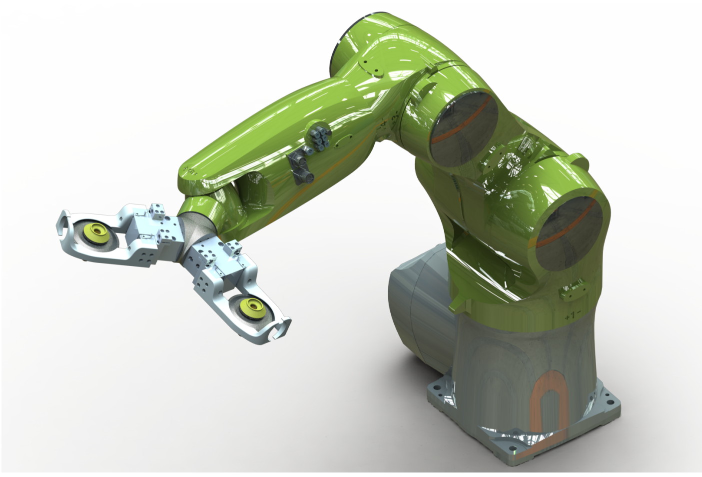
Robotic Automation of the Assembling Process of Rotors and Stators in the ALPHA2 Pump Production Line at Grundfos

Robotic manipulators

Project Report

Group B117



Aalborg University
Robotics

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STUDENT REPORT

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Abstract:

Based on an inquiry from the Danish pump manufacturing company Grundfos regarding an assembly operation in their ALPHA2 production line, this project investigates the possibilities of automatically assembling a rotor and stator by the use of one or more robotic manipulators, while fulfilling a certain set of requirements. In short, the rotors must be moved from a conveyor to a magnetizing unit and then from the magnetizing unit onto a second outlet conveyor with stators to create one assembled unit. A unit must be produced every fourth second and approximately every 50^{th} magnetized rotor must be quality checked. Ultimately, this investigation should result in the design of a robot system capable of completing this assembly operation. In order to design such a system, four cycles are proposed and analysed thoroughly to find the most efficient cycle and a gripper for the manipulator capable of handling the rotors is designed in the SolidWorks CAD program. Multiple tests on a KUKA KR6 R700 sixx concluded that two of the four proposed cycles were able to complete the assembly operation within four seconds and the most efficient cycle was achieved by moving two rotors at once by use of a double gripper as end-effector on the manipulator.

Contents

Nomenclature

Definitions

The paper will be using the following terms as defined below:

- Robotic manipulator:

  These are industry-specific robots which can rapidly do similar work tasks with highly accurate repeatability. Often seen in car-producing factories where these manipulators have welders as end-effectors.

- Repeatability:

  The root mean square difference between successive results when a manipulator is moved to the same set point. [1]

- End-effector:

  The tool which is mounted onto the a manipulator: This tool can be a gripping device, welding torch, etc.

Abbreviation

The following abbreviations will be used throughout the report.

SME Small and Medium Enterprises.

Preface

As a part of the Robotics education at Aalborg University Denmark, this project was conducted in collaboration with the Danish pump manufacturing company Grundfos. The collaboration involved a visit at Grundfos' plant in Bjerringbro, where a plant tour of the ALPHA2 pump production line was provided, and a visit from Grundfos in the robot laboratory at Aalborg University.

Aalborg University, May 24, 2016

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Part I

Prologue

Chapter | 1

Introduction

This chapter examines robots, the definition and history, how and when robots came to be a part of the manufacturing industry and how robots are performing today. The chapter will also deal with the social aspect of robots with focus on robots taking jobs, arguments for why this might be for the better, and why this assumption might be false. The main focus of this project will be on the danish pump manufacturing company Grundfos, therefore an introduction to the company and its robot history is given.

1.1 A bit of robot history

The word *robot* comes from the czechish word *robota* which means relentless work and was first used in 1921 [2]. Today, according to ISO 8373, an industrial robot is *"an automatically controlled, reprogrammable, multipurpose manipulator, programmable in three or more axes"*. In 1954 George Devol designed the first programmable industrial robot, this robot was able to transport an object from one place to another. At a cocktail party in 1956 Devol met Joseph Engelberger and together they developed and formed the first robot company called Unimation. In 1961 Devol and Engelberger sold their first industrial robot to General Motors (GM). This robot's job was to handle die casting and spot welding. GM wanted the robot to have a pay-off time in 18 months, so Devol and Engelberger sold the robot to GM for 18,000 $ even though the robot costed 65,000 $ to produce. They sold it cheap because they used it as a showcasing object. Their initial goal was to lend the robots out, in order to increase the demand and to show companies how efficient robots can be. [3]

The technical director at Ford, Del Harder, saw great potential in industrial robots and was interested in installing 2000 Unimation robots in the factories of Ford. Unimation could not deliver this amount of robots so Del Harder sought our other companies to produce the robots. This was an important step since it resulted in a large number of American companies entering the robot industry. [3]

The robot industry was not only expanding in the US. A Norwegian company Trallfa wanted to install a painting robot, because of the poor working environment. Such a robot would cost them 600.000 NOK which they thought was too expensive, so they decided to develop their own cheaper robot. The goal was to keep the cost under 15.000 NOK and in 1967 they presented an electro-hydraulic robot which could perform continuous movements and was easy to program. In 1971 ABB joined the robot industry and created a robot which was installed with the latest microcomputer Intel 8008, which had 16 KB memory. This robot was one of the first robots to be controlled by a microcomputer. Leif Jönsson, CEO of Magnussons, was the first to buy one of these robots, and because of the new robots Jönsson was able to operate an unmanned factory by himself. In the 1970s robots were mainly used for material handling, but in the 1980s companies began to request and ask for assembly robots. This required the robots to have higher repeatability, acceleration and velocity, which meant that the robots began to be more advanced and used more often. In the end of the 1980s different kind of advanced sensors had been implemented, which allowed the robots to "see and feel" the objects they work on.[3]

Since the late 1980s there has been an enormous growth of industrial robots implemented in factories. The most important reason for this is the cost efficiency compared to human labour, because over the last few decades the wages have increased. Along with that, the efficiency, flexibility, accuracy and the speed of the robots have increased, which helps with the comparison to human labour.[4] In the 20^{th} century, the field of industrial robots has been revolutionized, and the technology has advanced vastly over a few decades. It is predicted that mobile robotswill be exposed to a similar growth in the 21^{st} century as that of industrial robots in the previous century.[5]

In modern society robots are often used to help humans with both easy and repetitive tasks, or by replacing the human worker in tasks that can be dangerous for the human health.[6]

1.2 Social aspects

Propagation of industrial robots will inevitably take away many existing jobs which is a concern to many people. This has been a natural concern when new technology was implemented in the past. People had the same concern when vending-machines were introduced in the 1930s as they could take the jobs of store clerks. [7]. The loss of industrial jobs did not start with the implementation of robots. Industry has been incorporating automated machines for a long time and advanced manufacturing technology generally contributes to the replacement of manual labour, but most of the jobs that were lost have since been replaced by new ones[8]. It is worth mentioning that even though a lot of industrial automation was introduced in the 20^{th} century in the US, the overall number of jobs grew[7]. This was also the case in Denmark at Grundfos, as illustrated in figure 1.1.

That being the case one can argue that robots might create as many jobs as were lost in total, potentially even more, but it is worth noticing that some sections of the job market will be more affected than others as a result of automation. Older workers are particularly exposed to the consequences of automation as it, in general, is more difficult to re-educate them for the new jobs.[7]

A survey gathered from engineers and inspectors in different regions questioned the features of a conventional workplace compared to a robotized one. The survey was compiled of 102 files, where each file represented a company. The survey resulted in data showing that 82% described a conventional workplace tedious, where 73% claimed it repetitive. The survey also provided information regarding the hazards inherent in a conventional industrial workplace, which were divided into 5 categories. To each category a percentage was given to show how many of the companies who thought that the hazard was present in a conventional workplace. The 5 hazards are: Mechanical risks (45%), other physical risks (59%), chemical and biological risks (48%), static and dynamic strain - posture and applied working forces - (66%), neuropsychic strain (24%).[9]

Many of these risks can be greatly suppressed by the use of robots. In fact, a commonly mentioned benefit of industrial robots is that they can carry out monotonous and dangerous tasks that are not suited for humans. In addition, industrial robots can potentially eliminate existing human rights violations such as the use of child labor. Industrial robots may also be able to compensate for future shortages of

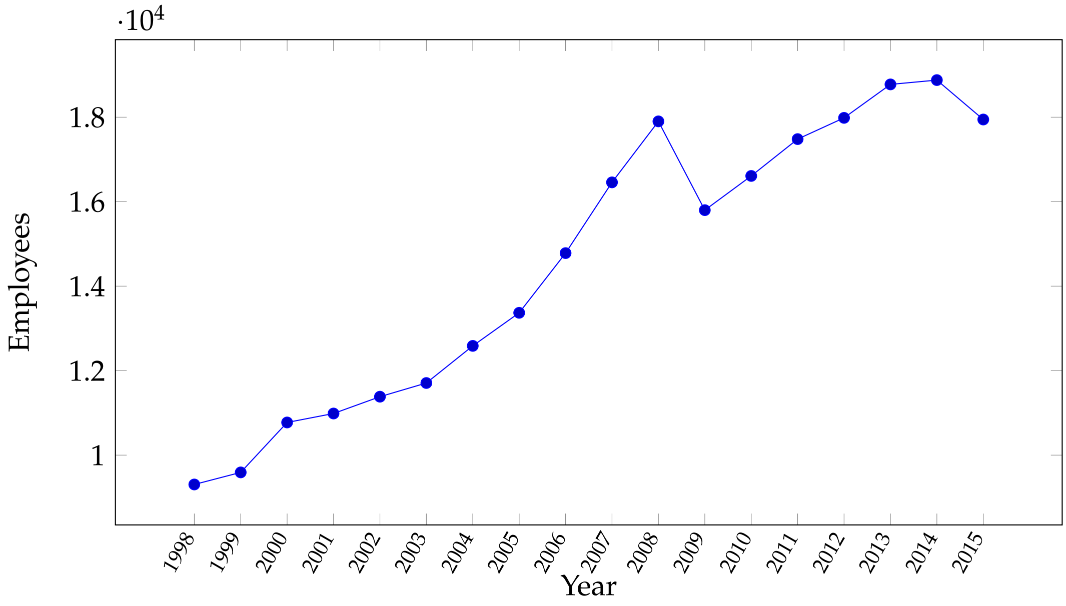


Figure 1.1: This figure shows the growth of Grundfos employees from 1998 to 2015. Data for this is collected from annual Grundfos reports.

work due to aging populations as well as decreasing fertility rates in certain countries around the world.[7]

Traditionally, manufacturing activities have moved to low-wage countries. However, the implementation of robots in the industry makes it possible to keep production lines in high-wage countries. This also enables the engineering and innovation departments to be in closer contact which can speed up the process from design to production[10]. However, when outsourcing is prevented through automation, jobs in foreign countries might be lost. Nevertheless, automation is an essential part of remaining competitive on a global scale.[7]

1.3 Competitiveness

A fear of robots currently exist among Smaller and Medium Enterprises (SMEs). The general assumption is that robots will take away jobs, but besides that, SMEs also fear that robots will not be able to generate profit if they are implemented. They think robots are too expensive, heavy, inflexible, time consuming or that their company is too small for a robot to be implemented. In general SMEs do not see the long term benefits.[11]

The project *A Helping Hand for Europe*, made by joint research in the Institute for Prospective Technological Studies, has shown that SMEs can handle a greater amount of complex and repetitive tasks by investing in robots. The point of the study was to encourage SMEs to invest in robots and get them to take advantage of the huge market potential. In order to encourage the SMEs, the study listed a number of points where robots can outcompete manual labour. The study stated that robots can work at a faster rate while at the same time taking some of the most dangerous jobs, both in terms of long term repetitive strain injury and immediate health risks, e.g. chemical sprays or high temperatures. [11]

Although not an SME, Grundfos is an example of a company where the previously mentioned assumption proved to be wrong. Today the implementation of robots have created more than 124 new jobs in the robotic personnel, and as they state themselves:

> *"Robots have contributed to making the work processes far more efficient. Thus, they have made way for increased earnings, and at the same time taken over most of the tedious routine tasks that used to cause attrition and monotonous work. At several production sites, the robots have even taken over job functions that were hazardous to the employees."*[12]

All the benefits that the study *A Helping Hand for Europe* stated, are matching with what Grundfos experienced when implementing robots. Grundfos have seen a huge benefit from the use of robots, and they are even going as far as developing their own work programs and systems, in order to take advantage of the possibilities. They now work in cooperation with the robot company KUKA and together they have developed advanced robotic manipulators with visual sensors, among other systems.[12]

1.4 Grundfos

In 1944 Poul Due Jensen founded the company Bjerringbro Die-casting Foundry and Machine Factory. The company was located in the basement of P. D. Jensens house in Bjerringbro, focusing on sanitation, heating and smithy. In 1945 P. D. Jensen received an order on automation of waterworks for a local farm. He needed a pump for the job but did not find any of the pumps on the market of satisfying quality, which is why P. D. Jensen created the first pump type which was able to pump water from wells with a depth up to 7 meters.[13]

In 1959 the first circulator pump was created and named VP 32. The VP 32 were used for central heating and domestic hot water circulation. The reliability of this pump was very high due to the materials used. This pump would later evolve into the company's most important asset.[13]

The company changed its name to Grundfos in 1967. Around 1989 Grundfos introduced their first robots into the production in form of the IBM SCARA. The SCARA type robots are fast and ideal for pick and place tasks.

In 1992 Grundfos started using robots for laser welding of impellers. In 2005 the concept of Bin Picking with a robot was implemented at Grundfos' manufacturing plant in Wahlstedt, Germany. Grundfos introduced their first low-energy pump, the revolutionary ALPHA Pro in 2005. The ALPHA Pro is able to control and adjust pressure and flow automatically during different times of the day and various seasons.[13, 14]

Figure 1.2: ALPHA2 pump produced by Grundfos since 2007

Through Grundfos' continuous evolution and development, a newer improved version of the ALPHA Pro was released under the name ALPHA2 in 2007. It can be seen in figure 1.2. The production line, consisting of 17 robots, is automated and works at a high speed producing a ALPHA2 every 10^{th} second as of 2007. The line has the possibility to increase the production with up to 400.000 pumps per year.[15]

Grundfos has expanded across the globe, with more than 18.000 employees spread across 12 manufacturing companies, 8 sales companies with manufacturing activity and 11 Non-Grundfos brand activities worldwide, but the headquarter is still located in Bjerringbro, Denmark.[12]

1.5 Initial problem statement

Grundfos has given the following task: A rotor has to be magnetized and assembled with a stator by robotic manipulators in a fully automated work cell with limited space.

A set of requirements has been given regarding input and output frequencies. At the same time the final solution must abide by certain standards and legislation.

There will be two input conveyors that will have a constant flow of parts, and the final solution must keep up with this flow in order to not reduce the daily output of products. One conveyor belt will have two rotors coming in every 8^{th} second, and another conveyor will have one stator coming in every 4^{th} second. Thus, a rotor and stator shall be assembled every 4^{th} second.

Part II

Analysis

Chapter | 2

Task description

In this chapter the task given by Grundfos will be described in detail and the specifications of the work cell will be described.

2.1 Description

The assignment, given by Grundfos, was to fully automate the assembly of a rotor and stator with the use a robotic manipulator(s). Before assembling the two parts, the rotor has to be magnetized in a magnetizing unit.

The solution has to follow some given specifications and requirements. The system has to work within a certain area, called a work cell, enabling it to function with existing conveyors and systems. A plan of the given area can be found in figure 2.1 on the next page and from that it can be seen that the space of the work cell is 4340 by 4200 mm. Within this space one or more manipulators should be implemented in order to reach the input and output conveyors, and the magnetizing units. The final solution must be able to conform to the given dimensions.

Part of the task is to pick up rotors, which are arriving upside down relative to how they are placed in the stator. See figure 8.4 on page 44. The rotors arrive on an incoming conveyor belt from which they are put into a magnetizing unit, then from the magnetizing unit into a stator on the outgoing conveyor. When the rotor is placed in the magnetizing unit, the manipulator or some other fixture must ensure that the bearing plate of the rotor is not touching the surface of the magnetizing coil, specifically there must be a gap of 2 mm between the bearing plate and the coil. The process of assembling the rotor with the stator is as follows: When the rotor is aligned with the rotor-can of the stator it is lowered in the stator to the point where the tip of the rotor is just above the bush of the stator. From here the manipulator drops the rotor the last 10 mm into the bush of the stator to complete the assembly. The manipulator must not direct the rotor completely into the bush due to possible damages to the rotor and the ceramic bush of the stator.

The rotors are arriving in pairs on a 200x200 mm pallet. Occasionally the rotor pair is pre-magnetized and can either be re-magnetized or placed directly in a stator.

In order to hold a certain quality, approximately every 50th rotor is going to be put on a 3rd conveyor belt for quality assurance. When the inspection has been made, the rotor is sent back into the work cell, where the rotor needs to be placed into a stator. The assembly is thereby completed.

Set-up of cell

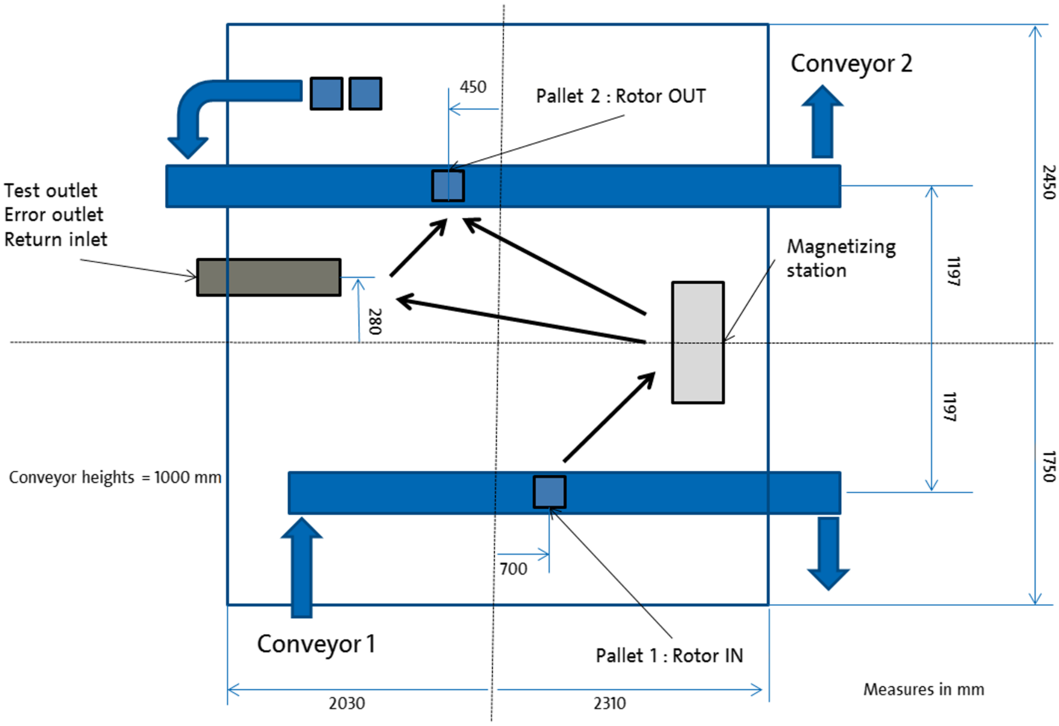


Figure 2.1: This figure shows the placement of the equipment within the work cell. The drawing is given by Grundfos.

Incoming Rotor

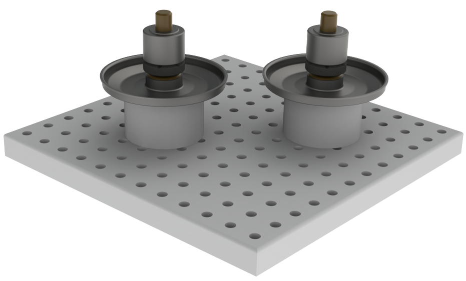


Figure 2.2: This figure shows the pallet and how the rotor is placed on the pallet.

The task given by Grundfos was specified with requirements for the work cell. Moreover, emphasis was put on the fragility of ceramic parts and the significance of these when assembling the rotor and stator. Quality assurance is another part of the process which must be taken into consideration when setting up the program for the manipulator.

Chapter | 3

Parts analysis

This chapter will analyse the specifications and dimensions of the most essential parts used in the assembly process.

In the previous chapter different parts were mentioned, namely: Rotor, stator, magnetizing unit and pallet.

These parts need to be analysed and described further in order to figure out how they can be handled. The rotor is especially important to analyse since a gripper needs to be designed later in development with adequate dimensions to ensure that it has a firm and accurate grip on the rotor. In this case, *firm* refers to the ability of being able to rotate and move the rotor between the conveyors and magnetizing units without dropping it while *accurate* refers to the ability of gripping the rotor centred in the same position every time. An accurate grip is very important as the rotors need to be inserted in the magnetizing unit and stator with high precision.

3.1 Rotor

The rotor in figure 3.1a on the next page is the only moving part of the ALPHA2 pump. It has a weight of 122,04 grams and consists of a ceramic shaft which has a plastic mill and a magnet attached. The mill works by drawing water through the center and then with centrifugal force, the mill forces the water out of the side. The mill is made of the plastic type Polyethersulfone (PES) which is reinforced with 30% glass fibre. The reinforced plastic composite is shortened to PESGF30%.

The magnet, sitting lowest on the shaft, is a permanent magnet that is magnetized in the magnetizing unit seen in figure 3.1c on the following page.

A bearing plate separates the mill and the magnet in order to hold a ceramic packing. The packing and the bearing plate is not watertight meaning there will be water around the magnet. Thereby, the ceramic bushes are lubricated with water and the rotor is water cooled.

A black rubber ring is located between the magnet and the ceramic packing, with the purpose of reducing the friction on the packing since the spinning mill will make a pulling force on the shaft when it pumps the water.

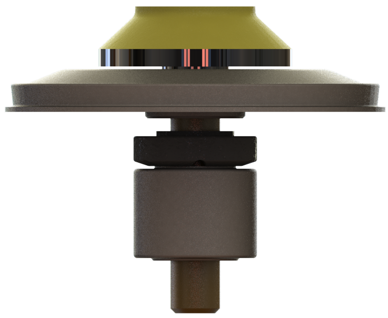
As mentioned earlier the shaft is made of a ceramic material which can splinter or crack if put under high compression. Also the magnet should not be touched since scratches, grease and dirt can potentially damage the surface of it.

A worksheet with precise measurements can be found on page 16.

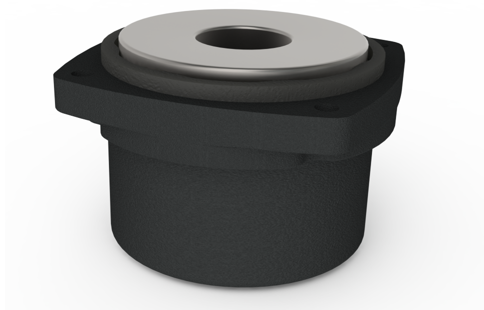
3.2 Stator

The stator in figure 3.1b contains the coil that drives the rotor. The coil and the rotor is separated by a non-magnetic rotor-can. The rotor-can fixates the rotor, and a ceramic bush is located in the bottom to keep the shaft of the rotor centred and locked in place. A rubber ring, also seen in the figure, is located where the stator and the rotor-can touches to ensure a tight seal between the can and the stator.

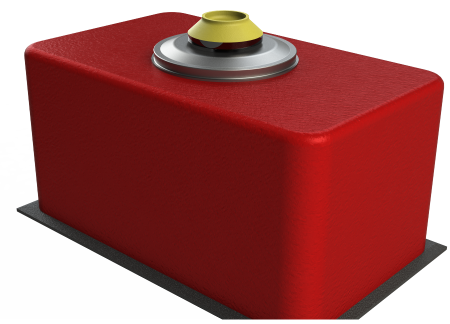
Further in the production line the stator is assembled with a frequency changer, electronic controller and pump house.



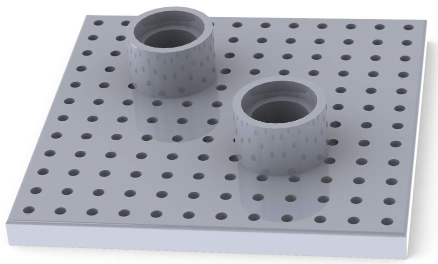
(a) Rotor



(b) Stator



(c) Magnetizing unit



(d) Pallet

Figure 3.1: This figure shows the four main components that takes part in the process of assembling the rotor (a) with the stator (b). The rotor and stator unit is a part of the ALPHA2 pump from Grundfos. The magnetizing unit (c) is used to magnetize the permanent magnet on the rotor. The pallet (d) is holding the rotors on the incoming conveyor.

The stator is not handled by the robot in this assembly process, but there is one constraint. Since the bush at the bottom of the can is made of ceramic it cannot be put under high compression when placing the rotor. Therefore, when placing the rotor it must be dropped the remaining 10 mm so the manipulator does not make any damage to the ceramic parts.

A worksheet with precise measurements can be found on page 17.

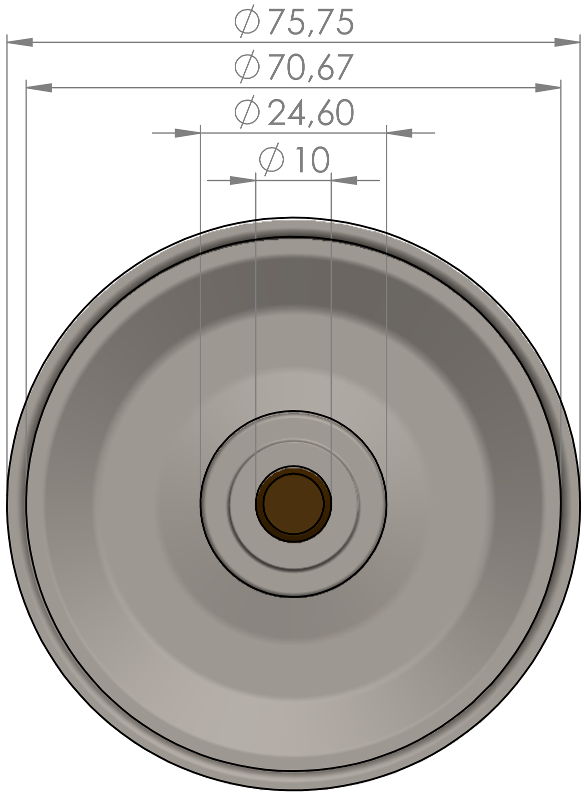
3.3 Magnetizing unit

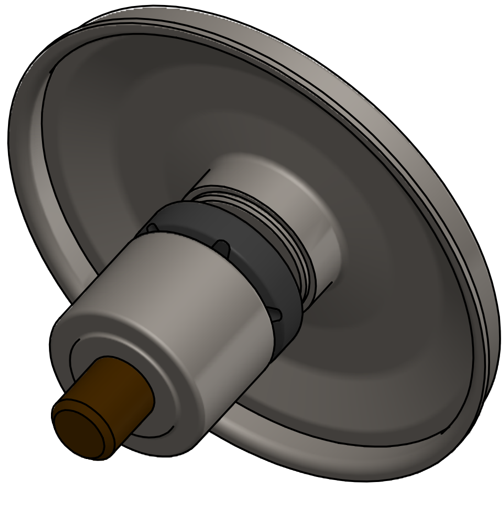
The magnetizing unit in figure 3.1c is where the magnet of the rotor is magnetized. In the device the capacitor is charged up with a high voltage, this voltage is then discharged which generates a magnetic field. It is in this field the rotor is magnetized. [16]

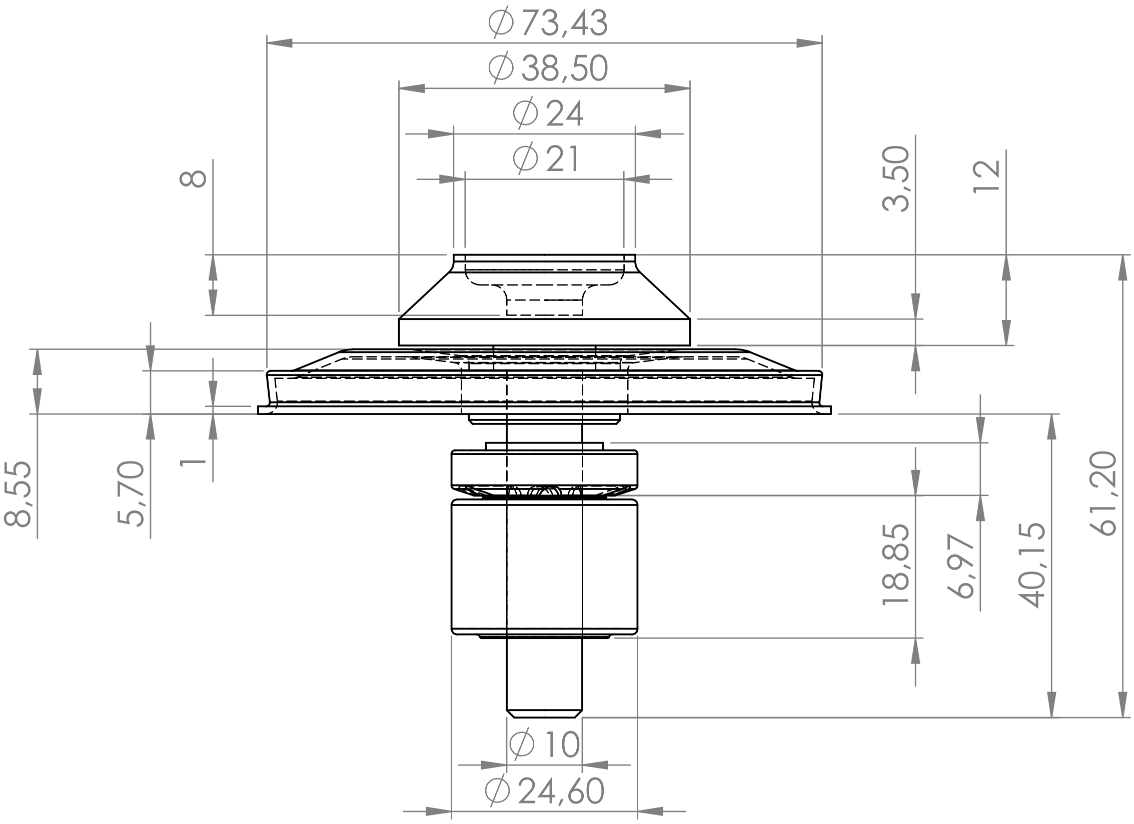
3.4 Pallet

The pallet on figure 3.1d is the platform the rotors arrive on. It is 200x200 mm in size and has two cylinders attached on the diagonal to fixate the rotors. It is made purely of plastic and is secured to the conveyor. The rotors are placed with the plastic mill facing downwards into the cylinders. The design process is described in section 8.3.

Each part handled in the assembly process was described and analysed in detail to discover constraints and other important data. It was discovered that the rotor has a weight of 122,04 grams, which is of importance when choosing the manipulator to handle it and designing the tool to grip it. In addition, the robot should not grip the magnet of the rotor and the rotor must not be forced into the stator because of the ceramics in the rotor and stator.







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Rotor assembled Worksheet

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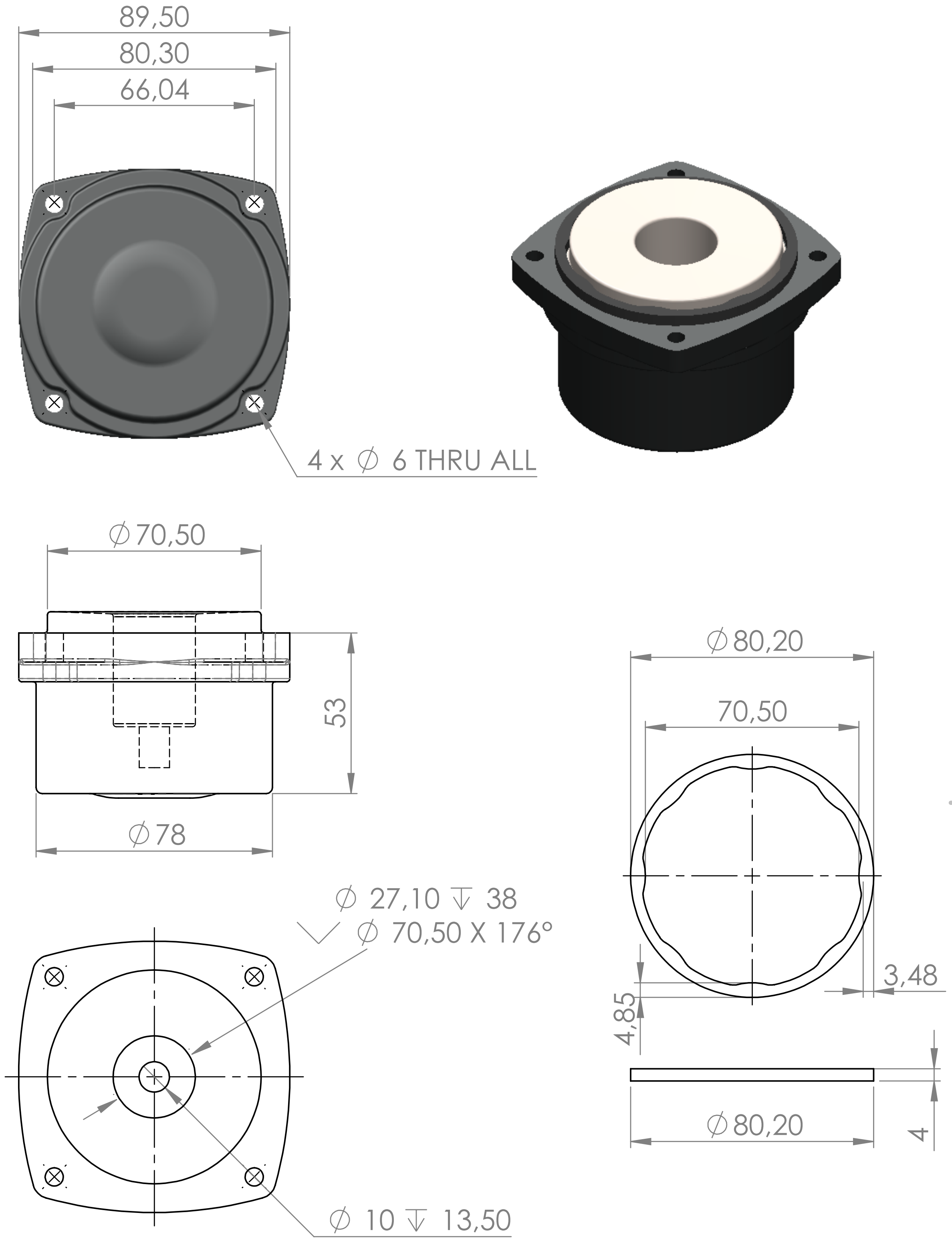
SHEET 1 OF 1



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SHEET 1 OF 1

Chapter | 4

Robot types

This chapter analyses 9 robots of 3 different types namely 6R serial chain, SCARA and parallel. The chapter examines how the different types of robots are either suited or ill-suited for the task.

Robotic manipulators come in many types, forms and variations. They all have different properties suited for different tasks. In order to figure out what type of manipulator that is best suited to deal with the problem in this project, it is necessary to know the differences between them. Three common types are: A 6R serial chain manipulator, a SCARA and a parallel link. To get some general data about speed, repeatability, reach etc. multiple models of each type are examined. Table 4.1 on the facing page lists nine examined manipulators. They are categorized in the three common types.

Each type of manipulator comes in multiple sizes with different payloads and reaches, but the manipulators investigated are of similar sizes making them easy to compare. The reason for not comparing manipulators of different sizes is that the flexibility, speed, repeatability and degrees of freedom does not scale or improve with size. It is exactly those parameters that are important when it comes to selecting the right type of manipulator.

The information gathered from the nine examined robots in table 4.1 on the next page is analysed and the information is put into the table 4.2 on page 20. Table 4.2 also lists some general pros and cons of each type.

As analysed in section 2.1, the rotors arrive upside down in relation to how they are oriented in the final assembly. That means the rotors need to be rotated somewhere along the way in the assembly process.

Kinematics show that in order to orient the end-effector in every possible direction, at least 6 degrees of freedom is needed. With that said, it can be concluded that the 6R serial chain manipulator is the only type that can solve the task by itself.

Making an advanced end effector for the SCARA could add an extra degree of freedom, making it able to rotate the rotors as required. This addition would make it possible to use a SCARA robot for the task.

The parallel robot type will not be practical to use since the movements are limited to XYZ with no or very little rotation around the axes. Adding an advanced end-effector with extra degrees of freedom would be impractical compared to implementing another robot type. A specialised mechanism that rotates the rotors before the manipulator gets to handle the rotors could be used. That way the manipulator does not need to take care of the rotation. Then both the parallel and SCARA types can be used.

Still the 6R serial chain robot is more practical because of its 6 degrees of freedom, and since it also can be made capable of handling two rotors at the same time. If an extra gripper is added, the manipulator might work even faster and have a more effective cycle. This will be discussed in chapter 5 on page 21 about cycles. Another advantage of choosing a 6R serial chain manipulator is its adaptability. If the orientation of rotors or stators change the manipulator is able to adapt through reprogramming without any major expenses.

The analysis of the 3 different types of manipulators, showed that the 6R serial chain manipulator is a feasible choice since it can rotate the rotors giving them the correct orientation. In addition, it has an excellent ability to adapt to changes in the production sequence.

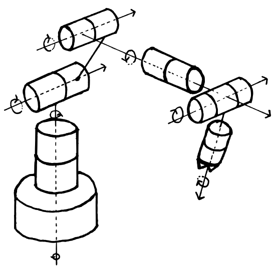
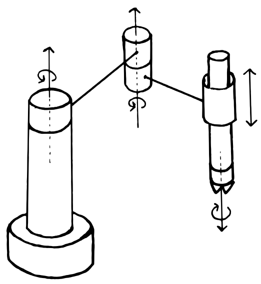
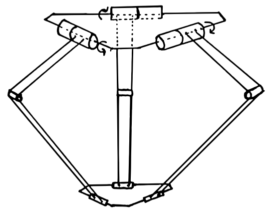
Examined robots

Table 4.1: This table lists the nine examined robots. The robots are categorized in three types, namely 6R serial chain manipulator, SCARA and Parallel link. The robots are examined in order to provide data for table. 4.2 on the following page

Type	Manufacturer	Name
6R serial chain manipulator	Denso	NY VS-087
	ABB	140/IRB 140T
	Adept	Viper 6-axis robots
	KUKA	KR6 R700 sixx
SCARA	Adept	eCobra
	Denso	HM-4070*G
	ABB	IRB 910SC
Parallel link	Adept	Quattro s650H
	ABB	IRB 360

Robot types

Table 4.2: This table lists three different types of robots and their different abilities.

	 **6R serial chain manipulator**	 **SCARA**	 **Parallel**
Definition	Multiple rotational joints in continuation of each other	"Has three parallel revolute joints[...], with a fourth prismatic joint for moving the end-effector normal to the plane."[4]	"Closed-loop kinematic chain mechanism whose end-effector is linked to the base by several independent kinematic chains."[17]
Reach	From base: Min 707 mm Max 912 mm	From base: Min 450 mm Max 800 mm	Diameter: Min 1300 mm Max 1600mm
Speed	Min 0.36 s Max 0.77 s 25/300/25 mm	Min 1.02 m/s Max 2,7 m/s	0.40 s 25/300/25 mm
Repeata-bility	$\pm$0.03 mm	Min $\pm$ 0.015 mm Max $\pm$ 0.020 mm	$\pm$ 0.10 mm
Degrees of freedom	6	4	4
Payload	Rated 3 kg Max 6-7 kg	Rated 2-3 kg Max 5.5-10 kg	Rated 1-2 kg Max 6 kg.
Other	Very flexible, adaptive and versatile.	Often a cheap solution. Can be mounted on both the ceiling and floor.	Very stiff. Mounted on the ceiling.

Chapter 5

Analysis of possible cycles

This chapter looks into the parameters found in the process of assembling a rotor with a stator. In the chapter, four different cycle algorithms will be presented and analysed to see which of the four that is best suited as a solution

5.1 Analysis of given cycle times

The cycle time consists of all parameters running in a consistent frequency and order. For the problem dealt with in this project, the ingoing conveyor will deliver two rotors every 8^{th} second, and another outgoing conveyor will supply a stator every 4^{th} second. The conveyor belt will stop and wait until the rotors are picked up, which means the manipulator can pick the part up from the same spot consistently. Part of the task is to make this pending time as low as possible. Another parameter is found in the magnetization process. Experience from Grundfos has shown that the magnetization of the rotor takes two seconds while the cool-down time afterwards takes 15 seconds. In addition, there is the quality assurance that will be conducted on approximately every 50^{th} magnetized rotor, which means the manipulator, at an unknown time, suddenly has to put aside a rotor on another conveyor belt instead of the usual assembly with a stator. The quality assurance results in magnetized rotors returning to the work cell at unknown frequencies, which means the robot has to adjust its cycle to put the inspected rotor into a stator. Table 5.1 gives an overview of the cycle times mentioned.

Overview over the frequencies

Table 5.1: This table shows the frequencies of rotors and stators as well as the process times for the magnetizing unit.

2 rotors	Every 8^{th} second
1 stator	Every 4^{th} second
Magnetization process	Approximately 2 seconds
Magnetization cool-down	15 seconds

5.2 Different cycle approaches

The procedure of grabbing a rotor, magnetizing it and putting it into a stator can be solved with different algorithms. The order in which the intermediate tasks of the algorithm are done needs to be determined after each task has been analysed to find the best and most efficient algorithm. Below, four possible algorithms are analysed as a thought experiment. This gives a rough estimate of which algorithm is the fastest. Additional calculations will be made in the development part to confirm or disprove the theories of this thought experiment.

When calculating how long each subtask takes, a term "pick and place" is used. This is understood as the time it takes to align the end-effector with a start target and activate the gripping mechanism, plus the time it takes to align the end-effector at the end target and deactivate the gripping mechanism. The time it takes to do a movement between the start position and end position is calculated separately.

Looking at the cycle times it can be seen that the manipulator has to assemble a rotor and a stator every 4^{th} second. For this reason the goal is to have at least one assembly done every 4^{th} second with one of the following cycles:

1^{st} cycle
A flowchart of the 1^{st} cycle approach can be found in figure 5.1 on page 26, and the steps are described in the following text.

In this approach the manipulator picks up one rotor and keeps holding on to it throughout the whole cycle until it is assembled with a stator. As seen in table 5.1 on the preceding page it takes two seconds to magnetize a rotor. Hence, with this approach the manipulator has to wait two seconds at the magnetizing unit. That means the remaining tasks done throughout the cycle e.g. picking up, moving and placing the rotor into a stator has to be done in the remaining two seconds. In these remaining seconds the manipulator will then move the rotor from the magnetizing unit to the output conveyor, and put it into the stator. Right after this step, the manipulator moves to the "grab rotor" position where it will grab a rotor, thereafter the cycle will start over.

The manipulator has to move 180 degrees two times i.e. from the input to the output conveyor and back again. The manipulator used for testing in this project (KUKA KR6 R700 sixx) is capable of turning 360 deg/s [18] around its base meaning that, theoretically, the movement back and forth can be done in just over one second. This means there is under one second left for pick and place since the calculation has to take the two seconds of magnetization into account. This cycle approach will, as a minimum, take up all of the four seconds available for one cycle.

2^{nd} cycle
Another cycle approach is to release the rotor into the magnetizing unit as an intermediate step. Figure 5.2 on page 27 shows a flowchart of this cycle approach, which can be followed for easier understanding.

In order to get the main cycle started, a few initial steps has to be executed: The manipulator will move one rotor to the 1^{st} magnetizing unit and leave it there while it is being magnetized. The cycle is now ready to start.

The manipulator will pick up a 2^{nd} rotor from the conveyor and place it in the 2^{nd} magnetizing unit. Immediately afterwards the manipulator will pick up the 1^{st} rotor from the magnetizing unit and place it in a stator. When the 1^{st} rotor is placed the cycle completes and can be repeated.

Assuming the magnetizing units are placed in the middle between the two conveyors, the cycle has a total of 360 degrees of rotation around its center, and includes two times pick and place of rotors and one magnetization. Since the two seconds used on magnetization is independent of the movements, they can be left out of the cycle time calculation. If the assumption is that a pick and place takes one second, and the rotational movements between the conveyors take one second, the theoretical cycle time is approximately three seconds.

3^{rd} cycle - A double gripper cycle
Another approach is to have a different end-effector, a double gripper, which will be able to hold two rotors at the same time. When having a different kind of end-effector the cycle will be different from the others, though similarities can be drawn. A flowchart of the cycle can be seen in figure 5.3 on page 28.

This cycle functions much like the 1^{st} cycle where the rotor is held in the magnetizing unit. The difference to this cycle is, instead of grabbing one rotor in the start, the manipulator picks up two rotors, one at a time, moves them to the magnetizing units and then releases one rotor into the magnetizing units while the other rotor is held by the gripper throughout the magnetization process. Describing the cycle furthermore, the manipulator waits two seconds till the rotors have been magnetized, then grabs the one it had released previously. The cycle ends when the rotors have been placed into the stators and the manipulator is moved to the "grab rotor" position.

Throughout the cycle the manipulator grabs and releases the rotors two times as well as move two times. Assuming the pick and place takes two seconds instead of one and moving 360 degrees will take about one second, the total cycle time should in theory be seven seconds because the magnetization of two seconds also has to be included.

4^{th} cycle - A double gripper cycle
In this cycle the manipulator picks up two rotors in the beginning, one at a time. Like the 2^{nd} cycle this cycle has an initialization cycle in order to get the main

cycle going. As with the 2nd cycle, the manipulator will release the rotors into the magnetizing units as an intermediate step and go back to get new rotors. Without a queue for this cycle, some time will be spent waiting for rotors as it is every 8th second a new pallet will arrive, allowing the manipulator to continue the cycle.

A flowchart of the following description can be found in figure 5.4 on page 29. The initialization cycle starts out by grabbing two rotors from a pallet and moving them over to the magnetizing units in which they are released into, one at a time. It is at this step the initialization cycle is done and the manipulator moves over to the input conveyor and awaits a new pallet with rotors. When the rotors arrive the manipulator grabs and place the rotors into the remaining magnetizing units. Afterwards the manipulator moves to, and grabs, the two previously placed and now magnetized rotors. At the output conveyor, two stators will be waiting in queue due to the initial waiting time from before. These will be assembled with the magnetized rotors one at a time. This completes the cycle and iterations will start.

Assuming that the same pick and place time applies for this as in the 3rd cycle, an approximated calculation of the cycle time for the 4th cycle will result in around five seconds. That is because the manipulator moves two times and picks and places the rotors two times.

Evaluating the cycles
The reason why the 1st cycle is an unfavourable approach is because the cycle time uses all of the available four seconds. One has to bear in mind that the calculations do not include the time it takes to put a rotor to the quality assurance conveyor, and if this is done the cycle time will exceed the four seconds.

With a cycle time of three seconds on the 2nd cycle, it can be deduced that with four magnetizing units, one magnetizing unit only has 12 seconds to cool-down. In order to increase productivity and keep up with the available four seconds, a 5th magnetizing unit must be implemented.

The same fact applies to the 3rd cycle and the 4th. They seem to be pretty fast even if quality assurance is included, but the cycles will not be able to continue after two cycles. The reason for this is the cool-down of the magnetizing units. In order to continue, two additional magnetizing units must be implemented for these cycles.

It can be deduced that the bottleneck of this production is the magnetizing units because of their long cool-down. Nevertheless, the overall conclusion is that the 1st cycle will be disadvantageous to choose and that the 2nd, 3rd and 4th cycles will be possible if one or two magnetizing units are added to the cell set-up. However, it is the 4th cycle that is the fastest of them all from this estimate.

Throughout the process of assembling a rotor with a stator there were four parameters: Every 8th second two rotors will enter the work cell and every 4th second one stator will *enter the work cell. The magnetization of the rotors takes two seconds and the magnetizing unit has a cool-down of 15 seconds. With these parameters taken into account, four different possible cycle algorithms were made, and evaluation of these cycles show that the 4^{th} cycle is the fastest.*

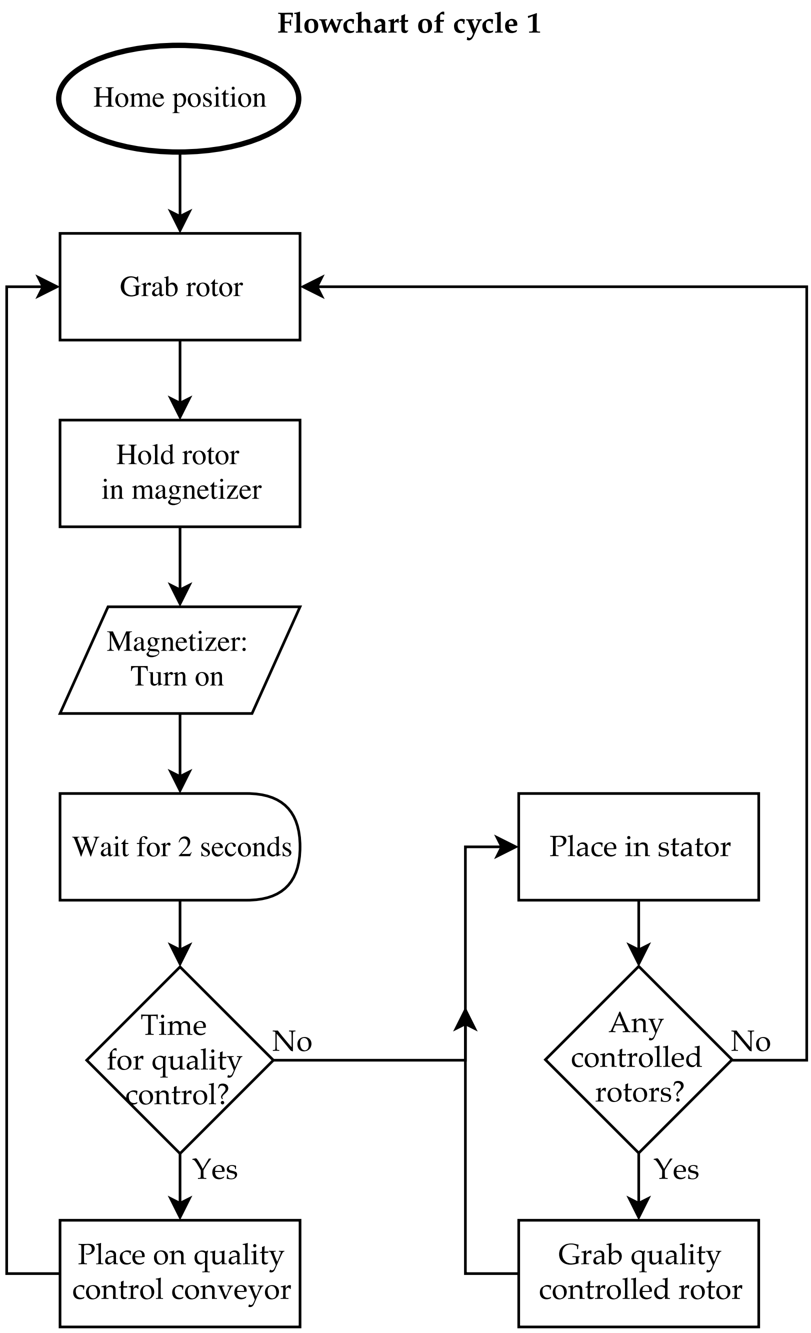


Figure 5.1: The first approach to a cycle.

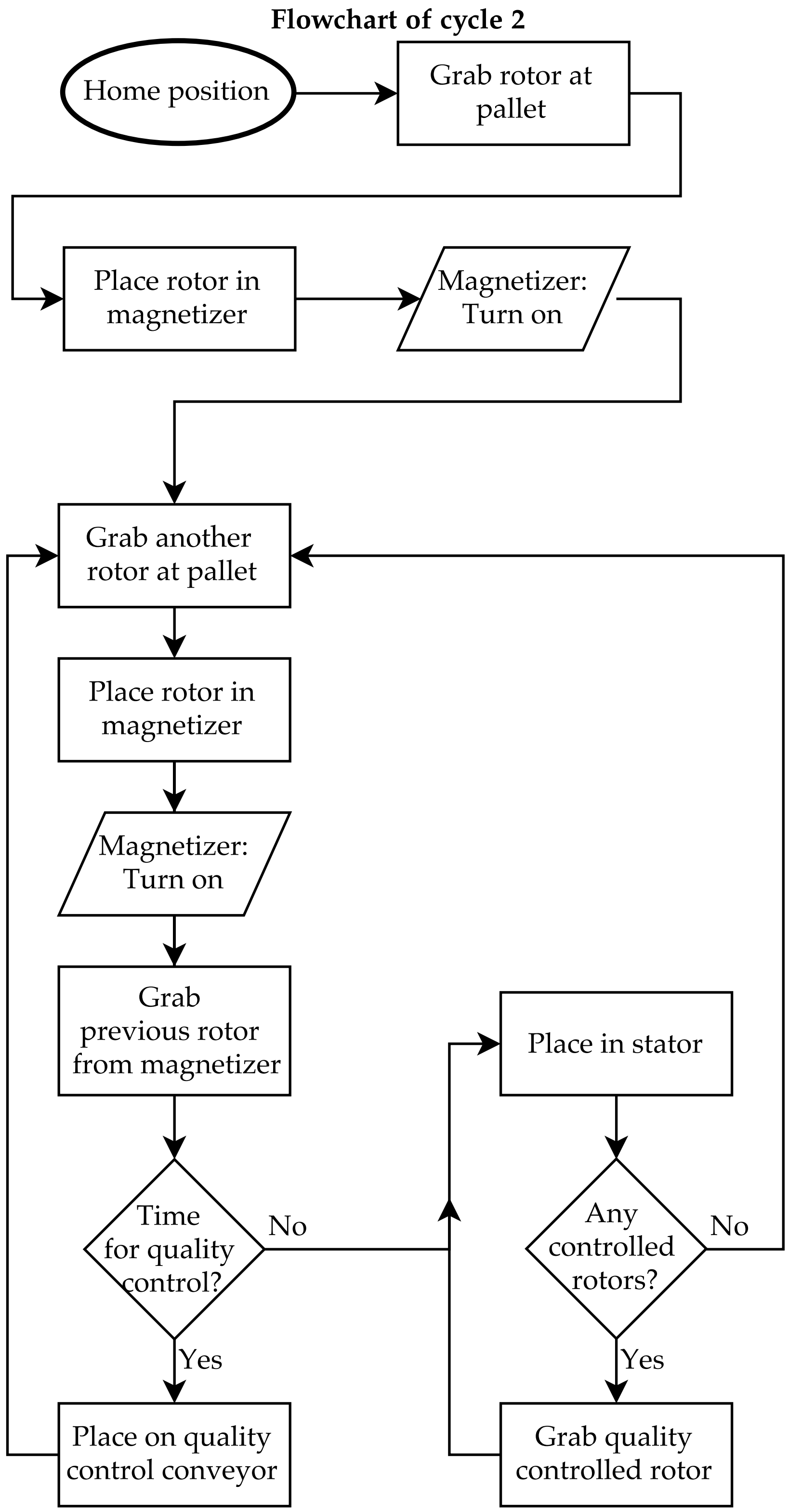


Figure 5.2: The second approach to a cycle.

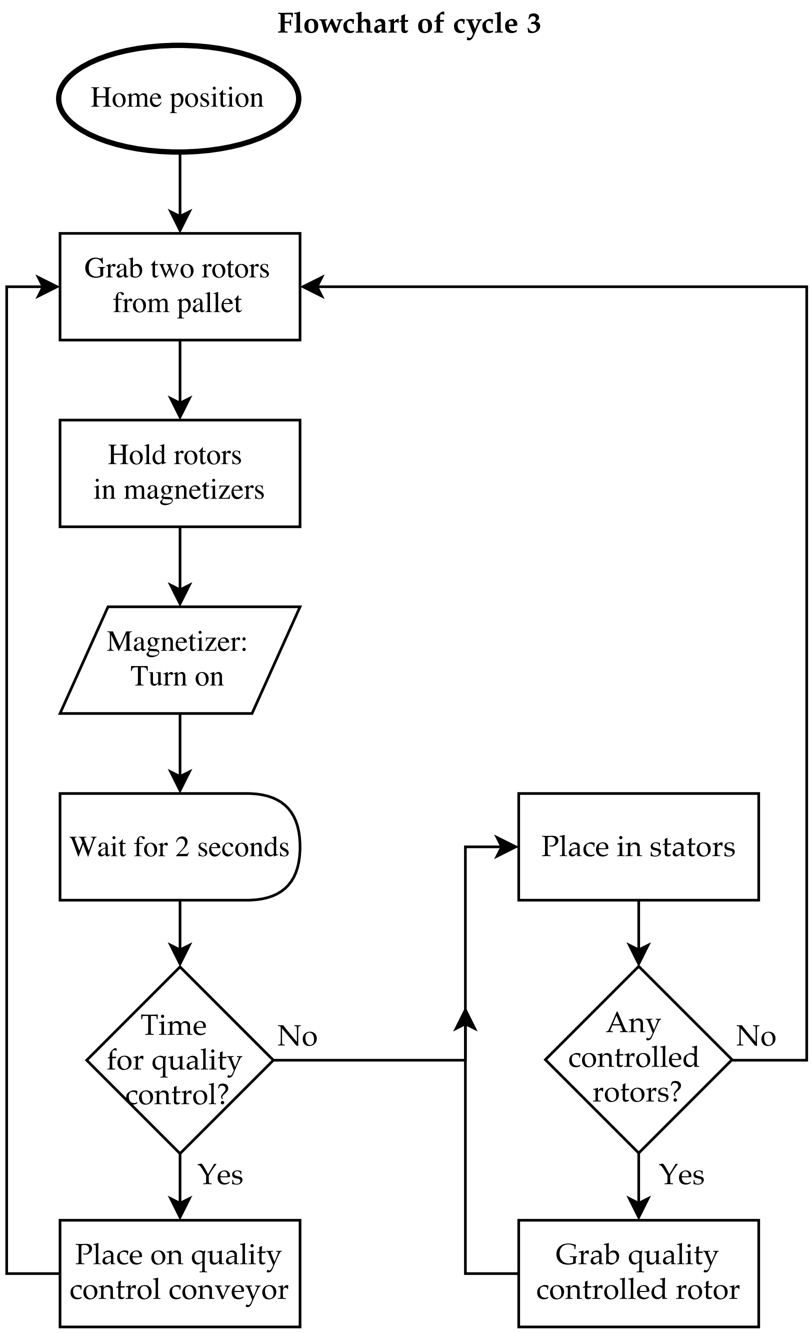


Figure 5.3: The third approach to a cycle

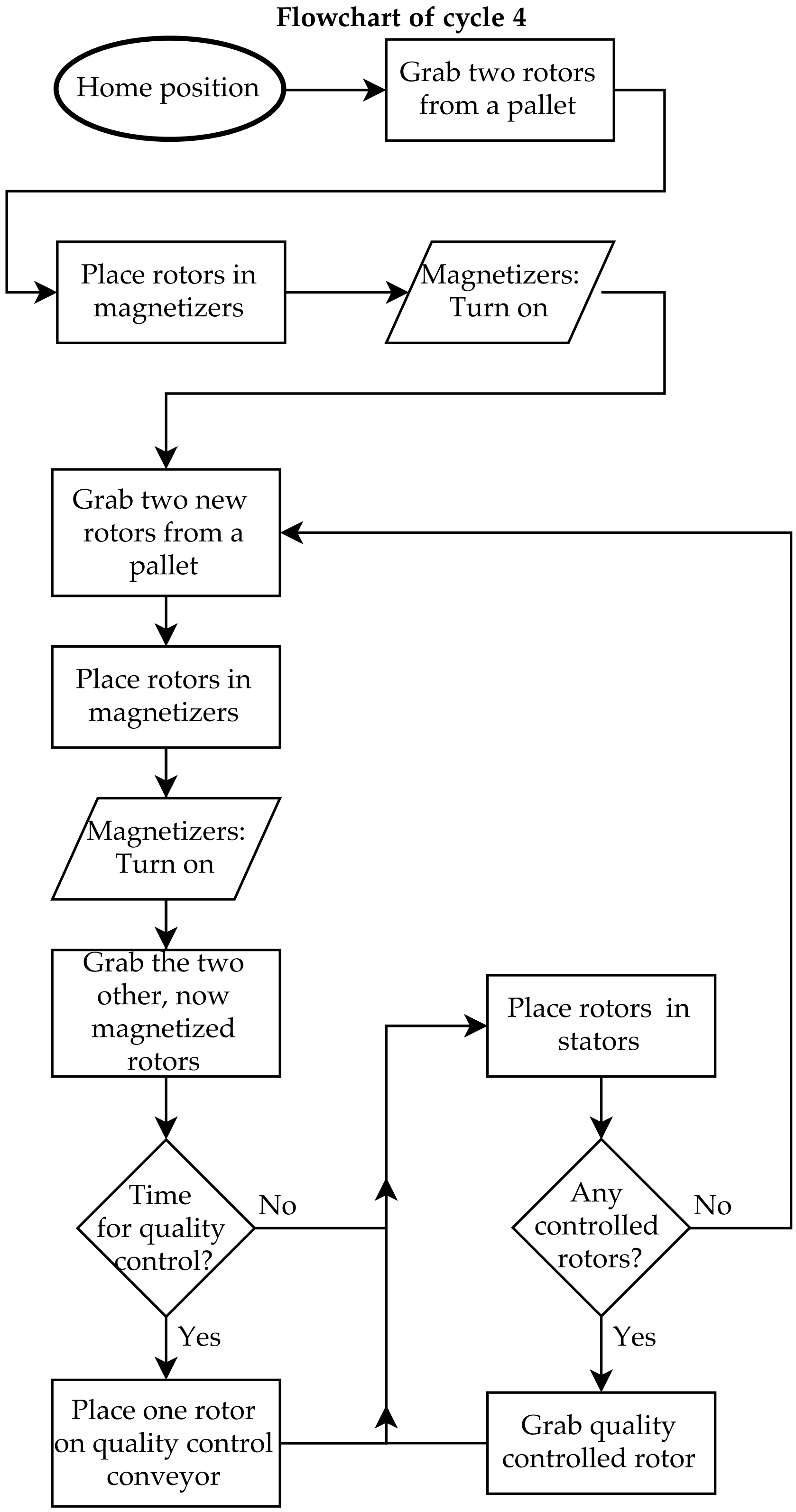


Figure 5.4: The fourth approach to a cycle

Chapter 6

SAFETY AND REGULATION

Robot systems have to conform to regulations and it is advised that they are constructed in compliance with certain standards. For this reason, the chapter examines the standards and regulations regarding integration of robotic systems. Furthermore general requirements to machinery in industry are investigated briefly.

6.1 European Machinery Directive

Industrial manipulators in Europe are by definition encompassed by the European Machinery Directive, which means that they have to comply with the regulations in this directive. Complying with the regulations in the European Machinery Directive as well as other associated harmonized standards will generally speaking approve machinery for the CE mark. However, as industrial manipulators are only defined as partly completed machines, these cannot be CE approved by themselves i.e. when they are not part of a functioning working cell. In turn this means that robot systems can be CE approved when the European Machinery Directive and its associated standards are followed. [19]. The CE mark assures the user of the fact that the product fulfils safety requirements and takes environmental considerations. Among many other things, the machinery directive lists health and safety requirements regarding protective equipment, operating systems and the workplace. As for workplaces it states that if a robot is used in a hazardous environment or the robot makes up a hazard by itself, protective measures must ensure safety and acceptable working conditions for the operator[20].

In regard to the operating system of the robots, the directive specifically states that foreseeable human errors must not lead to dangerous situations. Hardware or software errors must not lead to dangerous situations either[20].

6.2 The Danish Working Environment Authority

The Danish Working Environment Authority has listed a set of guidelines to the set-up of robotic work cells, which also applies to this project. The most relevant guidelines for this project are mentioned below.

- External disturbances e.g. electromagnetic fields, moist, temperature etc. must not interfere with the safety functions of the system.
- When the operator, after a breakpoint in the production, enters the safeguarded area in the work cell, a safety feature must send a stop signal. After restart, the work can continue from the breakpoint.
- Machinery must have the ability to be stopped in a fast and safe way through an emergency stop if uncontrolled and hazardous situations occur. The emergency stop must function in all operating modes, even if the work cell is partially deactivated. The emergency stop must be permanently installed and must, when initiated, remain in stop position until manually reset.
- Safety Distances, fixation and surveillance must be in compliance with the Danish Working Environment Authority's guidance regarding machines and machinery. During the construction of the work cell precautions against blinding, radiation, tossing of elements etc. must be taken.
- Access doors to the robot system must be electrically monitored and the height of the surrounding fence should generally be 1,8 meters of height in the case where ejection of objects is a possible danger. The fence can have a clearance of 0,3 meter off the floor.
- Pressure mats and contact plates must be placed in front of and in the hazard area, in such a way that it is impossible to stride over them.
- The safeguarded area must be clear of persons and the safety equipment must be functioning before automatic operation is initiated.

Reference [21].

6.3 DS/EN ISO 10218-2: 2012

ISO (the International Organization for Standardization) is a global union of national standardization organizations. International standards are created by technical committees and the committee behind ISO 10218:2012 is ISO/TC 184, subcommittee SC 2, *Robots and robotic devices*. ISO 10218:2012 consists of two parts:

1. Robots
2. Robot systems and integration

This section is only concerned with part 2 as it is of highest importance in relation to this project. Excerpts from the most relevant paragraphs in the standard are listed below.

- The tool must withstand expected stress loads throughout its estimated lifespan.
- The tool must be securely fastened.
- The tool must be mated correctly with the mounting flange.
- Forces created between the tool and the load must lie within the load capacity of the manipulator.
- Before the robot system is set in operation, the tool center point (TCP) must be calibrated by means of the offset feature provided by the manufacturer.
- Protective measures for perimeter security must be implemented by means of fencing or sensitive safety equipment. When setting up the perimeter security, every potential hazard source inside the protected area must be taken into account not just the ones stemming from the robot system.
- All fencing must perform under the regulations of ISO 12100 and ISO 14120. Interlocking devices connected to the fencing must comply with the regulations in ISO 14119.
- If practically possible, the set-up must allow operator tasks to be carried out outside of the safeguarded area.
- Permanent entries to the work cell, designed according to frequency and ergonomic aspects of the task, must be provided.
- Control devices should be placed closely to the entries, so that they are easily accessible to the operator.
- Doors must be able to open all the way and an escape route must always be accessible despite of mounted electrical cabinets, also when the doors of the cabinet are opened. This implies that the remaining size of the doorways cannot be of less than 500 mm when the cabinet doors are open.
- On locations of input and output conveyors, safety measures must prevent that employees get unnoticed access to the danger zone. Therefore, the dimensions of openings for material input and output should be reduced to the minimum size necessary for materials to enter the cell.

Reference [22].

The standards and legislative requirements mentioned in this section either should or must be fulfilled when the robotic work cell for Grundfos is designed. By following the guidelines from the Danish Working Environment Authority as well as the standards and *requirements from ISO 10218-2, the work cell should be qualified for the CE mark and be permitted for use in Danish industry.*

Chapter 7

Requirements specification

To solve the task given by Grundfos a set of specific requirements must be listed to guide the development of the robot system solution. All the requirements will be based on the problem analysis.

7.1 Purpose

The purpose of defining specific requirements is to guide the development phase, thereby ensuring that the final solution is able to perform as desired, and after development they can be used to evaluate the solution.

7.2 Scope

This project focuses on the process of assembling a magnetized rotor with a stator. Due to the well defined requirements from Grundfos regarding the layout of the robotic work cell, the project is not focusing on work cells of different sizes nor different configurations of equipment within the cell. Currently Grundfos has a collaboration with the robot manufacturer KUKA, meaning that the concept for the final solution should involve a KUKA robot. However, KUKA robots will not be part of the simulated solution, instead it will be simulated with an ABB robot through the offline programming software RobotStudio. Moreover, this requirement specification will not take every external system and their characteristics into account when creating requirements for this system. However, the requirement specification will show awareness for some external interfaces in section 7.7.1 and 7.6. The requirement specification will not list requirements specific to the predetermined equipment in the work cell, e.g. magnetizing units and conveyors.

7.3 Overview

This chapter will present requirements for the robot system regarding external interfaces, functions, performance as well as some design constraints. Requirements for external interfaces are concerned with how the robot system will interact with every other system in the production. Functional requirements refer to the functions of the robot system and thereby also the actions the manipulator has to perform in order to handle the input and produce the output. Performance requirements are numerical requirements, which are expressed in measurable terms and relate to the static and dynamic performance of the robot as well as the overall system while design constraints, in this project, only involve adherence to standards and regulations.

7.4 Constraints

The development of the robot system is restricted by different factors. It must comply to the overall ALPHA2 production line, e.g. the Enterprise Resource Planning (ERP) of Grundfos and certain safety standards and requirements must be followed as well.

7.5 Assumptions and dependencies

The requirement specification below is dependent on the work cell set-up from figure 2.1in chapter 2 which has been provided by Grundfos. Everything but the magnetizing units and the conveyor for quality assurance is fixated and if Grundfos change the set-up and dimensions of the work cell, the requirement specification will have to be modified as well. Other requirements are dependent on the equipment used by Grundfos, e.g. the magnetizing unit. A change to the equipment will require a change in the requirement specification as well. Performance requirements for the gripper of the manipulator are not mentioned as there are multiple ways to design the gripper and, the design will depend heavily on the choice of actuator as well. Functional requirements are given instead so that specific design details can be discussed in the development part of the project.

7.6 Apportioning of requirements

Additional requirements regarding external interfaces of the robot system would need to be specified in a complete and unambiguous way if the system was to be implemented as a part of the ALPHA2 production line.

7.7 Specific requirements

7.7.1 External interfaces

(a) The robotic system shall use either 230V or 400V connections as power supply.

(b) Network protocols must be able to work together with the existing systems at Grundfos.

(c) The robot system must be able to read RFID-tags on the pallets to get information about the incoming rotors.

7.7.2 Functional requirements

(a) According to section 2.1 the work cell must be equipped with a conveyor for quality assurance of rotors.

(b) The industrial manipulator shall, when equipped with a gripper, be able to carry out the following tasks:

  (i) Pick up of rotors seen in figure 3.1a from the pallet shown in figure 3.1d and rotate them 180° around a horizontal axis.

  (ii) Insert rotors into the magnetizing units shown in figure 3.1c and afterwards pick them up.

  (iii) Insert rotors into the stators shown in figure 3.1b

  The entire assembly process shall go off as described in detail in section 2.1

(c) All of the above requirements must be fulfilled within a workspace of 4340 X 4200 mm as it was described in section 2.1

(d) The gripper shall be able to centre the rotor every time it is gripped as it was mentioned on page 17 in chapter 3.

(e) According to section 3.1, the gripper on the manipulator shall not grip the rotor on the magnet.

7.7.3 Performance requirements

(a) Manipulator requirements

  (i) The manipulator must be able to rotate at least 180° from conveyor 1 to conveyor 2 in the work cell as seen in figure 2.1.

(ii) The manipulator must have a minimum reach of 1197 mm in order to reach both conveyor 1 and conveyor 2 of figure 2.1.

(iii) The manipulator must have a minimum payload of 122,04 g in addition to the weight of the gripper as this is the weight of the rotor described in section 3.1.

(b) Assembly requirements

(i) As described in chapter 2, there must be a gap of 2 mm between the bearing plate of the rotor and the surface of the magnetizing coil, when the rotor is being magnetized.

(ii) The manipulator must drop the rotor the last 10 mm into the stator to avoid damages to the parts as it was described in chapter 2.

(c) Cycle requirements

(i) As mentioned in section 5.1, the manipulator must, on average, place every 50^{th} rotor on the quality assurance conveyor.

(ii) Every non-magnetized rotor must be placed in the magnetizing unit for two seconds as described in section 5.1.

(iii) The magnetizing unit must cool down for 15 seconds after a rotor has been magnetized as mentioned in section 5.1.

(iv) Given the frequencies in table 5.1 on page 21, the robot system must produce one assembled rotor and stator at a takt time of four seconds per assembled unit.

7.8 Design constraints

The design of the robot system must adhere to the standards and regulations mentioned in chapter6

7.9 Problem formulation

How can a robot system capable of keeping up with a takt time of four seconds or less per assembled rotor and stator be developed in compliance with the above requirement specification and how can this system be simulated through offline programming and afterwards demonstrated through online programming with use of the KUKA KR6 R700 sixx 6R serial chain manipulator?

The requirement specification as well as the problem formulation will guide the development process from this point and onward. After development, testing will show if the requirements have been fulfilled and the conclusion to the project will review how the problem formulation was solved.

Part III

Development

CHAPTER | 8

SOLUTION

This chapter will go into details about the choice of manipulator, design of the work cell, and the thoughts behind it. This is to clearly show how the manipulator and the magnetizing units will be placed in order to fully solve the task from Grundfos. In addition, it will analyse the challenges of designing a gripper along with the different gripping positions which will affect the design of the gripper. Furthermore the design process and evolution of the gripper design will be documented and shown within this chapter.

8.1 Choice of manipulator

The analysis concluded that a 6R manipulator would be favourable for solving the task. 6R manipulators are made in a variation of different shapes and sizes. The manipulator has to cohere with the requirements presented in section 7.7. Grundfos has an agreement with the robot manufacturing company KUKA, therefore a manipulator from KUKA will be featured in this proposal.

The KUKA KR 16-2 is a manipulator that fulfills the requirements which makes it a feasible option for implementation, see figure 8.1 KR 16-2 has a maximum payload of 16 KG, a maximum reach of 1610 mm and is able to rotate enough to move between the conveyors.[23]

8.2 Cell Design

The design of the cell is visualized and simulated in the ABB RobotStudio software. The software has a library with multiple ABB manipulators and controllers. The final solution will use a KUKA manipulator, but for demonstrating purposes a manipulator from the ABB library will be used. The manipulators from ABB and KUKA are very similar, so this will not affect the overall correlation.

The design is derived from the initial requirements set out by Grundfos, and also the requirement specification, which includes the safety regulations e.g. the entrance to the cell must act as an emergency switch. The use of ABB RobotStudio is an effective tool to showcase the idea of the cell design to the customer because it will illustrate exactly how the manipulator can be implemented into an existing system with conveyors. Moreover, it provides the ability to test whether the calculations made on the cycle times are satisfying, or if the estimates are off.

A requirement from the customer was to design a work cell within the given dimensions of 4340 X 4200 mm, also stated in the requirements specification in section 7.7.2 (c). Furthermore, it is not allowed to move either the inlet or the outlet conveyor as stated in the requirements specification in section 7.5. This set some constraints concerning the best possible cycle, but in order to satisfy the customer, the idea must conform to these requirements.

The cycle time calculations are based on the concept of placing the magnetizing units in between the two conveyors and in front of the manipulator, therefore giving the manipulator 90° turns when moving the rotors to the magnetizing units and when moving the magnetized rotors to the stators. The manipulator will then perform a 180° turn when returning back to the inlet conveyor. This will also be the final set-up of the magnetizing units and the manipulator in the work cell as seen in figure 8.2 on the next page.

In order to utilize the manipulator's range most effectively the manipulator will be placed in the middle of the work cell. No matter where the magnetizing units are placed within the work cell, the manipulator will have to do the same amount of rotation, measured in degrees, as long as the conveyors are fixated in their position, so experimenting with different positions of magnetizing units should not be able

KUKA KR 16-2

Figure 8.1: The KUKA KR 16-2 manipulator is capable of solving the task.

to speed up the process of assembly significantly. Figure 8.2 below also shows the complete set-up with inlet- and outlet conveyors as well as conveyors for quality assurance. The leftmost conveyor is the inlet conveyor and the rightmost conveyor is the outlet conveyor.

Five red magnetizing units are placed in between the inlet- and outlet conveyors and the additional two conveyors (green and orange-brown) are used for quality assurance. The quality assurance conveyors are placed next to the outlet conveyor to minimize the manipulator's movements.

All magnetizing units must be placed apart from each other, because the magnetizing units create a magnetic field with a radius of approximately 350mm from the middle. The magnetizing unit is 250 mm in width, which means that the magnetic field will exceed the unit with approximately 100 mm, which is half of the width that will be needed in between the magnetizing units [16].

8.3 Pallet design

The design of the pallet depended on the dimensions and quantity of rotors, which was preset by Grundfos. Therefore, the only factors that were puzzled with was the distance between the rotors and the surface of the pallet as well as the gap between the two rotors on the pallet. Tests of the initial design showed that the bearing plate of the rotor was not placed high enough over the surface of the pallet for the gripper to grip it horizontally. This meant that the pallet had to be

Work cell design in RobotStudio

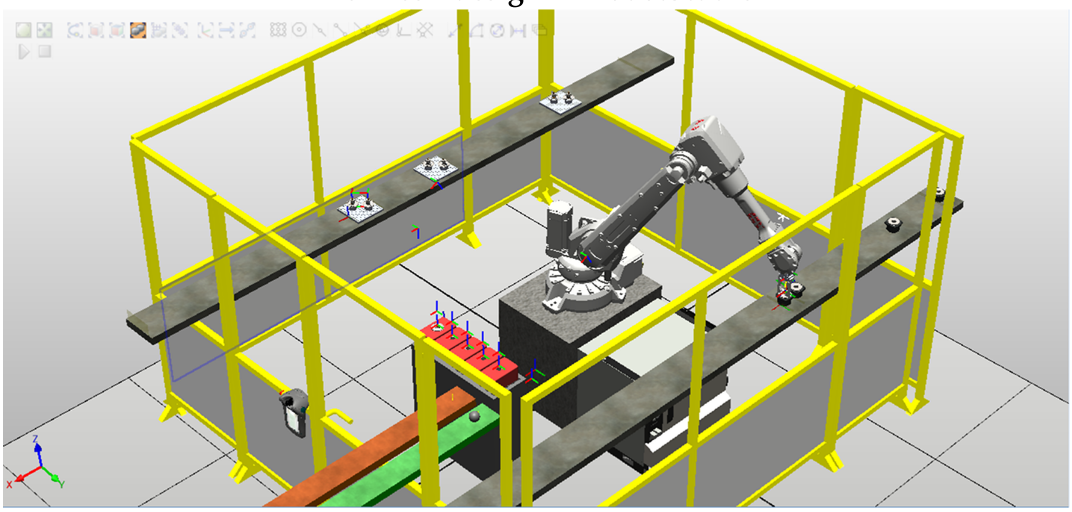


Figure 8.2: This figure gives an overview of the virtual environment made with RobotStudio. The green and orange conveyors are in- and outlet conveyors for rotor quality assurance.

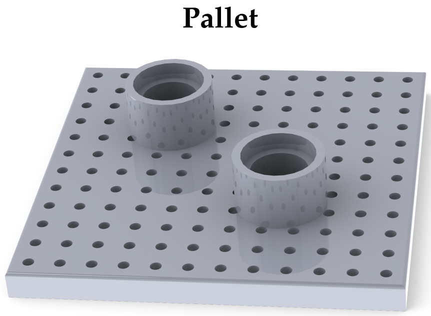


Figure 8.3: The pallet that holds the two rotors.

redesigned with taller cylinders to fixate the rotors. A design that allowed the manipulator to grip both rotors was finalized, drawn in SolidWorks and can be seen in figure 8.3.

It should be noted that implementing this pallet into Grundfos' system might require the pallet design to be adjusted to ensure conformity with other systems in the production. Otherwise, there could be complications and the design of the pallet would be needed to be compromised if the other system is not working satisfactorily.

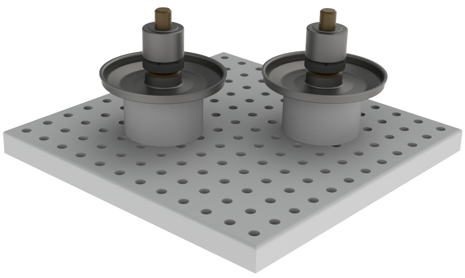
8.4 Gripper Design

The gripper used for this specific task needs to be able to function at certain positions to complete the full cycle.

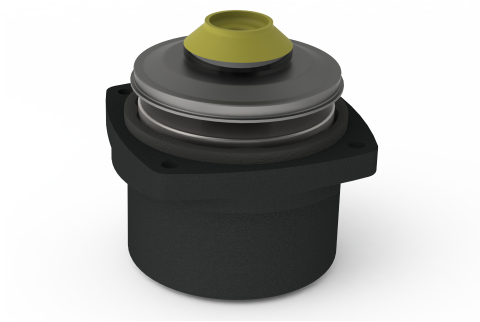
The first position required is located at the input-conveyor, specifically at the pallets where the rotors will be picked up by the gripper of the manipulator. Figure 8.4a shows the pallet with the incoming rotors. The limited space between the rotors and from the rotor cap to the pallet itself must be considered.

After gripping the rotors at the pallet, the manipulator will move the rotors to the magnetizing units and insert them. The gripper should be able to hold the rotors while rotating them 180 degrees upside down on the path to the magnetizing units. When the rotors are inserted into the magnetizing units, the rotor caps are positioned only 2 mm over the surface of the magnetizing units, which limits the ability to grip directly onto the rotor cap. Figure 8.5 shows the rotor inserted into the magnetizing unit.

Lastly the rotors have to be moved from the magnetizing unit and placed into the stators as seen on figure 8.4b.



(a) Two rotors placed on the pallet.



(b) Rotor inserted into the stator.

Figure 8.4: Placement of rotor on pallet and in stator.

Figure 8.5: Magnetizing unit with a rotor mounted.

The initial design idea

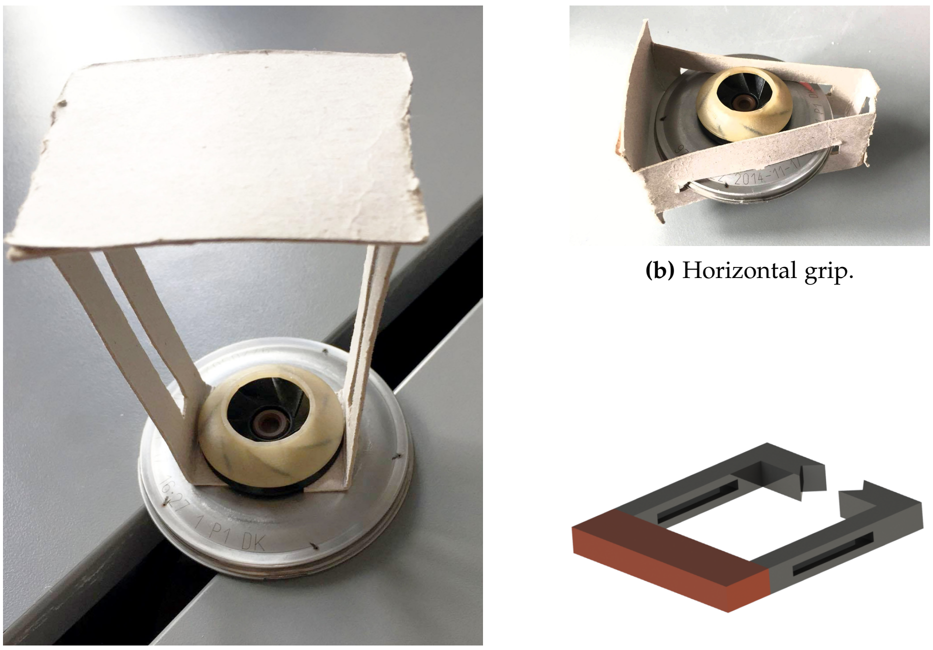
Through analysis of the different positions and rotations the gripper had to be accustomed to, an initial prototype were cut out of cardboard and tested for feasibility.

This prototype of the gripper has two positions where it can pick up the rotor. The first position will be referred to as the "horizontal", the second is the "vertical". Figure 8.6b and 8.6a shows the rotor inserted into the gripper in both the horizontal and the vertical position.

After testing of the prototype the first version was drawn in the CAD program SolidWorks. Figure 8.6c shows the first CAD drawing of the gripper.

This **version 1** gripper has the same characteristics as the prototype with the holes in the sides for the horizontal position. The vertical position has a triangle cut which should capture the plastic mill on top of the rotor. The idea is to scoop the rotor's plastic mill up into a fixed position. The brown part illustrates the actuator. It should be noted that this specific version does not have the correct dimensions according to the rotor. The horizontal position works by moving the gripper arms together capturing the rotor cap in the squared hole.

The **version 2** gripper, seen in figure 8.7b with the rotor in horizontal position and in 8.7a with the rotor in vertical position, has dimensions according to the rotor.



(a) Vertical grip.

(b) Horizontal grip.

(c) 3D sketch.

Figure 8.6: Initial steps of designing the gripper.

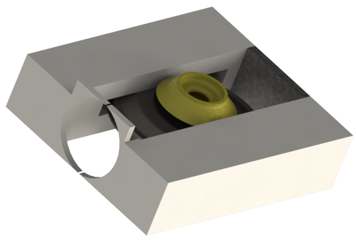
This allows for visualisation through SolidWorks with the rotor attached. The vertical position structure has changed from the previous version into a circle with diameter matching the plastic mill on the rotor. The pressure distributed around the circumference of the rotor mill should create enough pressure to hold the rotor firmly. The dim grey part between the gripper arms simulates an actuator.

The version 2 has a lot of unnecessary material usage and the vertical gripping position is a bit unstable and prone to damages. Figure 8.7c shows where the gripper is weak when pressure is applied to it.

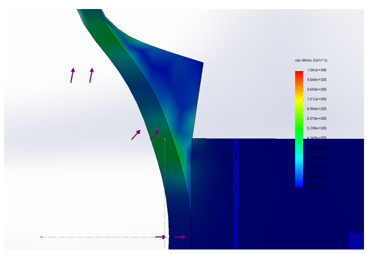
To improve these features a **version 3** was made with improvements regarding these two problems. Version 3 has the same gripping features as version 2 and a more stable vertical gripping position as seen in figure 8.8c. Figure 8.8a and 8.8b shows version 3.

None of the previous versions were attached to actual actuators, so in order to perform laboratory test with a robotic manipulator (KUKA KR6 R700 sixx) the gripper **version 4**, seen in figure 8.9 (b) and (a), was accustomed to be mounted on a GP75-B actuator. This actuator is a pneumatic actuator with 10 mm stroke per jaw. The stroke length will affect the offset required for the rotor to fit into the gripper. The vertical position was changed into a square shape in order to strengthen it even more. The hole for horizontal gripping is changed into a triangle to ensure that

(a) Vertical grip.



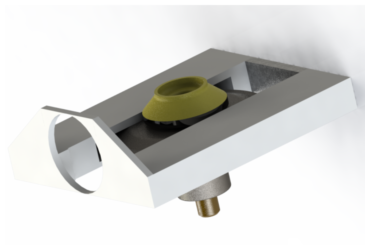
(b) Horizontal grip.



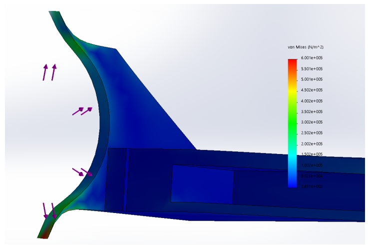
(c) Stress test.

Figure 8.7: Gripper V2.

(a) Vertical grip.

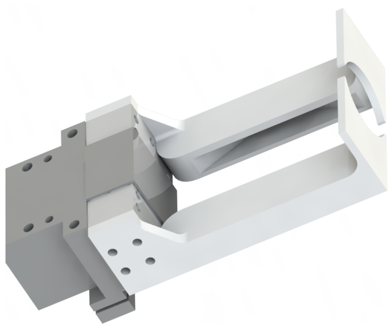


(b) Horizontal grip.

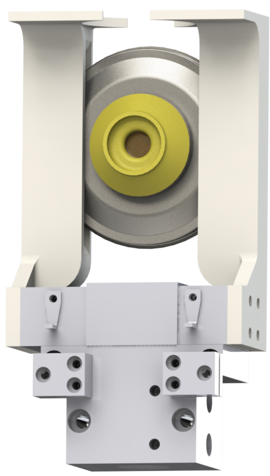


(c) Stress test.

Figure 8.8: Gripper V3.



(a) Gripper V4 mounted on GP75-B actuator.



(b) Horizontal grip.

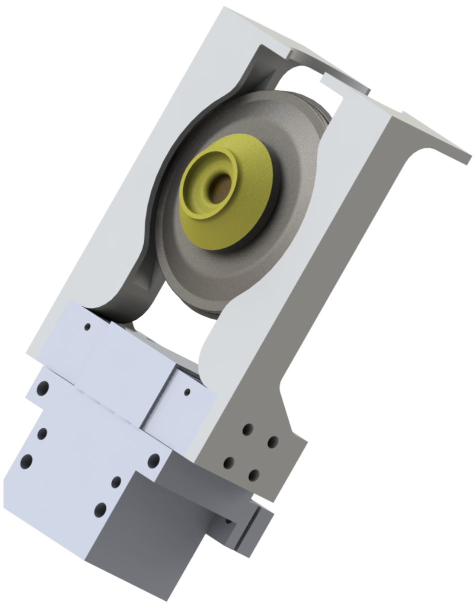
Figure 8.9: Gripper V4.

the rotor cap is securely placed, in a centered position, and thereby no movement occurs. A mounting plate with screw holes has been added so the gripper arms can be attached to the sides of the actuator. Lastly, the gripper was shortened due to the excessive length of the previous designs. This gives the gripper higher tolerances and makes it more compact than the previous versions.

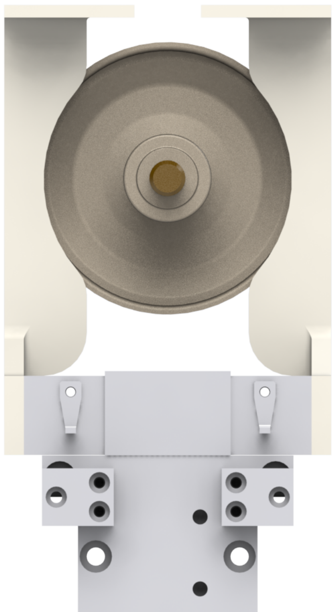
Testing of Version 4 in the simulation software ABB RobotStudio showed that it had some problems when picking up the rotor cap in the horizontal position. The gap between the gripper arms was not wide enough to be lowered around the rotor cap. This problem was accounted for in **version 5** where a cut shaped as a half circle was applied on each gripper arm in order to create space for the rotor cap. In addition, a small amount of the vertical grip's half circle had been cut off in order to avoid collision between the two gripper arms.

This version of the gripper was 3D printed on a MakerBot replica 2X printer in ABS plastic and tested on the KUKA KR6 R700 sixx in the lab. Figure 8.10 shows the gripper attached to the actuator holding a rotor, and figure 8.11shows version 5 attached to the manipulator in the lab.

The horizontal gripping position was tested which showed that the offset was not correct and this resulted in high pressure on the gripper arms causing them to bend when the actuator closed, see figure 8.11b

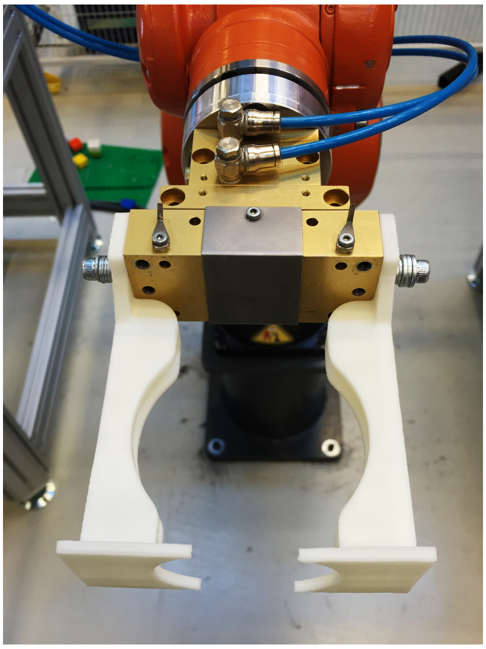


(a) Horizontal grip.

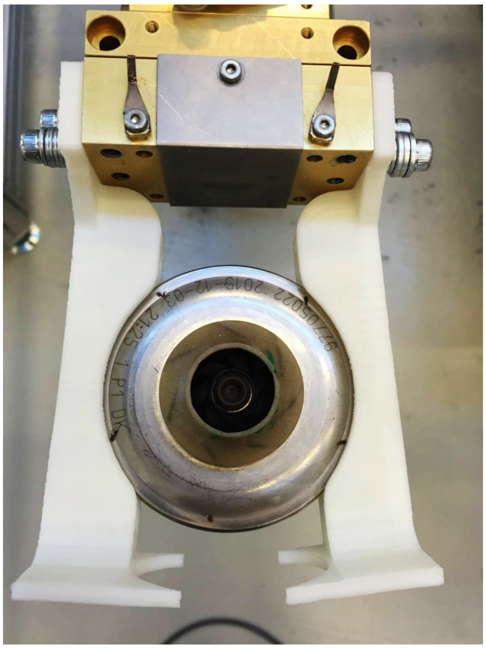


(b) Horizontal grip.

Figure 8.10: Gripper V5.



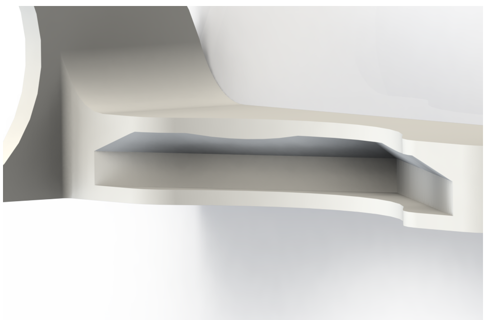
(a) Gripper V5 on GP75-B actuator in laboratory.



(b) Gripper V5 with rotor gripper in horizontal position.

Figure 8.11: Gripper V5 mounted on the KUKA KR6 R700 SIXX.

(a) Gripper V6.



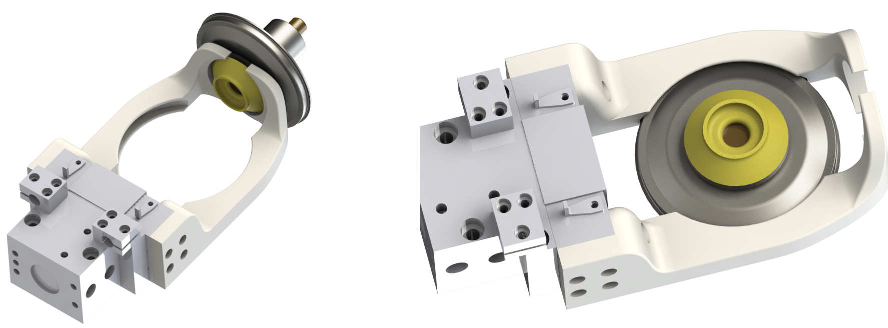
(b) Horizontal hole in with the oblique angled edge.

Figure 8.12: Gripper V6.

To correct these flaws in the design a **version 6** was created which can be seen on figure 8.12a. The mounting plate was thickened in order to decrease the bending of the grippers, when gripping a rotor. Because the mounting plate was thickened, more distance was created between the half circles for the vertical grip, making it impossible to grip the rotor in the vertical position. To compensate for this increase in distance, the half circles of the vertical grip were moved closer to each other. The corners of the vertical grip was altered as well because testing showed that the corners would hit some screws in the pallet used for testing when the gripper had to grip in the horizontal position. Testing showed that when the 5th version of the gripper held onto a rotor it was possible for the rotor to move up and down several millimeters. This design error would lead to the rotor having different positions when being grabbed. In order to counteract this, a small design change led to the insertion of an edge in the triangle horizontal slot, as seen in figure 8.12b

The previous version of the gripper has the triangle shaped hole as horizontal grip. The rotor cap will have two points of contact in the hole due to the triangle shape. This will both affect the wear and tear on the rotor and the gripper. The rotor caps will be exposed to all the pressure on four specific spots and the gripper will over time get damaged on these specific gripping spots. **Version 7** changed the triangle in the horizontal grip to a circle to distribute the pressure across the entire circumference of the rotor cap. Furthermore, additional support has been added to the mounting plate and to the vertical grip to make the mounting more stable and avoid bending of the gripper when the actuator closes. Version 7 can be seen on figure 8.13a with the rotor in vertical position and on figure 8.13b with the rotor in horizontal position.

Stress tests, seen on figure 8.14c, showed that version 7 is strong in the vertical position which had been a problem in previous designs.



(a) Vertical grip. **(b)** Horizontal grip.

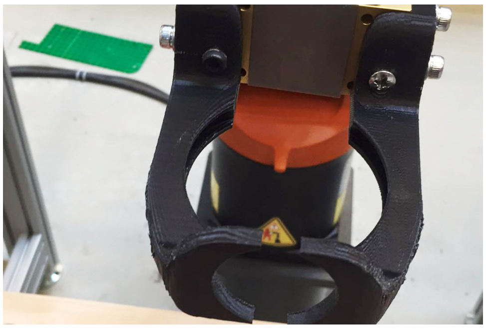
Figure 8.13: GripperV7.

The gripper was printed and attached to the manipulator for testing. Figure 8.14a shows this.

After 3D printing the gripper an additional feature was added. A piece of rubber was attached to the vertical gripping position to give it some padding which will alleviate some stress on the rotor mill and give it a tighter grip. Figure 8.14b shows the vertical position of the 3D printed gripper with the rubber added.

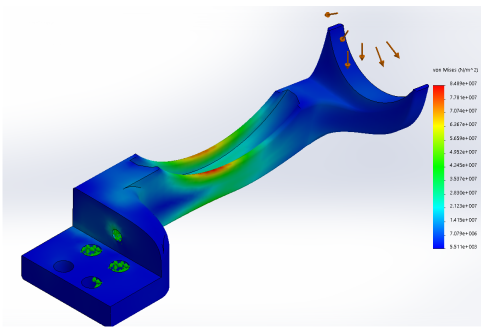
As calculated later in section 9.1, adding two grippers the manipulator will improve the cycle time with 0,8 seconds pr. assembled unit. A proposal for how a double gripper could be added can be seen on picture 8.14d

The KUKA KR 16-2 was chosen as a manipulator for the conceptual solution. The proposed work cell design was presented along with an elaboration of the choices made for placements of equipment within the cell. Furthermore, this chapter described the ideas and challenges behind the design of a pallet applicable to this project. The design of the gripper evolved through analysis, testing in simulation programs and in the lab. The final gripper version

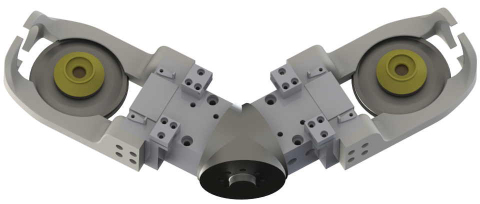


(a) Gripper V7 attached to GP75-B actuator on manipulator.

(b) Vertical with rubber attached.



(c) Stress test.



(d) Double gripper.

Figure 8.14: Gripper V7 and the double gripper configuration

proved to be feasible through testing in the laboratory. The designed gripper will be implemented in RobotStudio for simulation and also used in the laboratory for the cycle testing and demonstration.

Chapter | 9

Lab testing, programming and results

This chapter describes the tests conducted in the laboratory along with their results. It also explains simulation and offline programming in RobotStudio. Lastly the results are tested for compliance with the requirement specification.

9.1 Cycle calculations

Evaluation of the calculations made in section 5.2 on page 24, show that using a double gripper, more accurately the 4th cycle, gives the fastest cycle time and the largest buffer time. In the interest of calculating on the cycles with correct times for movement and pick and place, a test was conducted in the laboratory. Figure 9.1 on the next page show the set-up.

The manipulator was programmed to grab one rotor and then move it over to, and into one of the magnetizing units, then go back to get the other rotor and place it into the other magnetizing unit. This movement was recorded in slow motion, and processing afterwards show that the movement took 0,4 seconds and pick and place of the rotor took 0,4 seconds.

After these times were measured, calculations were made in a spreadsheet to illustrate the times of the each cycle. These spreadsheets can be found in appendix A on page 87.

Overview of the cycle times

Table 9.1: This table shows the cycle times of each cycle

1st cycle	4,4 seconds for **one** rotor
2nd cycle	3,2 seconds for **one** rotor
3rd cycle	7 seconds for **two** rotors
4th cycle	4,8 seconds for **two** rotors

The calculations show it is still the 4^{th} cycle which is the fastest with a cycle time of 4,8 seconds, meaning it has a buffer time of 3,2 seconds. It is worth mentioning that this cycle time assembles to units. The rest of the cycle times can be seen in table 9.1 on the previous page.

9.2 Offline Programming

Description
Offline programming enables the possibility of simulating a complete robotic work cell thereby removing the need for working physically on the manipulator. Engineers can make changes and optimize systems without shutting down the production which can reduce downtime of the current production and help companies to increase productivity.

This project utilizes offline programming by constructing a robotic work cell with magnetizing units, a manipulator and conveyors in a virtual environment thereby opening the possibility for testing of various cycles and designs and determine what cycle and/or design that gives the best desired outcome.

Bear in mind that RobotStudio has no incorporated physics, meaning there is no gravity, torque etc. This complicates determining whether the manipulator has a firm grip on the object it is holding or if the object would be dropped.

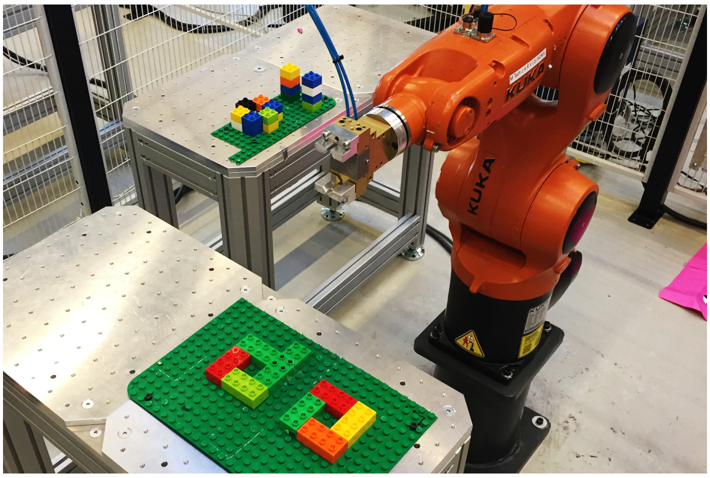


Figure 9.1: In the figure a set-up of the test can be seen where the KUKA manipulator is set in home-position and two plates are screwed to each table. On the plate farthest away two stacks of two by two LEGO Duplo bricks are stacked four blocks tall representing two rotors. On the other plate two squares where the "rotors" fit into can be seen. These squares represent the magnetizing units.

Figure 8.2 shows the set-up of the work cell. The manipulator used in the simulation is an ABB IRB 2600 with a payload of 12 kg and a reach of 1,85 m. As previously stated in section 8.2, this manipulator is used since it resembles the KUKA KR16-2 well. The ABB manipulator is a part of the library in RobotStudio, and therefore it already has a controller so it can be programmed right away.

The simulation is constructed of individual parts that communicate via I/O signals. For instance when a pallet arrives, it sends a signal to the manipulator stating that rotors can be picked up. Another example is the gripper which is a mechanism of its own. The manipulator tells the gripper to open/close, but since it takes a few milliseconds for the gripper to open and close, the manipulator must wait and listen for an I/O signal returned from the gripper, verifying that the command executed.

Code

The manipulator is controlled by placing target points in the virtual environment, and then letting the manipulator run through a list telling it which order and how to move between the targets. The target points can be seen as small coordinate systems on figure 9.2. The manipulator has to move accordingly to match the coordinate system of the target with the coordinate system of the tool. Movements can be done either linearly or as point to point (PTP). The fastest is the PTP movements since they simply rotate all the joints at the same time so they end up at their specified angle at the same time for the given tool position. For some movements it is sufficient to use PTP, but when it comes to picking and placing objects with high precision, linear movements are necessary to control the direction of the tool.

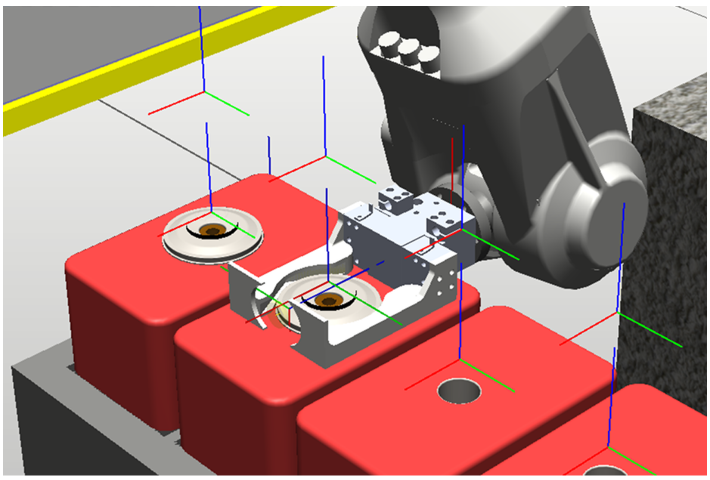


Figure 9.2: This is a screenshot from RobotStudio. All the small coordinate systems are target points that the gripper needs to align its end-effector with

When creating a pick or place movement two target points are needed. One target point is created at the final location of the object, and another is placed a bit above. This can be seen on figure 9.2. A linear *down* → *activate gripper* → *up* sequence is created between the two target points to avoid collision with objects. Without the extra target point above, the manipulator will move in an unpredictable direction directly to the final target point and may hit the pallet, magnetizing unit or stator on its way.

A way of setting up a cycle is to prepare all the small *down* → *activate gripper* → *up* sequences as small individual tasks, and then simply refer to them when needed. This avoids repetition of the same set of commands over and over again. An example of this can be seen in the code snippet 1

```
PROC stator()
    Movej stator_10_2,v1000,z10,gripperV5_endGrip\WObj:=outputConveyor;
    WaitDI waitStator,1;
    MoveL stator_10,v500,fine,gripperV5_endGrip\WObj:=outputConveyor;
        WaitRob \ZeroSpeed;
        setdo closeGripper,0;
    WaitDI waitGripper,1;
         MoveL \Conc, stator_10_2,v1000,z10,gripperV5_endGrip\WObj:= outputConveyor ;
    PulseDO giveMeNextStator;
     ENDPROC
```

Code 1: This code snippet shows an example where procedures are used to execute several commands with a single call.

RobotStudio uses ABB's robot programming language called RAPID, which, in the above snippet goes as follows. PROC stator() is a procedure that can be executed whenever it is needed. It is comparable with the void function in C. Movej and MoveL are commands to the manipulator telling it to move to the target either by joint angles or linearly respectively. The Move commands take a few inputs which is the target, speed, precision, tool and a reference frame. WaitDI simply pauses the program until a digital input is received and WaitRob pauses execution until a given condition of the manipulator is met. In this case it waits for the manipulator to come to rest. SetDO sets a digital output called "closeGripper" to 0, telling the gripper to open. The program then waits and listens for a digital pulse from the gripper, verifying that it is done executing. In the end, the code sends a digital output, telling the conveyor to move a new stator into position.

The PROC function can take an argument, making it possible to use the same procedure for multiple things. An example of this can be seen in the code snippet 2.

```
PROC Magnetizer(num magnetizerno, num isFlatGrip, num isPick)
        IF magnetizerno = 0 AND isFlatGrip = 1 THEN
        Movej magnetizer_1_1,v1000,z10,gripperV5_flatGrip\WObj:= MagnetizerTable;
        MoveL magnetizer_1_2,v500,fine,gripperV5_flatGrip\WObj:= MagnetizerTable;
        WaitRob \ZeroSpeed;
        setdo closeGripper,ispick;
        WaitDI waitGripper,1;
        MoveL \Conc, magnetizer_1_1,v1000,fine,gripperV5_flatGrip\WObj:= MagnetizerTable;

      ELSEIF magnetizerno = 0 and isFlatGrip = 0 THEN
        Movej \Conc, magnetizer_1_1,v1000,z10,gripperV5_endGrip\WObj:= MagnetizerTable;
             MoveL magnetizer_1_2,v500,fine,gripperV5_endGrip\WObj:= MagnetizerTable;
        WaitRob \ZeroSpeed;
        setdo closeGripper,ispick;
        WaitDI waitGripper,1;
        MoveL \Conc,magnetizer_1_1,v1000,fine,gripperV5_endGrip\WObj:= MagnetizerTable;

                      [...]
    ENDIF
ENDPROC
```

Code 2: This code snippet shows an example of a procedure that takes arguments. With 3 arguments in the procedure identified as 'Magnetizer' it is possible to choose magnetizing unit, grip and whether the gripper should open or close.

This function takes 3 arguments: magnetizerno, isFlatGrip and isPick. They are all integers and they serve the purpose of selecting a specific magnetizing unit to use, which grip to use on the gripper and whether the gripper should open or close. The first two arguments are evaluated by an if-statement and the last variable is used when setting the digital output signal for the gripper. The list of if-statements continues as long as there are magnetizing units available for use. A similar procedure is made for the two rotors, but that procedure only needs one argument namely which rotor to pick up. No more arguments are needed since the manipulator only needs to pick up a rotor and never place it on the pallet. Preparing the small procedures makes it easy to create a cycle. Cycle two from chapter 5.2 on page 23 can be made using the modulus operator on an incremental number, for instance the number of repeated cycles. The modulus operator makes it possible to determine which rotor and magnetizing units to use next. The main code snippet 3 uses that property and executes cycle two, though it must be said that the code below assumes there is a magnetized rotor placed in magnetizing unit 1, which is done by making a small initial routine not shown here.

```
WHILE TRUE DO
        FOR i FROM 0 TO 900 DO
            modOfI := i MOD 5;
            modOfIP1 := (i+1)MOD 5;

            rotor i MOD 2; ! i MOD 2 will oscillate between 0 and 1

            IF i MOD 2 = 1 THEN !keeps track of the number of rotors
                PulseDO giveMeNextPallet;
            ENDIF

            Magnetizer modOfIp1,1,0;
            Magnetizer modOfI,0,1;
            stator;
        ENDFOR
    ENDWHILE
```

Code 3: This little code snippet is the main function and it executes cycle 2 using the modulus operator. A few steps before this code is still needed to ensure there is a magnetized rotor in magnetizing unit 1.

The two variables modOfI and modOfIP1 (modulus of i and modulus of i plus one) serves as a workaround for not being able to execute the modulus calculation within the argument of the magnetizer procedure.

9.3 KUKA Online programming

Cycle calculations show that the 4^{th} cycle in theory fulfills the requirements, but in order to verify the results, a test of the cell set-up and the components had to be made. The testing revolved around the gripper and the 2^{nd}. Due to the lack of a double gripper testing was conducted of the 2^{nd} cycle instead of the 4^{th} cycle. The gripper will be tested for durability, gripping ability and free fit in both gripping positions. A test of the cycle will be conducted to test the efficiency of the 2^{nd} cycle which is described in 5.2.

When analysing the gripper, SolidWorks showed that the horizontal grip was strong enough to hold the rotor locked in place, but analysis of the vertical grip showed some weaknesses in the design, as seen in figure 8.14c on page 51, where the areas marked red show a high stress factor. The material used for 3D-printing of the gripper was not as tolerant and efficient as wanted, so a stress test of the vertical grip was made to document its durability. To improve the vertical grip on the print of the 7^{th} gripper elastic rubber was glued to the inner curve of each half-circle, thereby increasing the friction between the gripper and the rotor.

The KUKA KR6 R700 sixx manipulator which was used to simulate the cycle can be programmed in different ways. It can be done using a pre written program (offline-programming) or with the teach by showing method [4]. The way this works is by moving the end-effector to desired points which are memorised. The method used to program the cycle was the teach by showing method.

Before testing, the version 7 gripper was mounted onto the GP75-B actuator and calibrated so the KUKA software controlling the manipulator would know its position. Calibration of the different laboratory tables used in testing was done as well, making it possible to recreate the set-up in case the tables were relocated.

Testing was conducted with focus on the vertical grip to see if it could hold onto a rotor when running a program made specifically to test the mentioned grip. The test contained certain movements similar to those performed in the 2^{nd} cycle. The test cycle was initiated by simulating a pick-up movement, followed by continuous rotations. The test can be seen in the following video: `https://youtu.be/KO1i4Q9our4`. This created a centrifugal force which tested if the gripper would drop the rotor. The test had a duration of 10 minutes which resulted in a total of 260 cycles, and the rotor did not fall out of the gripper, making it possible to carry out the 2^{nd} cycle.

A video of the cycle demonstration can be found at the following link `https://youtu.be/eKhEFvAEXD4` and the source code can be seen in appendix B on page 88.

The recordings of the cycle show that the cycle took approximately 7,5 seconds, to assemble two units, and the rotors were not dropped or damaged. Thereby, it can be concluded that the task could be completed while satisfying the requirements.

9.4 Requirement verification

As mentioned in chapter 7 on page 34, a major purpose of a requirement specification is to verify them and thereby evaluate the developed solution. This chapter will do that by verifying functional- and performance requirements. The requirements regarding standards and regulations will not be verified in this report due to the fact that no physical work cell was designed in this project.

9.4.1 Functional requirements

(a) In the description of the work cell design, conveyors for quality assurance were shown as part of the solution. Thus, the solution meets requirement a) of 7.7.2

(b) This requirement was fulfilled by both the RobotStudio simulation and the demonstration of the KUKA manipulator in the lab as the manipulator was able to carry out the functions listed in this requirement with the equipped gripper in both scenarios.

(c) The conceptual solution from RobotStudio shown in figure 2.1 of section 8.2 on page 40 has the correct preset distance between the inlet and outlet conveyors i.e. a distance of 2394 mm. Given that the work cell simulated in RobotStudio is squared, this means that the conceptual solution is functioning inside a workspace of smaller dimensions than what was listed in the requirement specification and therefore the requirement is fulfilled.

(d) After iterative testing of various gripper designs in the lab, this requirement was met with version 7 of the gripper as documented in section 8.4.

(e) Neither the simulated conceptual solution nor the cycle demonstrated in the lab gripped the rotor by the magnetized part. Instead all rotors are gripped either around the bearing plate or the plastic mill. This way of handling the rotors ensures that this requirement is met.

9.4.2 Performance requirements

(a) **Manipulator requirement**
   (i) Both the ABB IRB 2600 from the simulation and the KUKA KR6 R700 sixx from the demonstration were able to rotate 180° between the inlet- and outlet conveyor. Thus, the requirement is fulfilled.
   (ii) The KUKA manipulator used in the lab has a max reach of only 706,7 mm. However, the KUKA manipulator was only used to conduct a feasibility study of certain aspects of the conceptual solution, and since the ABB IRB 2600 used in the simulation has a max reach of 1850 mm it can be concluded that this requirement was met.
   (iii) The KUKA manipulator used for the lab demonstration has a payload of 6 kg, while the ABB IRB 2600 from the simulation has a payload of 12 kg, making both manipulators suitable for the task. Thus, the requirement is fulfilled.

(b) **Assembly requirements**

(i) Neither the demonstration nor the simulation have incorporated a fixture to ensure that the rotors are placed with a gap of 2 mm over the magnetizing coil, therefore the requirement is not fulfilled. However, a simple plastic fixture added to the magnetizing units would ensure that the requirement is met.

(ii) Videos of the KUKA manipulator demonstrating the cycle shows that the rotors are dropped the last 10 mm into the stator to avoid damages to both the rotor and the stator and the requirement is therefore satisfied.

(c) **Cycle requirements**

(i) This has been accounted for in the cycle analysis and it is a feasible implementation. However, it has not been implemented into the simulation or the demonstration and strictly speaking the requirement has not been satisfied fully.

(ii) Both the demonstrated cycle and the simulated cycle have implemented a two second magnetization of the rotors to ensure that this requirement is fulfilled.

(iii) The magnetizing unit's cool-down has been accounted for by adding enough magnetizing units to make the 2^{nd}, 3^{rd} and 4^{th} cycle possible with the given cool-down time of 15 seconds.

(iv) Both the 2^{nd} cycle, which was demonstrated in the laboratory and simulated in RobotStudio, and the optimal 4^{th} cycle, which makes use of a double gripper, accomplishes the required takt time of 4 seconds. Thus, the requirement is met.

After evaluation of the requirements, it was concluded that most of the requirements has been fulfilled with the exception of (b)(i) and (c)(i) from subsection 9.4.2, which will have to be fulfilled before the solution can be implemented. In addition, requirements concerning external interfaces, standards and regulations must be verified before implementation of the robot system.

Testing of the actual speed of the KUKA manipulator used in this project concluded that the manipulator is able to solve the task with the 2^{nd} or 4^{th} cycle. Testing the 7^{th} gripper proved it adequate for solving the task. Verification of the requirement specification revealed that two specifications were not met.

Kinematic

In order to get a better understanding of how the manipulator plan its movements and showcase an overview of the manipulator's appearance, kinematics calculations are made with the use of the software MATLAB.

When working with manipulators it is useful to know about kinematics, since it allows one to calculate the position of different parts of the robot. In this report forward- and inverse kinematics will be used to calculate the location of the end-effector when the joint angles are known, and to calculate possible angles of each joint, when the location of the end-effector is known. All of these things can be calculated by utilizing the modified Denavit Hartenberg parameters, which are shown for the KUKA KR6 R700 sixx used in this project in table 10.1.

Table 10.1: Modified Denavit hartenberg parameters for the KUKA KR6 R700 sixx

i	α_{i-1}	a_{i-1}	d_{i-1}	θ_i
1	0	0	0	θ_1
2	$-\pi/2$	25	0	θ_2
3	0	315	0	θ_3
4	$-\pi/2$	35	365	θ_4
5	$\pi/2$	0	0	θ_5
6	$-\pi/2$	0	80	θ_6

Plotting the robot
The 3$^{\text{rd}}$ party software MATLAB can help calculate the location of the end-effector, but also provide a visual representation of the manipulator by utilizing the robotic toolbox. In MATLAB you first have to input all links one at a time in the following fashion:

```
L(1)=Link([d',x,'a',x,'alpha',x,'modified']);
L(2)=Link([d',x,'a',x,'alpha',x,'modified']);
L(3)=Link([d',x,'a',x,'alpha',␣x,'offset','modified']);
L(4)=Link(['d',x,'a',x,'alpha',x,'modified']);
L(5)=Link([d',0,'a',0,'alpha', x,'modified']);
L(6)=Link([d',x,'a',x,'alpha',x,'modified']);
```

The order is θ, d, a and α, from table 10.1 on the preceding page and by writing it as L(1) instead of L1 all data is saved in the same variable, and the code for creating the entire robot can be written as SerialLink([L]). The manipulator can then be presented visually by typing the following code ".plot([x x x x x x])" where x means theta for each link The code used for creating the robot in figure 10.1 is then:

```
>> L(1) = Link('d',0.4,'a',0,'alpha',0,'modified')
L(2) = Link('d',0,'a',0.025,'alpha',-pi/2,'modified')
L(3) = Link('d',0,'a',0.315,'alpha',0,'offset', -90/180*pi,'modified')
L(4) = Link('d',0.365,'a',0.035,'alpha',-pi 2,'modified')
L(5) = Link('d',0,'a',0,'alpha',pi/2,'modified')
L(6) = Link('d',0.08,'a',0,'alpha',-pi/2,'modified')
Kuka = SerialLink([L]. 'name', 'Jarvis')
Kuka.plot([0 0 0 0 0 0]);
```

10.1 Forward Kinematic

In order to calculate the forward kinematics, one should calculate the distance from link 1 to link 2, then from link 2 to link 3 and so on until the frame of the end-effector is reached. This is done by making a matrix for each link following the standard matrix seen in formel 10.1.

$$
{}^{i-1}_{i}T = \begin{bmatrix} \cos\Theta_i & -\sin\Theta_i & 0 & a_{i_{-1}} \\ sin\Theta_i \cos\alpha_{i_{-1}} & \cos\Theta_i \cos\alpha_{i_{-1}} & -\sin\alpha_{i_{-1}} & -\sin\alpha_{i_{-1}} d_i \\ sin\Theta_i \sin\alpha_{i_{-1}} & \cos\Theta_i \sin\alpha_{i_{-1}} & \cos\alpha_{i_{-1}} & \cos\alpha_{i_{-1}} d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{10.1}
$$

When all matrices are created, each one is multiplied starting from the first link to the end-effector. Through the Robotic Toolbox, by Peter Corke, it can also be done by writing the code fkine([x x x x x x]) in MATLAB where x is theta for each link, and the answer will be calculated like in equation 10.2

$$kuka.fkine([000000])$$
$$ans = \begin{bmatrix} 0 & 0 & 1 & 0,47 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0,75 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{10.2}$$

10.2 Inverse Kinematic

Inverse kinematics can be calculated in almost the same fashion if the Robotic Toolbox is used. If done on paper it gets a bit more complex since a robot can reach the same point and orientation using different joint values, and that can result in up to infinite solutions.To make it more comprehensible and to avoid any mistakes the location of the end-effector can be saved into one variable, if the result from "Forward kinematics" is saved to a variable called "I" then it should return

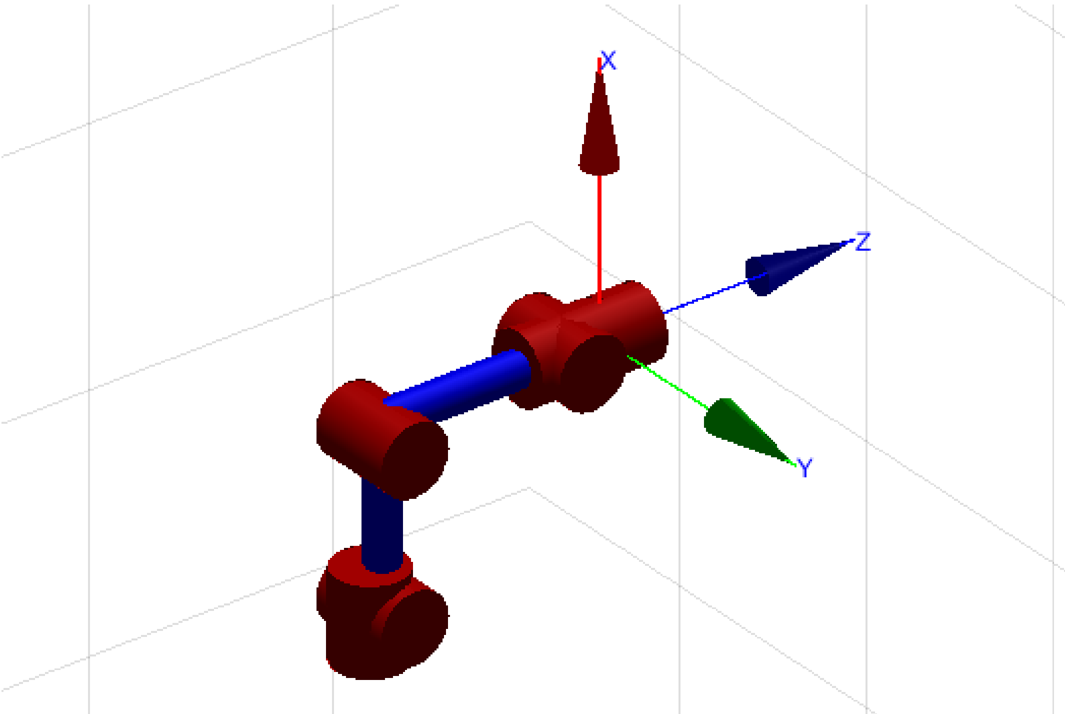


Figure 10.1: The robot plotted in MATLAB

the values used in "Forward kinematics" as one of the answers using the code ikine:

$$I = ans \tag{10.3}$$

$$I = \begin{bmatrix} 0 & 0 & 1 & 0,47 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0,75 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{10.4}$$

kuka.ikine([I]) Warning: Initial joint configuration results in a (near-)singular configuration, this may slow convergence. > In SerialLink/ikine

$$ans = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{10.5}$$

Because the result gives a singular configuration, it only gives one result which were the joint values used to calculate "Forward kinematics".

10.3 Trajectory Planning

In order get a visual presentation of the trajectory of each joint, two different positions are needed namely a start- and end position. A trajectory can then be created between the two points, it could look like the following:

$$T1 = transl(0.47, 0.00, 0.75) \tag{10.6}$$

$$T1 = \begin{bmatrix} 1 & 0 & 0 & 0,47 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0,75 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{10.7}$$

$$>> T2 = transl(0.39, 0.00, 0.67) \tag{10.8}$$

$$T2 = \begin{bmatrix} 1 & 0 & 0 & 0,39 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0,67 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{10.9}$$

$$>> T = ctraj(T1, T2, 50) \tag{10.10}$$

The inverse kinematics are then calculated for each point in order to plan a path and the movement of the joints can be presented visually as seen in figure 10.2.

```
Tr = kuka.ikine([T])
subplot(6,1,1); plot(Tr(:,1)); xlabel('Time␣(s)'); ylabel('Joint␣1␣(rad)')
subplot(6,1,2); plot(Tr(:,2)); xlabel('Time␣(s)'); ylabel('Joint␣2␣(rad)')
subplot(6,1,3); plot(Tr(:,3)); xlabel('Time␣(s)'); ylabel('Joint␣3␣(rad)')
subplot(6,1,4); plot(Tr(:,4)); xlabel('Time␣(s)'); ylabel('Joint␣4␣(rad)')
subplot(6,1,5); plot(Tr(:,5)); xlabel('Time␣(s)'); ylabel('Joint␣5␣(rad)')
subplot(6,1,6); plot(Tr(:,6)); xlabel('Time␣(s)'); ylabel('Joint␣6␣(rad)')
```

This graph will help to get an overview of the manipulator's joint movements, and the data from the graph allows visual representation of the movement, sketched in a simplified version of the manipulator which can be seen in the appendix.

This chapter described how the manipulator calculates its movement. The data could be used to move a physical robot with the software used in this chapter. Even though this report never managed to get the data from the manipulator and the calculated data to correspond with each other, it still serves to get a better understanding of how the robot works.

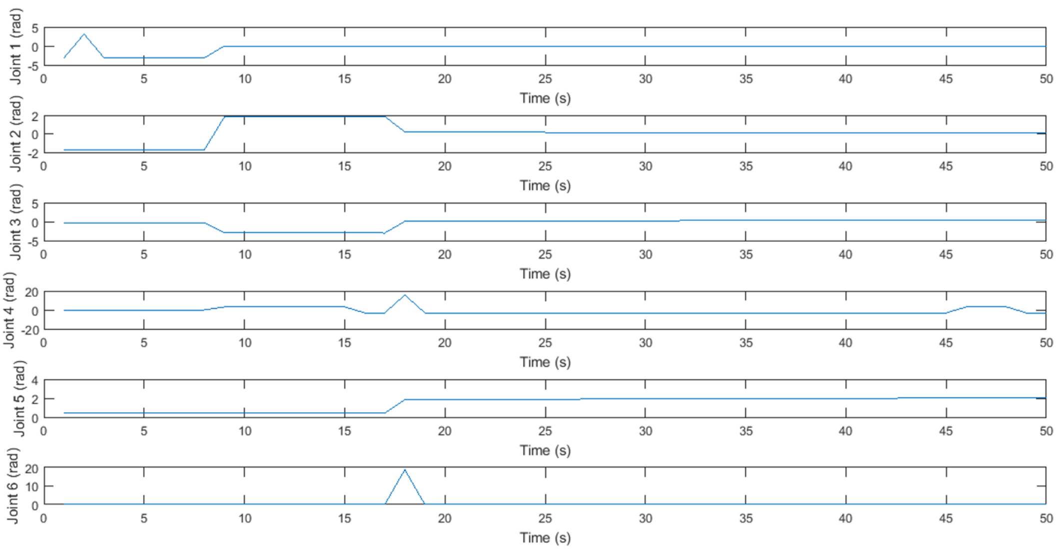


Figure 10.2: Joint 1-6 movement relating to time

Part IV

Discussion and conclusion

Chapter 11

Discussion

Even though the final solution has been proposed, adjustments can still be made to improve the project and the work cell. Regarding the RobotStudio demonstration the single gripper is used in the simulation. The double gripper which results in the best possible solution concluded in the analyses of cycle times should be used in RobotStudio for a simulation of the 4th cycle. The same goes for the implementation of the double gripper in the laboratory were currently the single gripper is mounted. The reasoning behind not choosing to 3D print and test the double gripper is due to the complexity of implementing it. Therefore, if more time and resources were to be invested in this project a main priority would be to implement a double gripper in both simulation and in the laboratory. Furthermore, a quality assurance conveyor would need to be incorporated in the simulation program and in the laboratory.

The manipulator that is chosen for the task, could be investigated further with KUKA as a consultant to ensure that the chosen manipulator is the best for the task in regard to reach, repeatability and speed. Moreover, an economical investigation of the different proposals will be needed in order to choose the proposal which is most economically advantageous. The reasoning behind leaving out the economical aspect in this paper is due to the difficulties of obtaining prices on the various products without specifically knowing the contract details between Grundfos and the different manufacturers.

For further development the work cell could be tested in the laboratory with both functioning conveyors, magnetizers and pallets. This would increase the accuracy of the cycle time calculations before implementation in the Grundfos factory, and thereby avoid misleading results that could stem from the simplified testing done in this project, which could be costly for Grundfos if the proposal were to implement the solution. In the *Requirement verification* chapter 7 all the requirements were compared with the solution, and it was found that a two requirements was not met. For optimization these would need to be met, together with safety- and internal interface requirements which were not focused on in this report.

To simplify and optimize the maintenance of the gripper some changes in the design is required. Making substitutable parts for the horizontal gripping position as well as the parts around the vertical positions would make it possible to easily change the worn parts of the gripper, instead of using more resources when making a new whole gripper. Furthermore to compensate for the weaknesses, which the stress test showed in 8.14c on page 51 a durable material, such as aluminium, should be used for a final product instead of the ABS plastic which was used for 3D-printing in this project.

Chapter | 12

Conclusion

The purpose of this project was to design a work cell for the Danish company Grundfos which could be implemented in their ALPHA2 production line. The task was to magnetize a rotor and assembly it with a stator. In order to carry out all tasks successfully, certain requirements for the work cell had to be fulfilled. This included a restriction on the dimensions of the work cell, fixed locations of equipment in the work cell and a takt time of four seconds per assembled unit which was derived from the frequency of incoming rotors and stators. Beside the mentioned requirements, others were found after analysing the task.

The quantity of magnetizing units was not preset and the magnetization proved to be the initial bottleneck of the assembly process, meaning that at least five magnetizing units were a necessity in the set-up of the work cell. Because of this, different solutions with different numbers of magnetizing units were proposed. Achieving a cycle time below four seconds was of utmost importance as it was necessary to successfully complete the task. The number of required manipulators was not preset either and could be changed if it was necessary to complete the task. However, the project concluded that one manipulator, namely the KUKA KR 16-2, was capable of completing the task by itself, while fulfilling the requirement specification of the project. With only one manipulator in the work cell it was found to be most efficient to utilize the concept of a double-gripper, capable of handling two rotors at once, as the cycle time could be lowered significantly this way. Despite of the fact that the approach with the double gripper was the fastest and most efficient, it was never simulated nor demonstrated in practice. However, the cycle calculations also showed that the 2nd cycle was able to complete the assembly task within the required takt time by use of a single gripper. To confirm whether the 2nd cycle would work in a solution set-up capable of completing the task in a satisfactory manner, tests were conducted in RobotStudio and in the laboratory. From these tests it could be concluded that a set-up utilizing the 2nd cycle was able to satisfactorily complete the assembly task despite it not being the most efficient solution.

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Appendix | A

Cycle calculations

Cycle 1	Command	Timespan	Unit
	new pallet	8	sec
	move	0,4	sec
	grab	0,4	sec
	hold into	2	sec
	new pallet incomming	3,6	sec
	place into	0,4	sec

Evaluation:

There are almost no time for the magnetizers to cooldown/recharge, but the reason for this is because of the cycle time which in fact takes one pallet 8,8 seconds, where it should take at maximum 8 seconds.

This means every second cycle a new pallet enters and the cycle is: 0,8 seconds behind.

					Magnetizers			
	Command	Description	Indidual time	Total time	1	2	3	4
Main cycle	move	to rotor-conveyor	0,4	4,4				
	grab	rotor at rotor-conveyor	0,4					
	move	to magnetizer	0,4					
	hold into	magnetizer	2		Magnetize			
	move	to stator-conveyor	0,4		Cooldown			
	place into	stator	0,4		15			
	move	to home	0,4					
Main cycle	move	to rotor-conveyor	0,4	4,4				
	grab	rotor at rotor-conveyor	0,4					
	move	to magnetizer	0,4					
	hold into	magnetizer	2			Magnetize		
	move	to stator-conveyor	0,4			Cooldown		
	place into	stator	0,4			15		
	move	halfway to rotor-conveyor	0,4					
Main cycle	move	to rotor-conveyor	0,4	4,4				
	grab	rotor at rotor-conveyor	0,4					
	move	to magnetizer	0,4					
	hold into	magnetizer	2				Magnetize	

	move	to stator-conveyor	0,4				Cooldown	
	place into	stator	0,4				15	
	move	halfway to rotor-conveyor	0,4					
	move	to rotor-conveyor	0,4					
	grab	rotor at rotor-conveyor	0,4					
	move	to magnetizer	0,4					
Main cycle	hold into	magnetizer	2	4,4				Magnetize
	move	to stator-conveyor	0,4					Cooldown
	place into	stator	0,4					15
	move	halfway to rotor-conveyor	0,4					
	move	to rotor-conveyor	0,4					
	grab	rotor at rotor-conveyor	0,4					
	move	to magnetizer	0,4					
Main cycle	hold into	magnetizer	2	4,4	Magnetize			
	move	to stator-conveyor	0,4		Cooldown			
	place into	stator	0,4		15			
	move	halfway to rotor-conveyor	0,4					
	move	to rotor-conveyor	0,4					
	grab	rotor at rotor-conveyor	0,4					
	move	to magnetizer	0,4					
Main cycle	hold into	magnetizer	2	4,4		Magnetize		
	move	to stator-conveyor	0,4			Cooldown		
	place into	stator	0,4			15		
	move	halfway to rotor-conveyor	0,4					
	move	to rotor-conveyor	0,4					
	grab	rotor at rotor-conveyor	0,4					
	move	to magnetizer	0,4					
Main cycle	hold into	magnetizer	2	4,4			Magnetize	
	move	to stator-conveyor	0,4				Cooldown	
	place into	stator	0,4				15	
	move	halfway to rotor-conveyor	0,4					

Main cycle	move	to rotor-conveyor	0,4	4,4				
	grab	rotor at rotor-conveyor	0,4					
	move	to magnetizer	0,4					
	hold into	magnetizer	2					Magnetize
	move	to stator-conveyor	0,4					Cooldown
	place into	stator	0,4					14,4
	move	halfway to rotor-conveyor	0,4					
Main cycle	move	to rotor-conveyor	0,4	4,4				
	grab	rotor at rotor-conveyor	0,4					
	move	to magnetizer	0,4					
	hold into	magnetizer	2					
	move	to stator-conveyor	0,4					
	place into	stator	0,4					
	move	halfway to rotor-conveyor	0,4					
Main cycle	move	to rotor-conveyor	0,4	4,4				
	grab	rotor at rotor-conveyor	0,4					
	move	to magnetizer	0,4					
	hold into	magnetizer	2					
	move	to stator-conveyor	0,4					
	place into	stator	0,4					
	move	halfway to rotor-conveyor	0,4					
Main cycle	move	to rotor-conveyor	0,4	4,4				
	grab	rotor at rotor-conveyor	0,4					
	move	to magnetizer	0,4					
	hold into	magnetizer	2					
	move	to stator-conveyor	0,4					
	place into	stator	0,4					
	move	halfway to rotor-conveyor	0,4					

Cycle 2	Command	Timespan	Unit
	new pallet	8	sec
	move	0,4	sec
	move to home	0,4	sec
	move to rotor-conveyor	0,8	
	grab	0,4	sec
	put into	0,4	sec
	init wait for new pallet	3,6	sec
	wait for new pallet	1,6	sec

Evaluation:

There are no time for the magnetizers to cooldown/recharge, the reason for this is because of the cycle time whic

In fact takes one pallet: 6,4

-where it should take at maximum 8 seconds. This means that every second cycle a new pallet enters the cycle is

-1,6 seconds done earlier than when the new pallet enters

If one more magnetizer was installed the cycle would be possible

					Magnetizers					Example Magnetizers				
	Command	Description	Individual time	Total time	1	2	3	4		1	2	3	4	5
	move	to rotor-conveyor	0,4											
	grab	rotor at rotor-conveyor	0,4											
Initial cycle	move	to magnetizer	0,4	1,6										
	put into	magnetizer	0,4											
	move to home		0,4		Magnetizing					Magnetizing				
	move	to rotor-conveyor	0,4		2					2				
	grab	rotor at rotor-conveyor	0,4		seconds					seconds				
	move	to magnetizer	0,4											
Main cycle	put into	magnetizer	0,4	2,8										
	grab	magnetized rotor at magnetizer	0,4		Cooldown	Magnetizing				Cooldown	Magnetizing			
	move	to stator-conveyor	0,4		15	2				15	2			
	put into	stator	0,4			seconds					seconds			
	move to home		0,4											
	init wait for new pallet		3,6			Cooldown					Cooldown			
	move	to rotor-conveyor	0,4			15					15			
	grab	rotor at rotor-conveyor	0,4											
	move	to magnetizer	0,4											
Main cycle	put into	magnetizer	0,4	3,2										
	grab	magnetized rotor at magnetizer	0,4				Magnetizing					Magnetizing		
	move	to stator-conveyor	0,4				2					2		
	put into	stator	0,4				seconds					seconds		
	move to home		0,4											
	move	to rotor-conveyor	0,4											
	grab	rotor at rotor-conveyor	0,4				Cooldown					Cooldown		
	move	to magnetizer	0,4				15					15		
Main cycle	put into	magnetizer	0,4	3,2										
	grab	magnetized rotor at magnetizer	0,4					Magnetizing					Magnetizing	
	move	to stator-conveyor	0,4					2					2	
	put into	stator	0,4					seconds					seconds	
	move to home		0,4											

	wait for new pallet		1,6											
Main cycle	move	to rotor-conveyor	0,4	3,2				Cooldown					Cooldown	
	grab	rotor at rotor-conveyor	0,4					15					15	
	move	to magnetizer	0,4											
	put into	magnetizer	0,4											
	grab	magnetized rotor at magnetizer	0,4											
	move	to stator-conveyor	0,4		Magnetizing									Magnetizing
	put into	stator	0,4		2									2
	move to home		0,4		seconds									seconds
Main cycle	move	to rotor-conveyor	0,4	3,2										
	grab	rotor at rotor-conveyor	0,4											
	move	to magnetizer	0,4		Cooldown									Cooldown
	put into	magnetizer	0,4		15									15
	grab	magnetized rotor at magnetizer	0,4			Magnetizing				Magnetizing				
	move	to stator-conveyor	0,4			2				2				
	put into	stator	0,4			seconds				seconds				
	move to home		0,4											
	wait for new pallet		1,6			Cooldown				Cooldown				
Main cycle	move	to rotor-conveyor	0,4	3,2		15				15				
	grab	rotor at rotor-conveyor	0,4											
	move	to magnetizer	0,4											
	put into	magnetizer	0,4											
	grab	magnetized rotor at magnetizer	0,4				Error, not				Magnetizing			
	move	to stator-conveyor	0,4				Possible				2			
	put into	stator	0,4				To insert				seconds			
	move to home		0,4				New rotor							
Main cycle	move	to rotor-conveyor	0,4	3,2										
	grab	rotor at rotor-conveyor	0,4											
	move	to magnetizer	0,4								Cooldown			
	put into	magnetizer	0,4								15			
	grab	magnetized rotor at magnetizer	0,4									Magnetizing		
	move	to stator-conveyor	0,4									2		
	put into	stator	0,4									seconds		
	move to home		0,4											
	wait for new pallet		1,6									Cooldown		
Main cycle	move	to rotor-conveyor	0,4	3,2								15		
	grab	rotor at rotor-conveyor	0,4											
	move	to magnetizer	0,4											
	put into	magnetizer	0,4											
	grab	magnetized rotor at magnetizer	0,4										Magnetizing	
	move	to stator-conveyor	0,4										2	
	put into	stator	0,4										seconds	
	move to home		0,4											
Main cycle	move	to rotor-conveyor	0,4	3,2										

	grab	rotor at rotor-conveyor	0,4					Cooldown	
	move	to magnetizer	0,4					15	
	put into	magnetizer	0,4						
	grab	magnetized rotor at magnetizer	0,4						Magnetizing
	move	to stator-conveyor	0,4						2
	put into	stator	0,4						seconds
	move to home		0,4						
	wait for new pallet		1,6						Cooldown
Main cycle	move	to rotor-conveyor	0,4	3,2					15
	grab	rotor at rotor-conveyor	0,4						
	move	to magnetizer	0,4						
	put into	magnetizer	0,4						
	grab	magnetized rotor at magnetizer	0,4		Magnetizing				
	move	to stator-conveyor	0,4		2				
	put into	stator	0,4		seconds				
	move to home		0,4						
Main cycle	move	to rotor-conveyor	0,4	3,2					
	grab	rotor at rotor-conveyor	0,4		Cooldown				
	move	to magnetizer	0,4		15				
	put into	magnetizer	0,4						
	grab	magnetized rotor at magnetizer	0,4			Magnetizing			
	move	to stator-conveyor	0,4			2			
	put into	stator	0,4			seconds			
	move to home		0,4						
	wait for new pallet		1,6			Cooldown			
Main cycle	move	to rotor-conveyor	0,4	3,2		15			
	grab	rotor at rotor-conveyor	0,4						
	move	to magnetizer	0,4						
	put into	magnetizer	0,4						
	grab	magnetized rotor at magnetizer	0,4						
	move	to stator-conveyor	0,4						
	put into	stator	0,4						
	move to home		0,4						
Main cycle	move	to rotor-conveyor	0,4	3,2					
	grab	rotor at rotor-conveyor	0,4						
	move	to magnetizer	0,4						
	put into	magnetizer	0,4						
	grab	magnetized rotor at magnetizer	0,4						
	move	to stator-conveyor	0,4						
	put into	stator	0,4						
	move to home		0,4						
	wait for new pallet		1,6						
Main cycle	move	to rotor-conveyor	0,4	3,2					
	grab	rotor at rotor-conveyor	0,4						

	move	to magnetizer	0,4	
	put into	magnetizer	0,4	
	grab	magnetized rotor at magnetizer	0,4	
	move	to stator-conveyor	0,4	
	put into	stator	0,4	
	move to home		0,4	
Main cycle	move	to rotor-conveyor	0,4	3,2
	grab	rotor at rotor-conveyor	0,4	
	move	to magnetizer	0,4	
	put into	magnetizer	0,4	
	grab	magnetized rotor at magnetizer	0,4	
	move	to stator-conveyor	0,4	
	put into	stator	0,4	
	move to home		0,4	
	wait for new pallet		1,6	

Cycle 3	Command	Timespan	Unit
	new pallet	8	sec
	move	0,4	sec
	grab	0,8	sec
	put into	0,8	sec
	wait for new pallet	1	sec
	move to home	0,6	
	wait until rotors are magnetized	2	sec

Grabbing 1 rotor =	0,4	
Magnetizing =	2	
Evaluation:		
This cycle is	1	second faster than the 8 second limit

					Magnetizers			Example Magnetizers		
	Command	Description	Indidual time	Total time	1 and 2	3 and 4		1 and 2	3 and 4	5 and 6
Main cycle	move	to rotor-conveyor	0,4	7						
	grab	rotors at rotor-conveyor	0,8							
	move	to magnetizer	0,4							
	put into	magnetizers	0,8							
	wait until rotors are magnetized		2		Magnetize			Magnetize		
	grab	magnetized rotors at magnetize	0,8		Cooldown			Cooldown		
	move	to stator-conveyor	0,4		15			15		
	put into	stator	0,8							
	move to home		0,6							
	wait for new pallet		1							
Main cycle	move	to rotor-conveyor	0,4	7						
	grab	rotors at rotor-conveyor	0,8							
	move	to magnetizer	0,4							
	put into		0,8							
	wait until rotors are magnetized		2			Magnetize			Magnetize	
	grab	magnetized rotors at magnetize	0,8			Cooldown			Cooldown	
	move	to stator-conveyor	0,4			15			15	
	put into	stator	0,8							
	move to home		0,6							
	wait for new pallet		1							
Main cycle	move	to rotor-conveyor	0,4	7						

	grab	rotors at rotor-conveyor	0,8						
	move	to magnetizer	0,4						
	put into		0,8						
	wait until rotors are magnetized		2		Error, not possible				Magnetize
	grab	magnetized rotors at magnetize	0,8		To insert new rotor				Cooldown
	move	to stator-conveyor	0,4						15
	put into	stator	0,8						
	move to home		0,6						
	wait for new pallet		1						
Main cycle	move	to rotor-conveyor	0,4	7					
	grab	rotors at rotor-conveyor	0,8						
	move	to magnetizer	0,4						
	put into		0,8						
	wait until rotors are magnetized		2			Error, not possible	Magnetize		
	grab	magnetized rotors at magnetize	0,8			To insert new rotor	Cooldown		
	move	to stator-conveyor	0,4				15		
	put into	stator	0,8						
	move to home		0,6						
	wait for new pallet		1						
Main cycle	move	to rotor-conveyor	0,4	7					
	grab	rotors at rotor-conveyor	0,8						
	move	to magnetizer	0,4						
	put into		0,8						
	wait until rotors are magnetized		2					Magnetize	
	grab	magnetized rotors at magnetize	0,8					Cooldown	
	move	to stator-conveyor	0,4					15	
	put into	stator	0,8						
	move to home		0,6						
	wait for new pallet		1						
Main cycle	move	to rotor-conveyor	0,4	7					
	grab	rotors at rotor-conveyor	0,8						
	move	to magnetizer	0,4						
	put into		0,8						
	wait until rotors are magnetized		2						Magnetize
	grab	magnetized rotors at magnetize	0,8						Cooldown

	move	to stator-conveyor	0,4							15
	put into	stator	0,8							
	move to home		0,6							
	wait for new pallet		1							
Main cycle	move	to rotor-conveyor	0,4	7						
	grab	rotors at rotor-conveyor	0,8							
	move	to magnetizer	0,4							
	put into		0,8							
	wait until rotors are magnetized		2							
	grab	magnetized rotors at magnetize	0,8							
	move	to stator-conveyor	0,4							
	put into	stator	0,8							
	move to home		0,6							
	wait for new pallet		1							
Main cycle	move	to rotor-conveyor	0,4	7						
	grab	rotors at rotor-conveyor	0,8							
	move	to magnetizer	0,4							
	put into		0,8							
	wait until rotors are magnetized		2							
	grab	magnetized rotors at magnetize	0,8							
	move	to stator-conveyor	0,4							
	put into	stator	0,8							
	move to home		0,6							
	wait for new pallet		1							

Cycle 4	Command	Timespan	Unit
	new pallet	8	sec
	move	0,4	sec
	grab	0,8	sec
	put into	0,8	sec
	initial cycle waiting for new pallet	5,6	sec
	main cycle waiting for new pallet	3,2	sec
	move to home	0,4	sec

Grabbing 1 rotor = 0,4

Evaluation:

Seems like a good cycle because there is a small waiting time - this is a good thing since this

means that the speed of the robot can be a bit slower, which concludes less wear and tear,

but the magnetizers cannot keep up unless 2 magnetizers are added

					Magnetizers		Example Magnetizers		
	Command	Description time	Indicidual time	Total time	1 and 2	3 and 4	1 and 2	3 and 4	5 and 6
Initial cycle	move	to rotor-conveyor	0,4	2,4					
	grab	rotors at rotor-conveyor	0,8						
	move	to magnetizer	0,4						
	put into	magnetizer	0,8		Magnetize		Magnetize		
	move to home		0,4		2		2		
	initial cycle waiting for new pallet		5,6		Cooldown		Cooldown		
Main cycle	move	to rotor-conveyor	0,4	4,8	15		15		
	grab	rotors at rotor-conveyor	0,8						
	move	to magnetizers	0,4						
	put into	magnetizers	0,8						
	grab	magnetized rotors at magnetizer	0,8			Magnetize		Magnetize	
	move	to stator-conveyor	0,4			2		2	
	put into	stators	0,8						
	move to home	rotor-conveyor	0,4						
	main cycle waiting for new pallet		3,2			Cooldown		Cooldown	
Main cycle	move	to rotor-conveyor	0,4	4,8		15		15	
	grab	rotors at rotor-conveyor	0,8						
	move	to stator-conveyor	0,4						
	put into	magnetizers	0,8						
	grab	magnetized rotors at magnetizer	0,8		Error, not possible				Magnetize
	move	to stator-conveyor	0,4		To insert new rotor				2

	put into	stators	0,8						
	move to home		0,4						
	main cycle waiting for new pallet		3,2						Cooldown
Main cycle	move	to rotor-conveyor	0,4	4,8					15
	grab	rotors at rotor-conveyor	0,8						
	move	to stator-conveyor	0,4						
	put into	magnetizers	0,8						
	grab	magnetized rotors at magnetizer	0,8			Error, not possible	Magnetize		
	move	to stator-conveyor	0,4			To insert new rotor	2		
	put into	stators	0,8						
	move to home		0,4						
	main cycle waiting for new pallet		3,2				Cooldown		
Main cycle	move	to rotor-conveyor	0,4	4,8			15		
	grab	rotors at rotor-conveyor	0,8						
	move	to stator-conveyor	0,4						
	put into	magnetizers	0,8						
	grab	magnetized rotors at magnetizer	0,8					Magnetize	
	move	to stator-conveyor	0,4					2	
	put into	stators	0,8						
	move to home		0,4						
	main cycle waiting for new pallet		3,2					Cooldown	
Main cycle	move	to rotor-conveyor	0,4	4,8				15	
	grab	rotors at rotor-conveyor	0,8						
	move	to stator-conveyor	0,4						
	put into	magnetizers	0,8						
	grab	magnetized rotors at magnetizer	0,8						Magnetize
	move	to stator-conveyor	0,4						2
	put into	stators	0,8						
	move to home		0,4						
	main cycle waiting for new pallet		3,2						Cooldown
Main cycle	move	to rotor-conveyor	0,4	4,8					15
	grab	rotors at rotor-conveyor	0,8						
	move	to stator-conveyor	0,4						
	put into	magnetizers	0,8						
	grab	magnetized rotors at magnetizer	0,8						

	move	to stator-conveyor	0,4	
	put into	stators	0,8	
	move to home		0,4	
	main cycle waiting for new pallet		3,2	
Main cycle	move	to rotor-conveyor	0,4	4,8
	grab	rotors at rotor-conveyor	0,8	
	move	to stator-conveyor	0,4	
	put into	magnetizers	0,8	
	grab	magnetized rotors at magnetizer	0,8	
	move	to stator-conveyor	0,4	
	put into	stators	0,8	
	move to home		0,4	
	main cycle waiting for new pallet		3,2	

Appendix | B

Source code

```
&ACCESS RVP
&PARAM EDITMASK = *
&PARAM TEMPLATE = C:\KRC\Roboter\Template\vorgabe
&PARAM DISKPATH = KRC:\R1\Program\Students\ROB2B117
DEF Cycle_4( )
;FOLD INI;%{PE}
  ;FOLD BASISTECH INI
    GLOBAL INTERRUPT DECL 3 WHEN $STOPMESS==TRUE DO IR_STOPM ( )
    INTERRUPT ON 3
    BAS (#INITMOV,0 )
  ;ENDFOLD (BASISTECH INI)
  ;FOLD USER INI
    ;Make your modifications here

  ;ENDFOLD (USER INI)
;ENDFOLD (INI)


;FOLD PTP HOME Vel= 100 % DEFAULT;%{PE}%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:HOME, 3:, 5:100, 7:DEFAULT
$BWDSTART = FALSE
PDAT_ACT=PDEFAULT
FDAT_ACT=FHOME
BAS (#PTP_PARAMS,100 )
$H_POS=XHOME
PTP XHOME
;ENDFOLD
;FOLD OUT 10 'open' State=TRUE ;%{PE}%R 8.3.31,%MKUKATPBASIS,%COUT,%VOUTX,%P 2:10, 3:open, 5:TRUE, 6:
$OUT[10]=TRUE
;ENDFOLD
;FOLD OUT 7 'close' State=FALSE ;%{PE}%R 8.3.31,%MKUKATPBASIS,%COUT,%VOUTX,%P 2:7, 3:close, 5:FALSE, 6:
$OUT[7]=FALSE
;ENDFOLD


;FOLD PTP Rotor1_1 CONT Vel=100 % PDAT4 Tool[2]:V9 Base[3]:pallet_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:Rotor1_1, 3:C_DIS, 5:100, 7:PDAT4
$BWDSTART=FALSE
```

```
PDAT_ACT=PPDAT4
FDAT_ACT=FRotor1_1
BAS(#PTP_PARAMS,100)
PTP XRotor1_1 C_DIS
;ENDFOLD
;FOLD PTP Rotor1_2 Vel=100 % PDAT1 Tool[2]:V9 Base[3]:pallet_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:Rotor1_2, 3:, 5:100, 7:PDAT1
$BWDSTART=FALSE
PDAT_ACT=PPDAT1
FDAT_ACT=FRotor1_2
BAS(#PTP_PARAMS,100)
PTP XRotor1_2
;ENDFOLD
;FOLD OUT 7 'close' State=TRUE ;%{PE}%R 8.3.31,%MKUKATPBASIS,%COUT,%VOUTX,%P 2:7,
    ↪ 3:close, 5:TRUE, 6:
$OUT[7]=TRUE
;ENDFOLD
;FOLD OUT 10 'open' State=FALSE ;%{PE}%R 8.3.31,%MKUKATPBASIS,%COUT,%VOUTX,%P
    ↪ 2:10, 3:open, 5:FALSE, 6:
$OUT[10]=FALSE
;ENDFOLD
;FOLD WAIT Time=0.1 sec;%{PE}%R 8.3.31,%MKUKATPBASIS,%CWAIT,%VWAIT,%P 3:0.1
WAIT SEC 0.1
;ENDFOLD
;FOLD PTP Rotor1_3 CONT Vel=100 % PDAT2 Tool[2]:V9 Base[3]:pallet_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:Rotor1_3, 3:C_DIS, 5:100, 7:PDAT2
$BWDSTART=FALSE
PDAT_ACT=PPDAT2
FDAT_ACT=FRotor1_3
BAS(#PTP_PARAMS,100)
PTP XRotor1_3 C_DIS
;ENDFOLD


;FOLD PTP Mag1_1 CONT Vel=100 % PDAT7 Tool[2]:V9 Base[4]:Magnetizer_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:Mag1_1, 3:C_DIS, 5:100, 7:PDAT7
$BWDSTART=FALSE
PDAT_ACT=PPDAT7
FDAT_ACT=FMag1_1
BAS(#PTP_PARAMS,100)
PTP XMag1_1 C_DIS
;ENDFOLD
;FOLD PTP Mag1_2 Vel=100 % PDAT9 Tool[2]:V9 Base[4]:Magnetizer_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:Mag1_2, 3:, 5:100, 7:PDAT9
$BWDSTART=FALSE
PDAT_ACT=PPDAT9
FDAT_ACT=FMag1_2
BAS(#PTP_PARAMS,100)
PTP XMag1_2
;ENDFOLD
```

```
;FOLD OUT 10 'open' State=TRUE ;%{PE}%R 8.3.31,%MKUKATPBASIS,%COUT,%VOUTX,%P 2:10, 3:open, 5:TRUE, 6:
$OUT[10]=TRUE
;ENDFOLD
;FOLD OUT 7 'close' State=FALSE ;%{PE}%R 8.3.31,%MKUKATPBASIS,%COUT,%VOUTX,%P 2:7, 3:close, 5:FALSE, 6:
$OUT[7]=FALSE
;ENDFOLD
;FOLD WAIT Time=0.1 sec;%{PE}%R 8.3.31,%MKUKATPBASIS,%CWAIT,%VWAIT,%P 3:0.1
WAIT SEC 0.1
;ENDFOLD
;FOLD PTP Mag1_3 CONT Vel=100 % PDAT15 Tool[1]:M4 Base[4]:Magnetizer_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:Mag1_3, 3:C_DIS, 5:100, 7:PDAT15
$BWDSTART=FALSE
PDAT_ACT=PPDAT15
FDAT_ACT=FMag1_3
BAS(#PTP_PARAMS,100)
PTP XMag1_3 C_DIS
;ENDFOLD


;FOLD PTP Rotor2_1 CONT Vel=100 % PDAT11 Tool[2]:V9 Base[3]:pallet_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:Rotor2_1, 3:C_DIS, 5:100, 7:PDAT11
$BWDSTART=FALSE
PDAT_ACT=PPDAT11
FDAT_ACT=FRotor2_1
BAS(#PTP_PARAMS,100)
PTP XRotor2_1 C_DIS
;ENDFOLD
;FOLD PTP Rotor2_2 Vel=100 % PDAT10 Tool[2]:V9 Base[3]:pallet_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:Rotor2_2, 3:, 5:100, 7:PDAT10
$BWDSTART=FALSE
PDAT_ACT=PPDAT10
FDAT_ACT=FRotor2_2
BAS(#PTP_PARAMS,100)
PTP XRotor2_2
;ENDFOLD
;FOLD OUT 7 'close' State=TRUE ;%{PE}%R 8.3.31,%MKUKATPBASIS,%COUT,%VOUTX,%P 2:7, 3:close, 5:TRUE, 6:
$OUT[7]=TRUE
;ENDFOLD
;FOLD OUT 10 'open' State=FALSE ;%{PE}%R 8.3.31,%MKUKATPBASIS,%COUT,%VOUTX,%P 2:10, 3:open, 5:FALSE, 6:
$OUT[10]=FALSE
;ENDFOLD
;FOLD WAIT Time=0.1 sec;%{PE}%R 8.3.31,%MKUKATPBASIS,%CWAIT,%VWAIT,%P 3:0.1
WAIT SEC 0.1
;ENDFOLD
;FOLD PTP Rotor2_3 CONT Vel=100 % PDAT12 Tool[2]:V9 Base[3]:pallet_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:Rotor2_3, 3:C_DIS, 5:100, 7:PDAT12
$BWDSTART=FALSE
```

```
PDAT_ACT=PPDAT12
FDAT_ACT=FRotor2_3
BAS(#PTP_PARAMS,100)
PTP XRotor2_3 C_DIS
;ENDFOLD
;FOLD PTP Mag3_1 CONT Vel=100 % PDAT38 Tool[2]:V9 Base[3]:pallet_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:Mag3_1, 3:C_DIS, 5:100, 7:PDAT38
$BWDSTART=FALSE
PDAT_ACT=PPDAT38
FDAT_ACT=FMag3_1
BAS(#PTP_PARAMS,100)
PTP XMag3_1 C_DIS
;ENDFOLD
;FOLD LIN Mag3_2 Vel=2 m/s CPDAT2 Tool[2]:V9 Base[3]:pallet_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VLIN,%P 1:LIN, 2:Mag3_2, 3:, 5:2, 7:CPDAT2
$BWDSTART=FALSE
LDAT_ACT=LCPDAT2
FDAT_ACT=FMag3_2
BAS(#CP_PARAMS,2)
LIN XMag3_2
;ENDFOLD
;FOLD OUT 10 'open' State=TRUE ;%{PE}%R 8.3.31,%MKUKATPBASIS,%COUT,%VOUTX,%P 2:10, 3:open, 5:TRUE, 6:
$OUT[10]=TRUE
;ENDFOLD
;FOLD OUT 7 'close' State=FALSE ;%{PE}%R 8.3.31,%MKUKATPBASIS,%COUT,%VOUTX,%P 2:7, 3:close, 5:FALSE, 6:
$OUT[7]=FALSE
;ENDFOLD
;FOLD WAIT Time=0.1 sec;%{PE}%R 8.3.31,%MKUKATPBASIS,%CWAIT,%VWAIT,%P 3:0.1
WAIT SEC 0.1
;ENDFOLD
;FOLD PTP Mag3_3 CONT Vel=100 % PDAT39 Tool[2]:V9 Base[4]:Magnetizer_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:Mag3_3, 3:C_DIS, 5:100, 7:PDAT39
$BWDSTART=FALSE
PDAT_ACT=PPDAT39
FDAT_ACT=FMag3_3
BAS(#PTP_PARAMS,100)
PTP XMag3_3 C_DIS
;ENDFOLD
;FOLD PTP MagV1_1 CONT Vel=100 % PDAT25 Tool[2]:V9 Base[4]:Magnetizer_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:MagV1_1, 3:C_DIS, 5:100, 7:PDAT25
$BWDSTART=FALSE
PDAT_ACT=PPDAT25
FDAT_ACT=FMagV1_1
BAS(#PTP_PARAMS,100)
PTP XMagV1_1 C_DIS
```

```
;ENDFOLD
;FOLD LIN MagV1_2 Vel=2 m/s CPDAT5 Tool[2]:V9 Base[4]:Magnetizer_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VLIN,%P 1:LIN, 2:MagV1_2, 3:, 5:2, 7:CPDAT5
$BWDSTART=FALSE
LDAT_ACT=LCPDAT5
FDAT_ACT=FMagV1_2
BAS(#CP_PARAMS,2)
LIN XMagV1_2
;ENDFOLD
;FOLD OUT 7 'close' State=TRUE ;%{PE}%R 8.3.31,%MKUKATPBASIS,%COUT,%VOUTX,%P 2:7, 3:close, 5:TRUE, 6:
$OUT[7]=TRUE
;ENDFOLD
;FOLD OUT 10 'open' State=FALSE ;%{PE}%R 8.3.31,%MKUKATPBASIS,%COUT,%VOUTX,%P 2:10, 3:open, 5:FALSE, 6:
$OUT[10]=FALSE
;ENDFOLD
;FOLD WAIT Time=0.1 sec;%{PE}%R 8.3.31,%MKUKATPBASIS,%CWAIT,%VWAIT,%P 3:0.1
WAIT SEC 0.1
;ENDFOLD
;FOLD LIN MagV1_3 Vel=2 m/s CPDAT4 Tool[2]:V9 Base[4]:Magnetizer_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VLIN,%P 1:LIN, 2:MagV1_3, 3:, 5:2, 7:CPDAT4
$BWDSTART=FALSE
LDAT_ACT=LCPDAT4
FDAT_ACT=FMagV1_3
BAS(#CP_PARAMS,2)
LIN XMagV1_3
;ENDFOLD
;FOLD PTP MagV1_4 CONT Vel=100 % PDAT19 Tool[2]:V9 Base[4]:Magnetizer_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:MagV1_4, 3:C_DIS, 5:100, 7:PDAT19
$BWDSTART=FALSE
PDAT_ACT=PPDAT19
FDAT_ACT=FMagV1_4
BAS(#PTP_PARAMS,100)
PTP XMagV1_4 C_DIS
;ENDFOLD
;FOLD PTP MagV1_5 CONT Vel=100 % PDAT20 Tool[2]:V9 Base[4]:Magnetizer_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:MagV1_5, 3:C_DIS, 5:100, 7:PDAT20
$BWDSTART=FALSE
PDAT_ACT=PPDAT20
FDAT_ACT=FMagV1_5
BAS(#PTP_PARAMS,100)
PTP XMagV1_5 C_DIS
;ENDFOLD


;FOLD PTP Stator1_1 CONT Vel=100 % PDAT21 Tool[2]:V9 Base[5]:Statot_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:Stator1_1, 3:C_DIS, 5:100, 7:PDAT21
$BWDSTART=FALSE
PDAT_ACT=PPDAT21
FDAT_ACT=FStator1_1
```

```
BAS(#PTP_PARAMS,100)
PTP XStator1_1 C_DIS
;ENDFOLD
;FOLD LIN Stator1_2 Vel=2 m/s CPDAT6 Tool[2]:V9 Base[5]:Statot_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VLIN,%P 1:LIN, 2:Stator1_2, 3:, 5:2, 7:CPDAT6
$BWDSTART=FALSE
LDAT_ACT=LCPDAT6
FDAT_ACT=FStator1_2
BAS(#CP_PARAMS,2)
LIN XStator1_2
;ENDFOLD
;FOLD OUT 10 'open' State=TRUE ;%{PE}%R 8.3.31,%MKUKATPBASIS,%COUT,%VOUTX,%P 2:10, 3:open, 5:TRUE, 6:
$OUT[10]=TRUE
;ENDFOLD
;FOLD OUT 7 'close' State=FALSE ;%{PE}%R 8.3.31,%MKUKATPBASIS,%COUT,%VOUTX,%P 2:7, 3:close, 5:FALSE, 6:
$OUT[7]=FALSE
;ENDFOLD
;FOLD WAIT Time=0.1 sec;%{PE}%R 8.3.31,%MKUKATPBASIS,%CWAIT,%VWAIT,%P 3:0.1
WAIT SEC 0.1
;ENDFOLD
;FOLD PTP Stator1_3 CONT Vel=100 % PDAT23 Tool[2]:V9 Base[5]:Statot_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:Stator1_3, 3:C_DIS, 5:100, 7:PDAT23
$BWDSTART=FALSE
PDAT_ACT=PPDAT23
FDAT_ACT=FStator1_3
BAS(#PTP_PARAMS,100)
PTP XStator1_3 C_DIS
;ENDFOLD


;FOLD PTP MagV2_1 CONT Vel=100 % PDAT29 Tool[2]:V9 Base[4]:Magnetizer_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:MagV2_1, 3:C_DIS, 5:100, 7:PDAT29
$BWDSTART=FALSE
PDAT_ACT=PPDAT29
FDAT_ACT=FMagV2_1
BAS(#PTP_PARAMS,100)
PTP XMagV2_1 C_DIS
;ENDFOLD
;FOLD PTP MagV2_2 Vel=100 % PDAT30 Tool[2]:V9 Base[4]:Magnetizer_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:MagV2_2, 3:, 5:100, 7:PDAT30
$BWDSTART=FALSE
PDAT_ACT=PPDAT30
FDAT_ACT=FMagV2_2
BAS(#PTP_PARAMS,100)
PTP XMagV2_2
;ENDFOLD
;FOLD OUT 7 'close' State=TRUE ;%{PE}%R 8.3.31,%MKUKATPBASIS,%COUT,%VOUTX,%P 2:7, 3:close, 5:TRUE, 6:
$OUT[7]=TRUE
```

```
;ENDFOLD
;FOLD OUT 10 'open' State=FALSE ;%{PE}%R 8.3.31,%MKUKATPBASIS,%COUT,%VOUTX,%P 2:10, 3:open, 5:FALSE, 6:
$OUT[10]=FALSE
;ENDFOLD
;FOLD WAIT Time=0.1 sec;%{PE}%R 8.3.31,%MKUKATPBASIS,%CWAIT,%VWAIT,%P 3:0.1
WAIT SEC 0.1
;ENDFOLD
;FOLD PTP MagV2_3 CONT Vel=100 % PDAT32 Tool[2]:V9 Base[4]:Magnetizer_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:MagV2_3, 3:C_DIS, 5:100, 7:PDAT32
$BWDSTART=FALSE
PDAT_ACT=PPDAT32
FDAT_ACT=FMagV2_3
BAS(#PTP_PARAMS,100)
PTP XMagV2_3 C_DIS
;ENDFOLD
;FOLD PTP MagV2_4 CONT Vel=100 % PDAT35 Tool[2]:V9 Base[4]:Magnetizer_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:MagV2_4, 3:C_DIS, 5:100, 7:PDAT35
$BWDSTART=FALSE
PDAT_ACT=PPDAT35
FDAT_ACT=FMagV2_4
BAS(#PTP_PARAMS,100)
PTP XMagV2_4 C_DIS
;ENDFOLD


;FOLD PTP Stator2_1 Vel=100 % PDAT36 Tool[2]:V9 Base[5]:Statot_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:Stator2_1, 3:, 5:100, 7:PDAT36
$BWDSTART=FALSE
PDAT_ACT=PPDAT36
FDAT_ACT=FStator2_1
BAS(#PTP_PARAMS,100)
PTP XStator2_1
;ENDFOLD
;FOLD LIN Stator2_2 Vel=2 m/s CPDAT8 Tool[2]:V9 Base[5]:Statot_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VLIN,%P 1:LIN, 2:Stator2_2, 3:, 5:2, 7:CPDAT8
$BWDSTART=FALSE
LDAT_ACT=LCPDAT8
FDAT_ACT=FStator2_2
BAS(#CP_PARAMS,2)
LIN XStator2_2
;ENDFOLD
;FOLD OUT 10 'open' State=TRUE ;%{PE}%R 8.3.31,%MKUKATPBASIS,%COUT,%VOUTX,%P 2:10, 3:open, 5:TRUE, 6:
$OUT[10]=TRUE
;ENDFOLD
;FOLD OUT 7 'close' State=FALSE ;%{PE}%R 8.3.31,%MKUKATPBASIS,%COUT,%VOUTX,%P 2:7, 3:close, 5:FALSE, 6:
$OUT[7]=FALSE
;ENDFOLD
;FOLD WAIT Time=0.1 sec;%{PE}%R 8.3.31,%MKUKATPBASIS,%CWAIT,%VWAIT,%P 3:0.1
```

```
WAIT SEC 0.1
;ENDFOLD
;FOLD PTP Stator2_3 Vel=100 % PDAT37 Tool[2]:V9 Base[5]:Statot_table;%{PE}%R
8.3.31,%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:Stator2_3, 3:, 5:100, 7:PDAT37
$BWDSTART=FALSE
PDAT_ACT=PPDAT37
FDAT_ACT=FStator2_3
BAS(#PTP_PARAMS,100)
PTP XStator2_3
;ENDFOLD


;FOLD PTP HOME Vel= 100 % DEFAULT;%{PE}%MKUKATPBASIS,%CMOVE,%VPTP,%P 1:PTP, 2:HOME, 3:, 5:100, 7:DEFAULT
$BWDSTART = FALSE
PDAT_ACT=PDEFAULT
FDAT_ACT=FHOME
BAS (#PTP_PARAMS,100 )
$H_POS=XHOME
PTP XHOME
;ENDFOLD

END
```