# Exploring the Possibilities of Replacing Mechanics with Magnets

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DIVISION OF PRODUCT DEVELOPMENT | DEPARTMENT OF DESIGN SCIENCES
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MASTER THESIS

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LUND UNIVERSITY

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# Abstract

This master thesis investigates the possibilities of implementing magnets for several functions in a knob. The project was carried out in collaboration with Sigma Connectivity.

During a previous project at Sigma Connectivity, there occurred an interest in using magnets in a product called ”the knob”. This product is used to select options by swiveling an outer part or pushing buttons at the top. Exchanging some mechanics for magnets could possibly improve the product. It was interesting to see if magnets also could affect the feedback to the user.

The objective is to explore the possibilities of magnets in this type of product. Some benefits of magnets can be to avoid mechanical wear and to seal electronics due to contactless sensoring. If magnets are found to be useful, the results of this master thesis could act as a foundation for Sigma Connectivity to implement magnets in their future products.

Background research about magnets and sensors was conducted as well as findings of existing magnet solutions in order to achieve a greater understanding about magnets implemented in products. This acted as the foundation for the concept generation. Promising concepts were evaluated by using CAD and 3D-printing to create prototypes. The final concept is a modified knob which utilizes magnets for several functions, both regarding the swivel function and the push top. Working prototypes with sensors demonstrates the functions.

The results of this thesis is the final concept as well as recommendations for further development.

**Key words**: magnet, sensor, product development, 3D-printing, Sigma Connectivity

# Sammanfattning


Detta examensarbete undersöker möjligheterna att implementera magneter för flera funktioner i en så kallad ”knob”. Projektet utfördes i samarbete med Sigma Connectivity.

Under ett tidigare projekt på Sigma Connectivity uppstod ett intresse för att använda magneter i en av deras produkter. Denna produkt används för att välja alternativ genom att rotera en yttre part eller trycka på knappar på toppen. Genom att byta ut några av de mekaniska lösningarna till magneter kan produkten potentiellt blir förbättrad. Det är också intressant att undersöka om magneter kan påverka feedbacken till användaren.

Syftet är att undersöka möjligheterna att implementera magneter i den här typen av produkt. Några fördelar med detta kan vara att reducera mekaniskt slitage och att innesluta elektronik genom kontaktlösa sensorer.

Bakgrundsforskning om magneter och sensorer samt att hitta existerande lösningar gav en större förståelse om hur magneter kan implementeras i en produkt. Detta användes som en grund för den kommande konceptgenereringen. Lovande koncept utvärderades genom CAD och 3D-printing för att skapa prototyper. Det slutgiltiga konceptet är en modifierad knob som använder magneter för flera funktioner, både rotationen och tryckknapparna. Fungerande prototyper med sensorer demonstrerar funktionerna.

Resultatet av detta examensarbete är det slutgiltiga konceptet samt rekommendationer för fortsatt utveckling.



**Nyckelord**: magnet, sensor, produktutveckling, 3D-printing, Sigma Connectivity

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Matilda Rosén & Maja Svensson

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# 1 Introduction

*This introduction to the master thesis includes a company background, the problem description, the goal of the thesis and the delimitations of the project.*

## 1.1 Company Background

Sigma Connectivity (SC) is a part of the Sigma Group which is *"a group of leading consulting companies with the objective to make our customers more competitive"*. Other included companies are: Sigma IT Consulting, Sigma Technology, Sigma Industry, Sigma Civil, and Sigma Software. Sigma Group is owned by Danir, a private investment company held by the Dan Olofsson family.

The Sigma Group has a long history, but SC was created in 2013. This was when Sigma Group acquired the development unit for mobile hardware and connectivity from Sony Mobile in Lund. As a result of this, many of the employees at SC have been a part of Sony Mobile and has extensive experiences within the many fields of product development. The means of SC are *"frontier know-how in technology, design, and engineering with a relentless passion for finding better solutions."* SC works with many types of customers and helps them from concept to realization. [1]

## 1.2 Problem Description

SC carried out a previous project where they developed a knob. For confidential reasons, the external customer of SC and the real product name will not be mentioned in this thesis. Neither will pictures including the product's appearance.

The product will be called "the knob" in this thesis. When the knob was developed, there was an interest in using magnets. An employee of SC also came across a special type of magnets called PolyMagnets®. Due to limited time, SC could not dive deep and explore using magnets for the functions. However, an interest to research if conventional magnets or PolyMagnets®are a possible choice in similar products was formed. Hence, this master thesis will investigate this opportunity.

A simplified sketch of the knob as it looks today can be seen in Figure 1.1. It is a device which has two main outer parts - a moving saddle and a rotating cylinder around it. The saddle can be pushed to select different options; in the middle, up, down, left and right. It can not rotate, only move up and down and tilt slightly. The swivel part can rotate clockwise and counterclockwise to scroll and adjust selections. The knob mainly uses mechanics for these main functions, such as a spring to lift the saddle back up and another spring which act as detents. An optical encoder is used to detect the rotating motion and tactile buttons are used to detect when the user pushes any button. These are simple and widely used solutions, but SC wishes to investigate if these problems can be solved with magnets instead.

Since the knob includes movement, feedback and sensoring, it is a good product to use as basis for this thesis to explore magnets. This thesis will therefore explore the possibilities of using magnets for such functions in the knob. This could improve the product in many ways. This leads to the problem formulation:

*"Can the mechanics of the knob's functions be replaced with magnets, in order to explore the possibilities for magnets in this type of application?"*

However, it is important to notice that the focus of the project is on the potential of magnets for the different functions of the knob and not the real product "the knob" itself. The knob is used to demonstrate how these functions could take form in an actual product. Relevant magnetic functions found that are not ideal for this exact product but for other similar ones should therefore be presented for SC and in this report.

If successful, this thesis and its results could act as a foundation for SC to implement magnets in other future projects with similar functions.

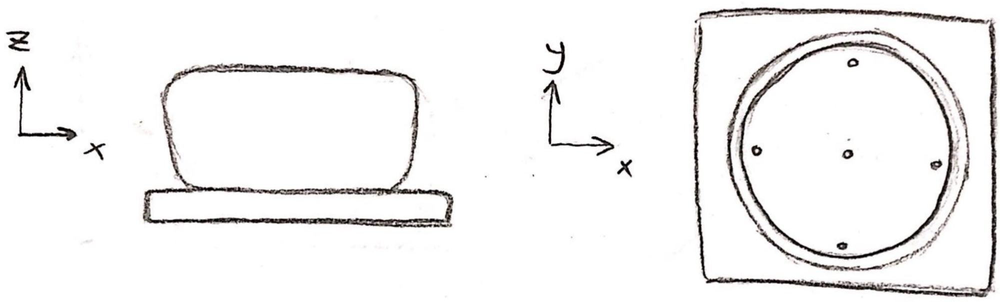



**Figure 1.1: Simplified sketch of the knob.**

## 1.3 Project Goals

This master thesis will investigate if it is possible to implement magnets to replace mechanics where it is possible and adds value. The basis of this project is the design of the knob. Focus will be on the main functions which are the swivel and pushing the top. The top can be pushed in the middle and in four corners; up, down, left and right. When the user is performing any of this, it is desirable to get feedback from the device. Additionally, the signals between the input and output need to function properly. Due to this, the problem can be divided into three subproblems: movement, feedback and sensoring.

The goal of the project is to deliver a proof of concept as well as a prototype. The prototype should have the functions of swivel and pushing, both mechanically and if possible for sensoring too.

In the end of this project, improvements and further development of the concept will be presented. SC will use the results of this thesis as know-how for their various future projects.

## 1.4 Delimitations

This thesis will mainly focus on developing a knob with magnets replacing the mechanic functions. Sensors and electronics are also a part of the development but since the authors have limited knowledge within this area, it will be prioritized secondary in the process. To make the sensors and electronics work properly, the authors will receive help from employees at SC.

Costs and cost calculations will not be included in the scope of the project. Nor will the ability to assemble the magnets in a simple way.

# 2 Methodology

## 2.1 Time Planning

During the first week of this thesis, a time plan was conducted. All tasks of the thesis were laid out and then they were organized in a Gantt chart with time allocated to each one. The initial Gantt chart can be seen in Figure A.1 in Appendix A. The actual Gantt chart can be seen in A.2.

## 2.2 Approach

The problem in this master thesis was approached using the methods presented in the book Product Design and Development written by Karl T. Ulrich and Steven D. Eppinger. [2] This approach was chosen due to its systematic nature which gives structure to this type of research and development. The methods of Ulrich and Eppinger are also well known and widely used in product development processes.

The different phases in the concept development process are shown in Figure 2.1. This is the generic concept development process by Ulrich and Eppinger. This master thesis is greatly inspired by these phases but the process has been modified to suit the time span of 20 weeks.

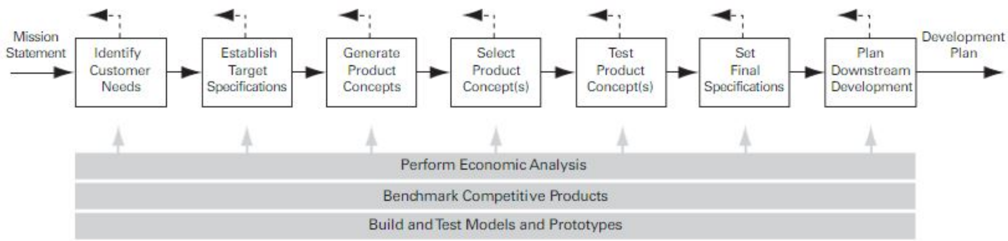



**Figure 2.1: The generic concept development process developed by Ulrich and Eppinger. [2]**

This project started with background research. This was in order to get a good foundation of knowledge before all the other phases. This in not an essential step in the traditional structure followed. According to Ulrich and Eppinger, the concept development process starts with identifying customer needs and establishing target specifications. In this project, the customer needs are mainly based on which functions the product needs to have and the needs are based on the requests from SC. Since these needs are hard to quantify, no target specifications are set.

With the outset in the needs, the next phase is generating product concepts. In this phase, the goal is to come up with as many concepts as possible for all sub problems. It is important to not discard any concepts yet even though they do not seem to have great potential in this initial state. After generating many concepts the next step is to combine them into full concepts that seem promising. After combining the concepts, it is possible to select which one och ones to move forward with. This can be done by several different methods that are recommended by Ulrich and Eppinger.

The next step is to test the promising concepts. According to Ulrich and Eppinger, testing is done by letting an end user test the product to seek possible improvements. This was not possible in this master thesis since there was no contact with actual end users. However, iterations can still be made to improve the final concept even more. In this thesis, the evaluations were mainly done by 3D-printing and an Arduino. The team improved the concepts several times. The final concept is then thoroughly described and the final specifications are. According to Ulrich and Eppinger, the final step is to plan the downstream development.

# 3 Background Research

*This chapter presents the research made in the primary phase of the project. This covers general theory about magnets and sensors. Patents and benchmarking of existing products have also been conducted. This research acted as the foundation of the project and the concept generation phase.*

## 3.1 Method

The background research in this thesis was focused on gaining knowledge about different types of magnets and sensors and how these can be used. This was essential to do before the concept generation phase. The background research was performed through internet search. No suitable literature was accessible and therefore books were not used. Since most of the background research is based on available similar products, internet sources were considered the most useful.

Firstly, conventional magnets and the theory about magnetic fields were researched. This was crucial to understand the very basics of magnets and how they can be implemented in products. The focus of this master thesis is applications of magnets and not magnetic field theory. In addition, different types of sensors were investigated. This is necessary to detect motion in the knob.

Patents were researched to gain inspiration. These patents were used to find different ways that magnets could be used and how they could be configured and positioned.

A study of existing implementations of magnets was conducted. Products which either had a swivel function or uses magnets in a relevant way were analyzed.

# 3.2 Magnets

Conventional magnets and software-based PolyMagnets® (PM) are described.

## 3.2.1 Conventional Magnets

A magnet is an object which has the ability to attract iron and create a magnetic field external to itself. [3] Conventional magnets have two poles - north and south. The magnetic field can be represented with field lines starting at the north pole and end at the south pole, see Figure 3.1.

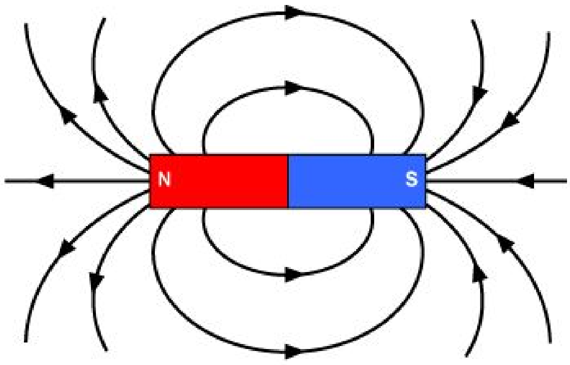
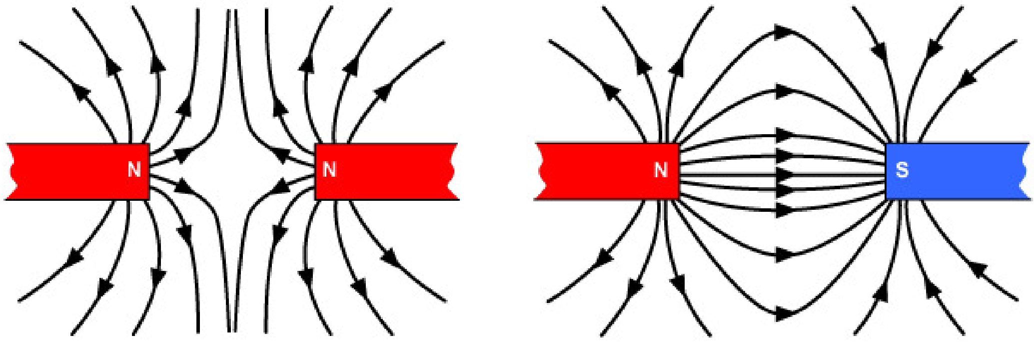



**Figure 3.1: Representation of magnetic field in a conventional magnet with one north pole and one south pole. [4]**

Magnetic force occur when two magnets come near each other. The force is caused by the two magnetic fields and the force is pointing in the direction of the field lines. If two north poles - or south poles - face each other, the field lines will move away from each other. This can be felt as a repelling force. If one magnet's north pole will face another magnet's south pole, the field lines will go directly from the first magnet's north pole to the next one's south pole. This will create an attractive force. [4] In conclusion, like poles repel and opposite poles attract. This is illustrated in Figure 3.2.




(a) (b)

**Figure 3.2: a) Like poles repel. b) Opposite poles attract [4].**

A magnetic field is the area around a magnet in which there is a magnetic force. Thus, it is within this area magnets can attract or repel each other. The magnetic field is created by moving an electric charge. In permanent magnets this happens by moving electrons which have a negative charge. [5]

Magnets do not just attract opposite poles on other magnets, they also attract certain metals such as iron, nickel and cobalt. Permanent magnets create their own magnetic field all the time while temporary magnets only produce magnetic fields in the presence of another magnetic field. There are also electromagnets which produce magnetic fields when electricity travels through their wire coils. [6]

### 3.2.2 PolyMagnets

Conventional permanent magnets are simple with a north pole and a south pole. Correlated Magnetics Research have invented a new type of magnet called PolyMagnets® (PM). These are software driven and can be programmed to create patterns in the magnetic field. Since this is done by software, customized PM can be manufactured considerable faster than conventional magnets. They can also achieve properties that are not feasible with conventional magnets. In addition, PM are up to five times stronger than conventional magnets. The product catalog contains magnets with the traits: attach, align, latch and spring. [7]

*3.2.2.1 Attach*

Attach PM are stronger than conventional magnets in both tension and shear force, both on thick metal and thin metal sheets. [8] The field lines of a PM are shown in Figure 3.3. They show that a conventional magnet is weaker because of the more sparse field lines. PM has more concentrated field lines and therefore the magnetic force is stronger to hold on to the metal piece. In addition, the range of the magnetic field is shorter compared to a conventional magnet. This allows the magnet to only attract or repel within a specific distance. [9]

This can also be illustrated by force curves, which in PM are shorter and steeper. Force curves for PM and conventional magnets are compared in Figure 3.4. The steeper force curve makes the magnet more precise and allows the product designer to choose a smaller magnet but keep a high force in the short range where it is needed. In addition, this lowers the risk of interference with nearby sensitive electronics. [10]

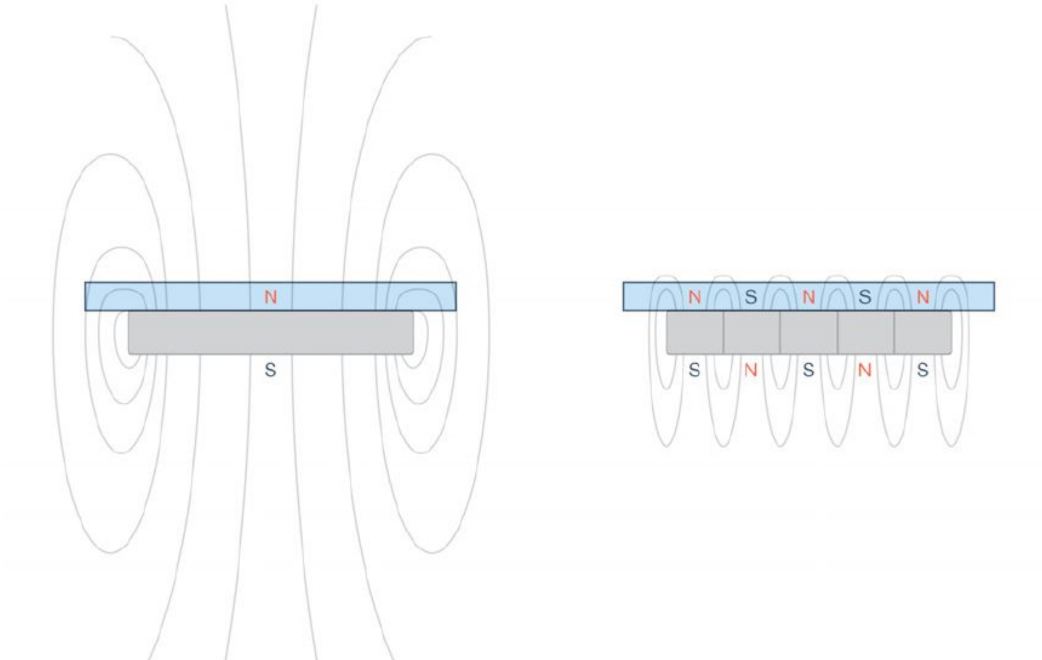



**Figure 3.3: Magnet fields of conventional magnet and PM attached to a metal piece. PM have a shorter and more concentrated magnetic field. [9]**

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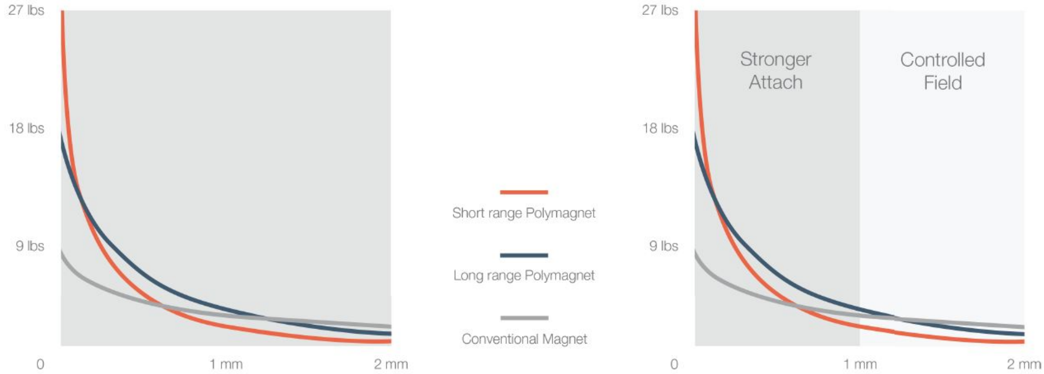


**Figure 3.4: Force curves for conventional magnets on the left and PM on the right. [9]**

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*3.2.2.2 Align*

Align PM will offer accurate positioning. If the magnet is made for centering, it will seek to align with the mid-point axis. This can be done without consideration to rotational position or at specific rotational positions. These specific rotational positions can be felt as detents. An example can be seen in Figure 3.5 where two Align PM are attached to each other, the distance is just for demonstration. The blue and red area demonstrates the magnetic poles. The blue area on one magnet is attached to the red area on the other magnet. In the right picture, one magnet has been rotated 90 degrees. The detents can be symmetric at e. g. 180, 90, 30 degrees or have any other customized pattern. The Align PM can also have lateral alignment. A great advantage is that there is no need for re-calibration or maintenance. [11]

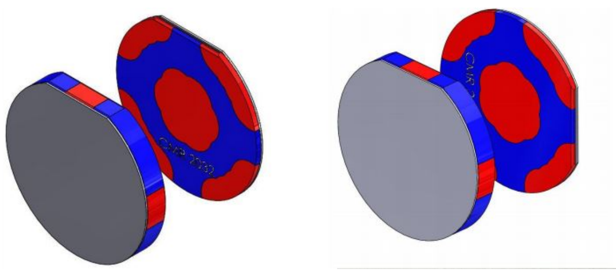
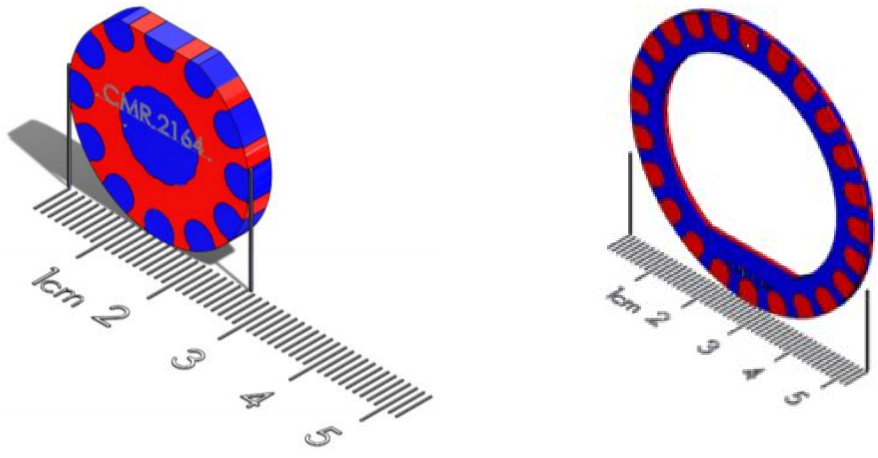


**Figure 3.5: Two Align PM. Rotated 90 degrees on the right. [11]**

The Align PM is available in several different versions, including versions with 12 and 24 detents, see Figure 3.6 [12]




**(a)** **(b)**

**Figure 3.6: a) PM with 12 detents. b) PM with 24 detents. [12]**

*3.2.2.3 Latch*

The Latch PM will repel each other until they are pushed together and reach a specific distance. At this defined distance, they will attract and close. The specified distance can be customized. They need to be constrained in at least one other dimension to not push each other to the side and attach. [13]

*3.2.2.4 Spring*

The Spring PM will rest at a defined distance from each other. If pushed together, they will repel. If pulled apart, they will attract. These properties will behave like a magnetic spring. An example can be seen in Figure 3.7 where two Spring PM are axially aligned. They will then repel at that distance but if pulled apart they will attract again and return to this state. The specified distance can be customized. They need to be constrained and centered to not push each other to the side and behave incorrectly. An application of this magnet can be to use it as a contactless attachment, which is a notably unique property. Since they are contactless and return to their position, they can also be used to dampen vibrations. [14]

**Figure 3.7: Two Spring PM that repel at a certain distance. [15]**

## 3.3 Detect Motion

Many different technologies can be used to sense motion. This section will describe magnetic encoders and two types of sensor technologies: Hall effect and magnetoresistivity.

### 3.3.1 Encoders

An encoder is a type of sensoring device that provides the user with feedback. It will convert linear och rotary motions into an digital output signal. This can be used to determine position, count, speed or direction. Encoders can use different technologies to create signals such as mechanical, magnetic, resistive and optical. The most common one is optical, which provides feedback based on the interruption of light. This technology is used in the knob today. [16]

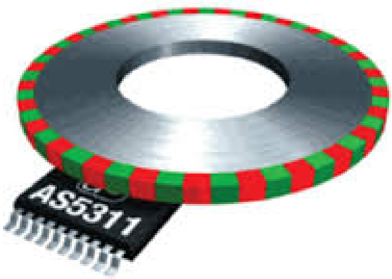
#### *3.3.1.1 Magnetic Encoders*

Magnetic encoders are a specific type of encoder which relies on changes in magnetic fields. Different technologies can be used such as Hall voltage or magnetoresistive sensors. Thus, an encoder contains one or several sensors. Types of sensors will be explained further in the following sections. Optical encoders have traditionally been the primary choice for high resolution applications. But with improved technology, the magnetic encoders challenges the optical technology in many applications. [17] Some benefits are:

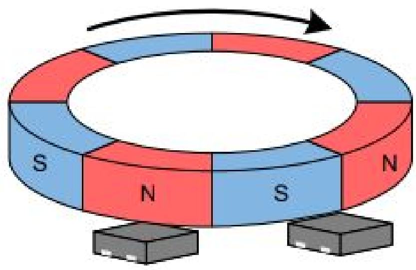
- There is no contact and therefore no friction and ware.
- The magnetic field will pass through most contaminants such as water and dirt.
- The PCB can be sealed from the surrounding environment.
- The input sensing and output signaling is digital which give low noise. [18]

Magnet encoders can be linear och rotary. A magnetic rotary encoder consists of the main components: a disk, sensors and a conditioning circuit. A disk and sensor can be seen in Figure 3.8a). The disk is magnetized and has several poles along the edge. When the disk rotates, the poles will move. This is detected by the sensor that senses the change in magnetic field. The sensors can be Hall effect sensors or magnetoresistive devices. The conditioning circuit will produce the desired output. The resolution is determined by the number of poles and the number of sensors. A linear encoder works in a similar way. See Figure 3.8b). [17]

If it is desired to detect both clockwise and counterclockwise movement, two sensors are needed. They can give two outputs with a phase offset. 90 phase offset is preferred because it maximizes the timing margin between each state. This is presented in Figure 3.8c). [18]




**(a)**

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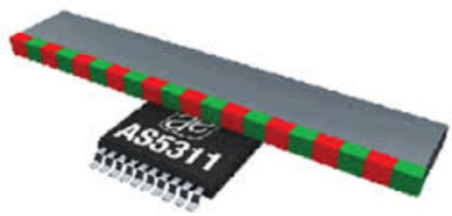



**(c)**

**Figure 3.8: a) Magnetic rotary encoder with one sensor. [17] b) Magnetic rotary encoder with two sensors. [18] c) Magnetic linear encoder with one sensor. [17]**

### 3.3.2 Magnetic sensors

Magnetic sensors are used to convert magnetic encoded information into electric signals. They can be used for sensing position, velocity or directional movement which makes them practical in many applications. Magnetic sensors can be of many characters. Hall effect sensors and magnetoresistive sensors will be described in this master thesis.

Magnetic sensors are used in the magnetic encoders, see 3.3.1.1, so the benefits described for encoders can be applied to any magnetic sensors depending on how they are used. Here it is described how the sensors work and how they can be used on their own together with magnets and not placed in an encoder. [10]

#### *3.3.2.1 Hall Effect Sensors*

Hall effect sensors are activated by an external magnetic field. When the magnetic flux density B changes, the sensor can detect this and send an output voltage to the user. This is called Hall voltage.

A Hall sensor can have either analogue (linear) or digital output. An analogue sensor gives a continuous voltage output that increases with a strong magnetic field and decreases with a weak magnetic field. The sensor can be saturated, which means that there is a maximum strength of magnetic field that it can detect. A digital sensor on the other hand only has two states: on or off. Therefore is it often called a Hall switch. The sensor switches when the magnetic flux exceeds a pre-set value. In practical terms, this means that a digital sensor will switch from off to on when a magnet approaches close enough.

The sensor consists of a semiconductor material passing a current through itself. When exposed to a magnetic field, the charge carriers, electrons and holes are deflected to one side, see Figure 3.9 . This results in a Hall voltage which gives the user an output signal. [10]

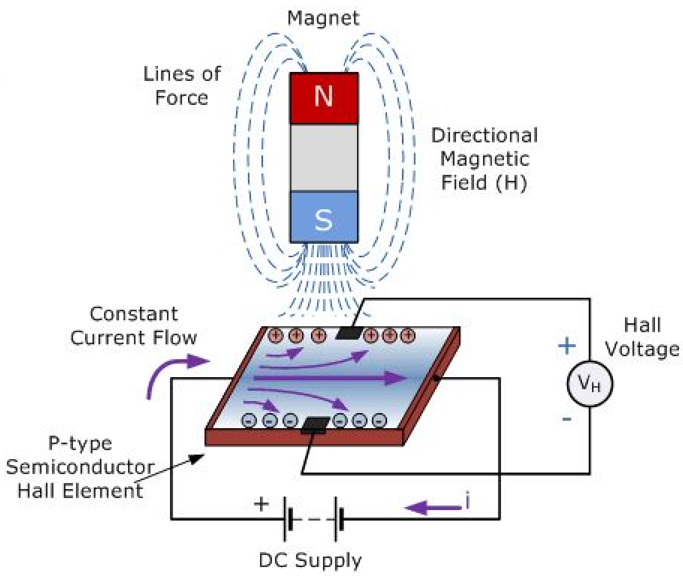
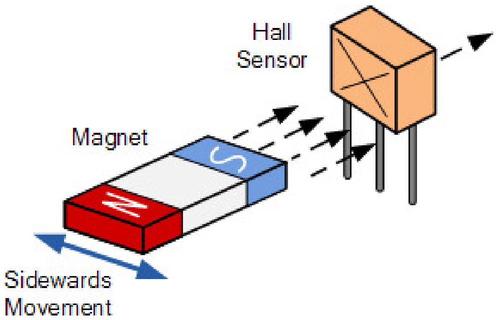
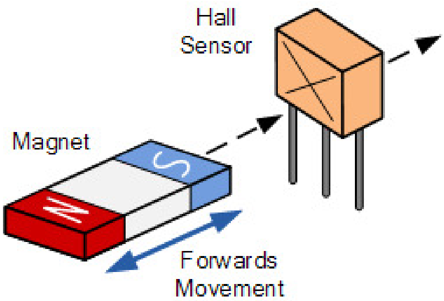



Figure 3.9: Illustration of hall effect sensor. [10]

For many applications a device can be operated by a single permanent magnet, being attached to a moving shaft or device. But Hall effect sensors have some demands on the magnet to work. The size of the magnet will decide the size of the magnetic field surrounding it. The magnetic flux lines of the magnet must be perpendicular to the flow of current in the sensor, see Figure 3.9, and be of correct polarity to get maximum sensitivity. That is why it is important to use the correct magnet movement to the specific sensor used. Two examples of magnet movement can be seen in Figure 3.10. These are head on and sideways. [10]




(a)




(b)

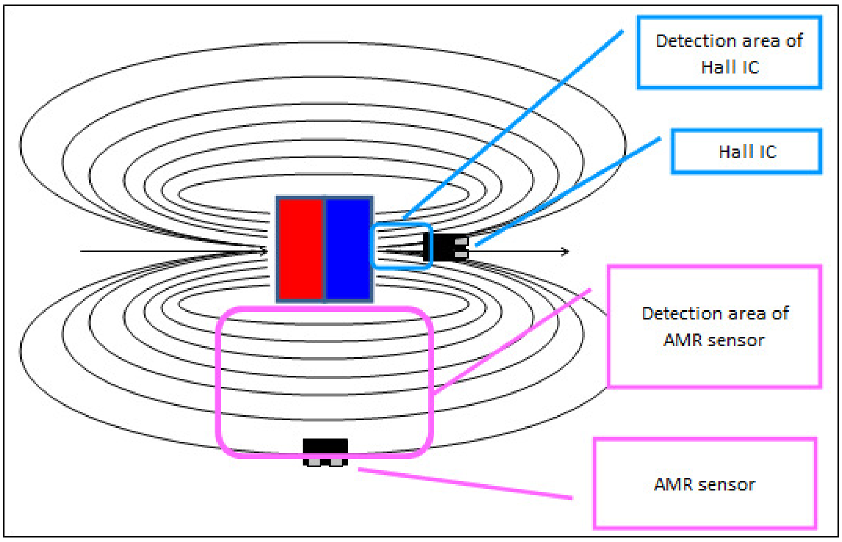
Figure 3.10: a) Sideways movement. b) Head on movement. [10]

#### *3.3.2.2 Magnetoresistive Sensors*

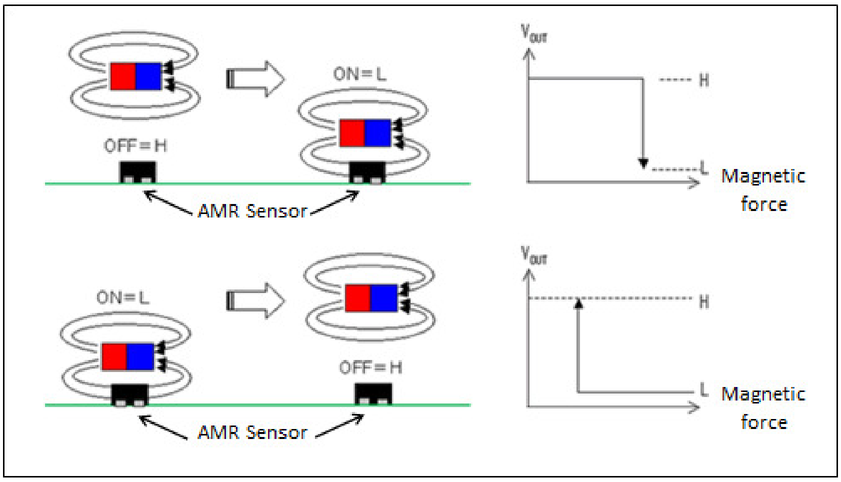
Magnetoresistivity is the ability of a material to change resistance under the influence of magnetic fields. The most commonly used phenomena is anisotropic magneto resistive (AMR) effect. This occurs in ferrous materials, which means that they contain iron. A sensor which utilizes this effect is called an AMR sensor.[19]

A magnetorestistive sensor also detects magnetic fields but in a different way than a Hall sensor does. It can be explained in a simplified way. The sensor is approached by an object with its own magnetic field. When this happens, the electrical resistance changes. The resistance is dependent on the angle between the current direction and the external magnetical field. The resistance is smallest at 90 degrees and highest when the current flows in parallel. This makes is possible to detect how the object is positioned and also its distance from the sensor. [20]

The measurements are very precise, even under extreme conditions. Magnetoresistive sensors are about 100 times more sensitive than Hall effect sensors. This can be either positive or negative depending on the application. They are more accurate but also saturate easier. Magnetoresistive sensors are used perpendicular to the magnetic field while Hall effect sensors are used in parallel. [19] This is illustrated in Figure 3.11.




**(a)**




**(b)**

**Figure 3.11: a) AMR sensor and Hall sensor should be placed differently in a magnetic field. [21] b) The direction of the magnet movements above an AMR sensor. [22]**

## 3.4 Existing Implementations

Several existing products that are using magnets in relevant ways are presented. These products are using magnets for providing feedback to the user or acting together with a sensor. Many other products may use magnets in other or similar applications, but it is difficult to detect this without performing tear downs.

### 3.4.1 Samsung Galaxy Watch

The Samsung Galaxy Watch, seen in Figure 3.12 is a smartwatch with the look of an analogue watch. The bezel surrounding the watch can be rotated to scroll on the screen. [23] The technique that reads the turning of the bezel might be useful for this project.

**Figure 3.12: Samsung Galaxy Watch. [23]**

The Samsung Galaxy Watch uses magnets and hall sensors to read the turning of the bezel. As seen in Figure 3.13, every third groove on the bezel contains a magnet. When the bezel is rotated, the magnets rotates with it. On the printed circuit board, PCB, inside the watch, three hall sensors are located. When the bezel is rotated, two of the sensors will read a change in their magnetic field. The third sensor does not read a change. With this method, it can be determined in which direction the bezel is rotated. [24]

**Figure 3.13: The rotating bezel of the Samsung Galaxy Watch. [24]**

### 3.4.2 Nest Thermostat E

Google Nest offers connected devices for the home, like cameras, alarm systems and thermostats. [25] The Nest Thermostat E can be seen in Figure 3.14.


**Figure 3.14: The Nest Thermostat E. [26]**

The outer ring of the Nest Thermostat E thermostat can swivel. Instead of using an optical encoder like previous versions of Nest's thermostats have used for reading the rotation, this version uses a magnetic angle sensor instead. It is visible in Figure 3.15 marked KMT39. The sensor is from TE Connectivity and uses the AMR effect. The outer ring contains a magnetic strip which the angle sensor can read a change in when rotated, see Figure 3.16a). Figure 3.16b) reveals that it is a flat magnetic strip that is adhered to the inside of the ring. [26] It is not clear how the magnetic poles are configured on the magnetic strip.

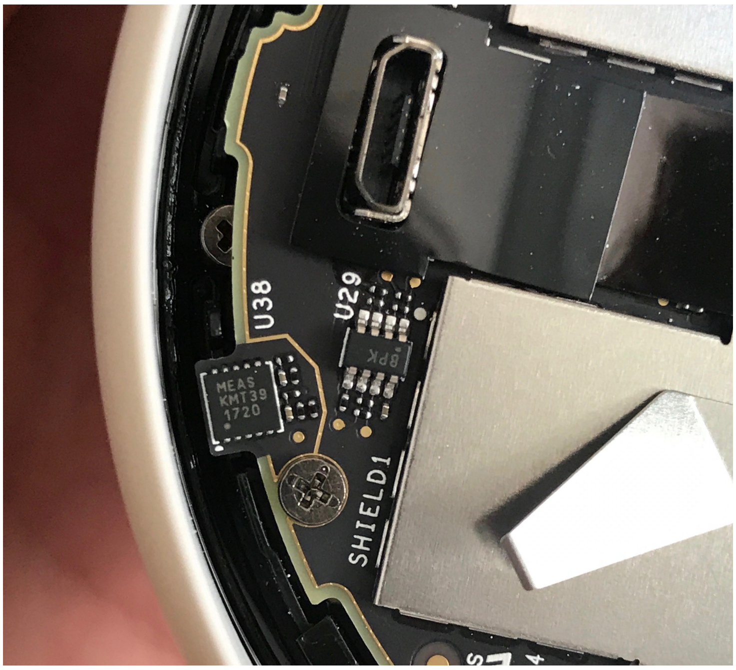



**Figure 3.15: The magnetic angle sensor used in the thermostat. [26]**

**(a)** **(b)**

**Figure 3.16: a) The magnetic strip used in the outer ring. b) Flat strip rolled up and adhered to the inside of the ring. [26]**

### 3.4.3 Magnetic Building Sticks

Magnetic building sticks together with steel balls are a children's toy. The sticks has magnets at the ends and allows the sticks and balls to be built together in different shapes and patterns. [27] A pyramid shape can be seen in Figure 3.17.

**Figure 3.17: Magnetic building sticks built as a pyramid. [27]**

The steel balls rest on a flat surface and the sticks are held up just above the surface due to the magnetic force. When pressing on a stick, this force will be stronger than the magnetic force. Therefore the stick will touch the surface underneath and the steel ball will move slightly away. When pressing, the user will sense and hear a clicking feedback. When the user releases, the stick is attracted back in place to its connection to the steel ball. This procedure can be seen in Figure 3.18 and Figure 3.19.

**Figure 3.18: Magnetic building sticks resting on a flat surface.**

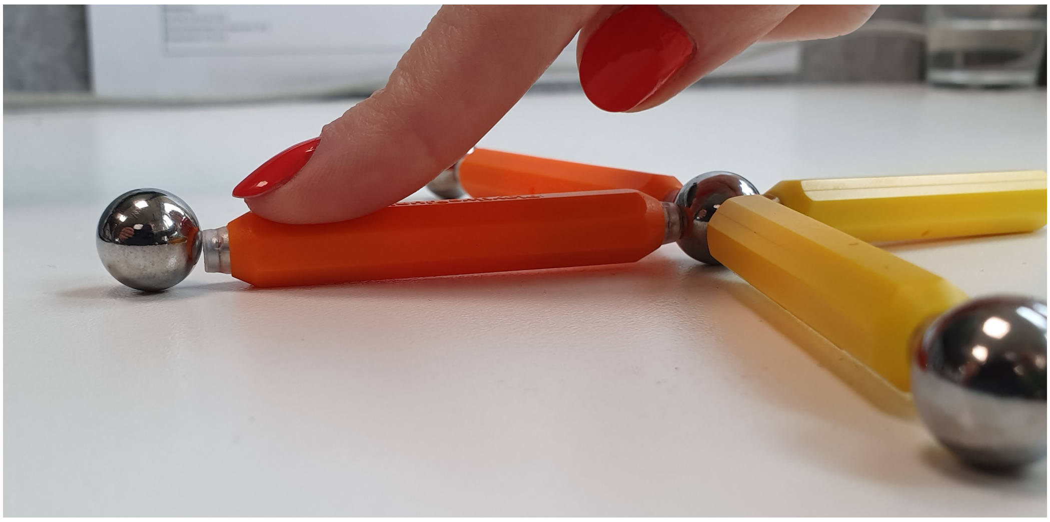


**Figure 3.19: Magnetic building sticks when pushed.**

### 3.4.4 Logitech MX Master 3

The Logitech MX Master 3 is an advanced computer mouse which uses a electromagnetic system that replaces the mechanical scrolling wheel. There are two modes for scrolling the wheel. The ”detent” mode is when the user scrolls slow and controlled with higher resistance. The ”free” mode is when the user scrolls fast, which gives a free and silent spin to the wheel.

The ”free” mode has no mechanical contact and the new technology of using magnets instead of a motor (as in the previous generation) have reduced the size noticeable. It is not explained exactly in detail how the electromagnetic system works, but voltage is applied to magnets in the middle which magnetizes a gear around it. The gear is seen in Figure 3.20. Depending if the voltage is on or off, this will turn the modes from ”detent” mode to ”free” mode. This happens automatically when the user spins the wheel fast. [28]

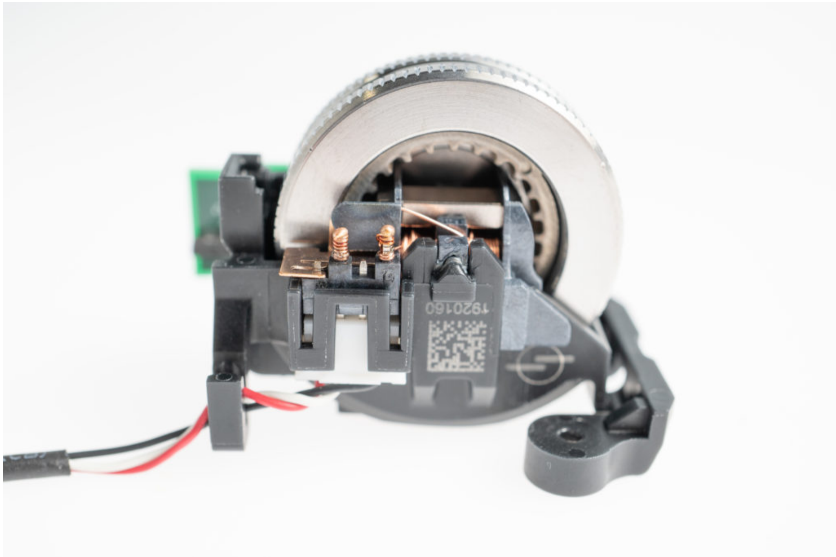


**Figure 3.20: The scroll wheel of Logitech MX Master 3. [28]**

## 3.5 Patents

Several patents that are using magnets in relevant ways are presented. These patents show swivel functions and push buttons with magnets.

### 3.5.1 Patent by K. Inada et al.

Koji Inada, Rina Matsuda and Akito Okamoto have invented a switch in the form of a push button. When pressing the push button, it lowers and comes in contact with a display panel. A magnet is attached to the push button and when it lowers, this leads to a change in the magnetic field. This is sensed by a Hall element. When the user releases the push button, the magnet returns to its initial state due to the attracting magnetic force of another magnet above. [29] The principle is shown in Figure 3.21.

The patent was published in 2003 and application status is expired.

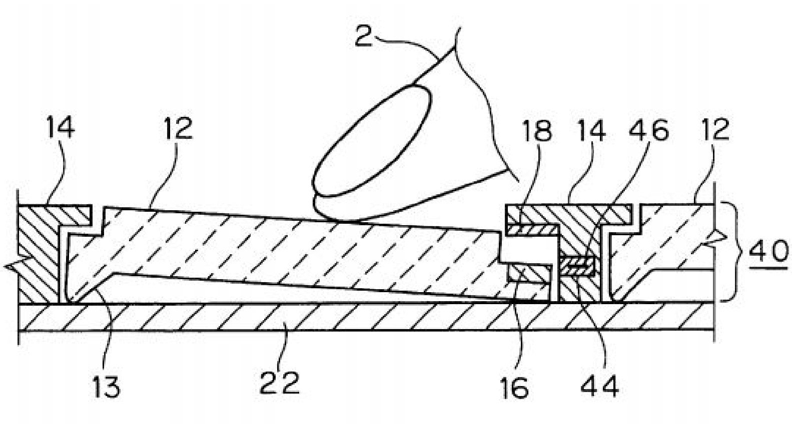



**Figure 3.21: Principle of the switch invented by Inada et al. [29]**

### 3.5.2 Patent by S. J. Scarlata

The inventor Stephen J. Scarlata have a patent which describes several interesting features. It is an apparatus for magnetically transferring control information from a rotary knob. The design consists of a rotating knob and a magnetic material in a circle around it with alternating poles. It also has an electronic detector to sense the change in the magnteic field. [30] Two designs can be seen in Figure 3.22 and Figure 3.23. These designs completely seals the sensor and other electronics. The principle of the alternating poles are shown in Figure 3.24.

The patent was published in 2001 and application status is expired.

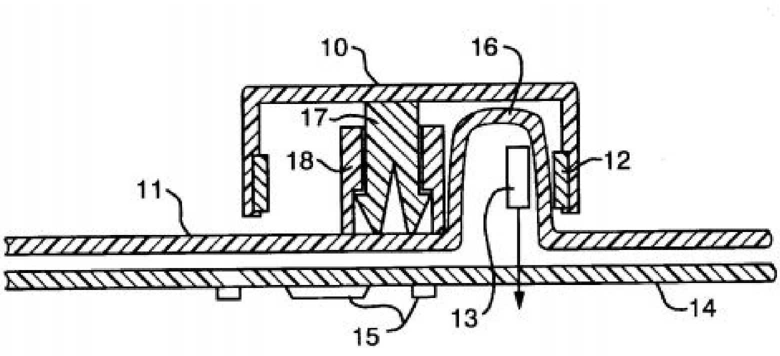



**Figure 3.22: Configuration of a knob with sealed sensor and electronics. The magnetic material and corresponding sensor are perpendicular to the flat surface underneath. [30]**

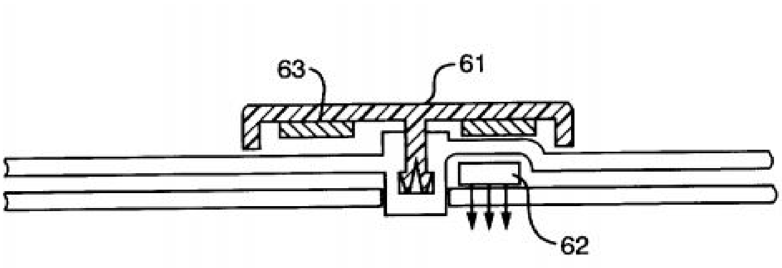



**Figure 3.23: Configuration of a knob with sealed sensor and electronics. The magnetic material and corresponding sensor are parallel to the flat surface underneath. [30]**

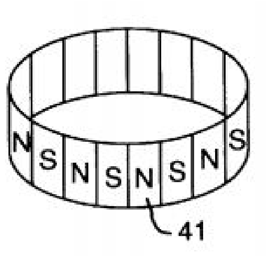



**Figure 3.24: Magnetic material with alternating poles. [30]**

### 3.5.3 Patent by T. K. Trudeau et al.

Timothy Krahn Trudeau and Gregory Seth Bandy have invented a dual knob. There are two independent knobs, the outer one can rotate and the inner one can both rotate and be pushed. When pushed, the inner knob rises back up using a leaf spring. [31] The outer design is shown in Figure 3.25.

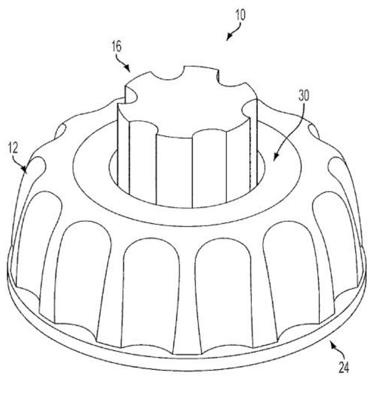



**Figure 3.25: The dual knob. [31]**

The inner knob holds a magnet in a bore. The outer knob holds a magnetic strip. Two encoders are used to detect motions. The encoder which is corresponding to the inner knob detects both angular motion and axial movement up and down due to the movements of the held magnet. The encoder which is corresponding to the outer knob detects the rotation due to the poles of the magnet strip. When the poles move in a circular motion, magnetic field changes near the encoder. A housing containing the electronics are placed underneath the knob and this is completely sealed. [31] A section of the detailed design is shown in Figure 3.26.

The patent was published in 2012 and application status is active.

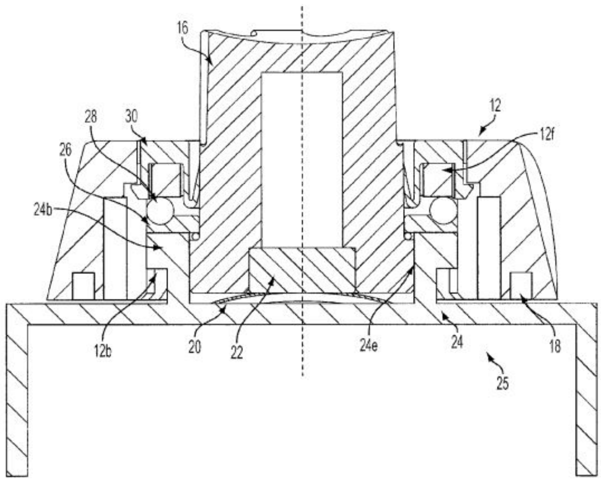



**Figure 3.26: Section showing a detailed design of the patent by T. K. Trudeau et al. [31]**

### 3.5.4 Patent by E. Serrus Paulet

The inventor Edouard Serrus Paulet has invented a rotary switch containing movable magnets. The magnets are places in bores where they can move freely in one direction. The switch will occur when the magnets are located in one end of the bore. The magnets will move from one end of the bore to the other due to magnetic force from other magnets. When rotaring the switch, magnets will change position and then affecting the magnets in the bores. Underneath the bores are sensors. A design can be seen in Figure 3.27. This design completely seals the sensor and other electronics. [32]

The patent was published in 1980 and application status is expired.

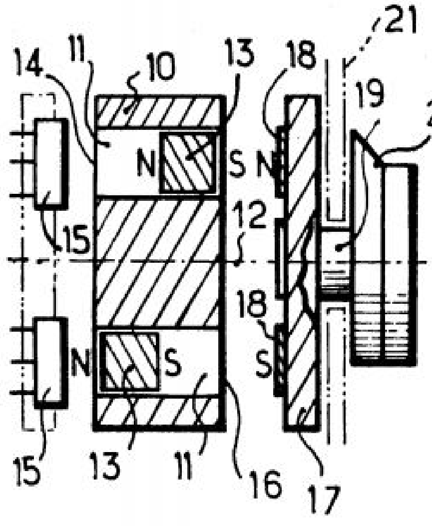



**Figure 3.27: Rotary switch with movable magnets inside of bores. [32]**

# 4 Customer Needs and Target Specifications

*This chapter presents the customer needs and target specifications and how they were obtained.*

## 4.1 Method

Traditionally when following the methods of Ulrich and Eppinger, there is a lot of focus on the customer needs. Usually the customer in mind is a real end user. However, in this master thesis there was no contact with any end users. In this project, the customer can instead be assumed to be SC. The method for obtaining the needs is therefore to discuss the matter together with the supervisor at SC and gather their requests.

Normally the customer needs are followed by target specifications according to Ulrich and Eppinger. Target specifications are similar to the customer needs but quantified. An example of this is that a product might require a low weight. The target specifications could then describe a maximum weight allowed.

## 4.2 Customer Needs

This thesis focuses primarily on the functions which can be obtained by using magnets. The goal is to explore the possibilities of magnets in this type of product and the list of customer needs is therefore rather short. A few non-essential needs were expressed to support the concept generation process. Legal standards, cost and other elements that are important for mass production were not focused on during this master thesis. Below follows a list of the needs with their importance. Three asterisks mark the highest importance and one asterisk mark the lowest importance.

*** The knob can rotate clockwise and counterclockwise.

*** The knob gives feedback to the user when the knob is rotated.

*** The knob should have 24 detents.

*** The knob can be pushed in the middle of the top to select an option.

*** The knob can be pushed at the upper, lower, left and right corner of the top to select different options.

*** The push top returns to its initial position after being pushed.

*** The knob gives feedback to the user when the top is being pushed.

** Signals are sent to the PCB when a function is performed.

* The electronics of the knob are sealed from the outer environment.

* The knob works even after being shaken.

## 4.3 Target Specifications

The customer needs describe the project goals in detail. It is not necessary to quantify the needs. Therefore no target specifications were set.

# 5 Concept Generation

*This chapter presents the procedure of concept generation. The problem is clarified and all generated concepts are described thoroughly.*

## 5.1 Method

The problem was clarified and then brainstorming was used to imagine solutions to the subproblems. After coming up with as many sub-concepts as possible, some of these were eliminated in an initial screening. This was to reduce the number of concepts in order to move forward with the most potential ones. The decisions were made through intuition and discussion with the mentor at SC.

The remaining concepts were combined in promising ways. The combined concepts which had great potential were then improved further. However, only the mechanical concepts were combined and there was no consideration to sensors at this stage. The reason for this was that it would be too time-consuming to have different types of sensors in mind when trying to create a mechanical concept which could work. The approach was instead to implement the suitable sensors when the mechanical concept was set.

## 5.2 Clarify the Problem

Since the knob consist of several parts and different types of functions, the problem needs to be clarified. This is necessary in order to be able to generate concepts to each one of these subproblems and then combine these in the most promising ways.

The problem can be divided into the two main parts of the device: the push top and the rotating part. Below follows decomposition by sequence of user actions.

**Problem decomposition for push buttons:**

1. The push top lowers (in the middle or tilting)
2. The user gets feedback
3. A signal is sent
4. The push top rises

**Problem decomposition for rotation:**

1. The rotating part moves from one detent to the next
2. The user gets feedback
3. A signal is sent

In summary, both the rotation and the push button functions basically happen by:

Motion $\Rightarrow$ feedback $\Rightarrow$ signal

This thesis aims to replace these functions with solutions containing magnets. However, magnet solutions can be hard to combine due to magnetic fields interfering. Therefore, some mechanical concepts are presented as well. For example, a knob containing magnets for button sensoring but that still requires a compression spring to return to its position is still of great interest.

## 5.3 Generated Concepts

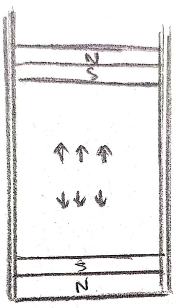
### 5.3.1 Concepts for the Push Top

#### *5.3.1.1 Compression Spring*

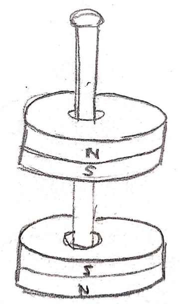
Metal or plastic springs are widely used in many typed of applications. A compression spring stores mechanical energy when compressed and the energy is released when the spring expands. Several compression springs are used in the knob today.

#### *5.3.1.2 Repelling Magnets Acting as Spring*

Two repelling dipole magnets can act as a spring. If two of the same poles are facing each other, their magnetic fields will always repel them away from each other. This could be used to lift up the top after the user releases. The magnets need to be axially aligned to not slide sideways or flip over. The phenomena of repelling magnets which are stabilized is called pseudo-levitation. [33] Some examples of how repelling magnets can be used instead of a spring can be seen in Figure 5.1.




**(a)**

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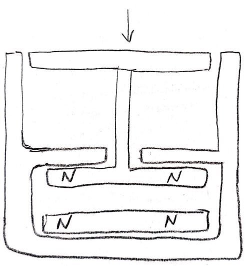


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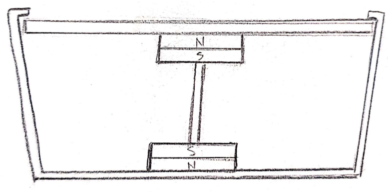



**(d)**

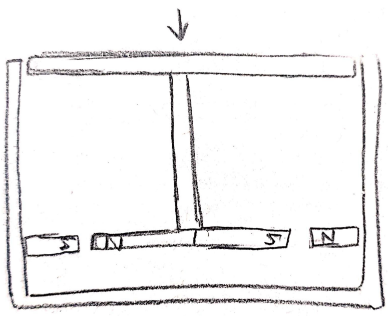
**Figure 5.1: a) Repelling magnets that are axially aligned by a tube. b) Repelling magnets that are axially aligned by a rod. c) An example of how the repelling magnets can be used in the knob. d) An example of how the repelling magnets can be used in the knob.**

*5.3.1.3 Spring PM*

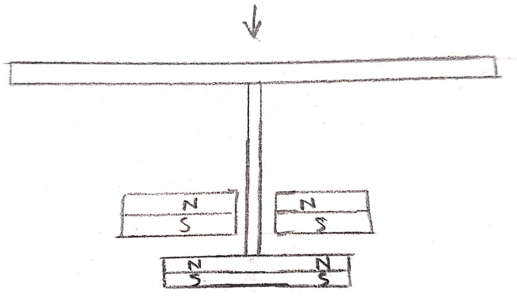
The Spring PM are a more advanced pair of magnets which will rest of a specific distance from each other. If they come too close to each other, they will repel. If they come too far away from each other, they will attract. This gives similar properties as a mechanical spring. An image can be seen in Figure 3.7.

*5.3.1.4 Attracting Magnets Acting as Spring and to Achieve Feedback*

Two attracting dipole magnets can act as a spring when pushed apart. If two of the opposite poles are facing each other, their magnetic fields will always attract them to each other. This could be used to lift up the top after the user releases when pushing the button. Two magnets which then clash together again when attracting will give feedback to the user in form of feeling and sound. The magnets could also be used to keep different parts in position. Examples of how attracting magnets can be used in the knob can be seen in Figure 5.2.




**(a)**

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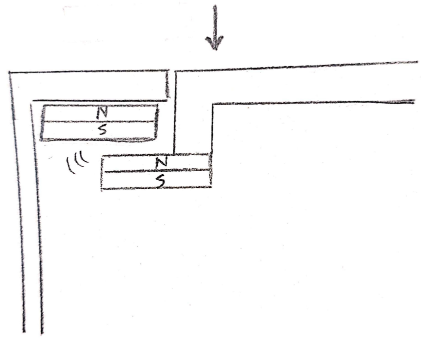



**(c)**

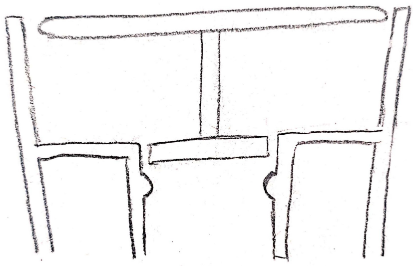
**Figure 5.2: Different configurations of attracting magnets which will separate when pushed and then attract back together again.**

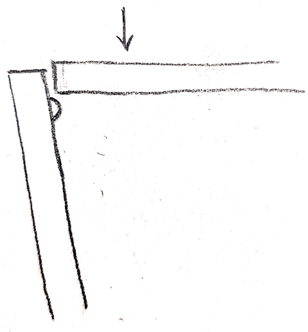
*5.3.1.5 Magnet Attracting Steel Acting as Spring and to Achieve Feedback*

Steel contains iron which act as a temporary magnet and becomes magnetic in the presence of a permanent magnet. A magnet which clashes together with a piece of steel will give feedback to the user in form of feeling and sound. It can also replace a spring in some configurations. The same concepts used in Figure 5.2 could be modified by replacing one of the attracting parts with a steel part.

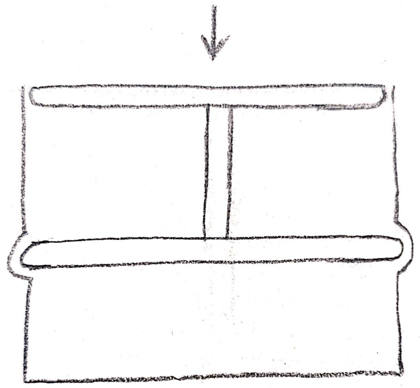
*5.3.1.6 Groove/Bump to Achieve Feedback*

A groove or a bump can give feedback to the user when pushing to overcome this. This is only applicable with ductile materials such as thermoplastics and elastomers. Examples can be seen in Figure 5.3.





**(a)** **(b)**

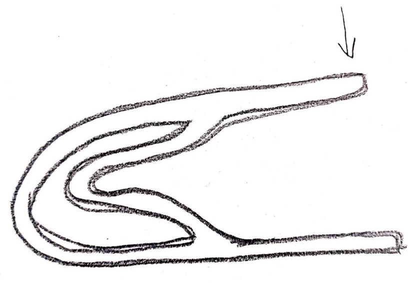


**(c)**

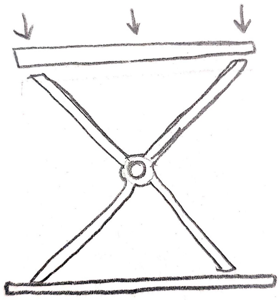
**Figure 5.3: Examples of design with bumps and grooves which gives feedback when the user pushes the top.**

*5.3.1.7 Compliant Mechanism*

A compliant mechanism is a flexible mechanism with flexible members or flexural pivots. [34] The application in the knob would be as spring function. Examples of what the compliant mechanisms could look like can be seen in Figure 5.4.



**(a)**



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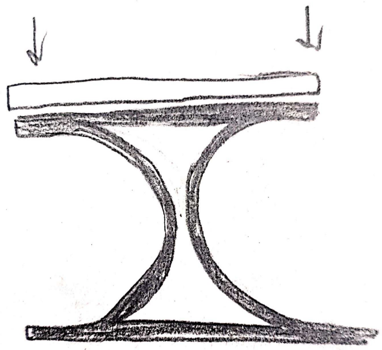

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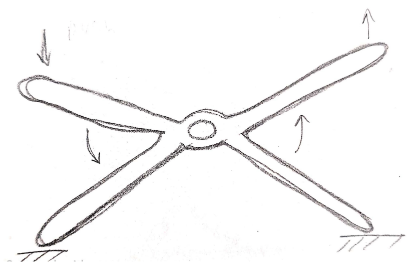
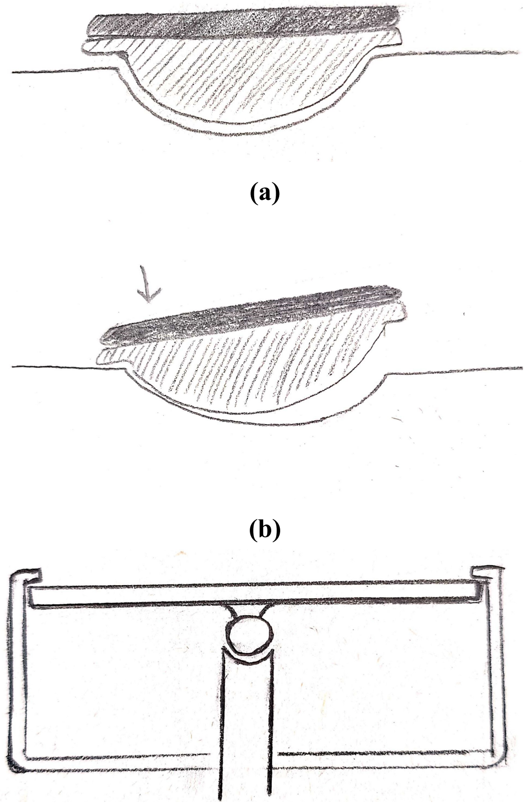


**(d)**

**Figure 5.4: Variants of compliant mechanisms.**

*5.3.1.8 Spherical Hollow to Stabilize Position*

A spherical hole instead of a flat surface allows for tilting motion. When pushing, the object is able to move. This could be used for the push top. This is presented in Figure 5.5.



(a)

(b)

(c)

**Figure 5.5: a) A spherical hollow with a spherical part in it. b) A user pressing on the spherical part. Tilting is allowed. c) How a spherical hollow could be implemented in the knob.**

*5.3.1.9 Ball and Socket Joint*

A ball is fixed in a socket and can not translate in any direction, but it is free to rotate around its own center. [35] This can be used to allow tilting motion. Several configurations are shown in Figure 5.6.

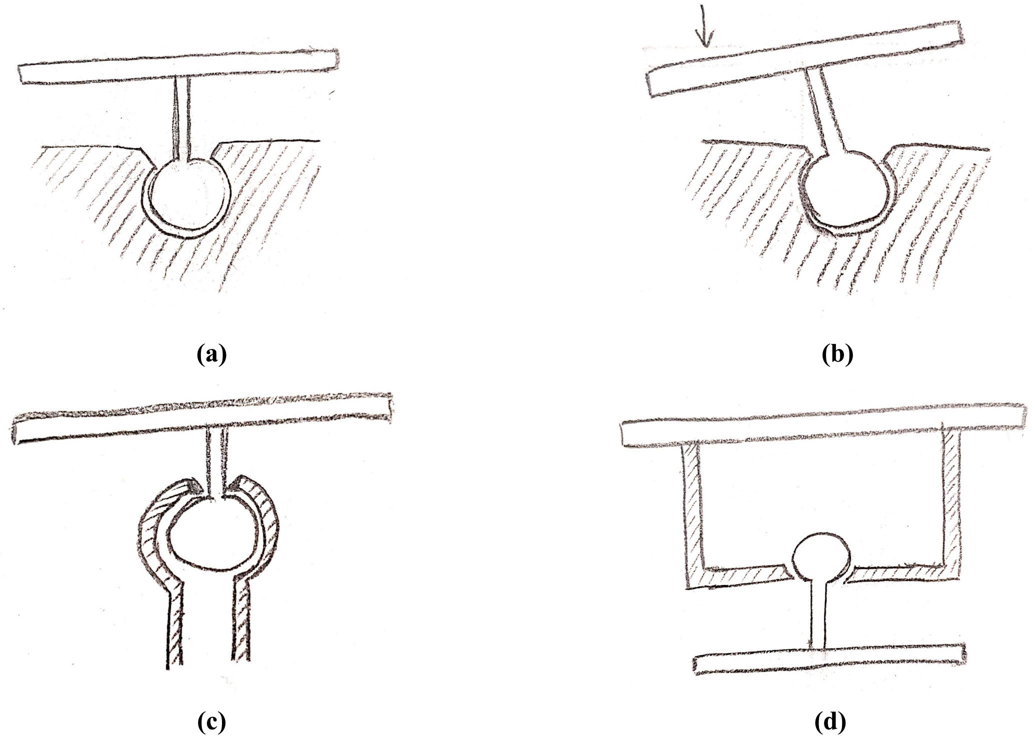
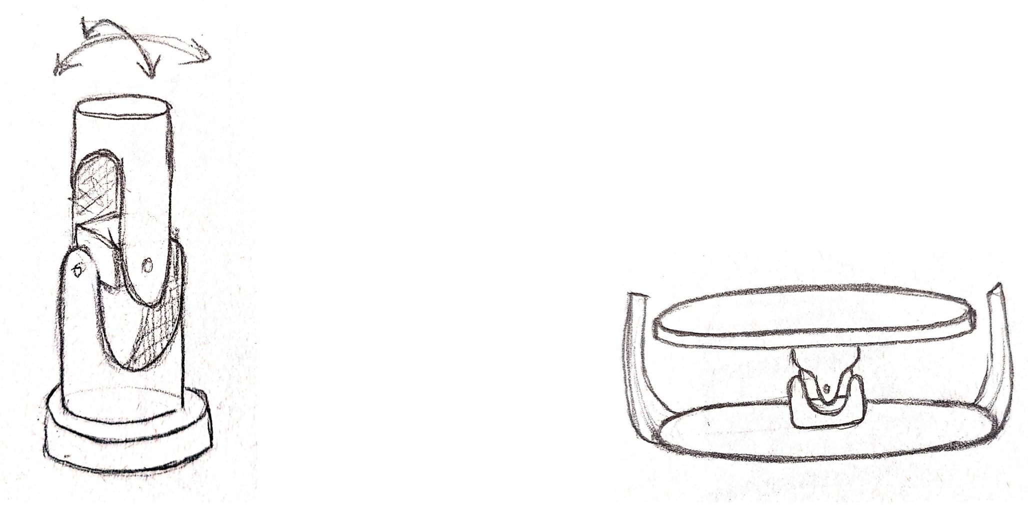



**Figure 5.6: Variants of ball socket joints.**

*5.3.1.10 Universal Joint*

A universal joint is a connection between two shafts. The shafts are intersecting but they are allowed to be unparalleled. The simplest and most common type is called the Cardan joint or Hooke joint. [36] The principle of a universal joint is shown in Figure 5.7a). This can be used to allow tilting motion. There are also micro universal joints in small sizes that might fit the knob, see Figure 5.7b).



**(a)** **(b)**

**Figure 5.7: a) Universal joint that allows tilting motion in two directions. b) How a universal joint could be implemented in the knob.**

*5.3.1.11 Spring Universal Joint*

A universal joint with a spring integrated. The spring makes the joint return to its initial position. This can be used to allow tilting motion. This is presented in Figure 5.8.

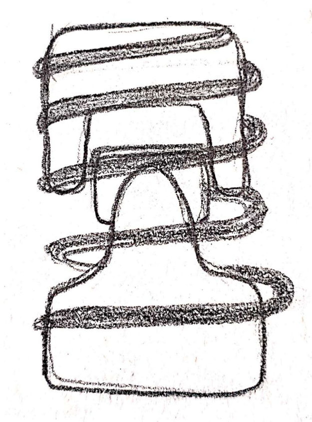


**Figure 5.8: Spring universal joint.**

*5.3.1.12 Self Aligning Bearing*

A bearing which has a fixed outer ring and a non-fixed inner ring. This type of bearing allows misalignment of a shaft through it. This can be used to allow tilting motion. The principle of self aligning bearings is shown in Figure 5.9.

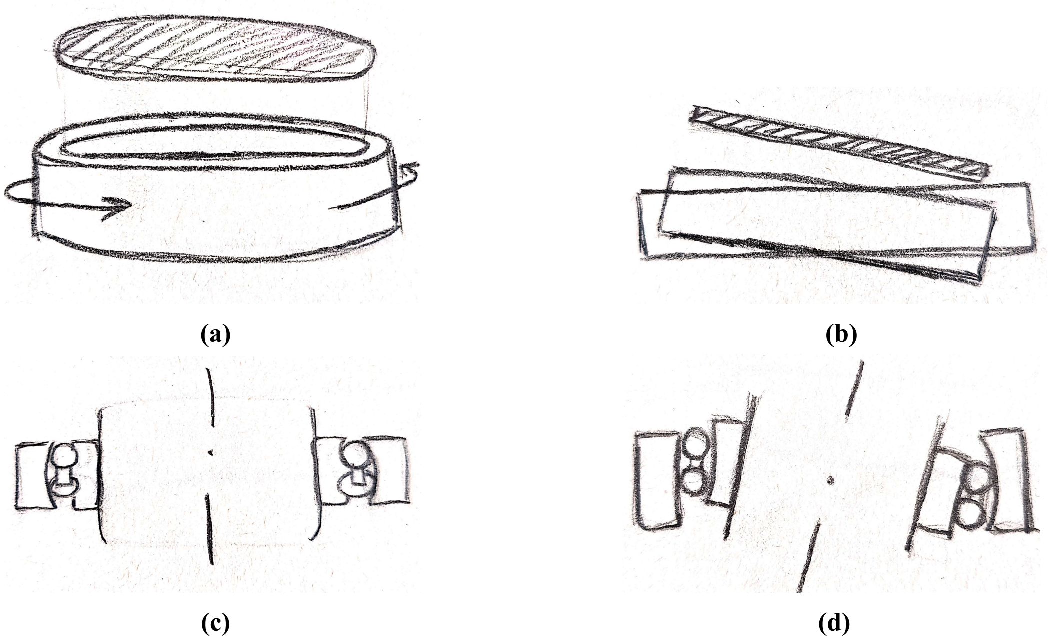


**Figure 5.9: a) Exploded view of the push top and the rotating part. b) Exploded view of the push top and a self aligning bearing inside of the rotating part. c) Self aligning bearing. d) Misalignment within a self aligning bearing.**

*5.3.1.13 Magnetic Levitation*

Magnetic levitation is a method by which an object is suspended with no support other than magnetic fields. Both repelling force and stability force are contact-less in true magnetic levitation. This can be used to levitate the push top and allow tilting motion. Using two simple dipole magnets is very unstable for magnetic levitation since they will slide sideways or flip over.To achieve stability, it is necessary to use diamagnetic materials, superconduction or systems involving eddy currents. [33] How magnetic levitation could be implemented in the knob is shown in Figure 5.10.

Two magnets with same poles facing each other will create a levitating effect. However, two simple dipole magnets are highly unstable and will move away from each other off-axis. Therefore this configuration needs some type of mechanical support and is called pseudo-levitation. [33] With a suitable mechanical support this can be used to levitate the push top and allow tilting motion. This is covered in section 5.3.1.2.

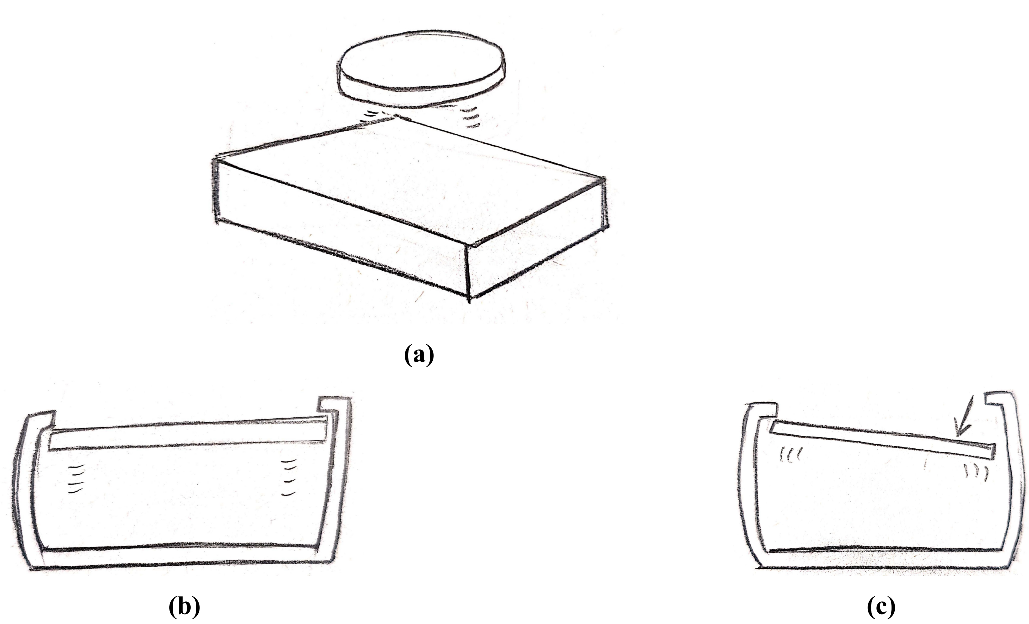



**Figure 5.10: a) Magnetic levitation. b) Push top hovering by magnetic levitation. c) Push top hovering by magnetic levitation and pressed down by user. Will go up when user releases due to magnetic force.**

### *5.3.1.14 Magnet Building Sticks*

A magnet attracting a steel ball will act as a connection. When pushed apart, the connection breaks but will attract back together. Therefore, this can be used as a spring function. When breaking the connection, the user also gets feedback in form of feeling and a sound. This is presented in Figure 5.11. The idea is to replicate the feeling and structure based on toy magnet sticks which are explained in section 3.4.3.

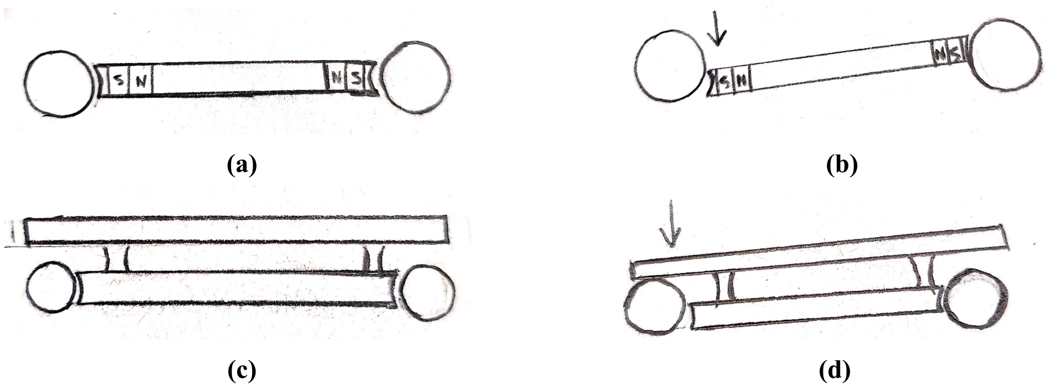



**Figure 5.11: a) Costumized magnet building sticks. A stick holds two magnets in each end. b) Connection between steel ball and magnet breaks when the stick is pressed down. c) Magnet building sticks implemented in the push top. d) Push top being pressed down by user.**

*5.3.1.15 Silicone Top*

Silicone is a type of plastic material which has ”rubbery” properties. SC uses this type of solution for push buttons in other products.

Silicone could be used in this product as a top. If the top is replaced with this flexible material instead of a sturdy one, that would allow the user to push at the desired position without lowering the entire top. The principle of this is presented in Figure 5.12.

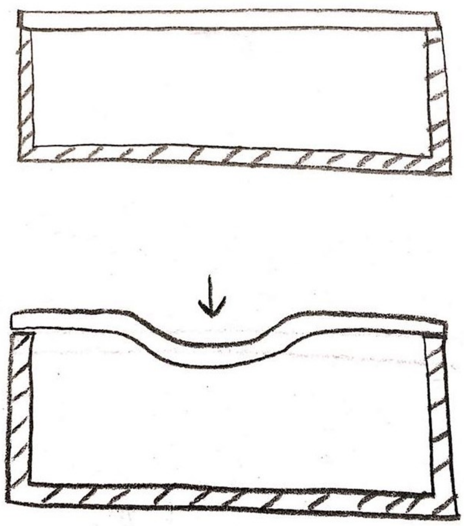


**Figure 5.12: A top made of a silicone material. When pushing of the top, it will lower at that specific position instead of the whole top lowering.**

### 5.3.2 Concepts for the Rotating Part

*5.3.2.1 Bearing*

A bearing allows a smooth swivel function. A bearing is used in the knob today. Figure 5.13 is showing an example of a bearing on the inside of the knob. This would allow the outer part to rotate but anything attached to the bearing to be fixed.

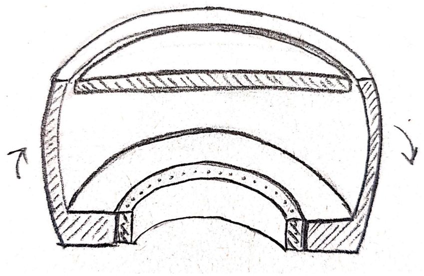
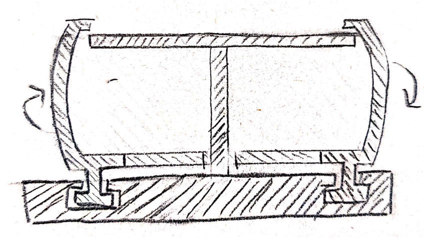


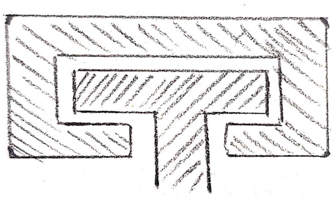
**Figure 5.13: Example of placement of a bearing in the knob. Here it is placed in the bottom.**

*5.3.2.2 Sliding Groove*

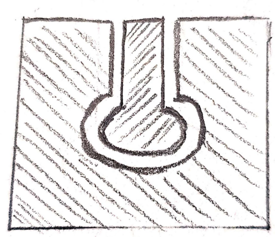
A sliding groove allows rotational movement between one fixed part and one that swivels. The groove can have several different appearances. See Figure 5.14.



**(a)**



**(b)**



**(c)**

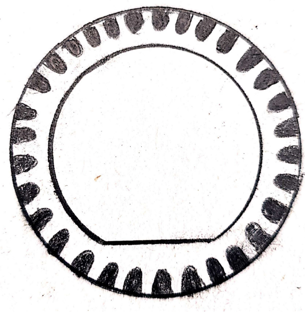
**Figure 5.14: a) A groove in the bottom part of the knob allowing the outer part to rotate. b) Square cross section of groove. c) Circular cross-section of groove.**

*5.3.2.3 Rotary Knob with Snap Fit*

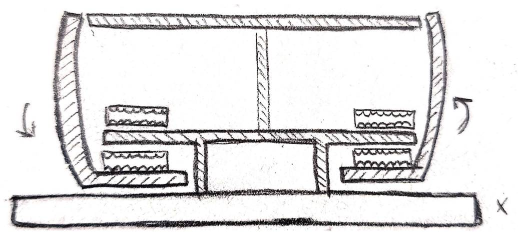
The concept is described in section 3.5.2 in the patent by S. J. Scarlata. The rotating part is mounted with a snap fit in the middle. When snapped into position, it can then swivel freely. This allows the electronics to be completely sealed.

*5.3.2.4 Align PM*

The Align PM are a more advanced pair of magnets which will align at specific positions. A pair of ring magnets with 24 detents can be used to achieve feedback when rotating the knob. One of the magnets is fixed and one magnet is rotating along with the outer part. See Figure 5.15.



**(a)**



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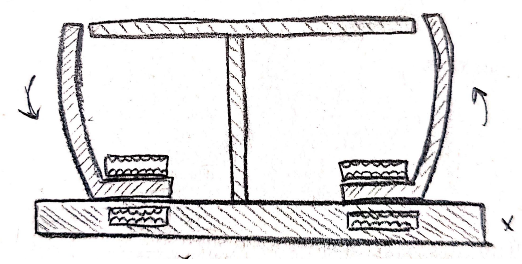
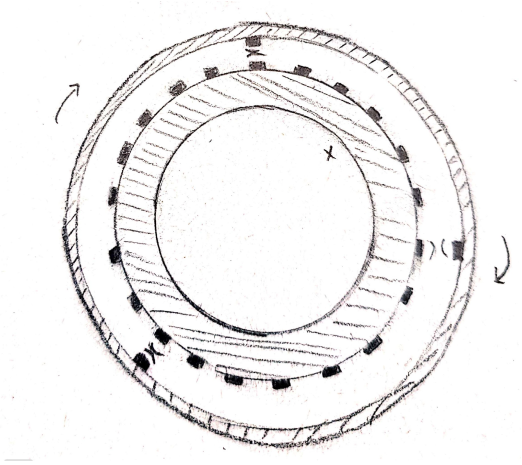


**(c)**

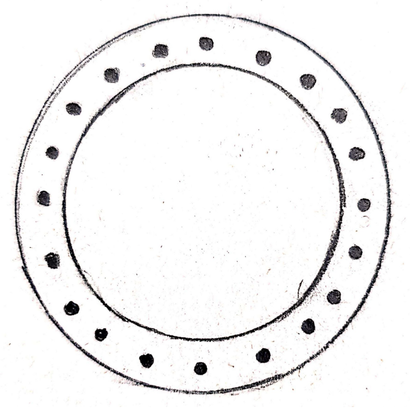
**Figure 5.15: a) Align PM. b) One rotating Align PM on the knob and another Align PM on the fixed part inside the knob. c) One rotating Align PM on the knob and another Align PM on the fixed bottom part of the knob.**

*5.3.2.5 Small Magnets in Circular Pattern*

Small magnets are placed in a circular pattern on two facing parts. One part is fixed and one part is rotating. See Figure 5.16. The magnets will attract when they are in a stable position. When rotating, the magnets will jump to the next incremental magnet. This attracting force will be felt as feedback to the user.



**(a)**



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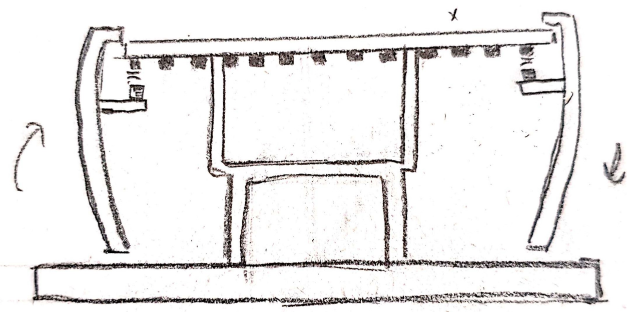
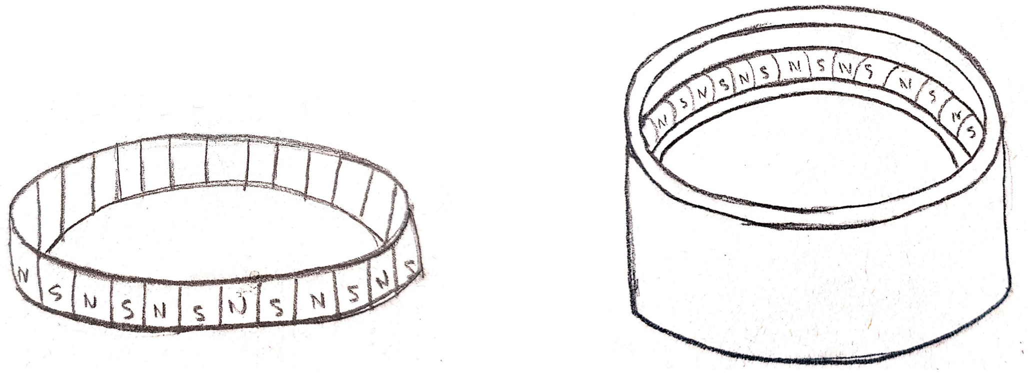


**(c)**

**Figure 5.16: a) The knob seen from above. Several small magnets placed on the fixed inner part. Three magnets placed on the outer rotating part. b) The magnets can also be placed on the top of a circular pattern. c) The magnets in b) placed inside a knob, facing other magnets on the rotating outer knob.**

### *5.3.2.6 Magnetic Strip*

A magnetic strip with alternating poles can be placed in a circle. One strip is placed on the inner fixed part and one strip is placed on the outer rotating part. See Figure 5.17. The strips will attract when they are in a stable position. When rotating, the poles of the strip will jump to the next opposite pole. This attracting force will be felt as feedback to the user.



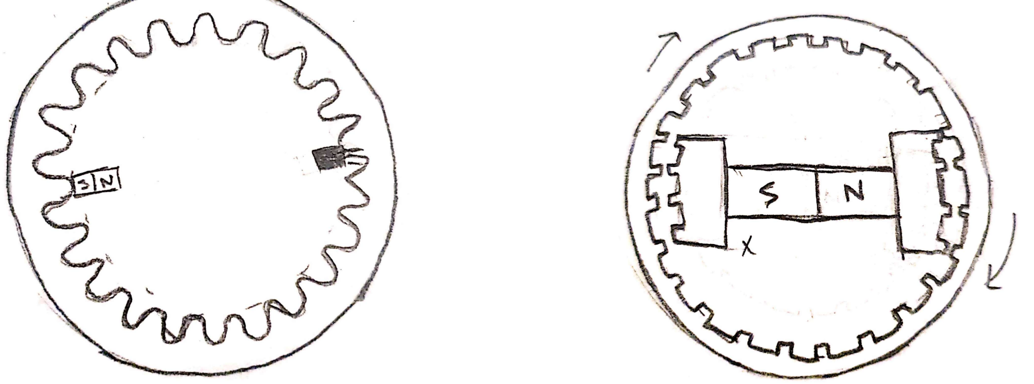
(a) (b)

**Figure 5.17: a) A multi-pole magnet strip. b) A multi-pole magnet strip placed on the inside of the knob.**

### *5.3.2.7 Magnetized Gear*

A steel gear can be magnetized. Since steel contains iron which is a temporary magnet, a steel gear in contact with a magnet will become magnetic. The gear can rotate and the teeth of a gear can pass over a sensor which could detect a magnetic field passing over it, see Figure 5.18a.

A way to get feedback when rotating could be to magnetize one outer gear, or part of one, just by letting it come in contact with a magnet. Then let an inner gear rotate on the outside. Since one gear is magnetized, it will seek the teeth of the other gear when rotating, Figure 5.18b. This would give feedback in the sense of a click feeling.




(a) (b)

**Figure 5.18: a) A magnetized steel gear passing over a sensor. b) A magnetized steel gear passing over detents in another gear, giving feedback.**

*5.3.2.8 Non-fixed Magnets*

Based on the patent by E. Serrus Paulet, the idea is to have magnets which are not fixed in position and can move in one direction. A sketch is seen in Figure 5.19. When the magnets are approached by another magnet, they will accelerate against the other magnet. This will give the user feedback.

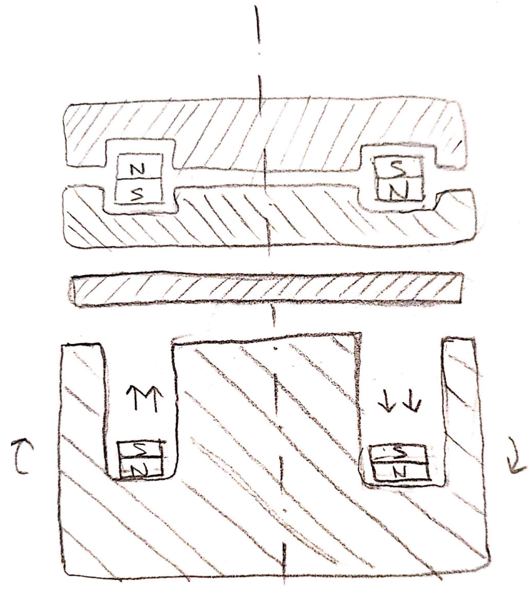



**Figure 5.19: Exploded view of non-fixed magnets accelerating when rotating.**

### 5.3.3 Detect Motion

Sensors are necessary to notice that the knob is rotating or that the buttons are being pushed. A signal is sent back as output and actions can be performed.

Since the goal of the project is to explore the possibilities of magnets and exchange as many parts as possible to magnet solutions, it was decided to not look into potentiometers or off-the-shelf encoder devices. These types of devices are common in other types of applications and it was desired to not use them in this project. Through discussion with the mentor at SC early in the project, it was decided to focus on individual sensors together with a PCB rather than those devices. This also generated more freedom regarding how the sensors could be places since they are individual, but if used correctly, have the same properties as a magnetic encoder.

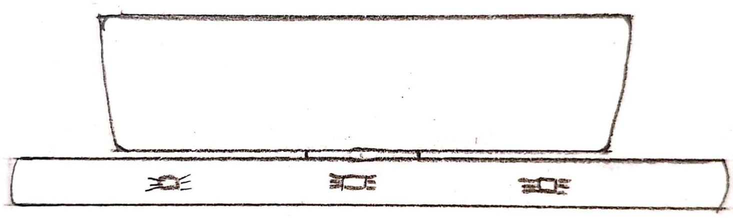
*5.3.3.1 General Sensor Placement*

The sensors need to be placed on or be connected to a PCB to work. Therefore they need to be placed thoughtfully.

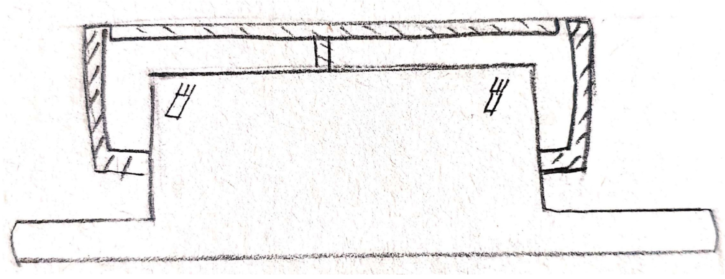
One concept, seen in Figure 5.20a), is to place all the sensors in the bottom part that the knob is attached to. If the PCB is placed in the bottom part and then sealed, the knob could be made water resistant. However, it is important to make sure that the sensors are close enough to whatever they should be sensing.

If the sensors need to be placed further up, the entire bottom could be elevated, see Figure 5.20b) but still sealed.

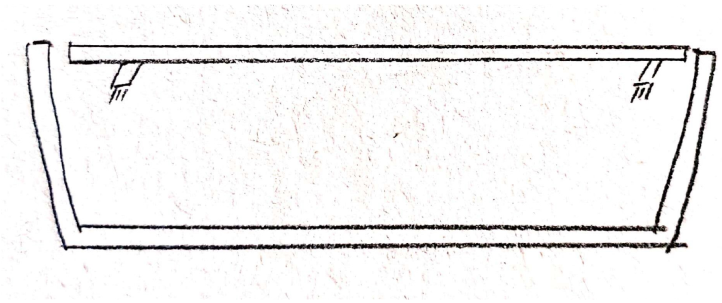
In the knob today, the PCB is placed under the push top. This is an option for this project too but with this placement, no sensors are sealed. See Figure 5.20c).



(a)



(b)

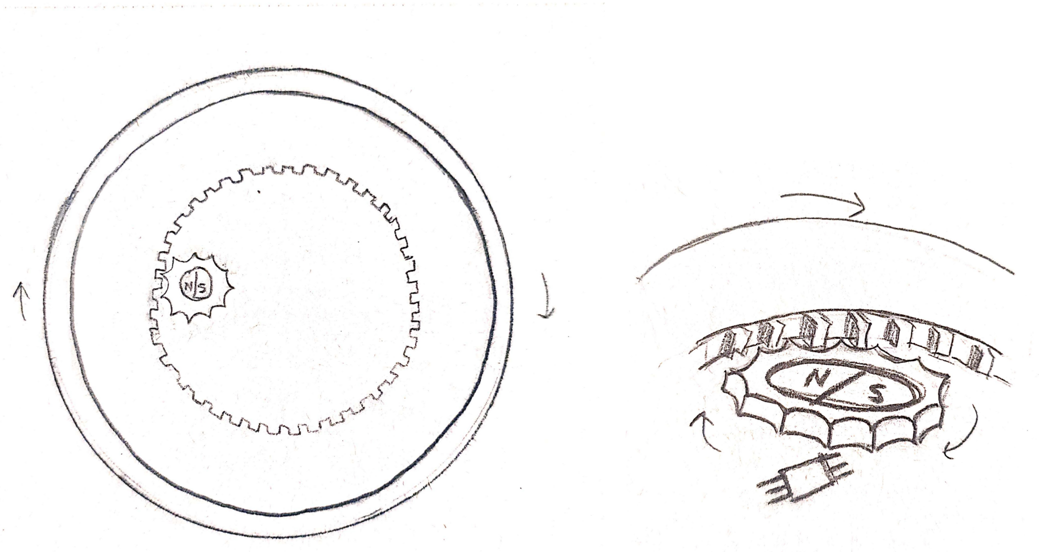


(c)

**Figure 5.20: a) Sealed sensor placement. b) Sealed sensor placement but the sensors are elevated. c) PCB is placed under the push top.**

*5.3.3.2 Two Gears in Contact to Allow Placing Rotating Magnet Off-Center*

Some sensors require a rotating magnet in the middle of the knob to work. If the center of the knob is not accessible to hold a magnet, one solution to this could be to place two gears in contact with each other, see Figure 5.21. While the outer part is rotating, the inner part will rotate around its own shoulder. If a magnet is placed inside, it will rotate together with the knob. With a sensor placed underneath, it could detect how the outer part is rotating but off-centered.




(a) (b)

**Figure 5.21: a) Outer rotating gear turning the inner gear with a magnet inside. b) A sensor can be placed underneath, reading the magnet.**

*5.3.3.3 Hall Sensor for Push Buttons*

Hall sensors can sense if magnet fields change due to a magnet approaching. They can be either linear sensors or switches. More can be read in Section 3.3.2.1. Hall sensors could therefore be used for the button functions together with a magnet. Some examples on how the magnets and the sensors could be placed can be seen in Figure 5.22.

One concept is to place the sensors on the push top, see Figure 5.22d) When a side button is pushed, the push top with sensors will approach the magnets placed further down.

Another concept is to do the same but the opposite, see Figure 5.22c). This way, the sensors could be sealed.

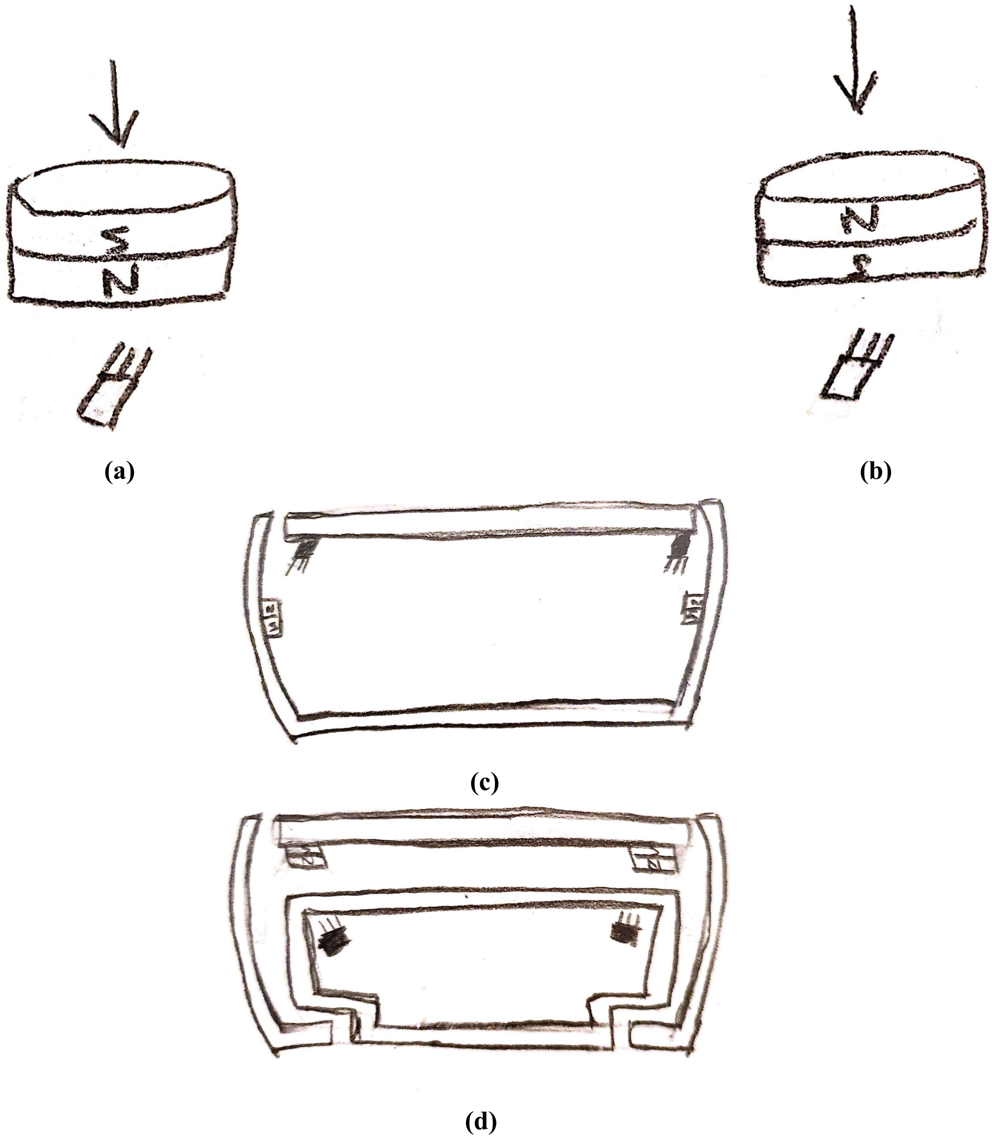
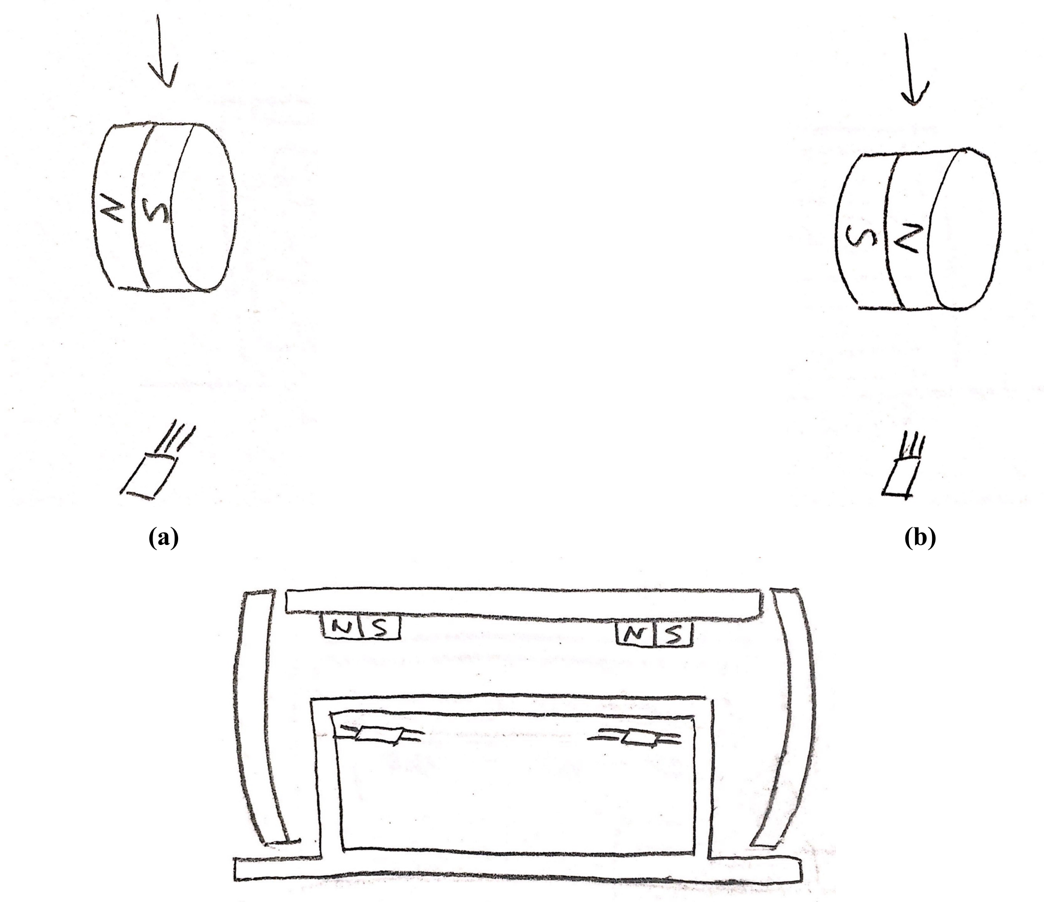



**Figure 5.22: a) Magnet approaching sensor with north-pole first. b) Magnet approaching sensor with south-pole first. c) Sensors placed on the top, approaching magnets when pushed. d) Magnets placed on the top, approaching sensors when pushed. Sensors placed in sealed box.**

### *5.3.3.4 AMR Sensor for Push Buttons*

An AMR sensor can be used for the same application as a Hall sensor. More can be read in Section 3.3.2.2. AMR sensors could therefore be used for the button functions together with a magnet. The sensor requires the magnet field to be perpendicular to the sensor, see Figure 5.23




(a) (b)

(c)

**Figure 5.23: a) Magnetic field approaching the sensor perpendicular. b) Magnetic field approaching the sensor perpendicular but with magnetic poles in opposite direction. c) How the concept could be implemented in the knob.**

### *5.3.3.5 Hall Switches for Detecting Rotation*

The knob's rotation can be read using the concept in the Samsung Galaxy Watch, see Section 3.4.1. For 24 detents, eight magnets are placed on equal distance from each other, see Figure 5.24. When the magnets are rotating they pass over three Hall sensors placed on a distance of 360/24 degrees from each other. When rotated one detent, two of the sensors will read a change in their magnetic field. The third sensor does not read a change. The sensors would be digital and their states are on or off. With this method, it can be determined in which direction the bezel is rotated. [24]

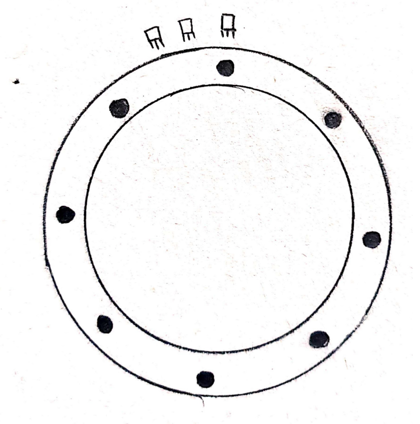


**Figure 5.24: Eight magnets and three hall switches detecting the rotation.**

*5.3.3.6 Melexis Triaxis® Sensor*

The company Melexis has developed more advanced Hall sensors. Unlike traditional Hall sensors, these do not have to be perpendicular to the magnetic flux density. One sensor that Melexis have developed is called micropower Triaxis® MLX90393. This sensor is able to measure the three magnetic components (Bx, By and Bz), see Figure 5.25. [37]

By using the sensor in a device with a magnet, the sensor can detect how the magnet is moving in three axes with precision. The sensor can be used for sliding switches, rotary knobs with push functions and joysticks, see Figure 5.26. The rotary position precision is 360 degrees, meaning the sensor can detect if the magnet is rotated only 1 degree. [38] It is recommended to use a diametrically magnetized magnet. [39]

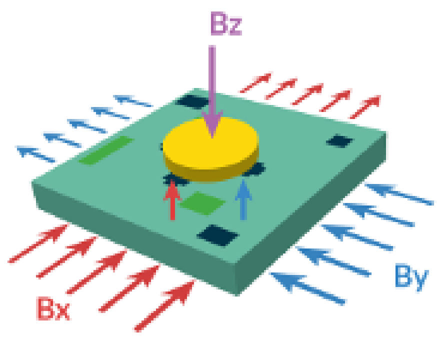
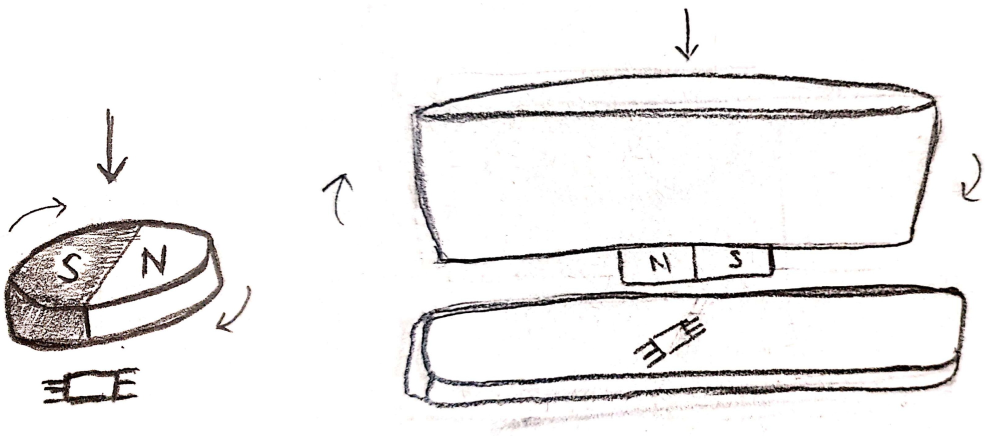



**Figure 5.25: The Triaxis sensor measures the three magnetic components. [37]**

Figure 5.26: How the Triaxis sensor can be used together with a magnet. [38]

If used in the knob it could detect how the knob is rotating but also when the top is being pushed, see Figure **??**). However, it is not clear how to implement this in the knob since the outer part is rotating and the push top is non-rotating.



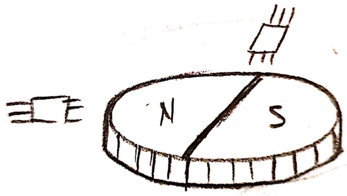

(a) (b)

Figure 5.27: a) Diametrically magnetized magnet rotating over the Triaxis sensor. b) Magnet placed under or in the knob, rotating over the Triaxis sensor.

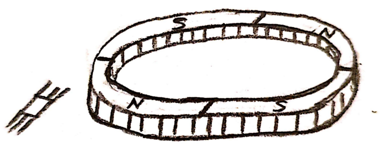
*5.3.3.7 KMT-series Magnetic Angle Sensors*

KMT from TE Connectivity is a series of magnetic field sensors based on the AMR effect. The series contains the KMT39, KMT37 and KMT32B sensors among others which work in the same way but require different strength on the magnetic field. They are sensing the magnetic field direction independently of the magnetic field. [40]

The sensor can be used in several ways, see Figure 5.28. Most importantly it can be placed as in Figure 5.28b). This way, it might be used together with a multipole magnetic strip or the Align PM, see Figure 5.29. The sensor can be found in an application in Chapter 4.4.3 Nest Thermostat E where a magnet strip is used.




**(a)**



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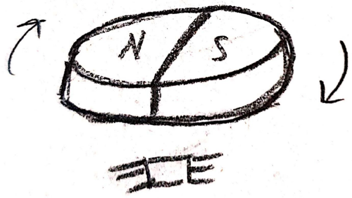
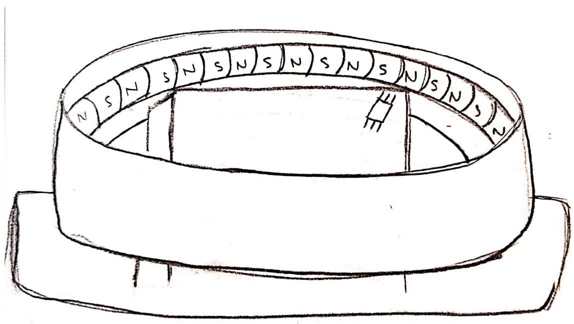
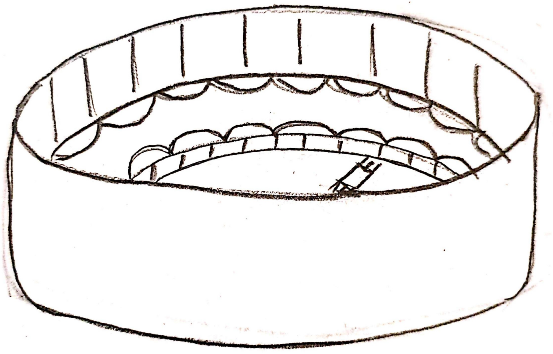



**(c)**

**Figure 5.28: How the KMT sensors need to be placed in order to read magnets.**



**(a)**



**(b)**

**Figure 5.29: a) Sealed sensor in the knob, reading the rotating multi-pole strip magnet. b) Sensor reading a rotating Align PM.**

## 5.4 First screening - Elimination of Non-Potentional Concepts

A first screening was conducted in order to reduce the number of concepts to move forward with. These concept were eliminated due to several reasons which are described in the section below. The sensor concepts are not included in this screening.

### 5.4.1 Eliminated Concepts

These are the eliminated concepts.

- Groove/bump to achieve feedback

This concept is widely used in different types of products to achieve feedback. However, in this project it would require a lot of focus on plastic design and material choice to get the desired feedback. Since this is not the focus of this thesis, the concept is eliminated.

- Compliant mechanism

This concept is eliminated due to its complex nature and the fact that this thesis is not focused on plastic design and material choice.

- Spherical hollow to stabilize position

It was hard to imagine how this concept would be integrated with the rest of the knob. Friction and stability would also be problems and therefore this concept was excluded.

- Universal joint

The concept seemed too complex for its purpose. We were also not able to get prototype material in a suitable size.

- Spring universal joint

The concept seemed too complex for its purpose. We were also not able to get prototype material in a suitable size.

- Self aligning bearing

This concept would need to be combined with some sort of spring function and therefore the value of the concept is not very high.

- Magnetic levitation

This concept is eliminated due to its complexity.

- Sliding groove

This concept would have a lot of friction and therefore a bearing seemed better and simpler.

- Rotary knob with snap fit

Difficult to imagine how to implement together with the push top since it is fixed and the outer part of rotating.

- Magnetize gear

Through discussion with our mentor at SC, this concept seemed unnecessary complex.

- Non-fixed magnets

This concept seemed unnecessary complex and focus was aimed towards other concepts.

### 5.4.2 Remaining Concepts

These are the remaining concepts that are considered to have high potential.

- Compression spring
- Repelling magnets acting as spring
- Spring PM
- Attracting magnets acting as spring and to achieve feedback
- Magnet attracting steel acting as spring and to achieve feedback
- Ball and socket joint
- Magnet and steel ball joint

- Bearing
- Align PM
- Small magnets in circular pattern
- Magnetic strip
- Silicone top

## 5.5 Concept Combinations

The remaining concepts were combined. These were explored more in detail and evaluated. Sensors were not included at this stage.

### 5.5.1 Concept Combination 1

The first concept combination consists of:

- Spring PM
- Align PM
- Bearing

The concept is presented in Figure 5.30. A pair of Spring PM are placed along an axis. The lower magnet is fixed but the upper one will slide up and down along the axis. Since they are not conventional magnets, they will keep their distance between them even if pushed together or pulled apart.

The outer swivel part has an Align PM with 24 detents. The inner part also has a corresponding Align PM with 24 detents. A bearing connects the rotating part and the inner fixed part.

This concept allows for lowering and rising the push top but it does not allow any tilting motion which is necessary in order for the side buttons to work. It may also be difficult to find the appropriate force on the repelling magnets. The force needs to be suitable to the designed distance between them. Customized magnet can be purchased from PM but the price is remarkably higher than conventional magnets.

The concept provides feedback for the swiveling motion but not for the pushing axial motion.

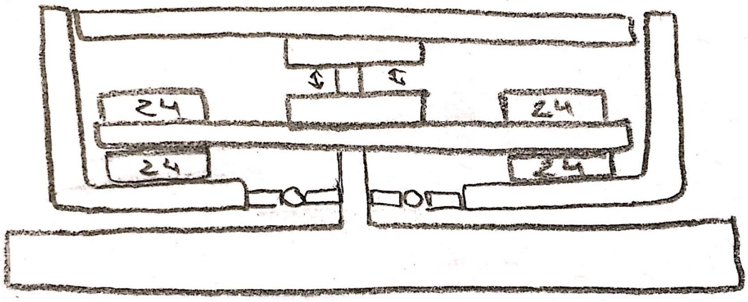



**Figure 5.30: Design which combines Spring PM, Align PM and a bearing.**

### 5.5.2 Concept Combination 2

The second concept combination consists of:

- Repelling magnets acting as spring
- Magnetic Strip
- Bearing

The concept is presented in Figure 5.31. Two repelling ring magnets are placed above each other. The lower magnet is fixed but the upper one will slide up and down due to the snap fits on the sides. They act as a stop so that the top can not slide too far up. They allow motion downwards.

A magnet strip is placed along the rotating part and the inner fixed part. A bearing connects the rotating part and the inner fixed part.

This concept allows for lowering and rising the push top but it does not allow any tilting motion which is necessary in order for the side buttons to work. It may also be difficult to find the appropriate force on the repelling magnets. The force needs to be suitable to the designed distance between them.

The concept provides feedback for the swiveling motion but not for the pushing axial motion.

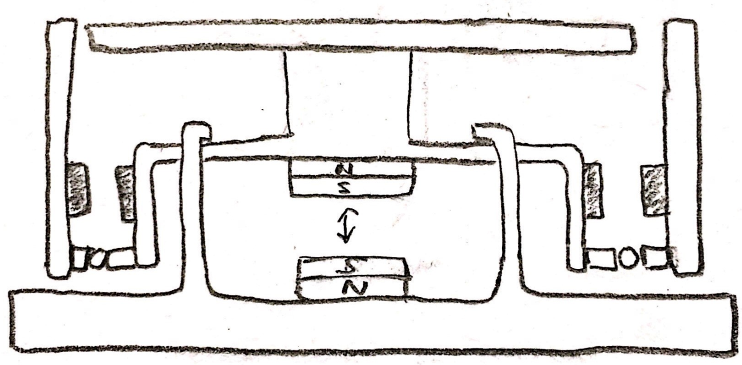



**Figure 5.31: Design which combines repelling magnets, two magnet strips and a bearing.**

### 5.5.3 Concept Combination 3

The third concept combination consists of:

- Small magnets in circular pattern
- Attracting magnets acting as spring and to achieve feedback
- Compression spring
- Bearing

The concept is presented in Figure 5.32. In terms of the rotating part, this is held in place by a bearing. The feedback comes from 24 pairs of small magnets which are places in a circle. There is one circle on the inner fixed part and one circle on the outer rotating part. When the user swivels, the magnets jump between each other and this gives feedback.

The concept uses a conventional compression spring for moving the push top up and down. The push top is secured by magnet pairs. When the top is resting, the magnets holds it in place. When the top is pushed in a corner, the connection between a magnet pair is broken. When the user releases, the connection is made again. This gives feedback to the user. This could possibly work without even using a spring since the magnets attract each other within a certain distance.

However, this configuration does not solve the middle push button. When pushing in the middle, one magnet pair would loose their connection before all magnet pairs would do that at the same time. This would make is impossible to click in the middle and get the correct feedback if the user would not be extremely aware of how to approach the push top.

Another problem is that the outer part is rotating and this makes it difficult to place the magnets which should give feedback when pushing the top. The push top would in this scenario be rotating with the outer part since the magnets are attracting. That is not a problem as long as the side buttons work. But if only four pairs are used, these pairs will not align when the user swivels the outer part slightly. If 24 pairs are user, there will be a total of 96 magnets in the product which is not reasonable. Even 48 magnets are not really reasonable.

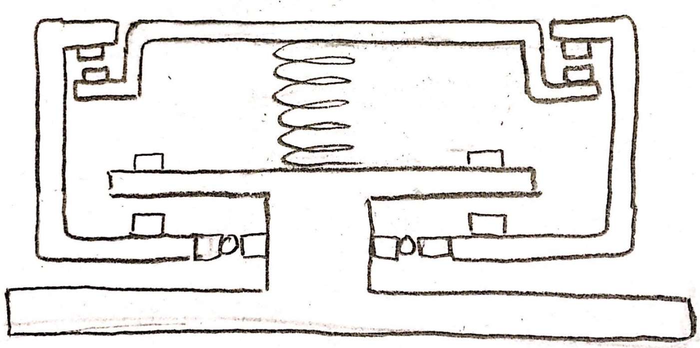


**Figure 5.32: Design which combines small magnets in a circular pattern, attracting magnets, compression spring and a bearing.**

### 5.5.4 Concept Combination 4

The fourth concept combination consists of:

- Ball and socket joint
- Compression spring
- Align PM
- Bearing

The concept is presented in Figure 5.33. The rotating part is held in place with a bearing and the feedback comes from a pair of Align PM with 24 detents.

The push top is stabilized by a type of ball socket joint. The idea is that the spherical shape will allow the push top to tilt. It also stops the push top from going to far up. The top is pushed upwards again by a compression spring.

Due to the lack of experience with this type of joint, it is not clear exactly how it works in a real product. In order to find out if this can be a good solution, it needs to be tested.

This concept does not give any feedback to the user when pushing the top.

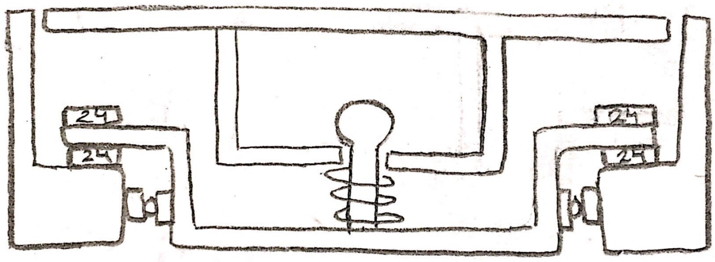



**Figure 5.33: Design which combines ball and socket joint, compression spring, Align PM and bearing.**

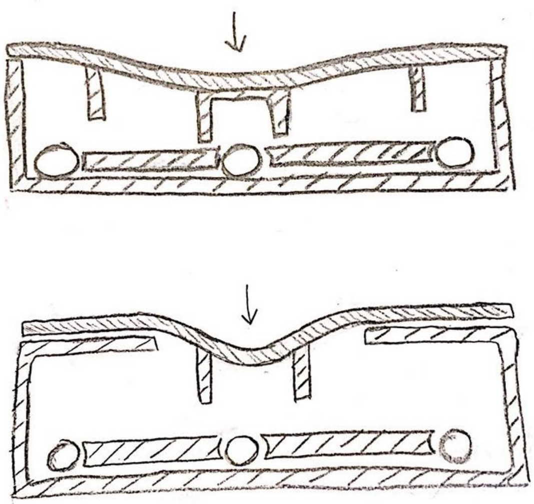
### 5.5.5 Concept Combination 5

The fifth concept combination consists of:

- Magnet building sticks
- Silicone top

The concept is presented in Figure 5.34. The flexible top allows pushing at the exact desired magnet and steel ball joint without lowering the entire top. The whole top can be flexible or only the middle part. The concept gives feedback and allows all the push buttons to be used.

This concept has a more complex design than only rigid bodies. It needs some reflection about how to assemble and combine together with other functions in the knob.



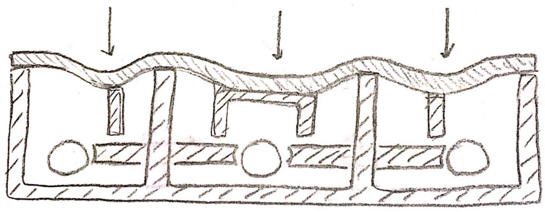


**Figure 5.34: Combinations of magnet and steel ball joint and silicone top.**

## 5.6 Second Screening - Conclusion After Concept Combinations

After going through all remaining concepts and the combinations, an extensive discussion with the mentor at SC was performed. Through this, it was decided which concepts that had the greatest potential and that should be further developed. This was greatly based on experience and intuition of the mentor at SC. It was also a matter of time, since the master thesis did not have infinite time for the further development and testing. Therefore not all concepts could be iterated and improved into prototypes.

The conclusion was to primarily move forward with the magnet building sticks and silicone top for the push top. This would be combined with a bearing and the Align PM for the rotating part. The magnet strip was of great interest but it was difficult to find a supplier. One was found but required a large order. Therefore it was decided to first try the Align PM and only order the magnetic strip if that was not successful. Spring PM had been ordered at the same time as Align PM and that would also be tested for that reason.

# 6 Further Concept Development

*This chapter describes the process of evaluating the concepts with prototypes. Subproblems were tested before testing full concepts.*

## 6.1 Method

Several magnets that were previously theoretically investigated were ordered and examined. Simple prototypes containing these magnets were made to investigate how to move forward with them. This was primarily done with 3D-printing. These prototypes tested subproblems individually and time could be saved by not testing the full concepts all at once. After testing simple prototypes, these were iterated to develop better versions.

Combined and full concepts were 3D-printed to be tested mechanically. The thesis focused mostly on making a prototype working mechanically with rotational feedback and push button spring and feedback. When achieving this, the project focused on sensors. Sensors were not the main focus of the thesis but for SC it was important to have a working prototype with sensors to emphasize the potential of magnets.

The team were at this point in the project placed in contact with an employee at SC who has in depth knowledge about sensors.

## 6.2 Initial Magnet Prototypes

These initial magnet prototypes were observed and their functions were evaluated.

### 6.2.1 Spring PM

The spring magnets received in the PM demo kit seemed to be of great potential. They repelled each other at a certain distance and when separated, they attracted back to that same distance. The demo kit spring magnet can be seen in Figure 6.1. It was necessary for the magnets to be completely axially aligned, otherwise they would attract each other with a strong force.

An order was made of the Spring PM, which are more advanced. The demo kit contains the black grip as well, while the new order only contained the magnets inside, see Figure 6.2, making it possible to place the magnets inside the knob. The size was also different.

When the order was received, the properties of the magnets was different from the ones of the demo kit. The magnets repelled each other but not at a certain distance. When separated, they did not attract again.

**Figure 6.1: Spring PM in the demo kit.**

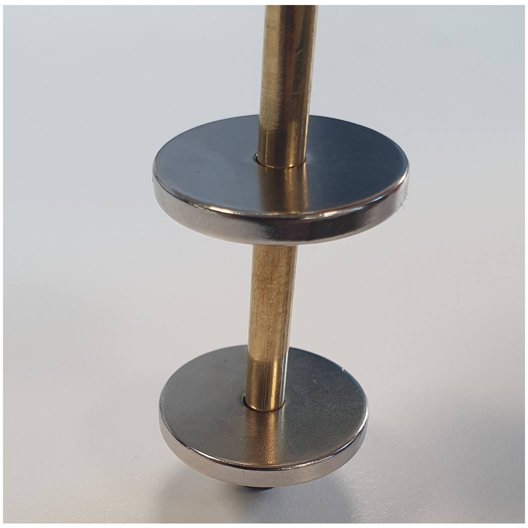


**Figure 6.2: Spring PM axially aligned on a rod.**

The Spring PM were also found to be soft and fragile, since they are neodymium magnets.

This was limiting and the magnets easily broke, see Figure 6.3.

**Figure 6.3: Broken Spring PM.**

### 6.2.2 Repelling Conventional Magnets

The properties of the Spring PM were similar to another test that was made. That test contained two conventional dipole ring magnets which were axially aligned and placed facing the same poles, see Figure 6.4.

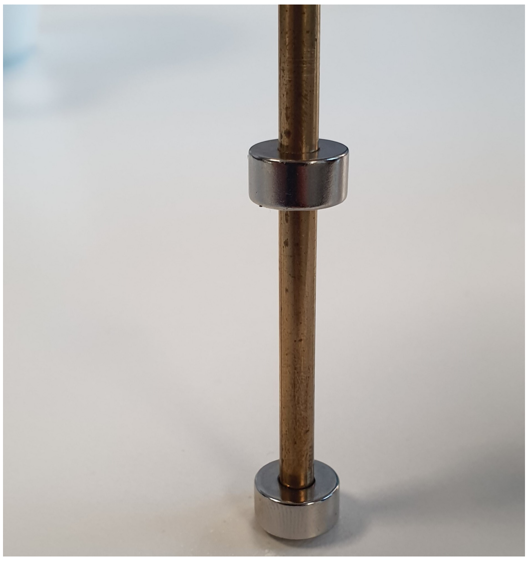


**Figure 6.4: Conventional dipole magnets axially aligned on a rod.**

However, instead of ordering expensive and fragile PM, conventional dipole magnets can be used instead. When axially aligned and facing the same poles, see Figure 6.4, they do work as a spring. When the top magnet is approaching the lower one, the repelling force separates them and makes it spring back up again. Depending on what magnets are used, the repelling force varies.

The conclusion of these simple spring tests is that neither the repelling conventional magnets or the Spring PM had great potential for acting as a spring in the knob. They were difficult to control and it would take several iterations to find magnets that would give the desired distance between them.

### 6.2.3 Align PM

#### *6.2.3.1 Evaluation Without Knob*

The Align PM were ordered with twenty-four detents. When they arrived they were separated with plastic distances in between. The reason for the distances were to hold the magnets apart and reduce magnetic forces. When rotating the magnets with a distance between them, they had nice feedback and stability. It was desired to test the same procedure without the distances in order to feel the difference in force. However, the force was incredibly strong when removing the distances and letting the magnets face each other directly. They were impossible to rotate and also impossible to separate from each other by hand. Pliers and two people were needed in order to separate the magnets.

Due to the high magnetic forces and the attempts to separate the magnets, there occured a crack in one magnet. The broken magnet is seem in Figure 6.5. It was realized that the Align PM were very ductile and fragile just like the Spring PM. The material is nothing like a conventional magnet which is hard and does not easily break.

The conclusion of this testing is that the Align PM have great potential and they work as intended as long as there is some distance between them. However, precaution needs to be taken due to the very high forces and the risk of the magnets breaking.

**Figure 6.5: Broken Align PM.**

### *6.2.3.2 Evaluation With Knob*

To evaluate the Align PM properly, a CAD-model dedicated for this was made to 3D print and test the magnets in a knob, see Figure 6.6. The model has one outer part which rotates and has a channel for one PM. It also has a bottom part representing any device that the knob could be attached to. The bottom part has a channel for another PM. The bearing in the middle allows one part to rotate and the other one to remain fix. The magnetic force of the PM also holds the two parts together. There is no top since the reason for this model is to simply test out the properties of the PM.

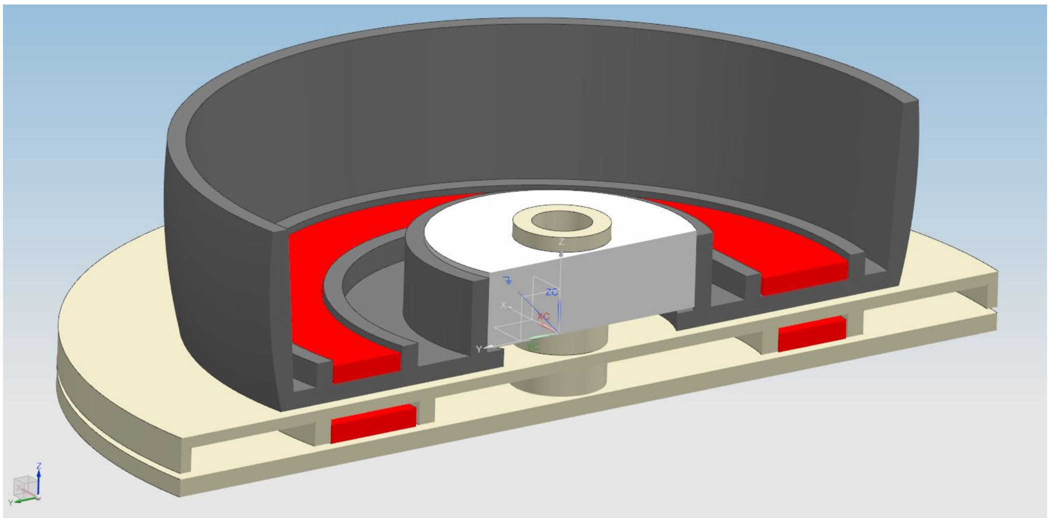


**Figure 6.6: CAD model of Align PM in a knob.**

The 3D printed model is shown in Figure 6.7. When the prototype was assembled, the PM worked just as intended. The two magnets creates twenty-four detents when in contact with each other.

The difference in feedback compared to the current knob is obviously hard to describe in words, but there is a noticeable difference. The current knob has a more ”clicking” feedback every detent due to the spring inside. The Align PM in this prototype gives a more distinct feedback. It is smooth and does not feel as mechanical. The 3D-printed plastic does not have a very smooth surface however and when the parts are rotated they are in contact with each other. The contact gives a slightly scraping sound.

The conclusion is that the Align PM held the parts together and gave good feedback when swiveling the knob. It worked as intended and it is a great choice for detent feedback. It is considered as proof of concept.

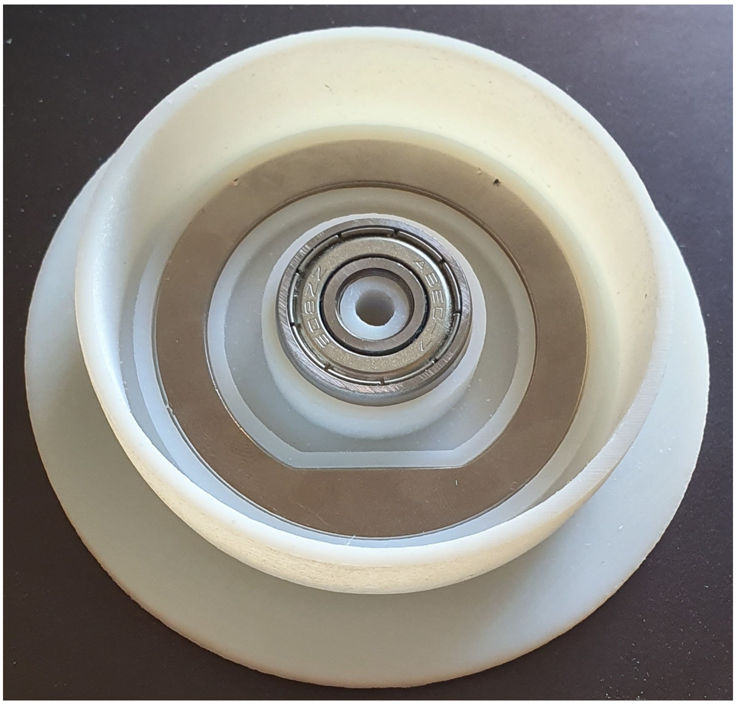


**Figure 6.7: 3D-printed model with Align PM for feedback.**

## 6.3 Magnet Sticks and Silicone Top

### 6.3.1 First Iteration

#### *6.3.1.1 Description*

The concepts of magnet sticks and the silicone top were tested together before combined together with other sub concepts involving the rotating part. The idea was to replicate the magnet building sticks toys and being able to press all five push buttons using a flat top. This was made in dimensions to suit a knob.

The first CAD-assembly can be seen in Figure 6.8. A cross section can be seen in Figure 6.9.

One steel ball is placed in the middle and four others are placed in the corners. The middle ball is glued for stability and to keep everything in place. The steel balls are connected with sticks which has room for two cylindrical magnets on each side. The stick's hollows are slightly longer than the magnets, which leaves room for the steel balls to slightly sink into the sticks. This acts as a cavity that hold the steel balls in place.

The orange part in the CAD-assembly is made with two materials. The dark orange is a silicone membrane which allows for flexibility. The light orange is sturdy plastic material. Due to the cut outs in the sturdy plastic underneath, the middle can be pushed down and allow the user to access the middle button without pushing down the outer buttons. The side buttons are pushed using tilting of the push top. Ribs were added to gain stability of the structure.

The blue part is a bottom plate with plateaus. These plateaus are used for the steel balls to rest on and therefore give the whole prototype stability. The steel ball in the middle is fixed due to the spherical cavity but the steel balls on the side have tracks to run in instead. This is due to allow the balls' translational movement outwards when pressing on the sticks.

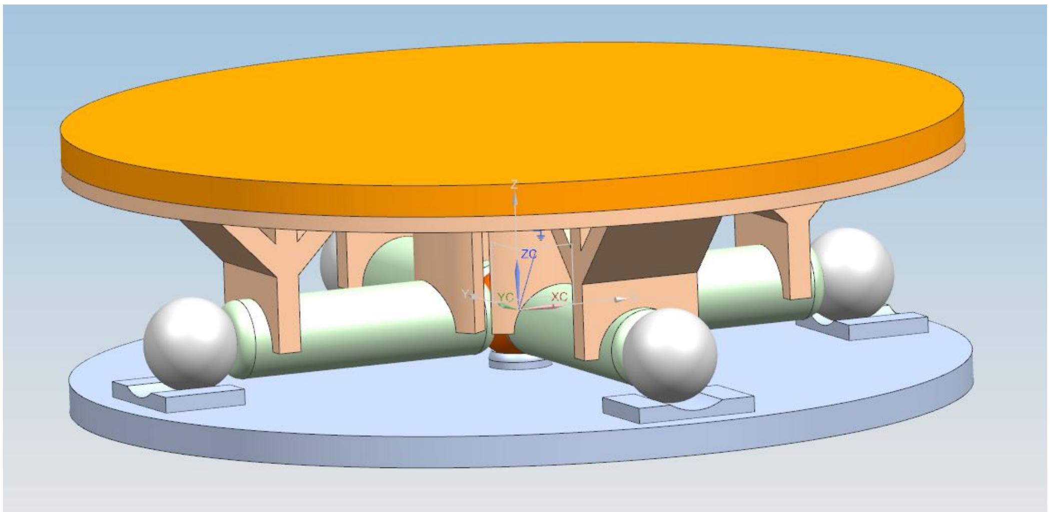



Figure 6.8: CAD-assembly of magnet sticks combined with an silicone top.

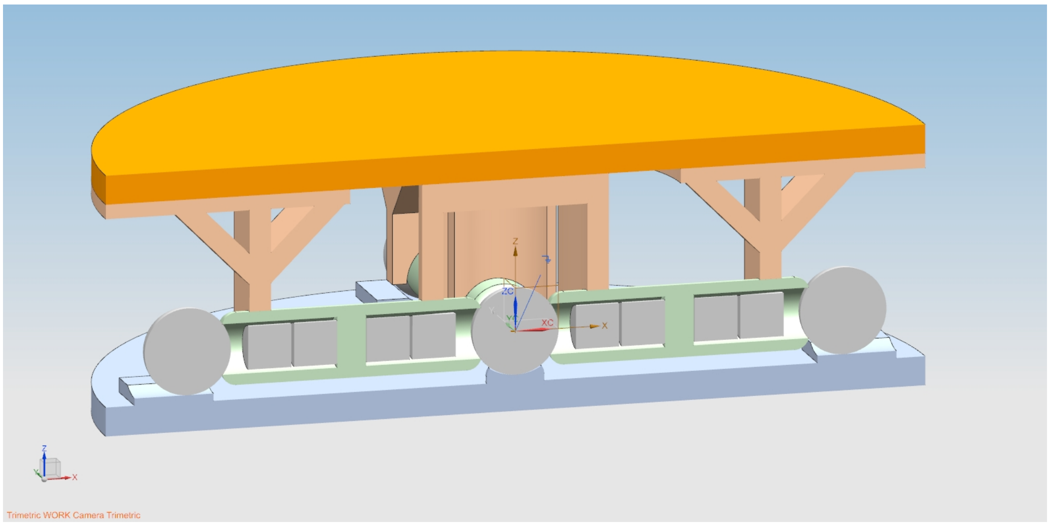



Figure 6.9: Cross section of magnet sticks combined with an silicone top.

*6.3.1.2 Evaluation*

The CAD-assembly was 3D-printed and the results can be seen in Figure 6.10. The 3D-printer at SC uses PolyJet [41] technology and it can print in several different materials.

The white material is sturdy plastic and the black material is silicone-like. The material that looks slightly blue is actually white but it is so thin than the black shines through.

The 3D-printed silicone-like material at SC is an acrylic composition with rubbery properties. The material has the Shore number 27. [42]

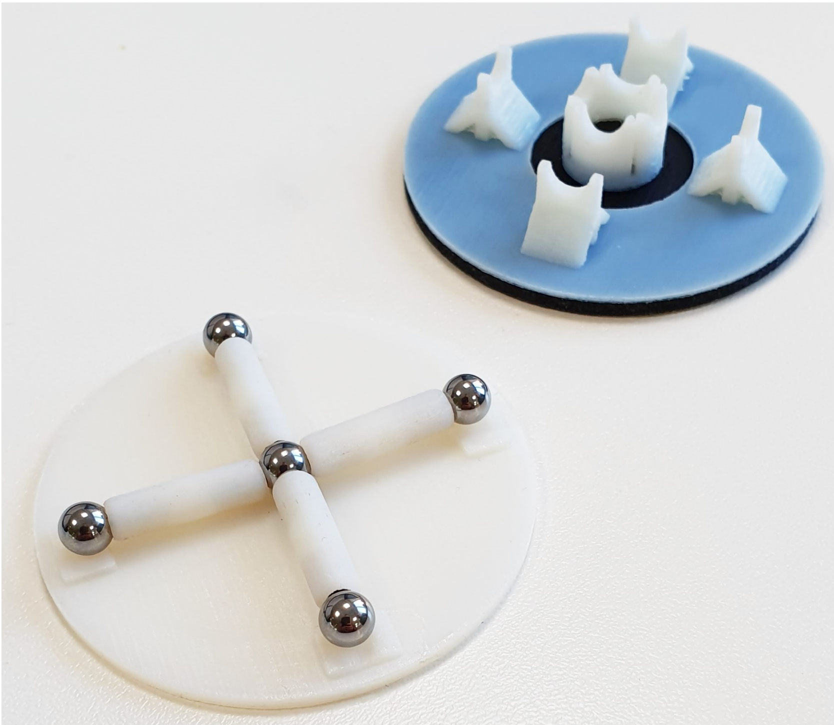


**Figure 6.10: 3D-printed prototype of the concept of magnet sticks combined with an silicone top.**

When evaluating the prototype, there seems to be no reason to have such a large height of the "pillars" that pushes on the sticks. This can be reduced and this would also remove the need of ribs.

When testing out the middle button, it unfortunately does not work at all. When the user pushes in the middle, the whole push top lowers and it is not possible to click only in the middle. It is not clear exactly how this problem can be solved, but the main reason why it is not working is probably because the force to click in the middle is to strong. A way to solve this could be to make the silicone thinner in order to allow more flexibility. Another way is to remove several of the "pillars" in the middle. In this prototype, four connections between magnets and steel balls need the be broken. If changing the design, fewer connections would break when pushing. Therefore, pushing in the middle would require less force.

When testing out side buttons, the clicking works decent. It is not a harsh clicking feedback, but it gives some feedback and the sticks spring up as intended after releasing.

An observation is that the magnets attract outwards to the steel balls and that does not leave a cavity as intended. An illustration of this is seen in Figure 6.11. The first image shows how it was intended to be and the second image shows the actual outcome.

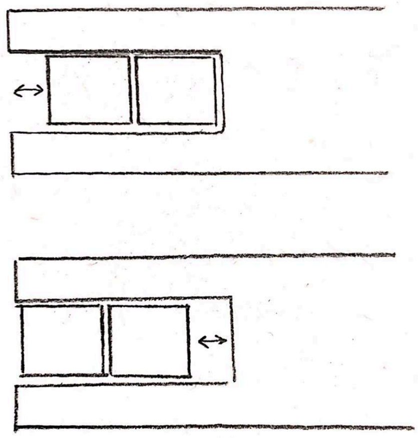


**Figure 6.11: The intended cavity and the actual outcome.**

In order to test how big the impact of this phenomena was, a small amount of plastic foam was inserted into the very end of the sticks. When doing so, the magnets were held into place in their bores and there was a cavity for the steel balls to rest. The result of this was a noticeable different in feedback. The feedback got more distinct with the foam. The conclusion is that the cavity is important and better feedback can be achieved without increasing the magnetic strength.

**Figure 6.12: A small amount of foam was inserted into the bores of the sticks in order to keep the magnets in place.**

### 6.3.2 Second Iteration

*6.3.2.1 Description*

The first testing of combining the concepts magnet sticks, steel balls and a silicone top was considered successful but had room for improvement.

In the previous prototype, the silicone material has been used for the middle button. The side buttons were pushes by the motion of a rigid body. An alternative is to use the flexible silicone for all five push buttons. The new design is similar to the second iteration, but with some changes. A cross-section can be seen in Figure 6.13. The magnet sticks were altered so that five magnet could fit in each and a stop at each end was added to see if the cavity would provide better feedback.

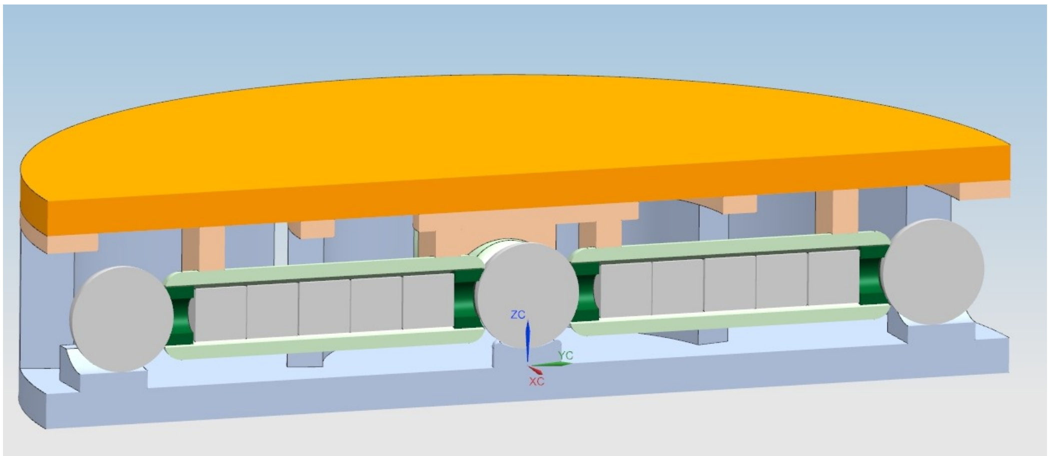



**Figure 6.13: Section of the design which utilizes silicone for all five buttons.**

The push top was modified and now had more flexible parts. In the previous design, only the middle part could lower down, now there were five areas which could individually lower down. There were two circles, one at the outer edge and one in between the middle button and the other buttons. These circles are sturdy plastic and the purpose of these are to give stability the structure and also to meet pillars which go up from the plate underneath. The design can be seen in Figure 6.14.

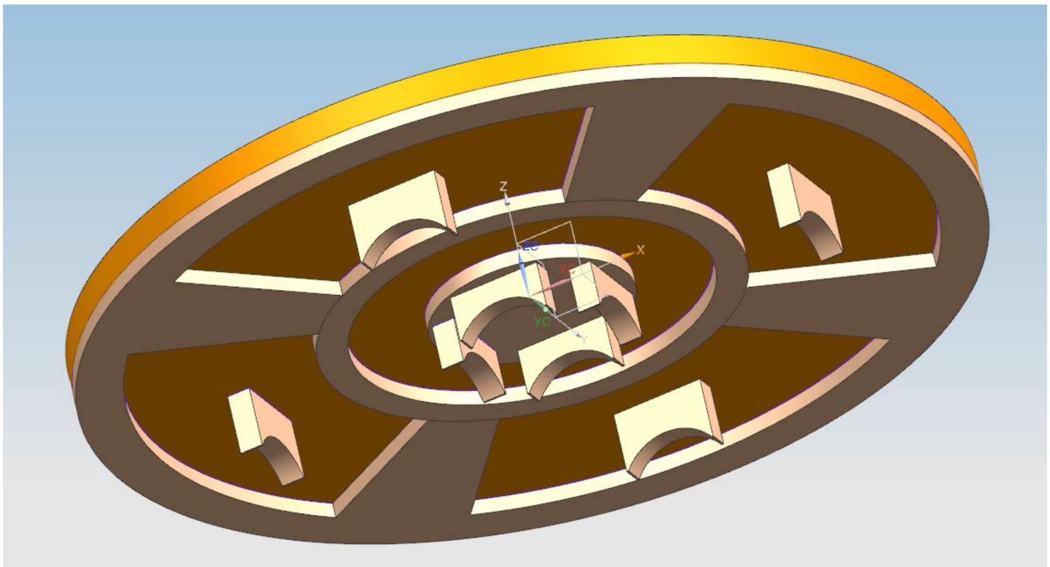


**Figure 6.14: Push top with five areas which can individually lower down.**

The plate has been modified to correspond to the push top. There are pillars which follow two circular patterns, just like the push top. These pillars will hold up the sturdy plastic parts of the push top. When the user clicks on any button, these parts will not lower down.

The pedestals for the steel balls have not been changed. The design can be seen in Figure 6.15.

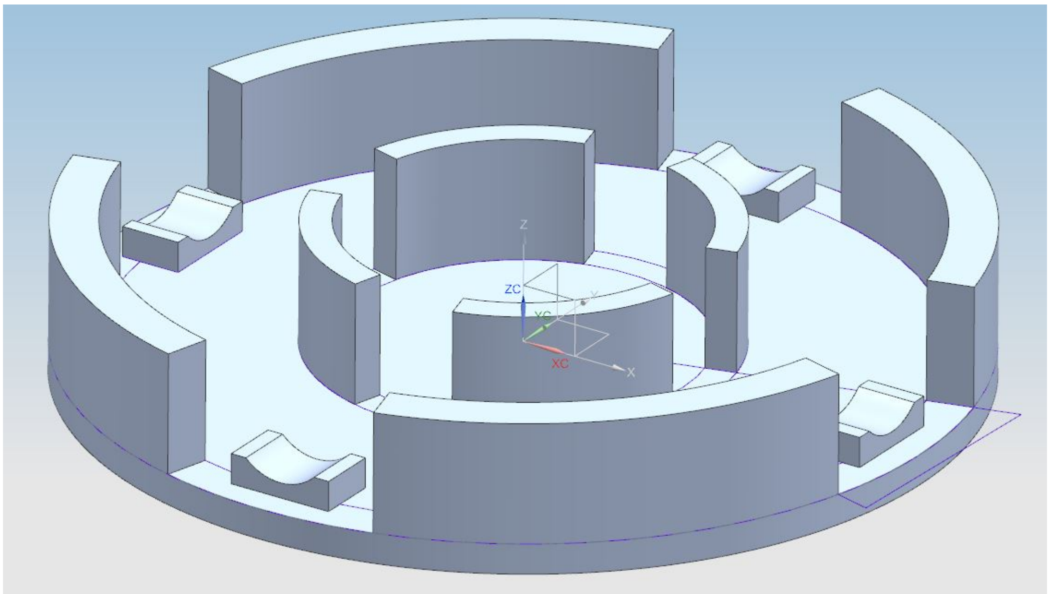
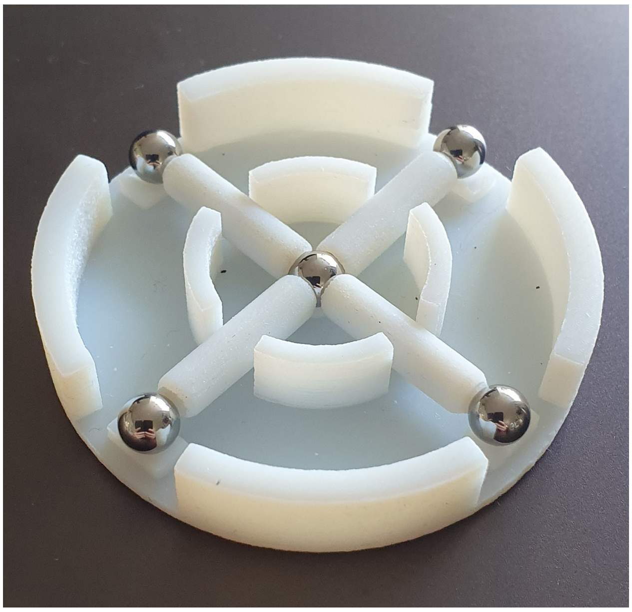


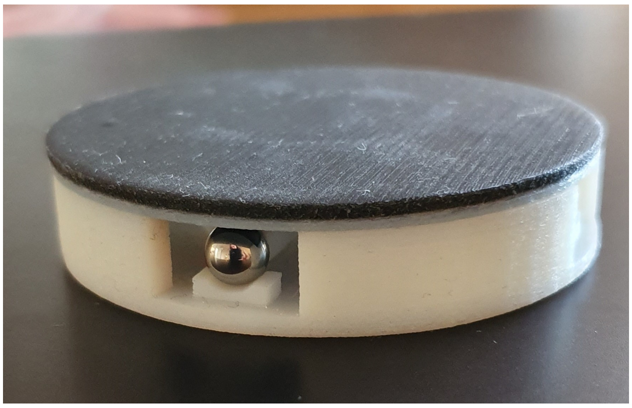
**Figure 6.15: Plate with pillars which correspond to the push top.**

*6.3.2.2 Evaluation*

The new design was 3D-printed, see Figure 6.16. The idea with silicone for all buttons was successful and now all buttons could be clicked. The plate created resistance which made it possible to use the buttons properly. However, side buttons did not give the same clicking feedback when using these buttons compared to the previous prototype. The silicone material is slightly ”slow”. Since the 3D-printed silicone cushions some of the click feedback the clicking is not as distinct. This was discussed with the mentor and the conclusion was drawn that the 3D-printed silicone material is simply not of high enough quality. If using a high-quality silicone, the material would be very light and flexible and the feedback would be significantly better. Therefore this prototype is considered proof of concept.



**(a)**



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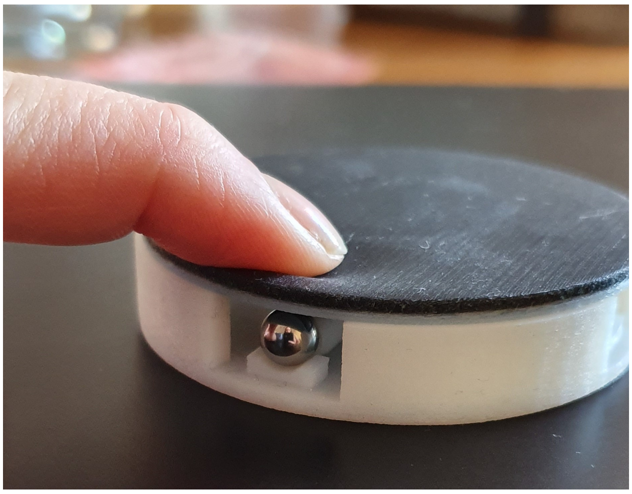


**(c)**

**Figure 6.16: a) The magnet sticks and the plate assembled with magnets. b) The printed push top and plate assembled with magnets sticks. c) Pushing the button. The magnet stick is recessed.**

## 6.4 Combining Magnet Sticks, Silicone Top and Align PM

After verifying the concepts separately, the next step was to combine the two prototypes into one complete concept. A cross section can be seen in Figure 6.17.

### 6.4.1 Description

The functions have not changed from the separate concepts, but adjustments to the design have been made and a part in the middle for holding the PCB has been added. This ”electronics box” is elevating the sensors up in between the magnet sticks and the Align PM. It is also sealing the electronics from the outer environment. The holes in the middle of the pink and light grey parts are for leading out wires. The PCB and the sensors are not described in detail yet since the primary focus was to get the mechanics to work first.

Some other slight changed were made. The bearing was changed in size. Screws were added. The sticks which holds the magnets were re-designed several times until the design in Figure 6.18 was obtained. The top part which pressed on the side buttons has slightly changed, see Figure 6.19. The part which holds the steel balls can be seen in Figure 6.20, the steel balls now rest in structures that are described as ”caves”. These prevent the steel balls from hopping out of place but still allows them to have translational movement.

With this full concept, both the swivel function and all the push buttons have been replaced with magnet solutions.

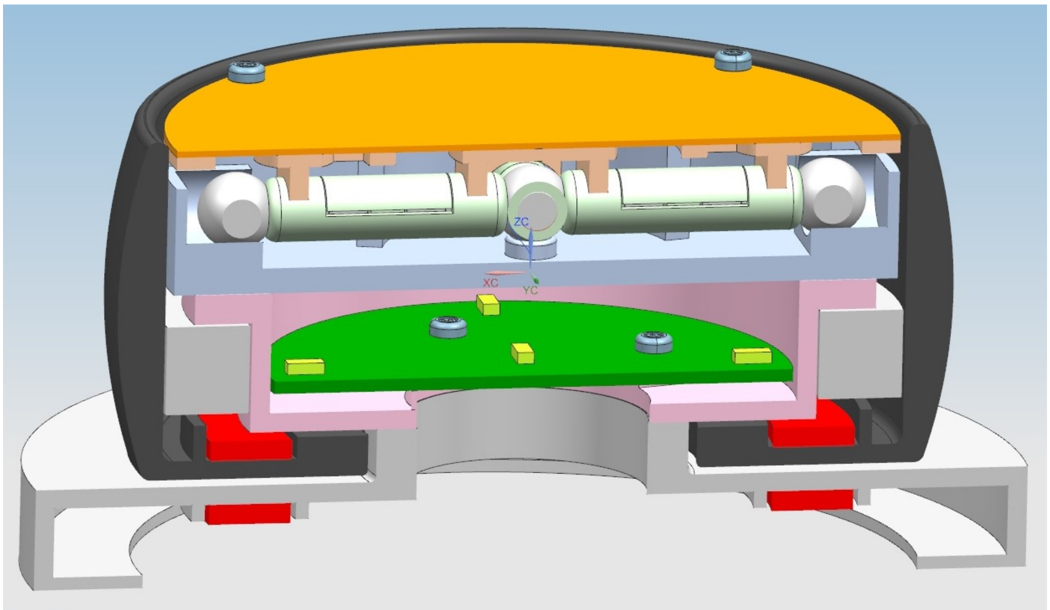



**Figure 6.17: Concept which combines magnet sticks, silicone top and Align PM.**

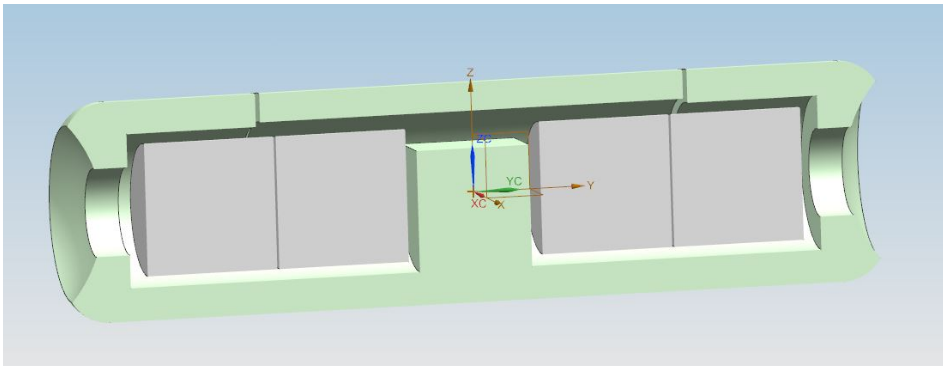



**Figure 6.18: Magnet stick.**

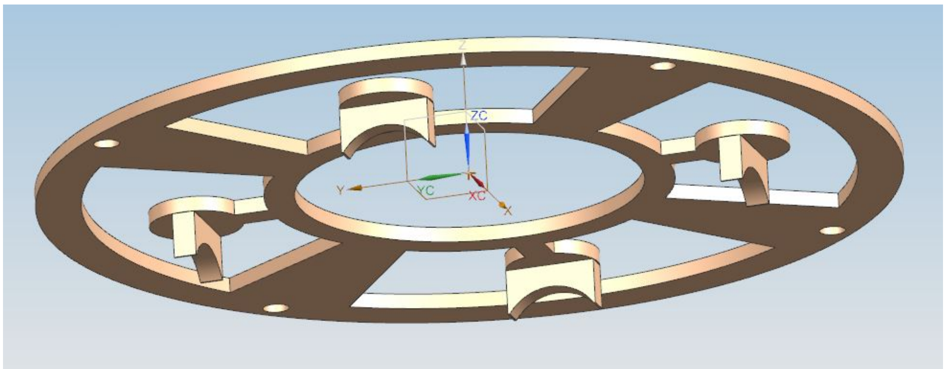



**Figure 6.19: The plastic part which presses on the side buttons.**

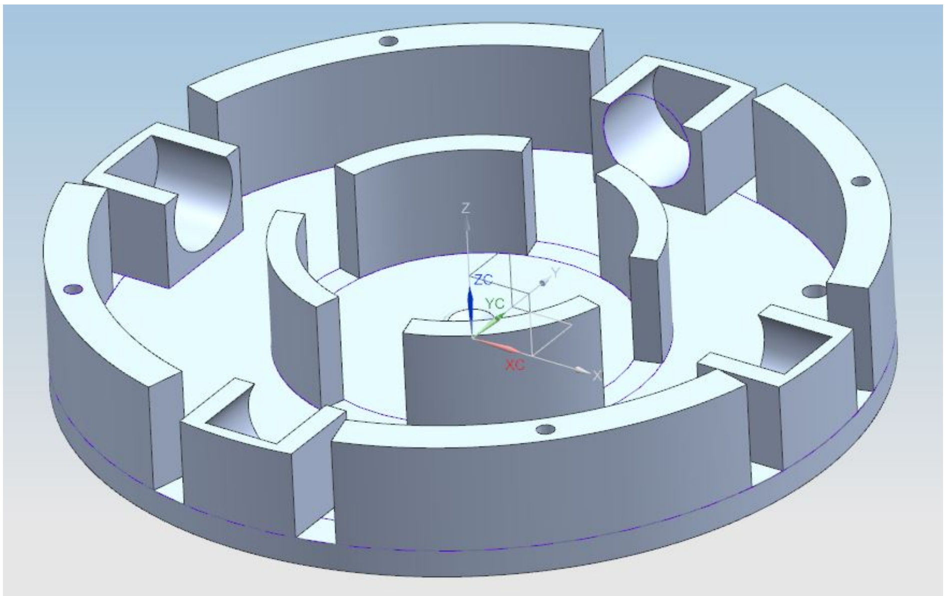



**Figure 6.20: The part which holds the steel balls.**

### 6.4.2 Evaluation

The concept was 3D-printed to be verified. Figure 6.21a shows the 3D-printed model without the silicone top in its initial state. The silicone top was not printed because the printer which uses silicone was not working at the time. However, it was not critical because the silicone top was already proofed as a concept. Instead, fused deposition modeling, an FDM-printer was used for this prototype. [43]

An arising problem was that the bearing acts as a temporary magnet. The bearing therefore became magnetic in the presence of a magnetic field. Since the bearing was placed close to the Align PM in the prototype, they attracted each other. This was not a problem in the initial PM prototype, probably because that bearing was smaller and placed inside the PM instead of over it.

Another problem is that the two combined magnet solutions are interfering with each other. Separately, they both work as predicted. But when placed in the same knob, their magnetic fields appears to be too close to each other. This is shown in Figure 6.21c. When the magnet sticks are pressed down, they can not spring back up again because the magnetic fields are interacting. The Align PM is promoted to have a very tightly controlled magnetic field and therefore this was not a predicted issue.

Together with the supervisor, it was decided to not spend more time trying to make the combined concepts work together due to these issues. Instead, separate prototypes would be prioritized when moving forward.

**(a)** **(b)**

**(c)**

**Figure 6.21: a) Prototype without the silicone top. b) Prototype seen from the side. c) The magnet sticks do not spring back up again due to the magnetic force from below.**

# 6.5 Sensors

When coming this far into the project, the team was put in contact with an employee at SC in order to select suitable sensors. It was previously decided to focus on independent sensors och then place those as desired on a PCB.

For the sensors, it is desired to get a signal every time the top is being pushed and whenever someone is rotating the knob.

### 6.5.1 Sensor Concept for Rotation

*6.5.1.1 Sensor Detecting Rotation of Align PM*

In order to get a signal when the knob is rotated, a sensor can notice when the Align PM is rotated. The Align PM have every other north and south pole, which could be read by a sensor.

In order to utilize the Align PM, a sensor can be placed on the bottom of the PCB, see Figure 6.22. In the figure, the sensor can be seen as a yellow block on the green PCB, placed above the Align PM. A sensor that might be used is one of the KMT angle sensors, see Section 5.3.3.7. As a suggestion the KMT32B might be used [44]. This is a magnetic angle sensor which uses the AMR effect. The sensor can notice when a south pole is shifted into a north pole and vice versa whenever someone is rotating the knob.

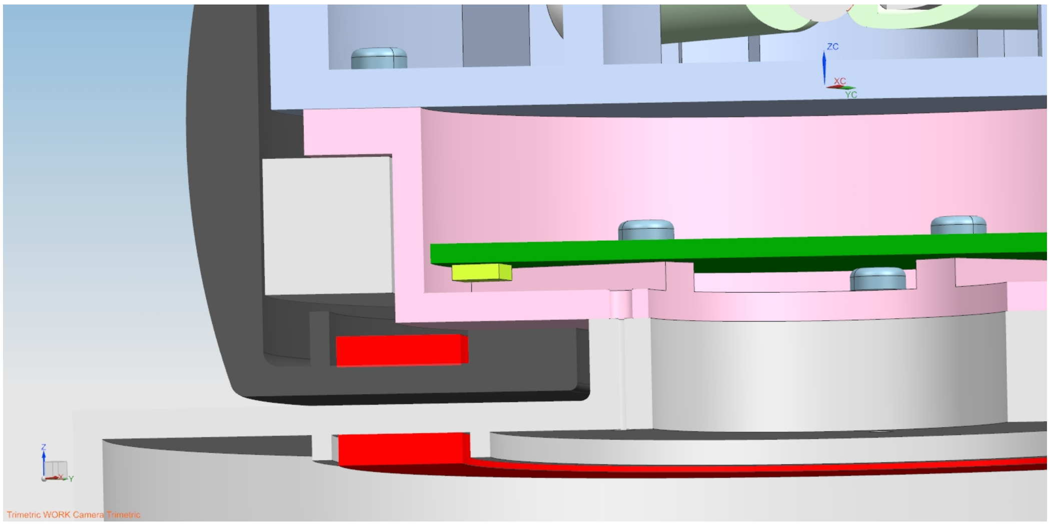


**Figure 6.22: The yellow sensor placed on the bottom of the PCB reads when the Align PM rotates.**

This concept would make the Align PM even more suitable to place in a knob. Together with a suitable sensor, it would replace both the optical rotary encoder and the spring which gives feedback in the knob today.

However, after talking to the employee at SC, it is discovered that this concept might require a lot of time and testing in order to work in the knob.

According to the employee, the tightly controlled magnetic field of Align PM will probably make it difficult for the sensor to read the magnetic field. It is too complicated to predict and calculate how it behaves so a trial-and-error test needs to be conducted in detail to see if it is possible.

The distance between the sensor and the Align PM is also very critical and needs to be tested properly to see if the results can be achieved.

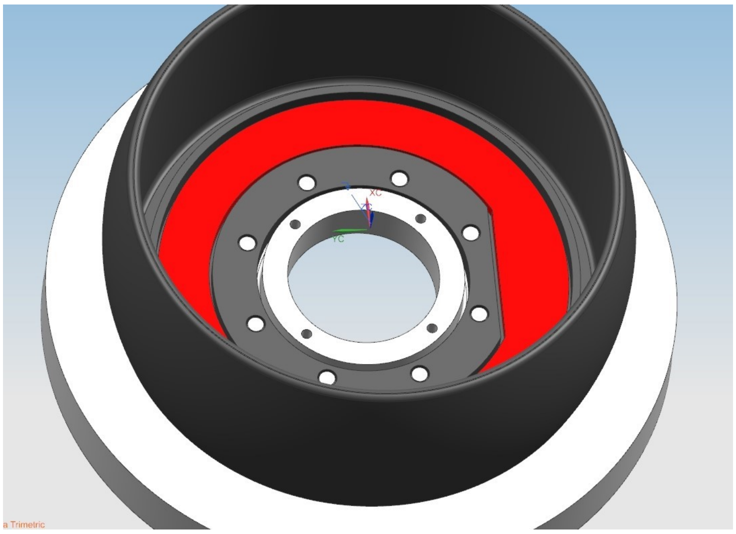
The team have tried to come in contact with Correlated Magnetics who produces Poly-Magnets, to see if they have a suggestion of a sensor that could work. The company have unfortunately not responded.

#### *6.5.1.2 Three Hall Switches Detecting Rotating of Eight Small Magnets*

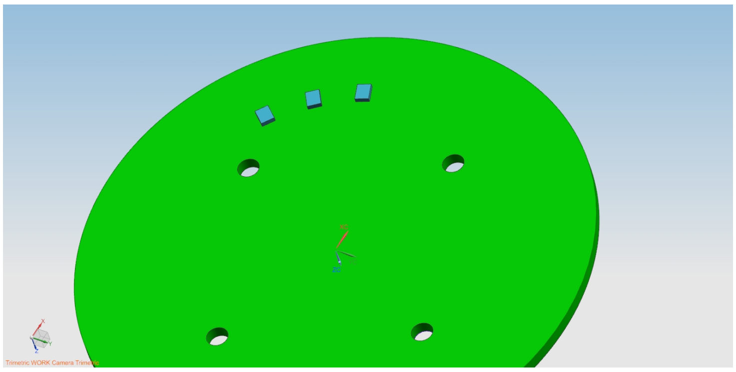
A concept for signaling the rotation that is known and verified is the one used in the Samsung Galaxy Watch, see section 3.4.1. This concept is not depending on the Align PM, but is fully independent. The concept has previously been described in detail in section 5.3.3.5. For 24 detents, eight magnets are used and these read the rotation. How this would be implemented in the knob is shown in Figure 6.23.

According to the employee at SC, this concept is straight forward and tested before.

The concept would require more parts in order to work and in this case the Align PM is only good for feedback and not sensoring at all.



**(a)**



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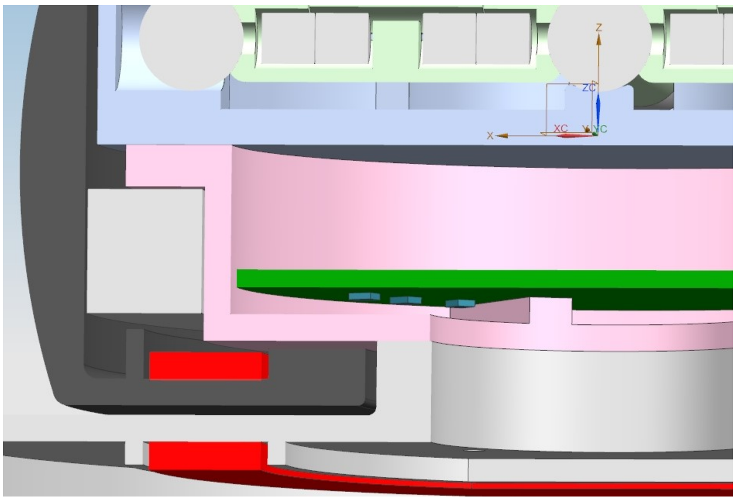


**(c)**

**Figure 6.23: a) A knob with eight magnets placed on the same distance from each other. b) Three hall switches placed on the bottom of the PCB. c) The sensors are placed above the small magnets in the knob.**

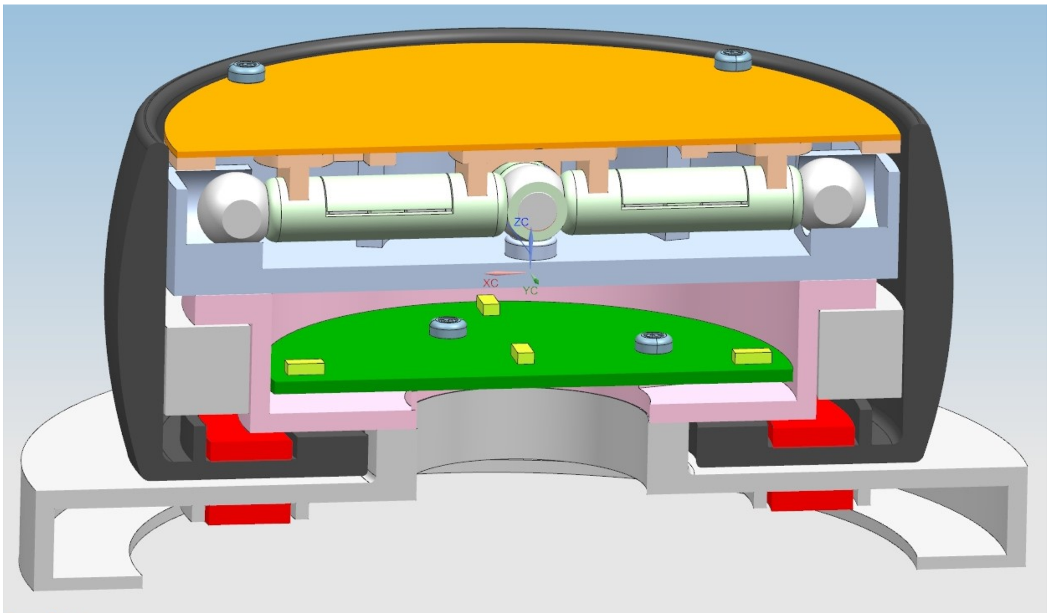
### 6.5.2 Sensor Concept for Push Buttons

*6.5.2.1 AMR Sensor Detecting Magnet Sticks*

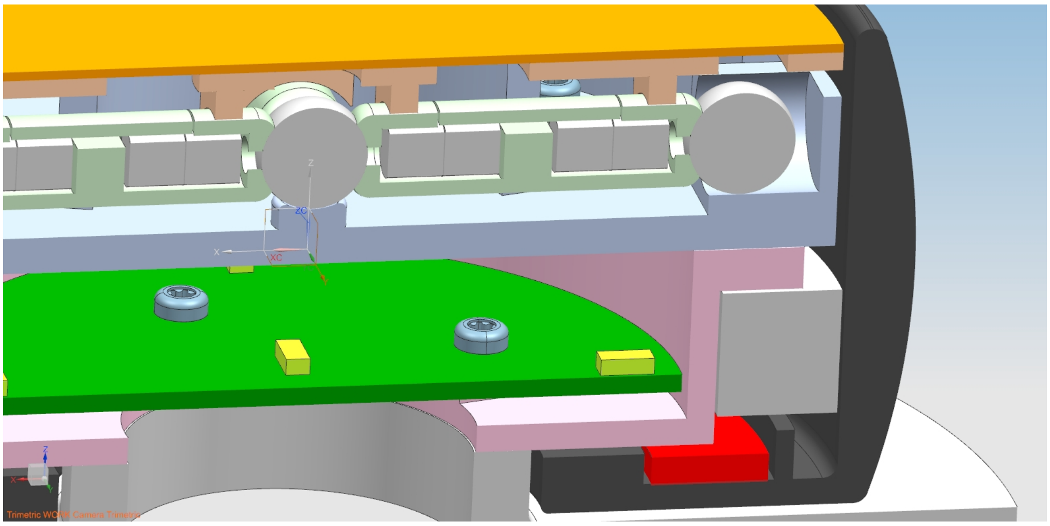
In order to get a signal when a button is being pushed, a sensor can notice that the magnet stick is lowered. The concept is shown in Figure 6.24. Five sensors, seen as yellow on the PCB in the figure, are placed underneath the magnet sticks, noticing a change in their magnetic field when the buttons are being pushed.

Since the magnets are placed horizontally, the sensor to be used for this is an AMR sensor.

After discussing it with the employee at SC, it is brought to light that this concept is not as simple as it looks to realize. He explains that an AMR sensor is easily saturated which means that it can not be placed too close to the magnetic field. The way forward here is also by a trial-and-error test to see what distances are required between the sensors and the magnet sticks.




**(a)**




**(b)**

**Figure 6.24: a) Sensors placed underneath the magnet sticks at the PCB. b) When the button is pushed, the magnets approach the sensor from above.**

*6.5.2.2 Analogue Hall Sensor Detecting Vertical Extension*

Instead of an AMR sensor, an analogue Hall sensor can be used. A Hall sensor reads magnetic fields different and the magnets need to face the sensor differently. If another dipole magnet is placed on a vertical extension of the magnet stick, it can approach the sensor vertically as well, with either north or south end first. The concept can be seen in Figure 6.25.

Through discussion with the employee at SC, this is an easier concept to realize in a prototype. An analogue Hall sensor does not saturate as easy as an AMR sensor. This concept would also require some testing but not in the same extent as an AMR sensor.

However, this concept makes it unable to seal the electronic box and requires more magnets to assemble in the knob. To simplify, the middle button would have no sensor if prototyping this concept.

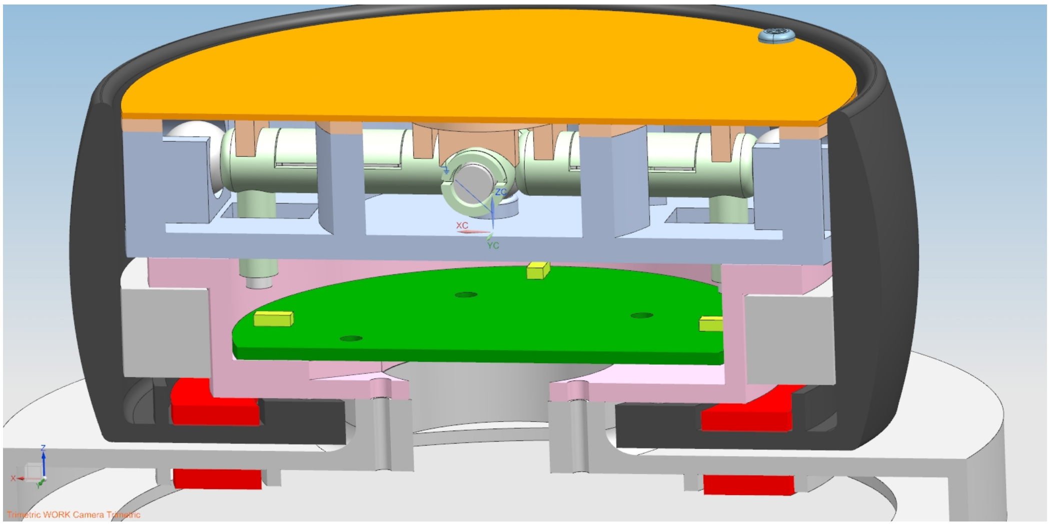


**Figure 6.25: Analogue Hall sensors underneath the vertical extensions. Magnet approaches the sensor vertically with north or south pole first.**

# 7 Final Prototypes with Sensors

*The two magnet solutions are from now on kept in separate prototypes to pursue working prototypes with sensors. One to demonstrate the rotation and one for the push buttons.*

## 7.1 Method

A PCB was designed and ordered which contained all sensors for both rotation and push buttons. Thus, the same PCB was used for both prototypes but the wires were connected differently.

Stainless steel, self-tapping screws were used. A non-magnetic material was chosen in order to prevent interfering with any magnets.

An Arduino together with codes for the two prototypes was used in order to perform testing of the sensors. An Arduino is a physical PCB together with a piece of software which is connected to a computer. [45] The codes are found in Appendix B.

The technology for 3D-printing these final prototypes is selective laser sintering, SLS [46]. This technology was chosen in order to get high quality prototypes with smooth surfaces and correct clearances.

## 7.2 Rotation Prototype with Sensors

A simplified knob containing only the rotation functions is tested.

### 7.2.1 Choice of Sensors

After discussing with the supervisor and the sensor employee at SC, it is decided that 6.5.1.1 Sensor Detecting Rotation of Align PM would be the best solution for detecting the rotation. It would make the magnet pair even more useful and result in a simple assembly. However, in order to make the sensor work, it would require too much testing and iterations.

Therefore, the thesis uses 6.5.1.2 Three Hall Switches Detecting Rotating of Eight Small Magnets when moving on with the prototype. It requires some changes and more parts but it is considered to have a higher chance of resulting in a working prototype.

The PCB can be seen in Figure 7.4. The three Hall sensors are seen to the left.

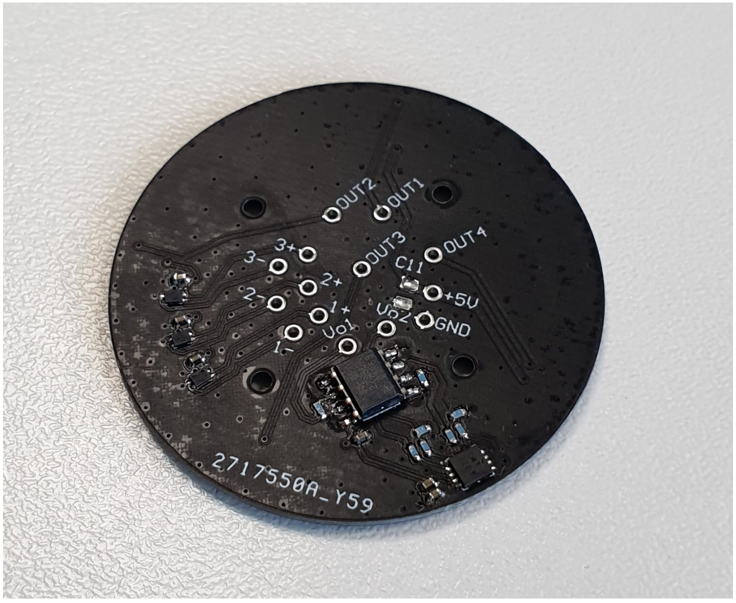
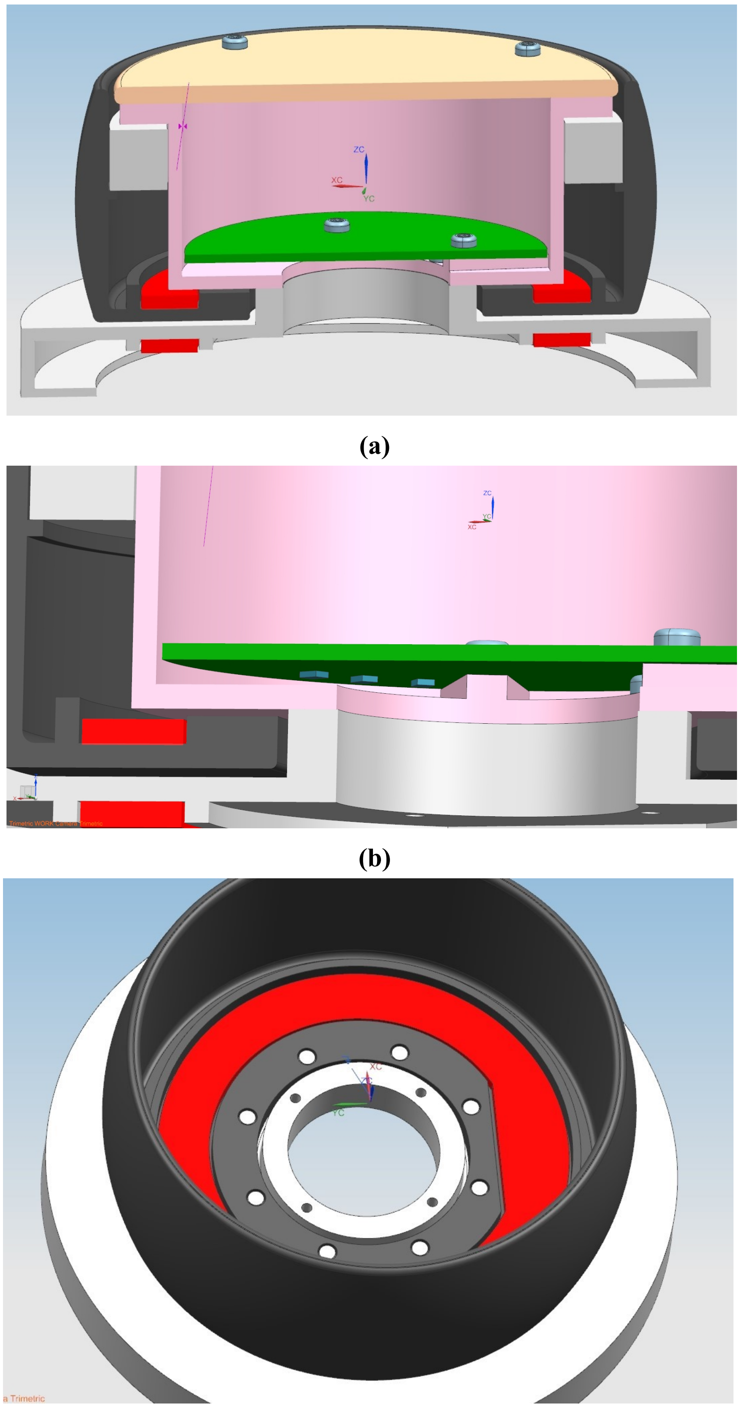



**Figure 7.1: One side of the PCB with sensors for the rotation.**

### 7.2.2 Prototype Description

The prototype is a stripped version of the combined one previously printed, see Figure 7.2a). The magnet sticks are removed and the push top is replaced with a simple plastic lid. It contains two Align PM for feedback. It still includes the bearing but placed on a greater distance from the Align PM so they will not interfere. To signal the rotation, eight small magnets are placed in a circular pattern, see Figure 7.2c).

Above the magnets, three hall switches are placed on the PCB, see Figure 7.2b).



(a)

(b)

(c)

**Figure 7.2: a) Simplified knob with only rotation function. b) Three hall switches are placed underneath the PCB. c) Eight magnets placed in a circle underneath the PCB.**

### 7.2.3 Testing Prototype

The assembly of this prototype works just as intended. When the bearing is placed on a distance from the Align PM, they do not attract each other. Since the prototype is assembled with screws, it can easily be disassembled. It feels stable and works well even after being shaken.

The feedback of the rotation in this prototype is considered a lot better then the one tested in 6.2.3.2. Feedback is subjective but the team agrees that this feedback is more suitable for this type of application. The feedback is smoother and more stable. This is because a little more distance was added between the two Align PM. The bearing used in this prototype gives a slight resistance which adds to the qualitative feedback feeling. The scraping sound has also disappeared. This is due to the 3D-printing technology, which is SLS, giving the material a more even surface.

The test setup can be seen in Figure 7.3. The code is designed to detect which of the three sensors is above a magnet. Also, the code keeps track of which previous sensor was above a magnet. This information together tells if the knob is rotated to left or right. The output from the code is a text message saying ”Left” or ”Right”. This means that every detent, there is a text message informing which direction the knob was rotated.

The test works almost as intended, but there is one glitch. Every lap of twenty-four detents, there is one text message which says the opposite direction of what it should. The reason for this is most probably because of the PM. The shape of PM is slightly unsymmetrical, see Figure 7.2c). When the knob is rotated, the sensors will pass over the PM as well and interpret the magnetic field incorrectly.

However, this glitch is considered to be a small concern since it might have been avoided if the diameter of the eight small magnets and the three sensors would have been just somewhat smaller. The sensor concept is considered to be proven.

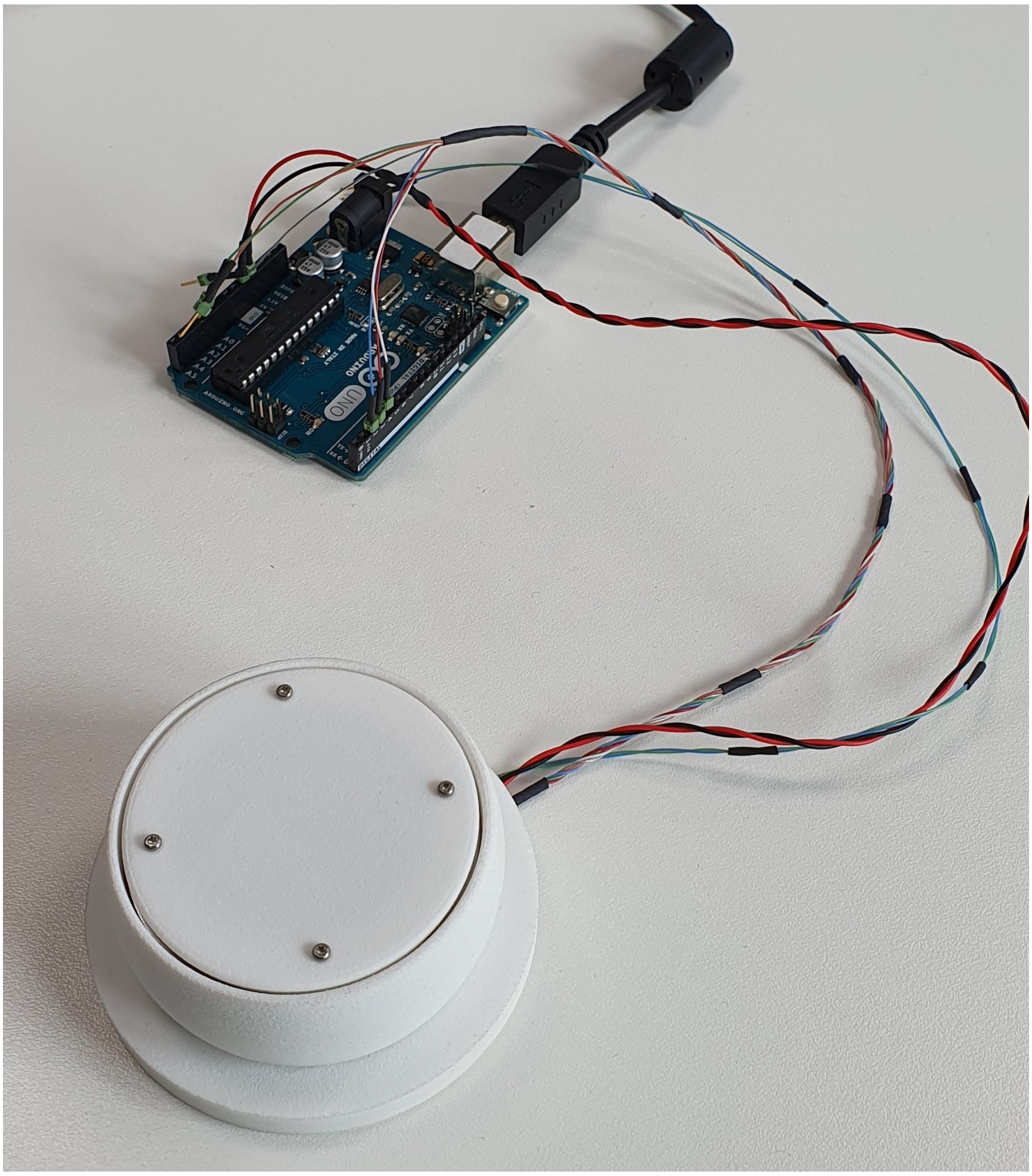


**Figure 7.3: Test setup with rotation prototype and Arduino.**

## 7.3 Push Button Prototype with Sensors

A simplified knob containing only the push button function is tested.

### 7.3.1 Choice of Sensors

The supervisor and the sensor employee at SC helped come to a decision on what sensors to use here as well. It is decided that 6.5.2.1 AMR Sensor Detecting Magnet Sticks would be the best solution for the push buttons. It requires less parts and enables the electronics box to be sealed with five working buttons.

However, since an AMR sensor get easily saturated and requires a lot of testing, this thesis will move forward with 6.5.2.2 Analogue Hall Sensor Detecting Vertical Extension. It is a simpler alternative that has higher chances of resulting in a working prototype.

When making this decision, it was decided to not have a sensor for the middle button. The push top and the magnet stick will keep the middle button mechanically, but without a sensor the knob can not detect a push on the middle button.

The PCB can be seen in Figure 7.4.

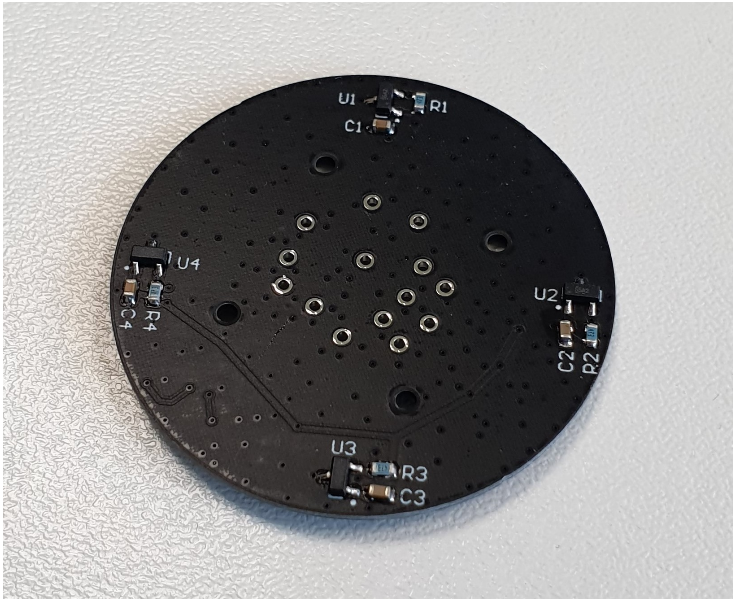



**Figure 7.4: The other side of the PCB contains sensors for the push buttons.**

### 7.3.2 Prototype Description

This prototype is a stripped version of the combined one, only keeping the magnet sticks, see Figure 7.5. This knob is not able to rotate since the Align PM, the bottom part and the bearing is removed. The magnet sticks also have a vertical extension with an extra magnet placed on it. This magnet is placed above a hall analogue sensor on the PCB which notices when a user presses the button.

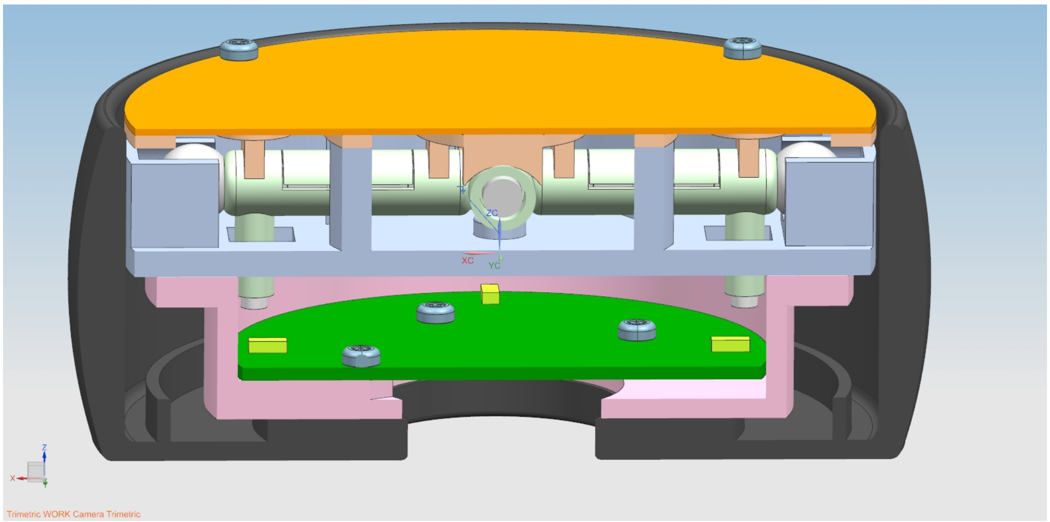


**Figure 7.5: A knob with only magnet sticks and sensors. This knob can not rotate.**

### 7.3.3 Testing Prototype

The prototype works as intended. The prototype is assembled with screws and can be easily disassembled. Everything stays in place even if shaking the prototype. Yet there is a slight noise from the moving parts but it does not affect the performance. This can probably be avoided if using a high-performance material instead of a 3D-printed one.

The feedback of the push buttons works well. There is a small clicking feeling and a slight feedback noise. The goal was to replicate the toy magnetic building sticks and the team considers this achieved.

The test setup can be seen in Figure 7.6. The sensors underneath the push buttons detect the magnetic field. The code translates this into numeric values of how near or far away the magnets are from the sensors. If someone pushes a button, the magnet approaches the sensor. The output of the code is a text message saying ”Up”, ”Down”, ”Left” or ”Right”.

The test works as intended. When pressing a button, there is a correct text message informing which direction. The sensor concept is considered to be proven.

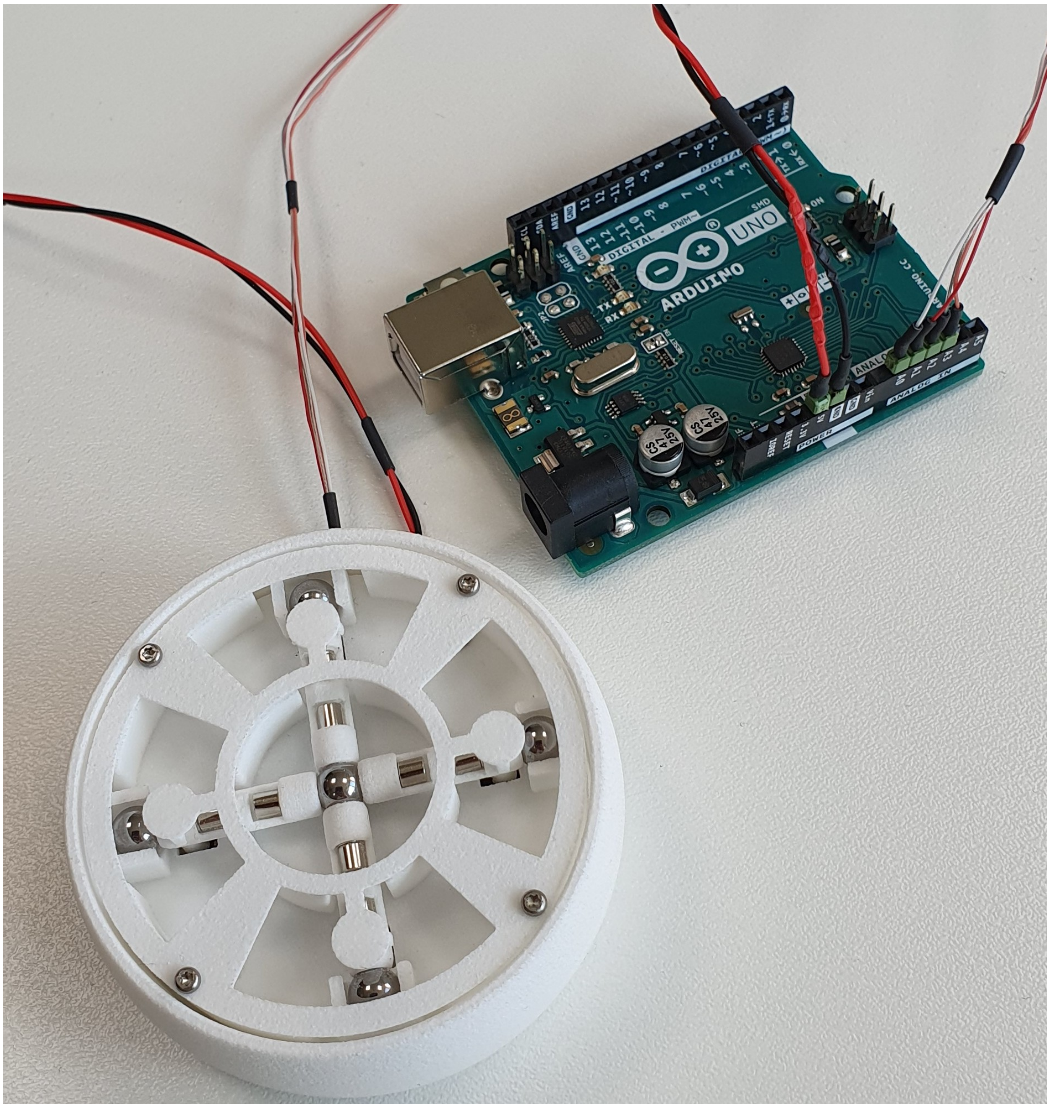



**Figure 7.6: Test setup with push button prototype and Arduino.**

## 7.4 Further Testing

To achieve a full working prototype, it is recommended to try to continue the iterations with the combined concept with both magnet sticks and Align PM, see Figure 7.7. A solution to the problem with the magnetic bearing is simply to use a bearing that is made of a non-magnetic material, like the one used in the knob today.

In order to solve the problem with the interfering magnetic fields, more testing is required. The distance between the Align PM and the magnet sticks could be explored and see at what distance they do not interfere with each other. The magnet sticks could also be tested with only one magnet at each end or smaller magnets to reduce the area of its magnetic field. Another possibility is to add a material with high magnetic permeability between the the magnet sticks and PM to separate the magnetic fields from each other. [47]

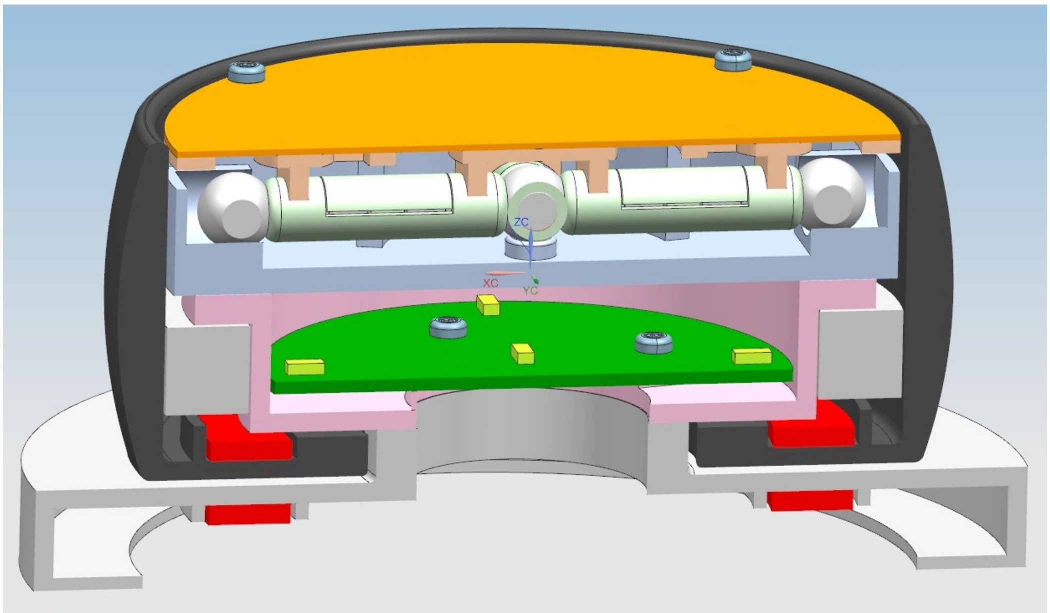


**Figure 7.7: Knob with all functions included.**

It is also recommended to spend more time on testing the different sensor concepts presented in Section 6.5. For the magnet sticks the sensors presented in 6.5.2.1 AMR Sensor Detecting Magnet Sticks is worth exploring. The concept contains AMR sensors that could be used together with the magnet sticks the way they are presented in Figure 7.7.

For the Align PM, 6.5.1.1 Sensor Detecting Rotation of Align PM should also be tested. This concept only contains one AMR sensor that could read the rotation from the Align PM. It would require a lot less parts than 6.5.1.2 Three Hall Switches Detecting Rotating of Eight Small Magnets does. It would also make the Align PM useful for sensoring as well which would make it even more suitable to use in upcoming applications. This concept does however require a lot of testing and depending on how the Align PM magnetic field looks like, is not guaranteed to work.

If the sensors work as hoped, the combined concept available in Figure 7.7 would be achievable. The electronic box could then be further explored to make the sensors sealed from water as well as dust.

# 8 Discussion and Conclusion

*In the following chapter, the project and its results are discussed. Proposals for further development and recommendations to the company are presented. Finally, a conclusion is formulated.*

## 8.1 Discussion

### 8.1.1 Project Evaluation

The team is satisfied with the project and its outcome. There is always a desire to explore even more, but this report presents many interesting findings. We hope these are valuable to SC in the future.

During this master thesis there was an outbreak of the virus Covid-19. The pandemic has affected all companies and universities, including Lund University and SC. To follow the recommendations from Swedish authorities, about half of this master thesis was done while working from home and getting support by distance. Some personnel at SC was unfortunately permitted or had reduced working hours. This slowed down the concept testing phase in a certain degree. The team is still happy with the outcome and developed working prototypes to the best of their ability.

This project has investigated the possibilities to implement magnets in a knob and found several ways of doing this which are presented in the chapter Concept Generation. Unfortunately, it was not possible to test all promising concepts. The project goal was to develop a working prototype. Therefore, only a few concepts were chosen for further development. This strategy was chosen in order to avoid spending to much time on subconcepts that had no success and risking not finishing in a working prototype in time.

The team focused mainly on the mechanical parts of the product since these were the most primary needs. The electronics had second priority in the customer needs. It would have been desirable to integrate sensors earlier on in the project, but that would have delayed the concept generation phase massively. For this reason, the team is happy with the decision to prioritize the mechanics. All needs regarding the mechanical functions are met.

There were two needs which had the lowest priority: sealing the electronics and that the knob would work even after being shaken. The team consider these needs to be somewhat met. A suggested concept is to seal the electronics in a knob where an AMR sensor is used for the magnet sticks, since there is no need for vertical extensions. However, that prototype was not tested in this project. The team aimed to give the knob stability and the final prototypes can definitely handle being shaken. They might break if being dropped or abused, but they can handle an aggressive shake.

### 8.1.2 Result Evaluation

The project ends in two working prototypes: one rotational with 24 detents and another with four push buttons. Throughout the project, there has been many results and conclusions which led the team forward.

The main results are proving that Align PM can be used for rotational feedback and magnet sticks can be used for push buttons. Both the rotation and buttons can also be detected by sensors with the use of magnets. Another result which is a theme throughout most of the testing, is that magnetic fields easily interfere with each other. This is a central and very important conclusion. The two concepts could not be implemented together in the same prototype due to this and the sensor solutions were limited by this. Therefore, if designing with magnets in any application it is crucial to have this in mind.

### 8.1.3 Further Development

If continuing this work, these are the areas that the team recommends to investigate:

- **Knob with all Functions**

  The subconcepts were merged together into a knob with magnets for both swivel function and push buttons. This prototype was not successful and therefore needs further improvement. A proposal for further testing is to implement a material with high magnetic permeability as a screen between the Align PM and the magnet sticks. This could possibly separate the magnet fields and allow the two functions to exist in the same knob. Another suggestion is to experiment with the size of the magnets and the distances between them in order to avoid interference.

- **Sensor Detecting Rotation of Align PM**

  Using a sensor which can detect the rotation of the Align PM will remove the need for additional magnets. This would be the prefered sensor concept. The team did not have time to realize this concept but it is adviced to aim towards this when continuing the development.

- **AMR Sensor Detecting Magnet Sticks**

  An AMR sensor can detect magnet fields at a different angle than a Hall sensor and therefore does not require any vertical extension. It would enable a simpler design and the electronics box could be sealed. An AMR sensor is very sensitive and gets easily saturated and the team did not have time to test this out in a prototype. We recommend that this type of sensor is used in a future product due to its advantages.

- **Non-Magnetic Bearing**

  Most common bearings are magnetic since they are made of steel but using a magnetic bearing was not successful in this project. During future testing, a non-magnetic bearing is strongly recommended.

- **Silicone Top**

  The silicone top can be further improved. The material used in the prototype for proof of concept is 3D-printed, therefore it does not have the most supreme properties. A superior material can be chosen with more research in this area.

- **Simulation**

  In order to create a successful product which includes magnets, software which can simulate magnetic fields can to be performed parallel to concept generation in order to avoid interference.

- **Dimensions**

  For the magnet sticks in the prototypes, the steel balls are 6 mm in diameter and the magnets are 3x3 mm. These figures can be further experimented with in order to achieve different feedback. Also, the size of the knob itself can be adjusted. The size of Align PM is fixed for twenty-four when ordering online, but it is possible to order smaller sizes with fewer detents. It is probably also possible to order custom made sizes if getting in contact with Correlated Magnetics. Note that price and delivery time changes.

- **Other Findings**

  - Magnetic Strip

    A magnetic strip with alternating poles was a highly interesting concept. The team decided to try out the Align PM first, and since it was a success the magnetic strip was never tried. However, it was not very simple to find a magnetic strip with alternating poles for purchase but it is recommended to look further into this concept if found interesting.

  - Melexis Triaxis

    The Melexis Triaxis sensor was not used in this knob due to having both rotating and fixed parts. However, we recommend using this sensor for products which only has rotation. In that application, this sensor is smart and simple.

## 8.2 Conclusion

The objective of this master thesis was to answer the problem formulation:

*”Can the mechanics of the knob’s functions be replaced with magnets, in order to explore the possibilities for magnets in this type of application?”*

The conclusion is that yes, it is possible to replace some mechanics with magnets. The key findings in this report are:

- Align PM can be utilized for rotational detents with feedback
- Magnet sticks can be utilized to achieve push buttons with feedback

However, it is problematic to replace all mechanics with magnets. Magnetic fields are complex and will interfere when close to each other. It is therefore hard to combine several magnet solutions within the same product.

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# A Work Distribution and Time Plan

## A.1 Work Distribution

The team of this master thesis are both students at the department of Mechanical Engineering at the Faculty of Engineering at LTH in Lund. The authors have therefore similar backgrounds and knowledge. Both team members participated in all activities and contributed to driving the project forward. Some parts of the report were written individually, but all content was still thoroughly discussed. When one team member focused more on prototype building, the other one focused on the report. However, the work load was distributed equally.

## A.2 Time Plan

The time plan was used as a guide to perform all tasks in time, but it was not followed rigorously. Some activities took longer time and some were faster than expected. The planned time plan can be seen below in Figure A.1 and the actual outcome of the project can be seen in Figure A.2.

The planned time schedule expected more time devoted to ’concept generation’ and less time to ’prototype building’. In reality, it was the opposite. Building all prototypes was spread out over a long period of time, mainly since several different 3D-printers were used and the implementing of sensors is included in this phase.

In February, there is a gap in the report writing. The team was recommended by the mentor to not focus to much on the report writing in the beginning of the project and instead give full dedication to the ’concept generation’ phase. This was a good decision and led to completing this activity faster than expected.

There is another gap in several of the activities around the change of April and May. During this period, the team was waiting for 3D-printed material and PCBs. Instead, the team focused on writing the report in general, the popular scientific article and starting to prepare the presentations.

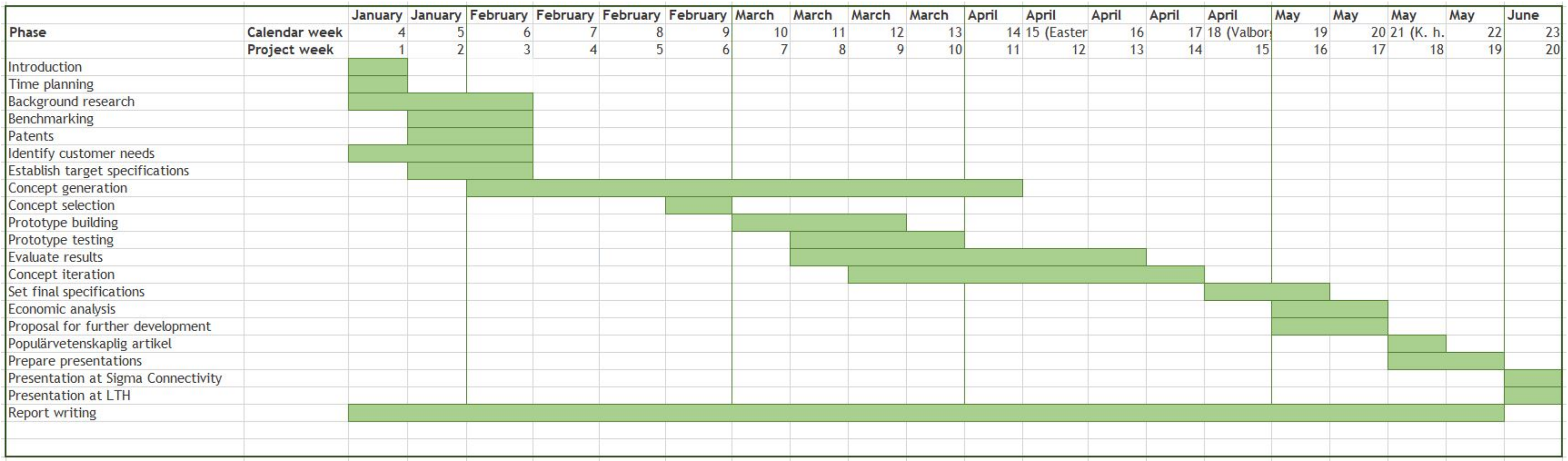


Figure A.1: The planned project time plan presented in a Gantt chart.

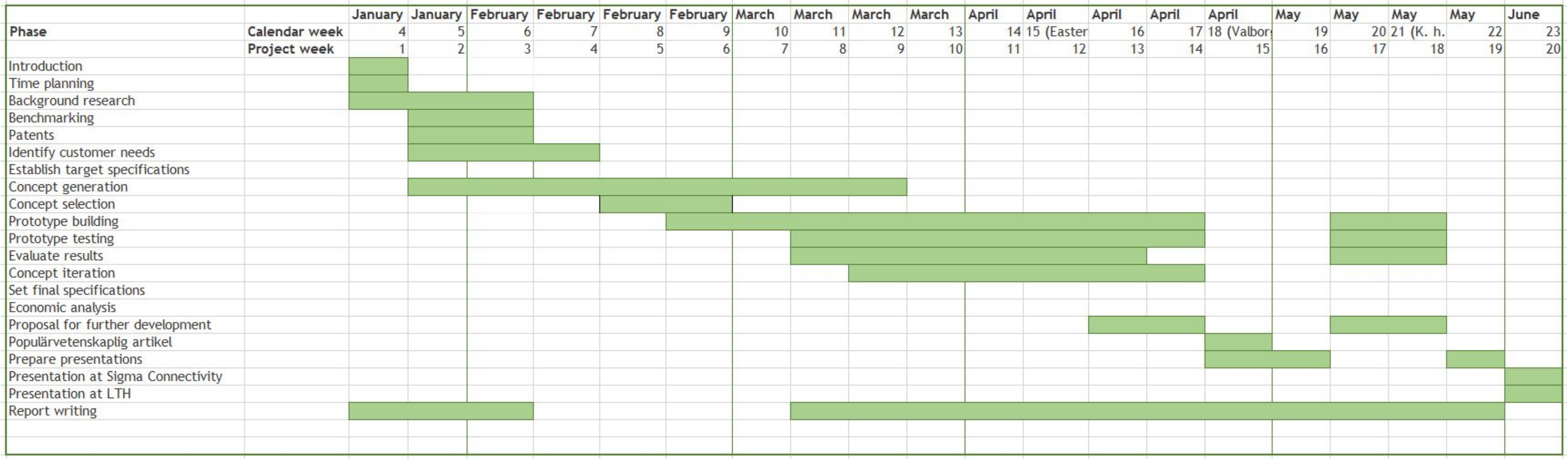


**Figure A.2: The actual outcome of the project time plan presented in a Gantt chart.**

# B Arduino Codes

## B.1 Rotation

```
const int  sensorPin1 = 2;
const int  sensorPin2 = 3;
const int  sensorPin3 = 4;

int sensorState = 0;
int lastState = 0;

int readSensor() {
  if (digitalRead(sensorPin1) == LOW) {
    return 1;
  } else if (digitalRead(sensorPin2) == LOW) {
    return 2;
  } else if (digitalRead(sensorPin3) == LOW) {
    return 3;
  } else return 0;
}

void setup() {
  Serial.begin(9600);
  pinMode(sensorPin1, INPUT);
  pinMode(sensorPin2, INPUT);
  pinMode(sensorPin3, INPUT);
  lastState = readSensor();
}
```

**Figure B.1: First part of the code for rotation.**

```
void loop() {
  sensorState = readSensor();
  if (sensorState != lastState) {
    switch (sensorState) {
      case 1:
        if (lastState == 2) {
          Serial.println("Right");
        } else if (lastState == 3) {
          Serial.println("Left");
        }
        break;
      case 2:
        if (lastState == 3) {
          Serial.println("Right");
        } else if (lastState == 1) {
          Serial.println("Left");
        }
        break;
      case 3:
        if (lastState == 1) {
          Serial.println("Right");
        } else if (lastState == 2) {
          Serial.println("Left");
        }
        break;
      default:
        break;
    }
    lastState = sensorState;
  }
  //delay(10);
}
```

**Figure B.2: Second part of the code for rotation.**

# B.2 Push Buttons

```
int sensorPin1 = A0;
int sensorPin2 = A1;
int sensorPin3 = A2;
int sensorPin4 = A3;
int sensorMin1 = 590;
int sensorMax1 = 1023;
int sensorMin2 = 661;
int sensorMax2 = 1023;
int sensorMin3 = 572;
int sensorMax3 = 924;
int sensorMin4 = 603;
int sensorMax4 = 947;

int pushValue = 70; // value to activate sensor

void setup() {
  Serial.begin(9600);
  pinMode(sensorPin1, INPUT);  // declare the sensorPin as an INPUT:
  pinMode(sensorPin2, INPUT);
  pinMode(sensorPin3, INPUT);
  pinMode(sensorPin4, INPUT);
}
```

**Figure B.3: First part of the code for push buttons.**

```
void loop() {

  // read the value from the sensor:
  int sensorValue1 = analogRead(sensorPin1);
  int sensorValue2 = analogRead(sensorPin2);
  int sensorValue3 = analogRead(sensorPin3);
  int sensorValue4 = analogRead(sensorPin4);

sensorValue1 = map(sensorValue1, sensorMin1, sensorMax1, 0, 255);
sensorValue2 = map(sensorValue2, sensorMin2, sensorMax2, 0, 255);
sensorValue3 = map(sensorValue3, sensorMin3, sensorMax3, 0, 255);
sensorValue4 = map(sensorValue4, sensorMin4, sensorMax4, 0, 255);

  if(sensorValue1>=pushValue){
  Serial.println("Up.");
  }
  else if(sensorValue2>=pushValue){
  Serial.println("Right.");
  }
  else if(sensorValue3>=pushValue){
  Serial.println("Down.");
  }
  else if(sensorValue4>=pushValue){
  Serial.println("Left.");
  }

  delay(180);

}
```

**Figure B.4: Second part of the code for push buttons.**