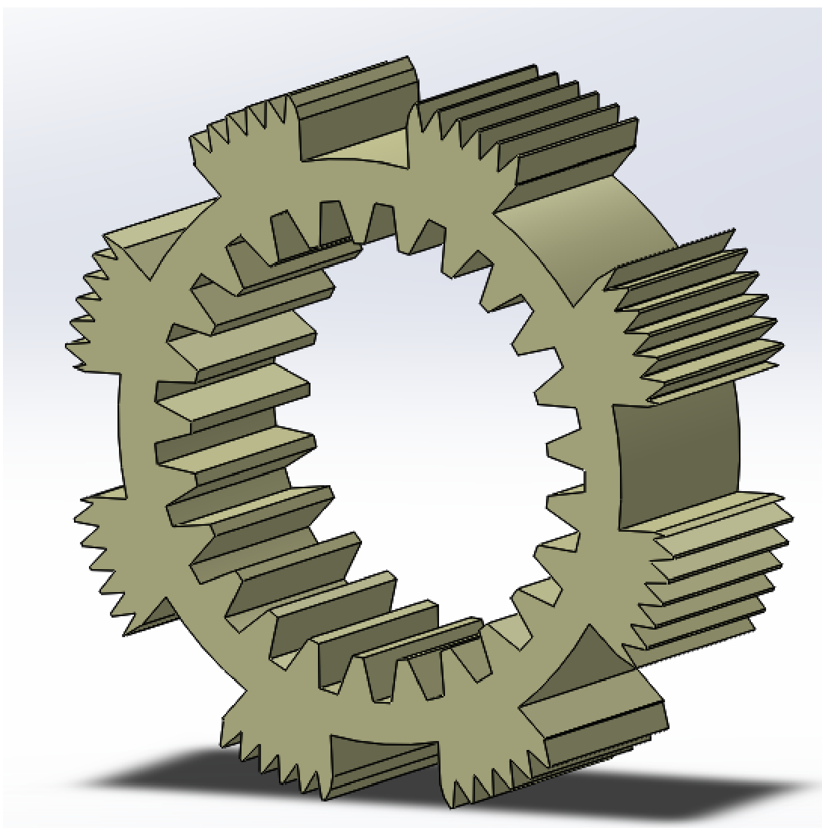

Figure 2: HUB

2.1.1 Analysis of operation

The Hub will take the entire radial load from the engine and convert to the axle. This exerts high stress to the mounting points between axle and hub, and between hub and solenoid house. The force exerted will be highest the closer to the pivot point of the axle, and lower closer to the periphery due to torque stress (See calculations). This means that the highest exerted torque stress is between the hub and the axle and this has been accounted for by use of robust gear engagement mounting shown in figure 2.
The tangential stress on the teeth will exert shear force divided by the combined area of engagement. The risk of elongation in this area is of no concern as long as it is not surpassing safety range of yield strength on that particular material.

2.1.2 Strength

There are no particular areas in the construction that stands out with need of particularly higher strength that varies from the rest of the Hub. Although, some areas are more exposed to failure. One area with risk of failure is the notch point shown in figure 3 shear stress will be concentrated in this area. Adjustments in geometry should be made to minimize the effect of the notch and so avoid risk of tear. If use of composite could be made, there could be enhanced strength in this area to avoid that certain risk by building layers with an-isotropic tensile strength in optimal orientation.

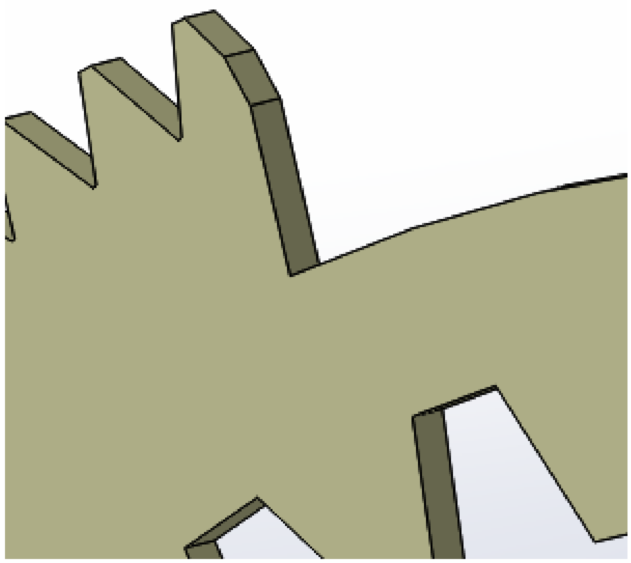

Figure 3: Notch

Calculations and CAD simulations will be used to determine highest stress on the Hub and where. This will be used when deciding material.

2.1.3 Corrosion resistance

By looking on the operation of the Hub, there should not be a high risk of corrosion due to the closed area of operation in the gear box. We should consider the risk of galvanic corrosion since the area of operation is in a closed container with a viscous liquid containing carbon-steel residues. This liquid could work as a electrolyte and then there is a risk of galvanized corrosion between materials with a high variation of electrode potential.

2.1.4 Fatigue resistance

Fatigue from repeated cycles are a common source of failure in materials and should always be accounted for. A cycle number above 1000 is generally considered dynamic[1, P. 446] and exerts risk of fatigue. The product shall undergo 2.5M cycles. Stress cycles on the Hub should therefore certainly

be exerting risk of fatigue in the materials and this must be considered and accommodated accordingly. During acceleration and engine controlled deceleration, stress is exerted from different orientation and generates an alternating load. This happens with a high number of cycles and will generate risk of failure due too fatigue. This must be considered in conjunction with the risk of tear or cavities by corrosion, abrasion or impact damage to the Hub. If there is a possibility for this to occur then there is a higher risk of fatigue. See 2.1.4 and 2.1.5
With use of Wöhler diagram for steel and results from calculations, it is possible to asses the risk of fatigue.

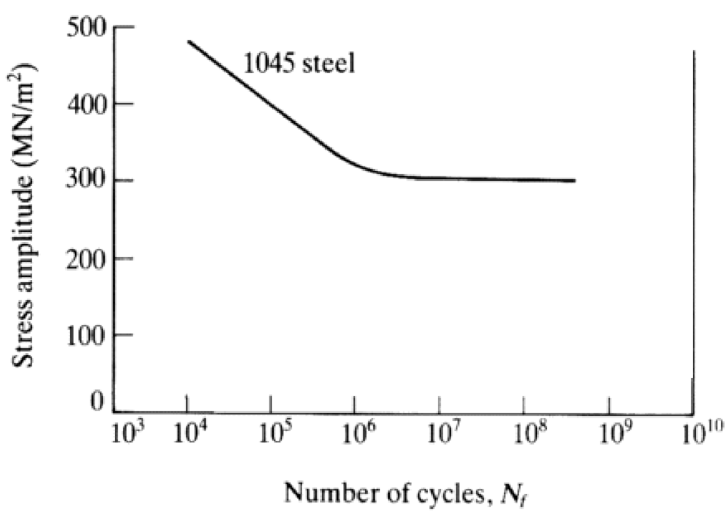

Table 1: Fatigue diagram

Calculated max stress in the Hub is 123 Mpa (14) so there can be assumed that the risk of fatigue is below the fatigue line.

With low variation in temperature, minus 40 degrees Celsius to 120 degrees Celsius, and temperature changes less than 1 degree/sec. there are no risk of thermal fatigue. The temperature span is far below 0.3 percent of the melting point of any material we are to use, and far above glass transition temperature. This will not be conducted further in this report

2.1.5 Surface treatment

Parts will be intersected and have a static relationship at all time so no sudden impacts or abrasive damage should generate shear and cavities. Tolerances should not deviate and low cross sectional areas in some of the geometry could be in risk of plastic deformation after continuous use. Hardened surface should be considered in vulnerable areas. Heat treatment to employ martensitic characteristics on teeth can be considered. Surface hardness must be in conjunction with fatigue risk.

2.1.6 Elasticity

Elasticity in the material can help absorb peaks in stress peaks in sudden high stress situations such as clutch activation malfunction where the clutch suddenly activates, or where spinning tires suddenly get traction which often happens in vehicles with traction control. These scenarios will exert higher than normal stress on the Hub. Allowing high resilience modulus in the material will also allow for absorption of some of that stress, much like a spring. Low elastic modulus in the material would be preferable in this concern. However, lower E-module is often in conjunction with lower strength in the material.

2.1.7 Conclusion

The Hub have an relatively easy to manufacture geometry, which could be manufactured by standard methods like Forging, casting or sintering and machining. There is not much to gain by an-isotropic behavior in the part which also point towards standard manufacturing methods. High stress must be accommodated. Also because of the tolerance restrictions on the geometry, there should be high creep strength in the material. The total mass of the Hub will not generate much gain by using light weight material, which would ensure either higher expenses or less strength or both.

2.1.8 Manufacturing

Hot forging a austenitic stein-less carbon-steel alloy is by conclusion a good method to manufacture the Hub. Cold forging would be preferable, but is difficult because of the geometry. Therefor heat treatment is needed to increases toughness to exposed areas, such as the section with small teeth.

Carburizing would ensure good elasticity in the core, and also enable the effect from heat treatment. The carburizing generates increase in volume and also exerts residual stress in the surface, that help withstand fatigue. Finishing machining is needed to accommodate low surface tolerance.

2.2 Solenoid housing

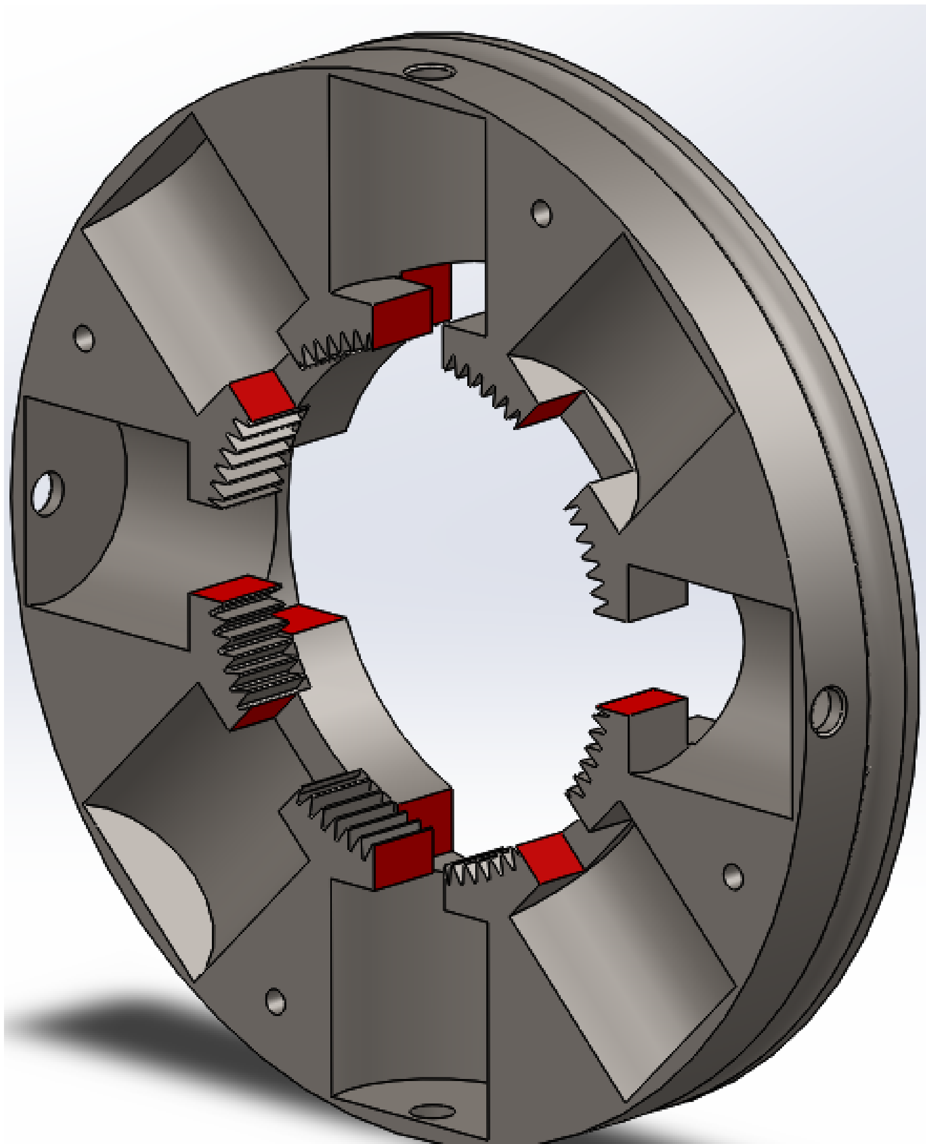

Figure 4: Solenoid Housing

2.2.1 Analysis of operation

The Solenoid house shall transfer torque from the gear to the Hub via intersecting teeth. Areas of operation that transfers torque from gear to Solenoid housing are marked with red in fig.4. Area of operation that transfers torque from Solenoid housing to Hub, are teeth shown in fig.4. High tension are expected in these areas. Also there will be dynamic forces relative to the housing that works in a concentric fashion. This will have a direct relation to the torque forces acting on the marked areas and creating friction. An electrical interface will be acting on the periphery and supply the solenoids with power and signals.

2.2.2 Strength

It is easy to understand that there will be concentrated areas of high stress, and areas with low stress in the construction. The variation in stress between these areas are considerable and should be exploited if possible. Solution could be to choose a different manufacturing/assembly method and separate the critical "red" radial area from the house as a unit into two separate parts, and then attach them after manufacturing with welding or bolts/screws. That would allow easy difference in characteristic between high stress and low stress areas without complex manufacturing.
There will be exerted great stress on the area marked red which generate risk of deformation and creep due too long duration of applied stress. Lateral geometry will accommodate for this to decrease the risk of malfunction or breakdown. There are four separate teeth that activate transmission and whereas one tooth experience creep, the next tooth will take a greater proportion of the load, thus relive the previous tooth from overload. This means that, while the product is still new, only one or maybe two will be activated during operation and handle the entire torque load. But after some time, all four teeth will be active at the same time.

2.2.3 Corrosion resistance

Just as with the Hub, there will not be high risk of corrosion due to enclosed area of operation. Risk of galvanic corrosion must be considered. Especially on the Hub where there are surfaces that act as interface for voltage supply. Slip rings of brass are mounted on the periphery of the housing. If use of stainless steel is used on the housing, the variation in electron charge in brass and stainless steel can become more than 0.2 and could generate galvanic corrosion, the brass must should be separated from the housing with ceramic based materials to avoid any risk of corrosion.

2.2.4 Fatigue resistance

In the Solenoid house, there are few moving parts. The house basically spinning around its pivot point. Stress affected areas are red marked areas and teeth in fig.4. The solenoid tooth shall maneuver in the red areas and will generate abrasion wear at each cycle of activation and deactivation. These areas will experience high shear stress for up too cycles = 2.5M. This generate risk of cavities in the surface, and with a high number of cycles with high stress the risk of fatigue is substantial.

2.2.5 Surface treatment

From section 2.2.1 and 2.2.4, the prejudice is fracture in the surface and malfunction of the product if this is not taken into account. Since, from the calculation (7), the max stress in the house is 208.32 Mpa, it can be assumed that surface finish from machining is within tolerance limit. (see table 1: surface/hardness in section 2.3.4)

2.2.6 Conclusion

The Solenoid house have high complex geometry which generates difficult manufacturing. Even composite methods are difficult for this geometry. There is need for high yield strength in some minor areas, while the main body is not affected by such characteristic requirements. 3D print of this part would be the most efficient manufacture method, but that depends on the how much 3D printing technology is further developed for commercial use. As by now this is to expensive for a mas-production part.

2.2.7 Manufacturing

The inner circle that experience significant stress should be manufactured separately and the main body should be cast. Inner circle can be shrink welded to the main body or attached by bolts. This would generate need for a less complex mould and also to manufacture the to parts in two different materials. From the analysis of operation, there can be found no substantial stress exerted on the body and could therefore be produced in a light metal with low yield strength such as aluminium. Inner circle must be manufactured in stainless steel with yield strength from 210 Mpa. Manufacturing method machining.

2.3 Engagement tooth

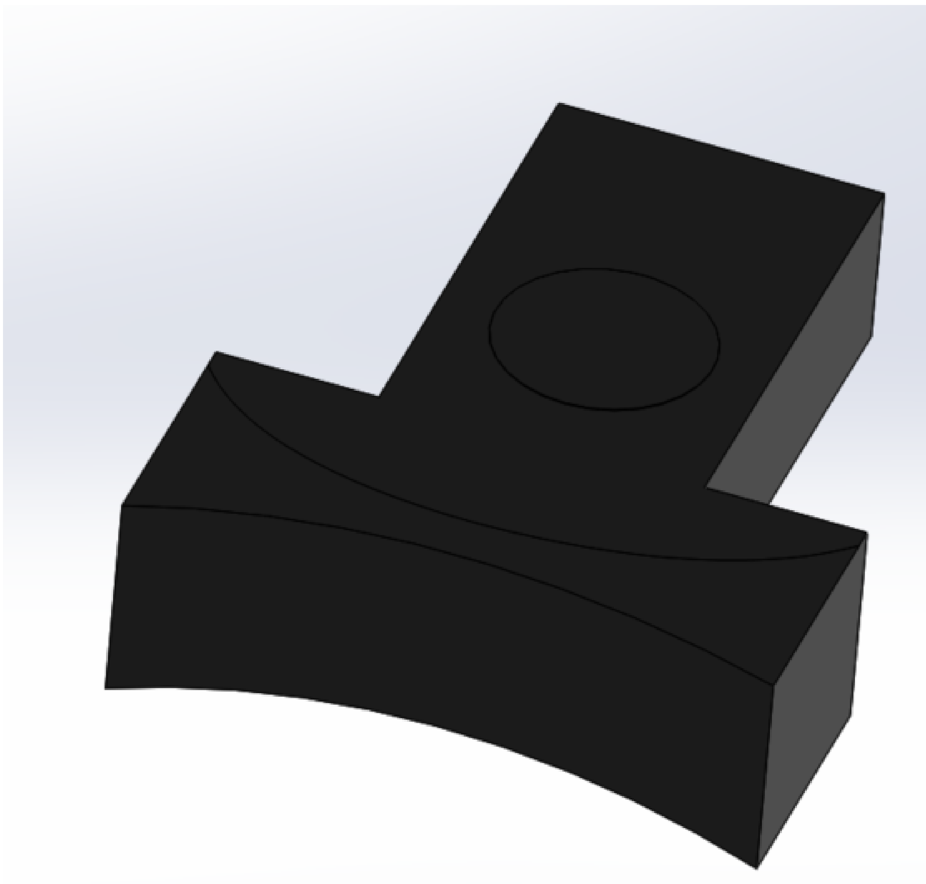

Figure 5: Solenoid Housing

2.3.1 Analysis of operation

Engagement tooth moves from neutral position to active position in 6.3 mSec. Maximum stress on teeth are 277.78 Mpa and are the area with highest stress that is being exerted in the product. During normal operation situations, gears will be deactivated with clutch while tooth engagement occurs, and re-activated to yield a linear stress increase on the tooth. This will reduce abrasive wear on the tooth surface and avoid rapid changes in stress in the material. Although some scenarios can occur that can create risk that the material suffers high abrasive wear and rapid changes in stress.

2.3.2 Strength

The engagement area of operation between the tooth and the gear are experiencing high stress and are a area with high risk of failure. The maximum stress is 277.78 Mpa which already is at the yield strength limit of many construction materials. On the account of fatigue, if the risk of surface wear is high, there should be implemented a safety factor of 3 on the tooth material, which gives a yield strength requirement of 833.34 Mpa on the material. This is above ultimate tensile strength on most industrial materials. Area of engagement should be considered enlarged and surface finish should accommodate a safety factor of 2 to lower the immense stress on the tooth.

2.3.3 Fatigue resistance

Cycles up to 2.5M, risk of abrasive wear combined with high stress is the most important factors for fatigue fracture. This must be accounted for. The max shear stress in the engagement tooth is 277.78 Mpa. This will generate a risk of fatigue.

2.3.4 Surface treatment

From table 2 it is possible to read the necessary surface treatment to accommodate risk of fatigue.
Surface finish factor needs to be between 0.7 - 0.8 with the stress of 277.78 Mpa

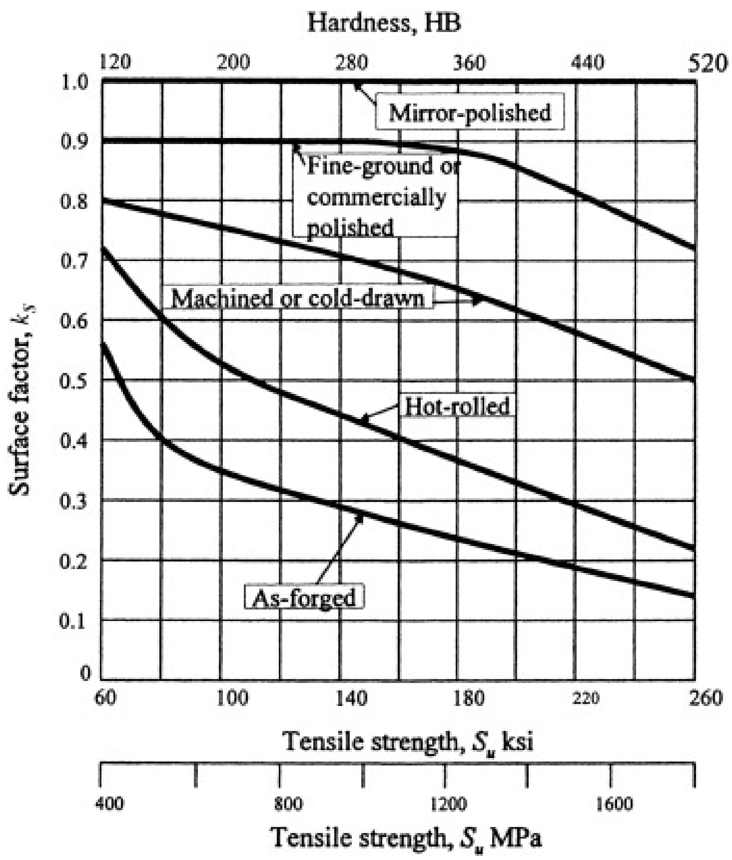

Table 2: Surface/Hardness

Surface hardening must be considered to maintain permissible load over the duration of 10 years.

2.3.5 Elasticity

In the engagement tooth, there are requirements to maintain a constant geometry at all times during operation. This will assert needs for high E-module in the tooth material. Hard/low ductile materials must be used to ensure this.

2.3.6 Conclusion

The complexity of the tooth geometry is low and the exerted stress is high. This would conclude with a high carbon steel-alloy. But there are possible to consider composite on the part, due to the low complexity. This would benefit the need for a surface that are strong against deformation and abrasive wear. Directions of composite layers can be oriented to withstand the shear stress in the tooth. The tooth would then have low weight that only benefits the intended dynamic operation. This will exclude any risk of corrosion

2.3.7 Manufacturing

Polymer matrix composite (POC) with carbon fibre. Orientation shall withstand shear stress and abrasion wear in contact areas against gear. Mounting to plunger with steel cover to enhance adhesion between layers in the composite.

3 Bearings

3.1 Introduction

Concept magnetic actuator relay on a static platform as an interface between the rotating solenoids and the electrical and digital in and outputs. This requires a mounting between a static and a dynamic part which must be solved. A typical solution are bearings, which are the first logical solution that we are looking into. To ensure bearings as a good solution, then we must look at some different aspects of how this solution will be operable in the concept.

3.2 Characteristics on bearings

Following situations must be considered:

1. What are the tension force that the bearings undergo?

2. What are the tension coordination? What are decomposed tension in the X-Y plane?
3. What un-expected tensions must be considered? (impulse stress, torsion, vibration, temperature)
4. Pre-fabricated or customize?
   (a) What is optimal size of the ball element and ring element?
   (b) What type of bearing are optimal for 100<RPM<2500
   (c) Are ball bearing or roller bearing optimal?
5. What consideration are needed concerning material.
6. Will the bearings be in a closed system or an open system?

3.2.1 Stress analyze

After analyzing the functionality of the bearings in the concept, it is easy to conclude that there are no noteworthy tensions acting on the bearings. This means that we can conclude that the bearings have only one functionality, and that is to ensure a seamless interface between the rotating solenoids and the mounting house and no tensions are to be considered. This does not conclude that there will be no tension acting on the bearings at all, and we must make sure to take every precaution, so the bearings can withstand 10 years in service.

3.2.2 Unexpected exerted stress

Un-intentional impact of tension can arise from multiple various situation and come in many different forms.

1. Vibration from:
   - Low RPM on Engine
   - Uneven terrain
     (a) Impacts

- (a) Parallel displacement between drive shaft and bearing
- (b) Tension on bearing

2. Impulse stresses from:
   - Hard object impact with drive shaft
   - Emergency breaking
   - Rough terrain
   - Tear of drive shaft.

   (a) Impacts
   - (a) displacement of bearing
   - (b) Parallel displacement between drive shaft and bearing
   - (c) Tension on bearing

3. Torsion from:
   - Eccentric dislocations in the hub
   - Moment of gear activation

   (a) Impacts
   - (a) Excessive wear of the bearing

4. Temperature from:
   - Friction
   - Poor lubrication
   - Surrounding elements

   (a) Impacts
   - (a) Malfunction of the bearing (overheating)
   - (b) Increased friction (higher energy consumption/rev)

3.2.3 Bearing type

If there are shelf items that fits the description of the bearing that is needed, then that is the absolute optimal choice. There are a huge variety of bearings with different characteristics so if there are is an option to customize the concept to accommodate a "shelf item bearing", then that would be strongly beneficial. Since there are proximately no tension acting on the bearings, then the variety of available bearing types increases significantly. If EGA needs to produce customized bearings, then the production costs will increase severely.

1. One of the characteristics of the bearings are the physical size which are being determined solely on the outer diameter, the bore diameter and the width. On this aspect there are possibilities to manipulate the bearings to fit to a "shelf item" quite a bit.

   The possible diameters to choose from are:

   - Outer diameter min: 121mm max: 180 mm
   - Bore diameter min: 116 mm max: 175 mm
   - Width min: 5 mm max: 15mm

2. Many bearings have a high tolerance for high speed revolution and are produced almost mainly for that purpose. When the average top revolution speed on the drive shaft on a commercial heavy-duty vehicle is 2500 RPM, there are no need for this beneficial characteristic and therefore are save cost by actively avoid bearing produced to accommodate high RPM. Bearing characteristic should be 100 <RPM <2500, while not assuming safety factor.

3. Difference between roller bearing and ball bearing are mainly contact area and ability to withstand pressure. Roller bearing have a bigger area of contact and therefore a more suitable bearing for high tension. Since there are almost no tension on this bearing there are only a mater of price to consider between roller and ball bearing.

4 Calculations

Torque forces that exerts stress on construction are sett to 2625Nm.
Critical areas that need to be calculated are the intersections between:

- Tooth and gear
- Tooth and Solenoid house
- Hub and Solenoid house
- Hub and axle

4.1 Engagement tooth/Gear

Radius tooth engaged 1: r1 = 35,0mm
Radius tooth engaged 2: r2 = 45,0mm

Force r1

$$F_1 = \frac{2625Nm}{0.035mm} = 75KN \tag{1}$$

$$F_2 = \frac{2625Nm}{0.045mm} = 58.333KN \tag{2}$$

Median Force on tooth:

$$F_{median} = \frac{75KN + 58.333KN}{2} = 66.6KN \tag{3}$$

Area of engagement tooth

$$H = 5mm \qquad L = 12mm \qquad A = 60mm^2 \tag{4}$$

Stress on engaged tooth

$$\sigma_{tooth/gear} = \frac{66.6KN}{60mm^2} = 1111.11Mpa \tag{5}$$

Four engagement teeth gives 1111.11Mpa/4 = 277.78Mpa.
With a safety factor of 3 gives a yield strength requirement of 833.34 Mpa

4.2 Engagement tooth/Solenoid house

Force is same since radius from axle is the same.
F = 66.6KN
Area of tooth/house engagement:

$$A = (5mm \cdot 12mm) + (7.82mm \cdot 23mm) = 239.86mm^2 \tag{6}$$

$$\sigma_{tooth/house} = \frac{66.6KN}{239.86mm^2} = 277.78Mpa \tag{7}$$

Four teeth gives stress on teeth/house = 69.44Mpa.
With a safety factor of 3 gives a yield strength requirement of 208.32 Mpa

4.3 Hub/Solenoid House

Applied torque from equation 1 give F = 75Kn
Area of Hub/house engagement:

$$83.67mm^2 \cdot 48 = 4016,16mm^2 \tag{8}$$

$$\sigma_{Hub/house} = \frac{75KN}{4016,16mm^2} = 18.67Mpa \tag{9}$$

With a safety factor of 2 gives a yield strength requirement of 37,34

4.4 Hub/Axle

Radius of Hub engagement 1: r1 = 30 mm
Radius of Hub engagement 2: r2 = 25 mm

Applied torque force:

$$F_1 = \frac{2625Nm}{0.030mm} = 87.5KN \tag{10}$$

$$F_2 = \frac{2625Nm}{0.025mm} = 105KN \tag{11}$$

Median force on Hub

$$F_{median} = \frac{87.5KN + 105KN}{2} = 96.25KN \tag{12}$$

Area of engagement:

$$A = 62.6mm^2 \cdot 25 = 1565mm^2 \tag{13}$$

$$\sigma \frac{96.25KN}{1565mm^2} = 61.5Mpa \tag{14}$$

With a safety factor of 2 gives a yield strength requirement of 123 Mpa.

5 Summary

From the complexity of the product, there cant be used pre-fabricated parts and this will drive the cost of the product. The entire product must be custom made part by part and assembled. Some parts such as the bracket to mount the actuator to the gearbox can be manufactured cheap, while other parts need more complex manufacture methods to accommodate the need of higher performance. The chosen assembly methods are mainly bolts. Materials that have been considered to accommodate a viable product is carbon-steel alloys, aluminium, ceramics and carbon fibre based polymer matrix composite. Although, aluminium can generate problems with corrosion from lack of oxygen in the enclosed area of the gearbox. This has not been considered further in this report. Galvanic corrosion have been considered and accounted for. Every part experience different stress relations and this have been evaluated so that it has been ensured possibilities to manufacture each part and that it can function without malfunction.

6 Conclusion

Further testing and analyzing is needed to complete the material report, but there is a fundamental analysis of each segment, to which different needs and requirements can be derived.

The possibilities of future manufacturing methods have been evaluated in the interest of both the contractor and author. Parts that are considered to be too complex today, can very well be easily produced in only a few years with a relatively low cost.

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Proof of Concept

EGA

May 21, 2018

Abstract

The purpose of this report is to shed light on why and how a proof of concept has been built. And to look at the different subsystems and how well they confirm the theoretical assumptions about the concept.

Contents

List of Figures

1 Introduction

This is a proof of concept report for the electrical gear actuator, which is developed for Kongsberg Automotive. The proof of concept shall demonstrate how the movement of the Electromagnet concept will be. With the help of this prototype, it will be possible to see if this concept is feasible. Kongsberg Automotive also requires a proof of concept in theirs assignment.

1.1 PoC

PoC is a Proof of Concept, which is something similar to a prototype. The difference from a PoC and a prototype, is the detail level. A prototype is almost developed, but the PoC on the other hand just needs to display something of the idea. In this case, it just needs to display the movement of the electrical gear actuator concept; Electromagnet.

Whenever a new item is developed, one of the most important step in a development is to create a PoC. With the help of a PoC it is possible to see if parts of the concept or the concept as a unit is feasible. In this specific case, the PoC is developed to see if the movement and force is good enough to determine if the concept is viable.

2 Description

The proof of concept is made to display how the movement of one gear tooth will play out in practice. An arduino will control a solenoid push/pull by sending a signal to a MOSFET-transistor, which in this setup, acts as a switch to ”turn on” the solenoids 12V power source. When switched on the solenoid will generate a electromagnetic field that will pull one side of the the plunger into the hollow section of the coil. The other part of the plunger has no magnetic properties and will then be pushed out in the same direction. On backside of the plunger, there will be a spring which is connected to the backside of the solenoid. The task for the spring is to retract the plunger, both in case of emergency, power loss, or simply a normal gear change operation.

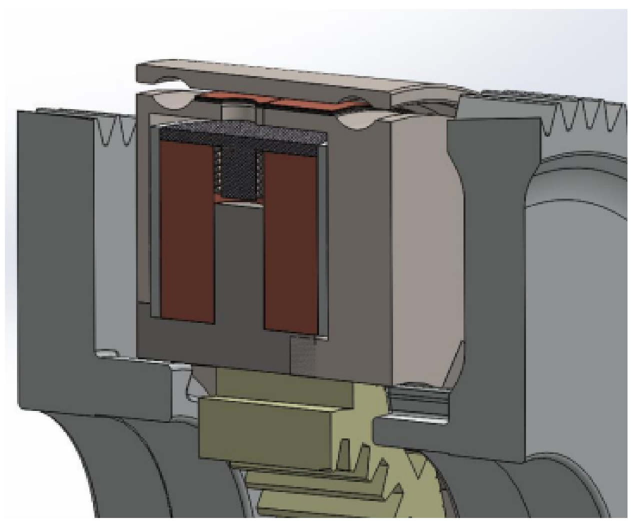

Figure 1: 3D model of the solenoid in system view

When the plunger is pushed to the centre of the inner circle, this will simulate a gear tooth being pushed into gear. The main task in the PoC is the movement of the plunger, or the actuation if you will.

3 Circuit

The circuit is constructed with Orcad Capture CIS software [3] and the wiring schematic is made with the free software Fritzing [2]. Electrical components are bought from Elfa Distrelec Norway [6]

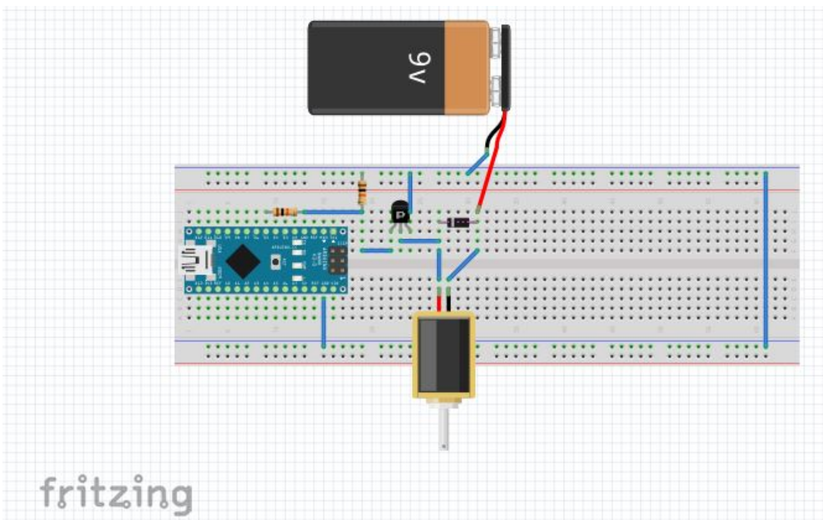

Figure 2: Wiring schematic via Fritzing

As it can be seen in the wiring schematic, the main controller in the circuit is a micro-controller called Arduino. The Arduino in question is a nano [1], which is the smallest type, but since this project requires few digital outputs to power the 1-4 switches and some sensors, a larger and more extensive micro-controller is not needed. The solenoid in question is larger then the Arduino can handle, and therefore it is required to power it with an external power source. It is however still necessary to control the activation of the solenoid with a micro-controller, and thus some sort of switching circuit is needed.

As a switch between the external power source, an N-channel MOSFET can be used [10]. MOSFETs are easy to operate with the Arduino, because they switch on with positive voltage on the gate. To expand on the reason as of why two power sources is needed, it is because of the Arduino can just deliver 5V or 3.3V and only a small amount of current in the range of 5-40mA to the solenoid. With an external power source it is possible to use more powerful solenoids, which this concept requires. This will also be doable in reality, where the system can not only utilize the normal 12, 24 or 48V battery of the vehicles of today, but also the large battery packs fully electric vehicles will use in the future.

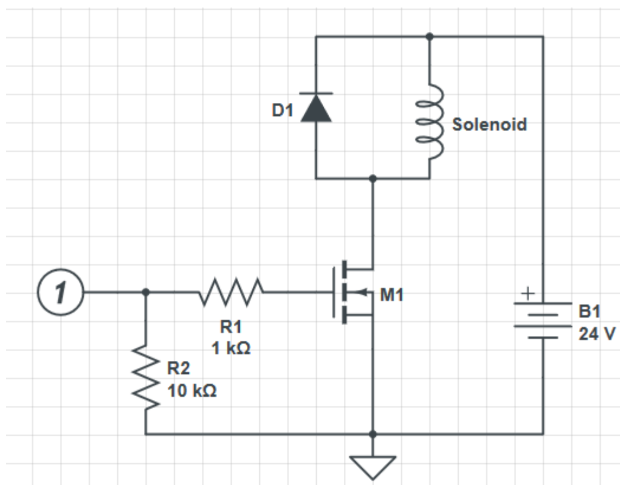

Figure 3: Circuit overview

In figure 3, it is possible to see what components are necessary to drive one solenoid with the setup that is described above. Note: The logic 1 in the figure represents the digital signal from the Arduino.

3.1 Required components: FET switching circuit

- D1: ”Flyback diode” [7]
  A diode is required in parallel with the solenoid, or in general terms any inductive load. The reason for this is that when you power off an inductive load, there is created a large reverse voltage while the electromagnetic field collapses. So to protect the transistor, and also the Arduino.

- R1: ”Gate resistor” [5]
  A gate resistor is a normal resistor connected to the gate of the MOSFET-transistor. This has several purposes. In normal applications it can relate to the switching times of the MOSFET, but since this is a PoC to show the movement, the milliseconds related to switch on/off times is negligible. However it will be placed there for safety as there should be a capacitance between the gate and the drain. And in case of worst case scenarios there could be higher voltage on the gate then what the MOSFET can handle.

- R2: ”Pull-down resistor” [9]
  A pull-down resistor is commonly used in switching circuits, where the switch is controlled by a low voltage micro-controller or other forms of digital signals. Occasionally a signal can be in a floating state, meaning that it can hover around 0 or 1 (0 or 5V in this case). In this case the signal is undefined and small amounts of current or voltage from other sources can for example switch the MOSFET on. When a pull-down resistor is placed towards ground you ensure that if the signal ”hovers” or floats, it is ”pulled down” towards 0.

- M1: ”N-channel MOSFET” [8]
  The main component in the switching circuit, a type field effect transistor which can be controlled by supplying a voltage to the gate of the device changes the conductivity between the source and drain terminals. In this setup we will control the gate with a digital signal from the Arduino nano.

4 Construction and assembly

This is a overview over all of the different parts the system is consisting of and how they are all put together. Data-sheets is available for all the electrical components in the referenced links.

The PoC is assembled by different parts that where needed to ensure that the PoC did its intended job. Segments that where needed:

1. Materials
   Ensure a viable PoC with low cost and high usefulness.
2. Sensors
   Needed to ensure movement of the solenoid.
3. Solenoid Housing
   This is for holding everything in place.
4. Solenoid Capsule
   Mounting bracket for a small solenoid.
5. Slip ring
   The slip ring is for power transfer, when the PoC is rotating.
6. Solenoid
   The Solenoid is for the push / pull movement that is needed to activate the gear.
7. Plunger /w Teeth
   The tooth is conected to the plunger, and is therefore moving in and out of gear.
8. Hub
   The Hub is needed so it can be connected to the axle.
9. Gears
   Gears is needed so it can simulate one gear in a transmission.

4.1 Materials

While creating a PoC is essential for the success of a concept, there is no need for accommodate structurally requirements. This will make it possible to create a PoC that is relatively cheap compared to an actual prototype.
Cheap materials such as plastic and plywood has been widely used to create the PoC with the help from precise manufacturing tools like 3D-printers and laser cutting. The construction consists of a makeshift axle in aluminum, gears cut from plywood and the main concept body printed in polymer. The casing is also cut from plywood. Inside the concept body is the solenoid, an electromagnetic component that shall serve as proof on the actuation of the concept. The solenoid where placed in a plastic capsule shaped like the original solenoid. This allowed to use the original sized Solenoid housing with the PoC intended solenoid. The PoC solenoid is explained in Section 4.6

4.2 Sensors

4.3 Solenoid Housing

The Solenoid housing has high complex geometry so 3D print where best solution on this part. In the PoC, the House has been split in two parts to enable the assembly of the solenoid. Each part needed approximately 18 hours to print.

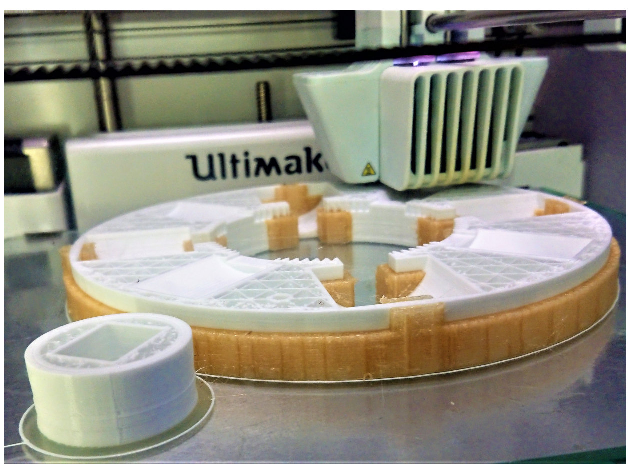

Figure 4: 3D-Print Solenoid Housing and Solenoid capsule

4.4 Solenoid Capsule

Since the PoC is manufactured in 1:1 size of the actual product, minor customization's where needed. The solenoid in the PoC has 1/30 of the power of the original solenoid and is by that smaller in size. A capsule where designed and 3D printed as a mounting for the PoC solenoid to fit the intended space for the original. Minor adjustment where also made to the PoC solenoid casing.

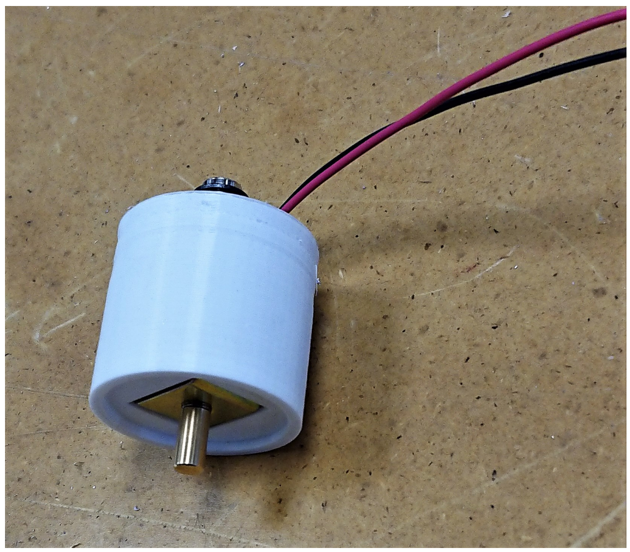

Figure 5: Solenoid capsule

4.5 Slip rings

4.6 Solenoid

The solenoid plunger is bought from AdaFruit [4], and has the following dimensions. This plunger is a 12V solenoid, which draws 250mA and deliver 5N from the start. From start will say at 0mm, then the force will reduce as the plunger moves from the center. The plunger have a "throw" on 5.5mm. A "throw" will say that the plunger has the ability to move a certain distance from center.

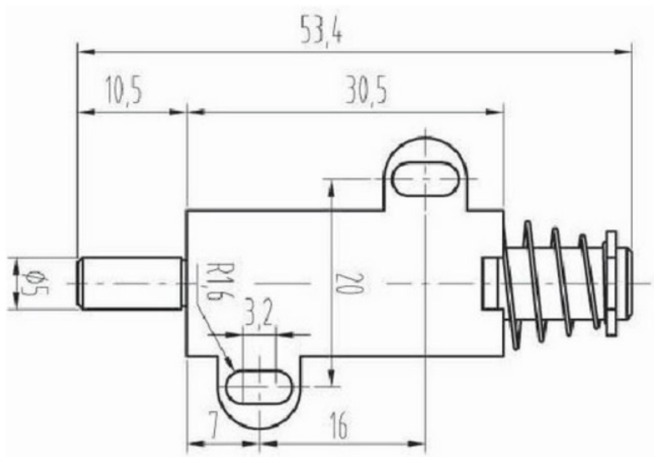

Figure 6: Solenoid plunger - dimensions

This is a standard push/pull solenoid and will be adequate for this PoC, since most of the used materials are general 3D-printer plastic filament. The weight of this filament are almost negligible, when compared with the strength of the solenoid.

4.7 Plunger /w Teeth

This was 3D printed and then a hole was drilled trough to fit to the solenoid. Some careful grinding had to be done to make the tooth fit to the indent in the Housing.

4.8 Hub

The Hub is the mounting between the Solenoid House and the axle. High concentric precision is needed. It is therefore cut from plywood with a high precision laser and assembled with the gears, see Gears.

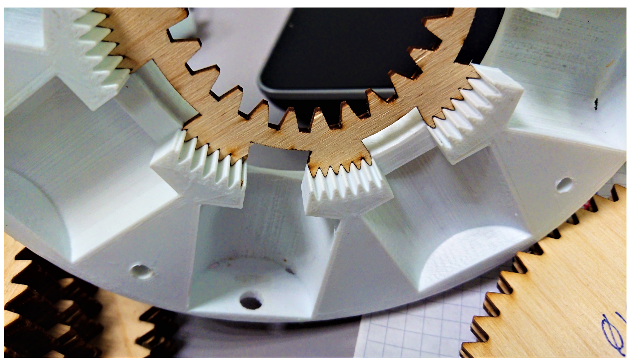

Figure 7: Hub mounted to House. Laser cut detail view.

4.9 Gears

Gears where produced with layers of 3mm plywood, cut with a high precision laser and layered adhesive mounting. All drawings for laser program where produced in CAD program.

Figure 8: Laser

4.10 System

In figure 9 the concept can be seen as a system. Here it is possible to see

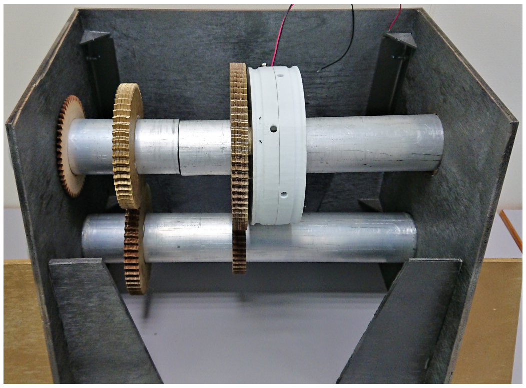

Figure 9: Picture of PoC

how the concept will look inside the transmission, and this helps the project team to see how the actuation movement will look like.

5 Conclusion

From the PoC, the project team can concluded that the movement is feasible. To see if this concept should be developed to prototype and construction stage, further research and testing is needed. Many subsystem requirements has been left out in the PoC, which will be essential factors in this decision.

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FMEA Report

EGA

May 21, 2018

Abstract

This is documentation about how a FMEA (Failure Mode and Effect Analysis) works, and how the project group have prioritized this over a standard risk analysis.

Contents

1 Introduction

Instead of using a regular Risk analysis, the EGA group have decided to use a FMEA. The difference between a FMEA and a risk analysis is that a FMEA is much more comprehensive. Instead of just having probability and severity, which is the norm in a risk analysis, it also have mentions the outcome of the different risks.

Even though the FMEA is more work, than a traditional risk analysis, EGA think that the extra work is worth it. With this FMEA, the project team will be able to trace risks and can be even more forthcoming regarding the risks.

2 FMEA

FMEA - Failure Mode and Effect Analysis.
The FMEA consists of 14 different aspects, instead of just the normal two in a risk analysis. The EGA project team believes that the FMEA gives a better understanding of the different risks, and how to treat them. This FMEA has also been used as a technical FMEA, and not as a project FMEA. In other words, this have been used for technical aspects, such as parts.

The different aspects are:

2.1 Item

The different kind of items, parts or components that are in the system. A good example on a item is: DC motor.

2.2 Potential failure mode

In this aspect, what can fail with the mentioned item, part or component. A good example of this, is that the DC motor is lacking power. This can be a real potentioal failure.

2.3 Potential cause(s) / mechanism

The question here is: what causes the item to fail. This can be almost anything, but if the DC motor is still in use, the lack of power can be explained because of a wrong calculation.

2.4 Mission Phase

Mission phase is the phase where this failure can be a problem. For example, this can be when the DC motor has to pull or drag the actuator.

2.5 Local effects of failure

The Local effect, is what this item failure affect local. In the case with the DC motor, it will be that it cannot pull or drag the actuator.

2.6 Next higher level effect

The next higher level effect is what is the next effect on the system. In the case with the DC motor, it will be that it cannot put the shift fork in gear.

2.7 System Level End Effect

System level end effect is what will this item failure affect the system as a whole. With the DC. motor, the system level end effect will be that the system or actuator does not work.

2.8 Probability (P)

This is also known from a regular risk analysis, which just says what the probability for the failure is. The main difference from a regular use, and in a FMEA is that the FMEA have a giving scoring board.

Table 1: Probability Table

A	Extremely Unlikely (Virtually impossible)
B	Remote (relatively few failures)
C	Occasional (occasional failures)
D	Reasonably Possible (repeated failures)
E	Frequent (failure is almost inevitable)

If using the example with the DC. motor; it would be extremely unlikely if the calculation is wrong. With todays simulating opportunities, it will be unlikely that the group calculate the motor strength wrong. Therefor the DC motor will get an A.

2.9 Severity (S)

This aspect is also in normal risk analysis, which determine how sever the failure is. Just as probability, this also have its own table.

Table 2: Severity Table

I	No relevant effect on reliability or safety
II	Very minor, no damage, no injuries
III	Minor, low damage, light injuries
IV	Critical
V	Catastrophic

If continuing with the DC motor example, it would be catastrochic if it was undersized! Therefore it gets a V.

2.10 Detection (D)

This aspect is for if the failure would be detected if something is about to fail. In the case of the DC motor, it should reveal itself when simulating. But if the DC motor passes the simulation, it will be visible when testing. Again, here the FMEA have its own table:

Table 3: Severity Table

1	Certain
2	Almost certain
3	High
4	Moderate
5	Low
6	Undetectable

In the DC motor example, it is certain that it would be detected. Therefore it gets a 1.

2.11 Detection Dormancy Period

The detection period is how long it will take before the failure is detected. In for example with the DC motor, this will be seconds when testing.

2.12 Risk Level

The risk level is also a table, which have been developed specifically for the FMEA. The table looks like this:

Table 4: Risk Level Table

Probability / Severity	I	II	III	IV	V	VI
A	Low	Low	Low	Low	Moderate	High
B	Low	Low	Low	Moderate	High	Unacceptable
C	Low	Low	Moderate	Moderate	High	Unacceptable
D	Low	Moderate	Moderate	High	Unacceptable	Unacceptable
E	Moderate	Moderate	High	Unacceptable	Unacceptable	Unacceptable

In the DC motor example, it would get: "Moderate" as risk level. The reason for this risk level is the score it got in probability and severity.

2.13 Actions for further Investigation / evidence

This aspect is for further investigation of the failure, try to find evidence for why it failed. The best to do here, is just to take out the DC motor and analyze what went wrong.

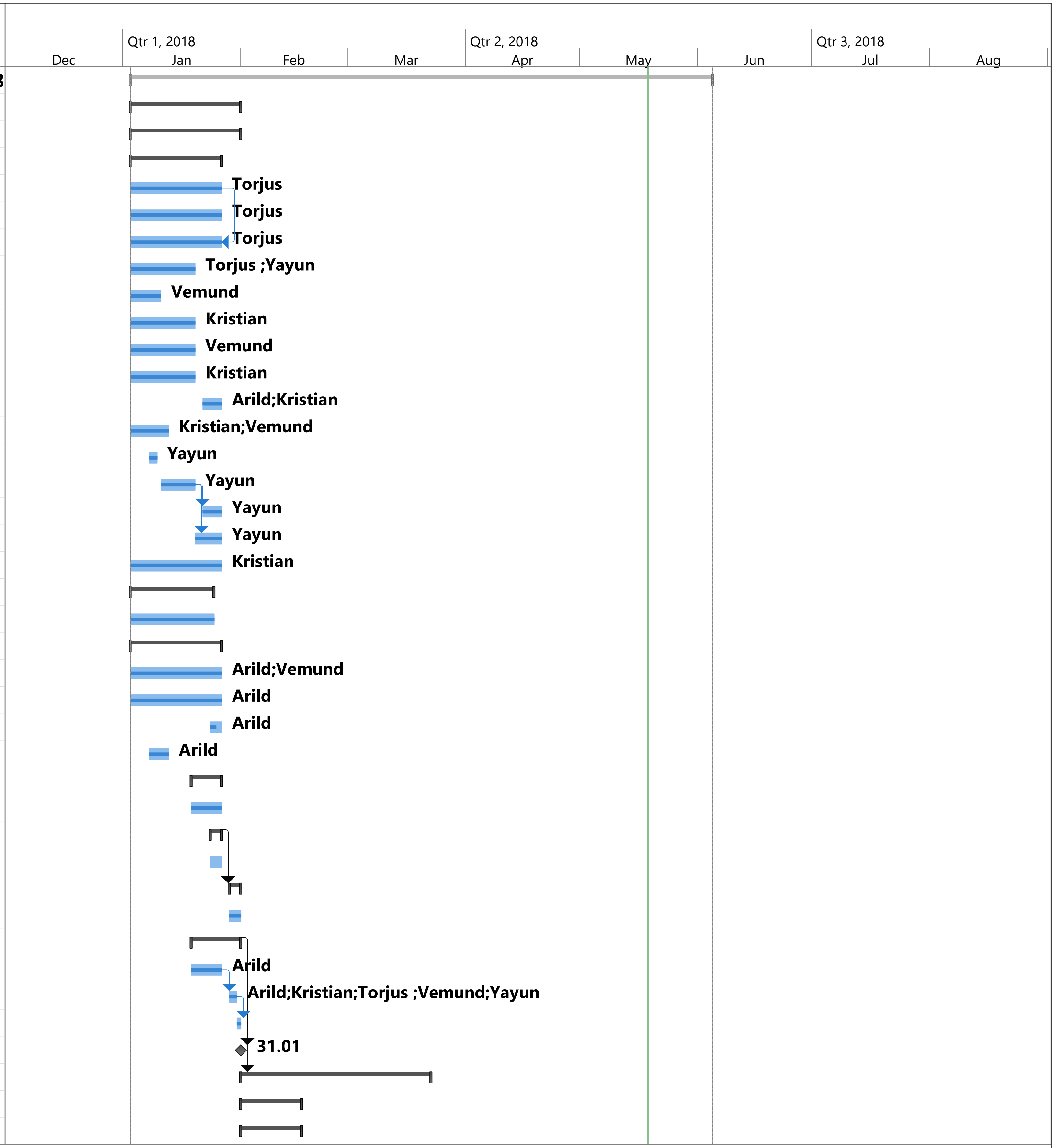
2.14 Mitigation / Requirements

What to do if it breaks down, usually it can be repaired or switched out. If it fails when it is still in the warranty time, it will probably be switched out, and the old one would come back to the factory and be analyzed for errors.

3 Conclusion

For a project like this, where there is a lot of moving parts and probably a lot of parts that has to be made or customized, it is important that it is more then a small risk analysis. When saying more than a risk analysis, the EGA team wants to be able to track risks. When the project team is able to track the risk, it is also possible to see what else of the product it will affect and what EGA has to think about. The project team thinks that the FMEA is adequate to this usage, and has decided to use it for technical potential failures.

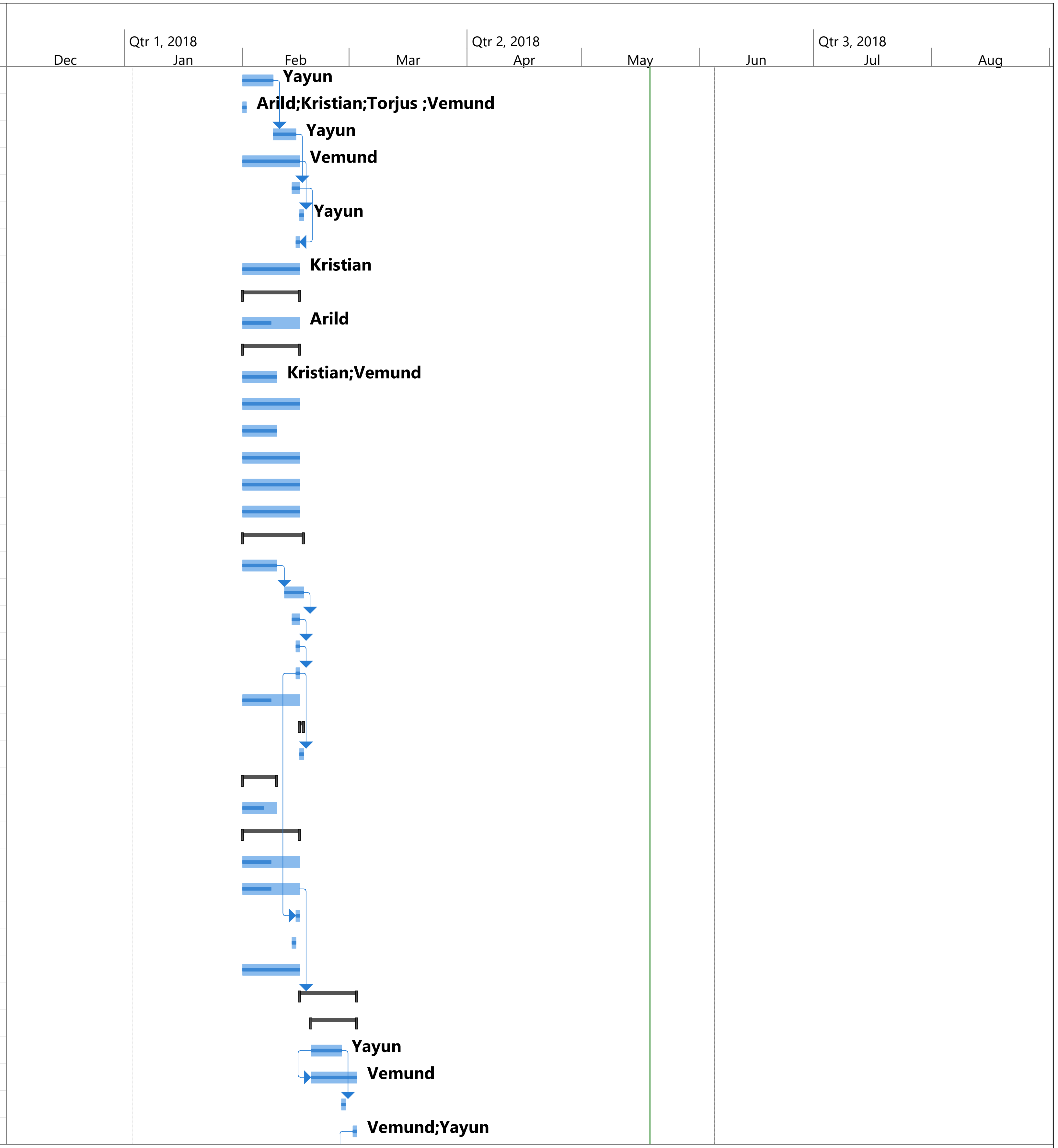
ID	Task Mode	Activity ID	Activity	Duration	Start	Finish
0			**EGA Bachelor Project**	**110 day**	**Wed 03.01.18**	**Mon 04.06.18**
1			**Inception**	**22 days**	**Wed 03.01.18**	**Wed 31.01.18**
2		**I1**	**Preliminary Iterations**	**22 days**	**Wed 03.01.18**	**Wed 31.01.18**
3			**Project management**	**19 days**	**Wed 03.01.18**	**Fri 26.01.18**
4		I1-20	Make team cooporation contract	19 days	Wed 03.01.18	Fri 26.01.18
5		I1-20-a	Make team overview list	19 days	Wed 03.01.18	Fri 26.01.18
6		I1-21	Make project contract	19 days	Wed 03.01.18	Fri 26.01.18
7		I1-22	Coordinate confidentiality agreement	13 days	Wed 03.01.18	Fri 19.01.18
8		I1-19	Design group logo	6 days	Wed 03.01.18	Wed 10.01.18
9		I1-23	Preliminary webpage design	13 days	Wed 03.01.18	Fri 19.01.18
10		I1-24	Make latex insruction	13 days	Wed 03.01.18	Fri 19.01.18
11		I1-25	Develop document template by Latex	13 days	Wed 03.01.18	Fri 19.01.18
12		I1-25-a	Develop a reference system template by	5 days	Mon 22.01.18	Fri 26.01.18
13		I1-26	Determine a system for time list	8 days	Wed 03.01.18	Fri 12.01.18
14		I1-27	Gantt Chart program	2 days	Mon 08.01.18	Tue 09.01.18
15		I1-28	Project model	7 days	Thu 11.01.18	Fri 19.01.18
16		I1-29	Preliminary project plan	5 days	Mon 22.01.18	Fri 26.01.18
17		I1-30	Initial documentation of project model	6 days	Sat 20.01.18	Fri 26.01.18
18		I1-39	Risk analysis	19 days	Wed 03.01.18	Fri 26.01.18
19			**Business modeling**	**17 days**	**Wed 03.01.18**	**Wed 24.01.18**
20		I1-41	Refine roles and responsibility	17 days	Wed 03.01.18	Wed 24.01.18
21			**Requirements**	**19 days**	**Wed 03.01.18**	**Fri 26.01.18**
22		I1-31	Initial literature study	19 days	Wed 03.01.18	Fri 26.01.18
23		I1-32	Preliminary requirement understanding	19 days	Wed 03.01.18	Fri 26.01.18
24		I1-32-a	Requirement documentation	3 days	Wed 24.01.18	Fri 26.01.18
25		I1--33	Vision document prepare	5 days	Mon 08.01.18	Fri 12.01.18
26			**Analysis and Design**	**7 days**	**Fri 19.01.18**	**Fri 26.01.18**
27		I1-38	Perform project management process	7 days	Fri 19.01.18	Fri 26.01.18
28			**Test**	**3 days**	**Wed 24.01.18**	**Fri 26.01.18**
29		I1-34	Preliminary test plan	3 days	Wed 24.01.18	Fri 26.01.18
30			**Knowledge development**	**3 days**	**Mon 29.01.18**	**Wed 31.01.18**
31		I1-40	Conclution what we learn	3 days	Mon 29.01.18	Wed 31.01.18
32			**Presentation #1**	**10 days**	**Fri 19.01.18**	**Wed 31.01.18**
33		I1-35	Make presentation slides	7 days	Fri 19.01.18	Fri 26.01.18
34		I1-36	Pratice the presentation	2 days	Mon 29.01.18	Tue 30.01.18
35		I1-37	Present	1 day	Wed 31.01.18	Wed 31.01.18
36			The Lifecycle Objectives Milestone	0 days	Wed 31.01.18	Wed 31.01.18
37			**Elaboration**	**36 days**	**Thu 01.02.18**	**Thu 22.03.18**
38		**E1**	**Iteration #1: E1**	**12 days**	**Thu 01.02.18**	**Fri 16.02.18**
39		**E1-1**	**Project Management**	**12 days**	**Thu 01.02.18**	**Fri 16.02.18**



Project: EGA Bachelor Project
Date: Sat 19.05.18

Task	Project Summary	Manual Task	Start-only	Deadline
Split	Inactive Task	Duration-only	Finish-only	Progress
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress
Summary	Inactive Summary	Manual Summary	External Milestone	

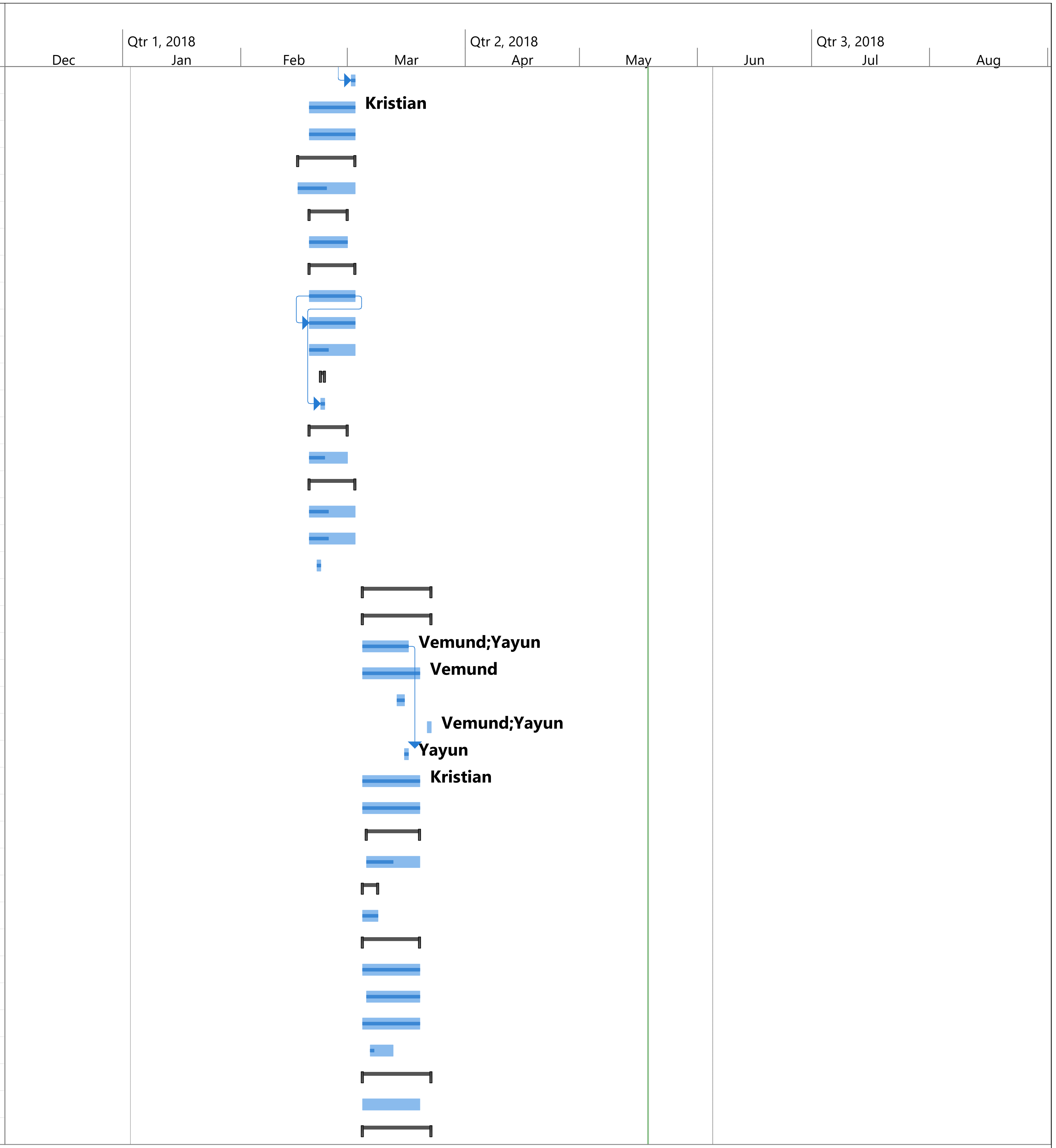
ID	Activity ID	Activity	Duration	Start	Finish
40	E1-1-1	Make activity plan	6 days	Thu 01.02.18	Thu 08.02.18
41	E1-1-2	Participate KA course	1 day	Thu 01.02.18	Thu 01.02.18
42	E1-1-7	Manage iteration	4 days	Fri 09.02.18	Wed 14.02.18
43	E1-1-8	Monitor and control project	11 days	Thu 01.02.18	Thu 15.02.18
44	E1-1-9	Evaluate project scope and Risk	2 days	Wed 14.02.18	Thu 15.02.18
45	E1-1-1	Plan for next iteration	1 day	Fri 16.02.18	Fri 16.02.18
46	E1-1-1	Refine project plan	1 day	Thu 15.02.18	Thu 15.02.18
47	E1-1-1	Update the website	11 days	Thu 01.02.18	Thu 15.02.18
48	**E1-2**	**Business Modeling**	**11 days**	**Thu 01.02.18**	**Thu 15.02.18**
49	E1-2-1	Cost/benefit analysis	11 days	Thu 01.02.18	Thu 15.02.18
50	**E1-3**	**Requirement**	**11 days**	**Thu 01.02.18**	**Thu 15.02.18**
51	E1-3-1	Define the stakeholders	7 days	Thu 01.02.18	Fri 09.02.18
52	E1-3-2	Understand Sakeholder needs	11 days	Thu 01.02.18	Thu 15.02.18
53	E1-3-3	Update the requirement	7 days	Thu 01.02.18	Fri 09.02.18
54	E1-3-4	Understand all requirements	11 days	Thu 01.02.18	Thu 15.02.18
55	E1-3-5	Analyze the problem	11 days	Thu 01.02.18	Thu 15.02.18
56	E1-3-6	Mange changing requirements	11 days	Thu 01.02.18	Thu 15.02.18
57	**E1-4**	**Analysis and Design**	**12 days**	**Thu 01.02.18**	**Fri 16.02.18**
58	E1-4-1	Analysis behavior	7 days	Thu 01.02.18	Fri 09.02.18
59	E1-4-2	Concept development	5 days	Mon 12.02.18	Fri 16.02.18
60	E1-4-3	Define concept candidate	2 days	Wed 14.02.18	Thu 15.02.18
61	E1-4-4	Refine the concept	1 day	Thu 15.02.18	Thu 15.02.18
62	E1-4-5	Sketch concept framework	1 day	Thu 15.02.18	Thu 15.02.18
63	E1-4-6	FMEA	11 days	Thu 01.02.18	Thu 15.02.18
64	**E1-5**	**Implementation**	**1 day**	**Fri 16.02.18**	**Fri 16.02.18**
65	E1-5-1	Present candidate concept in group	1 day	Fri 16.02.18	Fri 16.02.18
66	**E1-6**	**Test**	**7 days**	**Thu 01.02.18**	**Fri 09.02.18**
67	E1-6-1	Update the test plan	7 days	Thu 01.02.18	Fri 09.02.18
68	**E1-7**	**Knowledge development**	**11 days**	**Thu 01.02.18**	**Thu 15.02.18**
69	E1-7-1	Further Literature study	11 days	Thu 01.02.18	Thu 15.02.18
70	E1-7-2	Further Patent research	11 days	Thu 01.02.18	Thu 15.02.18
71	E1-7-3	Make brief description for every concept	1 day	Thu 15.02.18	Thu 15.02.18
72	E1-7-4	Paten course with KA	1 day	Wed 14.02.18	Wed 14.02.18
73	E1-7-5	K-Briefs(A3) template	11 days	Thu 01.02.18	Thu 15.02.18
74	**E2**	**Iteration #2: E2**	**11 days**	**Fri 16.02.18**	**Fri 02.03.18**
75	**E2-1**	**Project Management**	**10 days**	**Mon 19.02.18**	**Fri 02.03.18**
76	E2-1-3	Manage iteration	6 days	Mon 19.02.18	Mon 26.02.18
77	E2-1-4	Monitor and control project	10 days	Mon 19.02.18	Fri 02.03.18
78	E2-1-5	Evaluate project scope and Risk	1 day	Tue 27.02.18	Tue 27.02.18
79	E2-1-6	Plan for next iteration	1 day	Fri 02.03.18	Fri 02.03.18



Project: EGA Bachelor Project
Date: Sat 19.05.18

Task		Project Summary		Manual Task		Start-only		Deadline	
Split		Inactive Task		Duration-only		Finish-only		Progress	
Milestone		Inactive Milestone		Manual Summary Rollup		External Tasks		Manual Progress	
Summary		Inactive Summary		Manual Summary		External Milestone			

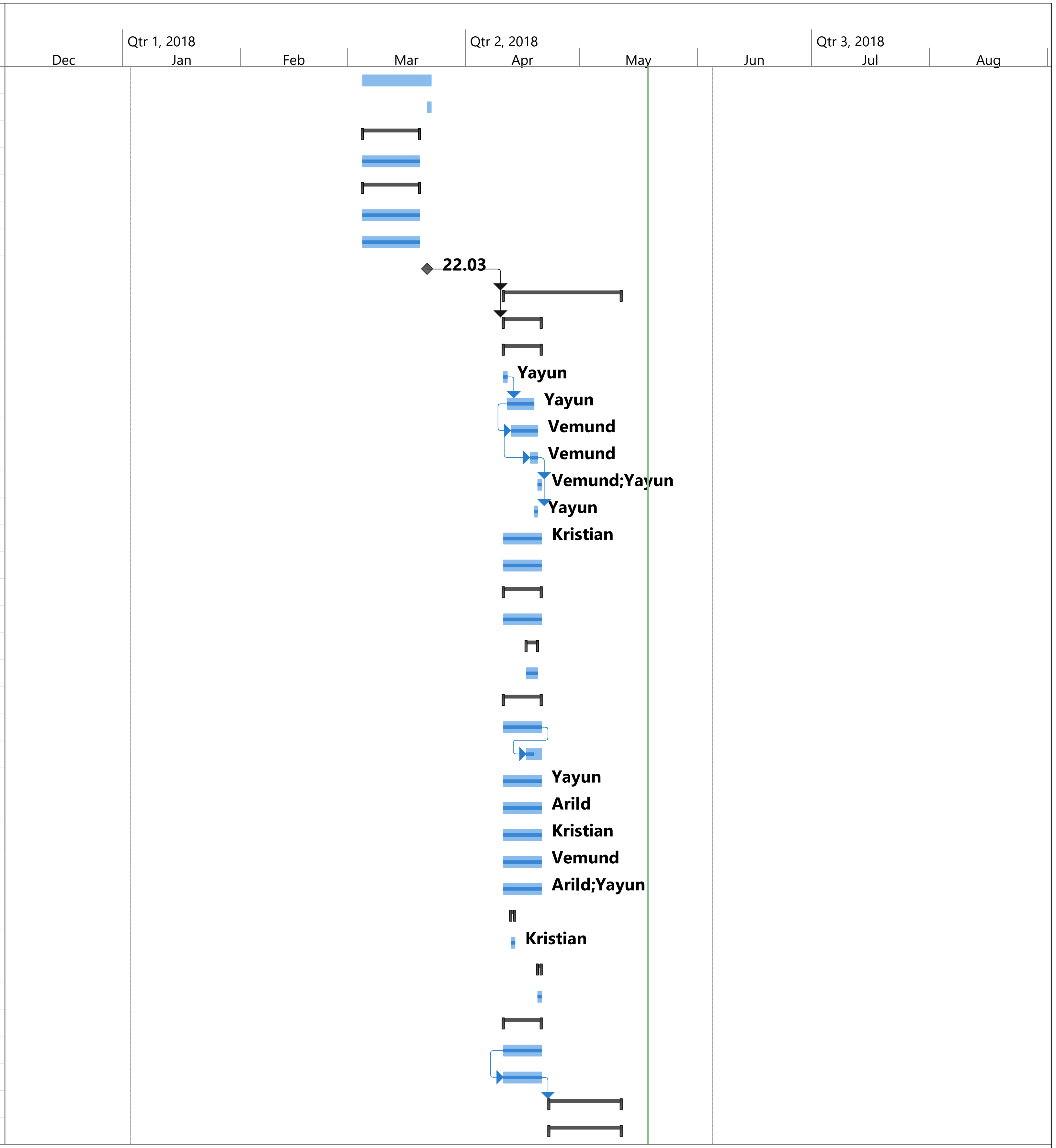
ID	Task Mode	Activity ID	Activity	Duration	Start	Finish
80		E2-1-7	Refine project plan	1 day	Fri 02.03.18	Fri 02.03.18
81		E2-1-8	Update the website	10 days	Mon 19.02.18	Fri 02.03.18
82		E2-1-1	Documentation	10 days	Mon 19.02.18	Fri 02.03.18
83		**E2-2**	**Business Modeling**	**11 days**	**Fri 16.02.18**	**Fri 02.03.18**
84		E2-2-1	Cost/benefit analysis	11 days	Fri 16.02.18	Fri 02.03.18
85		**E2-3**	**Requirement**	**8 days**	**Mon 19.02.18**	**Wed 28.02.18**
86		E2-3-1	Update the requirement	8 days	Mon 19.02.18	Wed 28.02.18
87		**E2-4**	**Analysis and Design**	**10 days**	**Mon 19.02.18**	**Fri 02.03.18**
88		E2-4-1	Concept development	10 days	Mon 19.02.18	Fri 02.03.18
89		E2-4-2	Refine the concept	10 days	Mon 19.02.18	Fri 02.03.18
90		E2-4-3	FMEA	10 days	Mon 19.02.18	Fri 02.03.18
91		**E2-5**	**Implementation**	**1 day**	**Thu 22.02.18**	**Thu 22.02.18**
92		E2-5-1	Present candidate concept to KA (skype r	1 day	Thu 22.02.18	Thu 22.02.18
93		**E2-6**	**Test**	**8 days**	**Mon 19.02.18**	**Wed 28.02.18**
94		E2-6-1	Update the test plan	8 days	Mon 19.02.18	Wed 28.02.18
95		**E2-7**	**Knowledge development**	**10 days**	**Mon 19.02.18**	**Fri 02.03.18**
96		E2-7-1	Further Literature study	10 days	Mon 19.02.18	Fri 02.03.18
97		E2-7-2	Further Patent research	10 days	Mon 19.02.18	Fri 02.03.18
98		E2-7-3	Make K-brief for every candidate concep	1 day	Wed 21.02.18	Wed 21.02.18
99		**E3**	**Iteration #3: E3**	**14 days**	**Mon 05.03.18**	**Thu 22.03.18**
100		**E3-1**	**Project management**	**14 days**	**Mon 05.03.18**	**Thu 22.03.18**
101		E3-1-9	Manage iteration	10 days	Mon 05.03.18	Fri 16.03.18
102		E3-1-1	Monitor and control project	11 days	Mon 05.03.18	Mon 19.03.18
103		E3-1-1	Evaluate project scope and Risk	2 days	Wed 14.03.18	Thu 15.03.18
104		E3-1-1	Plan for next iteration	1 day	Thu 22.03.18	Thu 22.03.18
105		E3-1-1	Refine project plan	1 day	Fri 16.03.18	Fri 16.03.18
106		E3-1-1	Update the website	11 days	Mon 05.03.18	Mon 19.03.18
107		E3-1-1	Documentation	11 days	Mon 05.03.18	Mon 19.03.18
108		**E3-2**	**Business modeling**	**10 days**	**Tue 06.03.18**	**Mon 19.03.18**
109		E3-2-1	Cost/benefit analysis	10 days	Tue 06.03.18	Mon 19.03.18
110		**E3-3**	**Requirement**	**4 days**	**Mon 05.03.18**	**Thu 08.03.18**
111		E3-3-1	Update requirement	4 days	Mon 05.03.18	Thu 08.03.18
112		**E3-4**	**Analysis and design**	**11 days**	**Mon 05.03.18**	**Mon 19.03.18**
113		E3-4-1	Concept development	11 days	Mon 05.03.18	Mon 19.03.18
114		E3-4-2	Refine the concept	10 days	Tue 06.03.18	Mon 19.03.18
115		E3-4-3	FMEA	11 days	Mon 05.03.18	Mon 19.03.18
116		E3-4-4	3D modelling	4 days	Wed 07.03.18	Mon 12.03.18
117		**E3-5**	**Implementation**	**14 days**	**Mon 05.03.18**	**Thu 22.03.18**
118		E3-5-1	Electro-Magnets concept prototype	11 days	Mon 05.03.18	Mon 19.03.18
119			**Presentation#2**	**14 days**	**Mon 05.03.18**	**Thu 22.03.18**



Project: EGA Bachelor Project
Date: Sat 19.05.18

Task	Project Summary	Manual Task	Start-only	Deadline
Split	Inactive Task	Duration-only	Finish-only	Progress
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress
Summary	Inactive Summary	Manual Summary	External Milestone	

ID	Tasl Mo	Activity ID	Activity	Duration	Start	Finish
120		E3-5-2	Prepare for presentation	14 days	Mon 05.03.18	Thu 22.03.18
121		E3-5-3	Participate the presentation	1 day	Thu 22.03.18	Thu 22.03.18
122		**E3-6**	**Test**	**11 days**	**Mon 05.03.18**	**Mon 19.03.18**
123		E3-6-1	Update the test plan	11 days	Mon 05.03.18	Mon 19.03.18
124		**E3-7**	**Knowledge development**	**11 days**	**Mon 05.03.18**	**Mon 19.03.18**
125		E3-7-1	Literature study	11 days	Mon 05.03.18	Mon 19.03.18
126		E3-7-2	Patent search	11 days	Mon 05.03.18	Mon 19.03.18
127			The Lifecycle Architecture	0 days	Thu 22.03.18	Thu 22.03.18
128			**Construction**	**23 days**	**Wed 11.04.18**	**Fri 11.05.18**
129		**C1**	**Iteration #1: C1**	**8 days**	**Wed 11.04.18**	**Fri 20.04.18**
130		**C1-1**	**Project management**	**8 days**	**Wed 11.04.18**	**Fri 20.04.18**
131		C1-1-1	Make activity plan	1 day	Wed 11.04.18	Wed 11.04.18
132		C1-1-7	Manage iteration	5 days	Thu 12.04.18	Wed 18.04.18
133		C1-1-8	Monitor and control project	5 days	Fri 13.04.18	Thu 19.04.18
134		C1-1-9	Evaluate project scope and Risk	2 days	Wed 18.04.18	Thu 19.04.18
135		C1-1-1	Plan for next iteration	1 day	Fri 20.04.18	Fri 20.04.18
136		C1-1-1	Refine project plan	1 day	Thu 19.04.18	Thu 19.04.18
137		C1-1-1	Update the website	8 days	Wed 11.04.18	Fri 20.04.18
138		C1-1-1	Documentation	8 days	Wed 11.04.18	Fri 20.04.18
139		**C1-2**	**Business modeling**	**8 days**	**Wed 11.04.18**	**Fri 20.04.18**
140		C1-2-1	Cost/benefit analysis	8 days	Wed 11.04.18	Fri 20.04.18
141		**C1-3**	**Requirement**	**3 days**	**Tue 17.04.18**	**Thu 19.04.18**
142		C1-3-1	Management changing requirements	3 days	Tue 17.04.18	Thu 19.04.18
143		**C1-4**	**Analysis and Design**	**8 days**	**Wed 11.04.18**	**Fri 20.04.18**
144		C1-4-1	Top level system design	8 days	Wed 11.04.18	Fri 20.04.18
145		C1-4-2	Design component	4 days	Tue 17.04.18	Fri 20.04.18
146		C1-4-3	Calculation input	8 days	Wed 11.04.18	Fri 20.04.18
147		C1-4-4	Material input	8 days	Wed 11.04.18	Fri 20.04.18
148		C1-4-5	Sensor input	8 days	Wed 11.04.18	Fri 20.04.18
149		C1-4-6	El.magnet input	8 days	Wed 11.04.18	Fri 20.04.18
150		C1-4-7	3D modelling input	8 days	Wed 11.04.18	Fri 20.04.18
151		**C1-5**	**Implementation**	**1 day**	**Fri 13.04.18**	**Fri 13.04.18**
152		C1-5-1	Prepare the POC prototype material	1 day	Fri 13.04.18	Fri 13.04.18
153		**C1-6**	**Test**	**1 day**	**Fri 20.04.18**	**Fri 20.04.18**
154		C1-6-1	Management changing test plan	1 day	Fri 20.04.18	Fri 20.04.18
155		**C1-7**	**Knowledge development**	**8 days**	**Wed 11.04.18**	**Fri 20.04.18**
156		C1-7-1	Further literature study	8 days	Wed 11.04.18	Fri 20.04.18
157		C1-7-2	Further Patent research	8 days	Wed 11.04.18	Fri 20.04.18
158		**C2**	**Iteration #2: C2**	**15 days**	**Mon 23.04.18**	**Fri 11.05.18**
159		**C2-1**	**Project management**	**15 days**	**Mon 23.04.18**	**Fri 11.05.18**



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Task	Project Summary	Manual Task	Start-only	Deadline
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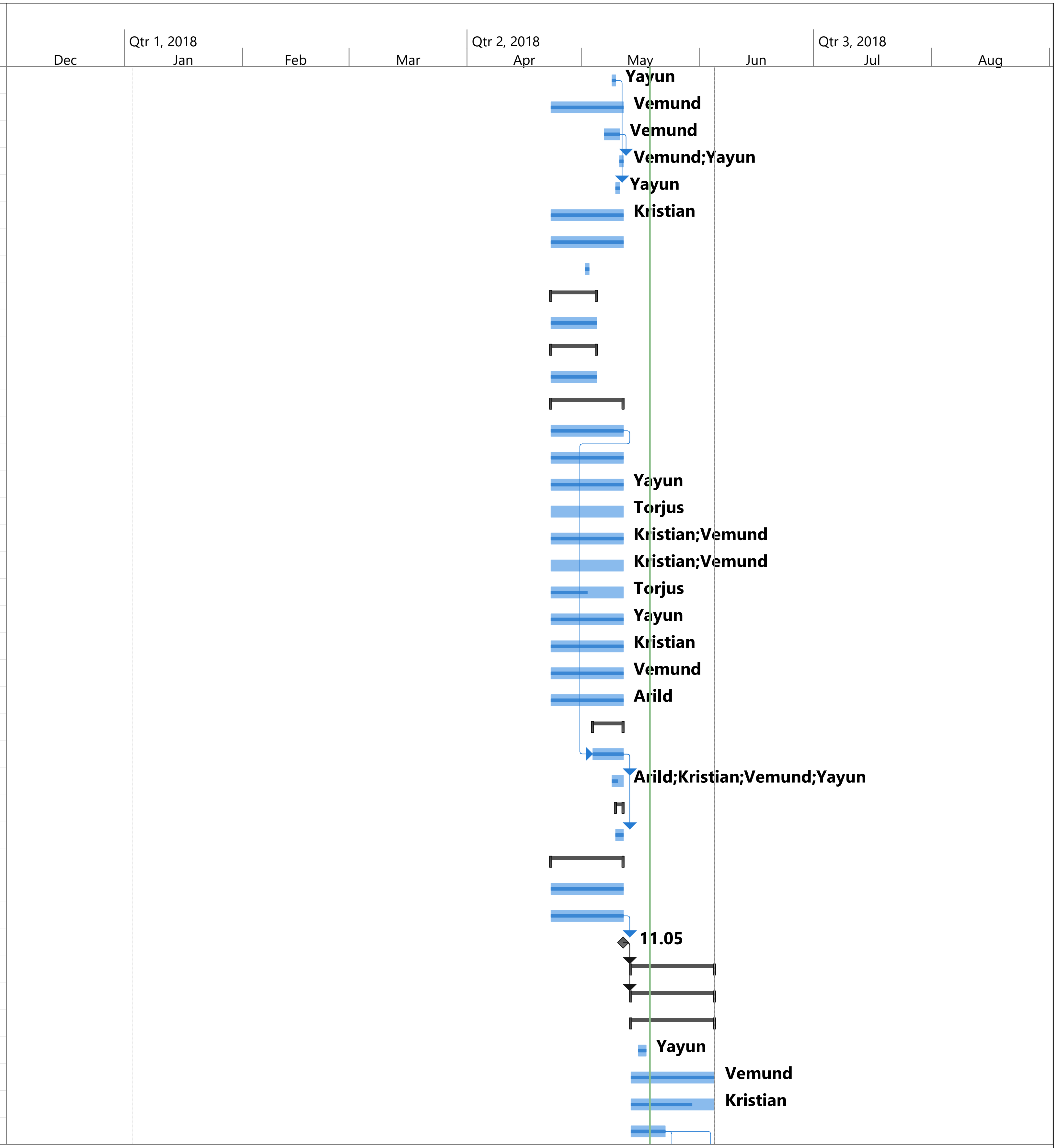
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress
Summary	Inactive Summary	Manual Summary	External Milestone	

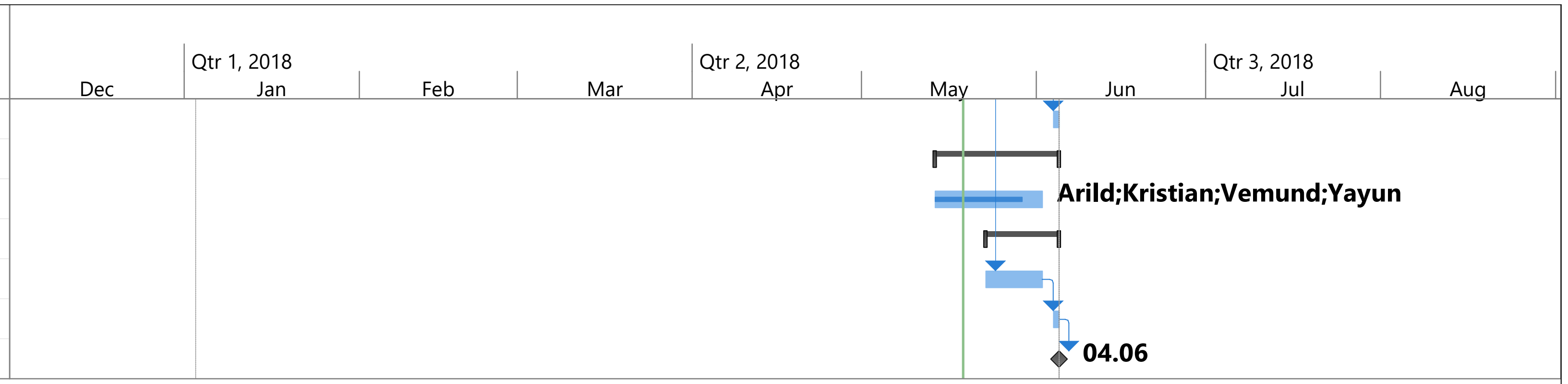
ID	Activity ID	Activity	Duration	Start	Finish
160	C2-1-9	Management iteration	1 day	Wed 09.05.18	Wed 09.05.18
161	C2-1-1	Monitor and control project	15 days	Mon 23.04.18	Fri 11.05.18
162	C2-1-1	Reevaluate project scope and risk	4 days	Mon 07.05.18	Thu 10.05.18
163	C2-1-1	Plan for next iteration	1 day	Fri 11.05.18	Fri 11.05.18
164	C2-1-1	Refine project plan	1 day	Thu 10.05.18	Thu 10.05.18
165	C2-1-1	Update the website	15 days	Mon 23.04.18	Fri 11.05.18
166	C2-1-1	Documentation	15 days	Mon 23.04.18	Fri 11.05.18
167	C2-1-1	Visit KA	1 day	Wed 02.05.18	Wed 02.05.18
168	**C2-2**	**Business modeling**	**10 days**	**Mon 23.04.18**	**Fri 04.05.18**
169	C2-2-2	Cost/benefit analysis	10 days	Mon 23.04.18	Fri 04.05.18
170	**C2-3**	**Requirement**	**10 days**	**Mon 23.04.18**	**Fri 04.05.18**
171	C2-3-1	Management changing requirements	10 days	Mon 23.04.18	Fri 04.05.18
172	**C2-4**	**Analysis and Design**	**15 days**	**Mon 23.04.18**	**Fri 11.05.18**
173	C2-4-1	Design component	15 days	Mon 23.04.18	Fri 11.05.18
174	C2-4-2	Refine the architecture	15 days	Mon 23.04.18	Fri 11.05.18
175	C2-4-3	Simulation: Simulink	15 days	Mon 23.04.18	Fri 11.05.18
176	C2-4-4	Simulation: FEM analysis	15 days	Mon 23.04.18	Fri 11.05.18
177	C2-4-5	Simulation: ORCAD-Circuit	15 days	Mon 23.04.18	Fri 11.05.18
178	C2-4-6	Simulation: Electric magnet field	15 days	Mon 23.04.18	Fri 11.05.18
179	C2-4-7	Final CAD	15 days	Mon 23.04.18	Fri 11.05.18
180	C2-4-8	Final calculation input	15 days	Mon 23.04.18	Fri 11.05.18
181	C2-4-9	Final sensor input	15 days	Mon 23.04.18	Fri 11.05.18
182	C2-4-1	Final magnet input	15 days	Mon 23.04.18	Fri 11.05.18
183	C2-4-1	Final material input	15 days	Mon 23.04.18	Fri 11.05.18
184	**C2-5**	**Implementation**	**6 days**	**Fri 04.05.18**	**Fri 11.05.18**
185	C2-5-1	Integrate subsystem/system	6 days	Fri 04.05.18	Fri 11.05.18
186	C2-5-2	Build POC prototype	3 days	Wed 09.05.18	Fri 11.05.18
187	**C2-6**	**Test**	**2 days**	**Thu 10.05.18**	**Fri 11.05.18**
188	C2-6-1	Test and evaluate	2 days	Thu 10.05.18	Fri 11.05.18
189	**C2-7**	**Knowledge development**	**15 days**	**Mon 23.04.18**	**Fri 11.05.18**
190	C2-7-1	Final Literature study	15 days	Mon 23.04.18	Fri 11.05.18
191	C2-7-2	Final Paten search	15 days	Mon 23.04.18	Fri 11.05.18
192		Initial Operational Capability Milestone	0 days	Fri 11.05.18	Fri 11.05.18
193		**Transition**	**16 days**	**Mon 14.05.18**	**Mon 04.06.18**
194	**T1**	**Iteration #1: T1**	**16 days**	**Mon 14.05.18**	**Mon 04.06.18**
195	**T1-1**	**Project management**	**16 days**	**Mon 14.05.18**	**Mon 04.06.18**
196	T1-1-3	Management iteration	2 days	Wed 16.05.18	Thu 17.05.18
197	T1-1-4	Monitor and control project	16 days	Mon 14.05.18	Mon 04.06.18
198	T1-1-5	Update the website	16 days	Mon 14.05.18	Mon 04.06.18
199	T1-1-6	Documentation	7 days	Mon 14.05.18	Tue 22.05.18



Project: EGA Bachelor Project
Date: Sat 19.05.18

Task	Project Summary	Manual Task	Start-only	Deadline
Split	Inactive Task	Duration-only	Finish-only	Progress
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress
Summary	Inactive Summary	Manual Summary	External Milestone	

ID	Task Mode	Activity ID	Activity	Duration	Start	Finish
200		T1-1-7	Close-out project	1 day	Mon 04.06.18	Mon 04.06.18
201		**T1-5**	**Implementation**	**16 days**	**Mon 14.05.18**	**Mon 04.06.18**
202		T1-5-1	POC prototype	15 days	Mon 14.05.18	Fri 01.06.18
203			**Presentation #3**	**9 days**	**Wed 23.05.18**	**Mon 04.06.18**
204		T1-5-2	Prepare for presentation	8 days	Wed 23.05.18	Fri 01.06.18
205		T1-5-3	Participate the presentation	1 day	Mon 04.06.18	Mon 04.06.18
206			The Product Release Milestone	0 days	Mon 04.06.18	Mon 04.06.18



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Split	Inactive Task	Duration-only	Finish-only	Progress
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress
Summary	Inactive Summary	Manual Summary	External Milestone	

Requirement		Priority (A-C)	Description	Functional/Non-Functional	Active stakeholder	Test ID
Req 01	Temperature					
R 01.1	Minus	A	The system shall withstand -40 degrees celsius	NF	Kongsberg Automotive, Hardware supplier	T01.1
R 01.2	Pluss	A	The system shall withstand +125 degrees celsius	NF	Kongsberg Automotive, Hardware supplier	T01.2
Req 02	Force					
R02.1	Solenoid Push	A	The solenoid shall push each indivdual tooth with 150.8N	F	EGA	T02.1
R02.2	Spring Pull	A	The spring shal retract the tooth with X N	F	EGA	T02.2
Req 03	Postion					
R03.1	Current draw	A	The system shall be able to measure if the solenoid is in start or end position based on the current draw	F	Kongsberg Automotive, Hardware supplier, Government, Software	T03.1
R03.2	Double gear activation	A	The system shall be designed in a way so that it is impossible for both gears to be activated at the same time	F	Kongsberg Automotive, Hardware supplier, Government, Software	T03.2
R03.3	Two postions	A	The system shall have the ability to switch between not in position (0), and in postion (1).	F	Kongsberg Automotive	T03.3
R03.4	Time: activated to neutral	A	From movement starts in neutral and until movement has completed gear activation shall be less than 60 ms.	F	Kongsberg Automotive	T03.4
R03.5	Time: Neutral to Activated	A	From movement starts in activation and until movement has reached neutral position there shall be less than 40 ms.	F	Kongsberg Automotive	T03.5
Req 04	Energy consumption					
R04.1	Electrical wiring	A	The electrical wiring shall have a reasonable power loss	NF	Kongsberg Automotive, Hardware supplier, Government	T04.1
R04.2	Power solenoid	A	The solenoid shall be able to use 12V/24V/48V	F	Kongsberg Automotive, Hardware supplier, Government	T04.2
R04.3	Power control system	A	The electrical control system shall be able to use 5V	F	Kongsberg Automotive, Hardware supplier, Government	T04.3
Req 05	Safety					
R05.1	Power loss neutral return	A	The actuator shall be able to revert to neutral in case of EG. Power loss, without increasing power consumption in normal use	NF	Kongsberg Automotive, Hardware supplier, Government, Software	T05.1
R05.2	Failure rate: 20,000rpm	A	The actuator shall have a failure rate (R) of less than 20.000PPM at 24 MIS R = 98% MIS = Months in service - includes all failure modes (Design, Quality).	NF	Kongsberg Automotive, Government	T05.2
R05.3	Failure rate: 50,000rpm	A	The actuator shall have a failure rate (R) of less than 50.000PPM at 60 MIS R = 98% MIS = Months in service - includes all failure modes (Design, Quality).	NF	Kongsberg Automotive, Government	T05.3
R05.4	Designed for 10 years	A	The actuator shall be designed for 10 years, 30.000 hours of operation or 1.930.000 km. The product shall be maintenance free over this period.	NF	Kongsberg Automotive	T05.4
Req 06	Analysis					
R06.1	Patent search	B	The concept shall not be patented in any form by others then Kongsberg Automotive	NF	Kongsberg Automotive	T06.1
Req 07	Size					
R07.1	Maximium outer diameter	A	The maximum size of the diameter outside is 180mm	F	Kongserbg Automotive	T07.1
R07.2	Minimum inner diameter	A	The minimum size of the diameter inside is 80mm	F	Kongsberg Automotive	T07.2
R07.3	Thickness	A	The maximum thicknes is 50mm	F	Kongsberg Automotive	T07.3

	Test	Goal	Approach	Testability (1-3)	Resources	Results	Verified	Requirement ID
Test 01	Temperature							
T01.1	Electrical Minus	Verify that the system shall withstand -40 degrees	1. Complete system test 2. Place electrical system in cooling room (-40C) 3. Test while cooled 4. Test after reheating 5. Test 64 hours in stable tempreature	2	- Cooling chamber /equipment - Temperature sensors			R01.1
T01.2	Electrical Pluss	Verify that the system shall withstand +125 degrees	1. Complete system test 2. Place electrical system in heating room (125C) 3. Test while heated 4. Test after cooling 5. Test 64 hours in stable tempreature	2	- Heating chamber /equipment - Temperature sensors			R01.2
Test 02	Force							
T02.1	Solenoid Push	Verify that the solenoid can push the gear tooth with the power that is needed	1) A weight which is similar to force which is needed 2) Push that weight with the solenoid	1	- Wheight xxxN			R02.1
T02.2	Spring Pull	Verify that the spring can retract the tooth with the power needed	1) A weight which is similar to force which is needed 2) Retract that weight with the spring	1	- Wheight xxxN			R02.2
Test 03	Positional measurement							
T03.1	Current draw	Test position readability	1) Activate current measurement subsystem 2) Read samples while system active 3) Confirm position in relation to current	1	- Fully assembled system - Oscilloscope			R03.1
T03.2	Double gear activation	Test that two gears can not be activated simultaneously	1) Set up system for normal use 2) Try to send both activation signals to control system simultaneously 3) Verify that gearbox did not explode	1	- Fully assembled system - Modified software or interface to program GCU			R03.2
T03.3	Two postions							R03.3
T03.4	Time: activated to neutral							R03.4
T03.5	Time: Neutral to Activated							R03.5
Test 04	Energy consumption							
T04.1	El wiring	Test electrical wiring for power loss	1) Measure from cable start to cable end 2) Compare with ideal power loss (0)	1	- Fully assembled system - Multimeter			R04.1
T04.2	Power solenoid	Test if solenoid can supply enough power in relation the input	1) Connect a 12V/24V/48V input to the solenoid 2) Perform T02.1 3) Confirm the values	1	- Adjustable power supply - Solenoid			R04.2
T04.3	Power control system	Test if control system runs on 5V	1) Connect control system to a 5V source 2) Run test over 64 hours with normal usage 3) Confirm that everything works properly	1	- Fully assembled system			R04.3
Test 05	Safety							
T05.1	Power loss neutral return	Test if the system returns to neutral position if there is power loss	1) Power on system 2) Activate gearchange 3) Power off system 4) Confirm actuator return to neutral		- Fully assembled system - Access to power source			R05.1
T05.2	Failure rate: 20,000rpm	Test failure rate after 20,000rpm						R05.2
T05.3	Failure rate: 50,000rpm	Test failure rate after 50,000rpm						R05.3
T05.4	Designed for 10 years	Test that the design last for 10,years						R05.4
Test 06	Adm							
T06.4	Patent search	Do a patent search, there are similar concepts already patented	1) Perform patent search 2) Document the process and results	2	- Internet	- Solution seems to be free from patent issues, see main report for more info	Yes	R06.1
Test 07	Size							
T07.1	Maximium outer diameter	Controll that the maximum diameter is not exceeded						R07.1
T07.2	Minimum inner diameter	Controll that the minimum diameter is not exceeded						R07.2
T07.3	Thickness	Controll that the thickness is not exceeded						R07.3

System/ Subsystem	F ID	Item	Potential failure mode	Potential cause(s) / mechanism	Mission Phase	Local effects of failure	Next higher level effect	System Level End Effect	(P) Probability (estimate)	(S) Severity	(D) Detection (Indications to Operator, Maintainer)	Risk Level P*S (+D)	Actions for further Investigation / evidence	Mitigation / Requirements
System (F01)														
	F01.1	System	Do not meet temp requirements	The different components does not work in extremely high or cold enviornment	Under use	Component does not work		Total system failure	B	V	1	High	Identfy component(s) that does not meet the temp req	Plan ahead, and use trust whorty suppliers
	F01.2	Material weakness	Material fracture	Inappropriate calculation procedure	Construction phase	Local critical tension	Material breaks	Fail to performe the task/ too expensive	B	V	1	High	Use simulink and test to double check	Verify by comparing with simulation and test
Solenoid F02)														
	F02.1	Solenoid	Lack of power	Wrong calculations	Elaboration phase	Cannot perform linear movement	System does not work properly		A	V	1	Moderate	Disassemble the system, removed solenoid and test it with test T02.1	Verify calculations and simulations
	F02.2	Solenoids	Not all solenoids are activated	Cable is broken, or fail with the controller	Under use	One of three solenoids is non functional	Two of three or one of three solneoids are activated	Still possible to make the gear change, but is not ideal	A	III	1	Low	Investigate why solenoids did not work	Make it possible to do the gear change, and inlcude an alarm which tells the driver to call a workshop for further information
	F02.3	Solenoids	Spring wont retract	Spring is broken	Under use	Solenoid will not go to neutral		It will not be possible to do a gearchange	B	V	2	High	Switch the spring	System will recognize if the spring is broken, and will not do a gear change to save the transmission
	F02.4	Solenoid	Overheating	Too long on-time	Construction phase	Cannot perform actuation (over time)	System does not work in allocated time	system does not work properly	B	IV	4	Moderate	Investigate why on-time is too long, and replace electromagnets	Test durability, especially on-time wear
Sensors (F03)														
	F03.1	Sensors	Signal error	Faulty sensor, electrical error	Construction phase	Unable to detect position	Risk of damaging system	Broken system	B	IV	1	Moderate	Replace sensor with a non-faulty one	Test sensors
Slipring(F04)														
	F04.1	Silpring	Brushes are teared down	Worn brush	Under use	Controller does not get signals / Power	The solenoids does not get power	The system does not make the gear change	D	IV	2	High	Swith the brushes	Make sure there is a system that tells the driver to do a service on the brushes
	F04.2	Slipring	High current	Wrong calculations gives too small surface for high current to pass	Construction phase	Controller does not get adequate power		Not enough power to make gear change	D	IV	2	High	Change design to higher surface area slip rings	Double and triple check design parameter
Controller(F05)														
	F05.1	Controller	Activates two gears at the same time	Controller gives "on" signal to two different gear	Under use	Both gears are activated		Total destruction of transmission	A	V	1	Moderate	It will be impossible to activate two gears at the same time	Use electrical hardware and software to make sure it is impossible to activate more than two gears at the same time
	F05.2	Controller	Activates no gear when supposed to	Controller will for some reason not give the gear signal even though user provides change signal	Under use	Transmission stuck in neutral	No forward momentum	Transmission not working	B	V	3	High	"Follow" the signal from user to GCU and find out where it stops	Thourough testing of the system before deployment

Ref.	Content	Release	Date published	Link
-	List of content		20 may 2018	https://www.dropbox.com/s/18qfpu60frz66fe/List%20of%20content.pdf?dl=0
#T.1	Reference list for Magshift		20 may 2018	https://www.dropbox.com/s/tjbh6m3iaghvw8d/%23T.1%20Referance%20list%20for%20Magshift.pdf?dl=0
#T.2	Magnetic properties of materials		20 may 2018	https://www.dropbox.com/s/40zxxzf2589j17d/%23T.2%20Magnetic%20properties%20of%20materials.pdf?dl=0
#T.3	Losses in transformers		20 may 2018	https://www.dropbox.com/s/t5v6xq2quyb1wa3/%23T.3%20Losses%20in%20transformers.pdf?dl=0
#T.4	Teknical formel		20 may 2018	https://www.dropbox.com/s/da0pptwqh3sxlc4/%23T.4%20Teknical%20formel.pdf?dl=0
#T.5	Referencee		20 may 2018	https://www.dropbox.com/s/nn6eteyx0uyvrue/%23T.5%20Reference.pdf?dl=0
#T.6	Verd at vite om fc		20 may 2018	https://www.dropbox.com/s/2t8j97mbzdssb28/%23T.6%20%20v%E2%80%98rd%20at%20vide%20om%20fc.pdf?dl=0
#T.7	Inductance		20 may 2018	https://www.dropbox.com/s/4fhqsebz1im9c3i/%23T.7%20Reference%20Indictance.pdf?dl=0
#T.8	L/R time		20 may 2018	https://www.dropbox.com/s/m6qz04gh6s5ozsn/%23T.8%20Reference%20L%20R%20time.pdf?dl=0
#T.9	Chosing solenoid		20 may 2018	https://www.dropbox.com/s/04dxutip2rvr949/%23T.10%2006003_2-EN-Needle-roller-bearings_Lowres.pdf?dl=0
#T.10	06003_2-EN-Needle-roller bearings_lowres		20 may 2018	https://www.dropbox.com/s/04dxutip2rvr949/%23T.10%2006003_2-EN-Needle-roller-bearings_Lowres.pdf?dl=0
#T.11	SKF-rolling-bearing-catalogue		20 may 2018	https://www.dropbox.com/s/98jh5ndokdblxka/%23T.11%20SKF-rolling-bearings-catalogue.pdf?dl=0
#T.12	Bakelite PF 31		20 may 2018	https://www.dropbox.com/s/mqay4so0ky1sk2c/%23T.12%20Bakelite%20PF%2031.pdf?dl=0
#T.13	small _push_pull_solenoid :304		20 may 2018	https://www.dropbox.com/s/g6gyxu0ta0cx9fj/%23T.13%20small_push_pull_solenoid_304.pdf?dl=0
#T.14	Referanse Skrue og muttere 30D84CA729CE439FBAD383EC8E5CB7BA		20 may 2018	https://www.dropbox.com/s/ra8llrdwmi8563v/%23T.14%20Referanse%20Skruer%20og%20muttere%2030D84CA729CE439FBAD383EC8E5CB7BA.pdf?dl=0
#T.15	Reference Brushes		20 may 2018	https://www.dropbox.com/s/kzw6867u57bkdpz/%23T.15%20Reference%20Brushes.pdf?dl=0

#T.16	Nødvendig samtale CONFIDENTIAL AND CENCORED	1.0	20 may 2018	https://www.dropbox.com/s/i3vxppat5qbqhx6/%23T.16%20N%C3%B8dvendig%20samtale%20CONFIDENTIAL%20AND%20CENSORED%20%201.0.pdf?dl=0
#T.17	Ballscrew maintance		20 may 2018	https://www.dropbox.com/s/zjg7lnslk9gb6um/%23T.17%20ballscrew_maintenance_en.pdf?dl=0
#T.18	Fag vinkel kontakt		20 may 2018	https://www.dropbox.com/s/lvnr4b8usfys6uh/%23T.18%20Fag_vinkelkontakt.pdf?dl=0
#T.19	2SL-3rd-20170403		20 may 2018	https://www.dropbox.com/s/p39zy330r4frq8u/%23T.19%202SL-3rd-20170403.pdf?dl=0
#T.20	Gjenger		20 may 2018	https://www.dropbox.com/s/t5weig4b123i9bp/%23T.20%20Gjenger.pdf?dl=0
#T.21	Ballscrew_maintenance_en		20 may 2018	https://www.dropbox.com/s/08ddxq1omn4gvmi/%23T.21%20Ballscrew_maintenance_en.pdf?dl=0
#T.22	Maintanence and Service	1.0	20 may 2018	https://www.dropbox.com/s/2mtmn46uwkhka3w/%23T.22%20Maintanence%20and%20Service%201.0.pdf?dl=0
#T.23	Knowledge-Brief Consept Ball Screw	1.0	20 may 2018	https://www.dropbox.com/s/xxtdckzy5ikyw9z/%23T.23%20Knowledge-Brief%20Consept%20Ball%20Screw%201.0.pdf?dl=0
#T.24	Knowledge-Brief Excel-PDF force analyzer	1.0	20 may 2018	https://www.dropbox.com/s/wzckzcpdhe1nptm/%23T.24%20Knowledge-Brief%20Excel-PDF%20force%20analyzer%20R%201.0.pdf?dl=0
#T.25	Knowledge-Brief Force ESTIMATE	1.0	20 may 2018	https://www.dropbox.com/s/c1o83sd9acv1h8t/%23T.25%20Knowledge-Brief%20Force%20ESTIMATE%201.0.pdf?dl=0
#T.26	Knowledge-Brief Force estimate	1.0	20 may 2018	https://www.dropbox.com/s/7f2gcila53831zs/%23T.26%20Knowledge-Brief%20Force%20estimate%201.3.pdf?dl=0
#T.27	Knowledge-Brief Force requirements	1.0	20 may 2018	https://www.dropbox.com/s/53uaki8q343698x/%23T.27%20Knowledge-Brief%20Force%20requirements%201.0.pdf?dl=0
#T.28	Knowledge-Brief Friction comparison	1.0	20 may 2018	https://www.dropbox.com/s/cdwwm00smblnwuj/%23T.28%20Knowledge-Brief%20Friction%20comparison%201.0.pdf?dl=0
#T.29	A3 Documentation method studie	1.0	20 may 2018	https://www.dropbox.com/s/2mzy5j4vbe5g7l7/%23T.29%20A3%20Documentation%20method%20studie%20R%201.0.pdf?dl=0
#T.30	References for Friction study	1.0	20 may 2018	https://www.dropbox.com/s/7mhdfzveratjb8s/%23T.30%20References%20for%20Friction%20study%201.0.pdf?dl=0

#T.31	Knowledge-Brief Concept assignemts	1.0	20 may 2018	https://www.dropbox.com/s/31p2fc9qg8m53zb/%23T.31%20Knowledge-Brief%20Concept%20assignemts%20R%201.0.pdf?dl=0
#T.32	Torque Calculation Sinus frontpage	1.0	20 may 2018	https://www.dropbox.com/s/prjviecoml52sop/%23T.32%20Torque%20Calculation%20Sinus%20frontpage%201.0.pdf?dl=0
#T.33	Torque calculatons Sinus	1.0	20 may 2018	https://www.dropbox.com/s/l992yyo5og0dl53/%23T.33%20Torque%20calculatons%20Sinus%201.0.pdf?dl=0
#T.34	Knowledge-Brief Motion analyzer INTRODUCTION	1.0	20 may 2018	https://www.dropbox.com/s/ji2w9bcfria6soy/%23T.34%20Knowledge-Brief%20Motion%20analyzer%20INTRODUCTION%20%201.0.pdf?dl=0
#T.35	University Physics		20 may 2018	https://www.dropbox.com/s/p3nfdyjm88nfy2x/%23T.35%20University%20Physics.pdf?dl=0
#T.36	Knowledge-Brief Initial Function description	1.0	20 may 2018	https://www.dropbox.com/s/4kbjcd817li7de9/%23T.36%20Knowledge-Brief%20Initial%20Function%20description%201.1.pdf?dl=0
#T.37	Knowledge-Brief Radac Elmag dog Concept description	1.0	20 may 2018	https://www.dropbox.com/s/k3ftn10lbvgcvpc/%23T.37%20Knowledge-Brief%20Radac%20Elmag%20dog%20Concept%20description%20R%201.0.pdf?dl=0
#T.38	Knowledge-Brief Radac Elmag dog Concept evaluation	1.0	20 may 2018	https://www.dropbox.com/s/rltox8sbyqbdcj1/%23T.38%20Knowledge-Brief%20Radac%20Elmag%20dog%20Concept%20evaluation%20R%201.0.pdf?dl=0
#T.39	Knowledge-Brief RadAc Reluctance motor	1.0	20 may 2018	https://www.dropbox.com/s/puoe3nl26vfff7u/%23T.39%20Knowledge-Brief%20RadAc%20Reluctance%20motor%20R%201.0.pdf?dl=0
#T.40	Knowledge-Brief Initial Position Calculation	1.0	20 may 2018	https://www.dropbox.com/s/ftjyekzjsk2030v/%23T.40%20Knowledge-Brief%20Initial%20Position%20Calculation%201.0.pdf?dl=0
#T.41	Solenoid force		20 may 2018	https://www.dropbox.com/s/aez0lbghgre2qeh/%23T.41%20Solenoid%20force%2010.1.1.428.9647.pdf?dl=0
#T.42	Knowledge-Brief Re-Act Initial Function description	1.0	20 may 2018	https://www.dropbox.com/s/w4b49yfk33tr373/%23T.42%20Knowledge-Brief%20Re-Act%20Initial%20Function%20description%201.0.pdf?dl=0
#T.43	Excel Force Position Curve	1.0	20 may 2018	https://www.dropbox.com/s/7m50m3zyidxn7zc/%23T.43%20Excel%20Force%20Position%20Curve%201.0.xlsx?dl=0

#T.44	Knowledge-Brief Force requirements	1.0	20 may 2018	https://www.dropbox.com/s/ongamnvj01d3eqb/%23T.44%20Knowledge-Brief%20Force%20requirements%201.0.pdf?dl=0
#T.45	Knowledge-Brief Motion study	1.0	20 may 2018	https://www.dropbox.com/s/695fvyqo75rxuoi/%23T.45.%20Knowledge-Brief%20Motion%20study%201.0.pdf?dl=0
#T.46	Motion study	1.0	20 may 2018	https://www.dropbox.com/s/sxr15ltlpa7xis8/%23T.46%20Motion%20study%201.0.xlsx?dl=0
#T.47	Knowledge-Brief Why K-Brief	1.0	20 may 2018	https://www.dropbox.com/s/4julltcoojojv9o/%23T.47%20Knowledge-Brief%20Why%20K-Brief%20R%201.0.pdf?dl=0
#T.48	Knowledge-Brief Template one side	1.0	20 may 2018	https://www.dropbox.com/s/3h6j6sthjod0u8z/%23T.48%20Knowledge-Brief%20Template%20one%20side%20R%201.0.pdf?dl=0
#T.49	Requirements evluation	1.0	20 may 2018	https://www.dropbox.com/s/6it6lht04iizvi1/%23T.49%20Requirements%20evluation%201.2.xlsx?dl=0
#T.50	Torque calculatons Sinus	1.0	20 may 2018	https://www.dropbox.com/s/w773xt9hm9xv1k4/%23T.50%20Torque%20calculatons%20Sinus%201.0.xlsx?dl=0
#T.51	References for Friction study	1.0	20 may 2018	https://www.dropbox.com/s/6icowwgmgpkfcka/%23T.51%20References%20for%20Friction%20study%201.0.pdf?dl=0
#T.52	Knowledge-Brief Friction comparison	1.0	20 may 2018	https://www.dropbox.com/s/orw0xlc652779oc/%23T.52%20Knowledge-Brief%20Friction%20comparison%201.0.pdf?dl=0
#T.53	Knowledge-Brief Bearing axial and radial both sides exploded view	1.0	20 may 2018	https://www.dropbox.com/s/ikok06445j90tiw/%23T.53%20Knowledge-Brief%20Bearing%20axial%20and%20radial%20both%20sides%20exploded%20view%20R%201.0.pdf?dl=0
#T.54	Knowledge-Brief Cog hub left side exploded view	1.0	20 may 2018	https://www.dropbox.com/s/srzmqr6bc8877cu/%23T.54%20Knowledge-Brief%20Cog%20hub%20left%20side%20exploded%20view%20R%201.0.pdf?dl=0
#T.55	Knowledge-Brief Cog hub right side exploded view	1.0	20 may 2018	https://www.dropbox.com/s/30n05y4125iv9pz/%23T.55%20Knowledge-Brief%20Cog%20hub%20right%20side%20exploded%20view%20R%201.0.pdf?dl=0
#T.56	Knowledge-Brief Connector brush unit exploded view	1.0	20 may 2018	https://www.dropbox.com/s/9cnuykitg3jojz6/%23T.56%20Knowledge-Brief%20Connector%20brush%20unit%20exploded%20view%20R%201.0.pdf?dl=0

#T.57	Knowledge-Brief Locking mechanism exploded view	1.0	20 may 2018	https://www.dropbox.com/s/46lsozzfl11cq3b/%23T.57%20Knowledge-Brief%20Locking%20mechanism%20exploded%20view%20R%201.0.pdf?dl=0
#T.58	Knowledge-Brief Main exploded view	1.0	20 may 2018	https://www.dropbox.com/s/5dvhlnvyrt15ak2/%23T.58%20Knowledge-Brief%20Main%20exploded%20view%20R%201.0.pdf?dl=0
#T.59	Knowledge-Brief Rotator exploded view	1.0	20 may 2018	https://www.dropbox.com/s/l8h2vro61ejon4e/%23T.59%20Knowledge-Brief%20Rotator%20exploded%20view%20R%201.0.pdf?dl=0
#T.60	Knowledge-Brief Solenoid tooth mechanism exploded view	1.0	20 may 2018	https://www.dropbox.com/s/fkynwxjjy37brrz/%23T.60%20Knowledge-Brief%20Solenoid%20tooth%20mechanism%20exploded%20view%20R%201.0.pdf?dl=0

9. februar 2018

Referat fra «Nødvendig samtale»

Tilstede:
XXXXXXXXXX
Torjus Haugerud

Referent:
Torjus Haugerud

I forkant av samtalen er det oppfordret til å vurdere
1. Hvilke informasjon det er greit å dele.
2. Om det er noe leder eller gruppa kan gjøre for å tilrettelegge for ifbm. gjennomføringen av prosjektet.

Bakgrunnen for samtalen er at det er foretatt en risikovurdering ifbm. et lengre sykefravær rett før jul. Det har foregått flere samtaler på telefon og uformelle face to face mellom undertegnede og XXXX der det er informert om og diskutert situasjonen der utenforstående «skaper problemer».

Det ble foretatt et møte med Karoline den 13 desember 2017. Referat fra denne er skrevet og sendt til XXXXX. Samtalen i dag er ment for å ivareta risikoen som ble diskutert med Karoline. Situasjonen har vært under løpende vurdering og dette møtet er ment som en oppsummering og avrunding, eller initiering av en mer permanent løsning.

Det har kun vært ett tilfelle der XXXXXX ikke har kunnet utføre avtalt arbeid (gjennomføring av møte han skulle lede).

XXXXX informerer om situasjonen og er klar på at risikoen for at det skal oppstå problemer der han blir satt tilbake og eller ikke blir i stand til å delta i prosjektet på lik linje med de øvrige gruppemedlemmene er sterkt redusert.

Han er klar på at situasjonen er under kontroll og at det ikke er behov for å tilrettelegge.

Vi blir enige om at situasjonen vurderes som normal og at denne saken avsluttes.

Møtet varer i en time.

____
Gruppeleder

PDF *Attachment*

K-Brief owner: Torjus Haugerud	Document name: Attachment: Maintenance and Service	References:
Date: 19 March 2018	**Revision number:** R 1.0	**Additional documentation:**

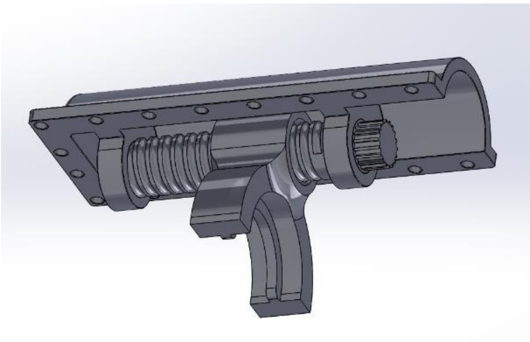
Attachment Maintenance and Service

File path:
S.U.D-Torjus-Attachments

Knowledege-Brief

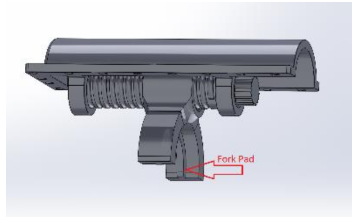
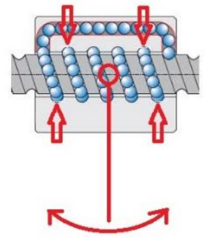
Concept evaluation:
Ball Screw

Author: Torjus Haugerud
Concept: Torjus Haugerud



Highligts

Advantages	Challenges/possibl solutions
Can be module based	
Well known technology	New application. Unusual tilting force
Large “radial” tolerance against sleeve, easy to mount	Little support.
Easy to modify with support rail/guide for handling of tilting forces on ball nut.	Draw new concept (later) with support rail
Linear forces well covered	
Linear force gear ratio	electronic dynamic force control
Linear speed gear ratio	eletric dynamic speed control
Deflection in ball nut towards screw due to unusual load	Bearing, durability test. R&D. Perhaps buy and test to failure ?
Can be made self-centering	Needs electric end stop and sensing of zero load for sensing of “in fore” and “in aft” gear position
Obvious concept	Obvious concept, thorough patent search neccesary
Few moving parts	
Good handling of axial and radial force in casing	Tilting force creates large “bending” torque.
Easy to operate manually by handle in end far from motor	Manually operation can be difficult to reach in vihecle.

	Force: 1. Max. 1200N on fork pad 2. Acceleration of sleeve.
	Wearing points due to tilting force. Assumes dist from fork pad to center of ballnut 150mm. Static torque in centerpoint: $torque = 1200N \times 150mm = 180Nm$ Assumes that ball nut is 80mm wide: $Force = \frac{180Nm}{80mm} = 2250N$

Excel-PDF force analyser *K-Brief*

K-Brief owner:	Document name:	References:
Torjus Haugerud	Knowledge-Brief Excel-PDF force analyser	
Date:	**Revision number:**	**Additional documentation:**
15 March. 2018	R 1.0	Excel force position curve 2.9

Objective:
This Brief shows the raw date from Excel file;
Excel force position curve 2.9

Change with linear acceleration

Time (s)	Position (mm) (S=v+v*t+0,5*a*t^2)	Velocity (m/s) v=v+a*t	Velocity > 0	Displacement margin	Displacement	Kumulativt displacement (Position)	Displacement Increments (s=v*t)	Max. acceleration (m/s^2)
0	0	0	0	0	0	0	0,00000	0
0,001	0,00001	0,018	0,018	0	0,000018	0,000018	0,00002	18
0,002	0,00004	0,036	0,036	0	0,000036	0,000036	0,00004	18
0,003	0,00008	0,054	0,054	0	0,000054	0,00009	0,00005	18
0,004	0,00014	0,072	0,072	0	0,000072	0,000162	0,00007	18
0,005	0,00023	0,090	0,09	0	0,00009	0,000252	0,00009	18
0,006	0,00032	0,108	0,108	0	0,000108	0,00036	0,00011	18
0,007	0,00044	0,126	0,126	0	0,000126	0,000486	0,00013	18
0,008	0,00058	0,144	0,144	0	0,000144	0,00063	0,00014	18
0,009	0,00073	0,162	0,162	0	0,000162	0,000792	0,00016	18
0,010	0,00090	0,180	0,18	0	0,00018	0,000972	0,00018	18
0,011	0,00109	0,198	0,198	0	0,000198	0,00117	0,00020	18
0,012	0,00130	0,216	0,216	0	0,000216	0,001386	0,00022	18
0,013	0,00152	0,234	0,234	0	0,000234	0,00162	0,00023	18
0,014	0,00176	0,252	0,252	0	0,000252	0,001872	0,00025	18
0,015	0,00203	0,270	0,27	0	0,00027	0,002142	0,00027	18
0,016	0,00230	0,288	0,288	0	0,000288	0,00243	0,00029	18
0,017	0,00260	0,306	0,306	0	0,000306	0,002736	0,00031	18
0,018	0,00291	0,306	0,306	0	0,000306	0,003042	0,00031	0
0,019	0,00321	0,306	0,306	0	0,000306	0,003348	0,00031	0
0,020	0,00352	0,306	0,306	0	0,000306	0,003654	0,00031	0
0,021	0,00383	0,306	0,306	0	0,000306	0,00396	0,00031	0
0,022	0,00413	0,306	0,306	0	0,000306	0,004266	0,00031	0
0,023	0,00444	0,306	0,306	0	0,000306	0,004572	0,00031	0
0,024	0,00474	0,306	0,306	0	0,000306	0,004878	0,00031	0
0,025	0,00505	0,306	0,306	0	0,000306	0,005184	0,00031	0
0,026	0,00536	0,306	0,306	0	0,000306	0,00549	0,00031	0
0,027	0,00566	0,306	0,306	0	0,000306	0,005796	0,00031	0
0,028	0,00597	0,306	0,306	0	0,000306	0,006102	0,00031	0
0,029	0,00627	0,306	0,306	0	0,000306	0,006408	0,00031	0
0,030	0,00658	0,306	0,306	0	0,000306	0,006714	0,00031	0
0,031	0,00689	0,306	0,306	0	0,000306	0,00702	0,00031	0
0,032	0,00719	0,306	0,306	0	0,000306	0,007326	0,00031	0
0,033	0,00750	0,306	0,306	0	0,000306	0,007632	0,00031	0
0,034	0,00780	0,306	0,306	0	0,000306	0,007938	0,00031	0
0,035	0,00811	0,306	0,306	0	0,000306	0,008244	0,00031	0
0,036	0,00842	0,306	0,306	0	0,000306	0,00855	0,00031	0
0,037	0,00872	0,306	0,306	0	0,000306	0,008856	0,00031	0
0,038	0,00903	0,306	0,306	0	0,000306	0,009162	0,00031	0
0,039	0,00933	0,306	0,306	0	0,000306	0,009468	0,00031	0
0,040	0,00964	0,306	0,306	0	0,000306	0,009774	0,00031	0
0,041	0,00995	0,306	0,306	0	0,000306	0,01008	0,00031	0
0,042	0,01024	0,288	0,288	0	0,000288	0,010368	0,00029	18
0,043	0,01052	0,270	0,27	0	0,00027	0,010638	0,00027	18
0,044	0,01078	0,252	0,252	0	0,000252	0,01089	0,00025	18
0,045	0,01103	0,234	0,234	0	0,000234	0,011124	0,00023	18
0,046	0,01125	0,216	0,216	0	0,000216	0,01134	0,00022	18
0,047	0,01146	0,198	0,198	0	0,000198	0,011538	0,00020	18
0,048	0,01165	0,180	0,18	0	0,00018	0,011718	0,00018	18
0,049	0,01182	0,162	0,162	0	0,000162	0,01188	0,00016	18
0,050	0,01197	0,144	0,144	0	0,000144	0,012024	0,00014	18
0,051	0,01211	0,126	0,126	0	0,000126	0,01215	0,00013	18
0,052	0,01222	0,108	0,108	0	0,000108	0,012258	0,00011	18
0,053	0,01232	0,090	0,09	0	0,00009	0,012348	0,00009	18
0,054	0,01240	0,072	0,072	0	0,000072	0,01242	0,00007	18
0,055	0,01247	0,054	0,054	0	5,4E-05	0,012474	0,00005	18
0,056	0,01251	0,036	0,036	0	3,6E-05	0,01251	0,00004	18
0,057	0,01254	0,018	0,018	0	1,8E-05	0,012528	0,00002	18
0,058	0,01255	-0,000	0	-1,61E-18	0	0,012528	0,00000	18
0,059	0,01254	-0,018	0	-0,001062	0	0,012528	-0,00002	18
0,060	0,01251	-0,036	0	-0,00216	0	0,012528	-0,00004	18

Input / Output

Acceleration (m/s^2)	Deceleration (m/s^2)	Acceleration/deceleration distribution (m/S^2)	Mass (kg)	Force acceleration (N)	Load magnitude (N)	Load distribution (N)	Displacement (mm) (Calculated)	Margin (mm) (Calculated)	Max. Velocity (m/s) (Calculated)	Max. acceleration (m/s) (Calculated)	Total force (N) Calculated
18	-18	0	0,5	0,00	1200		12,546	3,222	0,306	18	0,00
		18		9,00							9,00
		18		9,00							9,00
		18		9,00							9,00
		18		9,00							9,00
		18		9,00							9,00
		18		9,00							9,00
		18		9,00							9,00
		18		9,00							9,00
		18		9,00							9,00
		18		9,00		1200					1209,00
		18		9,00		1200					1209,00
		18		9,00		1200					1209,00
		18		9,00		1200					1209,00
		18		9,00		1200					1209,00
		18		9,00		1200					1209,00
		18		9,00		1200					1209,00
		18		9,00		1200					1209,00
		0		0,00		1200					1200,00
		0		0,00		1200					1200,00
		0		0,00		1200					1200,00
		0		0,00		1200					1200,00
		0		0,00		1200					1200,00
		0		0,00		1200					1200,00
		0		0,00		1200					1200,00
		0		0,00		1200					1200,00
		0		0,00		1200					1200,00
		0		0,00		1200					1200,00
		0		0,00		1200					1200,00
		0		0,00		1200					1200,00
		0		0,00		1200					1200,00
		0		0,00							0,00
		0		0,00							0,00
		0		0,00							0,00
		0		0,00							0,00
		0		0,00							0,00
		0		0,00							0,00
		0		0,00							0,00
		0		0,00							0,00
		0		0,00							0,00
		0		0,00							0,00
		0		0,00							0,00
		-18		9,00							9,00
		-18		9,00							9,00
		-18		9,00							9,00
		-18		9,00							9,00
		-18		9,00							9,00
		-18		9,00							9,00
		-18		9,00							9,00
		-18		9,00							9,00
		-18		9,00							9,00
		-18		9,00							9,00
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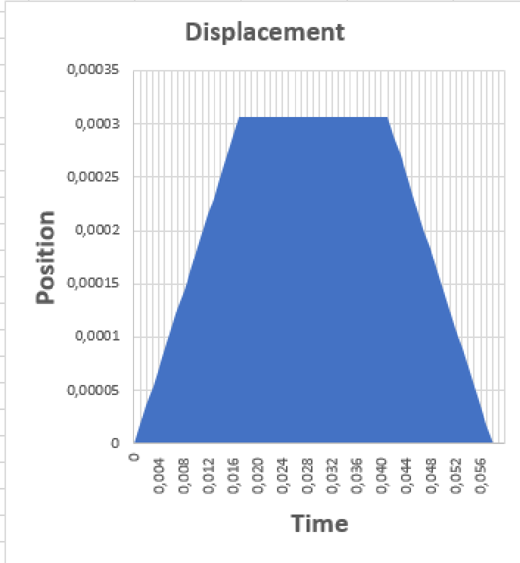
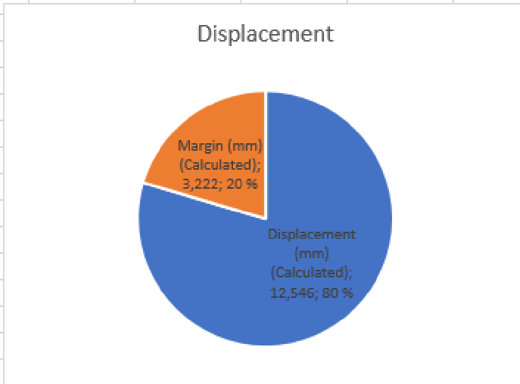
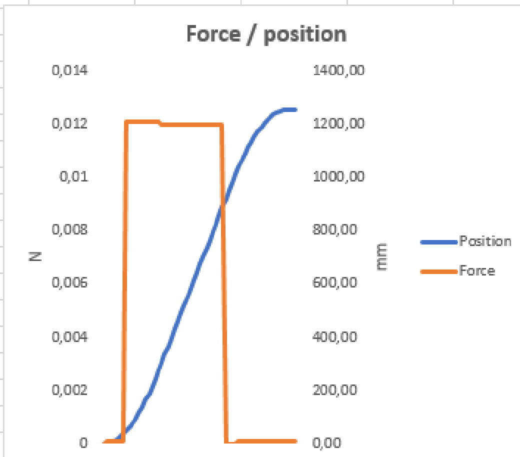
		-18		9,00							9,00







Force - *ESTIMATE* *K-Brief*

K-Brief owner: Torjus Haugerud	**Document name:** Knowledge-Brief Force ESTIMATE	**References:**
Date: 15 March. 2018	**Revision number:** R 1.0	**Additional documentation:** Excel force position curve 2.9

Objective:

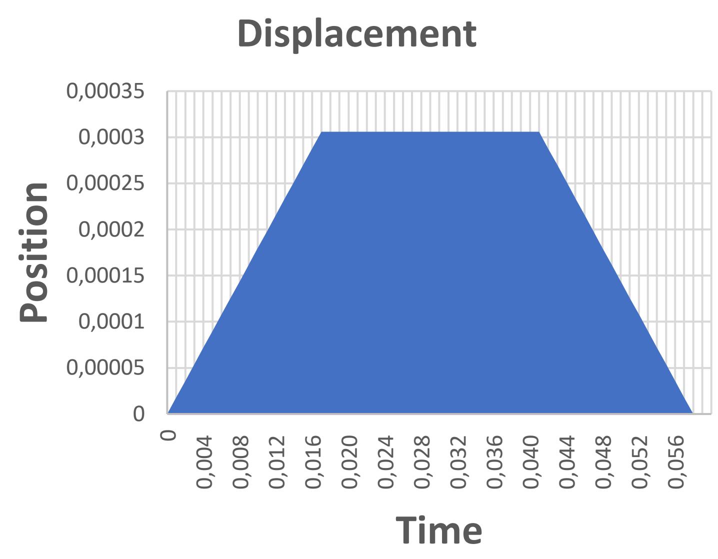
This Brief is aiming to broaden the knowledge about forces and motion involved in a gear change.
Calculations is a preliminary estimate. Further exact calculations will be executed at a later stage.

At this stage it is necessary to survey and estimate.
This Brief will show an approximation that gives a clue, an indication about where to start.

What	
What-Keys	Basic study.
Study of velocity	$v = v_0 + a \times t$ Evaluate adequate top speed.
Study of acceleration	Acceleration is a variable that will be the subject of much examination in this study. it will be examined as an input variable in regard to both intensity and magnitude. Influenced by • Weight and inertia. • Motor performances. • Evaluate adequate maximum acceleration.
Study of displacement/time	$S = S_0 + v_0 \times t + \frac{1}{2} a \times t^2$ Position is calculated as a function of time. Target displacement is 12,15 mm.
Study of forces	Force as a function of acceleration/deceleration and mass. Force as gear-change motion load.
Evaluate margin	To safeguard required operating conditions and performances there must be a margin. This study will enable an evaluation of operating margin. Margin is evaluated as excessive displacement, i.e. the shift fork will reach position before due time.
Why	
Why-Keys	Background - force study.
Streamline process	In accordance with lean process and unified project model. Bring facts to the table. Solve most difficult challenges first.
Refine literature search.	To delineate literature search there is a need for pinpointing what force requirements the actuator shall meet.
Delineate concept ideas.	To concentrate energy and time on relevant concept ideas there is a need for awareness about the choice of force needs.
Agree on basic facts	Increase number of constructive discussions. Decrease level/number of destructive disputes.
Evaluate force.	To increase number and level of relevant concept ideas there is a need for understanding the forces involved.
What not	
What not-Keys	Challenges/possible solutions
Limitations	These estimates are not intended to restrict creative thinking in any way.
Accuracy	The calculations are not meant to be exact. Final calculations must be done according to mathematical standards for greater accuracy.

Conclusion:

To find an optimal concept design there is a need for to study, evaluate and develop knowledge about what force the gearbox needs.
The

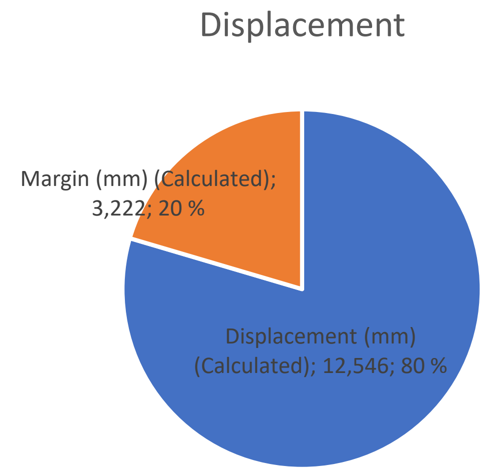


This picture shows how position changes with time.
The blue area shows total displacement.

The margin is removed from the diagram due to focus on reality.

In reality the actuator will not go backwards until it is time to change position.

The excess displacement is delt with in the pie chart

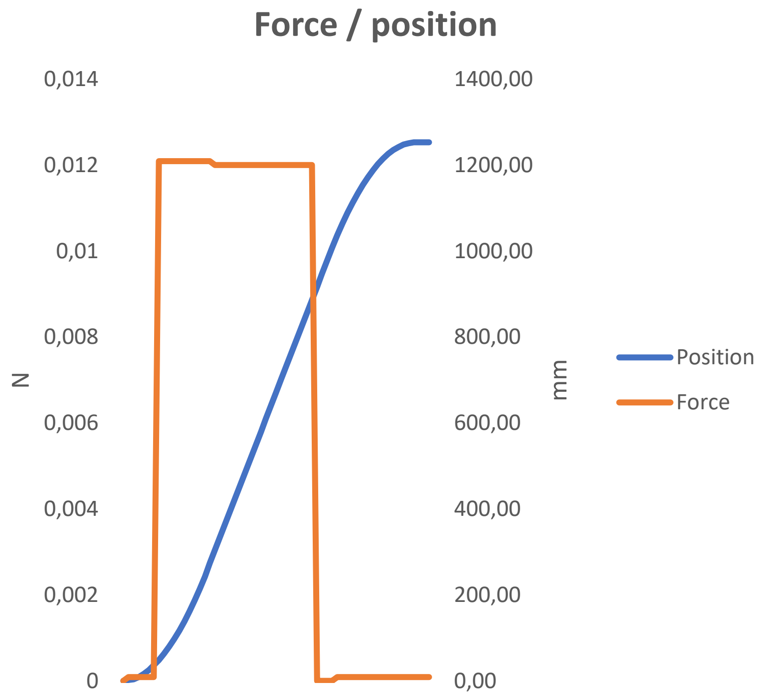


This pie chart shows displacement in blue.

The orange field shows the margin with which the actuator arrives at the stop with.

The actuator must be made with safety a margin as it will operate under changing environment.

Calculations will have to be done with excess to allow some leeway for wear and changing temperature or similar fluctuations.



This picture shows the position in blue. The rounded curve shows an even acceleration which transit into maximum velocity before it decelerates back to zero velocity and finally stop.

In the orange curve there is a remarkably step where the maximum forces occur.

On top of the main step there are a little step.
Here we can see that the forces are extra-large during acceleration.

Motion STUDIE *K-Brief*

K-Brief owner:	Date:	Revision	Aditional documentation:	References:
Torjus Haugerud	6 March 2018	NO.: 1.0	Excel PDF; Force Position Curve v/2.8	

WHAT

What-Keys	Basic study.
Study of velocity	$v = v_0 + a \times t$ Evaluate adequate top speed.
Study of acceleration	Acceleration is a variable that will be the subject of much examination in this study. it will be examined as an input variable in regards to both intensity and magnitude. Influenced by • Weight and inertia. • Motor performances. • Evaluate adequate maximum acceleration.
Study of displacement/time	$S = S_0 + v_0 \times t + \frac{1}{2} a \times t^2$ Position is calculated as a function of time. Target displacement is 12,15 mm.
Study of forces	Force as a funcion of acceleration/deceleration and mass. Force as gear-change motion load.
Evaluate margin	To safeguard required operating conditions and performances there must be a margin. This study will enable an evaluation of operating margin. Margin is evaluated as exessive displacement, i.e. the shift fork will reach position before due time.

WHY

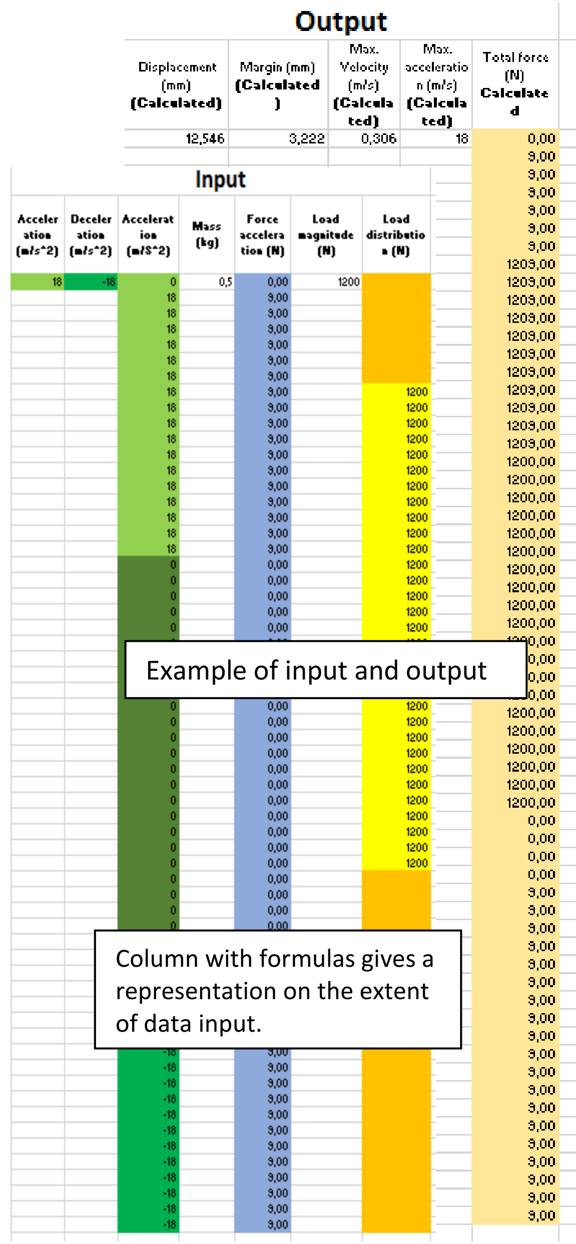
Why-Keys	Background - force study.
Streamline process	In accordance with lean process and unified project model. Bring facts to the table. Solve most difficult challenges first.
Refine litterature search.	To delineate litterature search there is a need for pinpointing what force requirements the actuator shall meet.
Delineate concept ideas.	To concentrate energy and time on relevant concept ideas there is a need for awareness about the choise of force needs.
Agree on basic facts	Increase number of constructive discussions. Decrease level/number of destructive disputes.
Evaluate force.	To increase number and level of relevant concept ideas there is a need for understanding the forces involved.

What NOT

What not-Keys	Challenges/possibl solutions
Limitations	This tool is not intended to restrict creative thinking in any way.
Accurancy	The calculations are not meant to be exactl. Final calculations must be done according to mathematical standards for greater accurancy.

HOW;

Motion analyser



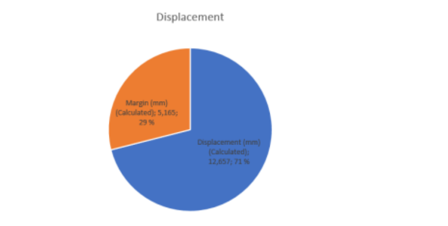
Analysis of motion, acceleration and variable force:

Motion analyzer gives an instant estimate of what the constructor needs to know in a dynamic way.
Key features as slide scales for acceleration, force and load distribution.

1. Put in relevant values.
2. Slide the formulas according to the timescale.
3. The motionanalyzer calculate and give relevant information on graphs and diagram.

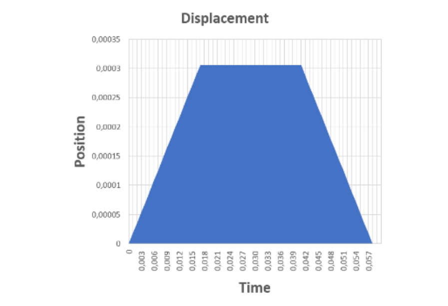
The motion analyzer can easily be adapted and expanded to suit future needs.

Link: ..\..\Force estimate\Excel Force Position Curve 2.8.xlsx



The blue part of displacement pie chart shows at what extent the position has been reached.

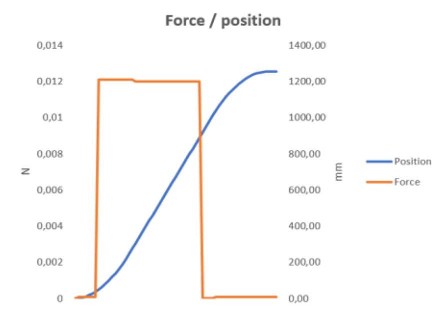
The orange slice shows at what margin the position was reached.



This displacement diagram shows from left; the acceleration phase where the velocity increases at a linear rate.

The flat top shows an even velocity with increasing displacement.

The last part shows deceleration and finally, standstill.



The graph shows how the force is acting in relation to the position.

The blue line shows the position of the shift fork.

The orange graph shows the force and how it is distributed along the motion.

Conclution:
The use of the motion analyzer can guide the team to a more efficient design process.

The motion analyzer must be used to aid unconventional thinking and can encourage the team to look for solutions outside the box by learning more about what type of forces occurs in a concept.

Concept selection *K-Brief*

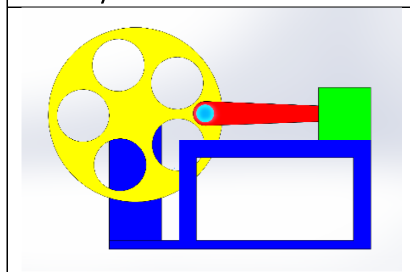
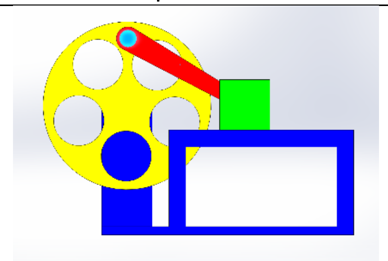
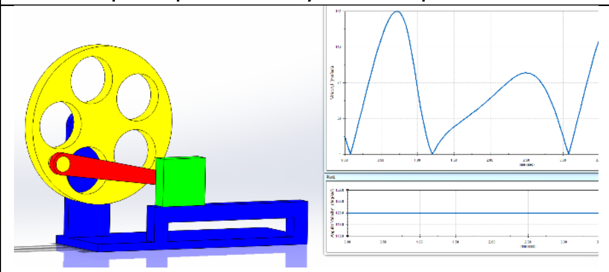
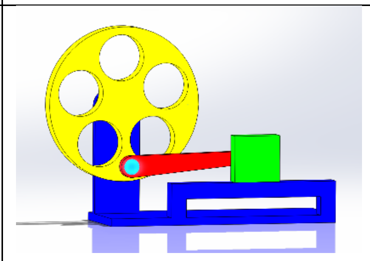
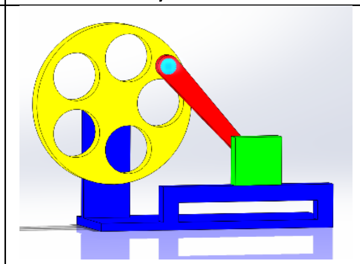
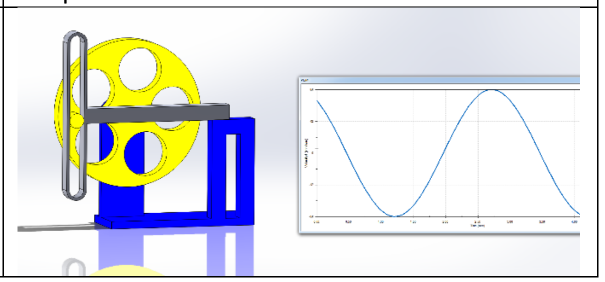
K-Brief owner: Torjus Haugerud	Revision NO.: 1.0	Author: Torjus Haugerud	References:
Concept NO.:	Date: 27 Feb. 2018	Initiated by: Torjus Haugerud	Aditional documentation: Excel PDF; Torque Calculations Sinus 1.0

Why	Background for concept-force study.
Efficiency	Bringing challenges up to the surface to remove botlenecks from the process in accordance with lean process and unified project model.
Refine litterature search.	To delineate litterature search there is a need for pinpointing what force requirements the actuator shall meet.
Delineate concept ideas.	To concentrate energy and time on relevant concept ideas there is a need for awareness about the choise of force needs.
Reduce conflict	To limit the level of conflict within EGA there is a need for basic mechanical understanding.
Evaluate force delivery principle	There seems to be a repeated discussion about concepts with camshaft. To evaluate these consepts there is a need for an analyse of the force delivered by camshafts. This document gives examples of a few similar versions of camshaft force. The force can be considered in multipple ways, this document will show some calculations and a few examples.

Highligts of Crankshafts

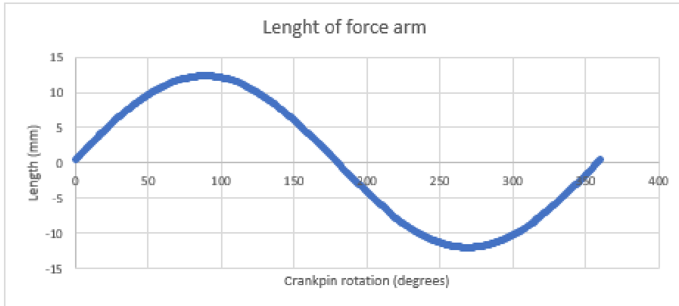
Main objective	Challenges/possibl solutions	References
Torque=Force X Length of arm		
Force characteristics	Nonlinear force	Torque Calculations Sinus 1.0
Expression and definition	TDC=Top Dead Center = 0˚in this document BDC=Bottom Dead Center	

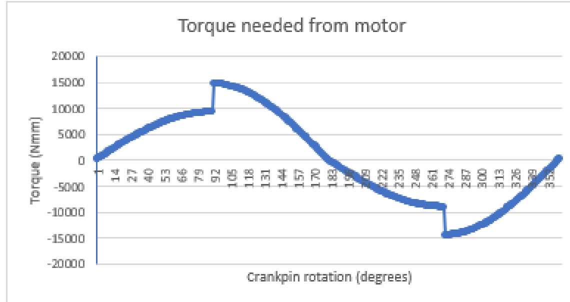
Examples of crankshaft arangments:

TDC, reciprocating motion inline with flywheel shaft	90,˚ velocity at max, exerted torque at min.	Recipricating motion direction *off center* gives uneven push pull velocity and torque.	Off center crank arangement at 270˚	Off center, aApproaching max velocity	Another crancshaft arrangment with horizontal reciprical motion. Gives similar carracteristics.
					

Analysis and calculations based on recipricating motion inline with main shaft:

Lenght (mm)	**12,15**
Maximum pushing force	**750**
Maximum pulling force (N)	**1200**





0˚	Arm lenght →absent
Angle>0˚	As arm lenght increass the torque exerted from the motor decreases.
Angle<90˚	Force from con rod is at it's lowest
Angle=90˚	There is step in the torque needed from the motor as the pulling force to change from "in gear" to "neutral" is greater than from "neutral" to "in gear".
Angle<180˚	As the crank approches half turn the leverage arm is getting shorter thus requiring less torque from the motor.
Angle=180˚	There is a step in the torque needed from the motor as the actuator is now pushing gearsleeeve into gear.
Angle prefix	Positiv/negative values of the graph is directional.
ascending / descending	ascending / descending are referring to which direction the actuation moves.

Conclution:
The use of crancshafts is a flywheels circular motion turned into recipricatong motion. When the flywheel shifts between quadrants the linear velocity either accelerate or decelerate. When the motion shifts between positive and negative the recipricating movement changes direction.
These crankshaft arrangements will give nonlinear velocity, acceleration and torque curve.

A3 documentation-method STUDIE *K-Brief*

K-Brief owner: Torjus Haugerud	**Document name:** Knowledge-Brief Template-two parted	**References:** • Paul Akers, 2 second lean, 2016 edition. • John Shook, http://www.leanuk.org/ general information. • The Toyota Way, Jeffery K. Liker and David Meier, 2006 edition
Date: 13 March 2018	**Revision number:** R 1.0	**Additional documentation:**

Topic: **Knowledge Briefs**	**Question:** **Can the use of K-Briefs benefit our project?**	**Secondarily:** **How can K-Briefs add value to our project?**	**Study:** • **How is K-Briefs utilized elsewhere?** • **Perform a literature study.**

	WHAT	*WHY*	*How*
Keys	*Description.*	*Background - study.*	*Benefits/possible solutions*
Documentation	Documenting: • The process. • Desisjon making. • Author of documents.	*To evolve there must be a process with a theory, and a conscientious plan. Thereafter the team can recap, learn and adjust for further actions* Examiner need grounds for evaluating.	*There is not only one way of documenting.* *Neither is it one way of making a Knowledge-Brief.* The documentation method and argument chosen is regarded as well-founded if it contains some elements like: • What; subject; problem; issue in question. • Why; background; study • How; solution; conclusion. Lean thinking uses a process called PDCA which is: 1. Planning; theory, ideas. 2. Doing; executing plans. 3. Check; learn, study, reflect. 4. Adjust; conclude, evaluate if the prior process where appropriate. Examiners can control the work done according to the documentation-revision list
Traceability	The documentation method needs to make the origin and the path of the process transparent. • Transparent process. • Background for decision. • Origin of decisions. • Trace evaluations. • Trace author.	*Increased awareness about the origins of decisions and the background for evaluations will enhance knowledge obtainment.* Examiners must be able to evaluate authors	Reference system and title bar on top of Brief
Knowledge	Two issues in focus; 1. Documenting knowledge. 2. Making the knowledge available.	The documentation of knowledge is central in every process. *To perceive knowledge the information must be available and visible.*	Concise and visible presentation. Remove unnecessary information.
Efficiency	• Utilize resources. • Focus. • Identify waste	The documentation method is a major part of the project. Resources are limited as it is in most processes. • Improved result. • Increased customer satisfaction. *The Lean way of thinking is focusing on value added work and on removing waste. The choice of documentation method can be either one of these categories depending on how it is executed, and in which form it is presented.*	Remove wasted time. Focus effort. Increase value adding work.
KBD	EGA's project model has a knowledge-obtaining stage in every iteration.	*To add value for the customer, the effort is focused on obtaining knowledge.* KBD is originating from Lean thinking and TPS which focuses on knowledge.	• Utilizing PDCA, Lean thinking and TPS. • Implementing KBD *Utilizing the potential of A3's.*

Conclusion

The use of K-Briefs will benefit our project by:

-Adding efficiency, simplicity, transability and traceability.

-Letting us utilize knowledge as otherwise risk being kept hidden.

Excel file *Attachment*

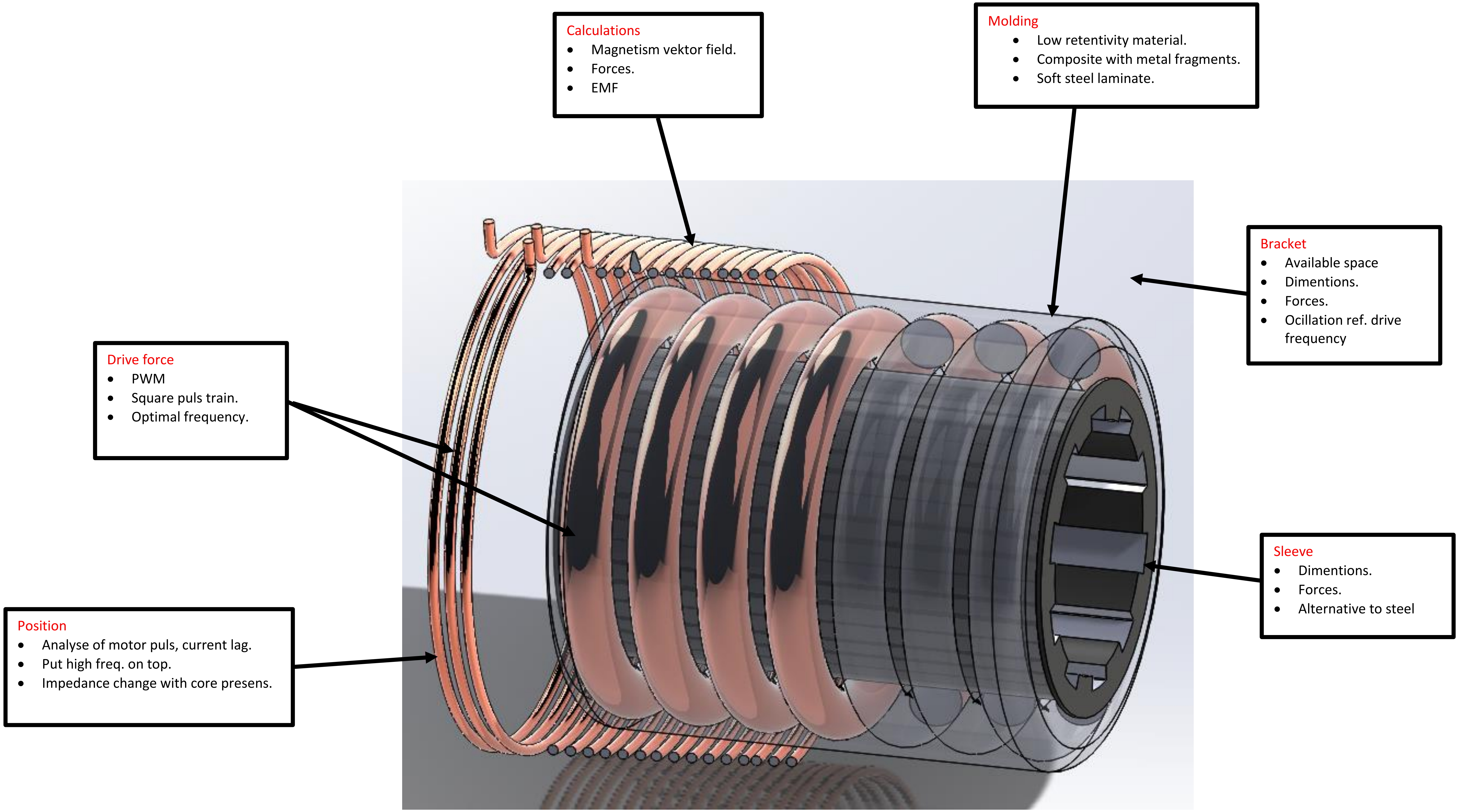
K-Brief owner: Torjus Haugerud	Document name: References for Friction study 1.0	References:
Date: 19 March 2018	**Revision number:** R 1.0	**Additional documentation:**

References for Friction study 1.0:

https://en.wikipedia.org/wiki/Trapezoidal_thread_form#CITEREFBhandari2007
https://etc.usf.edu/clipart/77200/77296/77296_mdrwsqr_scrw.htm
http://armyordnance.tpub.com/Od1645/Od16450132.htm
https://commons.wikimedia.org/wiki/File:Square_thread_form.svg
youtube: Michel van Biezen
Konstruksjonselementer, Dalvig, Christensen, Strømnes
http://mechanicaldesign.asmedigitalcollection.asme.org/article.aspx?articleid=1484895
http://mechanicaldesign.asmedigitalcollection.asme.org/article.aspx?articleid=1446747
https://www.linearmotiontips.com/common-ball-screw-terms-explained/
http://www.codecogs.com/library/engineering/theory_of_machines/screw-threads.php
.

Concept iteration ***K-Brief***

K-Brief owner:	Document name:	References:
Torjus Haugerud	Knowledge-Brief Concept assignments	
Date:	**Revision number:**	**Additional documentation:**
17 April 2018	R 1.0	



Excel file *Attachment*

K-Brief owner:	Document name:	References:
Torjus Haugerud	Torque Calculations Sinus 1.0	
Date:	**Revision number:**	**Additional documentation:**
19 March 2018	R 1.0	

Objective

This document shows the raw data from Excel.

Angle in degrees	Lenght of force arm normal to force	Torque due to pulling/pushing force (Nmm)
0	0	0
1	0,212046738	159,0350537
2	0,424028885	318,0216637
3	0,635881868	476,9114013
4	0,847541156	635,655867
5	1,058942274	794,2067058
6	1,270020829	952,5156215
7	1,480712522	1110,534392
8	1,690953177	1268,214882
9	1,90067875	1425,509063
10	2,109825359	1582,369019
11	2,318329294	1738,74697
12	2,526127043	1894,595283
13	2,73315531	2049,866483
14	2,939351032	2204,513274
15	3,144651398	2358,488548
16	3,348993873	2511,745405
17	3,552316212	2664,237159
18	3,754556482	2815,917361
19	3,955653077	2966,739807
20	4,155544741	3116,658556
21	4,354170587	3265,62794
22	4,55147011	3413,602583
23	4,747383211	3560,537408
24	4,941850213	3706,38766
25	5,13481188	3851,10891
26	5,326209433	3994,657075
27	5,515984572	4136,988429
28	5,704079488	4278,059616
29	5,890436886	4417,827664
30	6,075	4556,25
31	6,25771261	4693,284458
32	6,43851906	4828,889295
33	6,617364275	4963,023207
34	6,794193777	5095,645333
35	6,968953702	5226,715276
36	7,141590815	5356,193112
37	7,312052531	5484,039398
38	7,480286925	5610,215194
39	7,646242751	5734,682063
40	7,809869458	5857,402093
41	7,971117202	5978,337902
42	8,129936867	6097,45265

43	8,286280075	6214,710056
44	8,440099201	6330,074401
45	8,591347391	6443,510544
46	8,739978574	6554,983931
47	8,885947475	6664,460606
48	9,02920963	6771,907222
49	9,1697214	6877,29105
50	9,307439984	6980,579988
51	9,442323432	7081,742574
52	9,574330656	7180,747992
53	9,703421447	7277,566085
54	9,829556482	7372,167361
55	9,952697338	7464,523004
56	10,07280651	7554,60488
57	10,1898474	7642,38555
58	10,30378437	7727,838276
59	10,4145827	7810,937028
60	10,52220866	7891,656492
61	10,62662944	7969,972081
62	10,72781325	8045,85994
63	10,82572927	8119,296952
64	10,92034766	8190,260747
65	11,01163961	8258,729709
66	11,09957731	8324,682983
67	11,18413397	8388,100477
68	11,26528383	8448,962875
69	11,34300218	8507,251636
70	11,41726534	8562,949007
71	11,48805069	8616,03802
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77	11,83859629	8878,947215
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79	11,92677028	8945,077709
80	11,9654142	8974,060649
81	12,00041334	9000,310004
82	12,03175704	9023,817776
83	12,05943574	9044,576807
84	12,08344103	9062,580772
85	12,10376558	9077,824186
86	12,12040321	9090,302408
87	12,13334885	9100,011635
88	12,14259855	9106,948911
89	12,1481495	9111,112122
90	12,15	9112,5
91	12,1481495	14577,7794
92	12,14259855	14571,11826
93	12,13334885	14560,01862
94	12,12040321	14544,48385
95	12,10376558	14524,5187

96	12,08344103	14500,12923
97	12,05943574	14471,32289
98	12,03175704	14438,10844
99	12,00041334	14400,49601
100	11,9654142	14358,49704
101	11,92677028	14312,12433
102	11,88449335	14261,39202
103	11,83859629	14206,31554
104	11,78909307	14146,91169
105	11,73599879	14083,19855
106	11,67932961	14015,19553
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110	11,41726534	13700,71841
111	11,34300218	13611,60262
112	11,26528383	13518,3406
113	11,18413397	13420,96076
114	11,09957731	13319,49277
115	11,01163961	13213,96753
116	10,92034766	13104,4172
117	10,82572927	12990,87512
118	10,72781325	12873,3759
119	10,62662944	12751,95533
120	10,52220866	12626,65039
121	10,4145827	12497,49924
122	10,30378437	12364,54124
123	10,1898474	12227,81688
124	10,07280651	12087,36781
125	9,952697338	11943,23681
126	9,829556482	11795,46778
127	9,703421447	11644,10574
128	9,574330656	11489,19679
129	9,442323432	11330,78812
130	9,307439984	11168,92798
131	9,1697214	11003,66568
132	9,02920963	10835,05156
133	8,885947475	10663,13697
134	8,739978574	10487,97429
135	8,591347391	10309,61687
136	8,440099201	10128,11904
137	8,286280075	9943,53609
138	8,129936867	9755,924241
139	7,971117202	9565,340643
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141	7,646242751	9175,491302
142	7,480286925	8976,34431
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144	7,141590815	8569,908978
145	6,968953702	8362,744442
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352	-1,690953177	-2029,143812
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356	-0,847541156	-1017,049387
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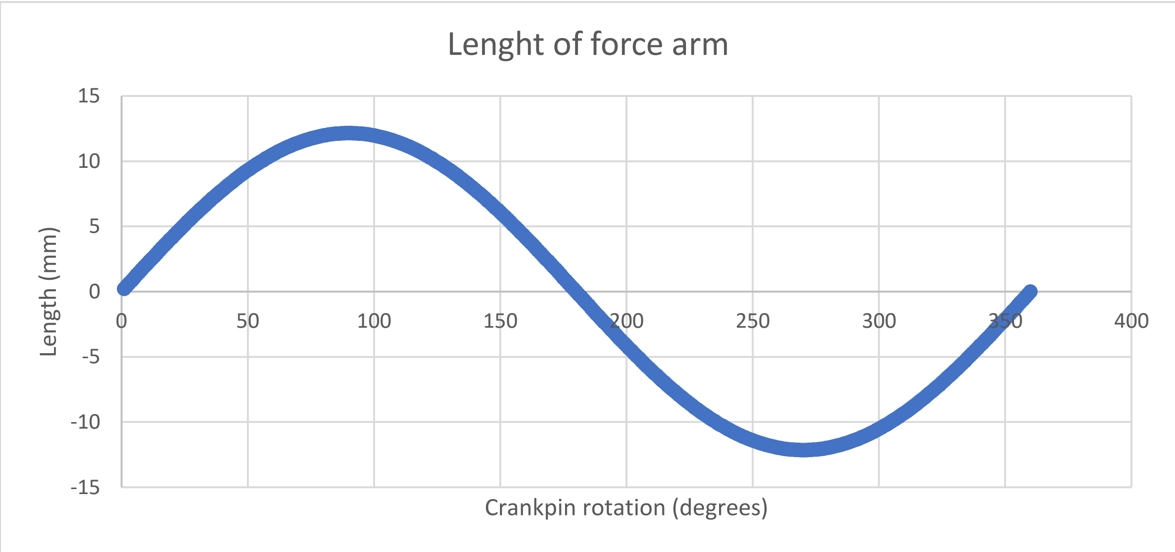
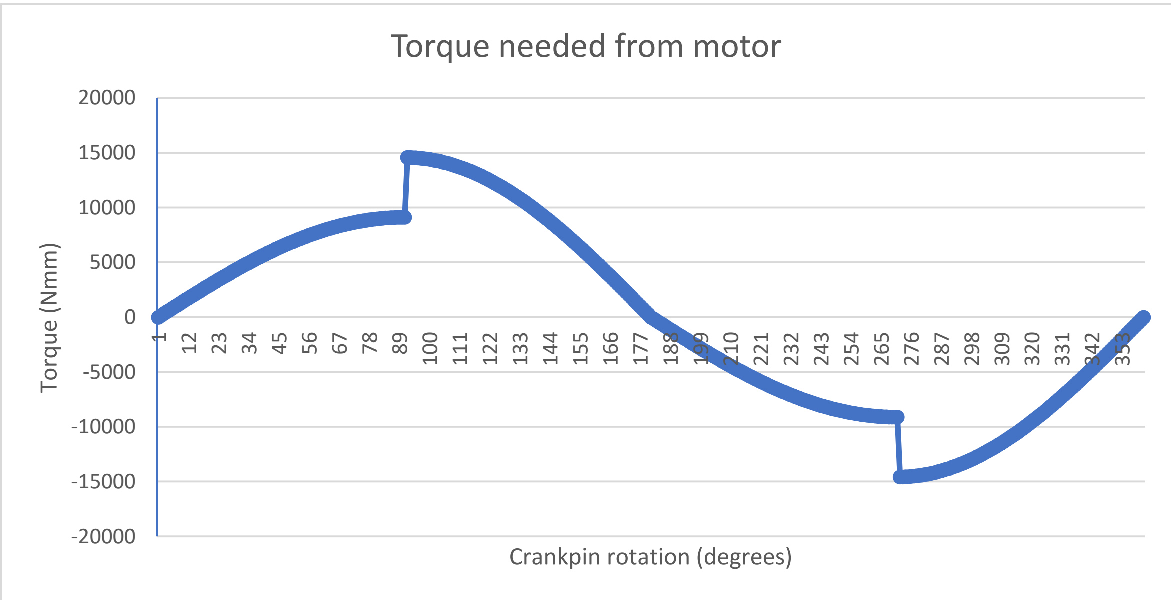
358	-0,424028885	-508,8346619
359	-0,212046738	-254,4560859
360	-2,97711E-15	-3,57253E-12

Lenght (mm)	**12,15**
Maximum pushing force (N)	**750**
Maximum pulling force (N)	**1200**





Motion analyser INTRODUCTION *K-Brief*

EGA

K-Brief owner: Torjus Haugerud	Document name: Knowledge-Brief Motion analyser INTRODUCTION	References:
Date: 15 March. 2018	**Revision number:** R 1.0	**Additional documentation:** Excel force position curve 2.9

Objective:

This Brief is a quick introduction to the use of motion analyzer.
The intention is to enable quick estimates in regard to:

- Forces and loads the actuator must overcome.
- Anticipating speed curve.
- Anticipating force curve.
- Present an overview of the motion sequence.

Introduction to use:

The motion analyzer let you put in a value and then you determine the distribution by dragging the formulas in the table. Hereafter you can read the result in output distribution columns and diagrams.

Output give an estimate for calculations with many variables where exact calculations are made easy by approximating and estimating a margin at the end of travel.

Sufficient margin is necessary as the actuator will operate under variable conditions.

How elements corelate in the analyzer:

	Origin	Influenced by	Value type
Time	Requirements		Table input
Position	Requirements	-Time -Acceleration -Top speed -Deceleration -Requirements -Safety margin	Calculated
Mass		-Design -Material -Construction	Value input
Load magnitude	Requirements	Requirements	Value input
Load distribution	-Load estimate -Gear construction		Input (drag and drop) Distribution
Load total		-Friction -Load distribution -Load magnitude	Calculated
Acceleration and deceleration force max. value		-Max limit -Motor	Calculated
Total force	-Acceleration -Mass- -Load total		Output distribution
Acceleration	Motor, materials	-Acceleration -Mass -Top speed -Deceleration -Safety margin	Value input
Margin		-Acceleration/deceleration distribution	Calculated
Deceleration		-Acceleration -Mass -Top speed -Acceleration -Safety margin	Value input
Acceleration/deceleration distribution		-Acceleration -Deceleration -Top speed -Safety margin	Input (drag and drop) Distribution
Top speed	Motor	-Acceleration -Deceleration -Time	Calculated

Further:

The use and results from the analyser can be seen in:

- Force estimate
- Friction concept-evaluation.
- Excel-PDF force analyser

Input							Output				
Acceleration (m/s^2)	Deceleration (m/s^2)	Acceleration/ deceleration distribution (m/S^2)	Mass (kg)	Force acceleration (N)	Load magnitude (N)	Load distribution (N)	Displacement (mm) (Calculated)	Margin (mm) (Calculated)	Max. Velocity (m/s) (Calculated)	Max. acceleration (m/s) (Calculated)	Total force (N) Calculated
18	-18	0	0,5	0,00	1200		12,546	3,222	0,306	18	0,00
		18		9,00							9,00
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		18		9,00		1200					1209,00
		18		9,00		1200					1209,00
		18		9,00		1200					1209,00
		18		9,00		1200					1209,00
		18		9,00		1200					1209,00
		18		9,00		1200					1209,00
		18		9,00		1200					1209,00
		18		9,00		1200					1209,00
		0		0,00		1200					1200,00
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		0		0,00							0,00
		-18		9,00							9,00
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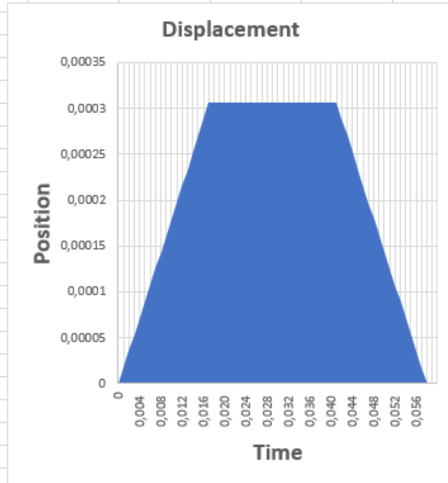
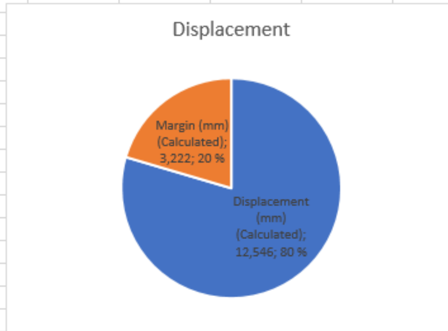
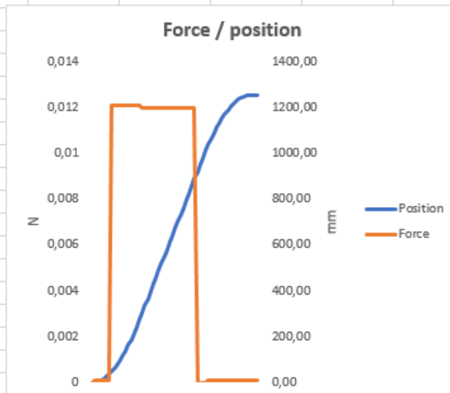






Concept iteration *K-Brief*

K-Brief owner:	Document name:	References:
Torjus Haugerud	Knowledge-Brief Induction shifter Function description	#T.35: University Physics #T.4: Teknisk Formelsamling
Date:	**Revision number:**	**Additional documentation:**
17 April 2018	R 1.1	#Solid Works initial 3D model, #Illustrating pictures from internet. #Oneote sketches

Objective:
Concept description; linear movement by induction.

Describe function and working prinsiples of electric field and the forces driving the actuator.

Teorem:
From Maxwel Faraday's law we can deduct that applying voltage onto a coil of electric wire will let a current flow thru the wire.
The current lags behind the voltage in time and produce an electric field which will be accompanied by a magnetic field, the magnetic field is in phase with the current.

The magnetic field will be present for as long as there is a current flowing in the coil circut.

When introducing a magnetic field to a wire there will be produced an electric current in the wire when the magnetic field is changing.

Theory:
The power applied to the wire in the outer stationary coil will induce an electric field that creates a magnetic field with a north and a south pole. The polarity of the induced electric field will change polarity in relation to time.

The magnetic field in the stator will induce an electric current in the copper rings in the linear moving part.
Copper rings in the moving part induces a magnetic field which magnetise the inner core and thus creating a force that will accelerate the moving part.

Sleeve | Secondary copper rings | Moulding core | Stationary coil | Stationary will be cast in moulding and fixed in bracket

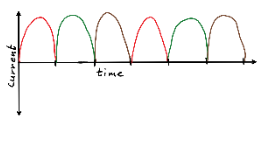
Evaluation keys in short

Pro	*Contra*
• Simple construction • No residual magnetizm. • No bearings. • No wear from moving parts touching eachother	• Permeability from oil residue inside between primary and secondary. • Unknown size/force capability. • Complex phase offset and lag calculations.

Force
Stator coils will be put under a pulsating voltage emulating a wave.

The voltage will result in a current that will lag the voltage in time and will vary with factors like resistance and inductance.

The current in the coil will change with time. The coil will produce a magnetic field which is in phase with the current.



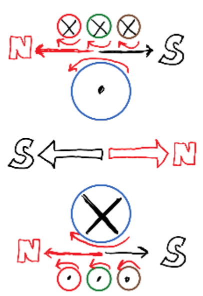
Change in the magnetic field will induce a current in the secondary copper ring.

Resultant of the magnetic fields will change like a wave.

Magnetic field will induce an electric current in the copper ring. The electric current will lag the resultant of the magnetic field.

Copper ring will be made so that there is very little resistance, i.e. manly inductive reactance. Current will lag the induced voltage.

Linear actuator will lag input voltage wave. Lag will depend on load.



Methods of creating a current wave
All motion will happen inside of stationary coil

Relative motion of the magnetic field induces current in the secondary.
Overlapping the curves as seen in fig. 1 may increase force and smothness of motion.
Further simulation and testing will show wether the physical circumstances will make overlapping possible.

Dependent on materials chosen, especially in the core there will be some residual magnetism as seen in the example on the hystereses graph, fig. 3. This may be compensated by adding some opposite polarity power as seen in fig. 4, however opposite power will affect performance, losses and heat development.

The method of rather than a pulsating dc current using an alternating current as in fig. 2 must be further explored by simulating and testing.
Stationary coils will be individually connected to the control unit which enable an easy way of testing by simply programming the sequence of firing order.

Return to center position can be done in two ways, wave pulse or by alternating current equally both ways.

By using alternating current rather than creating a wave there are utilized the effect of magnets centering within eachother on a larger scale.
Further testing will show wether by putting the stationary under full alternating current or a pulse train wave creates more force.

Theoretically a wave should create more force by adding all forces in the same direction.

Alternating current has the benefit of removing more of the residual magnetism, induce more voltage and thus create more force that way.
Simulating and testing are imperative.

If the method of altenating current is more effective and do not create to much heat the control can be done by simply adjusting the zero leve line. This will adjust both the force magnitude and the force direction.
Programming the force will then be about varying the level of the offset.

Fig. 1

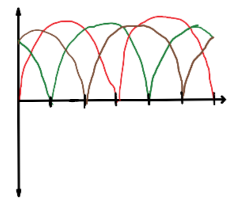


Fig. 2

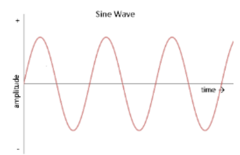


Fig. 3

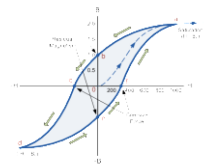
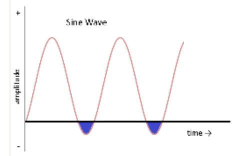


Fig. 4



Concept *K-Brief*

K-Brief owner:	Document name:	References:
Torjus Haugerud	Knowledge-Brief Elmag dog Concept description 1.0	
Date:	**Revision number:**	**Additional documentation:**
24 April 2018	R 1.0	SW drawing

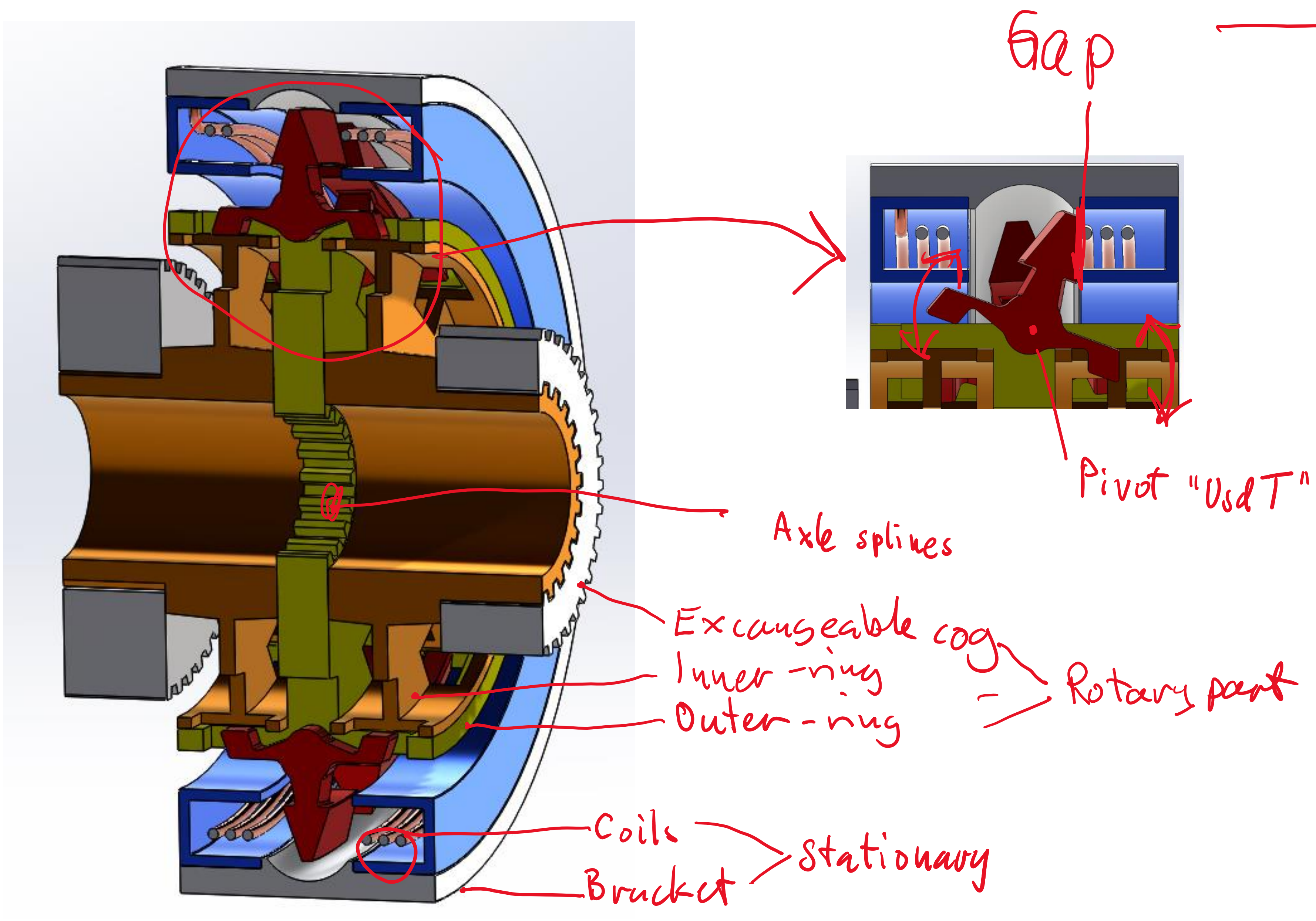
Introduction

Connections are made betwee center and either fore or aft cog.

To activate the gearchange an electric current are sent to the coil on either side, thus creating a magnetic force which is attracting the metal surface on the “UsdT”, or locking key.

The UsdT is pulled by the magnet and pivots into the slot in the inner ring which is then conected to the outer ring creating a mechanical connection between the splines on the inner shaft and the cog on either side of the gearunit.

Note; the actuation is made with a magnetic field thus eliminating any vear on the actuator. The gear unit has of coarse some mechanical conection, however strictly speaking that is not a part of this project which concerns the actuator part of the unit.

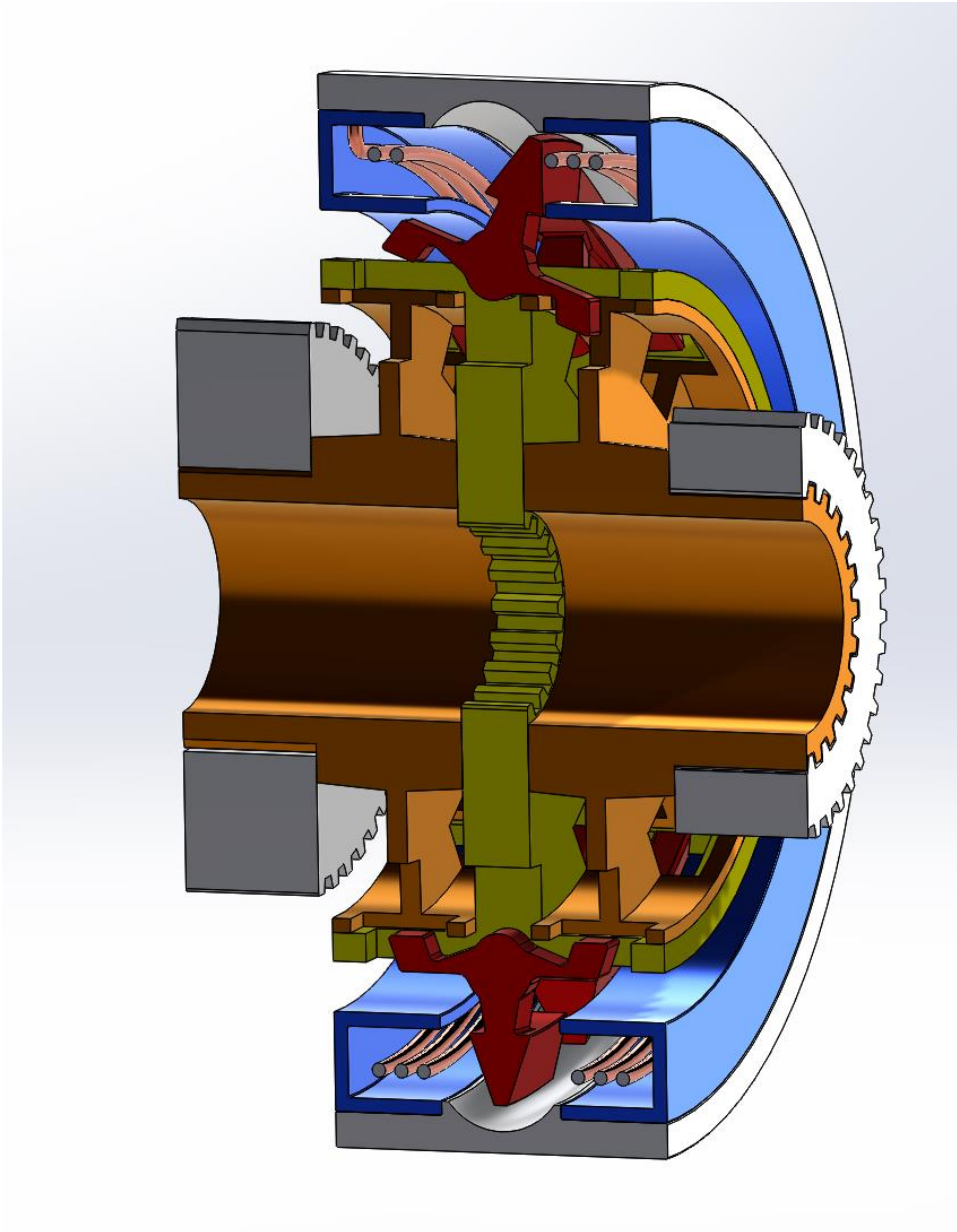


Description.
No mechanical contact between rotational and stationary parts of actuator.
Selection of one gear, either fore or aft.
Standard unit can be adapted by exchanging cogs

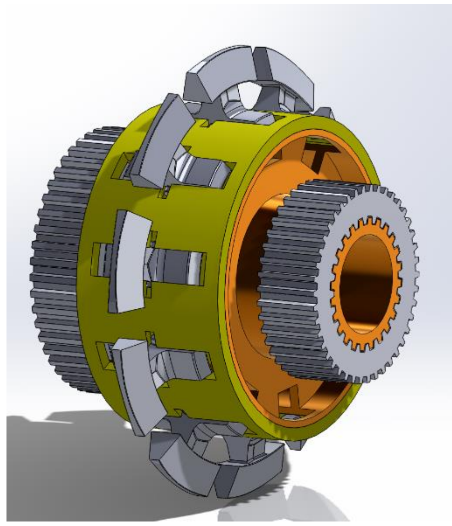
Concept *K-Brief*

K-Brief owner:	Document name:	References:
Torjus Haugerud	Knowledge-Brief Concept evaluation	
Date:	**Revision number:**	**Additional documentation:**
24 April 2018	R 1.0	SW drawing

Challenges	Solutions	Bottleneck
Actuator must never enter two gears simuntaniously	One piece gearshift, tilting either to fore or aft gear.	Good solution, no further risk.
Force requirements, min dist from magnet to tilt lever 3mm	Investigate design. Calculate diligently.	Look for further concept alterations
Smooth gear change.	Electric syncronisation	Simulate and stresstest.
	Mechanical syncronisation.	Needs further development.
Axial suppport	Axial bearings	Needs further development.
Elctro magnets force calculatons	Calculate	Start distance.
Asembling.	Further develop design.	Efficient, low cost.
Radial tooth conection.	Uncnown design	Unproven design, needs testing.
Forces related to angular velocity.	Simulation, calculation.	



Advantages
No mechanical contact between rotational and stationary parts of actuator.



Concept *K-Brief*

K-Brief owner: Torjus Haugerud	Document name: Knowledge-Brief Concept reluctance radial conection	References:
Date: 24 April 2018	**Revision number:** R 1.0	**Additional documentation:**

Pro	Contra
More controlled movement	More complicated movement
Possible to use induction motor, or the reluctance motor.	More complicated programming
New inovative design, outside the box construction. New product, possible improvements?	New unproven design
Unforseen possibilities	Needs extencive testing

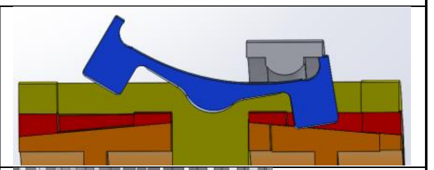
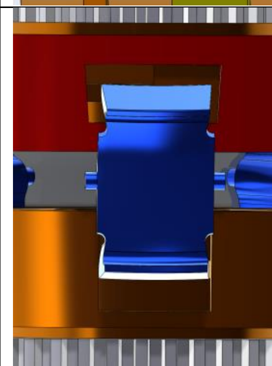
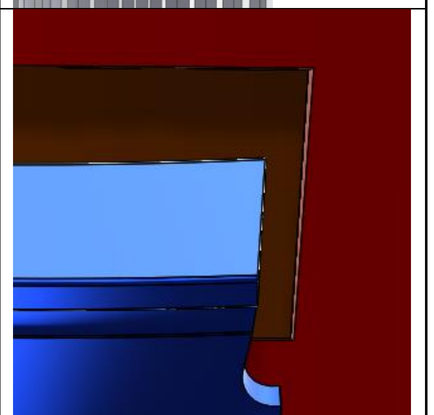
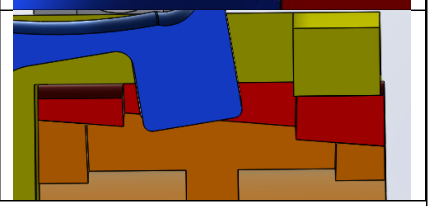
Introduction

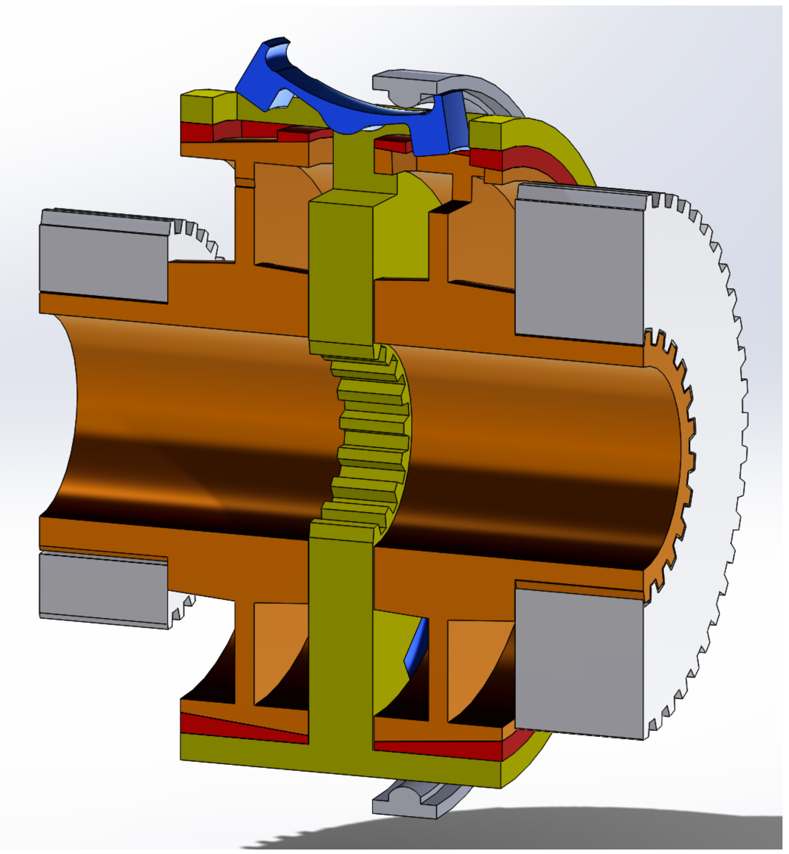
Connections are made betwee center and either fore or aft cog.
To activate the gearchange an electric current are sent to the coils descibed earlier in Reluctance Brief.
The ring is moved axially by the reluctance motor and push the locking key into it's slot.

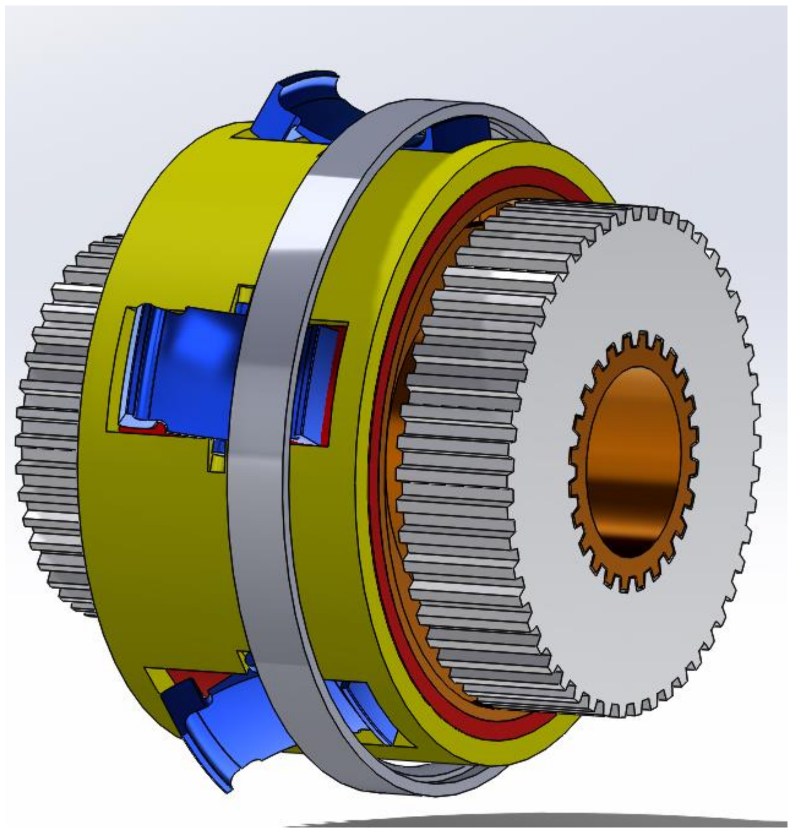
When the locing key first enters the slot it grabs the syncronisation ring. The syncronisation ring slides axially and wedges the inner and outer ring which syncronises the angular velocity making further coupling of the rings smoother.

Coupling of the rings is creating a mechanical connection between the splines on the inner shaft and the cog on either side of the gearunit.

Note; the actuation is made with a magnetic field thus eliminating any vear on the actuator. The gear unit has of coarse some mechanical conection, however strictly speaking that is not a part of this project which concerns the actuator part of the unit.

Lock and sync.	
A linear motor enables more control over positioning and will facilitate a mechanical syncronisation.	
The key locks into the slot.	
Resistance in the syncro ring will grab the key and slide axialy	
The syncro ring is cone shaped and will lock when slided axially.	





Con

Concept iteration *K-Brief*

K-Brief owner: Torjus Haugerud	**Document name:** Knowledge-Brief Induction shifter function	**References:** #T.1: University Physics	#T.4: Teknisk Formelsamling #T.5: All about circuits	#T.6: Verd at vite om FC #T. 7 Inductance and resistance	#T.8 LR circiut
Date: 17 April 2018	**Revision number:** R 1.0	**Additional documentation:** #Solid Works initial 3D model, #Illustrating pictures from internet. #Oneote sketches			

Objective:

To iluminate posible position measuring methods and prinsiples.

This brief is not meant to be exhaustively, but rather a suggestion or starting point.

Teorem:

The current lags behind the voltage in time and produce an electric field which will be accompanied by a magnetic field, the magnetic field is in phase with the current.

The current lag the voltage
The current lag depends on wheter the core

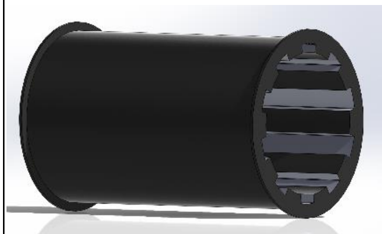
Theory:

The power applied to the wire in the outer stationary coil will induce an electric field that creates a magnetic field with a north and a south pole. The polarity of the induced electric field will change polarity in relation to time.

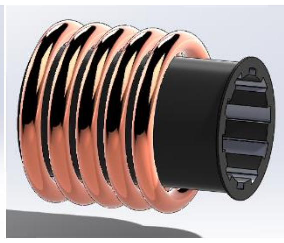
The magnetic field in the stator will induce an electric current in the copper rings in the linear moving part.
Copper rings in the moving part induces a magnetic field which magnetise the inner core and thus creating a force that will accelerate the moving part.

Concept of calculations:	Formula	Utilization
Flux density	$B = \mu \frac{IN}{l}$	The permability changes with the presens of the core, thus changing the magnetic capability.
Inductance	$L = \frac{\mu N^2 A}{l}$	The permabiity changes with the presence of the core thus changing the inductance.
Permabiity	$\mu = \mu_0 + \mu_r$	μ_0 for free space =1,25 EXP^{-6} μ_r for electrical steel 5 EXP^{-3}
Impedance	$Z = \sqrt{R^2 + (X_L + X_C)^2}$	
Inductive reactance	$X_L = \frac{V_p}{I_p} = 2\pi f L$	
Total current	$I = \sqrt{I_a{}^2 + (I_{qL} - I_{qC})^2}$	I_a=Current in resistance (A) I_{qL}=Current in inductive reactance. I_{qC}=Current in capasitive reactance.

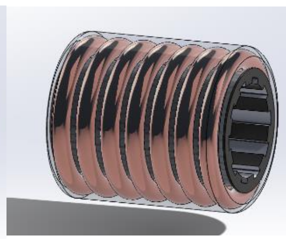
Sleeve



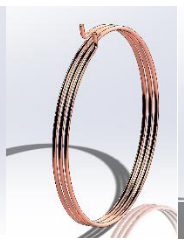
Secondary copper rings

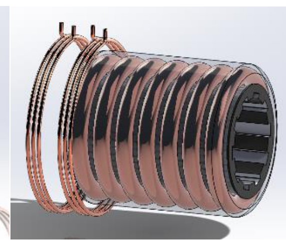


Moulding core

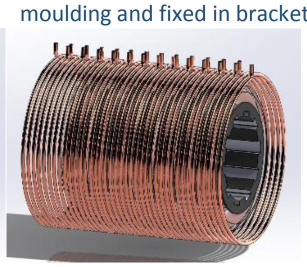


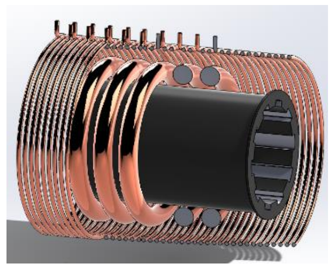
Stationary coil





Stationary will be cast in moulding and fixed in bracket





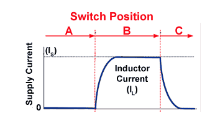
Position calculation

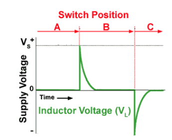
With the core positioned in the middle of the coils, and the coils slightly longer than the core so that the core is "inside" the coils the inductance is different on the ends where the sleeve acts like a core.

The current flowing in the coil will have a shape influenced by the core. As described in utilization the variation in inductance influences the current.

This phenomena produces a voltage peak that, as the current will vary with inductance.

The variation in inductance will be the basis for positions calculatons.

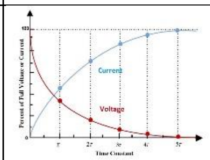




The influence on the impedance from the magnetic core will increase with higher frequencies.

Programming the position may be done by putting a high frequency signal on top of the driving pulse train.

Further calculations and empirical data will make us able to calculate the position.

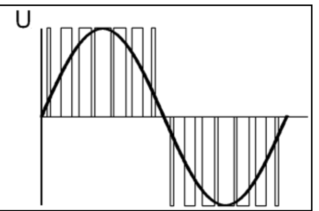


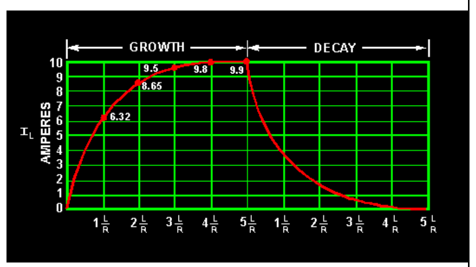
Power unit:

Current can be controlled by the use of Pulse Witdth Modulation (PWM), capasitors and inductors to produce an even sinus current curve.

A benefit with PWM is a softer start. It is possible that this effect also will occur in the stationary coil due to the inductance and thus the impedance of the coil.

The primary coil will act like a low pass filter for the current so we can possibly introduce square pulse voltage train.





Concept iteration ***K-Brief***

K-Brief owner: Torjus Haugerud	**Document name:** Knowledge-Brief Induction shifter Function description	**References:**
Date: 17 April 2018	**Revision number:** R 1.0	**Additional documentation:** #Solid Works initial 3D model

Objective:

Concept description; linear movement by inducing magnetism.

The working prinsiple here is emulating the reluctance motor.

To draft an initial description of the function and working prinsiples of the forces driving the reluctance actuator.

Force

Stator coils will be put under a pulsating voltage in a specific firing order.

The ferromagnetic secondary core will be magnetised and will try to align with the coil under power.

Stator is drawn with out its outer casing or mounting bracket.

This is due to limited time just a preliminary draft.

Short

The reluctance motor is like the induction motor using solenoids to induce a magnetic field in the secondary, moving part.

The reluctance motor differs from the induction motor in the way that it is indusing magnetism directly into the secondary, which is then pulled towards the closest "pole" or step.

These steps are therefore quit simple to pinpoint in position. The sequence easy to determine and therefore a more adekvate solution for this project with our limited resources.

This concept has due to the very short notice time deadline not been evaluated with regards to force, only for space.

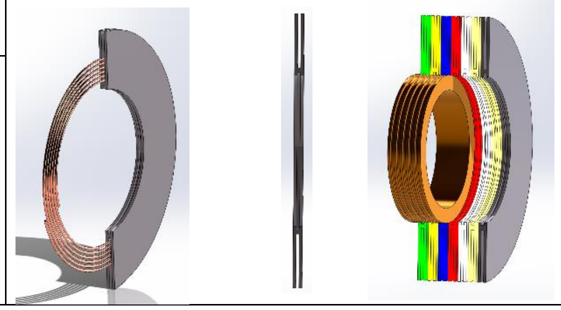
It is very likely to fail the requirement of out of gear force.

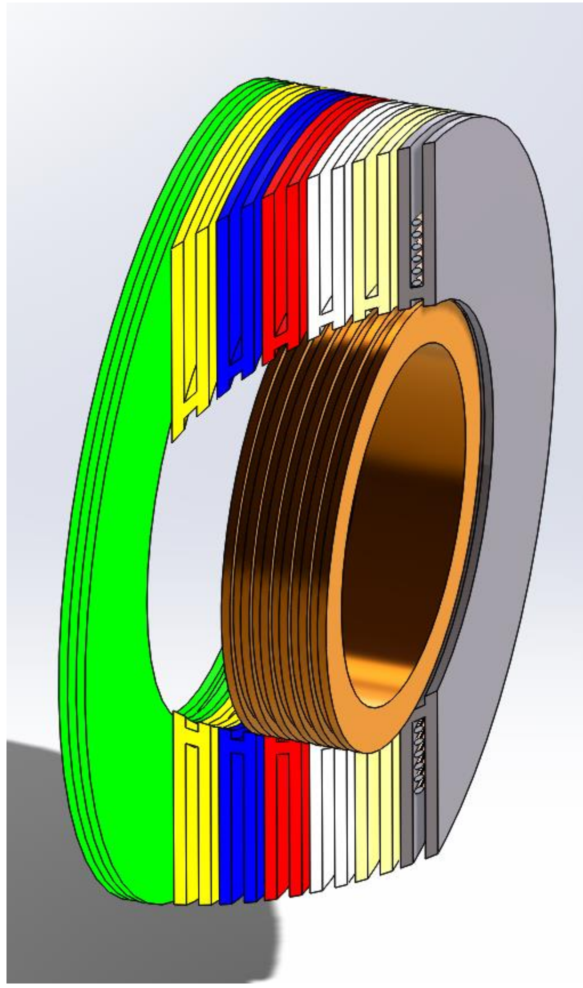
The eventually remenance of magnetism can easily be removed by running a very simple firing sequence.

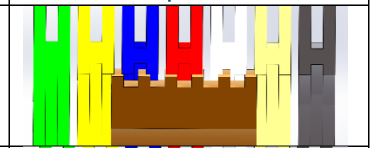
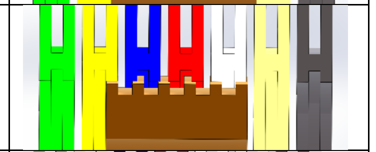
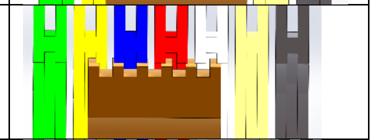
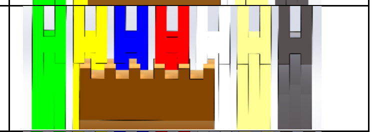
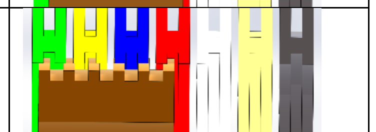
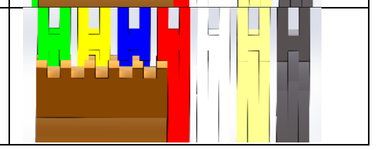
Detail of segment

One coil in each disc.

The discs are colored to tell them apart when alanysing the firing sequence.





Firing order	Sequence
Step 1 #4 red	
Step 2 #5 white	
Step 3 #3 blue	
Step 4 #4 red	
Step 5 #2 yellow	
Step 6 #3 blue	
Step 7 #4 red	
Step 8 #2 yellow	
Step 9 ## blue	
Step 10 #1 green	

Teorem:

From Maxwel Faraday's law we can deduct that applying voltage onto a coil of electric wire will let a current flow thru the wire.
The current lags behind the voltage in time and produce an electric field which will be accompanied by a magnetic field, the magnetic field is in phase with the current.

The magnetic field will be present for as long as there is a current flowing in the coil circut.

Evaluation keys in short

Pro	Contra
• Simple construction • No residual magnetizm. • No bearings. • No wear from moving parts touching eachother. • Simple function prinsipple.	• Permeability from oil residue inside between primary and secondary. • Unknown size/force capability.

Motion STUDIE *K-Brief*

K-Brief owner: Torjus Haugerud	Date: 6 March 2018	Revision NO.: 1.0	Aditional documentation: Excel PDF; Force Position Curve v/2.8	References:

WHAT

What-Keys	Basic study.
Study of velocity	$v = v_0 + a \times t$ Evaluate adequate top speed.
Study of acceleration	Acceleration is a variable that will be the subject of much examination in this study. it will be examined as an input variable in regards to both intensity and magnitude. Influenced by • Weight and inertia. • Motor performances. • Evaluate adequate maximum acceleration.
Study of displacement/time	$S = S_0 + v_0 \times t + \frac{1}{2} a \times t^2$ Position is calculated as a function of time. Target displacement is 12,15 mm.
Study of forces	Force as a funcion of acceleration/deceleration and mass. Force as gear-change motion load.
Evaluate margin	To safeguard required operating conditions and performances there must be a margin. This study will enable an evaluation of operating margin. Margin is evaluated as exessive displacement, i.e. the shift fork will reach position before due time.

WHY

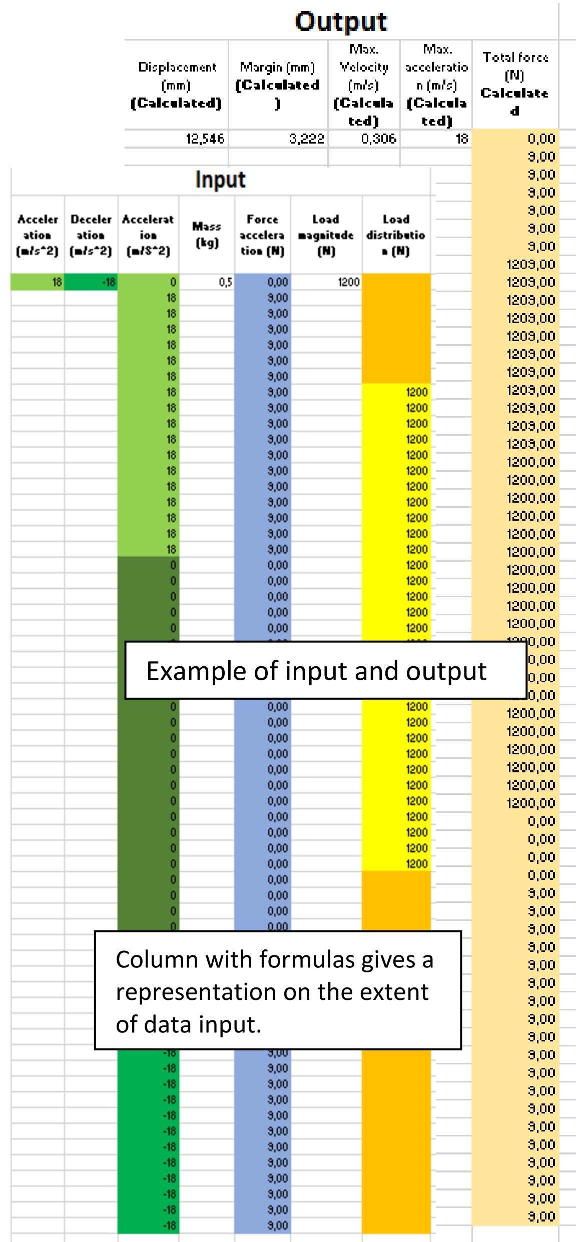
Why-Keys	Background - force study.
Streamline process	In accordance with lean process and unified project model. Bring facts to the table. Solve most difficult challenges first.
Refine litterature search.	To delineate litterature search there is a need for pinpointing what force requirements the actuator shall meet.
Delineate concept ideas.	To concentrate energy and time on relevant concept ideas there is a need for awareness about the choise of force needs.
Agree on basic facts	Increase number of constructive discussions. Decrease level/number of destructive disputes.
Evaluate force.	To increase number and level of relevant concept ideas there is a need for understanding the forces involved.

What NOT

What not-Keys	Challenges/possibl solutions
Limitations	This tool is not intended to restrict creative thinking in any way.
Accurancy	The calculations are not meant to be exactl. Final calculations must be done according to mathematical standards for greater accurancy.

HOW;

Motion analyser



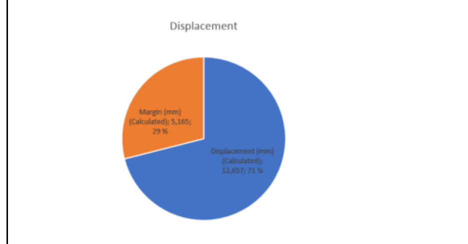
Analysis of motion, acceleration and variable force:

Motion analyzer gives an instant estimate of what the constructor needs to know in a dynamic way.
Key features as slide scales for acceleration, force and load distribution.

1. Put in relevant values.
2. Slide the formulas according to the timescale.
3. The motionanalyzer calculate and give relevant information on graphs and diagram.

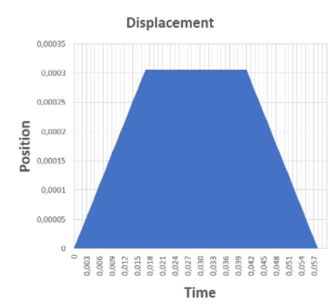
The motion analyzer can easily be adapted and expanded to suit future needs.

Link: ..\..\Force estimate\Excel Force Position Curve 2.8.xlsx



The blue part of displacement pie chart shows at what extent the position has been reached.

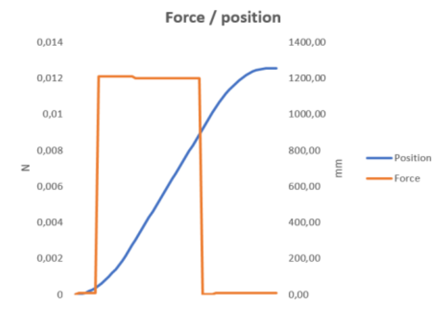
The orange slice shows at what margin the position was reached.



This displacement diagram shows from left; the acceleration phase where the velocity increases at a linear rate.

The flat top shows an even velocity with increasing displacement.

The last part shows deceleration and finally, standstill.



The graph shows how the force is acting in relation to the position.

The blue line shows the position of the shift fork.

The orange graph shows the force and how it is distributed along the motion.

Conclution:
The use of the motion analyzer can guide the team to a more efficient design process.

The motion analyzer must be used to aid unconventional thinking and can encourage the team to look for solutions outside the box by learning more about what type of forces occurs in a concept.

A3 documentation-method STUDIE *K-Brief*

EGA Electrical Gear Actuation

K-Brief owner: Torjus Haugerud	**Document name:** Knowledge-Brief Template-two parted	**References:** • Paul Akers, 2 second lean, 2016 edition. • John Shook, http://www.leanuk.org/ general information. • The Toyota Way, Jeffery K. Liker and David Meier, 2006 edition
Date: 16 March 2018	**Revision number:** R 1.0	**Additional documentation:**

Topic:	**Question:**	**Secondarily:**	**Study:**
Knowledge Briefs	**Can the use of K-Briefs benefit our project?**	**How can K-Briefs add value to our project?**	• **How is K-Briefs utilized elsewhere?** • **Perform a literature study.**

	What	*Why*	*How*	
Keys	*Description.*	*Background - study.*	*Benefits/possible solutions*	
Documentation	Documenting: • The process. • Desisjon making. • Author of documents.	*To evolve there must be a process with a theory, and a conscientious plan. Thereafter the team can recap, learn and adjust for further actions* Examiner need grounds for evaluating.	*There is not only one way of documenting.* *Neither is it one way of making a Knowledge-Brief.* The documentation method and argument chosen is regarded as well-founded if it contains some elements like: • What; subject; problem; issue in question. • Why; background; study • How; solution; conclusion. Toyota model (TPS) is based on learning and making knowledge avaialble. Lean thinking uses a process called PDCA which is: 1. Planning; theory, ideas. 2. Doing; executing plans. 3. Check; learn, study, reflect. 4. Adjust; conclude, evaluate if the prior process where appropriate.	
Traceability	The documentation method needs to make the origin and the path of the process transparent. • Transparent process. • Background for decision. • Origin of decisions. • Trace evaluations. • Trace author.	*Increased awareness about the origins of decisions and the background for evaluations will enhance knowledge obtainment.* Examiners must be able to evaluate authors	Reference system and title bar on top of Brief	
Knowledge	Two issues in focus; 1. Documenting knowledge. 2. Making the knowledge available.	The documentation of knowledge is central in every process. *To perceive knowledge the information must be available and visible.*	Concise and visible presentation. Remove unnecessary information.	
Efficiency	• Utilize resources. • Focus. • Identify waste	The documentation method is a major part of the project. Resources are limited as it is in most processes. • Improved result. • Increased customer satisfaction. *The Lean way of thinking is focusing on value added work and on removing waste. The choice of documentation method can be either one of these categories depending on how it is executed, and in which form it is presented.*	Remove wasted time. Focus effort. Increase value adding work.	
KBD	EGA's project model has a knowledge-obtaining stage in every iteration.	*To add value for the customer, the effort is focused on obtaining knowledge.* KBD is originating from Lean thinking and TPS which focuses on knowledge.	• Utilizing PDCA, Lean thinking and TPS. • Implementing KBD	*Utilizing the potential of A3's.*

Conclusion

The use of K-Briefs will benefit our project by:

-Adding efficiency, simplicity, transability and traceability.

-Letting us utilize knowledge as otherwise risk being kept hidden.

Template *K-Brief*

EGA
Electrical Gear Actuation

K-Brief owner:	Document name:	References:
Torjus Haugerud	Knowledge-Brief Template one side	
Date:	**Revision number:**	**Additional documentation:**
23 Feb. 2018	R 1.0	

#T.53 References for Friction study 1.0:

https://en.wikipedia.org/wiki/Trapezoidal_thread_form#CITEREFBhandari2007

https://etc.usf.edu/clipart/77200/77296/77296_mdrwsqr_scrw.htm

http://armyordnance.tpub.com/Od1645/Od16450132.htm

https://commons.wikimedia.org/wiki/File:Square_thread_form.svg

youtube: Michel van Biezen

Konstruksjonselementer, Dalvig, Christensen, Strømnes

http://mechanicaldesign.asmedigitalcollection.asme.org/article.aspx?articleid=1484895

http://mechanicaldesign.asmedigitalcollection.asme.org/article.aspx?articleid=1446747

https://www.linearmotiontips.com/common-ball-screw-terms-explained/

http://www.codecogs.com/library/engineering/theory_of_machines/screw-threads.php

Friction concept-evaluation *K-Brief*

K-Brief owner:	Document name:	References:
Torjus Haugerud	Knowledge-Brief Template one side	According to list: References for Friction study 1.0
Date:	**Revision number:**	**Additional documentation:**
17 March 2018	R 1.0	Excel Force position curve 2.9

Objective:

To evaluate lead screw solutions:

- Sensitivity to friction.
- The frictions influence on electric power consumption.
- Estimate possibility to use current as measuring force.
- Estimate measuring sensitivity in relation to current.

Theorem:

To survey the mechanical construction, it will be an opportunity to measure by the use of current measurement.

The current is proportional to the force applied and will reflect discrepancies in mechanical equipment

The current will be influenced by the friction. The measurement will be more accurate if friction is low.

Formula

Pitch angle	Efficiency	Friction angle	Pitch is the distance the nut will travel every round of winding-	Torque-linear transformation
$\varphi = \tan^{-1}\left(\frac{P}{\pi \times d_2}\right)$	$\eta = \frac{\tan\varphi}{\tan\varepsilon_1 + \varphi}$	$\varepsilon_1 = \tan^{-1}\left(\frac{\mu}{\cos\alpha}\right)$	$P = \tan\varphi \times \pi \times d_2$	$M_v = F \times r_m \times \tan(\varepsilon_1 + \varphi)$

	Normal metric (and imperial) profile 60°.	***Lead trapezoidal thread 29° profile "ACME"***	***Lead thread 90°profil Square thread.***	***Ball Screw.***
Thread types	Large radial friction component.	Not designed to withstand radial forces due to "wedge" issues. Possible to use a split nut as countermeasure for wear.	Best in respect to production method, radial tolerance of receiving radial load Prone to develop axial backlash due to wear. Countermeasure to wear, two opposite nuts with preload.	Little wear. Withstand radial and axial load.
Friction $\varepsilon_1 = \tan^{-1}\left(\frac{\mu}{\cos\alpha}\right)$	Rule of thumb is 90% of torque is wasted overcoming friction in normal bolts (Konstruksjonselementer) Thread angle creates radial force ε_1 which is wasted energy.	Much lower radial force, nearly ideal profile.	No thread angle therefore minimal ε_1	Naturally there must be some thread angle, however there has not been obtained any information weather such angle creates any problem. Very little friction due to rolling action of balls.
Efficiency $\eta = \frac{\tan\varphi}{\tan\varepsilon_1 + \varphi}$	Low efficiency $\eta = \frac{\tan\varphi}{\tan\varepsilon_1 + \varphi}$	$\varphi = \tan^{-1}\left(\frac{P}{\pi \times d_2}\right)$	Best efficiency of the conventional lead screws.	80% to 90 %. Ref. Konstruksjonselementer s.110 Max. RPM 1500
Production simplicity	Machining for accurate lead screw purpose with radial force requires high precision.	Complex production method for achieving accuracy between radial support face and thread width due to two tolerances at once. Requires small tolerances, high accuracy.	Easier to produce with accurate tolerances than ACME due to only one concern i.e. one tolerance at the time..	Advanced production method. Can be rolled or grinded.

Conclusion:

The ball nut concept is

- Less prune to wear, and thus more reliable.
- It is possible to carry radial loads as well as axial loads.
- It has a higher efficiency than non-bearing solutions.

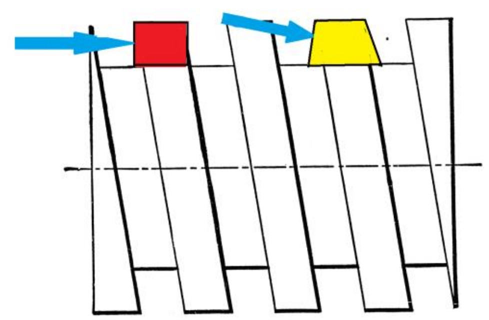
The difference in current related to friction is significant.

It's estimated that ball screw concept will provide a significant higher accuracy than compared solutions.

Forces

The blue arrows show the resultant force that applies as a result of linear force and torque. Square angle in red and a trapezoidal thread profile in yellow.

Note that the arrows have different angles related to the center of the screw. I.e. they are acting normal to the thread flank.

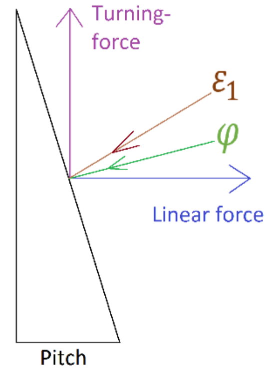


Ideal

The ideal is putting in turning force and getting linear for out.

Unfortunately, there are friction which applies in the counterproductive direction. Here marked with brown arrow as ε_1.

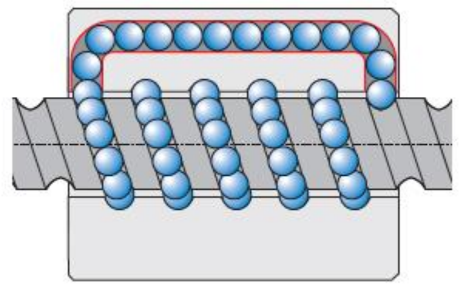
The green arrow marked φ is the angle with which the resultant force of turning and linear force attacks.



Ball nut screw

Balls are circulated in an endless loop.

Similar to ball bearing



Assumption / theory:

The current will be influenced by friction. Calculations below are based on worst case scenario and shows that there is a significant current that goes to overcome waste as friction.

The actual normal current will be much lower and will only peak to these extreme values under maximum load. Scenario is based on peak load which is described in Excel force position curve 2.9

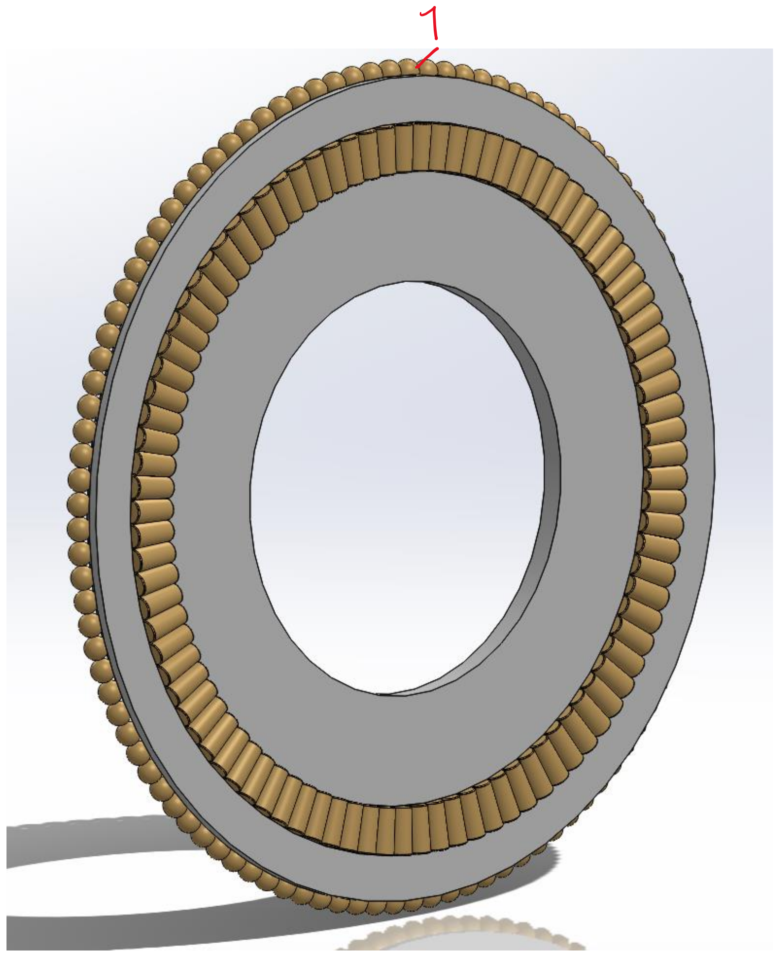
Friction may lead to problems regarding measuring accuracy related to the forces that may occur.
Poor measuring accuracy may lead to inaccurate positioning, damage as a result of undiscovered wear and so on.

$P = \frac{F \times s}{t}$	$P = U \times I \times \eta$	$\frac{F \times s}{t} = U \times I \times \eta$	$I = \frac{F \times s}{t \times U \times \eta}$

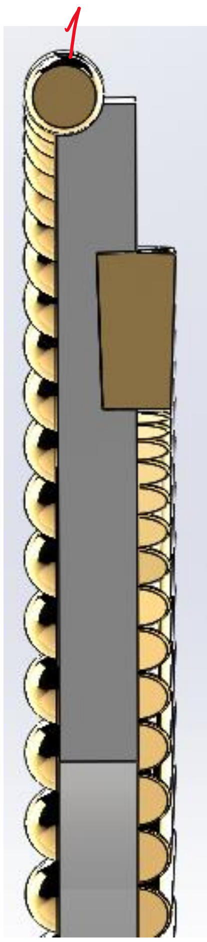
$I = \frac{1209\ N \times 0{,}0057\ m}{0{,}02\ sec. \times 24\ V \times 0{,}9}$ 16 ampere	$I = \frac{1209\ N \times 0{,}0057\ m}{0{,}02\ sec. \times 24\ V \times 0{,}5}$ 29 ampere

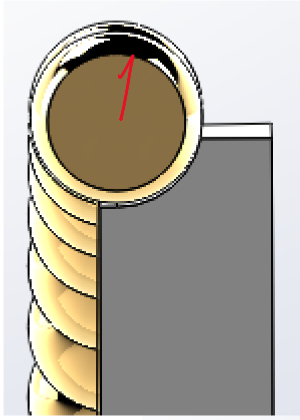
Construction parts ***K-Brief***

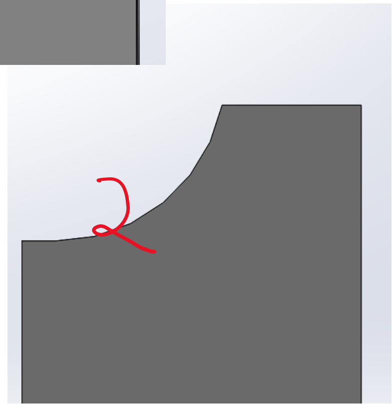
K-Brief owner: Torjus Haugerud	**Document name:** Knowledge-Brief Cog hub bearing left side exploded view	**References:**
Date: 19. May 2018	**Revision number:** R 1.0	**Additional documentation:**

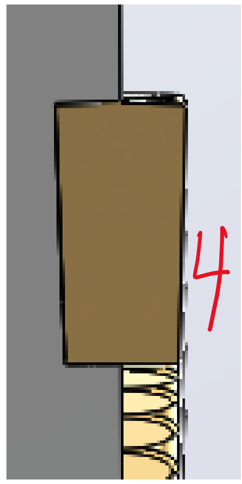


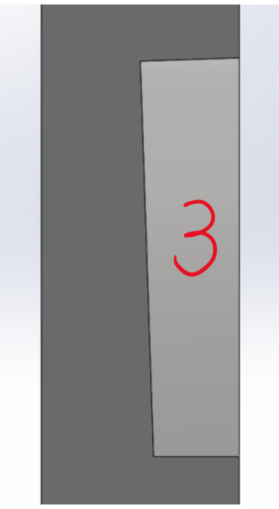
Pos 1	Radial and axial support Ø175 roller bearing Ø5 balls	
Pos 2	Radial and axial support angular contact bearing for Ø175	106 balls
Pos 3	Machined roller bearing track for conical roller bearing Ø150	
Pos 4	Roller bearing Ø150	93 rollers
Pos 5		
Pos 6		
Pos 7		
Pos 8		
Pos 9		
Pos 10		
Pos 11		
Pos 12		
Pos 13		
Pos 14		
Pos 15		
Pos 16		
Pos 17		
Pos 18		
Pos 19		
Pos 20		





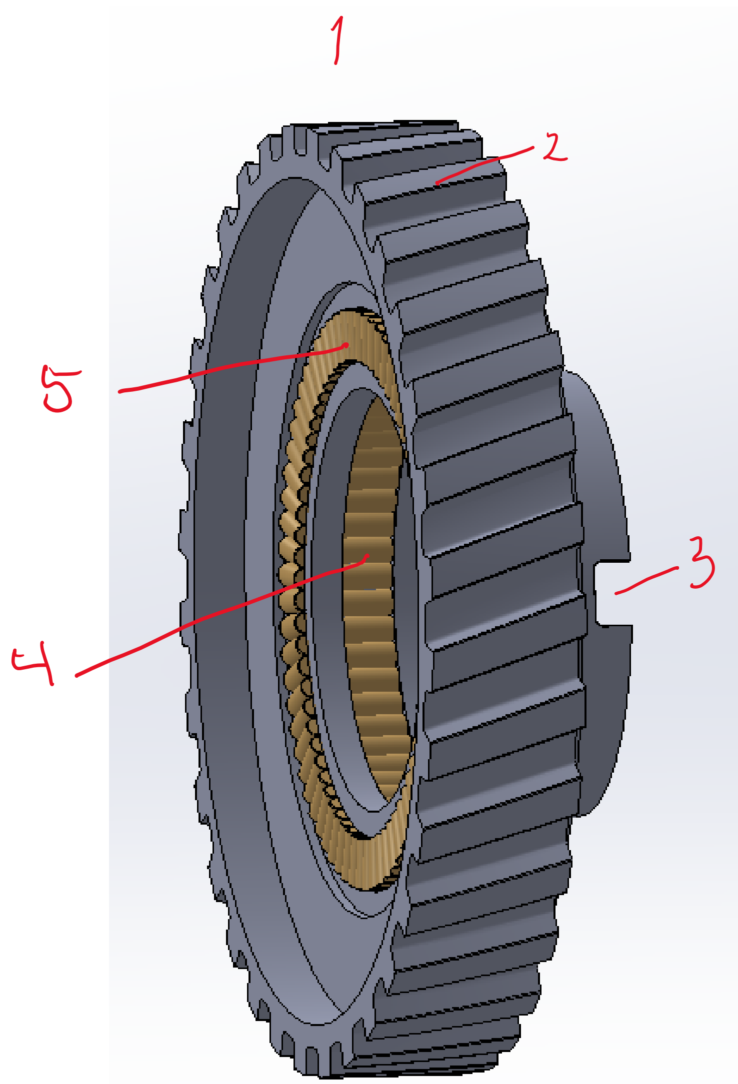




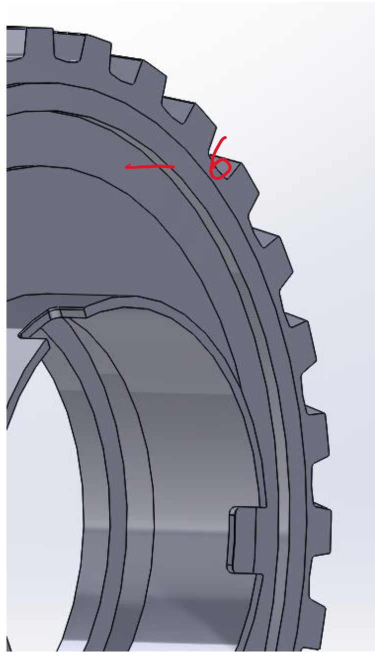


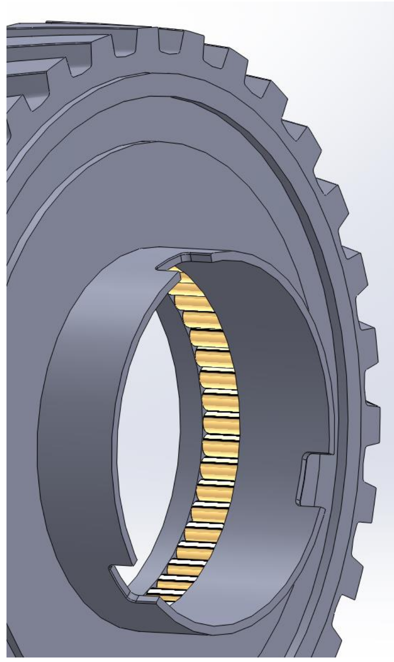
Construction parts ***K-Brief***

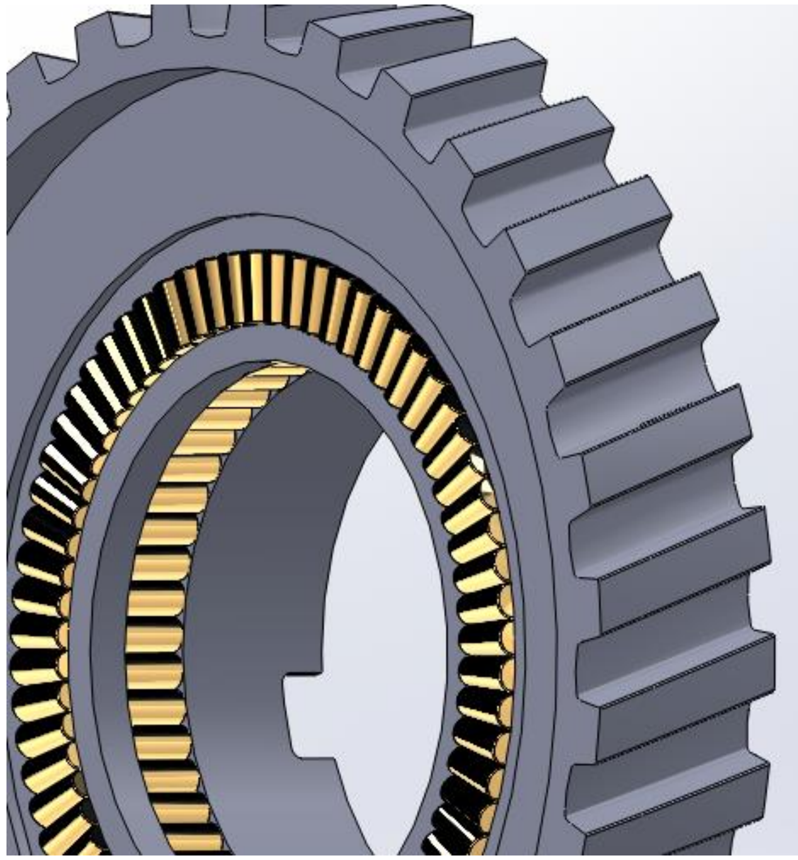
K-Brief owner: Torjus Haugerud	Document name: Knowledge-Brief Cog hub bearing left side exploded view	References:
Date: 19. May 2018	**Revision number:** R 1.0	**Additional documentation:**



Pos 1	Small diameter cog with less number of teeth	1 pc
Pos 2	Cog teeth	32
Pos 3	Tooth engaged slot	3 pos
Pos 4	Radial support roller bearing Ø5x10 rollers	53 roller
Pos 5	Axial support conical roller bearing for Ø110	68 rollers
Pos 6	Machined roller bearing track for conical roller bearing Ø150	
Pos 7		
Pos 8		
Pos 9		
Pos 10		
Pos 11		
Pos 12		
Pos 13		
Pos 14		
Pos 15		
Pos 16		
Pos 17		
Pos 18		
Pos 19		
Pos 20		

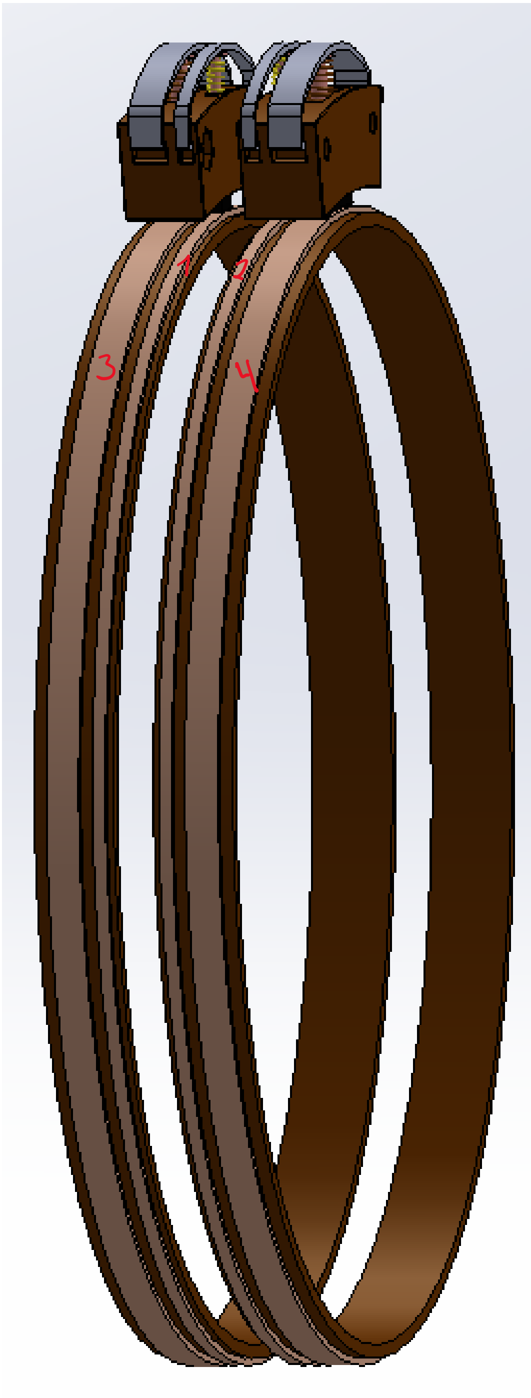




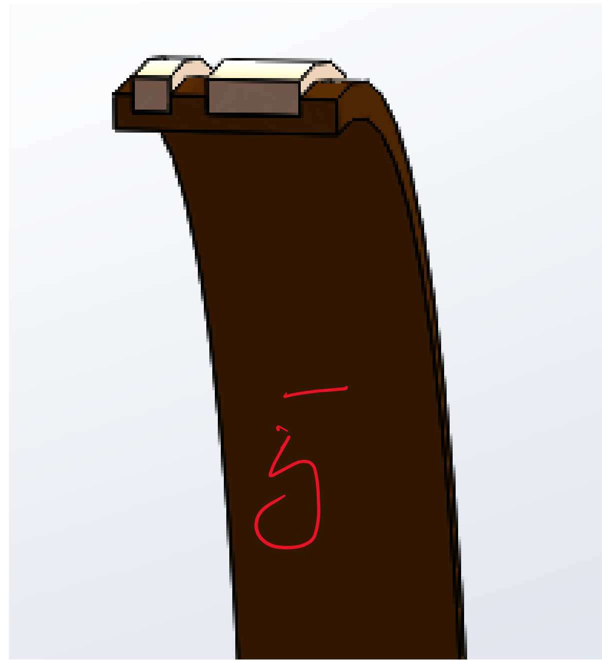


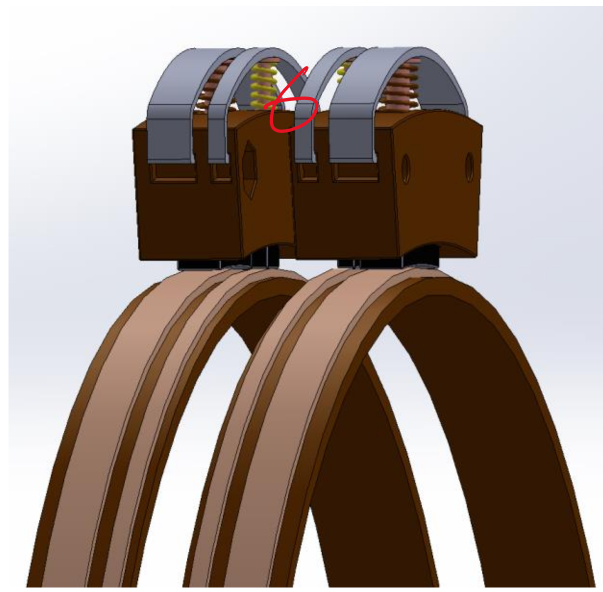
Construction parts *K-Brief*

K-Brief owner:	Document name:	References:
Torjus Haugerud	Knowledge-Brief Power transfer unit exploded view	
Date:	**Revision number:**	**Additional documentation:**
19. May 2018	R 1.0	



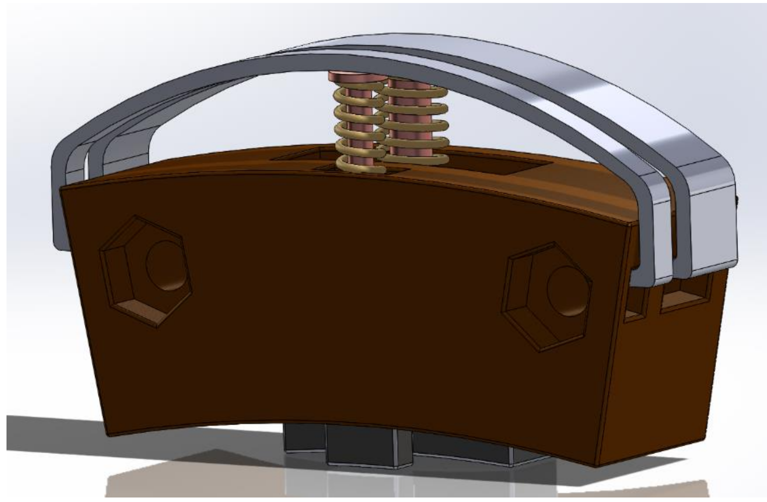
Pos 1	Slip ring for signal 2x2mm	1 pc
Pos 2	Slip ring for option 2x2mm	1 pc
Pos 3	Slip ring for power transfer 2x5mm	1 pc
Pos 4	Slip ring for ground 2x5mm	1 pc
Pos 5	Isolating slip ring mould	2 pc
Pos 6	Connector brush unit	2 pc
Pos 7		
Pos 8		
Pos 9		
Pos 10		
Pos 11		
Pos 12		
Pos 13		
Pos 14		
Pos 15		
Pos 16		
Pos 17		
Pos 18		
Pos 19		
Pos 20		



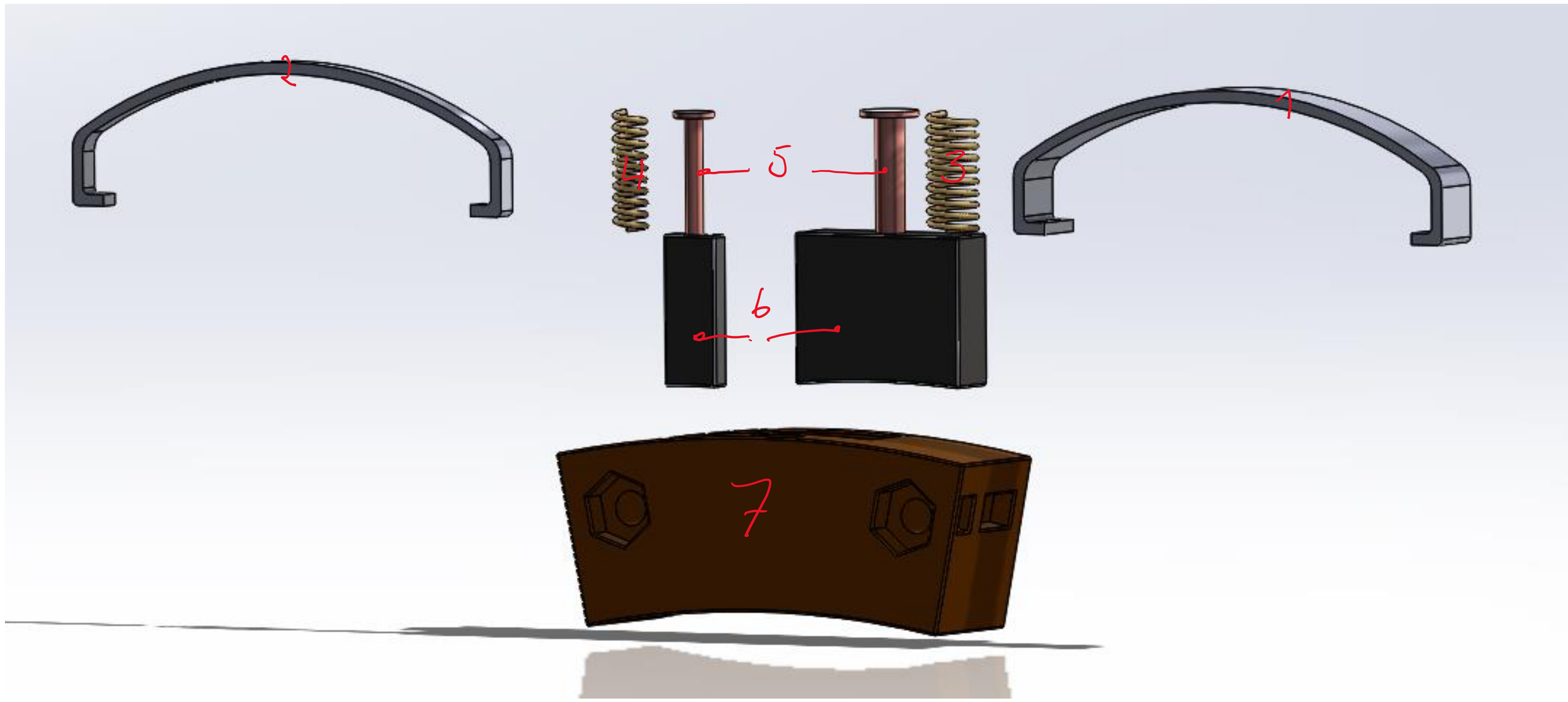


Construction parts *K-Brief*

K-Brief owner:	Document name:	References:
Torjus Haugerud	Knowledge-Brief Connector brush unit exploded view	#T.12 Bakelite
Date:	**Revision number:**	**Additional documentation:**
19 May. 2018	R 1.0	



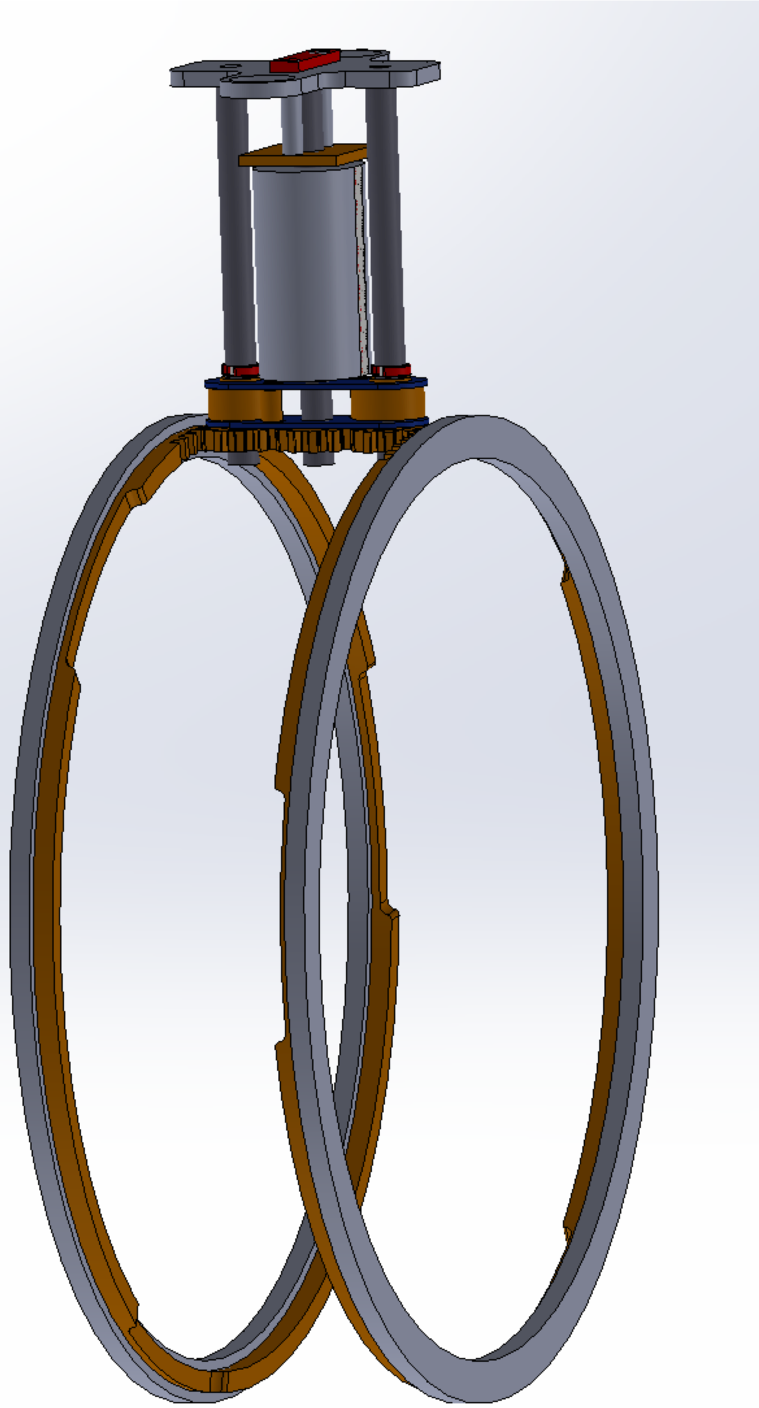
Pos 1	Pos 2	Pos 3	Pos 4	Pos 5	Pos 6	Pos 7	Pos 8
Connector brush mount bow large, spring steel	Connector brush bow mount small, spring steel	Connector brush spring large	Connector brush spring small	Brush wire	Brush graphite	Connector brush mount holder, Bakelite	Connector brush unit



Construction parts ***K-Brief***

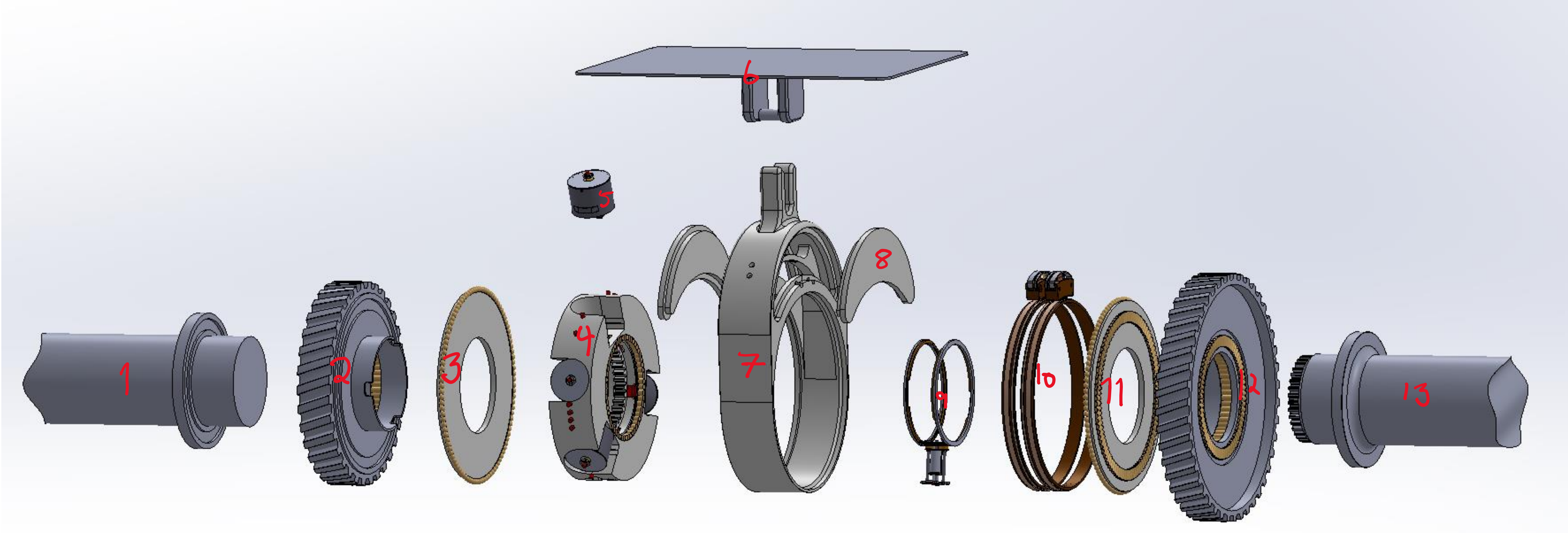
K-Brief owner: Torjus Haugerud	Document name: Knowledge-Brief Locking mechanism exploded view	References:
Date: 19. May 2018	Revision number: R 1.0	Additional documentation:

Pos 1	Flag (option)	
Pos 2	Flag support (option)	
Pos 3	Flag nut (option)	
Pos 4	Flag locking mechanism bracket	
Pos 5	Tooth lock mechanism side cog (plane configuration)	2 pc
Pos 6	Tooth lock mechanism side cog (Windings configuration)	
Pos 7	Locking mechanism motor (motor dummy by T.H design)	
Pos 8	C-clip	2 pc
Pos 9	Lock mechanism spring unit distance washer	4 pc
Pos 10	Locking mechanism spring return disengage plate	2 pc
Pos 11	Locking mechanism spring return spiral spring	2 pc
Pos 12	Locking mechanism return spring support stud	2 pc
Pos 13	Tooth lock support ring	2 pc
Pos 14	Tooth lock ring	2 pc
Pos 15	Locking mechanism	1 unit
Pos 16		
Pos 17		
Pos 18		
Pos 19		
Pos 20		



Construction parts *K-Brief*

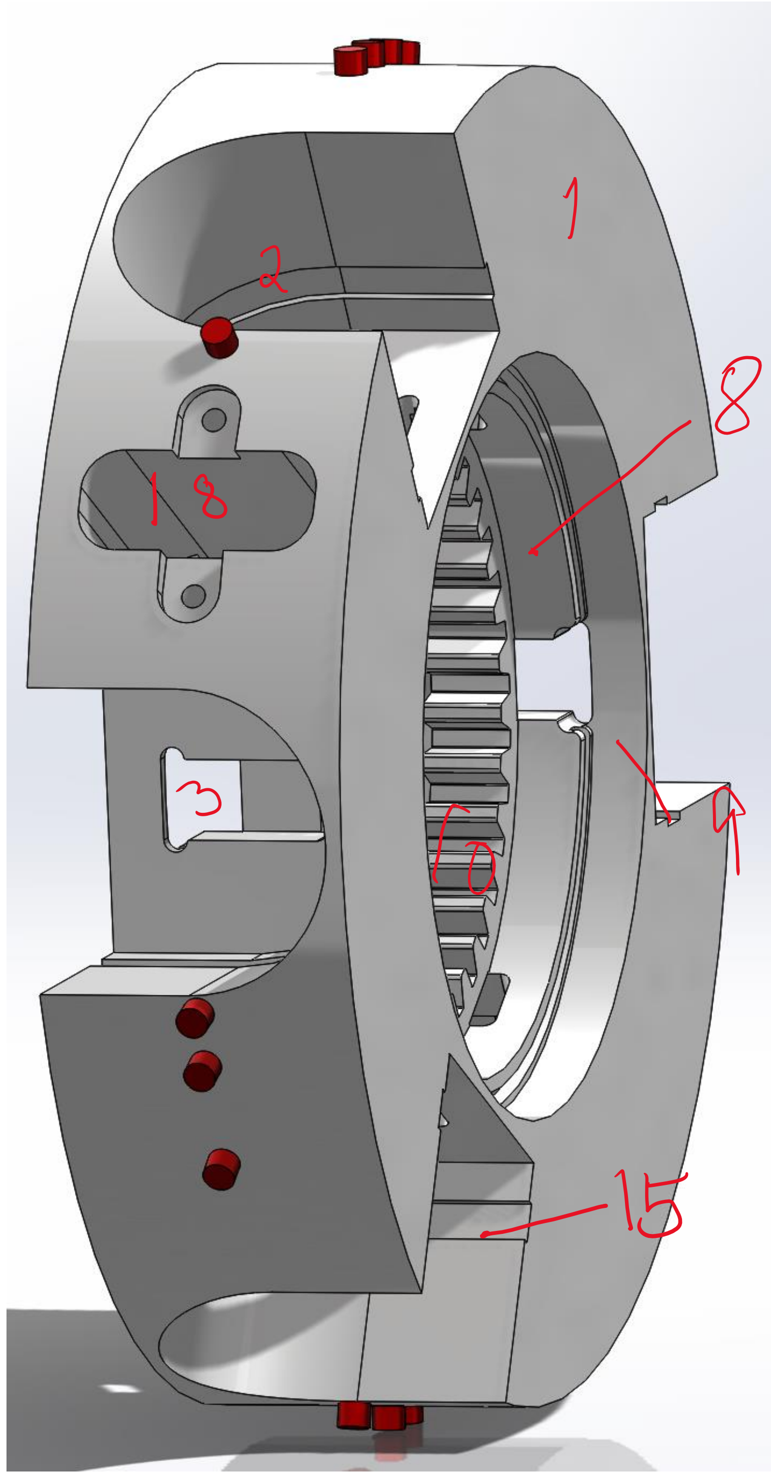
K-Brief owner:	Document name:	References:
Torjus Haugerud	Knowledge-Brief Main exploded view	
Date:	**Revision number:**	**Additional documentation:**
19 May 2018	R 1.0	



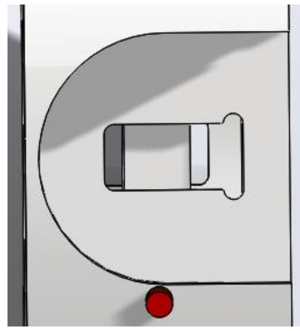
Pos 1	Pos 2	Pos 3	Pos 4	Pos 5	Pos 6	Pos 7	Pos 8	Pos 9	Pos 10	Pos 11	Pos 12	Pos 13
Floating shaft	Left cog hub	Left main bearing	Rotator	Radial coupler	Fixation bracket lid	Bracket	Lid for connections	Lock	Power	Right main bearing	Right cog hub	Right shaft

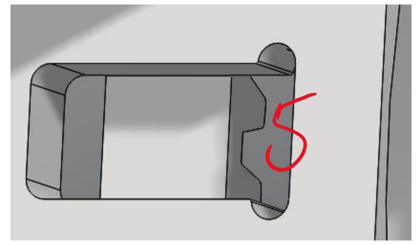
Construction parts ***K-Brief***

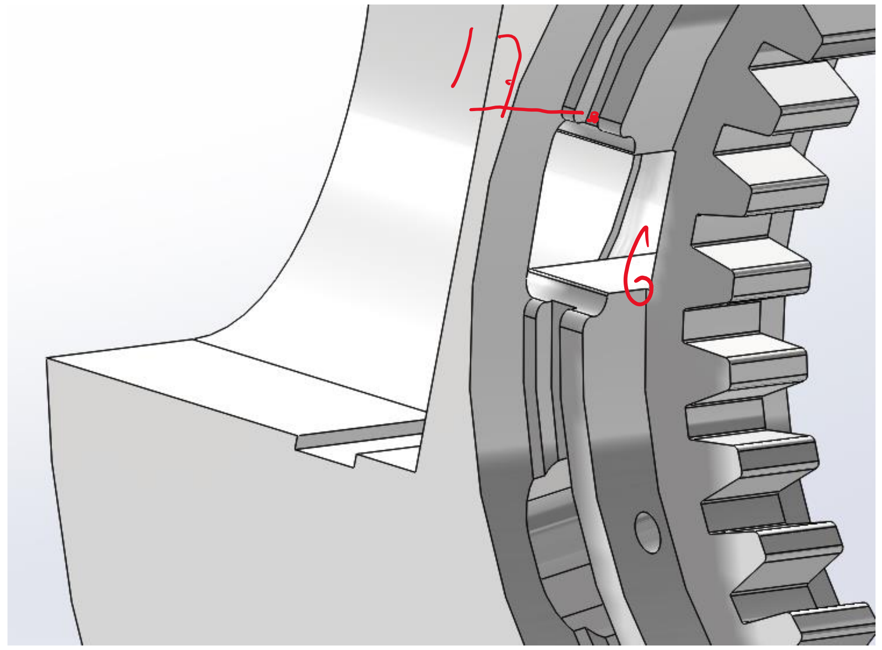
K-Brief owner:	Document name:	References:
Torjus Haugerud	Knowledge-Brief Rotator exploded view	
Date:	**Revision number:**	**Additional documentation:**
19. May 2018	R 1.0	

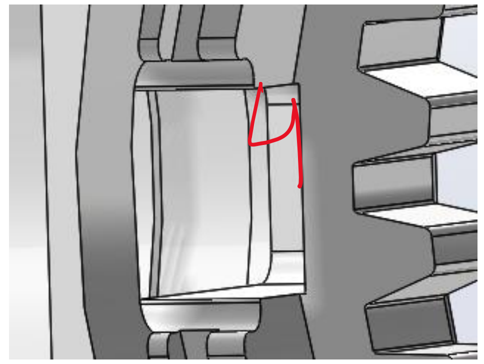


Pos 1	Rotator	1 pc
Pos 2	Solenoid cavity	
Pos 3	Tooth slot	
Pos 4	Tooth entering cavity	
Pos 5	Tooth mounting clearance	
Pos 6	Tooth seating	
Pos 7		
Pos 8	Cog hub clearance surface	
Pos 9	Roller bearing outer ring	
Pos 10	Center spline hub, for shaft connection	
Pos 11		
Pos 12	Option, position barcode dots for proximity sensor	
Pos 13		
Pos 14		
Pos 15	Solenoid fixation groove	
Pos 16		
Pos 17	Lock ring groove	
Pos 18	Locking mechanism cavity	
Pos 19	Locking mechanism cog shaft mount holes	
Pos 20	Screw holes for locking mechanism mount	

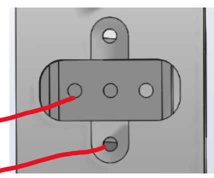


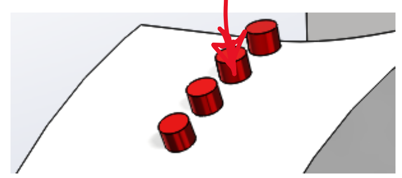






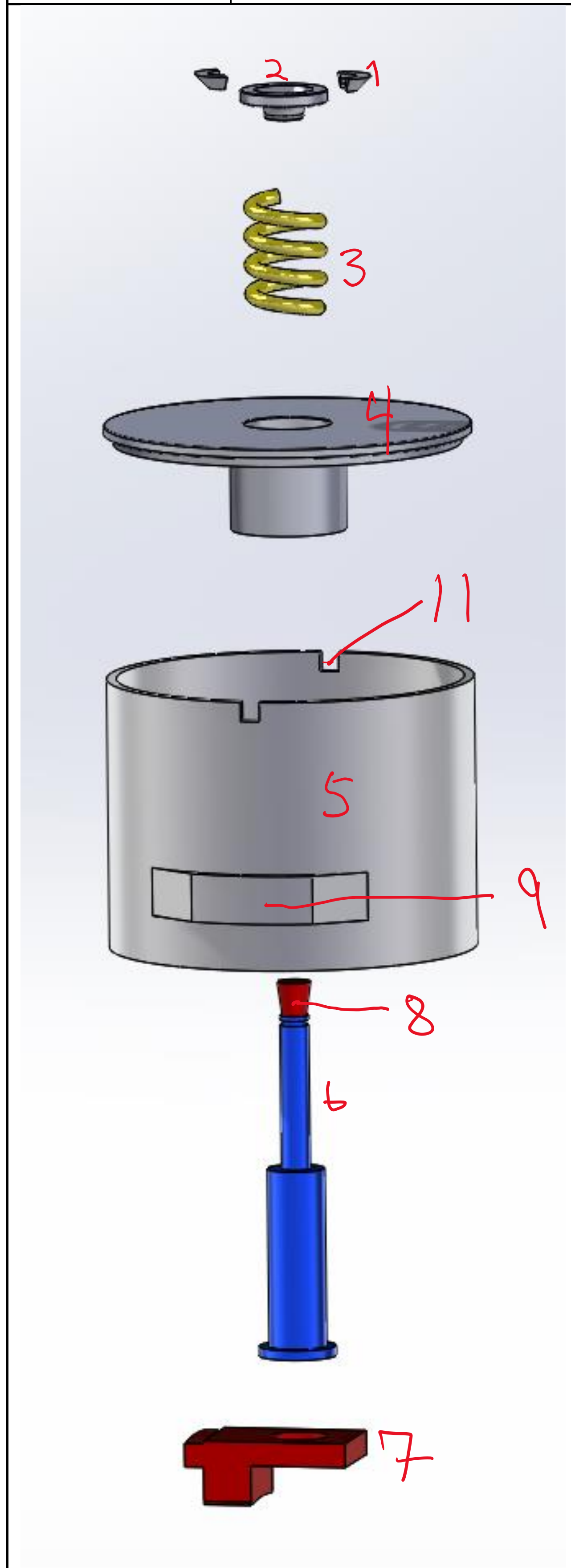
12





Construction parts ***K-Brief***

K-Brief owner:	Document name:	References:
Torjus Haugerud	Knowledge-Brief Solenoid mechanism exploded view	
Date:	**Revision number:**	**Additional documentation:**
19 May. 2018	R 1.0	



Pos 1	Solenoid stem upper disc mount cone	2 pc
Pos 2	Solenoid plunger stem washer upper	1 pc
Pos 3	Solenoid spring	1 pc
Pos 4	Solenoid plunger stem washer lover	1 pc
Pos 5	Solenoid 5.0	1 pc
Pos 6	Solenoid plunger stem	1 pc
Pos 7	Tooth 3.2	1 pc
Pos 8	Plunger flag (option)	1 pc
Pos 9	Fixation ear	2 pc
Pos 10	Gap 1mm	
Pos 11	Slot for mount tool	2 slots
Pos 12