LUT UNIVERSITY
LUT School of Energy Systems
LUT Mechanical Engineering

Risto Tella

DESIGN AND DEVELOPMENT OF THE MAGNET INSERTING DEVICE FOR ELECTRIC MOTORS

Master's Thesis

Supervisors: Doc. Harri Eskelinen
M.Sc. Mikko Piispanen

ABSTRACT

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2019

60 pages, 15 figures, 9 tables

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Keywords: Assembly of electric motors, rotor of electric motor, industrial robot

The purpose of the thesis was to create and compare different assembly solutions for the assembly process of the rotors of electric motors. Solutions were created, evaluated and compared with the systematic design method VDI 2221, Morphological Classification and Value Analysis. The goal was to find reliable and cost efficiency solution to implement assembly step of the rotor of electrical motors. The aim was to design and find three different magnet insertion solutions and compare them with value analysis.

Based on the Morphological classification three different solutions were chosen for value analysis. The first chosen device for further development was a manual device, the second one was a robotized assembly system with automated magnet storage and the third one was a robotized arm with an integrated magnet separator.

Based on the value analysis and costs magnet insertion process it was decided to use the industrial robot system where the robot process with magnets and inserts them in to the rotor. The robot system consists of an industrial robot, a magnet storage system, a rotating table for rotors, a separating machine for magnet piles and a gluing device.

As a conclusion in this thesis the industrial robot system, which utilize external magnet storage system and external magnet separating machine is the most suitable solution for the magnet insertion process when considering scalability with changes in rotor geometry, reliability and costs.

TIIVISTELMÄ

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Risto Tella

SÄHKÄMOOTTORIEN MAGNEETTIEN ASENNUSLAITTEEN SUUNNITTELU JA KEHITYS

Diplomityö

2018

60 sivua, 15 kuvaa, 9 taulukkoa

Tarkastajat: Dosentti. Harri Eskelinen
DI Mikko Piispanen

Hakusanat: Sähkömoottori, sähkömoottorin roottori, robotti

Tämän työn tavoitteena oli suunnitella ja vertaille erilaisia vaihtoehtoja joilla voidaan toteuttaa sähkömoottorin roottorin kokoonpanoprosessi. Tutkimuksessa haettiin luotettavaa ja kustannustehokasta ratkaisua jolla voidaan toteuttaa kestomagneettisähkökoneen roottorin asennusprosessi. Tavoitteena oli tuottaa kolme erilaista vaihtoehtoa jatkokehitystä, vertailua ja arvoanalyysiä varten.

Vaihtoehtoja luotiin arvioitiin ja vertailtiin systemaattisen suunnittelun methodilla VDI2221:n, Morphologisen luokittelun ja arvoanalyysin avulla. Näiden tutkimusmenetelmien avulla valittaisiin vaatimuslistan mukainen järjestelmä jatkokehitystä varten.
Morphologiseen luokittelun avulla tehdyistä ratkaisuvaihtoehdoista valittiin järjestelmätoimittajien avulla kolme systeemiä jatkokehitystä varten. Ensimmäinen valittu ratkaisu oli mekaaninen magneettien asennuslaite, toinen robotilla toteutettu jörjestelmä ja kolmas robottijärjestelmä jossa on itse suunniteltu mekaaninen tarttuja.

Arvoanalyysin perusteella kolmesta edeltävästä ratkaisusta valittiin jatkokehitystä varten robotilla toteutettu järjestelmä, jossa robotti käsittelee magneetteja ja asettaa ne oikeaan uraan sähkömoottorin roottoriin. Järjestelmä koostuu robotista, magneettivarastosta, roottorien kääntöpöydästä, magneettien erottelulaitteesta ja liiman levityslaitteesta.

Johtopäätöksenä tässä työssä voidaan pitää sitä, että robotilla toteutettu järjestelmä, joka hyödyntää ulkopuolista magneettivarastoa sekä magneettien erottelulaitetta on kaikkein sopivin ratkaisu sähkömoottorin roottorin magneettien asennusprosessin hoitamiseen, kun otetaan huomioon skaalautuvuus, luotettavuus ja kustannukset.

ACKNOWLEDGE

First, I would like to thank the company where I work for supporting my studies and enabling flexible working during the past four years. Many thanks also for my co-workers who have helped me during this project.

Thanks for my supervisor Harri Eskelinen who has patiently guided and supported me during this project and for my superior Mikko Piispanen who was closely involved in this research. Special thanks for my family and girlfriend who have supported me through my whole studies.

Lappeenranta March 18, 2019

Risto Tella

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LIST OF SYMBOLS AND ABBREVIATIONS

CAD	Computer Aided Design
D end	Electric motor drive end
Magnet pile	Many magnets together, block between each of them
N end	Electric motor Non-Drive end
Rotor	Rotating part in electric motor which holds also magnets
SCARA	Selective Compliant Articulated Robot Arm
Shaft	Part in motor, which transmits the torque
VDI	Germany engineer covenant (Verein Deutscher Ingenieure)

1 INTRODUCTION

This thesis focuses in researching assembly conditions of permanent magnet electrical motors, which consist of the frame, stator, rotor and shaft. The permanent magnets themselves are located to the rotor which is most typically manufactured from steel. The rotor has slots for permanent magnets and the number of magnets depends on the size of the rotor. In this research the company to which this research was done for is later referred as “company”. Permanent magnet motors relating to this work consist of from 100 to 300 magnets per a rotor depending on size of the motor. The magnet insertion process is currently done by hands and the work step is very recursive and because of this the company has intend to improve this process.

The research and development work are done in this research to clarify different possibilities to implement this magnet insertion assembly step more reliable and more cost efficiency than the current process. One manner to approach this subject is to utilize an industrial robot in this assembly step. With proper gripper arms an industrial robot can be programmed to follow exact the same assembly procedure than a human employee. Another approach is to design a totally new device just for this assembly step. The third option is a device which is combined from both. The industrial robot could be equipped with an integrated magnet separator which could assist with the magnet insertion process.

The main aim in this work is to compare different assembly solutions in the electric motor rotor assembly process. The criteria for comparison are based on scalability with different rotor geometries and flexibility against changes in production. Also, the reliability of the assembly process must be increased compared to the current process. In addition, this assembly process needs to fill the specifications required by Company. Value analysis is used as a criterion of evaluation when comparing different assembly solutions.

At this stage, Company has no intend to fully automatize this process so there can be work steps done by operator working with machine. Anyhow, in the future this assembly process must be able to be modified to work fully automatic without need of employee. It would be of benefit, if the chosen solution can be utilized in a fully automated assembly process.

2 BACKROUND OF MAGNET INSERTION PROCESS

Assembling a rotor of an electric motor is very monotonous work because of its reproducible work steps. Improving this assembly step has been considered also earlier just because of the monotonous work. Anyhow, the most reasonable assembly process hasn't been researched yet. This chapter aims to open background of possible robotised systems used for analogical application fields to describe the possibilities of modern production of electrical motors.

2.1 Motivation

Attaching magnets to a rotor is problematic step in assembly work because all magnets must be placed in to the rotor one by one. Attaching of the magnets takes approximately 10 per cent of the total assembly time according production monitoring done during year 2017. This work step is the most time-consuming singular step in the motor assembly. Magnetism brings own roughness to this process because the rotor and many other materials near the magnet slots are made of steel or other magnetic materials.

In addition, there is always a risk for failure while attaching magnets inside the rotor. In the worst case there comes additional work of almost 150% of the total assembly time because the motor that is ready for delivery must be disassembled and the manufacturing failure must be repaired. The magnets can be placed backwards, or an assembly worker can forget to place a singular magnet. In both cases there is a risk that these failures can be detected not until the motor is ready for the routine testing. If there are missing magnets or magnet pole of one or more magnet is pointing incorrect direction, the electric motor must be disassembled. Permanent magnets are storage in magnet piles before the assembly process. The 3D-model of example magnet pile shown in Figure 1. Single permanent magnet (1) and block between magnets (2).

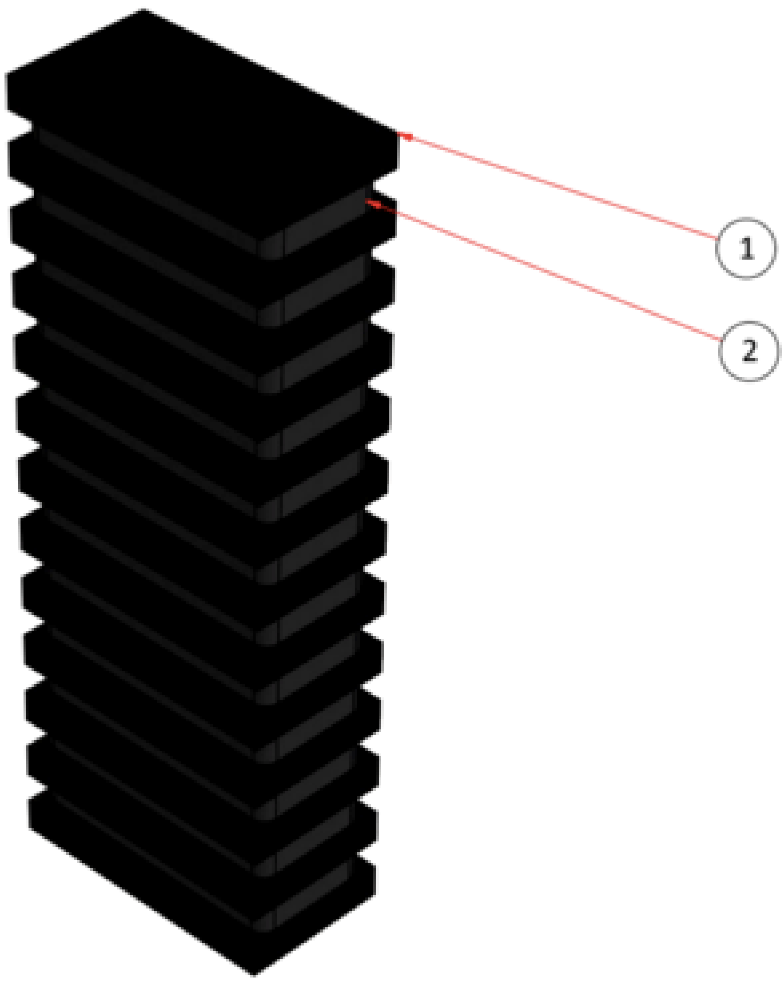

Figure 1. Permanent magnets in the magnet pile

With new assembly procedure production, volume should be able to be increased by factor of ten from current production volume. The motor size with highest annual volume is used as reference motor in this research. High reliability is the most important aim in this development process so high volume is not the main purpose for this work.

2.2 Previous research

Electricity and electrifying are currently global trends and it can be seen from statics made by International Energy Agency. For example, number of electric cars in Global circulation has grown with almost factory of 10 during the past five years, from 2013 to 2018. The statics of electric cars in circulation made by International Energy Agency shown in Figure 2. Because of this growth in the markets there comes pressures to electric motor manufactures to expand their production capacities and productivity. (International Energy Agency, 2019)

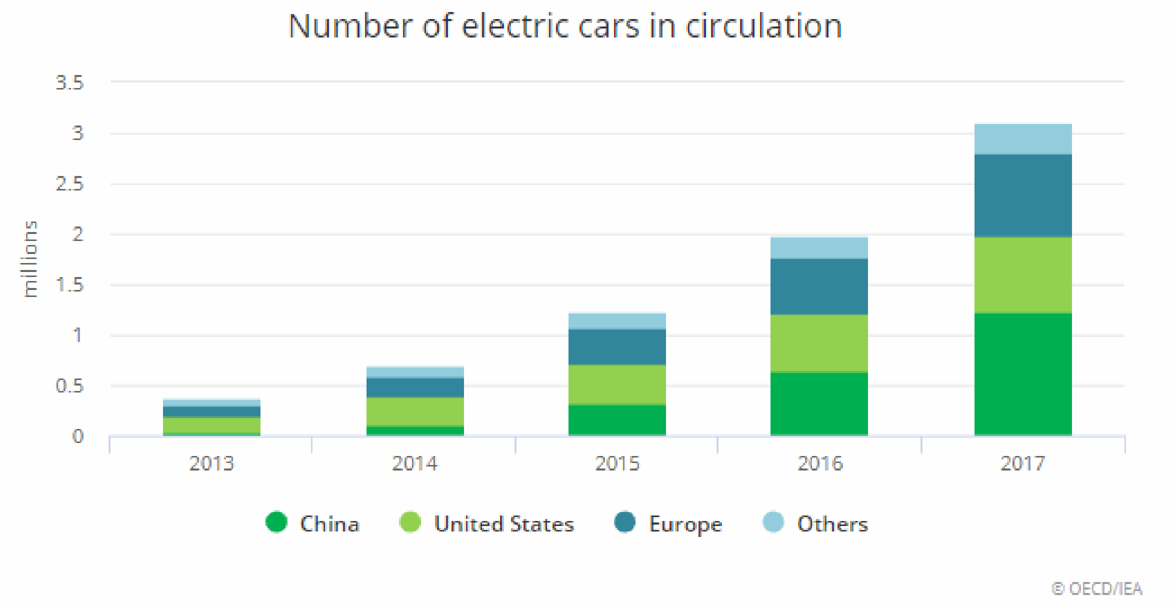

Figure 2. Global number of electric cars by the end of 2017 (International Energy Agency, 2019)

What comes to the magnet insertion process there could be found only researches where is studied one solution. In these researches the focus hasn't been to study or compare different solutions for implementing magnet insertion process. (Akbarzadeh et al., 2015, pp. 642–643; TM Robotics, 2018)

2.2.1 By target company

Company to which this research was done was founded at 2009 it started to design and manufacture electric motors and other electrical components for electrical drivetrains. The main segments of the customers are work machines, public transportation and marine. All electric machines manufactured by Company are permanent magnet motors with inner or outer rotor. Company intend is to produce and sell whole drivetrains which includes also all other electric devices what full electric or hybrid system needs. like AC/DC converters and DC/DC choppers.

Company has done some design work about the magnet inserting device at the end of 2014. This design work concentrated on self-designed mechanism and design state of it is not ready yet. So there exists an idea but quite little concrete so far. This device was self-designed but there were many things that needs to be solved before this solution would work reliable for production purposes. Reliability must increase from the current assembly procedure done manually by operator. Reliability will be measured and evaluated based on failures in manufacturing process.

2.2.2 By other companies

In many of founded researches about magnet insertion applications this assembly step has been implemented with SCARA robot. Basically, SCARA robot is industrial robot with 4 degrees of freedom. Benefits of SCARA robot for magnet insertion application are mainly based to this simply structure. The main benefits are price, velocity and placement accuracy. Repeatability of SCARA robot is good because of geometry of robot arm. According (Akbarzadeh et al., 2015, p. 643) this type of robot can reach repeatability tolerance of 0,0139mm. (Akbarzadeh et al., 2015, pp. 642–643)

One of SCARA robot advantages leads to one of its greatest disadvantages too. Payload capacities (lifting capacities) of SCARA robots are not so great than industrial robotic arms with six degrees of freedom. In application where is handled-bigger magnets with greater magnetic force there might be not enough lifting capacity in SCARA robot. In addition, rotating magnets are not possible when the gripper arm already has gripped the magnet. The work flow of magnet insertion device with SCARA robot solution shown in Figure 3.
(TM Robotics, 2018)

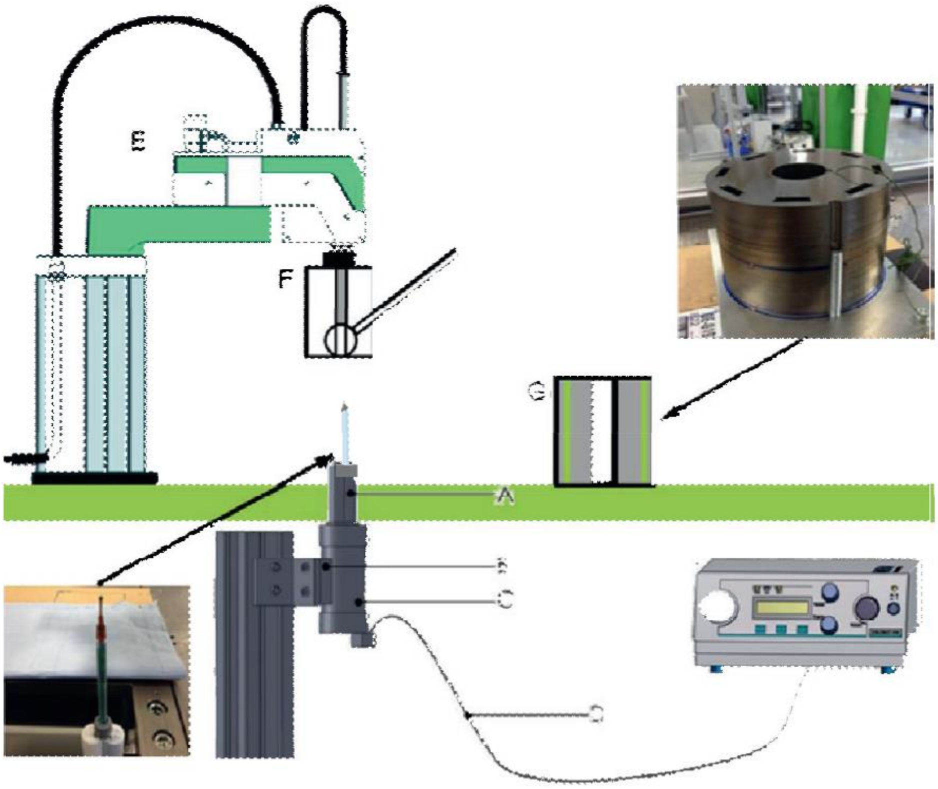

Figure 3. Magnet insertion machine implemented with SCARA robot. A: Glue nozzle, B: Cylinder attachment, C: Glue cylinder, D: Power Supply, E: SCARA Robot, F: Gripper arm, G: Rotor stack (Franke et al., 2015, p. 728)

2.3 Companies offering solutions for magnet insertion process

One company was found who produces custom made magnet insertion machines for electric machines magnet insertion process. These assembly solutions are always manufactured from customer order so Miotti doesn't have general solutions for customer which would be ready to use. (Miotti, 2019)

This Italian company produces different kind of solutions for the assembly process of rotors of electric motors. They are offering solutions to brushless electrical motors with inner or outer rotors. In addition, according their website their solutions will be suitable for magnets which are magnetized after the assembly process and also for permanent magnets already magnetized before the assembly process. (Miotti, 2019)

2.4 Robotized assembly

According to the standard ISO 8373:2012: an industrial robot is a programmable device with more than three axels and with many different using purposes. It is also automatically controlled and its possible to modify its program. (“ISO 8373,” 2012)

Costs of industrial robots have decreased about 25% during passed years because of technic evolution. According to the research made by ARK Invest performance improvements in industrial robots have influenced to costs of all size industrial robots (Korus and Analyst, 2017).

Annual robot deliveries will increase from 200 000 units to 500 000 units between years 2014 and 2025 according Rose J, Sirkin H and Zinser M. Estimated robot units in circulation worldwide shown in Figure 4. (Rose. J, et. al., 2015)

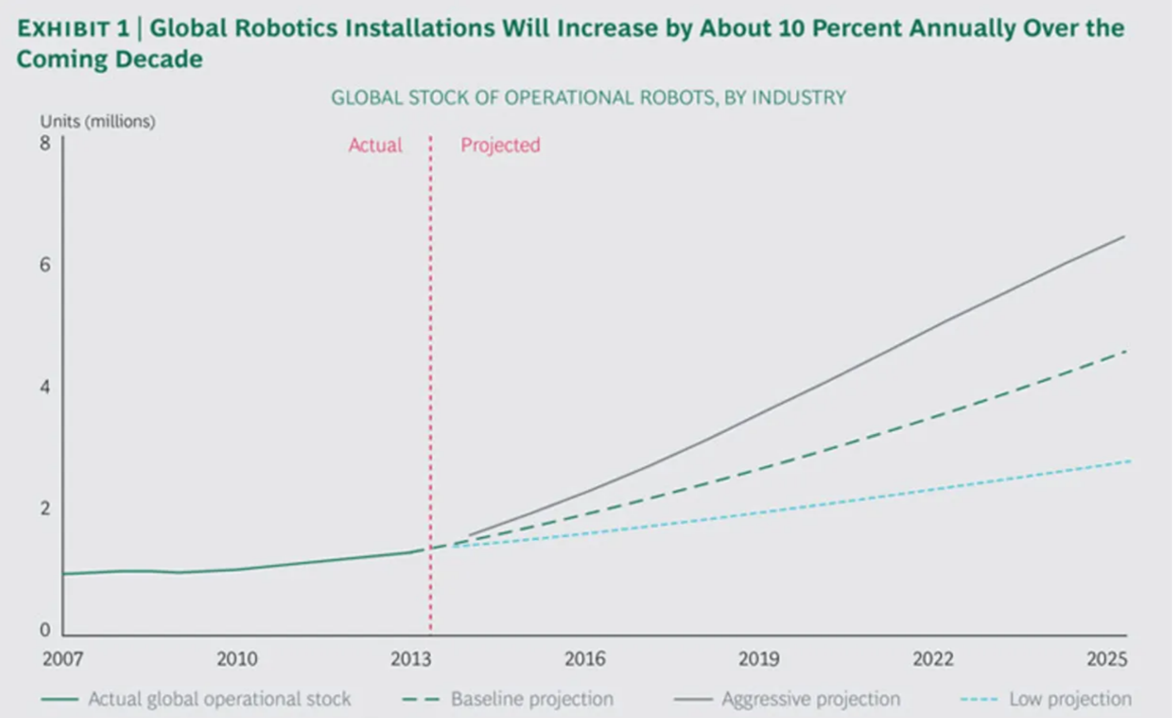

Figure 4. Estimated robot installations from 2007 to 2025 (Rose. J, et. al., 2015)

Artificial intelligence and machine learning will affect to costs of industrial robots in following years. According ARK Invest costs of industrial robots will decrease even 65% within following seven years. Certain size industrial robot cost decline from 1995 to year

2015 is shown in Figure 5. Figure also includes estimated cost decline until 2025. (Korus and Analyst, 2017)

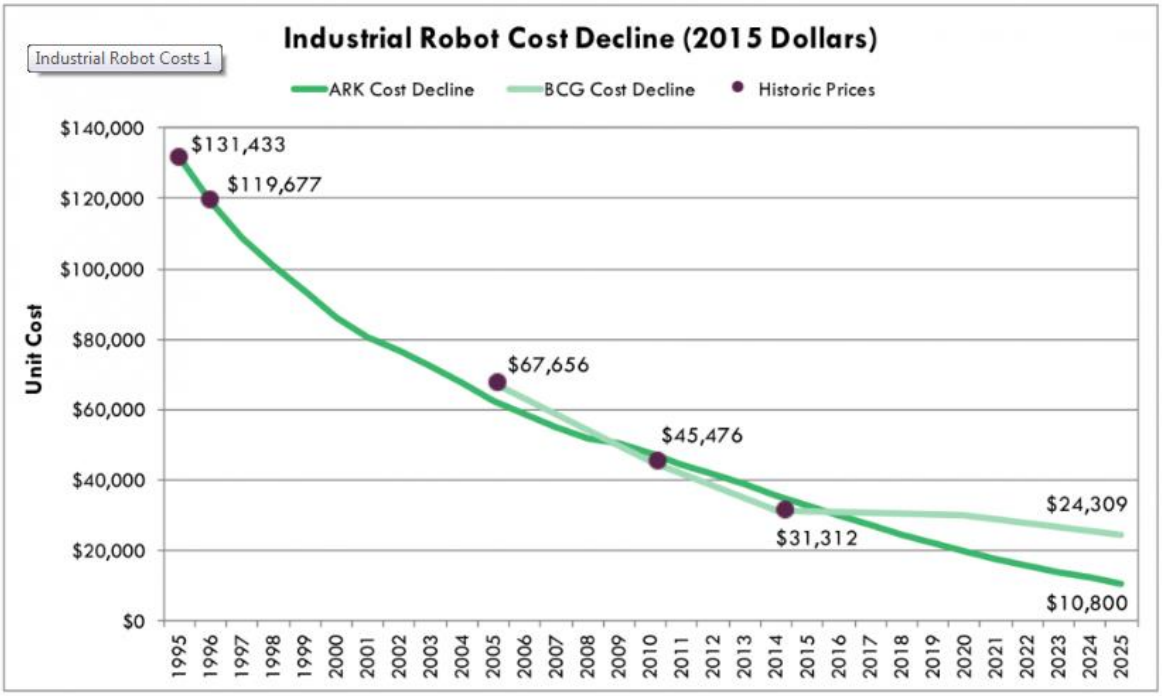

Figure 5. Industrial robot cost decline according ARK Invest (Korus and Analyst, 2017)

Based on analysed references, ARK Invest and analysis done by Rose, J et. al. (2015), the most relevant factors, which should take into consideration during the process of productivity analysing are as follows:

-It is evident that need of electrical motor is rabidly increasing

-There are number of companies working in the field of electrification engineering who have selected a commercial solution for production automation

-The costs of robotization have been decreasing since 1995 and the trend seems to continue

(Korus and Analyst, 2017) (Rose. J, et. al., 2015)

3 RESEARCH PROBLEM

There are three aspects to be considered in research problem of attaching magnets to rotor of permanent magnet motor.

First issue to be handled is to clear out, is this assembly step the most reasonable to be done with self-designed device or with industrial robot. The industrial robot just replies same working steps as a human, but it does not get tired or make mistakes. A self-designed magnet insertion device could be faster, but it might be less reliable than the industrial robot.

Second issue to be handled in this research is that magnet insertion is time-consuming because there are many work steps done by an employee. Assembly work is very monotonous for the employee, which leads to variable assembly times.

Third issue is that operator can place magnets backwards or leave one or more magnets off from the rotor. This is also consequence from monotonous work. Furthermore, robotic solution should be able to identify magnets to their serial numbers.

In addition to these three issues, proper magnet storage system must be considered in all solutions to be designed.

In this research it is studied reliable and cost efficiency solution to implement this assembly step. At least three different magnet insertion solutions will be designed and compared with value analysis to find out the most suitable solution. The solutions from a single industrial robot unit to a self-designed manual device will be utilized. Also benefits of combined solutions between the industrial robot and the self-designed mechanics will be studied.

The main design methods in this research are: morphological classification, value analysis and VDI 2221.

4 OBJECTIVES

The purpose of this research is to evaluate different magnet insertion solutions and compare those with value analysis.

In this research is used external knowledge from only few robots manufactures so objectivity of this research isn’t the most desirable.

4.1 Research questions

The main research question in this research is:
What is the best solution to attach magnets to the rotor of an electric motor when scalability with different rotor geometries and flexibility against changes in production has been considered and when also reliability in the production quality should increase by 50 to 80 per cent?

The secondary questions in this research are:

What are the advantages and disadvantages of chosen device compared to the current solution?

How the magnets storing is reasonable to produce in each solution. The storage system must be reliable and ease to use so that filling it wouldn’t take more time than the rotors placing.

4.2 Scope

The goal of this research is to present three different functional solution concepts. These solution concepts and compare them with value analysis and put them in the order of priority according to scalability against changes in rotor geometry, reliability and performance. All specifications required has been implemented to value analysis with design and manufacturing costs.

Scalability will be evaluated based on the number of changes to mechanics in case of new rotor geometry. The amount of failures in assembly process effects to evaluation of each system reliability and performance will be evaluated bases on working time with single rotor.

5 RESEARCH METHODS AND APPLIED SUPPORTING MEANS

Designing work, creation of product requirement specification and finding the criteria for value analysis are based on systematic engineering design methodology according to VDI2221. Mechanisms design, and motion path analyses are made with Inventor software.

Value analysis is used as a criterion of evaluation when comparing different assembly solutions. As a baseline for evaluating reliability analysis has been used experiences of production workers.

5.1 Value Analysis

Value analysis will be utilized in this work for evaluating differences between each solution. With value analysis it’s ensured that the chosen system is the most suitable system from all solution options.

Value analysis was founded for controlling these costs.(Bastič et al., 2014, p. 91) The main purpose for value analysis in these days is to support systematic product development process to create properly working devices and products. System to be designed will be divided to sections according system functionalities. Different implementation methods will be created for each function as its done in this work with Morphological Classification. Measurable requirements will be chosen from the requirement list and all chosen functional combinations will be evaluated according these chose requirements. Finally, all evaluated systems will be compared to the costs of each system. The most suitable and properly working solution can be chosen based on this information.
(Meskanen, 2008, p. 93)

5.2 Morphological classification

In the morphological classification there are created many different options to produce different functions in different solutions. Listing all needed functions of the product or system to be designed starts this method. After this, several different implementation methods for every function are composed and listed. When all functions have several implementation methods, these solutions can be marked in the table. Illustration of Morphological matrix shown in Table 1 below. (Beitz & Pahl 1990, s. 129—130.)

Table 1. Morphological classification illustrated in simple table (Beitz & Pahl 1990, s. 130.)

		Solution					
		S_1	S_2	…	S_j	…	S_m
Function	F_1	E_{11}	E_{12}		E_{1j}		E_{1m}
	F_2	E_{21}	E_{22}		E_{2j}		E_{2m}
	…						
	F_i	E_{i1}	E_{i2}		E_{ij}		E_{im}
	…						
	F_n	E_{n1}	E_{n2}		E_{nj}		E_{nm}

Combined principle solutions

5.3 VDI 2221

The goal in the systematic design method VDI 2221 standard is to a create method to reach systematic and organized design. The methods and principles to reach organized design have been told in VDI2221. The standard also guides a developer to consider possible problems during the design process and it consists document recommendations during the development process. The product development process guideline of this research is shown in **Table 2**. This guideline has been done according VDI2221 guideline. (Jänsch and Birkhofer, 2006, pp. 47–50)

Table 2. Product development guideline in this research (Jänsch and Birkhofer, 2006, p. 49)

Tasks	Results	In this thesis	Phase
Clarify and define The task	Specification	6th. chapter	Phase 1
Determine functions and their structure	Function structures	7th chapter	Phase 2
Search for solution principles and their combinations	Principle solutions	7th chapter	Phase 2
Divide into realizable modules	Module Structures	8th chapter	Phase 2 and 3
Develope layout of keymodules	Preliminary layouts	10th chapter	Phase 3
Complete overall layout	Definitive Layouts	10th chapter	Phase 3 and 4
Prepare production and operating instrutions	Product documents	Not included in this thesis	Phase 4

Excluded from this work

5.3.1 General specification of magnet insertion system

The basis in all design projects is need for change or new feature or new product. Inclusive research about need for new product or about specified problem is needed before starting new design project.

After clearing out the specified problem or need for new product is time to create different implementation solutions for this project. This brainstorming is needed already at this point to clarify that it is even possible to solve this problem with new product or feature. Seriously taken product development process needs executable preliminary model before its reasonable to start actual development project says Tapani Jokinen in his book “Tuotekehitys” (Eng. Product development). Process described in Figure 6 according Tapani Jokinen. (Jokinen, 2010, p. 17)

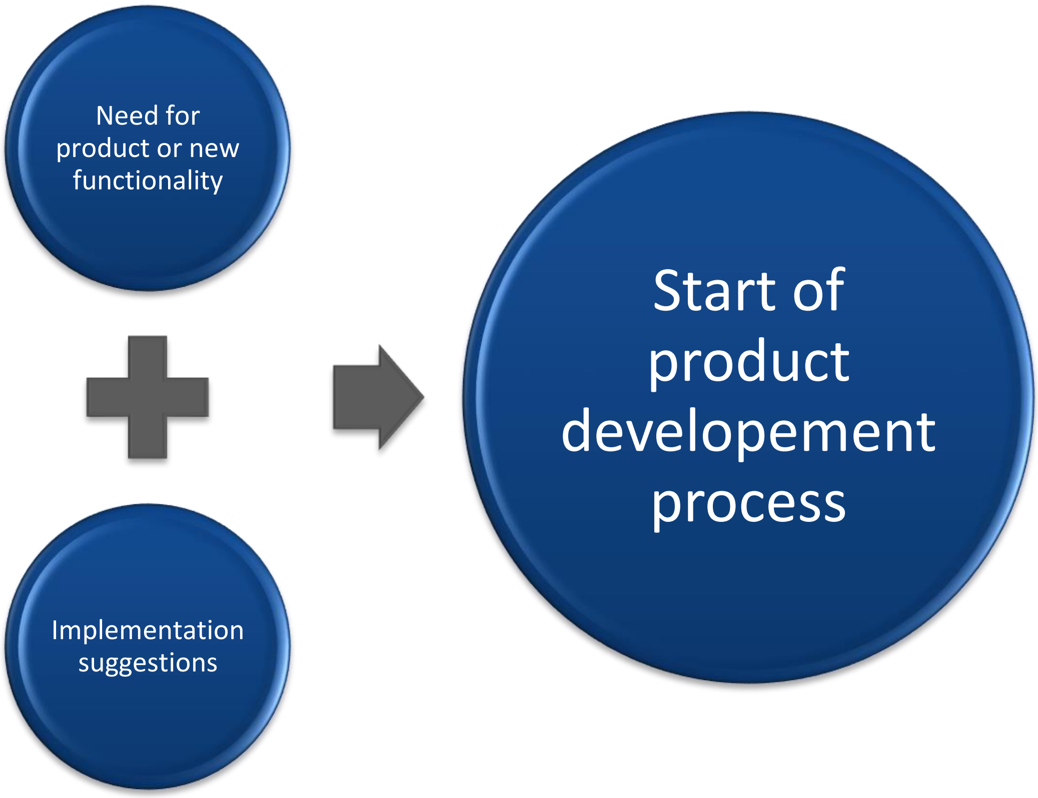

Figure 6. Start of development process according Tapani Jokinen (Jokinen, 2010, p. 18)

Knowledge must be found comprehensively inside the company about the researched subject to reach successful development process. In addition to this external consultation services can be used to bring new knowledge, fulfil already existing experience inside the company or to bring resources to the company. About starting a project can be decided after preliminary mock-up exist. If it seems to be working properly can be moved to draft phase. (Jokinen, 2010, p. 20-21)

Few different preliminary mock-ups are created in this phase to prove that there exists possibility to design improved method for the magnet insertion process. One mock-up was already created in the beginning and implementation this assembly step with the industrial robot system was the second mock-up.

5.3.2 Principle solutions based on morphological classification

Second phase, drafting, is the most important thing to be done carefully. If there are lacks in design at this phase all problems and errors reflect all way through design process into final version. Requirement specifications are created in this phase and whole design process bases on this document. Some main priorities in this project might not be missed or the final product can become inoperative if these requirements are lacking or designed careless. (Jokinen, 2010, p. 22)

The solution must be separated into functional segments according its functional requirements. Different implementation methods are being crated for these functional segments according requirement specification. After successfully improvement these functional segments methods are being evaluated with some evaluating method and the best solutions are chosen.
(Jokinen, 2010, p. 17)

An entity functional system has to be built from functional segments after they are developed and chose. This developed system must be compared and evaluated based on the requirement specification and the goals determinate to this process. In this phase its verified that the most important requirements are being fulfilled with a sufficient level. (Jokinen, 2010, p. 22)

The requirement specification and dividing magnet insertion process to functionalities was done in this research at this phase. Drafting was done by utilizing Morphological Classification and from three to four different principle solution were created for each functionality.

5.3.3 Module structures chosen with value analysis

After preliminary structure is ready it must be separate into sections and functional segments one more time. Each section and segment must be considered one more time to ensure it fulfils and it corresponds needed requirement specifications. It is still ease to modify these sections at this point if needed.(Jänsch and Birkhofer, 2006, p. 49)

After its verified that each functional segment fits to requirement specification these segments are being considered according design for manufacturing and assembly (DFMA). Of course, this needs to be considered also earlier but at this point it every functional segment is being evaluated and improved according its producibility. The costs and assembly steps in these segments are also tried to reduce.

Value analysis has been utilized in this phase has to compare different solution. Different solutions are evaluated based on scalability against changes in rotor geometry, reliability and performance.

5.3.4 Final layout and documentation

Final layout is being evaluated based on the requirement specification one more time as final step in VDI2221. After it’s obvious that all requirements are fulfilled can design team start creating manufacturing documents. (Jänsch and Birkhofer, 2006, p. 48)

A design and production ready products need accurate documentation. Manufacturing drawings and part lists are the first one of those. Assembly instructions are needed right after parts have been manufactured. User manuals and instructions are needed finally when product is ready for deliver to the customer. All these documents are recommended to produce in VDI2221 are shown in **Figure 7**.

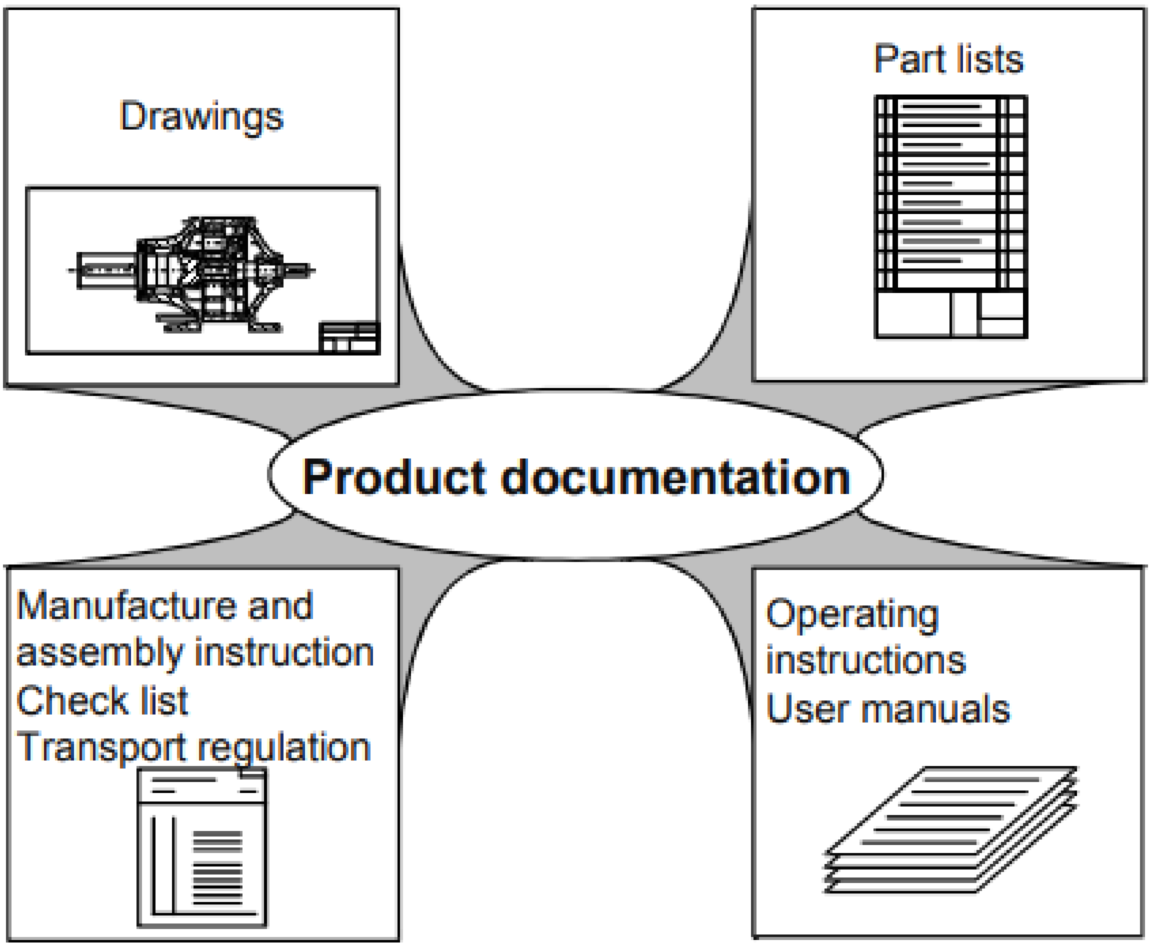

Figure 7. Documentation needed in VDI2221 (Schuh, 2007)

The systematic product design methods mentioned in this chapter are used in this research to ensure that the assembly process to be chosen and designed for the rotor of the electrical motor will be workable and operational. (Jänsch and Birkhofer, 2006, p. 48)

6 REQUIREMENT SPECIFICATION

The solution to be designed must be able to be implemented to work with the most generic motors made by Company. There are four different rotor geometries included in the requirement specification.

There is also variation between stack lengths within every diameter. The stack with a same diameter has from two to five different length options. Because of this designed system must be able to assemble all different length of stacks between length of 50mm and 500mm. The requirement specification shown in Table 3 was created during this research. All these requirements are relevant regardless which the assembly procedure is being used.

Table 3. Requirement specification for magnet insertion assembly process

Requirement	Required	Wish
Possibility to use with multiple rotor geometries / lengths	Own machine for each rotor geometry. One machine can do multiple lengths of single geometry to agreed limit	One machine can do any rotor geometry/ length up to agreed length
Prevention of access of operator in vicinity of machine during processing	Fence around machine with enough distance and height to machine to prevent operator touching any part of machine during processing. All the control functions of the machine are located outside the fence.	
Prevention of processing starting when operator is in vicinity of machine	Door with safety switch which prevents machine to start if door is open	
Prevention of fragments flying out of the machine	Transparent wall around the machine to prevent fragments colliding operator	

Table 3 about requirement specification for magnet insertion assembly process continues.

Requirement	**Required**	**Wish**
Prevention of machine starting processing when there is wrong rotor on the platform	Clear visual instructions about choosing correct rotor model attached in vicinity of the machine	Weight based automatic system to recognise which rotor model is placed on the platform
Prevention of placement of wrong magnet type in machine	Clear visual instructions about choosing correct magnet size attached in vicinity of the machine	
Prevention of rotor falling off from platform during processing/ fault situation		Non-magnetic housing around the rotor during processing
Prevention of machine starting processing when there is no rotor on the platform		Weight based safety switch system which prevents machine starting to operate if there is no rotor on the platform

7 CLASSIFICATION CRITERIA AND PRODUCT VARIANTS

The generating ideas about the different implementation methods to build up the rotor of the electric motor according the requirement specification is done in this chapter by adapting the Morphological classification.

The workflow in the magnet insertion assembly step:

1. The storage including enough magnets for assemble of the three motors according the requirement specification
2. The separating single magnet from the magnet pile
3. The adding glue on the top of the magnet
4. The inserting magnet into the right groove in the rotor
5. The pushing magnet to the bottom of the groove

7.1 Magnet storage

Implementing this step depends much about the solution to be used. In the different solutions need for this storage might variate or even disappear. In the different solution there exists also different requirements for this assembly process.

Anyhow there are still general requirements and baselines, which can be used in the designing. It can be thought that there are roughly two different options for the magnet storage. The magnets can be placed to the outer storage from where they will be moved to the device implementing step two. Or as the second option the device implementing step two can be able to storage enough magnets to fulfil the specifications required. The most important thing is the storage capacity.

Three implementation methods were developed for this assembly step.

7.2 Separating magnets

The separating magnets can be roughly divided to be done from three directions. The magnet can be pulled up in horizontal or vertical direction. The magnets can also be pushed away from the pile.

When pulling the magnet away from the pile, the pile needs to be hold steady. In addition, the mechanic which grabs from the magnet is needed. This gripper arm mechanism should work with the different size of magnets. Also, if the magnets are lifted up from the magnet pile, the magnet pile should be attached to the storage somehow. With this style is also needed a mechanic which grabs from the magnet. The support structure and flat bar is only needed if the magnets are pushed aweigh from the pile. The support structure keeps the pile steady and flat bar would push one magnet aweigh.

Four implementation methods were developed for this assembly step.

7.3 Magnet gluing

The gluing is also an assembly method what can be implemented as an own work step or it can be combined with the following work step. The separate machine for this work step is needed whichever way it will be chosen.

The glue can be added on the top of one single magnet as an own work step or optional it can be done right before the magnet insertion to the rotor. The glue can be added on the top of whole magnet pile or it can be added on the top of only one magnet. Two implementation methods were developed for this assembly step.

7.4 Inserting magnets to the rotor

The magnet insertion in to the rotor groove can be done from two different directions and with both directions can be inserted one magnet at the time or optional more than one at the same time. The magnets can be inserted from the rotor D end or N end.

Placing the magnet into groove can be done by pulling or pushing the magnets. Pushing will be lot easier because pulling should be done through the rotor groove. Pushing can be done at least by two different styles. A single magnet can be grabbed with the gripper arm or a similar mechanic and pushed in to the groove one by one. Optionally the whole magnet pile can be hold above the rotor and the magnets can just be pushed in to the groove with straight movement.

Four implementation methods were developed for this assembly step.

7.5 Ensure magnets correct positioning

The placing magnet to the correct position in the groove can be done by pushing or pulling the magnet. Other magnets or a separate tool for just this purpose can be used to pushing. If using other magnets, it demands lot more force than it would demand when using own tool for pushing.

The magnets or the gripper arm can be used for pulling the magnet to the right position. Four implementation methods were developed also for this assembly step.

The analysis of classification criteria and produt variants resulted from two to four different product variants for each sub funtions. The different combinations of these variants will be avaluated with value analysis.

8 SOLUTIONS CHOSEN BASED ON MORPHOLOGICAL CLASSIFICATION FOR FURTHER COMPARISON

The basis in this research were to compare manual and robotized assembly solutions in the electric motor rotor assembly process. The criteria for comparison are based on scalability with different rotor geometries and flexibility against changes in the production. Finding three of the most promising solutions from the manual assembly device to the robotized assembly is being hold as the goal in this research.

Many combinations based on the Morphological Classification are improper, useless or impossible to implement. Three different combinations were chosen in to more detailed inspection: The manual device, the industrial robot with automated magnet storage and the robotized arm with the integrated magnet separator. First one of those combinations was chosen because its same kind of as solution, which was designed in previous research done by Company. Other two solutions were chosen based on suppliers offers and suggestions.

In the first solution it would be utilized combined magnet storage and magnet insertion machine. The magnets would be inserted in to rotor from down side of the rotor and the magnets would be pushed into the bottom of the groove right away with the same tool, which does also the insertion process. The tool length should be correct and it movement should be variable. In the research done by Company, the solution state of the design wasn't ready, so it would need a lot more work to get it ready for manufacturing. Anyhow, the state of design was advanced enough for this comparison.

The second option which was chosen for further design was the system with the industrial robot. The external magnet storage, the rotor rotating table, the external magnet separating machine, and the external glue insertion machine would be utilized in this solution. The industrial robot would have the gripper arm with which it could place the magnets into the rotor from upwards. In addition to the robot itself the system should be prepared with an external magnet storage with enough storage capacity for the motors required in the requirement specification. The robot should be able to work without fulltime witness of the operator. Perhaps the greatest benefits for this system would be its great scalability.

Scalability would be remarkable better than in the manual device. In addition, reliability of the industrial robot system would be much higher than in the other solutions. The price compared to the manual solution is higher and estimate speed of the assembly process a bit lover.

The combination of first two solutions was chosen to be as the third option. In this solution would utilize the industrial robot as in the second option but the gripper arm would be self-designed. In this solution would utilize the combined magnet storage. The magnets would be placed from the integrated magnet separator which is moved by the industrial robot arm. In that gripper arm is enough magnets to build up that one rotor. With this kind of solution, a lover assembling time compared to the traditional industrial robot system could be reached. The price of this system would be also probably higher than in the other two solutions.

The general function principle of the magnet assembly process is shown in Table 4 below. In this table all functions during the magnet insertion process has been separated in their own section.

Table 4. General function principle of magnet assembly process

Step	**Function**
1	Magnet placement to the machine
2	Magnet serial number documentation
3	Glue placement to the machine
4	Rotor placement in the machine
5	Rotor type identification (if needed in solution)
6	Ejecting magnets from magnet pile
7	Adding glue to magnet to be inserted

Table 4 about general function principle of magnet assembly process continues.

Step	Function
8	Inserting magnet/magnets in to the rotor
9	Ensure that inserted magnets are at the bottom of the magnet groove
10	Repeat steps 6-9 until
11	Remove ready rotor from the machine

8.1 Manual magnet insertion device

The manual magnet insertion device bases on research done at Company previously. New, faster, more reliable and cost efficiency solution to the magnet insertion process was tried to design in that research. In that research was designed only principle solution so the system would need much more design before it would be ready for production. Despite of this, the state of design was advanced enough for this comparison and solution didn't need further development at this point.

The principle idea in the manual solution is to push several magnets in to the rotor at the same time with the same movement. The pushing tool would be placed so that there are several flat bars positioned identically with the magnet grooves. A hydraulic or pneumatic cylinder would move the pushing tool. The magnet piles would be placed to tangential direction on the rotor outer surface. There would be correct size support frames for each magnet piles and these would also support the magnets during the pushing tool pushes the magnets in to the rotor. The pushing tool length should be correct, and its movement should be able to be varied.

The whole structure would be assembled around the frame which supports all parts of the system. The frame also includes guide housing which places the rotor correctly according to the magnet piles. The illustrated 3D-model of whole system shown in **Figure 8**.

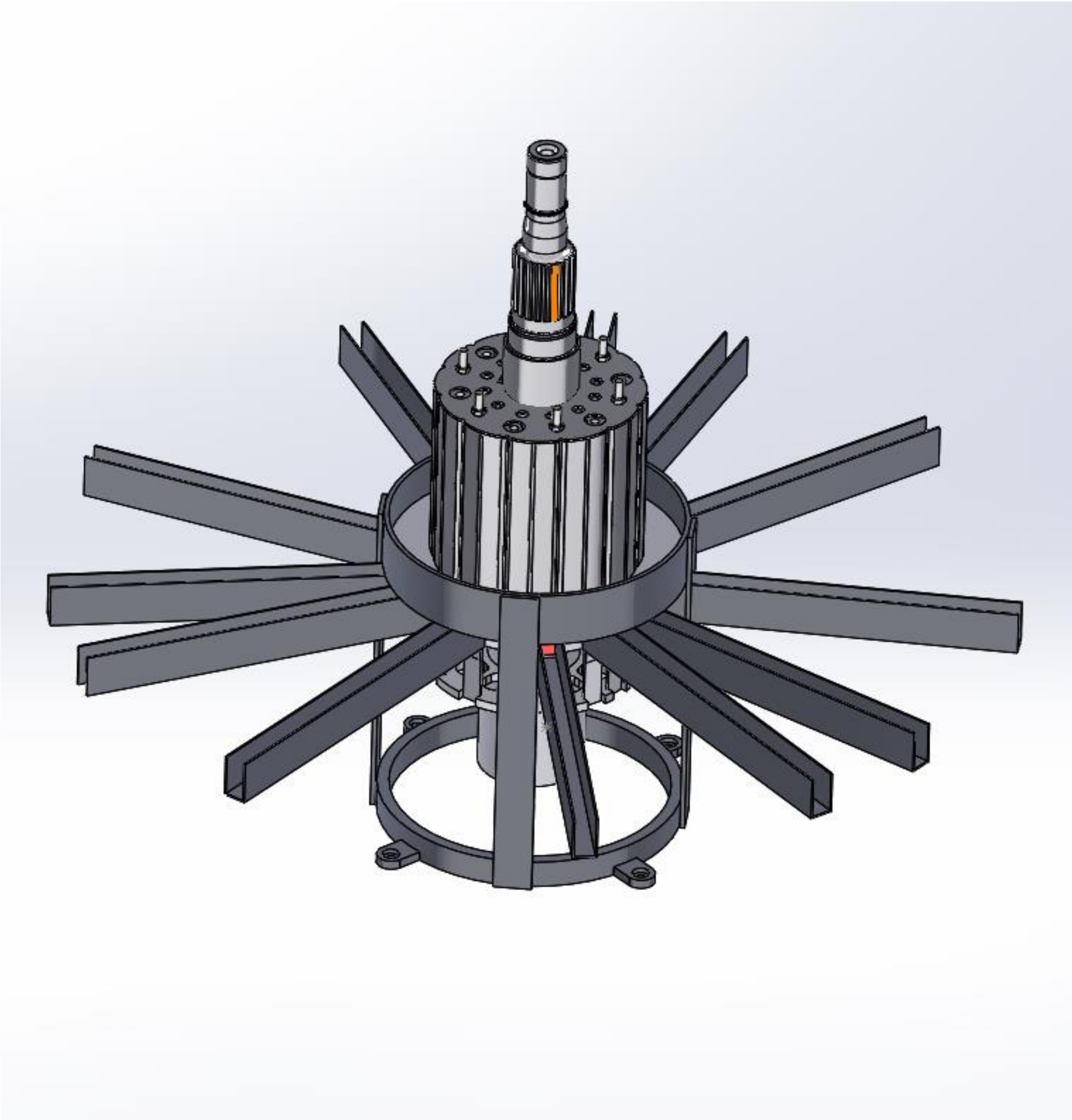

Figure 8. Principle 3D-model of manual magnet insertion device which inserts 12 magnets with single movement.

The greatest benefits in this kind of manual device are low costs. The structure is simple to manufacture so manufacturing costs from three to four times lower than in the other solutions implemented with the industrial robot. In addition, the whole design or at least the most of it can be done internally inside the company. The manual system can be designed to be multiple times faster when comparing to other solutions implemented with the industrial robot. The own designed manual system can be able to insert even 12 magnets in to the rotor with the same movement. In this case system would be twelve times faster compared to the solution which inserts one magnet at the time.

The disadvantages and issues in this kind of manual issues bases to same things than advantages of this solution. The structure is so simple that it has no scalability options and features. If the manual device is being used, company would need own device for each rotor geometry or rotor size. Also, even small changes will affect to the manual assembly device and force it under change.

The system could also be quite unreliable because there must be lot of adjustments such as the magnet pile and the magnet pushing tool adjustment to all directions in the device and every time when the production worker must do some changes to the system it exposes under possible errors. If an operator does some mistake during the adjustment of the device, it doesn’t work properly.

8.2 Robotized rotor assembly system with automated magnet storage

The basic idea behind the robotized assembly is that the industrial robot repeats approximately the same work steps as the human. The assembly procedure or the assembly method is not going to be changed remarkable during this research.

The general work steps for the robotized assembly:

1. The unfastening singular magnet from the magnet pile
2. Adding glue to the magnet to be inserted
3. Placing magnet in to the right groove in the rotor
4. Pushing magnet to the correct position (to the bottom of the groove)

To be able to do phase one robot has to get the magnet pile from somewhere. The external magnet storage is going to be utilized for this step. The magnet storage should be working so that the operator is able to add the magnet piles in to the storage during the robot working. The robot can get new magnet piles from the storage which are matching to the rotor to be assembled.

In addition to this, to implement first phase of assembly the magnets have to be separated from the magnet pile. The external magnet separating machine is going to be used for this step. The machine would separate a singular magnet from the pile with the tool moved by the hydraulic or pneumatic cylinder.

The robot moves a correct magnet pile from the magnet storage to the magnet separating machine. From this machine the robot can pick up singular magnets for phase two.

The external gluing device would be used for adding glue on the top of the magnets. The device would be able to insert right amount of glue on the top of the magnet when the rotor places the magnet under a nozzle.

The rotors can be placed so that the robot might be able to know the correct groove placement based on programming. There is a chance that tolerances in the rotor rotating table and in the rotor laminate stacks varies so that repeatability of the robot is not accurate enough for inserting the magnets straight into the groove. Because of Company tense tolerances there is a chance that force sensor needs to be used. Repeatability of the industrial robots might be about 0,05mm according Yaskawa. (Yaskawa America Inc, 2018)

The robot needs to be sure about the magnet position before it tries to push the magnet in to the groove. For this purpose, it can be used for example a force sensor which enables the robot to detect when the gripper arm is above the hole or groove. According Yaskawa this kind of force sensor fits excellently to the solutions with high tolerance requirements. With the MotoFit force sensor the robot is able to find the groove from the rotor laminate stack and it is able to push the magnet in it with higher reliability. (Yaskawa Europe GmbH, 2018a)

At the current assembly procedure, the magnet position in rotor stack is ensured by pushing the magnet downwards in the magnet groove using a flat bar tool made from non-magnetic material. In the robotized assembly this work step can be fulfilled with the same procedure. The robot picks the pushing tool up from the holder near the working place and pushes the magnet or magnets to their right positions. Preliminary 3D-model of industrial robot system shown in Figure 9.

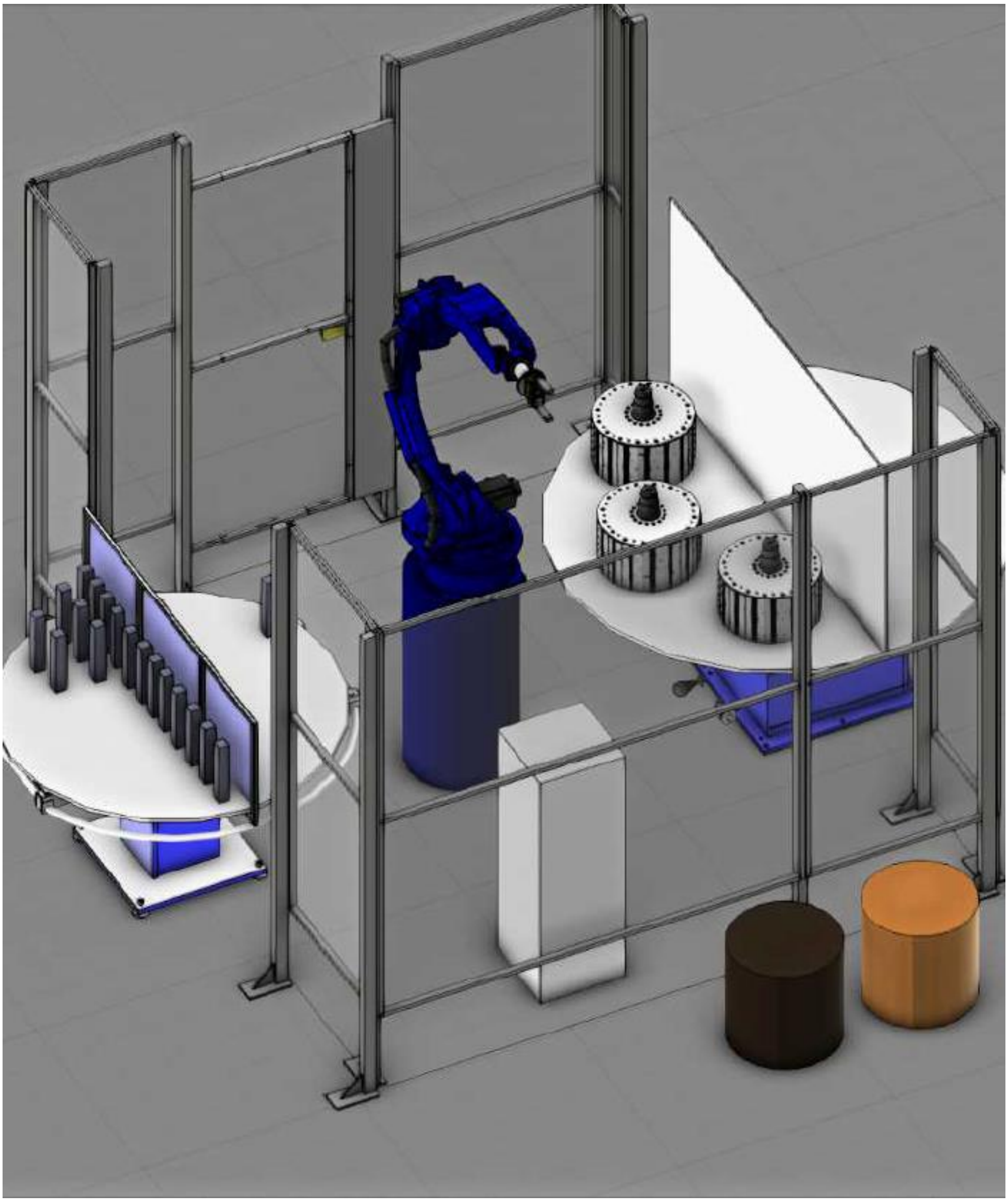

Figure 9. Preliminary 3D-model of industrial robot system

The greatest advantages in the robotized assembly are reliability in the repeatability. The robot works and repeats the same routes within repeatability accuracy of a robot and it doesn’t make any mistakes if other parts of the system work properly. In addition to this the robot is reprogrammable with small effort in case of a new rotor geometry or rotor stack length. In case of new rotor geometry there might be need for change or modifying some parts from the rotor rotating table or from the magnet storage if the magnets have changed too. These parts should be designed to be changed and modified easily. As summary, the industrial robot is modular solution and it has good scalability inn case of changes in rotor geometries.

The disadvantages in the robotized systems are its complexity functions. A lot of external help and support is needed to design the whole system. The system with the industrial robot has much more external devices than the manual and the system with the integrated magnet separator. These external devices increase the overall costs. In addition, the maintenance costs are also more expensive because there is always need for external support during maintenance work. The work time with this system is lower than in the other two solutions to be compared. This is because almost all functions have been executed with the different devices and moving time from the device to another is quite remarkable. Also, it is assumed that the robot doesn’t find the groove immediately but needs to use the force sensor to find it.

Despite of the bigger costs compared to the manual device, the system with the industrial robot might become cheaper in long term. This is estimated based on better reliability and better scalability than with the manual device.

The working time compared the current solution when a work step is done by a human is not going to change remarkable. According Yaskawa, the magnet insertion process would take time approximately 12 seconds. The working time would change approximately from -10 per cent to +10 per cent. The working time might even increase a bit when considering only a singular rotor assembly time because the robot is able to work without breaks and it doesn’t do any mistakes working time might decrease to over half when compared to the current solution.

8.3 Robotized arm with integrated magnet separator

The robot system with the integrated magnet separator gripper arm utilizes pallets to where the rotors can be placed by the operator before starting the assembly process. The magnets would be placed also into same kind of pallets. The robot would move the magnet palette and it would be able to insert the magnets into the rotor straight from the palette. This would able the system to insert the magnets faster because it doesn’t have to pick each magnet from the external storage.

The industrial robot places the pallet to the right position according the grooves in the rotor. The first magnet in the magnet pile would be pushed in to the groove with the external tool moved by the pneumatic cylinder.

The same tool which pushes the magnet into the rotor groove would move the blocks from the magnet pile to rubbish pin with a back movement. The glue will be added to the magnet right before the magnet insertion from the glue which is included to the robot gripper arm

The benefits in this solution are speed and the solution compact size. Because of only few external components this solution can be designed in small protective covering.

This solution would need close present of a production worker during the magnet insertion process because there should be the operator adding the new magnet palettes during the robot working. Also, the costs are increasing because the robot gripper arm and the magnet insertion palette would become very complicated system because it includes so many different functions.

Based on the Morphological classification three different solutions were chosen for the value analysis:

- Manual device
- Robotized assembly system with the automated magnet storage
- Robotized arm with the integrated magnet separator

9 VALUE ANALYSIS FOR DIFFERENT ASSEMBLY SOLUTIONS

The deliverers that the company has consulted can offer three different types of solution based on the Morphological classification. These solutions were introduced in the paragraph ”Solutions based on Morphological classification”. Each function is stored based on their functionality and point price is calculated for these points.
(Meskanen, 2008, pp. 11–14)

9.1 Functional requirements

The requirements of value analysis are based on a list of the requirements. The requirements, which are the most important and easy to measure are picked from the list of requirements so that the functions can be ranked by the order.

Reliability, scalability about rotor geometry and the speed of assembly were selected as assessment criteria. These criteria were chosen because of their easy assessment ability.

Reliability is evaluated based on the number of errors during assembly process. The number of errors increases as the number of stages of employee increases or if the employee can do one stage in many ways. By assessing this way, a fairly reliable result is obtained from the reliability of implementation, even though no corresponding implementations have actually been made yet.

Scalability about rotor geometry means the flexibility of the system when the new rotor geometry wanted to integrate into the same assembly system. This can also be easily evaluated by examining what kind of changes is needed so that the new rotor geometry can be fitted to the system.

The scale factories for the different chosen requirements are shown in Table 5. The different requirements are compared between each other, and determinative requirement is chosen between each pair of the requirements.

Table 5. Scale values for different requirements

-	**Reliability**	**Scalability**	**Working time**	**Value factor (V_a)**
Reliability	Reliability	Reliability	Reliability	V_r = 10
Scalability	Reliability	Scalability	Scalability	V_s =7
Working time	Scalability	Scalability	Working time	V_t =3
Total				20

Reliability has been evaluated based to the operator work steps. The more work steps exists, the more also exists possibilities for failures. Scalability has been evaluated based on parts needed to change to get new rotor geometry working with each assembly solution. Working time is basically evaluated based on the working time with single magnet. These all times are hypothesis based on information from each solution supplier. All these values have been gathered in to Table 6. System with the robotized arm with the integrated magnet separator is marked as Robot 2.

Table 6. Estimated values for different functionalities

Requirement	**Qualifier 5 points**	**Qualifier 4 points**	**Qualifier 3 points**	**Qualifier 2 points**	**Qualifier 1 point**
Solution 1					
Solution 2					
Solution 3					
Reliability	Operator work steps ≤ 1	Operator work steps = 2	Operator work steps = 3	Operator work steps =4	Operator work steps ≤ 5
Manual					X
Robot		X			

Table 6 about estimated values for different functionalities continues.

Requirement	Qualifier 5 points	Qualifier 4 points	Qualifier 3 points	Qualifier 2 points	Qualifier 1 point
Reliability	Operator work steps ≤ 1	Operator work steps = 2	Operator work steps = 3	Operator work steps =4	Operator work steps ≤ 5
Robot 2			X		
Scalability	Parts needed to change ≤ 1	Parts needed to change = 2	Parts needed to change = 3	Parts needed to change = 4	Parts needed to change ≥ 5
Manual					X
Robot	X				
Robot 2			X		
Working time	Time per one magnet ≤ 2s	Time per one magnet ≤ 4s	Time per one magnet ≤ 6s	Time per one magnet ≤ 8s	Time per one magnet ≥10s
Manual	X				
Robot					X
Robot 2			X		
Total	Reliability * $\mathbf{V_r}$ =+ Scalability * $\mathbf{V_s}$ + Working time * $\mathbf{V_r}$ **= Total points**				
Manual	1***10** + 1***6** +5***4=36**				
Robot	4***10** + 5***6** +1***4=74**				
Robot 2	3***10** + 3***6** +3***4=60**				

Based on information shown in Table 6 assembly process is the most reasonable to implement with industrial robot when costs are not considered. However, costs almost always influence to company decision making. Price of one point in each solution can be calculated by dividing estimated costs with combined points from value analysis. These values have been calculated in Table 7**.**

Table 7. Estimated values for different functionalities

Solution	Points	Cost	$\frac{Cost}{Points}$
Manual	36	40 k€	1,11
Robot	74	150 k€	2,02
Robot 2	60	200 k€	3,33

The costs of the manual assembly device are a lot lower than the other solutions because there exist almost only mechanical solutions and very few components need to be controlled by computer. Almost the whole design process can be done inside the company. When comparing solutions according to the costs, the industrial robot is there in the middle. Cost difference between the industrial robot and the robot with the integrated magnet separator system is because in the industrial robot system can be used more standard components than in the robot with the integrated magnet separator where must be designed the whole gripper arm from scratch. Based on this previous information the magnet insertion system implemented with the industrial robot is the most reasonable solution to be used in this assembly step.

The industrial robot will be also good investment when thinking about the future. The robot will keep its price well and it can be sold if it turns out to be useless. The robot can be also programmed to do many other things than this it’s meant now.

10 DETAILED DESCRIPTION OF SELECTED ROBOTIZED MAGNET INSERTION SOLUTION WITH AUTOMATED MAGNET STORAGE

The magnet insertion process decided to implement with the industrial robot system where the robot moves and handles the magnet piles and singular magnets. The system shown in Figure 10 consists of industrial robot (1), magnet storage (2), rotor rotating table (3), magnet pile separating machine (4) and gluing device (5). In addition to these systems has security systems, protection fence (6) to prevent access inside robot working area during robot working and light curtain (7) which is able to tell the system that is there a production worker inside the rotor rotating table loading area (8).

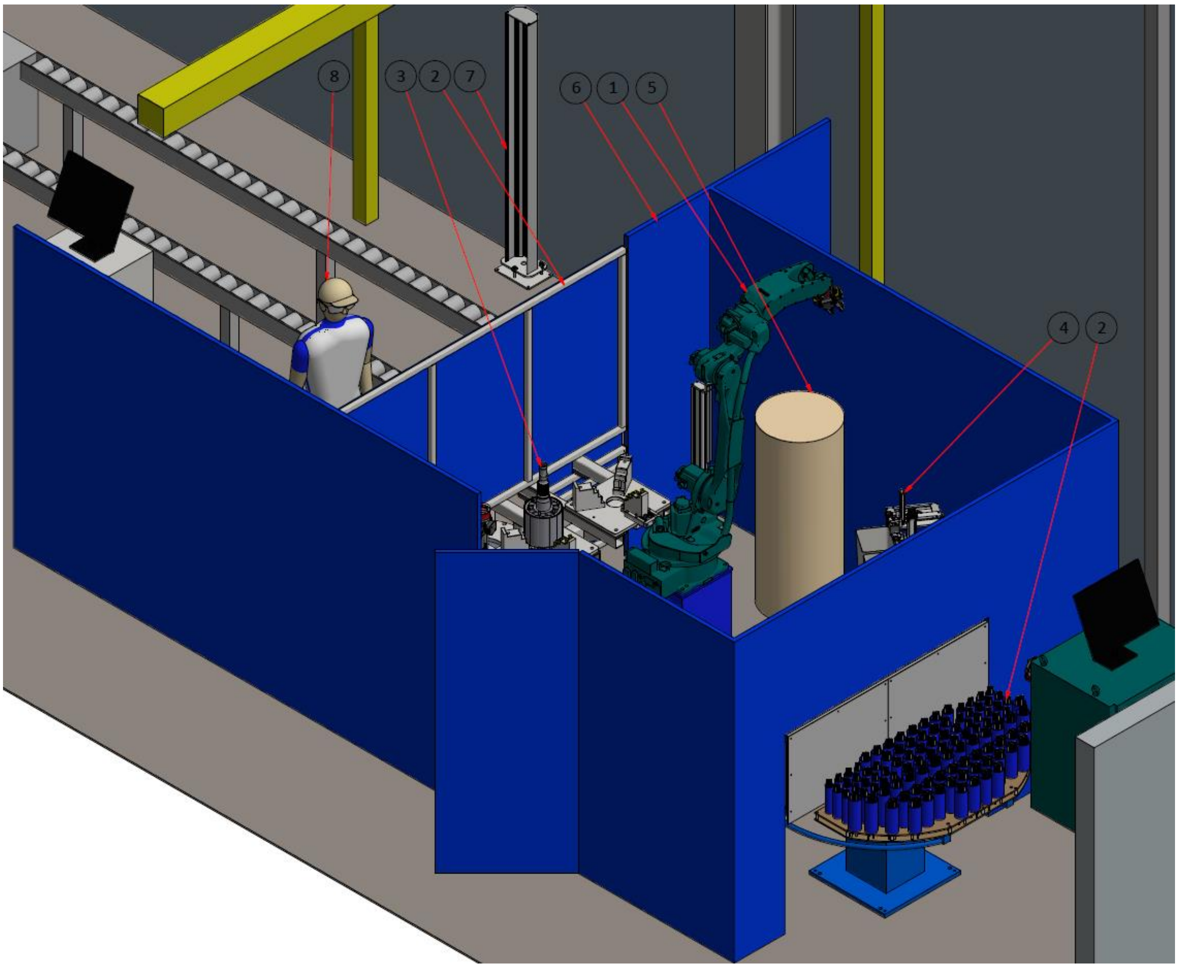

Figure 10. Preliminary layout of robot system

There exist also two computers for the operator to be used. The operator has access to the computer near the rotor rotating table and near the magnet storage. The system layout without protection fence shown in Figure 11.

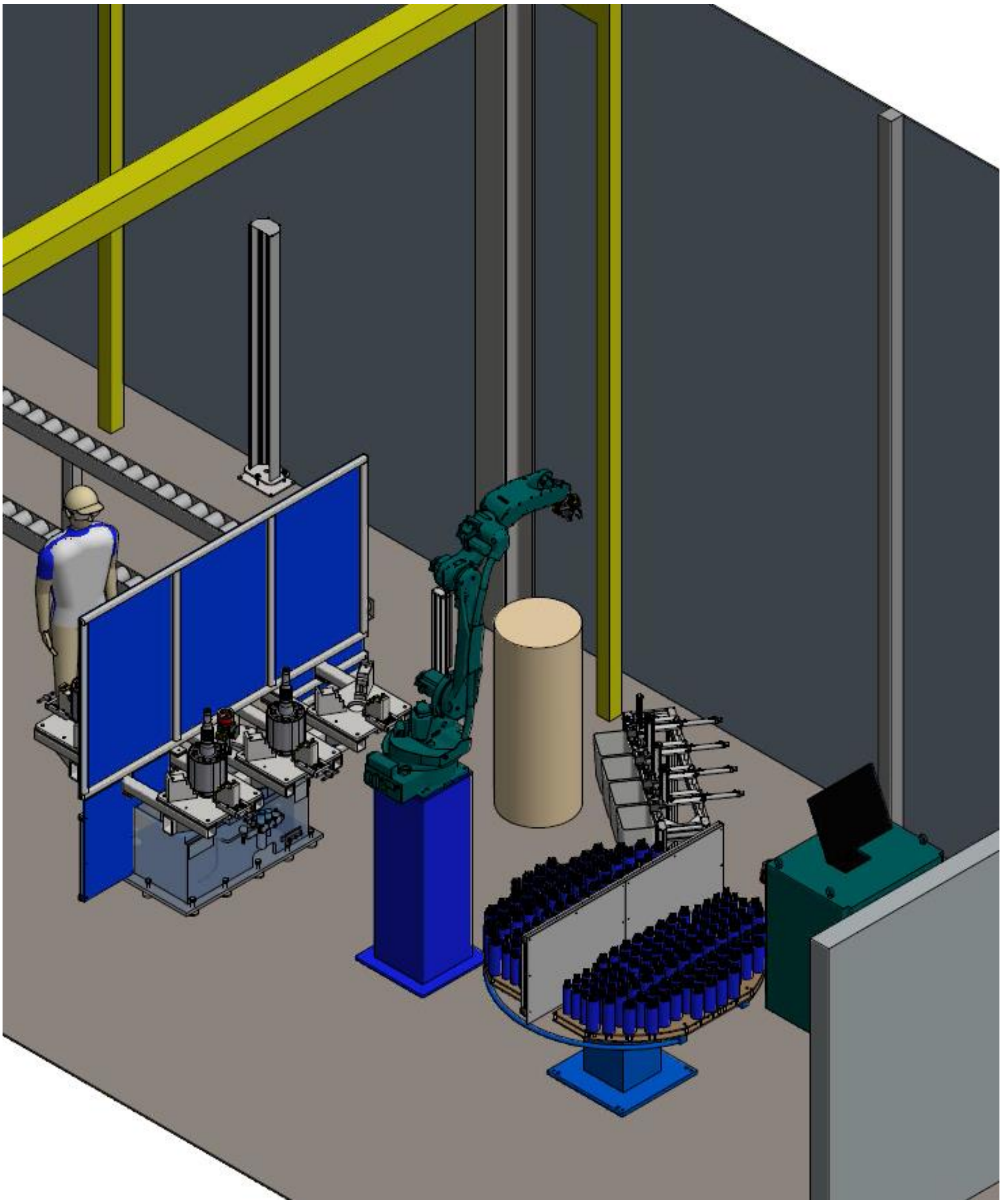

Figure 11. Preliminary layout of robot system without protection fence

The robot will be designed to be able to work with three rotors without a production worker action. Because of this there are six places in rotor rotating table. The operator will be able to remove the ready rotors and add new rotors to table during the industrial robot working. The magnet storage is also designed to be two sided also so that a worker is able to fill storage during the robot working.

10.1 Principle solution for magnet insertion machine

The workflow has been separated into 16 phases before the magnet is inside the rotor. The function table shown in Table 8 also shows actions after that.

Table 8. All funtions step by step for magnet insertion system

Function	**Determination**	**Additional specifications**
Magnet placement in the storage	Manually by operator	Magnet storage has exactly right size magnet slots for each magnet size. Slots are also marked apparently. Magnetic direction needs to be confirmed at this point.
Magnet serial number documentation	Operator gives values to the computer	Operator writes magnet serial numbers to the computer. Operator also determinates in which slot number these magnet piles are located.
Rotate magnet storage table	Manually by operator	Rotate magnet storage table 180 degrees to get just filled side to robot reach area.
Glue placement in the machine	Manually by operator	Operator places glue barrel to glue insertion machine. **Note.** Does this need testing?
Rotor placement in the machine	Manually by operator	Each rotor platform (6 platforms total) has correct size housings for three rotor geometries.

Table 8 about all funtions step by step for magnet insertion system contsinues.

Rotor type identification	Operator gives information to computer about rotors to be assembled.	Also, sensors in rotor platforms detects which size of the rotor is on platform.
Starting of the machine	Manually by operator	Operator gives information to computer about rotors to be assembled.
Rotate rotor table to get new rotors to robot working area.	Automatically after start confirmation	
Magnet pile externalization from storage	Robot gripper picks up magnet pile from magnet storage	Robot detects right magnet size based on location of magnet slots and magnet id based on value given by operator.
Magnet pile placement to machine which separates magnets and magnet blocks	Robot gripper places magnet pile in to magnet storage	
Ejecting single magnet from pile	External device separates one magnet and one magnet block from pile	Magnet block moves automatically to rubbish bin
Picking up single magnet	Robot gripper picks up single magnet from the table	
Glue insertion	Robot takes one magnet under gluing machine	Gluing machine automatically dishes out right amount (**0,5ml**) of glue on top of the magnet. Can amount of glue be changed how easily.

Table 8 about all funtions step by step for magnet insertion system contsinues.

Inserting magnet in to the rotor	Robot gripper takes magnet in close of magnet groove and pushes it in.	In case of magnetic forces affecting too much to robot arm there might be need for plastic (or non-magnetic) guider for magnets.
Check that magnet is at the bottom of the groove	Robot checks location of previous magnet/magnets	
Adding magnet serial number information to rotor information	Magnet information must be documented	
Repeat functions 9-14 until magnets separation machine is empty		Robot detects when magnet separation machine is empty.
Repeat functions 7-16 until rotor is ready		
Fill other rotors with magnets	Robot starts automatically working with other rotors placed on platform	After first rotor is ready machine starts automatically working with other rotors according information given by operator (Step 6)
Rotate rotor table to get ready rotors out from robot working area.	Automatically after all rotors are ready	
Robot moves to "ready" position	Automatically	Operator recognize that there are ready rotors in the machine
Remove the ready rotor from the machine	Manually by operator	Operator cleans the rotor and attach missing end plate.

10.2 Industrial robot

The requirements for the industrial robot relate to accuracy, payload and working area. Based on magnetic forces and magnet weight payload from 20kg to 30kg estimated to be enough for this application. Accuracy should be more less than 0,1mm and working area more than 1500mm.

Six axes MH24 Motoman robot was chosen to be used in this solution based on these requirements. The payload for that robot is told to be 24kg and it has wide working area. The diameter of working area is over 1700mm, which is enough for this application. Motoman MH24 robot shown in **Figure 12**. (Yaskawa Europe GmbH, 2018b)

Figure 12. Yaskawa Motoman MH24 industrial robot (Yaskawa Europe GmbH, 2018b)

The gripper arm of the robot must be made of aluminium or from other non-magnetic material. The gripper arm might have to be modified a bit before it is suitable for this application. The robot doesn't grab the magnet pile from very long distance; it carries the pile from only few magnets, so the gripper arm must be exactly right shape.

10.3 Rotating table for rotors

The rotating table will be able to carry load of six different rotors. The operator should be able to place any of four size rotors to each. Also, length of rotor stacks should be able to vary between 50mm and 500mm. Shaft is also shrink fitted inside the rotor before magnet insertion process. So, there must be space for shaft spline in both sides of rotor. Table width is 1860mm and its shown in Figure 13.

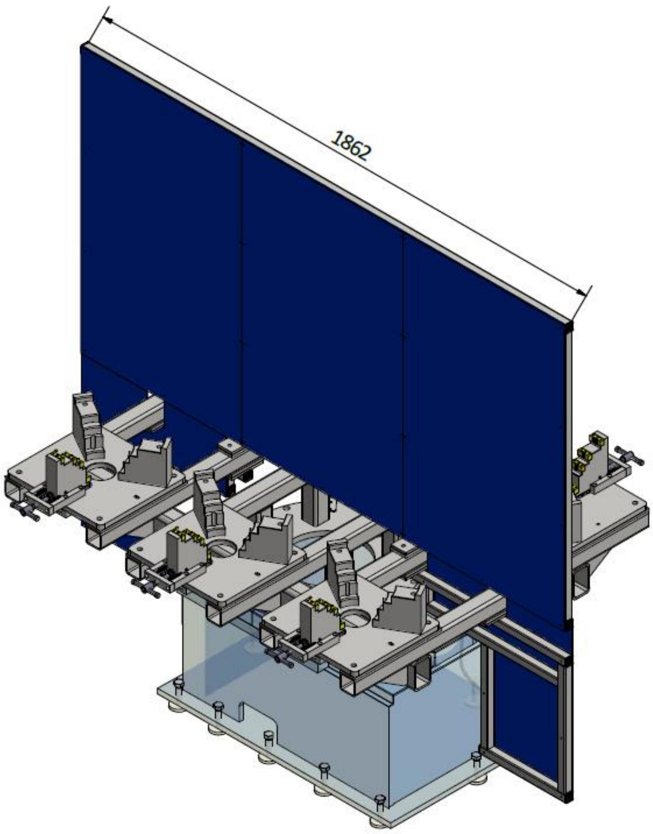

Figure 13. Rotating table for rotors

The benefits for the rotating table are that it allows operator working during the industrial robot is working. The operator can remove ready rotors from table and place new rotors as substitute. The robot can insert magnets to three rotors without any actions from production worker and robot is able to insert magnets to six rotors with that magnet table rotating is operator only action. Fence in the middle of rotating table prevents operator access to industrial robot working area. Light curtain prevents table rotating when operator is close to rotor table.

The rotating table needs to be steady because the rotors can weight totally approximately 1000kg. It’s also possible that the operator has loaded the table only from other side and the table must be able to carry these loads and torsion.

10.4 Magnet pile separating machine

The magnet separating machines were designed to be four in the system, one device for each size of magnets. With this action we prevent complicated structure which all dimensions should be able to variable because between the different magnets all dimensions can be changed. Also, a separating machine suitable for all magnets would be problematic because in requirement specification is requires that the system is able to work with the three rotors without the operator actions and these rotors might be including different magnets. As a conclusion, it will be cheaper and simpler to manufacture four disconnected magnets separating machine.

The device has guiders attached to the machine frame so that there is a correct size groove for the magnet pile. These guiders will place the magnet piles to the correct position. The pneumatic cylinder will push one magnet out of the pile when the pile is supporting the guiders. The pneumatic cylinder pushes a singular magnet to the right place where the robot arm is able to pick it up. The blocks between the magnets are still going to stay in the magnet pile and the same pneumatic cylinder will push them to the rubbish bin with a bit longer movement as first push.

The magnet separating machine shown in **Figure 14**. The hydraulic cylinder can be found from the balloon 1, the pushing tool (2), the guiders for magnet pile (3) and the rubbish bin for the magnet blocks (4).

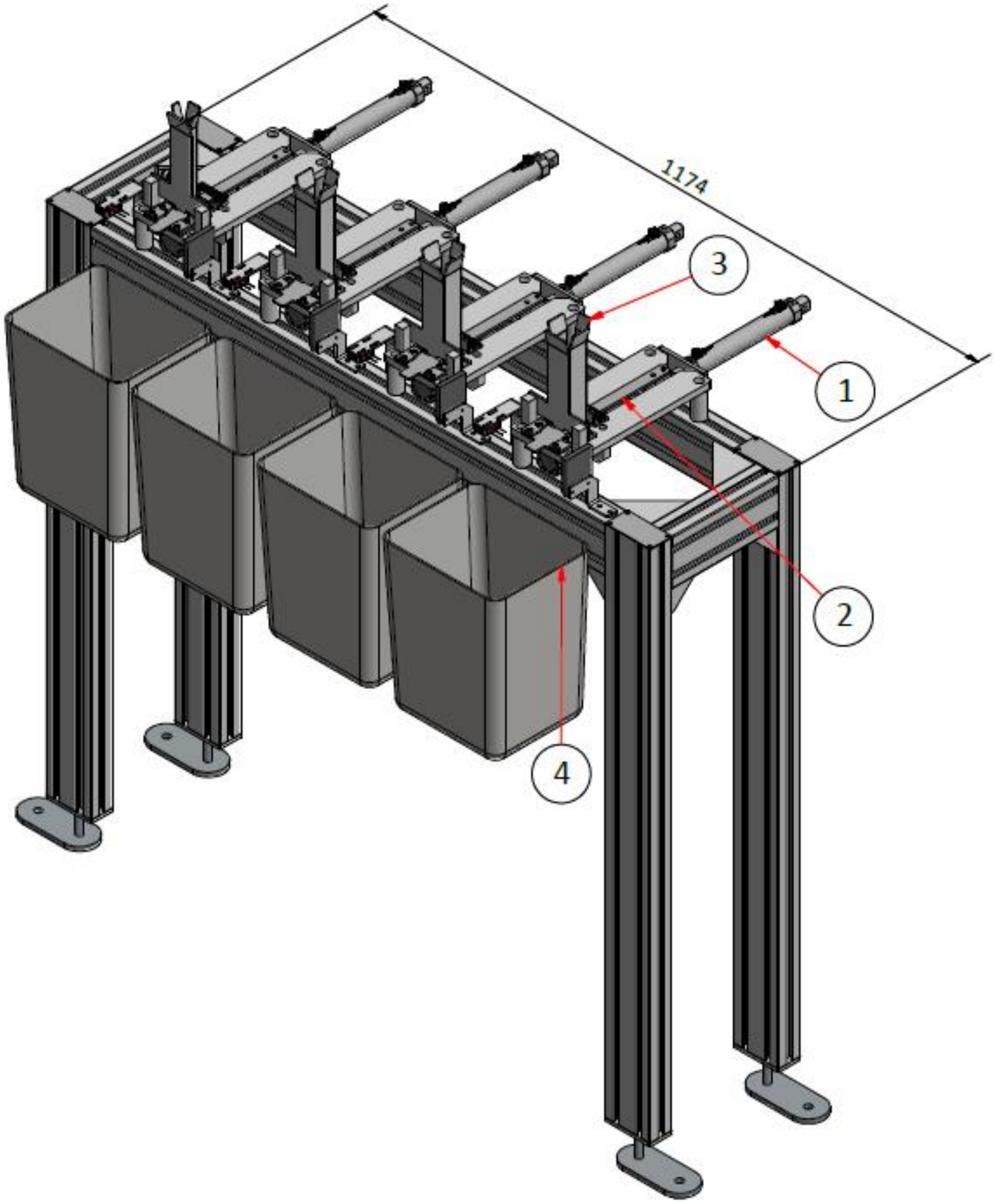

Figure 14. Magnet separating machine

10.5 Magnet storage

The magnet storage is intending to be able to storage the magnets of all motor sizes. As the rotating table for the rotors, also the magnet storage will be implemented with two sides to ablaze the operator working during the industrial robot working. Principle picture of magnet storage shown in **Figure 15.** below.

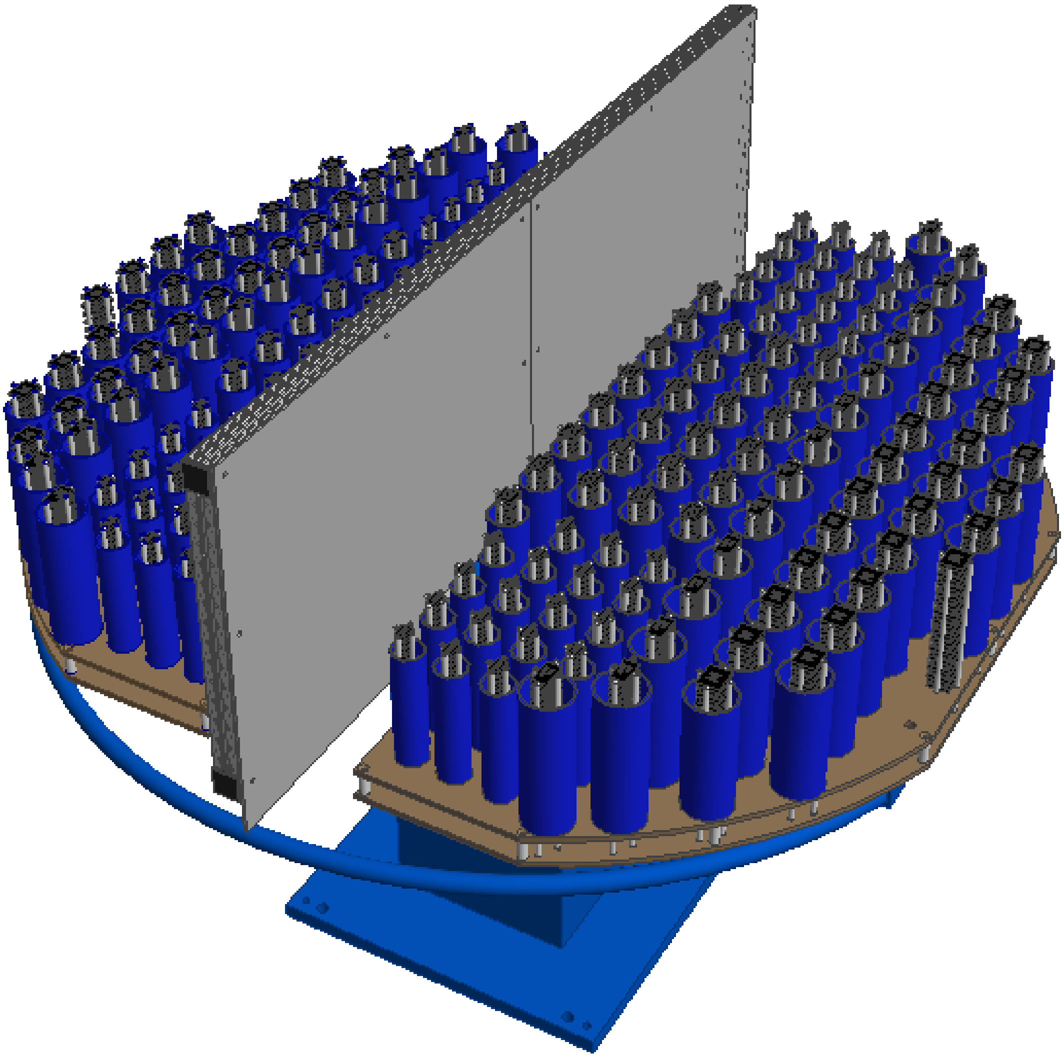

Figure 15. Magnet storage for 200 magnet piles

The magnet storage should be able to storage so many magnet piles that the robot will be able to assemble the magnets into the most generic motors without storage filling up. In Table 9 is presented magnet mounts in motors with highest annual volumes. There is the most generic model used as reference motor from each rotor size. In addition, to the table is gathered information about average magnet amount in one pile in every magnet size.

Table 9. Magnet storage capacity

Motor name	Average magnet amount per pile	Piles needed per rotor	Total need of piles
Motor A	14 pcs.	11,5 piles	35
Motor B	28 pcs.	4,3 piles	13
Motor C	20 pcs.	8,4 piles	26
Motor D	14 pcs.	11,5 piles	23

From Table 9 can be seen how many magnet piles is needed to assemble one motor from each motor size. The motor with the highest produce volume from each size have been used in calculation. Below listed amount of the motors required to build without the operator work effort:

- Three pcs. Motor A electric motors
- Three pcs. Motor B electric motors
- Three pcs. Motor C electric motors
- Two pcs. Motor D electric motor

Sometimes the magnet amounts might have some variations between the magnet slot in separate deliveries. The total amount of each magnet piles has been rounded upwards to ensure that there will be enough magnets in storage in any case.

10.6 Contribution of the research

The main research question in this research was:

What is the best solution to attach the magnets to the permanent magnet rotor of the electric motor when scalability with different rotor geometries has been considered, flexibility against changes in production and reliability in the production quality?

The best solution according to this research is to implement magnet inserting process with the industrial robot system which includes separately a magnet storage system, a magnet separating machine for a separating magnet from the magnet pile.

The secondary questions in this research were:

What are the advantages and disadvantages of the chosen device compared to the current solution?

The most important requirement in this research was to increase reliability of this assembly step. This also turned out to be the greatest advantage to the current assembly procedure. The industrial robot has also great scalability properties because of it is a reprogrammable system and only few components need to be changed in a case of new rotor geometry.

How magnets storing is reasonable to produce in each solution? The storage system must be reliable and ease to use so that its inserting wouldn’t take too much time.

The reasonable solution for the magnet storage system variables between different assembly procedures. However, the system implemented with the industrial robot it is the most reasonable to implement the magnet storage with separated storage. The operator should be able to fill the storage during the industrial robot works with the rotors. The magnet storage decided to implement with the rotating table which has two symmetrical sides. The table rotates 180 degrees and has always the other side away from the industrial robot working area.

10.7 Expected scientific contribution

The systematic design methods VDI2221, Morphological Classification and Value Analysis were getting to known before starting actual design work. All these methods were used during this work.

Basic knowledge about performance differences between the different kind of magnet inserting solutions were got comprehensively. Different companies and studies were also getting to known during this research. It clarified that also other companies and universities have studied singular magnet inserting devices, but no research was found about comparing the different kind of solutions to implement this assembly step.

10.8 Concrete application

The concrete result of this research was a properly working magnet-inserting device which performance matches with company’s requirements. The system consists of the single arm industrial robot with the payload capacity of 24kg, one rotating table for 6 pcs. rotors and one rotating table for 200 magnet piles. The system also has its own machine for each magnet size to separate a single magnet from the magnet pile and its own machine to spread glue on the top of each magnet.

11 SUMMARY

The goal in this research was to compare different assembly solutions in the electric motor rotor assembly process. The solutions were evaluated and compared based on scalability with different rotor geometries and flexibility against changes in production. Also, reliability in this assembly process were considered. Scalability was evaluated bases on the number of the changes in the mechanics in case of new rotor geometry, reliability based on amount of failures in assembly process and performance based on working time with single rotor. In addition, this assembly process needed to fill the specifications required by Company. Value analysis was used as a criterion of the evaluation when comparing the different assembly solutions.

In this research it was tried to find reliable and cost efficiency solution to implement the assembly step of the rotor of the electrical motor. The goal was to design three different magnet insertion solutions and compare them with value analysis to find out the most suitable solution.

At the theory section it is aimed to open background of possible robotised systems used for analogical application fields to describe the possibilities of modern production of electrical motors. Also increasing need of electric motors in every field of industry is presented and based on analysed references shown in this report. The main design and development guidelines used in this research are: morphological classification, value analysis and VDI 2221.

Requirement specification was created during this research. All these requirements are accurate regardless which assembly procedure is being used. The analysis of classification criteria and produt variants resulted from two to three different product variants for each sub funtions. The different combinations of these variants will be avaluated with value analysis.

The generating ideas about the different implementation methods to build up the rotor of the electric motor according the requirement specification is done in this chapter by adapting the Morphological classification.

Based on the Morphological classification three different solutions were chosen for value analysis:

-Manual device

-Robotized assembly system with automated magnet storage

-Robotized arm with integrated magnet separator

The magnet insertion process decided to implement with the industrial robot system where the robot process magnets and inserts these to the rotor. This system ranked to be the best solution according to value analysis and second best when also costs are considered. Despite the price, the robot system was chosen because of its great scalability and reliability. This solution needed only one mechanical change in case of new geometry when other compared solutions needed three and more than five mechanical changes. The chosen solution includes two work steps done by the operator when the other compared solutions again needed three and more than five mechanical changes. The industrial robot system with automated magnet storage parts needed to be changed. The magnet insertion solution includes following functional sections:

-Industrial robot
-Magnet storage system
-Rotating table for rotors
-Separating machine for magnet piles
-Gluing device

In this research there were no demands, which would have been abandoned. The design process may be retained successfully because all required and specified functionalities can be found from the final solution.

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